Module 1. Evaporation

Lesson-3

Different Types of Evaporators Used In Dairy Industry

3.1. 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

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3.2. 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

(i) Source of heat,

(ii) Position of tubes for heating

(iii) Method of circulation of product

(iv) Length of tube

(v) Direction of flow of film of product

(vi) Number of passes

(vii) Shape of tube assembly for heat exchanger

(viii) Location of steam

(ix) 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.

3.2.1. 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.

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 disadvantages of this type are the relatively large hold up of liquid in the lower regions of the tube giving long contact times (15-30 min.) Also evaporation ratio in a single pass is usually not sufficient to reach the required concentration, so that recycling is necessary, extending residence time. In the central portion of the tubes formation of scale, protein deposits and other fouling is often found to be most severe.

Vapour is removed by the separation chamber and the concentrated product removed or recirculated through the evaporation chamber again, depending on the concentration desired.

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 other wise 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.

The smaller the tubes for a given output the easier it is to get even distribution, also small tubes result in a larger pressure drop across their length. The ideal plant might well have conical tubes which would maintain a good initial velocity, would prevent overloading with vapour at the bottom of the tubes and might make the distribution of the feed easier.

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. The other advantages are as stated below.

1. The overall heat transfer coefficient is much larger than vacuum pan or other types of evaporator. The U-value of vacuum pan is 500-700 W/m^2 K, while for multi effect evaporators it is 1500-2200 W/m^2 K.
2. More than one effect can be used in series with great saving in steam per kg of vapour.
3. There is no static head and hence no change in the boiling point due to hydrostatic head.
4. It can be used for concentrating most of the heat sensitive products including milk and fruit juices, due to lower temperature gradient.
5. Evaporation is carried out at lower temperature due to higher vacuum and temperature difference required is relatively low.

Disadvantages are as under:-

1. Chocking of tubes due to scale formation and difficulty in cleaning of tubes.
2. Operation is highly sensitive to fluctuation in steam pressure to plant.
3. Sudden failure of vacuum causes heavy entrainment losses and fouling of tubes.
4. Great care is needed in keeping all joints leak proof to maintain desired vacuum.

Fig.3.1 Single Effect Rising Film Evaporator (courtesy Kessler H.G.)

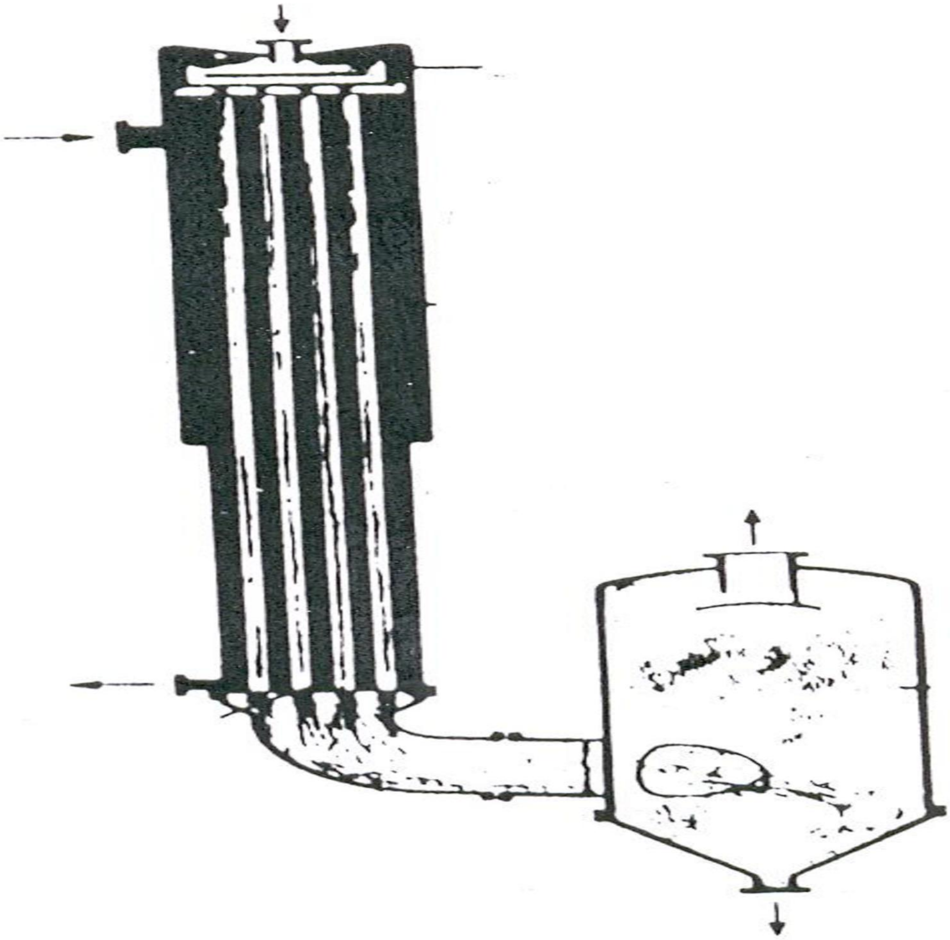

Fig.3.2 Single Effect Falling Film Evaporator (courtesy Kessler H.G.)

Table-3.1: Difference between rising and falling film evaporators

Rising Film Evaporators	Falling film Evaporators
More residence time	Less residence time
More temperature difference is required between heating medium and feed	Less temperature difference is required between heating 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 hence 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 products as gentle heating
More fouling problem	Less fouling problem

Materials of construction

Evaporator bodies and tubes are fabricated from the materials mostly of stainless steel (AISI-SS-316) is used when corrosive action is to be prevented.

Design consideration

Evaporator drums invariably operate under vacuum. These are designed for an external pressure of 0.1 N/mm^2 (100 kPa). The bottom head may be conical in many cases and may be designed for similar pressure rating. The top head may be flanged for flared and dished shape or conical. The calandria which has the tubular heating surface is designed as a shell and tube heat exchanger. Since steam under pressure in usually accepted as the heating medium, the design is based on the pressure of steam. The entire evaporator body must be rigid. The conical head, the calandria and the vapour drum are connected by flanged joints or directly welded. The vapour drum may be made up to separate cylindrical pieces and joined by flanges. Large openings like manholes, sight glasses must be reinforced with compensating rings. Supports may be placed below the brackets welded to the vapour drum or to the calandria. External calandria is also designed as a shell and tube heat exchanger.

3.2.2. 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.

Fig- 3.3: Plate evaporator

The advantages of plate evaporator are its, flexibility, low head space, sanitary construction and shorter residence time which makes evaporation 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.

3.2.3. 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.

Fig-3.4: Mechanical film evaporator (SSHE)

The Figure 3.4 depicts the cross-section of an evaporator with a rotating inner section. 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.

3.2.4. 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. The alternative passages for feed and steam is provided.

Fig-3.5: Expanding flow evaporator

Entrainment separators

The entrainment separators are basically depend on principles of impingment theory, where liquid droplets get returned due to spiral tubes and baffles installed in the path of the vapour. The other principle is change in direction as well as velocity. For industrial applications centrifugal type of entrainment separators are in use.Entrainment results whenever a vapour is generated from a liquid. So the vapour carries these liquid droplets. Separators provide a separation of liquid from vapour.

Vapour Release Chamber

A large chamber is used to reduce the velocity of vapour stream. This enables the droplets to settle out by gravity. The vapour release drum may either be placed just above the bundle shell or it is a separate unit placed adjoining to tube bundle shell, being connected to it by a large pipe. It may not be economically practical to make the vapour head large enough to accomplish the entire decontamination of the vapour. Further, increasing vapour space decreases entrainment of larger drops, but has not effect on small drops.

The vapour disengagement rate from a boiling liquid surface should not normally be more than 30 cm per second for normal solutions at atmospheric pressure and may be about 3 cm per second with crude solutions. Even allowing for sufficient vapour disengagement space it is common practice to provide spray traps. These traps are merely a series of baffles giving rapid changes of direction to the vapour stream.

Wire Pad

Pads of finely woven wire set in the vapour release chamber at right angles to the vapour flow are used for entrainment. As the vapour and its entrained liquid pass through the pad, the liquid particles agglomerate, eventually falling back into the vapour release chamber. A highly purified dry vapour leaves the top of the pad. Application of such pads may be difficult for vapours with suspended solids, fibers or scale forming materials, which will block the wire mesh. In such cases washing facilities at proper intervals may be provided. Wire pads are not generally used in the food industry for the unhygienic condition it creates.

Vapour Release Drum Size

The size of drum provided above the tube bundle in most of evaporators, is decided by three important considerations. They are: (a)the foaming of the liquid in the evaporator, (b)the vapour velocity, and (c)entrainment separation. Foaming takes place above the liquid level and occupies a certain space of the vapour drum. The vapour velocity sets the minimum drum diameter.

A thumb rule commonly employed in evaporator design of this kind is that the height of the vapour space above the calandria should not be less than one vessel diameter and the bottom space below calandria should be one-fourth of vessel diameter. In cases where the entrainment separator forms an independent unit, the main drum can have a shorter disengaging height.

Centrifugal Separator

This is a separate drum in which the vapours are admitted tangentially and are made to flow in a helical path by use of baffles. The vapours leave either from the top of the drum or through a central pipe. A centrifugal type baffling system as shown in figure is fitted at the top of the drum. The vapours enter from the central passage and are diverted by the baffles separating the liquid in the process.

Fig- 3.6 (a) Centrifugal Separator

Fig- 3.6 (b) Centrifugal Separator