

Dairy Process Engineering



J.B. Upadhyay

Sunil M. Patel

Dairy Process Engineering

Author

J.B. UPADHYAY & SUNIL M. PATEL

Department of Dairy Engineering

AAU, Anand



AGRIMOON.COM

All About Agriculture...

Course Outline

Lesson	Page No
Module 1. Evaporation	
Lesson 1. Basic Principles of Evaporators	5-8
Lesson 2. Construction and Operation of Evaporators	9-13
Lesson 3. Different Types of Evaporators Used In Dairy Industry	14-22
Lesson 4. Calculation of Heat Transfer Area and Water Requirement of Condensers	23-34
Lesson 5. Basic Concepts of Multiple Effect Evaporators	35-42
Lesson 6. Operations and various feeding systems	43-46
Lesson 7. Economy of operation, Thermo processor and MVR system	47-51
Lesson 8. Care and maintenance of evaporators	52-55
Module 2. Drying	
Lesson 9. Introduction to Principle of Drying	56-59
Lesson 10. Equilibrium Moisture Content, Bound and Unbound Moisture etc.	60-62
Lesson 11. Rate of drying constant and falling rate, Effect of shrinkage	63-70
Lesson 12. Classification of Dryers, Spray Dryers, Drum Dryers and problems on Dryers	71-87
Lesson 13. Air Heating Systems, Atomization & Feeding System	88-94
Lesson 14. Factors Affecting Bulk Density of Powder, Spray Drying Controls	95-107
Lesson 15. Theory of Solid Gas Separation, Cyclone Separators, Bag Filters etc.	108-117
Lesson 16. Care and Maintenance of Spray and Drum Dryers	118-120
Module 3. Fluidization	
Lesson 17. Mechanisms of Fluidization, Characteristics of Gas Fluidization Systems, Minimum Porosity, Bed Weight, Pressure Drop in Fluidized Bed.	121-124
Lesson 18. Application of Fluidized Bed in Drying	125-128
Lesson 19. Batch Fluidization, Fluidized bed Dryer	129-133

Module 4. Mechanization in manufacture of indigenous dairy products	
Lesson 20.Butter making machines	134-141
Lesson 21.Ghee making machines	142-143
Lesson- 22.Ice-cream making equipment	144-151
Lesson- 23.Cheese making equipment	152-156
Module 5. Packaging Machines for Milk & Milk Products	
Lesson 24.Packaging Machines for Milk	157-168
Lesson 25.Packaging Machines for Milk Products	169-174
Module 6. Membrane Processing	
Lesson 26.Ultra Filtration	175-182
Lesson 27.Reverse Osmosis	183-186
Lesson 28.Electro dialysis	187-192
Lesson 29.Materials for Membrane Construction	193-197
Lesson 30.Ultra Filtration of Milk	198-201
Lesson 31.Effect of Milk Constituents on Operation of Membrane Process	202-205
Lesson 32.Membrane for Electro Dialysis	206-209

Lesson-1

Basic Principles of Evaporators

1.1.INTRODUCTION

Evaporation and vapourization are two processes in which simultaneous heat and mass transfer process occurs 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.

1.2. VAPOURIZATION AND EVAPORATION

Evaporation and vaporization are quite different from each other. The differences are shown in Table 1.1.

Table-1.1: Differences between evaporation and vaporization

	Vapourization		Evaporation
(i)	Vapourization occurs when entire mass of liquid is raised to the boiling point.	(i)	It is only a surface phenomenon with only surface molecules escaping at a rate depending upon area of open surface.
(ii)	It is a much faster process for the production of vapours.	(ii)	It is a relatively slow process and depends mainly on temperature difference and on difference of vapour pressure between air and liquid.
(iii)	Boiling point is related to the pressure above the liquid surface and the amount of solute.	(iii)	Evaporation occurs at normal room temperature and application of heat is not necessary under normal evaporation

			process.
(iv)	Vapourization of liquid is visual in the form of vapour bubbles rising and escaping at the surface.	(iv)	Evaporation is not usually visual and hence not detected easily.
(v)	Vapourization can be controlled by variation in pressure.	(v)	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 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 °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, weldability, 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.



Lesson-2

Construction and Operation of Evaporators

2.1. INTRODUCTION

A number of evaporators of different design have been developed. The need of large scale operation and of improvement in quality has replaced the batch type evaporators. We shall discuss here the most important types of evaporators which are of interest to the dairy industry.

2.2. EVAPORATOR SYSTEMS

Basically an evaporator system consists of a heat exchanger, supplying the sensible heat to raise the product to its boiling point and provide the latent heat of vaporization, a separator for the separation of vapour and concentrate, a condenser to remove the resultant vapour as condensate and a vacuum system as the process is carried out under reduced pressure. The heating medium is steam. For vacuum, barometric leg condenser, vacuum pump and steam ejector are generally used. The evaporators may employ natural or forced circulation of the product. In natural circulation units, circulation of the liquid is brought about by convective currents arising from the heating surface. In forced circulation evaporators, the increased velocity of the liquid over the heat transfer surface will bring about a marked increase in the liquid heat transfer coefficients. The circulation is achieved with the aid of an external circulating pump generally a centrifugal pump.

The simplest evaporator as shown in following figure, consists of an open pan and kettle in which liquid is boiled. The heat is supplied by condensation of steam in one side of a metal surface and the liquid material to be evaporated on the other side. Sometimes heating coils immersed in the liquid. In some cases the kettle is indirect fired. These evaporators are inexpensive and simple to operate, but the heat economy is poor. Paddles and/or scrapers are used to improve the economy and quality of the product.

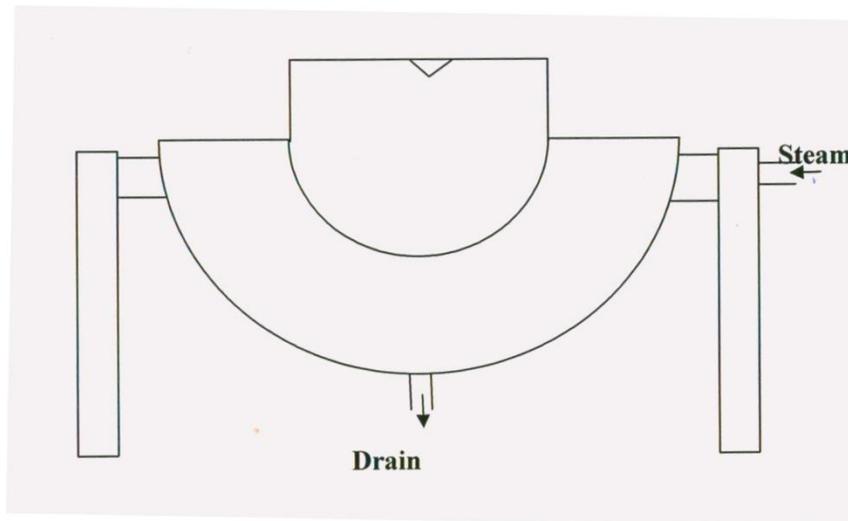


Fig-2.1: Evaporator System

Based on the nature of the heat transfer surface, evaporators can be classified as:

- (1) Tubular surface with natural or forced circulation.
 - a. Horizontal tube evaporator
 - b. Vertical short tube evaporator
 - c. Falling film evaporator
 - d. Rising /Ascending / climbing film evaporator
- (2) Flat heating surface: plate evaporator
- (3) Stationary cylindrical surfaces with scraped surface evaporator.

2.3. TYPES OF EVAPORATORS

Evaporators used in food industry may also be classified in different ways as under.

1. Operating pressure – Vacuum and Atmospheric
2. Number of effects – Single effect and multiple effect
3. Type of convection – Natural convection and forced convection
4. Continuity of operation – Batch and continuous
5. Type of heat exchanger – Tube type, plate type, scraped surface etc.

(i) Horizontal Tube Evaporator

A simple unit, not used to a great extent on new installations, is the horizontal tube evaporator. Horizontal tubes from 2 to 3 cm diameter extended across the bottom of a cylindrical chamber from one to three meters in diameter and 2.5 to 4.5 meter high. Steam

enters a chest on the end of the tubes, moves through the tubes and the condensate is removed from the chest at the opposite end. The vapour is removed from the top of the chamber and the product circulation is by natural circulation over the heating coil.

(ii) Vertical Tube (short tube calandria) Evaporator:

Tubes carrying the steam internally are placed vertically in the bottom of the cylindrical evaporator chamber. It is easier to clean the tubes in a vertical unit than in a horizontal tube evaporator, here also the product circulation is by natural convection. This type of unit is known as the Roberts evaporator in Europe and is the calandria evaporator in the United States.

(iii) Basket Type Evaporator:

In a basket type evaporator the tubes may be placed in the shape of a ring or tubes. This unit provides an open space on the periphery so that the liquid may circulate more freely through the coils, with the liquid moving up through the coils as it is heated and the colder product moving down through the annulus around the basket.

Components of evaporator system other than heat exchanger are as under :

Vapour and Entrainment separators

These are used in most evaporators to obtain vapours without product particles. Entrainment results wherever a vapour is generated from a liquid boiling vigorously. When this occurs the vapour carries with it varying quantities and sizes of liquid droplets. Separators provide a means for separating the vapour from the liquid with minimum liquid carry-over. Various mechanisms such as inverted U-tube, spiral, baffle, centrifugal type are adopted for such separation.

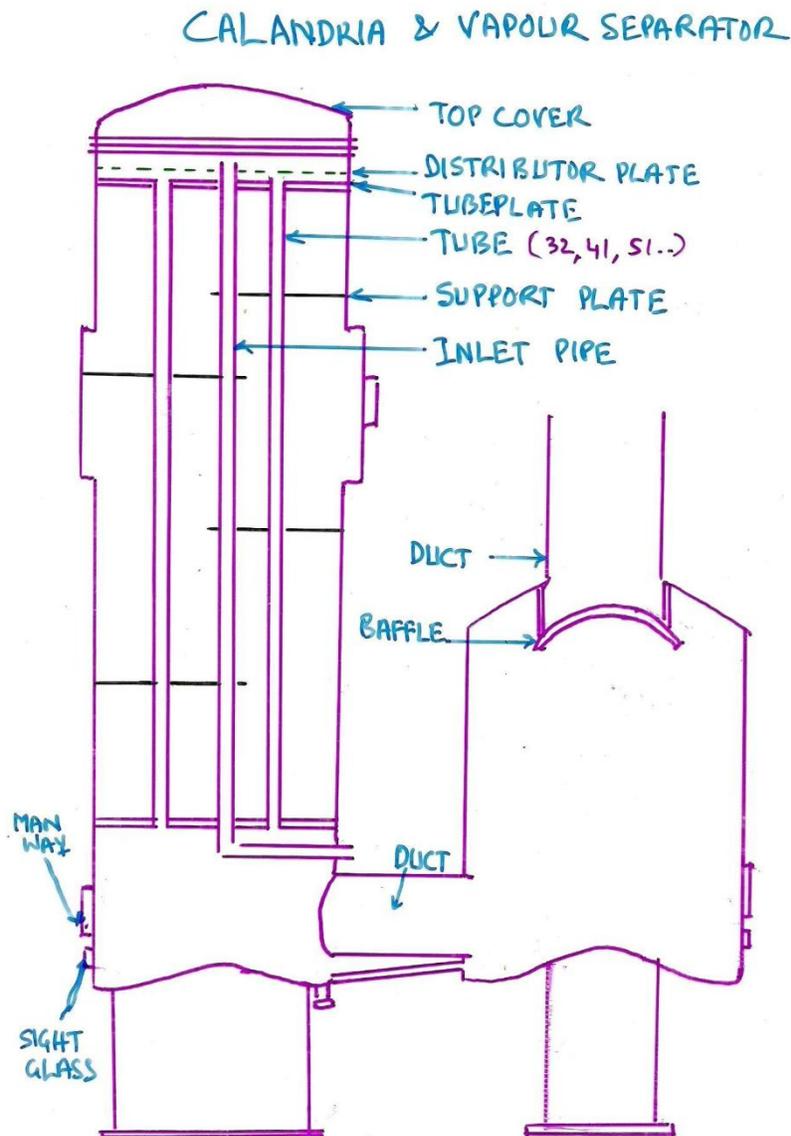


Fig 2.5 (c) Evaporator with vapour separator and Entrainment separator

Vacuum producing device

In an evaporator, evaporation of milk occurs at temperature ranging from 45-75 °C and operated under vacuum. To create vacuum, it is necessary to remove vapour and other gases and. The vapour constitutes by far the greatest part of the total volume of the gases. As the vapour is condensed, vacuum is maintained because the volume occupied by the liquid is considerably less than the original vapour. To change vapour to liquid requires that the latent heat must be removed from the vapour. The heat is extracted through an indirect or a direct heat exchanger. The vapour is removed after last calandria by condensation either by condensing on water cooled surfaces or by condensing through direct contact with cooling

Dairy Process Engineering

water. The condenser is therefore the main vacuum pump and additional vacuum pumps such as steam jet air suction pumps, liquid seal pumps and others have only the purpose of removing non-condensable gases and thus maintaining the vacuum.



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
 -

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/m² K, while for multi effect evaporators it is 1500-2200 W/m² 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.

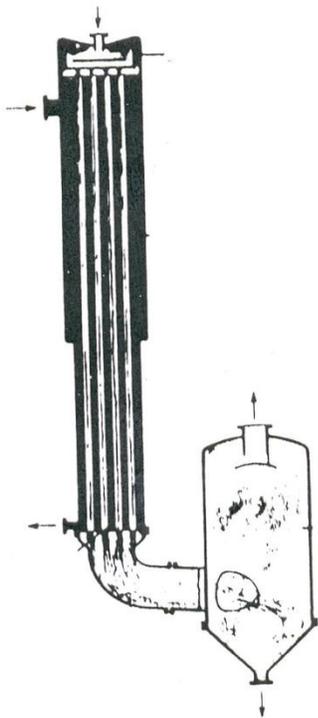


Fig.3.2 Single Effect Falling Film Evaporator (courtesy Kessler H.G.)

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/mm² (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 is 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.

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.

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.

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.



Lesson-4

Calculation of Heat Transfer Area and Water Requirement of Condensers

4.1. INTRODUCTION

In the evaporation system, steam is used as a heating medium as well as vapour produced from the previous effect is used as a heating medium in next effect. While the vapour from the final effect enters in the vapour condenser where cooling water is circulated to condense the vapour and thereby maintains the vacuum. The proper calculation of heat transfer area and the water requirement will decide the energy requirement and the capacity of each system components.

4.2. HEAT TRANSFER IN BOILING LIQUIDS

Heat transfer in boiling liquids and condensing vapour is accompanied by a change in the phase of liquid or vapour, the saturation temperature of the forming vapour (t_s) is determined by the ambient pressure P . This temperature t_s remains constant through out the process of boiling of any liquid at constant pressure. Experience however shows that the boiling liquid is usually overheated. (feed temperature, t_f is greater than t_s).

Experience shows that a sharp increase in the temperature is observed only in a layer 2-5mm thick over the heated surface. Hence the temperature of the liquid on the heating surface is higher than the saturation temperature by $\Delta t = t_w - t_s$. The value of Δt rises with an increase in the rate of heat transfer q ($W/m^2.K$). The temperature profile of liquid near heating surface is shown in following curve.

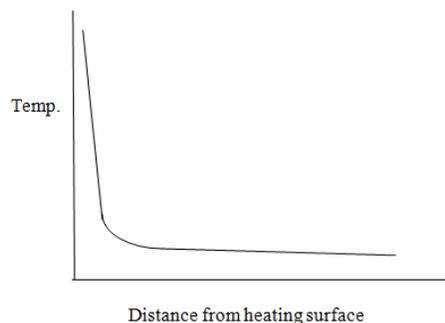


Fig-4.1: Temperature profile in heating tube

It has been established by visual observation that vapour bubbles form only on the heated surface, where liquid superheat is maximum, and only at individual points of that surface called starting boiling. The surface where the effect of adhesion is minimum may become evaporation starting points. Adhesion is defined as the effort required detaching the liquid from unit area of the hard surface.

Further, experience shows that the number of starting points of bubble (Z) depends on the degree of superheat at the heating surface, i.e. on the temperature difference, $\Delta t = t_w - t_s$. A rise in Δt entails an increase in Z and boiling intensifies. Essentially, this dependence is traced to the phenomenon of surface tension appearing at the liquid vapour interface.

Surface tension is defined as the stress causing the free surface of the fluid to contract; this stress is tangential to the surface. The pressure inside a bubble p_1 is greater than the surrounding liquid pressure p owing to surface tension. According to the Laplace equation, for a bubble in equilibrium the difference between the two pressures is determined by the equation $\Delta p = p_1 - p = 2s/r$, Where s = surface tension kg/m, r = curvature radius of bubble, m.

After their formation, the bubble grows rapidly and detach from the surface on attaining a certain size. The size of bubble at the moment of its separation from the surface is determined mainly by the interaction of the weight of gravity and surface tension. Besides, the generation of bubbles and their separation from the surface depend to a great measure on whether or not the liquid wets the surface.

The wetting capacity of a liquid is characterized by the contact angle θ , formed between the wall and the free surface of the liquids, the larger the angle θ , the poorer the wetting capacity of the liquid. Following figures illustrate the same.

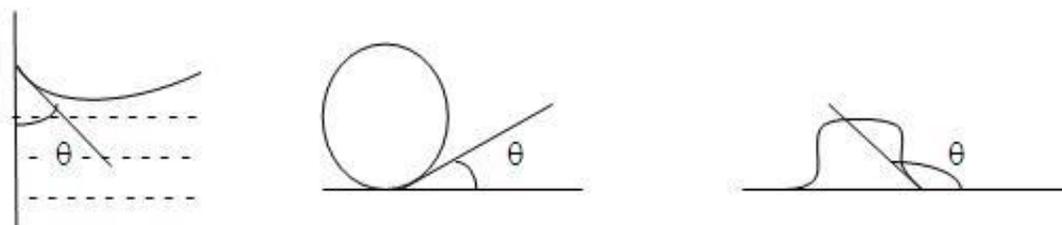


Fig-4.2: wetting capacity of the liquid based on angle θ

Since the temperature of the boiling liquid t_i , is higher than the saturation temperature t_s , intensive heat transfer between the liquid and bubble takes place, and that causes the bubble to continue to grow after its separation from the surface. The bubble increases in volume dozens of times, this depending on the rise time and degree of liquid superheat.

The multiple increase in the volume of separated bubbles evidences that from the heating surface that is transferred mainly to the liquid; it is then transported into the volume by convection and is further utilized to evaporate the liquid into bubbles. Direct transfer of heat from the heating surface to the vapour is possible only during the growth of bubbles prior to their detachment from the surface. But, owing to the small bubble-to-surface contact area and the low thermal conductivity of vapour, only a relatively small amount of heat can be transferred to the bubbles in that period.

Boiling is classified in three types:

- 1) Interface evaporation
- 2) Nucleate boiling
- 3) Film boiling.

In interface evaporation, regime first, liquid contacts heated surface to produce vapour which rises due to convection forming convection currents to circulate the liquid, the phenomenon is free or natural convection. With further rise in temp, $\Delta t = (t_w - t_s)$ bubbles are formed adjacent at the surface due to high energy in liquid particles; they rise above the water surface but condense before reaching liquid surface.

The phenomenon, nucleate boiling commences in the next regime in figure. With further rise in temperature, Δt , liquid gets heated up, bubbles do not condense, they help evaporation, and this phase is known as nucleate boiling as shown in the next regin in the diagram. There is limit to this phenomenon as shown by crest of the curve in the figure. The peaking point is a critical point and heat flux at this critical state is called critical heat flux.

Beyond the crest of the curve, bubbles cover metal surface providing an insulating effect, thereby decreasing heat flux. The film of bubble is unstable during the next regime, it reforms and collapses. On further increase of Δt the stable film forms and the heat flow is low. Any further increase of Δt involves heat transfer by radiation also.

4.3. HEAT TRANSFER DURING CONDENSATION

The condensation phenomenon is very important in the evaporators for efficient heat transfer. The condensation of steam in the calandria is of two types i.e. (i) Film condensation (ii) Drop wise condensation. Film condensation gives steam side film co-efficient in the range of 10,000 to 12,000 W/m²K, where as drop wise condensation gives steam side film co-efficient in the range of 25,000 to 30,000 W/m²K.

a) Factors affecting the boiling point:

(1) The pressure or vacuum respectively in the evaporating space.

Vapour and liquid are in equilibrium with each other and their temperature at any time is a function of the saturated vapour pressure. A lowering of the pressure lowers the boiling point.

(2) The concentration of the solution (as osmotic pressure)

Boiling point is influenced by the amount of dissolved matter. Dissolved substances exert osmotic forces which lower the vapour pressure of a solution at constant temperature or raise the boiling point if the pressure is constant.

(3) The hydrostatic pressure of a column of liquid.

Due to hydrostatic pressure boiling point increases. A column of liquid of height H produces an increase in pressure of $P=H.\rho.g$

b) Factors affecting the size of heating surface:

It depends upon the amount of heat to be exchanged.

If milk enters at boiling point: Then $m_w.L = A.U(t_H-t_B)$, t_B =Boiling point, t_H =Temp. of steam

If cold milk enters: $m_wL + m_M C_M (t_B - t_o)$, t_o =Initial temp., t_B milk at boiling point.

For superheated milk: $m_w.L - m_M C_M (t_V-t_B)$, t_V =High temp. than boiling point.

Surface area is also dependent on the over all heat transfer coefficient and the temperature difference.

In practice, following table gives the normal range of values of overall heat transfer coefficients (U):

Table-4.1: Normal range of values of overall heat transfer coefficients

Number of Effect	Skim milk (W/m²K)	Whole milk (W/m²K)
1st effect	2300-2600	2000-2200
2 nd effect	1900-2200	1700-1900
3 rd effect	1000-1200	900-1100

Note: 1 Watt=0.86 kcal/h, 1kcal/h =1.163 Watt

During continuous operation ‘U’ drops as deposition of precipitated protein or calcium phosphate on the calendria tubes. Deposits may also form on steam side if complete separation of product from vapour is not carried out in vapour separator and this vapour taken in steam chest of the next effect. So plant must be cleaned at regular interval with sequence of water-caustic soda solution-water-nitric acid-water.

c) Factors affecting the heat transfer coefficients:

(i) Steam side film coefficient:

- (a) It depends on the temperature drop.
- (b) Condensing temperature of steam. (a) and (b) are fixed by condition of operation.
- (c) Amount of non condensable gas present. It depends on evaporator construction.

(ii) Boiling liquid side surface coefficient:

- (a) Velocity of flow of milk
- (b) Viscosity of fluid
- (c) Cleanness of the heating surface.

4.4. HEAT AND MATERIAL BALANCE OF SINGLE EFFECT EVAPORATOR:

Heat Balance

$$F.h_f + S.H_s = L.h_L + V.H + Sh_c \text{ (neglecting heat losses)}$$

$$\text{Therefore , } F.h_F + S(H_s - H_c) = Lh_L + VH \dots\dots\dots(1)$$

Where, F= Feed rate, kg/h

h_f = heat content of feed, kJ/kg

S =steam supply rate, kg/h

H_s = Enthalpy of steam, kJ/kg

L = output rate of concentrate, kg/h

h_L = heat content of concentrate, kJ/kg

V = rate of vapour production, kg/h

H = Heat content of vapour, kJ/kg

h_c =heat content of condensate, kJ/kg

Material Balance:

$$F = L + V \dots\dots\dots(2)$$

Based on the total solid, we have

$$F x_F = L x_L + V y \dots\dots\dots(3)$$

Where, x_F = Feed concentration, % TS

x_L = Concentration of condensed milk, % TS

y = solids in vapour (taken as zero)

Capacity:

From equation (3)

$$F x_F = L x_L \text{ as } V y = 0$$

Therefore , $F = L (x_L / x_f)$ and $L = F (x_f / x_L)$

Therefore , $(F - V) = F (x_f / x_L)$, (as $L = F - V$)

$$\text{Therefore , } V = F [1 - (x_f / x_L)] \dots\dots\dots(4)$$

4.5. MATERIAL AND HEAT BALANCE OF DOUBLE EFFECT EVAPORATOR

Material Balance:

$$\text{1st effect, } F = L_1 + V_1 \dots\dots\dots(1)$$

$$\text{2nd effect, } L_1 = L_2 + V_2 \dots\dots\dots(2)$$

Substituting for L_1 in equation (1) from equation (2)

$$F = L_2 + V_2 + V_1$$

$$\text{Therefore , } F = L_2 + E \dots\dots\dots(3) \text{ where, } V_1 + V_2 = E$$

Based on solid,

$$\text{1st effect, } F \cdot x_F = L_1 x_{L1} \dots\dots\dots(4)$$

$$\text{2nd effect, } L_1 x_{L1} = L_2 x_{L2} \dots\dots\dots(5)$$

$$\text{Therefore, } F \cdot x_f = L_2 x_{L2} \dots\dots\dots(6)$$

$$\text{Therefore, } L_2 = F (x_f / x_{L2})$$

Substituting the value of L_2 into equation (3) we get,

$$F = (F x_F / x_{L2}) + E \text{ or } F = (F x_F / x_{L2}) + V_1 + V_2 \dots\dots\dots(7)$$

In terms of total evaporation, E kg/h

$$E = F - (F x_F / x_{L2})$$

Therefore , $E = F [1 - (x_F / x_{L2})]$ (8)

Heat balance:

$$F.h_F + S H_s = L_1 h_{L1} + V_1 H_1 + S h_{c1}$$

Therefore, $F h_F + S(H_s - h_{c1}) = L_1 H_{L1} + V_1 H_1$ (i)

Therefore, $F h_F + S(H_s - h_{c1}) = (F - V_1) h_{L1} + V_1 H_1$ (as $L_1 = F - V_1$)

Therefore, $F h_F + S(H_s - h_{c1}) = F h_{L1} - V_1 h_{L1} + V_1 H_1$

Therefore, $F (h_F - h_{L1}) + S (H_s - h_{c1}) = V_1 (H_1 - h_{L1})$ (ii)

Similarly taking heat balance on 2nd effect,

$$L_1 h_{L1} + V_1 H_1 = L_2 h_{L2} + V_2 H_2 + V_1 h_{c2}$$

Therefore , $L_1 h_{L1} + V_1 (H_1 - h_{c2}) = L_2 h_{L2} + V_2 H_2$ (iii)

Therefore , $L_1 h_{L1} + V_1 (H_1 - h_{c2}) = (L_1 - V_2) h_{L2} + V_2 H_2$ (as $L_2 = L_1 - V_2$)

Therefore , $L_1 h_{L1} + V_1 (H_1 - h_{c2}) = L_1 h_{L2} - V_2 h_{L2} + V_2 H_2$

Therefore , $L_1 (h_{L1} - h_{L2}) + V_1 (H_1 - h_{c2}) = V_2 (H_2 - h_{L2})$ (iv)

4.6. HEAT AND MATERIAL BALANCE OF TRIPLE EFFECT EVAPORATOR

1st effect:

$$F h_F + S H_s = V_1 H_1 + S h_{c1} + L_1 h_1$$

Therefore , $F h_F + S(H_s - h_{c1}) = V_1 H_1 + L_1 h_1$

Therefore , $F h_F + S(H_s - h_{c1}) = V_1 H_1 + (F - V_1) h_1$

Therefore , $F(h_F - h_1) + S(H_s - h_{c1}) = V_1 (H_1 - h_1)$ (i)

2nd effect:

$$L_1 h_1 + V_1 (H_1 - h_{c2}) = V_2 H_2 + L_2 h_2$$

$$= V_2 H_2 + (F - V_1 - V_2) h_2$$

$$= V_2 H_2 + (L_1 - V_2) h_2$$

$$= V_2 H_2 + L_1 h_2 - V_2 h_2$$

Therefore , $L_1 (h_1 - h_2) + V_1 (H_1 - h_{c1}) = V_2 H_2 - V_2 h_2$

$= V_2 (H_2 - h_2)$ (ii)

3rd effect :

$$V_2 H_2 + L_2 h_2 = V_3 H_3 + V_2 h_{c2} + L_3 h_3$$

Therefore , $V_2 (H_2 - h_{c2}) + L_2 h_2 = V_3 H_3 + (F - V_1 - V_2 - V_3) h_3$

$$= V_3 H_3 + (L_2 - V_3) h_3$$

$V_2 (H_2 - h_{c2}) + L_2 (h_2 - h_3) = V_3 (H_3 - h_3)$ (iii)

Material balance:

$$F = L_1 + V_1, L_1 = L_2 + V_2, L_2 = L_3 + V_3$$

Therefore, $L_1 = L_3 + V_3 + V_2$

Therefore, $F = L_3 + V_1 + V_2 + V_3 \dots\dots\dots(i)$

Based on solids,

$$F x_f = L_1 x_1, L_1 x_1 = L_2 x_2, L_2 x_2 = L_3 x_3$$

Therefore, $F x_f = L_3 x_3$, Therefore, $F = L_3 (x_3 / x_f)$

Therefore, $F = (F - V_1 - V_2 - V_3) (x_3 / x_f)$

Therefore, $E = F - F(x_f / x_3) = F [1 - (x_f / x_3)]$

Combined:

$$F h_F + S H_s = S h_{c1} + V_1 h_{c2} + V_2 h_{c3} + V_3 H_3 + L_3 h_3$$

Different Vacuum producing devices:

Production and maintenance of vacuum in the evaporator is very important for the smooth and efficient evaporation operation. The various vacuum producing devices used in dairy industry are as follows

- 1) Indirect (Shell and Tube) type condenser
- 2) Direct type condenser

1) Indirect type:

The surface condenser is an indirect type heat exchanger in which cold water on one side causes vapour coming from the product to condense on the other side. A common indirect heat exchanger used as a surface condenser is the tubular unit.

2) Direct type:

A jet condenser is a heat exchanger in which cooling water is sprayed into the unit where vapour is to be condensed. Jet type condenser can be further classified as parallel flow or counter flow type. The parallel flow condenser is normally operated as a wet condenser and the counter current flow condenser as a dry condenser. In parallel flow condenser, air and water are removed at the same temperature whereas in counter current condenser, the non-condensable are removed at the temperature of incoming water.

In case of dry condenser, the cooling water is removed by one pump and the non-condensable including the air removed by another pump. In a wet condenser, condensed vapour and non condensable are all removed together.

A jet condenser will use cooling water amounting 20 to 50 times the weight of vapour. Thus, the vapour being removed from the product and the cooling water is mixed. A jet condenser is normally used in milk evaporating operation in preference to a surface condenser, the surface condenser being more expensive

The quantity of water required is less for a counter flow type of condenser. Another advantage is that the air and vapour need not enter at the top of the unit as is done with parallel flow. The quantity of air removed from the evaporator system is about 15-25% of the volume of cooling water. Leaks in the system can cause the quantity of air to be considerably higher and result in expensive operation.

Table 4.1 Pressure, volume and boiling point relationship

Boiling Point °C	mm of Hg absolute pressure	Specific Volume of Vapour (m ³ /kg)
75	434	2.8
70	233	4.8
60	149	7.7
50	92	12.0
40	55	19.6

Barometric Leg Condenser:

It is placed high enough so that water and condensate from the condenser escapes from it by a **barometric leg**. In order to remove water and condensate from the plant without losing vacuum it is necessary that a leg of liquid be maintained with a hydrostatic head $H\rho$, equal to the difference between vacuum and atmospheric pressure; where H is the height and ρ is the density. In this manner the upper surface of the liquid in the tail pipe is at a pressure corresponding to the vacuum and the liquid at the bottom of the tail pipe is at atmospheric pressure due to the weight of the hydrostatic head. Thus liquid under vacuum continuously enters the tail pipe and liquid at atmospheric pressure continuously leaves from the bottom of the tail pipe by way of the hot well at the bottom. Atmospheric pressure corresponds to a hydrostatic head of 10.35 meters of water and complete vacuum corresponds to zero hydrostatic head. To maintain a process at substantially complete vacuum requires a leg of 10.35 meter of water be maintained between the barometric condenser and the hot well.

If a pump is used to remove the tail pipe liquid instead of a total barometric height, whatever head is supplied by the pump can be deducted from the total barometric height and the assembly is known as a low-level condenser.

$P = H\rho$, where $P = 1.013 \times 10^5 \text{ Pa} = 1.013 \text{ bar}$ i.e. Atmospheric pressure

Specific steam consumption and water requirement:

The following table gives the idea about steam required to vapourize one kg of water and cooling water requirement.

	Range (Steam in kg.)	Average (Steam in kg.)	Water required in kg. per kg vapor to condense
Single effect	1.83-1.00	1.17	20.00
Double effect	0.63-0.50	0.57	9.00
Triple effect	0.40-0.34	0.37	6.00
Quadruple effect	0.30-0.26	0.28	5.00
Quintuple effect	0.24-0.22	0.23	4.00

Water requirement in condenser:

In a condenser the circulating water extracts heat from the vapour to be condensed and the temperature of the circulating water is raised. In direct condenser the cooling water and vapour come in direct contact, hence the temperature of condensate is same as that of outlet temperature of circulating water.

Heat received by circulating water from one kg. of vapour = $m \times S \times (t_2 - t_1)$ kJ (i)

Heat given out by one kg. of vapour to circulating water = $H - h_1$ kJ (ii)

From equation (i) and (ii), we get $m \times S \times (t_2 - t_1) = H - h_1$

Therefore $m = (H - h_1) / [S \times (t_2 - t_1)]$ kg.

Where, m = quantity of circulating water required to condense one kg. vapour

S = specific heat of water kJ/kg K

t_1 and t_2 = Inlet and outlet temperature of circulating water

$H = h + x L$ = Heat content of one kg vapour at corresponding vacuum

$h_1 = S \times t_2$ = Heat of one kg condensate of vapour

Example:

Determine the amount of cooling water required in jet condenser to condense one kg vapour, if cooling water inlet and outlet temperature is 20 °C and 30 °C respectively. Take heat of vapour (H) as 2556 kJ/kg at 30 °C and specific heat of cooling water as 4.187 kJ/kg.

Solution:

$$m = (2556 - 125.6) / 41.87 = 58 \text{ kg}$$

Working of steam jet ejector:

Positive pump of reciprocating type and steam jet ejectors are commonly used to produce a vacuum. The pump is normally used for producing 24” Hg vacuum or less. The single stage steam jet ejector may be used for 25” Hg vacuum. The two stage steam jet ejector may be used for 28.8” Hg vacuum or three stages to produce 29.8”Hg vacuum using steam at 7.0 bar.

High pressure is admitted to a nozzle A that sends a jet of very high velocity into throat of a venturi.-shaped tube. The non condensable gases to be removed enter through suction chamber as shown in figure. By proper proportioning of a throat of the venturi, volume and velocity of steam used, the steam can be made to entrain (suck) non-condensable gases from the space under vacuum. For a very high vacuum, the steam air mixture from these jets goes to a condenser B, where the water vapour is condensed by a jet of cold water and the residual air passes to a second nozzle c. The discharge from second nozzle can usually be made to reach atmospheric pressure and is discharged at D to the air. Another important advantage of steam jet over reciprocating vacuum pump is that it has no moving parts and repairs are reduced to a minimum.

Fig. 4.10 steam jet ejector

Different type of pumps may be used for evacuation such as mechanically operating pump (ring pump) or steam ejectors which operates on similar principles to steam jet vapour compressors.

Oil lubricated vacuum pumps

The diagram shows a cross-section of a typical rotary vacuum pump. It consists of a horizontal cylindrical casing, with a rotor mounted eccentrically so that it is virtually in contact with the casing at one point of the circumference. The space between the rotor body

and the casing is thus crescent shaped, and communicates through the elongated inlet port with the vacuum pipeline, and through the elongated outlet port with the exhaust pipe. The rotor has longitudinal slots, usually four, which house vanes free to slide radially as the rotor turns. The vanes, which are usually made of asbestos fiber composition, are kept in contact with the casing by centrifugal force. In some designs the vanes slide tangentially, the purpose being to reduce frictional losses. As the rotor turns, pockets of air are enclosed between the vanes and transferred from the inlet to the outlet.



Lesson-5

Basic Concepts of Multiple Effect Evaporators

5.1. INTRODUCTION

Milk condensing in vacuum pan uses high amount of steam to evaporate water. Multiple effect evaporator is used for steam economy.

5.2. MULTIPLE-EFFECT EVAPORATION

In any evaporation operation, the major process cost is the steam consumed. Therefore, methods of reducing steam consumption (or of increasing economy, defined as mass of vapour produced per unit mass of steam consumed) are very important. The most common of the available methods is to use the vapour generated in the first evaporator as the heating medium for a second evaporator. Ideally, this method should produce almost 2 kg of vapour for every kg. of steam consumed. The method is feasible if the second evaporator is operated at a lower pressure than the first, so that a positive value of Δt is obtained across the steam-chest surface of the second evaporator. Several evaporators can be connected in series. In this way the amount of vapour (kg) produced per kg of steam consumed equal to the number of evaporator bodies. The increase in latent heat with decreasing pressure and additional radiation losses affect , the economy as the number of evaporators used is increased. This method of evaporation in series is called multiple-effect evaporation, and each stage is called an effect. The amount of steam consumption in multiple effect evaporators is already mentioned in Lesson 4.

5.2.1. Different level of vacuum in each effect of Multiple effect Evaporator

Here we assume that initially in all the calandria the level and temperature of feed is same. Now during starting of the plant steam is introduced in first calandria. So in that calandria milk initially will be heated and then raised to corresponding boiling point and vapour will be released. This vapour is going in the next calandria's heating jacket where the milk is cold and now start heating thereby the temperature difference between heating vapour and milk will decrease. It gives less condensation of vapour in second calandria. This gives rise of back pressure in first calandria tube and thereby the boiling point in first calandria will rise. The

same principle will work for subsequent calandrias and last calandria will correspond to condenser vacuum. Once this established than all the calandrias will operate at different vacuum levels.

By controlling the opening of orifice plates present in the airline of heating jackets is also used to control different vacuum levels in all the calandrias.

5.2.2. Multiple effect Evaporator capacity and steam economy

In addition to the economy increase in multiple-effect evaporation, a capacity variation would be expected. Note, however, that the temperature difference from initial steam to the final condenser which was available for a single-effect evaporator will be unchanged by inserting any additional effects between the steam supply and the condenser. For the simplest case, where each effect has area and coefficient equal to that of every other effect and where there are no boiling point rises $q_t = q_1 + q_2 + q_3 + \dots$ where q_t is the total heat-transfer rate in all effects and q_1, q_2, q_3 are the heat transfer rates in each of the individual effects.

$$q_t = U_1 A_1 \Delta t_1 + U_2 A_2 \Delta t_2 + U_3 A_3 \Delta t_3 + \dots$$

Since the areas and heat transfer coefficients are equal,

$$q_t = U_1 A_1 (\Delta t_1 + \Delta t_2 + \Delta t_3 \dots) = U_1 A_1 (\Delta t)_{total}$$

This rate of heat transfer is the same as that obtained with a single effect operating between the same ultimate temperature levels. Thus, multiple-effect evaporation using n effects increases the steam economy but decreases the heat flux per effect by a factor of about 1/n relative to single-effect operation under the same terminal conditions. Therefore, no increase in capacity is obtained and in fact, the additional complexity of equipment usually results in increased heat losses to the surroundings and a reduction in capacity. The increased steam economy must then, be balanced against the increased equipment cost. The result is that the evaporation using more than five or seven effects is rarely economical.

When the solution being evaporated has a significant boiling-point rise, the capacity obtained is very much reduced, for the boiling-point rise reduces the Δt in each effect.

5.2.3. Calculations for Multiple- Effect Evaporators

For a multiple – effect evaporator system calculations, the values required to be obtained are

- (i) The area of the heating surface in each effect,
- (ii) The kg of steam per hour to be supplied, and
- (iii) the amount of vapour leaving each effect, particularly in the last one.

The given values are usually as follows

- (1) Steam pressure to the first effect,
- (2) Final pressure in the vapour space of the last effect,
- (3) Feed conditions and flow to the first effect,
- (4) Final concentration in the liquid leaving the last effect,
- (5) Physical properties such as enthalpies and / or heat capacities of the liquid and vapours, and
- (6) Overall heat – transfer coefficients in each effect.

Usually, the areas of each effect are assumed equal.

The calculations are done using material balances, heat balances, and the capacity equations $q = UA\Delta T$ for each effect. A convenient way to solve these equations is by trial and error. The basic steps to follow are given as follows for a triple – effect evaporators.

5.2.4. Triple – Effect Evaporators' Calculation Method

- 1.** Determine the boiling point in the last effect from the known outlet concentration and pressure in the last effect,
- 2.** Determine the total amount of vapor evaporated by performing an overall material balance,
- 3.** Estimate the temperature drops ΔT_1 , ΔT_2 and ΔT_3 in the three effects. Then calculate the boiling point in each effect,

4. Calculate the amount vaporized and the flows of liquid in each effect using heat and material balance in each effect,
5. Calculate the value of heat transferred in each effect. Using the rate equation $q=UA\Delta T$ for each effect, calculate the areas, A_1 , A_2 and A_3 . If these areas are reasonably close to each other, the calculations are complete and a second trial is not needed. Otherwise a second trial should be performed.

Example: Evaporation of Milk in a Triple – Effect Evaporator

A triple effect forward – feed evaporator is being used to evaporate a milk containing 10 % solids to a condensed milk of 50% T.S. The boiling point rise of the milk (independent of pressure) can be estimated from $BPR^{\circ}C = 1.78x + 6.22x^2$, where x is weight fraction of T.S. in milk (K1). Saturated steam at 205.5 kPa (121.1°C saturation temperature) is being used. The pressure in the vapor space of the third effect is 13.4 kPa. The feed rate is 22680 kg / h at 26.7 °C. The heat capacity of the milk is (K1) $C_p = 4.19 - 2.35x$ kJ/kg.K. The heat of milk is considered to be negligible. The coefficients of heat transfer have been estimated as $U_1 = 3123$, $U_2 = 1987$, and $U_3 = 1136$ W / m² . K. If each effect has the same surface area, calculate the area, the steam rate used, and the steam economy.

Solution : Following the above steps outlined, the calculations are as follows:

Step 1. For 13.4 kPa, the saturation temperature is 51.67°C from the steam tables. Using the equation for BPR for evaporator number 3 with $x = 0.5$,

$$BPR_3 = 1.78x + 6.22x^2 = 1.78(0.5) + 6.22(0.5)^2 = 2.45 \text{ }^{\circ}C, \text{ so } T_3 = 51.67 + 2.45 = 54.12 \text{ }^{\circ}C$$

Step 2. Making an overall and a solids balance to calculate the total amount vaporized ($V_1 + V_2 + V_3$) and L_3 ,

$$F = 22680 = L_3 + (V_1 + V_2 + V_3)$$

$$Fx_F = 22680(0.1) = L_3(0.5) + (V_1 + V_2 + V_3)(0)$$

$$L_3 = 4536 \text{ Kg/h}$$

$$\text{total vapour} = (V_1 + V_2 + V_3) = 18\,144 \text{ kg/h}$$

Assuming equal amount vaporized in each effect, $V_1 = V_2 = V_3 = 6048$ kg/h. Making a total material balance on effects 1, 2, and 3 and solving.

$$(1) F = 22\,680 = V_1 + L_1 = 6048 + L_1, L_1 = 16\,632 \text{ kg/h}$$

$$(2) L_1 = 16\,632 = V_2 + L_2 = 6048 + L_2, L_2 = 10\,584 \text{ kg/h}$$

$$(3) L_2 = 10\,584 = V_3 + L_3 = 6048 + L_3, L_3 = 4536 \text{ kg/h}$$

Dairy Process Engineering

Making a solids balance on effects 1, 2 and 3 and solving for x ,

$$(1) 22\,680(0.1) = L_1 x_1 = 16\,632 (x_1), x_1 = 0.136$$

$$(2) 16\,632(0.136) = L_2 x_2 = 10\,584 (x_2), x_2 = 0.214$$

$$(3) 10\,584(0.214) = L_3 x_3 = 4536 (x_3), x_3 = 0.50$$

Step 3. The BPR in each effect is calculated as follows:

$$(1) \text{BPR}_1 = 1.78 x_1 + 6.22(x_1)^2 = 6.22(0.136)^2 = 0.36^\circ\text{C}$$

$$(2) \text{BPR}_2 = 1.78(0.214) + 6.22(0.214)^2 = 0.65^\circ\text{C}$$

$$(3) \text{BPR}_3 = 1.78(0.5) + 6.22(0.5)^2 = 2.45^\circ\text{C}$$

$$\Sigma \Delta T \text{ available} = T_{s1} - T_3 \text{ (saturation)} - (\text{BPR}_1 + \text{BPR}_2 + \text{BPR}_3)$$

$$= 121.1 - 51.67 - (0.36 + 0.65 + 2.45)$$

$$= 65.97^\circ\text{C}$$

Now

$$\Delta T_1 = \sum \left(\Delta T \frac{\frac{1}{U_1}}{\frac{1}{U_1} + \frac{1}{U_2} + \frac{1}{U_3}} \right)$$
$$= \frac{(65.97)(1/3123)}{\left(\frac{1}{3123}\right) + \left(\frac{1}{1987}\right) + \left(\frac{1}{1136}\right)}$$

$$\Delta T_1 = 12.40^\circ\text{C} \text{ similarly } \Delta T_2 = 19.50^\circ\text{C} \text{ and } \Delta T_3 = 34.07^\circ\text{C}$$

However, since a cold feed enters at effect number 1, this effect requires more heat.

Increasing ΔT_1 and lowering ΔT_2 and ΔT_3 proportionately as a first estimate,

$$\Delta T_1 = 15.56^\circ\text{C}, \Delta T_2 = 18.34^\circ\text{C}, \Delta T_3 = 32.07^\circ\text{C}$$

To calculate the actual boiling point of the milk in each effect,

$$(1) T_1 = T_{s1} - \Delta T_1$$

$$= 121.1 - 15.56 = 105.54^\circ\text{C}$$

$$T_{s1} = 121.1^\circ\text{C} \text{ (Condensing temperature of saturated steam to effect 1)}$$

$$(2) T_2 = T_1 - BPR_1 - \Delta T_2$$

$$= 105.54 - 0.36 - 18.34 = 86.84^\circ\text{C}$$

$$T_{s2} = T_1 - BPR_1 = 105.54 - 0.36$$

$$= 105.18^\circ\text{C} \text{ (Condensing temperature of steam to effect2)}$$

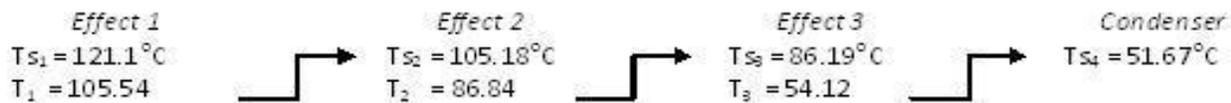
$$(3) T_3 = T_2 - BPR_2 - \Delta T_3$$

$$= 86.84 - 0.65 - 32.07 = 54.12^\circ\text{C}$$

$$T_{s3} = T_2 - BPR_2 = 86.84 - 0.65$$

$$= 86.19^\circ\text{C} \text{ (Condensing temperature of steam to effect3)}$$

The temperatures in the three effects are as follows:



Step 4. The heat capacity of the liquid in each effect is calculated from the equation $c_p = 4.19 - 2.35x$

$$F : c_p = 4.19 - 2.35(0.1) = 3.955 \text{ kJ/kg K}$$

$$L_1 : c_p = 4.19 - 2.35(0.136) = 3.869 \text{ kJ/kg K}$$

$$L_2 : c_p = 4.19 - 2.35(0.214) = 3.684 \text{ kJ/kg K}$$

$$L_3 : c_p = 4.19 - 2.35(0.5) = 3.015$$

The values of the enthalpy H of the various vapour streams relative to water at 0°C as a datum are obtained from the steam table as follows:

Effect 1:

$$T_1 = 105.54^\circ\text{C}, T_{s2} = 105.18, \text{BPR}_1 = 0.36 \quad T_{s1} = 121.1$$

$$H_1 = H_{s2} (\text{Saturation enthalpy at } T_{s2}) + 1.884(0.36^\circ\text{C superheat})$$

$$= 2684 + 1.884(0.36) = 2685 \text{ kJ/kg}$$

$$\lambda_{s1} = H_{s1} (\text{vapour saturation enthalpy}) - h_{s1} (\text{liquid enthalpy at } T_{s1})$$

$$= (2708 - 508) = 2200 \text{ kJ/kg latent heat of condensation}$$

Effect 2:

$$T_2 = 86.84^\circ\text{C}, \quad T_{s3} = 86.19, \quad \text{BPR}_2 = 0.65$$

$$H_2 = H_{s3} + 1.884(0.65) = 2654 + 1.884(0.65) = 2655 \text{ kJ/kg}$$

$$\lambda_{s2} = H_1 - h_{s2} = 2685 - 441 = 2244 \text{ kJ/kg}$$

Effect 3:

$$T_3 = 54.12^\circ\text{C}, \quad T_{s4} = 51.67, \quad \text{BPR}_3 = 2.45$$

$$H_3 = H_{s4} + 1.884(2.45) = 2595 + 1.884(2.45) = 2600 \text{ kJ/kg}$$

$$\lambda_{s3} = H_2 - h_{s3} = 2655 - 361 = 2294 \text{ kJ/kg}$$

Flow relations to be used in heat balance are

$$V_1 = 22\,680 - L_1, \quad V_2 = L_1 - L_2, \quad V_3 = L_2 - 4536, \quad L_3 = 4536$$

Write a heat balance on each effect. Using 0°C as a datum

$$(1) \quad F c_p (T_F - 0) + S \lambda_{s1} = L_1 c_p (T_1 - 0) + V_1 H_1$$

Substituting the known values,

$$22\,680(3.955)(26.7 - 0) + S(2200) = L_1(3.869)(105.54 - 0) + (22\,680 - L_1)(2685)$$

$$(2) \quad L_1 c_p (T_1 - 0) + V_1 \lambda_{s2} = L_2 c_p (T_2 - 0) + V_2 H_2$$

$$L_1(3.869)(105.54 - 0) + (22\,680 - L_1)(2244) = L_2(3.684)(86.84 - 0) + (L_1 - L_2)(2655)$$

$$(3) \quad L_2 c_p (T_2 - 0) + V_2 \lambda_{s3} = L_3 c_p (T_3 - 0) + V_3 H_3$$

$$L_2(3.684)(86.84 - 0) + (L_1 - L_2)(2294) = 4536(3.015)(54.12 - 0) + (L_2 - 4536)(2600)$$

Solving the last two equations simultaneously for L_1 and L_2 and substituting into the first equation,

$$\begin{array}{lll} L_1 = 17\,078 \text{ kg/h} & L_2 = 11\,068 & L_3 = 4536 \\ S = 8936 & V_1 = 5602 & V_2 = 6010 \quad V_3 = 6532 \end{array}$$

The calculated values of V_1 , V_2 and V_3 are close enough to the assumed values that steps 2, 3, and 4 do not need to be repeated. If the calculation were repeated, the calculated values of V_1 , V_2 , and V_3 would be used starting with step 2 and a solid balance in each effect would be made.

Step 5. Solving for the values of q in each effect area,

$$q_1 = S\lambda s_1 = \left(\frac{8936}{3600}\right)(2200 \times 1000) = 5.460 \times 10^6 \text{ W}$$

$$q_2 = V_1\lambda s_2 = \left(\frac{5602}{3600}\right)(2244 \times 1000) = 3.492 \times 10^6 \text{ W}$$

$$q_3 = V_2\lambda s_3 = \left(\frac{6010}{3600}\right)(2294 \times 1000) = 3.830 \times 10^6 \text{ W}$$

$$A_1 = \frac{q_1}{U_1\Delta T_1} = \frac{5.460 \times 10^6}{3123(18.56)} = 112.4 \text{ m}^2$$

$$A_2 = \frac{q_2}{U_2\Delta T_2} = \frac{3.492 \times 10^6}{1987(18.34)} = 95.8 \text{ m}^2$$

$$A_3 = \frac{q_3}{U_3\Delta T_3} = \frac{3.830 \times 10^6}{1136(32.07)} = 105.1 \text{ m}^2$$

The average area $A_m = 104.4 \text{ m}^2$.

$$\text{Steam economy} = \frac{V_1 + V_2 + V_3}{S} = \frac{5602 + 6010 + 6532}{8936} = 2.03 \text{ kg. of water evaporation / kg. of steam}$$

Specific steam consumption = 0.49 kg. of steam used / kg. of water evaporation

***** 😊 *****

Lesson- 6

Operations and various feeding systems

6.1 Introduction:

The most commonly used evaporation plant in the dairy is falling film evaporating plant consists of the following components which are assembled together in the required manner.

- a) Heat transfer surface or calandria
- b) Liquid/vapour separation system
- c) Vapour removal system and vacuum control system
- d) Ancillary equipment such as pumps for extracting and conveying milk, cooling water pumps, valves, gauges, thermometers etc.

a) Heat transfer Surface:

Efficient heat transfer from steam to liquid product is vital; both to the process and to the quality of the final product. Chemical, physical and biological changes in the product depend partly on time as well as temperatures. In general, high temperature and short time heat treatment produce less chemical and more biological effect than lower temperature sustained for long times. For economy it is important to keep the temperature as high, heating time as short as possible. Heat transfer rates and flow of product through the plant creates specific conditions within each type of equipment.

During heat transfer to milk, protein denaturation may take place on milk side if temperature of milk is high and when steam is condensing at high temperature. The build up of scale, which is hard and difficult to remove, reduces the rate of heat transfer at a much faster rate. Thus there is a need to wash the calandria after a period of operation to remove scale and restore the evaporation rate.

The use of two or more evaporators in series with gradually decreasing temperatures may be used to reduce the heat shock, especially when the more viscous product approaches final density. Thus, a triple effect plant operating at 70 °C, 57 °C and 44 °C in the final stage will give desirable product quality, concentration level and plant economy. This arrangement permits use of vapour from one effect to be reused for the next effect and so on, thus achieving greater economy as well as more gentle heat treatment.

The liquid product moves along the heating surface by convection assisted by vapour propulsion. The liquid is fed from the top of the tubes by means of weir or other device so as to form a thin film on the tube surface. Vapour from the evaporating liquid occupies the center of the tubes. Thus, only a thin quickly moving film is in contact with the heating surface. The falling film evaporator tends to provide a gentle heat treatment if properly operated.

b) Liquid/Vapour Separation System:

The separation of vapour from boiling liquid is possible by giving centrifugal or rotary motion at the entry to vapour separator. The adaptation of cyclone principle has removed the need for deflecting plants, baskets and entrainment separators in the vapour space. The tendency is to reduce the vapour system in size, because of the higher efficiency of separation.

c) Vapour Removal and Vacuum Control System:

The heart of the evaporator is the vacuum system, on which depends the successful operation, ease of operation and final product quality. It is important to remove vapour evaporated from the product as well as the noncondensable gases, which enter through leaks or are entrained in the product

d) Ancillary Equipment:

The main economy in evaporation is obtained by the continuous re-use of vapour. This vapour may be recompressed by live steam (TVR). The use of preheaters, interstage heaters and raw product heaters in the final condensate stage, all provide for economical operation. The use of heaters in this way also requires pumps to transfer the liquid product. These pumps are often operating against vacuum, and require water seals to maintain the vacuum.

6.2 Different feed flow arrangements in Multiple-effect evaporators .

In a forward feed system, the flow of process fluids and of steam are parallel. Forward feed has the advantage that no pumps are needed to move the solution from effect to effect (not applicable to modern calandria type evaporator). It has the disadvantage that all the heating of cool feed is done in the first effect, so that less vapour is generated here for each kg of steam resulting in lower economy. It has the further disadvantage that the most concentrated solution is subjected to the coolest temperatures. Low temperatures may be helpful in preventing decomposition of organics, but the high viscosity that may be found sharply reduces the heat transfer coefficient in this last effect.

In a backward feed system, the feed flows counter to the steam flow. Pumps are required between the effects. The feed solution is heated as it enters each effect, which usually results in better economy than that obtained with forward feed. The viscosity spread is reduced since the concentrated product evaporates at the highest temperature but heat sensitive materials may be affected. Forward feed system is generally used for heat sensitive product , while the backward feed is used for highly viscous product.

For best overall performance, evaporators may be operated with flow sequences that combine these two (i.e. mixed feed), or they may be fed in parallel with fresh feed evaporating to final concentration in each effect.

6.3 Capacity of Multiple – effect evaporators:

Although the use of the multiple-effect principle increases the steam economy, it must not be thought that there are no compensating disadvantages coordinate in importance with the economy of an evaporator system is the question of its capacity. By capacity is meant the total evaporation per hour obtained since latent heats are nearly constant over the ranges of pressure ordinarily involved, capacity is also measured by the total heat transferred in all effects. The heat transferred in these effects can be represented by the following equations

$$q = q_1 + q_2 + q_3 = U_1A_1 \Delta t_1 + U_2A_2 \Delta t_2 + U_3A_3 \Delta t_3$$

Assume, now that all effects have equal areas & that an average coefficient U_{av} can be applied to the system. Then equation can be written as

$$q = U_{av} A (\Delta t_1 + \Delta t_2 + \Delta t_3)$$

However, the sum of the individual temperature drops equals the total over-all temperature drop between the temperature of the steam and the temperature in the condenser & therefore $q = U_{av} A \Delta t$.

Suppose now that a single-effect evaporator of area A be operated with the same over-all temperature difference viz. with steam at 110°C and a vapour temp of 52°C Assume also that the over-all coefficient of the single-effect is equal to the U_{av} of the triple effect. The capacity of the single effect will be $q = U_{av} A \Delta t$.

This is exactly the same equation as that for the triple effect. No matter how many effects one use, provided the average over-all coefficients are the same exactly the same equation will be obtained for calculating the capacity of any evaporator. It follows from this that if the number of effects of an evaporation system is varied and if the total temperature difference is kept constant, the total capacity of the system remains substantially unchanged.



Lesson- 7

Economy of operation, Thermo processor and MVR system

7.1 Introduction

The economy of the evaporation system increases with number of effects, simultaneously the capital investment is also increase with number of effects. Hence overall economy of the operation is based on the cost benefit ratio. Further the improvement in economy Is possible by the use of vapour recompression system.

7.2 Cost factors in evaporator selection

If the cost of 1 m² of heating surface is constant, regardless of the number of effects, the investment required for an N-effect evaporator will be N times that of a single effect evaporator of the same capacity. The choice of the proper number of effects will be dictated by an economic balance between the saving in steam obtained by multiple effect operation and the added investment costs brought about by the added effect.

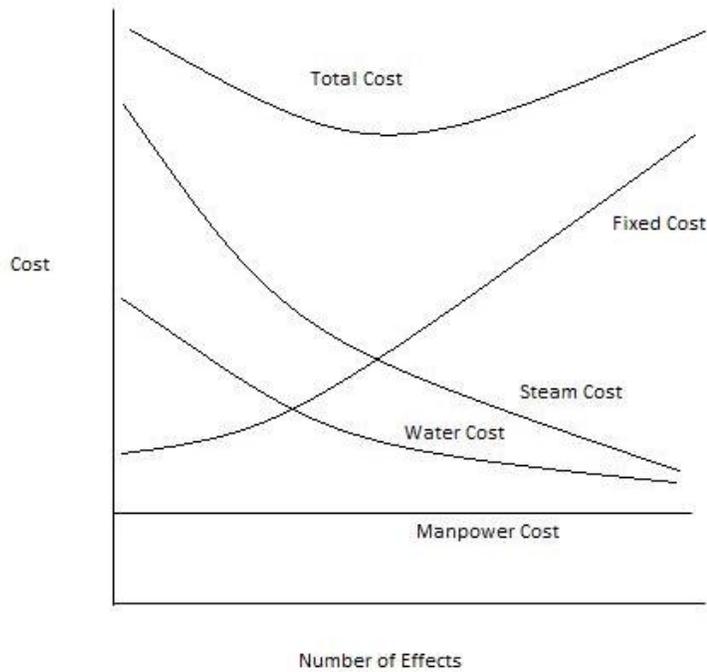


Fig.7.1 Cost factors in evaporator selection

The relations are shown in the graph. The annual fixed charges may be taken as a percentage of the first cost of the evaporator. Since the cost per sq.mt. of heating surface increases somewhat in small sizes, the curve for the first cost is not a straight line except in the upper part of its range. The cost of steam and water fall off rapidly at first but soon show the effect of the law of diminishing returns. Labour costs may be considered constant, since only one operator is needed except with a very large number of effects. The total cost of operating the evaporator is the sum of all these curves and usually shows a marked minimum for the optimum number of effects.

7.3 Vapour Recompression in Milk Condensing Plant:.

Vapour recompression is a process by which the low pressure vapour produced from the boiling milk in the calandria is recompressed to a higher pressure. This recompressed vapour is used for heating the milk again in either same effect or in previous effect. Because of this, the steam consumption per kilogram of evaporated water is reduced considerably, lowering the processing cost for the condensed milk.

There are two ways for recompressing the low pressure steam i.e. Thermal Vapour Recompression (TVR) by steam-jet vapour compressor or thermo compressor and Mechanical Vapour Recompression (MVR). At present in India TVR is common, while MVR is getting importance recently due to its extremely favourable characteristics for conservation of energy.

7.3.1 Thermal Vapour recompression (TVR)

In thermo compressor, the kinetic energy of a jet of steam is used to compress the vapour. It consists of a steam nozzle, suction chamber with inlet for sucking in the vapour, mixing chamber and recompression chamber as shown in Figure.

The process of thermo compression on enthalpy-entropy (h-s) diagram is depicted in Figure. Here, live steam at pressure P_1 (state-1) is almost isentropically expanded in the nozzle to suction pressure P_2 (state-2). Steam pressure usually employed in the condensing plant is about 8-12 bar and suction pressure about 0.2-0.3 bar depending on the effect from which the vapour is drawn. The expanded steam emerges from the nozzle as a jet of steam. The velocity of the steam is about 1000 m/sec.

In the mixing chamber the sucked-in vapour is entrained and carried away by the expanded steam. The vapour is accelerated as the steam transfers its kinetic energy to it. The mixing occurs at constant pressure, the enthalpy is increased and state point-3 is reached. From this point onwards, the cross-section of the thermo compressor increases, and so the kinetic energy of mixture is converted into potential energy. The pressure of the mixture is increased almost isentropically from state-3 to state-4. In this way the low pressure steam taken from a lower effect is compressed to a higher pressure corresponding to the inlet pressure of previous stage operating at higher pressure and temperature.

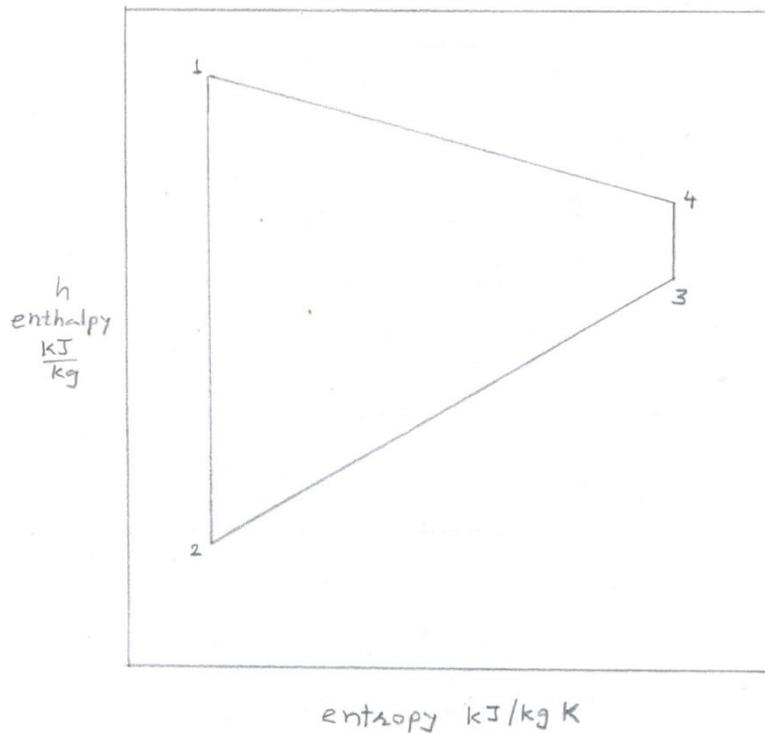


Fig.7.3 Enthalpy - Entropy diagram of Thermal Vapour recompression (TVR)

The amount of vapour, M_v and amount of live steam, M_s are related as follows (Kessler, 1981).

$$M_v/M_s = [0.8 (h_1 - h_2) / (h_4 - h_3)] - 1$$

Where h_1, h_2, h_3, h_4 is enthalpies of steam at various state points.

It can be seen from the above equation, that if the vapour to live steam ratio is higher, the factor $h_4 - h_3$ decreases. This means that rise in temperature of compressed vapour is smaller. A thermo compressor with a vapour to live steam ratio of 50 : 50, gives a temperature rise in

the compressed vapour of about 15°C. But, if the proportion is 60 : 40, the temperature rise is only 11°C.

Generally, the vapour drawn from the first effect is recompressed and used for the same effect again. However, more recently, the trend is to draw vapour from the second or third effect and use the recompressed vapour in the first effect. This is due to the fact that the evaporating capacity of earlier effects is increased.

With thermo compressor drawing vapour from the second effect, one must choose the right thermo compressor to achieve a temperature which lies at least 5°C above the boiling temperature of the first effect. The performance of thermo compressor is influenced by the heat transfer rate in calandria, suction pressure, discharge pressure and the motive steam pressure.

7.3.2 Mechanical Vapour Recompression (MVR)

Here, the low pressure vapour is compressed mechanically i.e. employing single or multiple stage radial flow compressors or by axial flow compressors. These compressors may be driven by electric motors, I.C. engines or steam turbines.

Layout for single effect evaporation and the process of mechanical compression is shown on enthalpy-entropy diagram. The quantity of vapour M_V drawn from the evaporator is at saturation condition with pressure P_1 , temperature t_1 and enthalpy h_1 . This condition is shown on h-s diagram as state-1. The mechanical compressor compresses the vapour almost isentropically to a pressure P_2 , temperature t_2 and enthalpy h_2 . This is superheated steam, which is not suitable for heating the milk as such, because of its bad heat transfer properties. It is cooled down to saturated state-3 i.e. temperature t_3 and enthalpy h_3 at constant pressure P_2 .

This is done by diverting a portion of condensate at temperature t_4 and injecting it in the superheated steam. The condensate evaporates by consuming superheat from the compressed vapour. The mixture thus achieves final state-3 with temperature t_3 enthalpy h_3 and pressure P_2 . The amount of steam available is thus increased by the amount of condensate mixed.

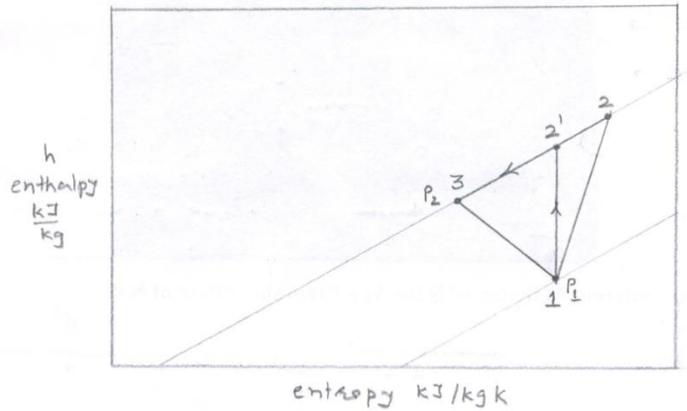


Fig.7.5 Enthalpy - Entropy diagram of Mechanical Vapour recompression (MVR)

At this stage it should be remembered that the energy required to drive the MVR may be costlier than steam. Thus actual saving will be somewhat less depending on the prices of steam and other forms of energy employed to run MVR.

With increasing energy costs, evaporators with MVR become increasingly competitive with multi effect evaporators with TVR. Apart from being extremely economic MVR has other advantages.

1. The maximum evaporating temperature of first effect can be reduced to such an extent that burning on of product is minimized.
2. The lowest effect of evaporating temperature i.e. of last effect can be high enough which results in lower viscosity of the concentrate facilitating easy handling of concentrate. The pre-heating of concentrate before drying may be avoided or may be reduced to a less drastic treatment.
3. The higher temperature in the final effect results in reduced choking of calandria. Thus the plant can be run for a longer period before cleaning.
4. The need for cooling water is considerably reduced or totally eliminated.

A major disadvantage of MVR is the greater expenditure on equipment, maintenance cost and noise problem, but most of the studies indicate that the payback period for MVR is about 2-2.5 years.

Lesson- 8

Care and maintenance of evaporators

8.1 Introduction:

The dairy plants mostly use tubular falling film evaporators for concentrating milk to the desired level of total solids. Most of the equipment, fittings, gauges, valves and density measuring devices are selected by individual plant manufacturer, but special care is needed in their selection and operation to get satisfactory results. The flow rates and flow pattern and the temperature gradients are of vital importance to efficient operation. Thus, loose jets, spindles and seats in steam valves can produce a fluctuating vacuum.

8.2 Operation of the Plant:

After going through general discussion on various components of the plant, we can now look into the details of operating parameters which affect the performance of the complete plant.

The performance of the evaporating plant is generally based on economy in the use of steam and the output capacity of the given plant. The economy is improved by either increasing the number of effects or by utilizing the outgoing vapour separated from milk. The increase in number of effect involves additional cost of calandria, pumps, piping system and also the operating cost. The other limitation is due to smaller temperature difference between heating medium and product as the numbers of effect are increased. Hence three to five effect plants are common in our country. On the other side, the thermo-compressor system is less costly and can give economy of steam equivalent to one additional effect, if steam pressure and other operating conditions remain steady as per the design of thermo-compressor operation. The thermo-compressor is most suited where high pressure steam is available and the evaporator can be operated with low pressure steam. Space limitation would favour a thermo-compressor installation.

The following table gives steam and cooling water consumption of evaporator.

SN	No. of effect	Kg of steam to Evaporate one Kg of water	Kg of water to condense one Kg of vapour
1	Single effect	1.17	20.00
2	Single effect using recompression of vapour	0.57	9.00
3	Double effect	0.57	9.00
4	Double effect using recompression of vapour	0.37	7.00

The term capacity of evaporating plant gives the output in terms of water evaporated per hour. It depends on the surface area of heat transfer, temperature difference and the overall heat transfer coefficient. The surface area may be used on the external or inner diameter of the tube. The number of tubes and the length of tube will decide the area of heat transfer with fixed diameter of tubes. Thus the capacity of plant increases in direct proportion to the number of tubes of same diameter and length. With larger number of effects, the total surface area may be distributed among different effects keeping in mind the product flow rate. Thus the first effect has always larger number of tubes while the subsequent effects will have reduced number of effect.

The other important parameter is the temperature difference which is the difference in temperature of steam condensing in the first effect jacket and the temperature of vapour condensing after the last effect. With first effect temperature of 70 °C, the steam temperature may be assumed to be around 80 °C and the last effect vapour may be assumed to condensing at 45 °C. Thus, the available temperature difference (80-45=35) is about 35 °C. With the increase in number of effects the available temperature difference will decrease and hence the capacity will remain constant or may even decrease because of increased loss of heat from surface of calandria.

The last and one of the important parameter is the overall heat transfer coefficient expressed in W/m².K. The U-value or the overall heat transfer coefficient is affected by number of factors, such as flow velocity, thermal conductivity of metal and the scale and the turbulence of the liquid product flowing down the tube. The change in specific gravity with change in concentration also affects the U-value. Thus the U-value is much higher for the first effect but goes on decreasing with increased concentration of liquid flowing in subsequent effects. The surface tension and viscosity indirectly affects the flowing velocity and thickness of film causing reduced heat transfer rate. The fouling of milk contact surface

with hard scale is the main cause of reduction in U-value with time. The scale formation is basically due to inverse solubility of calcium and phosphorus salts present in milk at the tube wall temperature and protein denaturation at temperature above 70 °C occurring at heat transfer wall. In addition to this low flow rate or inadequate wetting of tube wall causes burning of the thin film at the tube wall even at slightly low temperature. Therefore, care is required in the operation of the plant to avoid conditions for hard and tough scale formation in the evaporator calandria. Over hard scale deposit, softer deposits are also formed causing reduction in heat transfer rate.

The other factors which affect the plant operation are live steam pressure, flow rate of product, even distribution of feed to all tubes, maintaining constant vacuum, preventing leakage of air and operation of condenser for rapid condensing and removal of condensate. If thermo-compressor is used, the working of plant is affected by variation of steam pressure at inlet to thermo compressor. The provision of separate steam main from boiler with regulating valve will solve the problem. The flow rate can be easily controlled by feed pump of adequate size and type and needle valves for flow regulation. Automatic flow controller and flow measuring device may be used.

The uniform distribution of product to all the tubes is another major problem in the design and operation of falling film evaporator. The term wetting rate indicates the relationship between product feed rate and heating surface. Every tube requires a certain minimum quantity of product to cover the entire surface. Therefore in a single pass evaporator, the number of tubes per calandria will decrease from effect to effect, because the milk volume is constantly reduced as the concentration is increased. The first effect is always the largest, and in large evaporators, the calandria will be divided in two sections in order to overcome the problem of distribution of the product over a very large number of tubes, and to obtain the correct wetting rate. When the first effect is in two sections, the milk flow will be in series, but the steam flow will be parallel.

8.3 Care and maintenance:

1. Follow the preventive maintenance norms from the manufacturer guidelines.
2. Check the air leaks which may develop around valves, joints, cover and observation posts, as it fluctuates the operating vacuum and temperature.
3. All gaskets must be changed periodically.
4. Avoid the use of high pressure steam.
5. Economy of cooling water to the water cooled condenser should be checked.
6. Keep about 3°C temperature difference between condenser discharge water and cooling water for better economy.
7. Ensure heating surfaces are clean and free from deposits.
8. Scaling of heat transfer surfaces constitutes a problem and it should be cleaned after an optimum operation time. Descale the plant at least once a year with a suitable acid solution.
9. Check water vacuum system (working of vacuum pumps).
10. Periodical detection of steam coil leakage by hydraulic pressure test.
11. Condensate must be removed properly from the heating surface.
12. Release vacuum immediately in case of sudden power failure. Also steam valves and cooling water supply must be shut off at once.



Lesson 9

Introduction to Principle of Drying

9.1 Introduction:

The purpose of drying food products is to allow longer periods of storage with minimized packaging requirements and reduced shipping weights. The quality of the product and its cost are greatly influenced by the drying operation. The quality of a food product is judged by the amount of physical and biochemical degradation occurring during the dehydration process. The drying time, temperature, and water activity influence the final product quality. Low temperatures generally have a positive influence on the quality but require longer processing times. Low water activity retards or eliminates the growth of microorganisms, but results in higher lipid oxidation rates. Maillard (nonenzymatic) browning reactions peak at intermediate water activities (0.6 to 0.7), indicating the need for a rapid transition from medium to high water activities. Many dried foods are rehydrated before consumption. The structure, density and particle size of the food plays an important role in reconstitution. Ease of rehydration is increased with decreasing particle size, and the addition of emulsifiers such as lecithin or surfactants. Processing factors which affect structure, density, and rehydration include puffing, vacuum, foaming, surface temperature, low temperature processing, agglomeration, and surface coating. Storage stability of a food product increases as the water activity decreases, and the products that have been dried at lower temperatures exhibit good storage stability. Since lipid-containing foods are susceptible to lipid oxidation at low water activities, these foods must be stored in oxygen impermeable packages. Poor color retention has been a problem in the freeze-drying of coffee because the number of light-reflecting surfaces is decreased during rapid drying. This problem has been improved by slow freezing, partial melting, and refreezing to insure large ice crystal formation. Other food materials have different drying problems and specific solutions must be developed.

Drying should fulfill the following goals:

- (i) Minimal chemical and biochemical degradation reactions
- (ii) Selective removal of water over other salts and volatile flavor and aroma substances
- (iii) Maintenance of product structure (for a structured food)
- (iv) Control of density
- (v) Rapid and simple rehydration or redispersion
- (vi) Storage stability: less refrigeration and packaging requirements

- (vii) Desired color
- (viii) Lack of contamination or adulteration
- (ix) Minimal product loss
- (x) Rapid rate of water removal (high capacity per unit amount of drying equipment)
- (xi) Inexpensive energy source (if phase change is involved)
- (xii) Inexpensive regeneration of mass separating agents
- (xiii) Minimal solids handling problems
- (xiv) Facility of continuous operation
- (xv) Noncomplex apparatus (reliable and minimal labor requirement)
- (xvi) Minimal environmental impact

9.2 Drying Fundamentals:

Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. Heat transfer from the surrounding environment evaporates the surface moisture. The moisture can be either transported to the surface of the product and then evaporated or evaporated internally at a liquid vapor interface and then transported as vapor to the surface. The mechanisms of water transfer in the product during the drying process can be summarized as follows-: water movement due to capillary forces, diffusion of liquid due to concentration gradients, surface diffusion, water vapor diffusion in pores filled with air, flow due to pressure gradients, and flow due to water vaporization–condensation. In the pores of solids with rigid structure, capillary forces are responsible for the retention of water, whereas in solids formed by aggregates of fine powders, the osmotic pressure is responsible for water retention within the solids as well as in the surface. The type of material to be dried is an important factor to consider in all drying processes, since its physical and chemical properties play a significant role during drying due to possible changes that may occur and because of the effect that such changes may have in the removal of water from the product.

The transfer of energy (heat) depends on the air temperature, air humidity, air flow rate, exposed area of food material, and pressure. The physical nature of the food, including temperature, composition, and in particular moisture content, governs the rate of moisture transfer. The dehydration equipment generally utilizes conduction, convection, or radiation to transfer energy from a heat source to the food material. The heat is transferred directly from a hot gas or indirectly through a metal surface. The model equations for dryers cannot be discussed without a thorough understanding of the basic heat and mass transfer concepts. The typical drying cycle consists of three stages: heating the food to the drying temperature, evaporation of moisture from the product surface occurring at a rate proportional to the

moisture content, and once the critical moisture point is reached, the falling of the drying rate. The critical moisture point depends greatly on the drying rate since high drying rates will raise the critical point and low drying rates will decrease them.

9.3 Principle of drying:

Dehydration involves the simultaneous application of heat and removal of moisture from foods. Factors that control throughout the food processing are many and it varies for thermal drying. Some involve the removal of moisture or volatiles from various food ingredients or products that differ in both chemical and physical characteristics. Others involve the drying of solutions or liquid suspensions and different approaches to the problem.

Three basic methods of heat transfer are used in industrial dryers in varying degrees of prominence and combinations, specifically, convection, conduction, and radiation. In the food processing industry and dairy industry, the majority of dryers employ forced convection with continuous operation. With the exception of the indirectly heated rotary dryer and the film drum dryer, units in which heat is transferred by conduction are suitable only for batch use. This limitation effectively restricts them to applications involving somewhat modest production runs. Radiant, or "infrared," heating is rarely used in drying materials. Direct heating is used extensively in industrial drying equipment where much higher thermal efficiencies are exhibited

than with indirectly heated dryers. This is because there are no heat exchanger losses and the maximum heat release from the fuel is available for the process. However, this method is not always acceptable, especially where product contamination cannot be tolerated, particularly in dairy industry. In such cases, indirect heating must be used. With forced-convection equipment, indirect heating employs a condensing vapor such as steam in an extended surface tubular heat exchanger or in a steam jacket where conduction is the method of heat transfer. Alternative systems that employ proprietary heat-transfer fluids also can be used. These enjoy the advantage of obtaining elevated temperatures without the need for high-pressure operation as may be required with conventional steam heating. This may be reflected in the design and manufacturing cost of the dryer. Furthermore, in addition to the methods listed above, oil- or gas-fired indirect heat exchangers also can be used. In general, dryers are either suitable for batch or continuous operation.

Dehydration or drying of food is a complex phenomenon involving momentum, heat and mass transfer, physical properties of the food, air and water mixtures, and macro and microstructure of the food. There are many possible drying mechanisms, but those that control the drying of a particle product depend on its structure and the drying parameters, like drying conditions, moisture content, dimensions, surface transfer rates, and equilibrium

moisture content. These mechanisms falls in to three classes: (i) evaporation from a free surface, (ii) flow as a liquid in capillaries, and (iii) diffusion as a liquid or vapour. The first mechanism follows the laws for heat and mass transfer for a moist product. The second mechanism becomes difficult to distinguish from diffusion when one sets the surface tension potential to be proportional to the logarithm of the moisture potential (or water activity). The third set of mechanisms follows Fick's second law of diffusion, which is analogous to Fourier's law of heat transfer when the appropriate driving force is used.

In convectional drying the heating medium, generally air, comes into direct contact with the solid. Various oven, rotary, fluidized bed, spray, and flash dryers are typical examples. In conduction drying, the heating medium is separated from the solid by a hot conduction surface. Examples are drum, cone and through dryers. In radiation dryers, the heat is transmitted as radiant energy. Some dryers also use microwave energy to dry food materials at atmospheric pressure or at vacuum.



Lesson 10

Equilibrium Moisture Content, Bound and Unbound Moisture etc.

10.1 INTRODUCTION

The removal of moisture from a food product is one of the oldest preservation methods. By reduction of water content of food product to a very low levels the opportunity for microbial deterioration is eliminated and rates of other deterioration reactions are reduced significantly. In addition to preservation, dehydration reduces product weight & volume by significant amounts and improves efficiency of product transportation and storage. Often, the dehydration of a food product results in a product that is more convenient for consumer use.

All solid materials have a certain equilibrium moisture content when in contact with air at a particular temperature and humidity. The material will tend to lose or gain moisture over a period of time to attain this equilibrium value. Fig. 10.1 shows various moisture content regions of a food material such as bound, unbound and free.

When hot air is blown over a wet food, heat is transferred to the surface, and latent heat of vaporization causes water to evaporate. Water vapour diffuses through boundary film of air and is carried away by moving air.. This creates a region of lower water vapour pressure at the surface of the food and a water vapour pressure gradient is established from the moist interior of the food to the dry air. This gradient provides the 'Driving force' for water removal from the food. Water moves to the surface by following mechanisms.

1. Liquid movement by capillary forces.
2. Diffusion of liquids caused by difference in concentration of solutes in different regions of the food.
3. Diffusion of liquids, which are absorbed in layers at the surface of solid components of the food.
4. Water vapour diffusion in air spaces within the food caused by vapour pressure gradients.

Foods are characterized as hygroscopic and non-hygroscopic. Hygroscopic foods are those in which the partial pressure of water vapour varies with the moisture contents. The difference is found by sorption isotherms. When food is placed into a dryer, there is short initial settling down period as surface heats-up to the wet bulb temperature. Drying then commences and, provided that water moves from the interior of the food at the same rate as it evaporates from the surface, the surface remains wet. This is known as constant rate period and continues until a certain critical moisture content is reached. In practice different areas of food surfaces dry out at different rates, and overall, the rate of drying declines gradually. Thus the critical point is not fixed for a given food and depends on the amount of food in the dryer and the rate of drying. The three characteristics of air that are necessary for successful drying in the constant rate period are:

1. A moderately high dry bulb temperature
2. Low RH
3. High air velocity

The boundary film of air surrounding the food acts as a barrier to the transfer of both heat and water vapour during drying. The thickness of the film is determined primarily by the air velocity. If air velocity is too low, water vapour leaves the surfaces of the food and increases the humidity of the surrounding air, to cause a reduction in water vapour pressure gradient and rate of drying.

When the moisture content of the food falls below the critical moisture content, the rate of drying slowly decreases until it approaches zero at equilibrium moisture content. This is known as falling rate period. Non-hygroscopic foods have single falling rate period where as hygroscopic foods have two periods. In the first period the plane of evaporation moves inside the food water diffused through dry solid to the drying air. It ends when plane of evaporation reaches the center of the food and the partial pressure of water falls below the saturated water vapour pressure. The second period occurs when the partial pressure of water is below the saturated vapour pressure as drying is by desorption.

During falling rate period the rate of water movement from the interior of the food to the surface falls below the rate at which water evaporates to the surrounding air. The surface therefore dries out. This is usually the longest period of drying operation.

The surface temperature of the food remains close to the wet bulb temperature of the drying air until the end of the constant rate period, due to cooling effects of evaporating water. During the falling rate period the amount of water evaporating from the surface gradually decreases but as the same amount of heat being supplied by the air the surface temperature rises until it reaches the dry bulb temperature of the drying air. Most heat damage to food occurs in the falling rate period.

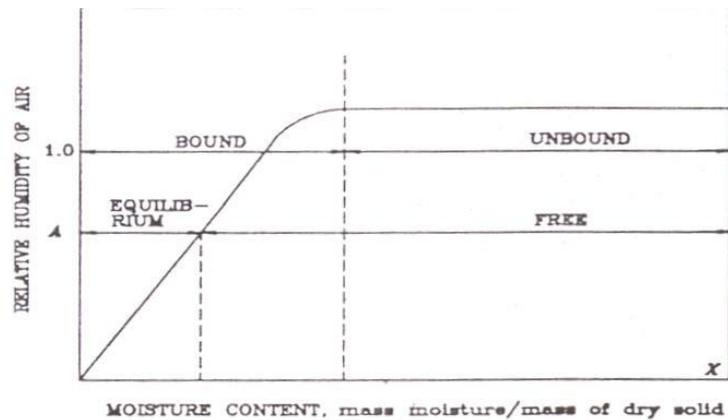


Fig- 10.1: Equilibrium moisture isotherm for a material showing various moisture content.



Lesson 11

Rate of drying constant and falling rate, Effect of shrinkage

11.1 Rate and time of drying:

Drying process can be divided in to three periods

- (i) constant drying rate period and
- (ii) first falling drying rate period and
- (iii) second falling rate period.

Fig: 11.1 shows general rate of drying curve for solid material.

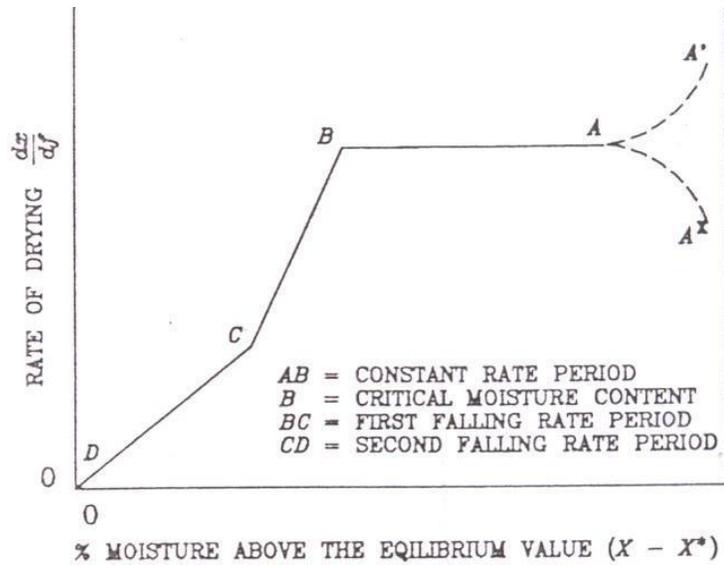


Fig- 11.1: General rate of Drying Curve for solid material

Free Moisture is equal to $x - x^*$

(i) Constant drying rate period

In a constant drying rate period, a material or mass of material contain so much water that liquid surface exists will dry in a manner comparable to an open faced body of water. Diffusion of moisture from within the droplet maintains saturated surface conditions and as long as these lasts, evaporation takes place at constant rate. When a solid is dried under constant drying conditions, the moisture content x_t typically falls. The graph is linear at first, then curves and eventually levels off. Constant rate drying period will proceed until free moisture appears from the surface, the moisture removal rate will then become progressively less. The moisture content at which the drying rate ceases to be constant is known as the critical moisture content. During the constant rate period, the moisture from interior migrates to the surface by various means and is vapourised. As the moisture content is lowered, the rate of migration to the surface is lowered. If drying occurs at too high temperatures, the surface forms the layer of closely packed shrunken cells which are sealed together. This presents a barrier to moisture migration and tends to keep the moisture sealed within. This condition is known as 'case hardening'.

The constant rate period is characterized by a rate of drying independent of moisture content. During this period, the solid is so wet that a continuous film of water exists over the entire drying surface, and this water acts as if solids were not there. The temperature of the wetted surface attained the wet bulb temperature.

Web bulb Temperature(WBT)

WBT is the steady state temp shown by the thermometer whose bulb is covered with a wet wick and from which water is evaporating into a high velocity air stream. The quantity of water evaporated is not high enough to alter the temperature and humidity of the air stream.

The air blown at high velocity (minimum recommended is 300 m/min). It causes evaporation of water from the wick. Evaporation requires latent heat. This heat comes from surface of glass bulb of thermometer. So the temperature of the glass bulb decreases. The the heat comes from the temperature difference between T_w and T_a (large). It is the case of simultaneous heat and mass transfer. This heat is latent heat for phase change of water to water vapor.

q = amount of latent heat transfer

$$q = M_w N_w \lambda_w A \text{----- (i)}$$

M_w = mol. Mass of water kg/kg mol

Dairy Process Engineering

N_w = molar flux of water vapour, $\text{kg mol m}^{-2} \text{s}^{-1}$

λ_w = Latent heat of vaporization kJ/kg

A = surface area of the bumb m^2

$N_w = k_y (y_w - y)$

k_y = mass transfer coefficient $\text{kg mol m}^{-2} \text{s}^{-1}$

y_w = mole fraction of water vapour in the stagnant air layer adjacent to the wet cloth

y = mole fraction of water vapour in the air stream, some distance away from the wet cloth

$(y_w - y)$ is the driving force.

As long as the rate of surface evaporation continues, the rate of drying is governed by equation:.

$$\frac{dw}{d\theta} = \frac{h \cdot A (t_a - t_s)}{\Delta H_v} = k_a \cdot A \cdot (H_s - H_a)$$

Where,

w = kg of moisture

θ = time

h = heat transfer coefficient between air and moisture $\text{kcal/ kg hr } ^\circ\text{C}$

t_a = dry bulb temperature of air, $^\circ\text{C}$

t_s = surface temperature, $^\circ\text{C}$

A = area, m^2

ΔH_v = heat of vapourisation at t_s , Kcal/ kg

k_a = mass transfer coefficient (kg/ hr m)

H_s = humidity of saturated air at the surface temperature

H_a = humidity of air

The constant rate period ends when the migration rate of water from the interior of the surface becomes less than the rate of evaporation from the surface. The period subsequent to the critical point is called 'the falling rate period'. Beyond this point, the surface temperature rises, and the drying rate falls off rapidly. The falling rate period takes a far longer time than the constant rate period, even though the moisture removal may be much less. The drying rate approaches zero at some equilibrium moisture content.

Drying in falling rate period involves two processes:

- a) movement of moisture within the material to the surface
- b) removal of the moisture from the surface

The method used to estimate drying rates and drying times in the falling rate period depends on whether the solid is porous or non porous. In a non porous material, once there is no superficial moisture, further drying can occur only at a rate governed by diffusion of internal moisture to the surface. In a porous material other mechanism appears, and drying may even takes place inside the solid instead of at the surface.

(ii) First falling drying rate period

Point B, the moisture content at the end of the constant rate period, is the 'critical moisture content'. At this point the surface of the solid is no longer saturated, and the rate of drying decreases with the decrease in moisture content. At point C, the surface moisture film has evaporated fully, and with the further decrease in moisture content, the drying rate is controlled by the rate of moisture movement through the solid.

(iii) Second falling drying rate period

Period C to D represents conditions when the drying rate is largely independent of conditions outside the solid. The moisture transfer may be by any combination of liquid diffusion, capillary movement, and vapour diffusion.

11.2 Estimation of Drying Time

In order to determine the time required to achieve the desired reduction in product moisture content, the rate of moisture removal or drying rate must be predicted. The rate

of drying depends on properties of drying air (the dry bulb temperature, RH, and velocity of air and the surface heat transfer coefficient), the properties of food (moisture content, surface to volume ratio and the surface temperature) and rate of moisture loss. The size of the pieces has an important effect on the drying rate in both the constant and falling rate periods. In the constant rate period, smaller pieces have a larger surface area available for evaporation where as in falling rate period smaller pieces have a shorter distance for moisture to travel through the food. Other factors which influence the rate of drying include:

1. The fat content of the food (higher fat contents generally results in slower drying, as water is trapped with in the food).
2. The method of preparation of food (cut pieces lose moisture more quickly than losses through skin).
3. The amount of food placed in a dryer in relation to its size (in a given dryer faster drying is achieved with smaller quantities of food).

For constant rate drying period the following general expression would apply:

$$R_c = d_w / dt = w_o - w_c / t_c \text{ -----(1)}$$

Where,

w_c = Critical moisture content (kg water / kg dry solid) and

t_c = Time for constant rate drying

During falling rate drying, the following analysis would apply.

$$- d_w/dt = R_c / w_c (w) \text{ or}$$

$$w_c / R_c \square - d_w / w = \square dt$$

Where the limits of integration are between critical moisture content w_c or end of constant rate drying, t_c and some desired final moisture content, w .

On integration:

$$t - t_c = w_c/R_c \ln(w_c/w) \text{ or time for falling rate becomes}$$

$$t_f = w_c/R_c \times \ln (w_c/w) \text{ -----(3) and}$$

The total drying times becomes

$$t = (w_o - w_c) / R_c + W_c/R_c \times \ln (w_c/w) \text{ -----(4)}$$

The above equation indicates that the time for complete drying from some initial moisture content w_o to a desirable final moisture content w depends on knowledge of critical moisture content w_c , the time for constant rate drying t_c , and the rate for constant drying R_c .

Example-11.3

A tunnel dryer is being designed for drying apple halves from initial moisture content of 70 % (wet basis) to final moisture content of 5 % (wet basis). An experimental drying curve for the product indicates that the critical moisture content is 25 % (wet basis) and the time for constant drying is 5 min. Based on the information provided, estimate the total drying time for product.

Solution:

Initial product moisture content, $w_o = 0.7 / 0.3 = 2.33 \text{ kg H}_2\text{O} / \text{kg solids}$

Critical moisture content, $w_c = 0.25 / 0.75 = 0.333 \text{ kg H}_2\text{O} / \text{kg solids}$

Final moisture content, $w = 0.05 / 0.95 = 0.0526 \text{ kg H}_2\text{O} / \text{kg solids}$

Time for constant rate drying, $t_c = 5 \text{ min}$

Required:

Total drying time

$R_c = (w_o - w_c) / t_c = (2.33 - 0.33) / 5 \text{ min} = 0.4 \text{ kg H}_2\text{O} / \text{kg solids min}$

Falling rate drying time $t_F = w_c/R_c \times \ln(w_c/w)$

$$= 0.333/0.4 \times \ln (0.333 / 0.0526)$$

$$= 1.54 \text{ min}$$

Total drying time becomes $t = 5 + 1.54 = 6.54$ min.

Example-11.4

Estimate the drying rate and time needed to reduce the moisture content of a 100 μ m diameter spherically shaped droplet, falling in a spray dryer from 60 to 35 %. The initial density of the droplet is 900 kg/m³. The droplet is in an air stream such that $T_{\infty} = 200$ °C, $P = 101.3$ k Pa, $h = 200$ w/m² °C and $T_{wb} = 60$ °C. Assume that constant rate drying applies over the total drying process and droplet doesn't change in size.

Solution

The surface area of the droplet is $\pi D^2 = \pi (0.0001)^2 = 3.14 \times 10^{-8}$ m²

The volume of the droplet is $1/6 \pi D^3 = \pi /6 \times (0.0001)^3 = 5.24 \times 10^{-13}$ m³

The initial mass of the droplet is $\rho \times V = 900 \times 5.24 \times 10^{-13}$
 $= 4.71 \times 10^{-10}$ kg

Applying solids balance: $m_p \times 0.4 = m_f \times 0.65$

So final mass of the product $m_f = m_i \times 0.4 / 0.65 = 2.9 \times 10^{-10}$ kg.

Drying rate $R = h A (T_{\infty} - T_s)$

$<v:line id="_x0000_s1031" style='position:absolute;left:0;text-align:left;z-index:251659776' from="81pt,1.5pt" to="135pt,1.5pt"/> \quad h_{fg} \times 1000$

where,

h_{fg} = latent heat of evaporation corresponding to given pressure in kJ / kg.

$<v:line id="_x0000_s1032" style='position:absolute;left:0;text-align:left;z-index:251660800' from="1in,18.3pt" to="207pt,18.3pt"/> \quad = 200(3.14 \times 10^{-8}) (200 - 60)$

2370.7×1000

$= 3.71 \times 10^{-10}$ kg s

The drying time is given by $t = (m_i - m_f) / R = (4.71 - 2.9) 10^{-10} / 3.71 10^{-10}$

= 0.49 seconds.

Effect of Shrinkage:

A factor often greatly affecting the drying rate is the shrinkage of the solid as moisture is removed. Rigid solids do not shrink appreciably, but colloidal and fibrous materials such as milk, vegetables and other foodstuffs do undergo shrinkage. The most serious effect is that there may be developed a hard layer on the surface which is impervious to the flow of liquid or vapor moisture and slows and drying rate. In many foodstuffs, if drying occurs at too high temperature, a layer of closely packed, shrunken cells, which are sealed together, forms at the surface. This presents a barrier to moisture migration and is known as *case hardening*. Another effect of shrinkage is to cause the materials to warp and change its structure. Some times, to decrease these effects of shrinkage, it is desirable to dry with moist air. This decreases the rate of drying so that the effects of shrinkage on warping or hardening at the surface are greatly reduced.

Example to be incorporated. And modify the above paragraph



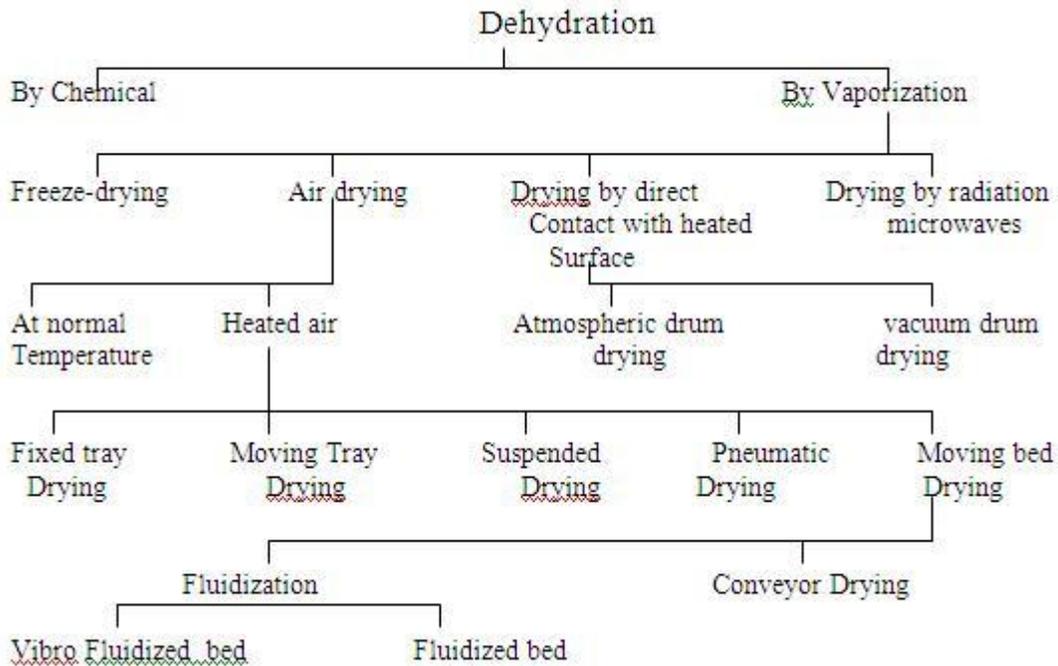
Lesson 12

Classification of Dryers, Spray Dryers, Drum Dryers and problems on Dryers

Introduction:

There are different types of dryers available to meet the wide range of requirement of food and dairy industry. Depending on the quantity of moisture present initially and the final moisture content to be retained in the food, the type of drier, air supply temperatures etc are chosen. The dryers can also be classified as per the scale of operation, source of energy, the physical state of the feed.

12.1. CLASSIFICATION OF DEHYDRATION SYSTEMS



Dehydration systems can be classified as per the scale of operation

Domestic Open sun drying

Solar drying

Small scale Roller drying

Tunnel drying

Cabinet/ Tray

Trough drying

Microwave drying

Dielectric

Medium and Large scale Spray

Fluidized bed
 Freeze
 Puff
 Vacuum
 Bin
 Pneumatic
 Rotary
 Tower

12.2 Drum Drying

The drum dryer is an indirect type dryer in which the milk to be dried is maintained in a thin film on a rotating steam heated drum. The milk being dried is spread over the outside surface of the dryer. Clinging to it and drying continues as the hot drum rotates. At the end of a revolution, the drum comes to a 'doctor blade' which scrapes the dried film from the drum, when the product has made about three-quarter of a complete rotation on the drum surface. The process is also known as roller drying or film drying.

Drum drying requires less space and is more economical than spray dryers for small volumes. The ratio of steam consumption to water evaporation is from 1.2 to 1.6:1. The major disadvantages are that the product may have a scorched flavour, and solubility is much lower (85%) because of protein denaturation.

12.2.1 Classification of Drum Dryers

The drum dryers may be classified according to:

1. Number of drums (a) single drum, (b) double drum, or (c) twin drum
2. Pressure surrounding the product (a) atmospheric, and (b) vacuum
3. Feeding arrangement: (a) nip feed, (b) splash feed, (c) dip feed or (d) roller feed
4. Material of construction: (a) alloy steel, (b) stainless steel, or (c) chrome, or nickel plate steel

Fig. 12.1; 12.2; 12.3; 12.4; 12.5; 12.6; & 12.7 shows different types of drum dryers and their feed mechanisms.

12.2.2 Construction of Drum Dryers

The double drum atmospheric dryer is most commonly used in the dairy industry (Fig. 12.1). Liquid is fed at about 70 °C from a trough or perforated pipe into a pool in the space above and between the two rolls. Heat is transferred by conduction to the liquid, which is partly concentrated in the space between the rolls. Subsequently, all the liquid is vapourized as the drum turn, leaving a thin layer of dried product which is scraped off by doctor blades into conveyor below.

Water vapour above the dryer has a lower density than the air surrounding the unit, and will rise. Vaporized moisture is removed through a vapour hood above the drums. The lower edge of the hood is formed into a trough to drain away moisture which may accumulate because of condensation. Adequate air flow must be over the drum surface to carry away moisture.

The different feeding arrangements are shown in Fig: 12.2 . Dip feed is the most simplest type of feed, suitable for materials with a high rate of sedimentation. Dip feed is used for certain suspensions of solids, usually with recirculation of material in the tray. Roller feed is suitable for glutinous materials such as starch. The product may be placed in its natural form or condensed before it is fed to the dryer. Milk is usually precondensed (not more than 30%) for single drum units, and preheated for double drums.

The doctor blade, a sharp hard flexible knife, scrapes the dried material from the drum. The blades are made of spring steel if the surface of the drum is hard and for soft drum bronze is used. The blades are positioned at an angle of 15 to 30° with the surface. The conveyor for each drum discharges the product into for sizing the dried product.

The inside of drum is heated with steam at 3-6 kg/cm². Drum temperatures of below 130 °C

is suggested, as the product temperature approaches the temperature of the steam. The drums used are 60 to 120 cm in diameter, and upto 360 cm in length. Drums are carefully machined, inside and outside, otherwise a difference in thickness will change heat transfer rate and drying will not be uniform. The speed of the drums is adjustable from 6 to 24 rpm. The speed is important as it affects the thickness of milk film and the time of solid contact with metal. The speed of the drum depends upon the concentration of the milk and the final moisture content. Both drums turn at the same speed.

The time that the solid is in contact with metal is 3 s or less. The product is removed after $3/4$ to $7/8$ of a revolution of the drum has taken place. The thickness of the film is quite critical in controlling the operation. It is important that the material be spread evenly over the drum in order to have a uniform product. The surface tension and the rheological properties of the material controls this.

The spacing between the drum affects the film thickness. One drum of a double drum dryer is mounted on a stationary bearing and the other on a movable bearing to adjust the spacing between the drums. The spacing between the drums is about 0.5 to 1.0 mm. If the clearance is below this, there will be product damage.

As the heat is removed from steam, it is condensed. The condensate moves to the bottom of the drum and must be removed by a pump or siphon. Flooding of the inside with condensate reduces the heat transfer rate. The drying capacity is proportional to the active drum area.

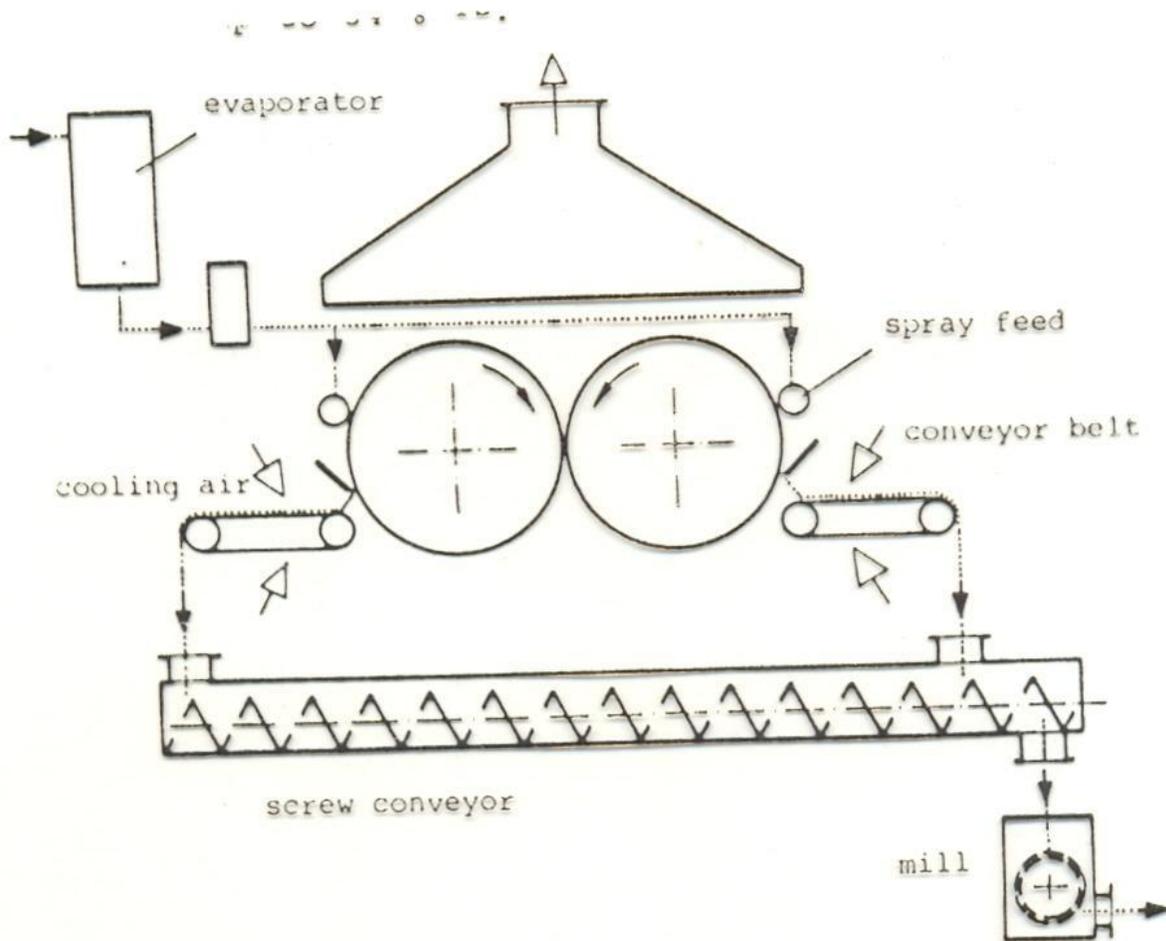


Fig: 12.1 Twin drum dryer

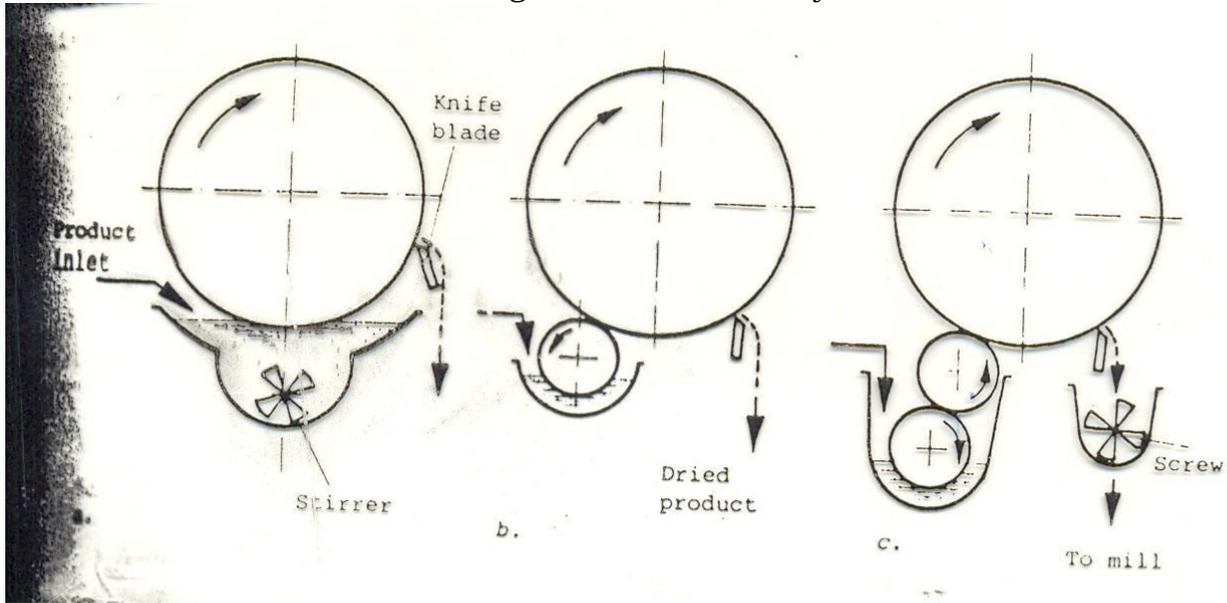


Fig. 12.2 Roller dryers with (a) dip feed (b) application by roller and (c) thin layer application with dip feed roller and transfer roller

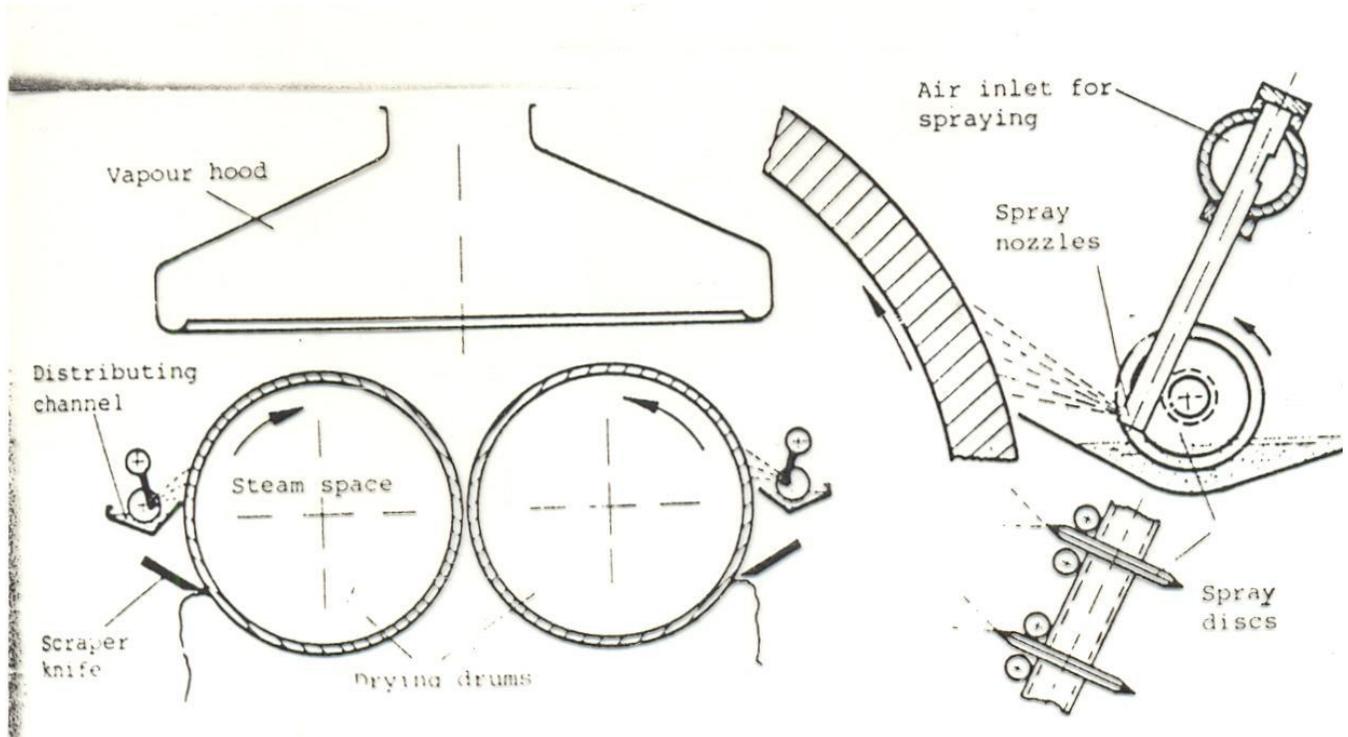


Fig:12.3 Twin roller dryer with spray film feed

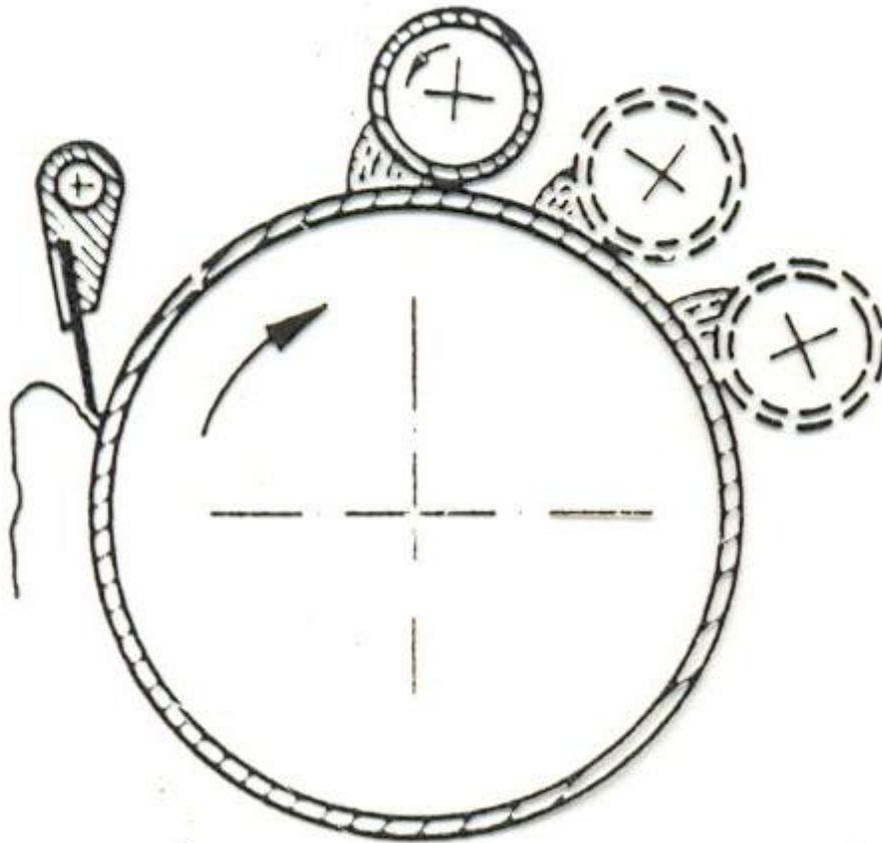


Fig. 12.4 Single roller dryer with feed rollers fitted on top

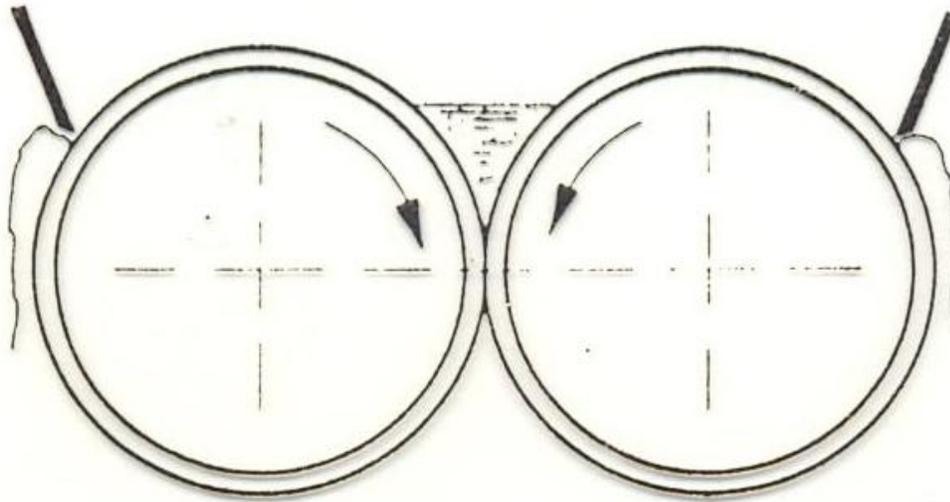


Fig. 12.5 Twin roller dryer with reservoir

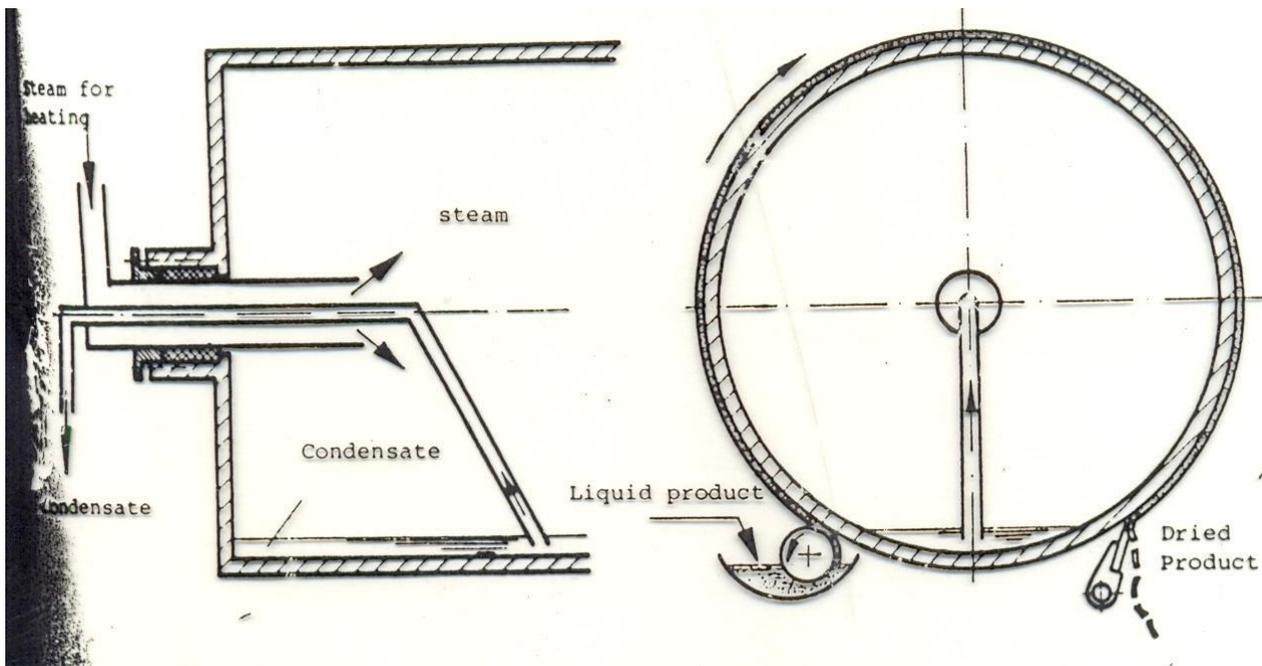


Fig. 12.6 Steam inlet in to drum for heating and the condensate discharge in roller driers

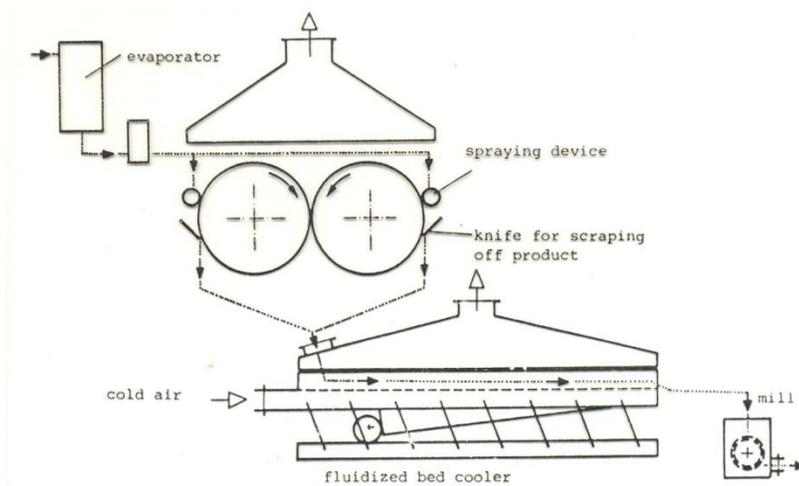


Fig. 12.7 Roller dryer with fluidized bed

12.2.3 Rate of evaporation in drum dryers

The rate of moisture removal by a drum dryer is essentially a constant rate of water evaporation as the product is continuously fed between the drums and the dried product is removed. The equation governing the rate of evaporation in a drum dryer is:

Where, $\Delta T = t_s - t_a$

latent heat of vaporization.

the mean temperature difference between the roller surface and the product.

The overall coefficient is from 1000 to 1800 kcal/hr m² c under optimum condition, although it may be only 1/10th of these values when conditions are adversed. Since the thickness of drum wall is small compared to the diameter of the drum, the area A can be regarded simply as the outer surface area of the drum. The U depends on h_s , k and h_p and other coefficients.

Where, h_s : equivalent film coefficient of steam, Kcal/ hr m²c

x : thickness of metal , m

k : thermal conductivity of metal, kcal/ m hr c

h_p : equivalent film coefficient of product

h_c : convection coefficient

h_r : radiation coefficient

h_e : evaporation film coefficient

The factor having the greatest effect on U is the condition of the liquid film and the drum speed. Drying rates for drum dryers can be extremely high when thin film of low viscosity is evaporated, and it is thus permissible to use high temperature. In addition to assuring the adequate heat transfer the drying system must provide for removal of water vapour. If the speed of a particular drum is measured, then the U value and the moisture content of the product will be increased, if the conditions are unchanged. The overall thermal efficiency of drum dryer is 35 – 80 %.

The moisture content x of a milk product containing m_w amount of water and m_s amount of dry matter including fat is given by:

The proportion of dry matter (TS) is given by :

During the evaporation of a product from the original moisture content x_0 containing amount of water m_{w0} to a final moisture content x containing an amount of water m_w , the following amount is removed.

Calculated as a fraction of the water originally present, the following is obtained:

12.3 Spray Drying

Spray drying is the transformation of feed from a fluid state into a dried particle form by spraying the feed into a hot drying medium. Spray drying is considered to be one of the best methods for drying of food materials. This method is applied to fluids of high moisture content and high viscosity or of a slightly paste like character. The major advantages of spray drying are:

- (i) High production rate
- (ii) Gentle drying
- (iii) Short drying period
- (iv) Superior flavour, appearance, and solubility of product
- (v) Continuous single step operation
- (vi) Uniform product
- (vii) Plant can be easily automated
- (viii) No product contamination
- (ix) High thermal efficiency

A conventional spray dryer consists of the following main components (Fig. 12.8):

- (1) Drying chamber
- (2) Hot air system and air distribution
- (3) Feed system
- (4) Atomizing device
- (5) Powder separation system
- (6) Pneumatic conveying and cooling system
- (7) Fluid bed after-drying/cooling
- (8) Instrumentation and automation

In a spray dryer, the milk is pumped to a nozzle or rotary valve disc atomizer which sprays the feed in fine droplets into a drying chamber. The droplets are subject to a stream of hot air flowing either counter-currently or cocurrently in relation to the falling droplets. Thereby, the droplets of milk are dried so the dry matter remains as powder particles, which fall down towards the bottom of the chamber from where it is removed more or less continuously, as shown in the Fig. 12.8. On account of the large liquid surface created by atomization, the evaporation takes place very quickly, usually at a very low temperature, irrespective of whether drying air of a very high temperature is used. The hot air applies heat to the droplets and carry away the vapour evolved. The temperature of the milk droplets is kept down to the wet bulb temperature and does not exceed the calculated value of 49-54 °C. The fig. 12.9 shows heat recuperate type air-liquid-air, while Fig-12.10 shows single stage spray dryer with heat recuperator type air-liquid-air., Fig. 12.11 shows animation of condensing and drying plant.

The spray dryer consists of mainly four components:

1. Heating of the drying air: air heaters with accompanying fans, air filters dampers and ducts.
2. Atomization of feed into a spray: atomizer with feed supply system of pumps, tanks and feed pretreatment equipment
3. Contacting of air and sprays and drying of sprays: drying chamber with air disperser, product and exhaust air outlets.
4. Recovery of dried products and final air cleaning: complete product recovery with product discharge, transport and packing, air exhaust system with fans, wet scrubbers, damper and duct.

12.4 Classification of Spray Dryers:

Spray dryers are mainly classified according to:

1. Method of atomization: (a) pressure atomization (b) centrifugal atomization, (c) pneumatic atomization
2. Method of heating air (a) steam (b) furnace oil, (c) electricity
3. Position of drying chamber (a) vertical (b) horizontal
4. Direction of air flow in relation to product flow (a) counter current (b) co current (c) mixed current
5. Pressure in dryer (a) atmospheric (b) vacuum
6. Shape of the bottom of the chamber (a) flat bottom (b) conical bottom

PROBLEMS ON DRYERS

Drum Drying:

The rate of moisture removal by a drum dryer is essentially a constant rate of water evaporation as the product is continuously feed between the drums and the dried product is removed. The equation governing the rate of evaporation in a drum dryer is:

Where, $\Delta T = t_s - t_a$

latent heat of vaporization.

the mean temperature difference between the roller surface and the product.

The overall coefficient is from 1000 to 1800 kcal/hr m² c under optimum condition, although it may be only 1/10th of these values when conditions are adversed. Since the thickness of drum wall is small compared to the diameter of the drum, the area A can be regarded simply as the outer surface area of the drum. The U depends on h_s , k and h_p and other coefficients.

Where, h_s : equivalent film coefficient of steam, Kcal/ hr m²c = 4000

x: thickness of metal, m

k : thermal conductivity of metal, kcal/ m hr c

h_p : equivalent film coefficient of product = 4000

h_c : convection coefficient = 5.0

h_r : radiation coefficient = 7.5

h_e : evaporation film coefficient = 25.0

The factor having the greatest effect on U is the condition of the liquid film and the drum speed. Drying rates for drum dryers can be extremely high when thin film of low viscosity is evaporated, and it is thus permissible to use high temperature. In addition to assuring the adequate heat transfer the drying system must provide for removal of water vapour. If the speed of a particular drum is measured, then the U value and the moisture content of the product will be increased, if the conditions are unchanged. The overall thermal efficiency of drum dryer is 35 – 80 %.

the moisture content x of a milk product containing m_w amount of water and m_s amount of dry matter including fat is given by:

The proportion of dry matter (TS) is given by :

During the evaporation of a product from the original moisture content x_0 containing amount of water m_{w0} to a final moisture content x containing an amount of water m_w , the following amount is removed.

Calculated as a fraction of the water originally present, the following is obtained:

Mechanism of drying solids:

Drying process can be divided into two period:

(a) constant rate period (b) falling rate period

In a constant drying rate period, a material or mass of material contain so much water that

liquid surface exists will dry in a manner comparable to an open faced body of water. Diffusion of moisture from within the droplet maintains saturated surface conditions and as long as these last, evaporation takes place at constant rate. When a solid is dried under constant drying conditions, the moisture content $x-t$ typically falls as shown in the graph A in the figure.

The graph is linear at first, then curves and eventually levels off. Graph B shows the drying rate: it is horizontal at first indicating that the drying rate is constant, then it curves downward and eventually falls. When the material has reached its equilibrium moisture content, reaches zero.

Constant rate drying period will proceed until free moisture appears from the surface, the moisture removal rate will then become progressively less. The moisture content at which the drying rate ceases to be constant is known as the critical moisture content. During the constant rate period, the moisture from interior migrates to the surface by various means and is vapourised. As the moisture content is lowered, the rate of migration to the surface is lowered. If drying occurs at too high temperatures, the surface forms the layer of closely packed shrunken cells which are sealed together. This presents a barrier to moisture migration and tends to keep the moisture sealed within. This condition is known as 'case hardening'.

The constant rate period is characterized by a rate of drying independent of moisture content. During this period, the solid is so wet that a continuous film of water exists over the entire drying surface, and this water acts as if solids were not there. As long as the rate of surface evaporation continues, the rate of drying is governed by equation:

Where,

w = kg of moisture

θ = time

h = heat transfer coefficient between air and moisture kcal/ kg hr °C

t_a = dry bulb temperature of air, °C

t_s = surface temperature, °C

A = area, m²

ΔH_v = heat of vapourisation at t_s , Kcal/ kg

K_a = mass transfer coefficient (kg/ hr m)

H_{-s} = humidity of saturated air at the surface temperature.

H_{-a} = humidity of air

The constant rate period ends when the migration rate of water from the interior of the surface becomes less than the rate of evaporation from the surface. The period subsequent to the critical point is called 'the falling rate period'. Beyond this point, the surface temperature rises, and the drying rate falls off rapidly. The falling rate period takes a far longer time than the constant rate period, even though the moisture removal may be much less. The drying rate approaches zero at some equilibrium moisture content.

Drying in falling rate period involves two processes:

- a) movement of moisture within the material to the surface
- b) removal of the moisture from the surface.

The method used to estimate drying rates and drying times in the falling rate period depends

on whether the solid is porous or non porous. In a non porous material, once there is no superficial moisture, further drying can occur only at a rate governed by diffusion of internal moisture to the surface. In a porous material other mechanism appears, and drying may even take place inside the solid instead of at the surface.

Problem: skim milk of $x_0 = 0.91$ is evaporated to $x = 0.55$. find out the % of water evaporated based on the original water content.

Solution:

$$= 1 - [0.55 (1 - 0.91) / 0.91 (1 - 0.55)] = 0.88$$

i.e. 88 % of the water, based on the original water content, has been removed by evaporation.

Problem: Find out the evaporation rate in a drum dryer for given data: steam temp = 150 °C , vapourisation temperature of milk 103 °C, overall heat transfer coefficient 1200 kcal / h m² °C, drum diameter = 60 cm, length of the drum = 100 cm, latent heat of vapourisation = 540 kcal / kg. the product is scraped at $\frac{3}{4}$ of a revolution of the drum.

Solution: heat transfer area, $A = 1 \times 0.6 \times \pi \times \frac{3}{4} = 1.413 \text{ m}^2$

$$dw / d\theta = 1200 \times 1.413 \times (150 - 103) / 540 = 147.5 \text{ kg/ hr}$$

Problem: A drum dryer is designed for drying a product from an initial TS of 12 % and a final moisture content of 4 %. An average temperature difference between the roller surface and the product of 65 °C will be used and the overall heat transfer coefficient is 1500 kcal/ hr m² °C. Determine the surface area of the roller required to provide a production rate of 50 kg product / hr.

Solution: Basis : 1 kg of product $P = F - V$

F : amount of feed / kg of product

V : amount of vapour / kg of product.

Solid balance:

$$0.96 \times 1 = 0.12 F$$

$$F = 8 \text{ kg} ; V = 7 \text{ kg}$$

From 50 kg product, $F = 50 \times 8 = 400 \text{ kg/hr}$

Vapour removed = $50 \times 7 = 350 \text{ kg/hr}$

Using equation:

$$350 = 1500 \times A \times 65 / 540$$

Thus, $A = 1.93 \text{ m}^2$

The effective surface area needed for drying is 1.93 m². Assuming that about $\frac{1}{4}$ of the surface area would not be used . Then the total surface area required would be : $1.93 \times 4/3 = 2.583 \text{ m}^2$. If the length of the drum is taken as 1.37 m, then the diameter of the drum d will be:

$$\pi d \times 1.37 = 2.58$$

Thus, $d = 0.6 \text{ m}$

Problem: milk of 18.5 % TS is dried to 3.8 % on a drum dryer at a rate of 10.5 kg of dried product / hr. The diameter of the drum is 60 cm and length 90 cm and the product is

scrapped at $\frac{1}{2}$ of a revolution. The steam temperature is 160°C and vaporization point of the moisture is 104°C . Find out the overall heat transfer coefficient.

Solution: basis: 1 kg of milk

$V + P = 1$ (material balance)

Where, V = amount of water evaporated

P = amount of the product

$0.185 + 1 = 0.962$ (material balance)

Thus, $V = 0.808$ kg and $P = 0.192$ kg / kg wt.

Where, $P = 10.5$ kg, then,

$dw/d\theta = 10.5 \times 0.808 / 0.192 = 44.18$ kg / hr

The heat transfer area, $A = 0.9 \times 0.6 \times \pi / 2 = 0.84$

Using the equation:

$44.18 = U \times 0.847 (160 - 104) / 540$

Thus, $U = 0.5029$ kcal / hr m^2 $^\circ\text{C}$

SPRAY DRYING:

Where, W = mass flow rate of air, kg/hr

C = specific heat of air, kcal / kg $^\circ\text{C}$

t_1 = inlet air temperature of dryer, $^\circ\text{C}$

t_2 = outlet air temperature of dryer, $^\circ\text{C}$

q = total rate of heat transfer kcal / hr

U_a = volumetric heat transfer coefficient (150 – 270 kcal/ hr m^2 $^\circ\text{C}$)

= mean temperature difference throughout the dryer, $^\circ\text{C}$

V_d = volume of dryer, m^3

2. Dryer efficiency:

Where, R = radiation loss, % of total temperature drop in dryer

t_0 = atmospheric air temperature, $^\circ\text{C}$

t_1 = temperature to which air is heated, $^\circ\text{C}$

t_2 = temperature of air leaving dryer, $^\circ\text{C}$

overall efficiency of dryer ranges between 50 – 60 %

Problem:

500 kg of milk containing 60 % water is dried to a moisture content of 3 %, at an initial temperature of 20°C in a spray dryer. An inlet temperature to heater is 30°C and air is heated to 150°C to dry the product. The temperature of air leaving the dryer is 90°C and that of milk particles are 54°C . calculate (a) the amount of air required (m^3) to dry the milk. (b) thermal efficiency of air drying (c) the amount of steam required at 7.2 kg/ cm^2 pressure to heat the air if the efficiency of the air heater is 80 % (d) the amount of steam required/ kg of water evaporated, and (e) if the radiation loss is 10 %, find out the overall thermal efficiency.

Solution:

Solution: basis: 1 kg of milk

$V + P = 1$ (material balance)

Where, V = amount of water evaporated

Dairy Process Engineering

P = amount of the product

$$0.4x 1 = 0.97 P \text{ (material balance)}$$

Thus, $P = 0.413 \text{ kg}$ and $V = 0.587 \text{ kg / kg wt.}$

The amount of dried product from 500 kg milk = $500 \times 0.413 = 206.5 \text{ kg}$

Total amount of water removed = $500 \times 0.587 = 293.5 \text{ kg}$

Heat supplied to milk = sensible heat to raise the raw milk.

Temperature from 20°C to 54°C + latent heat of vapourisation.

The latent heat of vapourisation corresponding to a saturation temperature of 90°C is about 545 kcal/kg

$$\text{Heat supplied to dry 500 kg milk} = (500 (54 - 20) \times 0.93) + (293.5 \times 545)$$

$$= 175767 \text{ kcal.}$$

The specific heat of air can be taken as $0.24 \text{ kcal/ kg }^\circ\text{C}$ and the mass density of air at the mean temperature i.e. 120°C is 0.9 kg/m^3

Using eq.:

$$175767 = W \times 0.24 (150 - 90)$$

$$\text{Thus, } W = 13562 \text{ m}^3$$

The amount of air required to dry the milk = 13562 m^3 or 12205 kg .

(B)

The temperature of hot air should have been brought down to 54°C i.e. equal to the temperature of dried milk, but in actual the air outlet temperature is 90°C .

The maximum amount of heat which can be given by the hot air

$$= 13532 \times 0.9 \times 0.24 \times (150 - 54) = 281221 \text{ kcal}$$

But the actual amount of heat which is used to dry 500 kg milk = 175767 kcal

The thermal efficiency of air drying = $175767 / 281221 = 0.62$

(c)

The amount of air required in kg = $13562 \times 0.9 = 12205 \text{ kg}$

Heat taken by air in the air heating section = $12205 \times 0.24 (150 - 30)$

$$= 351504 \text{ kcal}$$

At 1.2 kg/ cm^2 absolute pressure, the latent heat of steam about 490 kcal/kg

The amount of steam required at 80°C heating efficiency =

$$351504 / (490 \times 0.8) = 896.7 \text{ kg}$$

(d)

The amount of steam required per kg of water evaporated = $896.7 / 293.5 = 3.05 \text{ kg}$

(e)

Using eq.:

$$= (1 - 0.1)(150 - 90) / (150 - 30) = 0.45$$

Problem:

Skim milk of 89% water content is evaporated to 54% moisture content. Find out the % water evaporated based on original water content.

Problem:

Find out the evaporation rate in a drum dryer when steam temperature is 145°C , vapourisation temperature of milk is 104°C , overall heat transfer coefficient 1300 kcal/hr m^2 , drum diameter = 50 cm , drum length 90 cm , and latent heat of vapourisation = 539

kcal/kg. The product is scraped at $7/8$ of a revolution of the drum.

Problem:

A drum dryer is designed for drying a product from initial total solid content of 16% and a final moisture content of 4%. An average temperature difference between the roller surface and the product of $70\text{ }^{\circ}\text{C}$ will be used, and overall heat transfer coefficient is $1400\text{ kcal/ m}^2\text{ hr }^{\circ}\text{C}$. Determine the surface area of the roller required to provide a production rate of $40\text{ kg product / hr}$.

Problem: milk of 17 % solids is dried to 3 % on a drum dryer at a rate of 15 kg of dried product per hr . the drum dryer diameter is 45 cm and length is 75 cm and the product is scrapped at $3/4$ revolution. The steam temperature is $150\text{ }^{\circ}\text{C}$ and vapourisation point of the moisture is $103\text{ }^{\circ}\text{C}$. find out the overall heat transfer coefficient.

Problem: 1000 kg of milk containing 52 % water is dried to a moisture content of 2.5 % at an initial temperature of $30\text{ }^{\circ}\text{C}$ in a spray drier. An inlet to heater is $35\text{ }^{\circ}\text{C}$ and air is heated to $160\text{ }^{\circ}\text{C}$ to dry the product. The temperature of air leaving the dryer is $85\text{ }^{\circ}\text{C}$ and that of milk particles $52\text{ }^{\circ}\text{C}$. Calculate (a) amount of air required in m^3 to dry the milk (b) thermal efficiency of air drying (c) amount of steam required at 7 kg/cm^2 pressure to heat the air if the efficiency of the air heater is 75 %. (d) amount of steam required / kg of water evaporated (e) if the radiation loss is 8 %, find out the overall thermal efficiency.

Problem: 1000 kg/hr of dried product (4 %moisture) is produced in a spray dryer. The atmospheric air at $30\text{ }^{\circ}\text{C}$ and 40 %RH is heated to $190\text{ }^{\circ}\text{C}$ and it is exhausted at $80\text{ }^{\circ}\text{C}$. the concentrated milk having 45 % TS by weight. Feed temperature of concentrated milk is $30\text{ }^{\circ}\text{C}$. dried product comes out at 50°C . heat losses from the dryer is 25000 kcal/hr . Find out the air rate required.

Solution:

Based on enthalpy and moisture balance:

Q_a = quantity of air

T_{a1} = temperature of air feed

H_{a1} = enthalpy of concentrate feed, kcal/ kg of dry air

W_1 = moisture, kg of water/ kg of dry air

Q_1 = heat loss / hr

W_2 = moisture after drying, kg of water/ kg of dry air

M_s = solid in feed = solid in final product (assuming no loss)

H_{s1} , H_{s2} = kcal/ kg of solid

W_s = kg of water/ kg of solids

From psyc. Chart:

Air contains $0.011\text{ kg water/kg of dry air} = w_1$

Assuming dry milk solids have specific heat of $0.534\text{ kcal / kg of ----}$

Feed rate = $1000 \times 0.96 \times 100 / 45 = 2133\text{ kg / hr}$

$W_{s1} = 53745\text{ moisture/ solid concentration of milk}$

Dairy Process Engineering

= 1.22 kg of water / kg of dry solids

$W_{s2} = 4/96 = 0.042$ kg of water / kg of dry solids.

Enthalpy:

$H_{a1} = 0.24$ (dbt) + $W_1(597.2 + 0.45$ dbt)

= 0.24 (190) + $W_1(597.2 + 0.45 \times 190)$

= 53.11

$H_{a2} = 0.24$ (80) + $W_2(597.2 + 0.45 \times 80)$

= $19.2 + 693.2 W_2$

H_{s1} = feed is hot air

= enthalpy of dry solids + enthalpy of moisture

= (specific heat $\times t \times 1$) + ($W_{s1} \times 1 \times t$)

= $(0.554 \times 30 \times 1) + (1.22 \times 1 \times 30)$

= 53.22 kcal / kg of dry solids

H_{s2} = enthalpy of dry solid + enthalpy of moisture

= $(0.554 \times 50 \times 1) + (0.042 \times 1 \times 50)$

= 29.8 kcal / kg of dry solids

Enthalpy balance:

Enthalpy in system = enthalpy out system

$H_{a1} + H_{s1} = H_{a2} + H_{s2} + Q_1$ per unit

Thus, $(Q_a \times H_{a1}) + (H_{s1} \times 2133) = H_{a2} + H_{s2}$

Thus, $53.11 Q_a + (960 \times 53.22) = 25000 + Q_a (922 + 633.2 W_2)$

So, $33.91 Q_a = 633.2 Q_a W_2 = 2517$ ----- eq. (1)

Moisture balance:

Moisture lost by product = moisture gained by air

$960 (W_{s1} - W_{s2}) = Q_a (W_2 - W_1)$

Thus, $Q_a (W_2 - 0.011) = 1130.88$ ----- eq. (2)

By solving both equations:

$Q_a W_2 = 1130.88 + 0.11 Q_a$

$Q_a = 26663$ kg/hr

$W_1 = 0.011$

$W_2 = 0.0534$

Humidity of air exhaust = total moisture / quantity of air

Problem:

From the following data given for the spray dryer, determine air flow rate and steam consumption.

Specific humidity of inlet air (32°C, 40 % RH) = 0.0119 kg water/ kg of dry air

Specific humidity of outlet air (90°C) = 0.052 kg water/ kg of dry air

$W_{s1} = 58 / 42 = 1.380$ kg of water/ kg of dry solid

$W_{s2} = 3 / 97 = 0.0309$ kg of water/ kg of dry solid

C_p = specific heat of air = 0.24 kcal/ kg of dry air

t_o = outlet air temperature

t_i = inlet air temperature

H_s = enthalpy of steam at inlet of heater = 668.7 kcal / kg

H_c = enthalpy of condensate outlet = 84.95 kcal / kg

n = efficiency

moisture balance:

moisture lost by the product = moisture gained by the air

thus, $2(970)(1.38 - 0.0309) = Q_a (0.052 - 0.0119)$

thus, $Q_a = 63835.463$ kg/hr

steam consumption (kg/hr) = $L_a \cdot C_p \cdot (t_0 - t_1) / [(H_s - H_c) \cdot h]$

= 3038.89 kg/hr (by putting values)

Total water evaporated in dryer / hr = total concentration of milk - total powder

Thus, $2000 - [2000 \times 42 \times 1.03 / 100]$

= 1134.8 kg/hr

Specific steam consumption = kg of steam / kg of H₂O evaporated

= 2.677 kg steam / kg H₂O evaporated

Problem:

Data:

Feed rate = 50000 kg / hr

W_1 , Specific humidity of inlet air (33°C, 45 % RH) = 0.14 kg water/ kg of dry air

W_2 , Specific humidity of outlet air (85°C) = ? kg water/ kg of dry air

$W_{s1} = 59 / 41 = 1.439$ kg of water/ kg of dry solid

$W_{s2} = 3.5 / 96.5 = 0.03626$ kg of water/ kg of dry solid

specific heat of feed = 0.554 kcal/ kg of dry air

t_i = inlet air temperature (dbt) = 210 °C

calculate the quantity of feed to be taken for the system.

Solution: $H_{a1} = 0.24 \text{ dbt} + W_1 (597.2 + (0.45 \times 210))$

= 60.08 kcal/ kg of dry air

$H_{a2} = 0.24 \text{ dbt} + W_2 (597.2 + (0.45 \times \text{dbt}))$

= 20.4 + 635.45 W_2

Problem

Find out the steam consumption of roller dryer for the given data:

Water evaporation rate = 25 kg H₂O / hr

Initial feed concentration = 30 % TS

Final product TS = 96 %

Drum diameter = 1.5 m, drum length = 2.5 m

Solution:

Total surface area = $2\pi r l = 11.775$ m²

Total water evaporated /hr = $25 \times 11.75 = 294.25$ kg H₂O

For 100 kg of feed, feed with TS = 30% and final TS = 96 %;

Total water evaporated = concentration x (milk / hr - powder / hr)

= $1.04(100 - 30) = 68.8$ kg/hr

For 294.25 kg water evaporated, kg of powder = $31.2 \times 294.25 / 68.8$

Dairy Process Engineering

$$= 133.438 \text{ kg/hr} \text{ --- (1)}$$

Heat supplied by steam = heat gained by the product

Thus, steam quantity \times latent heat of steam at 2 kg/cm²

$$= m.s.dt + (\text{heat of vapourisation} \times \text{vapour})$$

$$V = F (1 - X_f/X_l) = 294$$

$$(X) \cdot (525.9) = (427.65)(0.554)(100.45) + 294 \times 540$$

$$X = 326.67 \text{ kg/hr}$$

Steam consumption = 326.67 kg steam / hr

(it is assumed that condensate is at 98 °C)

Thus, specific steam consumption

$$= (\text{kg of steam / hr}) / (\text{kg of water evaporated/hr})$$

$$= 326.67 / 294.25 = 1.11 \text{ kg of steam/ kg of water evaporated}$$

(losses are neglected)

Hs1 = enthalpy of dry solid + enthalpy of moisture

$$= (\text{sp. Heat} \times t \times 1) + (W_{s1} \times t \times 1)$$

{where, t = temperature of feed = 45 °C and let sp. Heat of feed = 0.554}

$$\text{Thus, } H_{s1} = (0.554 \times 45 \times 1) + (1.439 \times 45 \times 1) = 84.68 \text{ kcal/ kg of dry solids}$$

Hs2 = enthalpy of dry solid + enthalpy of moisture of product

$$\text{Thus, } H_{s2} = (0.554 \times 60 \times 1) + (0.03626 \times 60 \times 1)$$

$$= 35.4156 \text{ kcal/ kg of dry solids}$$

Enthalpy balance:

Enthalpy in system = enthalpy out of the system

$$H_{a1} + H_{s1} = H_{a2} + H_{s2} + Q_1 \quad (\text{where } Q_1 = \text{heat loss, kcal/ hr})$$

$$(Q_a \times H_{a1}) + (H_{s1} + 4825) = Q_1 + Q_a (H_{a2}) + (H_{s2} \times 4825)$$

$$211828.62 = 80.48 Q_a + 635.45 W_2. \quad Q_a \text{ ----- (1)}$$

Moisture balance:

Moisture lost by the product = moisture gained by the air

$$4825 (1.439 - 0.036267) = Q_a (W_2 - 0.014)$$

$$6768.22 = Q_a W_2 - 0.014 Q_a \quad \text{----- (2)}$$

By solving eq. 1 & 2

$$Q_a = 45750.949 \text{ kg/hr (air flow)}$$

Thus, total kcal required/ hr = $Q_a \times \text{sp. Heat} \times \text{temperature difference}$

$$= 45750.949 \times 0.24 \times (210 - 33)$$

$$= 1943499.9 \text{ kcal / hr}$$

Calorific value of oil = 9985 kcal/kg

But heat transferred = 85% (efficiency)

$$\text{Thus, actually we get} = 9985 \times 0.85 = 8487.25 \text{ kcal/kg}$$

Thus quantity of oil required = total Kcal required/ (kcal / kg of oil)

$$= 1943499.9 / 85 = 228.99 \text{ kg/hrs}$$

Lesson 13

Air Heating Systems, Atomization & Feeding System

Introduction:

The success of the drying and obtaining uniform product in spray drier depends very much on the degree of atomization, hot air to spray contact. The distribution of air near the nozzle very much affects the drying process.

13.1 Hot Air System and Air Distribution

13.1.1 Air Filtration

The quality and condition of the air supplied to the air heating system is to be properly controlled, to avoid contamination and chocking of filters frequently. To achieve this, the following points are to be considered:

- (i) The air should be prefiltered and supplied by a separate fan to the fan/filter/heater room. This room must be preferably under pressure to avoid unfiltered air to enter.
- (ii) For air to be heated above 120 oC filtration is needed. The filter is generally placed on the suction side of the fan.

13.1.2 Air Heating System

The drying air can be heated in different ways:

- (i) Indirect : Steam / Gas/ Hot oil
- (ii) Direct : Gas / Electricity

Indirect Heating

A steam heater is a simple radiator. The temperature to be obtained depends on the steam pressure available. Under normal conditions it is possible to obtain air temperatures 10oC lower than the corresponding saturation enthalpy of the steam.

Modern steam heaters are divided in sections, so that the cold air first meets the condensate section, then a section with low steam pressure (which is usually the biggest one in order to utilize as much low-pressure steam as possible), and then the air finally enters the high-pressure steam section. The air heater consists of rows of finned tubes housed in an insulated metal case. The heat load is calculated from the quantity and specific heat of the air. The heater size depends upon the heat transfer properties of the tubes and fins and is usually about 50 Kcal/oC x h x m³ for an air velocity of 5 m/sec. Steam-heated air heaters will usually have an efficiency of 98-99%. As the steam boiler is usually placed at some distance from the air heater, 2-3 bar g extra pressure on the boiler should be anticipated due to pressure loss in the steam pipe and over the regulating valve. To avoid corrosion of the tubes in the air heater it is recommended to use stainless steel. Dampers are provided to control the velocity and quantity of air flow to and from the air heaters.

In indirect gas heaters, drying air and combustion gases have separate flow passage. The combustion gases pass through galvanized tubes that act as heat transfer surface for the

drying air. The combustion chamber is made of heat-resistant steel. The end cover of the heater should be removable for cleaning of tubes. Heaters of this type will in the range of 175-250°C have an efficiency of about 85% .

Hot oil liquid phase air heaters are used either along, or when high inlet drying air temperatures are required, and the steam pressure is not high enough. The heater system consists of a heater, which can be gas- or oil-fired, and an air heat exchanger. Between these two components a special food-grade oil or heat transfer fluid, which does not crack at high temperature, is circulated at high speed. The main advantage of hot oil liquid phase is the open pressure-less system.

Direct Heating

Direct gas heaters are only used when the combustion gas can be allowed to come into contact with the product. They are therefore not common in the dairy industry, and in some countries it is even not allowed when the powder is to be used for human consumption. The direct gas heater is cheap, it has high efficiency, and the obtainable temperature can be as high as 2000°C. When a plant is designed with an air heater with direct combustion, it is necessary to calculate the amount of vapour resulting from the combustion (44 mg/kg dry air/°C), as this will increase the humidity in the drying air. The outlet temperature has therefore to be increased in order to compensate for this increase in the humidity and to maintain the relative humidity. This type of air heaters are not used in dairy industry

The direct heating causes absorption of certain Combustion products in to the milk powder., especially Nitrous oxide. The level of NO_x in the process air after the direct fired natural gas air heater will depend on many variable factors, however, with a well adjusted air heater it should be limited. The specially designed CAX low NO_x gas burners shown in the Fig. 13.3.

Electric air heaters are common on laboratory and pilot spray dryers. The heater has low investment costs, but is expensive in operation and therefore not used in industrial size plants.

13.1.3 Air Distribution

The air distribution is one of the most vital points in a spray dryer. There are various systems depending on the plant design and the type of product to be produced. Dryer design falls into three categories: co-current, counter-current and mixed flow. However, as the goal in the dairy industry is to get the best mixture of the hot incoming air and the concentrate droplets in order to obtain a fast evaporation, only co-current dryer design is used.

If the dryer is with a horizontal chamber, the air disperser is arrange like a plenum chamber, and each nozzle will be surrounded by an air stream. However horizontal dryers are not used in dairy industry, the most common is that the air disperser is situated on top of the vertical dryer ceiling, and the atomizing device is placed in the middle of the air disperser thus ensuring an optimal mixing of the air and the atomized droplets. In cylindrical vertical dryers it is also seen that the whole ceiling is perforated plate in order to ensure that the air is cooled by the concentrate. This system, however, makes fines return complicated. It should be noted that an air disperser should have the ability to guide the air and the atomized droplets in the right direction in order to avoid deposits in the drying chamber.

Two different types of air dispersers are used in spray dryers for food and dairy products: Fig. 13.5 shows Rotary type ceiling air disperser with adjustable guide vanes. The air enters tangentially into a spiral-shaped distributor housing from where the drying air is led radially and downward over a set of guide vanes for adjustment of the air rotation. This type of air disperser is used for rotary atomizers and nozzle atomizers placed in the center of the air disperse. Plug-flow air stream, (Fig. 13.6) The air enters radially through one side and is distributed through an adjustable air guiding arrangement. This type of air disperser is used for nozzle atomizers, where a laminar plug-flow air stream is wanted.

13.2 Feeding System

The feed system, is the link between the evaporator and the spray dryer and comprises:

- (1) Feed tanks
- (2) Water tank
- (3) Concentrate pump
- (4) Preheating system
- (5) Filter
- (6) Homogenizer/high-pressure pump
- (7) Feed line, including Return line for CIP

Feed Tanks

It is recommended to use two feed tanks and change from one to the other at least once an hour. This is due to the risk of bacteria growth in the food normally having a temperature of 40-45 oC . One is therefore in use while the other one is being washed. The size of each tank should correspond to 15-30 min. of the capacity of the dryer and provide with a lid to avoid contamination from the air. Very often the feed tanks are equipped with spray nozzles for automatic CIP cleaning.

Water Tank

The water tank is used during start and stop of the plant, and if during the run there will be a sudden shortage of concentrate. Level controls can be placed on the feed tanks, so that the change-over can be automatic.

Concentrate Pump

If a rotary atomizer is used, the most common feed pump is either the mono type or a centrifugal pump. The mono pump requires less energy and can handle concentrates of a higher viscosity than the centrifugal pump, but is more expensive.

Pre heating System

Nozzle atomization requires higher feed temperature than that coming from the evaporator. Therefore, a concentrate pre heater is necessary. Two types can be used, either indirect or direct.

(A) Indirect pre heaters

A plate heat exchanger system is cheap, but if the concentrate should be heated to 60-65 oC

and the solids content is 45-46%, and if 20 hours run is aimed at, it is necessary to have two interchangeable heaters allowing one to be cleaned while the other one is being used. Steam, warm water or condensate from the first effect of the evaporator can be used as heating medium.

1. Spiral Tube Heat Exchanger

The spiral tube heater is able to heat concentrate with a higher solids content to a higher temperature without frequent cleaning due to high product velocity and low Δt , but it is more expensive. Fig. 46. If a total blockage due to deposits on the heat surface occurs, then the cleaning becomes complicated.

2. Scraped Surface Heat Exchanger

In the scraped surface heater the heat transfer surface is continuously being scraped off by a fast rotating scraper made of food-grade synthetic material to avoid any product adherence resulting in burnt deposits with reduced heat transfer as a consequence. The scraped surface heater is especially suited for products with high solids content if high temperatures are required. They can operate continuously for 20 hours and are cleaned together with the remaining feed system.

(B) Direct pre heaters are of the type:

- (i) Direct Steam Injection DSI
- (ii) Lenient Steam Injection LSI

(i) Direct Steam Injection DSI

In the DSI unit the steam is introduced into the milk concentrate via a nozzle producing relatively big steam bubbles resulting in a superheating of the some parts of the concentrate which leads to protein denaturation.

(ii) Lenient Steam Injection LSI

In the LSI unit (patented) the steam is mixed into the concentrate by a dynamic mixer. Very small steam bubbles are created, and superheating/denaturation is avoided. Therefore, a much higher steam pressure can be used. The LSI unit is often used in combination with the scraped surface heat exchanger, if temperatures above 75°C are required in the concentrate.

Preheating of concentrate is advantageous, not only from a bacteriological point of view. It also produces viscosity decreases, which together with the applied calories results in a capacity increase of minimum 4% on the spray dryer and an improved solubility of the produced powder.

Filter

An in-line filter is always incorporated in the feed system to avoid lumps etc. passing to the atomizing device.

Homogenizer/High-Pressure Pump

If whole milk powder should be produced, it is recommended to incorporate a homogenizer in

order to reduce the free fat content in the final powder. A two-stage homogenizer is preferred. First stage is operated at 70-100 bar g, and the second stage at 25-50 bar g. Usually the homogenizer and feed pump are combined in one unit. If nozzle atomization is used then a higher pressure (up to 250 bar g for the nozzles + 150 bar g for homogenizing) is required, and a combined homogenizer/high-pressure pump is chosen. A variable speed drive for controlling the outlet temperature is preferred, as a return valve tends to give uncontrollable holding time resulting in viscosity problems.

Feed Line

The feed pipe should naturally be of stainless steel and of course of the high-pressure type, if the atomization is to be carried out by means of nozzles. The dimension should be so that the feed velocity is approx. 1.5 m/sec. In a feed system a return pipe should also be included for the cleaning solution, so that the entire equipment can be thoroughly cleaned.

13.3 Atomization

The aim of atomizing the concentrate is to provide a very large surface, from which the evaporation can take place. The smaller droplets, the bigger surface, the easier evaporation, and a better thermal efficiency of the dryer is obtained. The ideal spray should have same droplet size, to have uniform drying time for all particles and to have an equal moisture content. In practice, however, no atomizing device has yet been designed to produce a completely homogenous spray, although present designs have a high degree of homogeneity. From a powder bulk density point of view a homogenous spray is not wanted, as this would mean powder with low bulk density, and that would mean an increase in packing material.

Function of atomization is:

- (i) A high surface to mass ratio resulting in high evaporation rates,
- (ii) Production of particles of the desired shape, size and density.

Common types of atomizers:

- (i) Pressure energy as in pressure nozzles
- (ii) Kinetic energy as in two-fluid nozzles
- (iii) Centrifugal energy as in rotating discs

(i) Pressure Nozzle Atomization

The basic function of pressure nozzles is to convert the pressure energy supplied by the high-pressure pump into kinetic energy in form of a thin film, the stability of which is determined by the properties of the liquid such as viscosity, surface tension, density and quantity per unit of time, and by the medium into which the liquid is sprayed.

Most commercially available pressure nozzles, see Fig. 13.7 & 13.8, are designed with a swirl chamber giving the liquid a rotation, so that it will leave the orifice, the second main component of a pressure nozzle, as a hollow cone. In addition to above characteristic design, the obtained spray pattern is a function of the operating pressure. Capacity can usually be assumed directly proportional to the square root of the pressure.

The high-pressure low – capacity nozzles are mainly used in box dryers and operate at a high pressure 300-400 bar g. Each nozzle will have a capacity of 50-150 kg concentrate,

usually with only 40-42% solids, if a reasonable solubility should be maintained in the powder. The actual plant will therefore be equipped with numerous nozzles, all of which are with very small orifices which get easily blocked. Normally, the powder has high bulk density, but tends to be dusty, as it consists of small particles. Due to the low solids requirements the drying becomes at the same time expensive.

The low-pressure high-capacity nozzles with a capacity of up to 1000-1500 kg/h have gained more and more use after the development of the two-stage drying process, where the particle temperature is much lower. The solids content can therefore be increased to 48% and the pressure decreased (150-200 bar g) without affecting the solubility, thus making nozzle atomization interesting also from an economical point of view.

The advantages of pressure nozzles can be summarized as follows:

- Powder with low occluded air
- Powder with high bulk density
- Improved flowability, especially in whole milk
- Tendency to give less deposits in the drying chamber when difficult products are produced
- Ability to produce big particles

Two-Fluid Nozzle or Pneumatic Atomization

The energy available for atomization in two-fluid atomizers is independent of liquid flow and pressure. The necessary energy (kinetic) is supplied by compressed air. The atomization is created due to high frictional shearing forces between the liquid surface and the air having a high velocity even at sonic velocities and sometimes rotated to obtain maximum atomization. (Fig. 13.9 and 13.10). Two-fluid atomization is the only successful nozzle method of producing very small particles, especially from highly viscous liquids.

Rotary Atomization

In rotary atomizers (Fig 13.11) the liquid is continuously accelerated to the wheel edge by centrifugal forces, produced by the rotation of the wheel. The liquid is distributed centrally and then extends over the wheel surface in a thin sheet, discharged at high speed at the periphery of the wheel. The degree of atomization depends upon peripheral speed, properties of the liquid, and feed rate.

The wheel should be designed, so that it will bring the liquid up to the peripheral speed prior to the disengagement. Very often the wheels are therefore with vanes of different design to prevent liquid slippage over the internal surface in the wheel. The vanes also concentrate the liquid at the disc edge, producing there a liquid film analogous to the one considered in pressure nozzles.

In spite of intensive investigations into the mechanism of atomization from rotating atomizer wheels, the prediction of spray characteristics still remains uncertain. The effect of individual variables has been established over a limited range and there is only a few dealing with high capacity, high speed industrial atomizers.

The peripheral speed is widely accepted as the main variable for adjustment of a specified

droplet size. However, it has been shown that droplet size does not necessarily remain constant, if equal peripheral speeds are produced in wheel designs of various diameter and speed combinations, and there is a tendency that bigger wheels produce bigger particles all other things being equal. However, in the choice of wheel diameter one should rather look at the reliability of the atomizer, as the differences in spray characteristics are negligible. Further, smaller wheels are easier to handle when cleaned.

The rotary atomizer has been known and used in the dairy industry for many years, the main advantages are:

- Flexibility as to through-put
- Ability to handle large quantities
- Ability to handle highly viscous concentrates
- Different wheel designs giving different powder characteristics
- Ability to handle products with crystals
- Higher solids content in the feed is possible, therefore better economy

The use of pressure nozzle or rotary wheel is affect the physical properties of final product.

13.4 Drying Chamber

All the drying chambers are intended to achieve complete mixing of the milk droplets with the hot air, followed by as rapid drying as possible in a space of reasonable dimensions without heat degradation and unwanted wall deposits. Product discharge must be continuous and the method of discharge conducive to the desired form of dried product. Drying chambers are designed to discharge the majority of the product at the base or to convey all the product with the exhaust air to a product separation and recovery unit. The drying chamber may be of different designs.

The drying chamber is the most space demanding part of the dryer and requires heavy investment to house a large drying chamber. The drying chambers can be designed to erect in the open space without a building. The insulation of the chamber is increased from 100 mm to 200 mm. The insulation is provided by cladding of plastic coated, mild steel sheets. The cladding is extended downwards to cover the support for the chamber and upwards to cover a light steel structure on the top of the chamber to accommodate the atomizer.



Lesson 14

Factors Affecting Bulk Density of Powder, Spray Drying Controls

Introduction:

Pneumatic Conveying and Cooling System

A pneumatic conveying system is established when powder has to be conveyed from one place to another. Products with high fat content require more air (5 times powder) than skim milk (4 times powder). It is however not recommended to convey powders with high fat content than 30% otherwise blocking may occur in the ducts.

Air of any temperature may be used, and the powder temperature will naturally follow the air temperature. If hot air is used there will be a drying effect. This will, however, be minimal, as the residence time is short (air velocities of 20 m/sec.).

A pneumatic conveying system is usually established in connection with a spray dryer of conventional design. Ambient air is used thus providing a dual advantage, namely both conveying and cooling of the powder. In order to get the full benefit of the cooling effect it is recommended that there is a lock between the chamber outlet and the duct, which will prevent warm moist air from entering the conveying system. This is usually done by means of a rotary valve. Pulsations in the powder flow as a result of deposits falling from the wall should also be avoided. This can be done using an air conveyor with a perforated plate through which cold air is blown. This will simultaneously have a cooling effect.

The conveying air duct will be passed via the outlet of the main cyclones picking up powder from here. The air/powder stream is passed to a cyclone separating the particles from the air. At the base of the cyclone the powder should be shifted after which it is ready to be bagged off. If climatic conditions are so that a suitable powder temperature cannot be obtained due to high air temperatures, or the humidity in the air is so high that the powder may pick up moisture from the air, cooling and dehumidifying equipment, where the cooling is done by circulating chilled water at 0-1°C, can be established. The temperature to which the air should be cooled depends on the product and ambient conditions, but it is usually around 8°C. Water will then in most cases condense, and it is necessary to include a section for removing this water which is usually done by passing the air over a set of labyrinths. At

the outlet the air will be free from water droplets, but the relative humidity will be 100%. To avoid the risk of further condensation and development of water droplets, which will be picked up by the powder thus increasing the moisture content, the air is heated in a subsequent heater to 15-20 °C reducing the relative humidity.

The cooling can also be done by a refrigerator with direct expansion in coils in the airstream. A pneumatic conveying system is cheap and can handle big quantities of powder, and it will brake up any tendency of agglomeration resulting in powder with maximum bulk density. For powders with agglomerates the pneumatic conveying system can naturally not be used.

Fluid Bed After Drying/Cooling

In order to improve the drying economy the drying is divided in two or more steps. The first step is done in a spray drying chamber transforming the liquid into powder particles and evaporating the main portion of the water. The evaporation of moisture from a particle will become more difficult and require more time, as the residual moisture content approached 0%.

The subsequent drying is done in a fluid bed. The fluid bed drying technology has proved especially suited; as the residence time in the fluid bed is so long that the moisture from the center of the particle can reach the surface from where the evaporation takes place.

In a fluid bed the drying air is introduced to the powder through a special perforated plate. The fluid bed can be vibrating, or stationary. The fluid bed offers at the same time a very efficient and lenient tool for cooling of fat-containing and agglomerated products.

Instrumentation and Automation

In order to control the drying process and at any time to be able to record the drying parameters the installation should include instrumentation and control equipment. This is usually placed together with a mimic diagram in a control panel which in many factories is placed in a separate control room, partly to keep the panel and instruments dry, but also because the operators here can be in a place with reduced noise level.

A control panel, for a modern spray dryer should contain instruments for all relevant processing parameters, incl. Inlet drying air temperature for the main chamber and fluid

beds, as well as outlet air temperature. It is an advantage. If all temperatures are recorded on a printer enabling the operator to see the trend of the temperature development, and also to go back and find the reason why a powder has been downgraded in the laboratory. An ammeter and hour counter for the atomizer or high-pressure pump are also necessary.

Spray Dryer Control System:

The aim of a spray dryer control system is the maintenance of the desired dried product quality, irrespective of what disturbances occur within the drying operation and variations in feed supply. The most effective product parameter to control is the moisture content. Outlet air temperature is the parameter controlled. This temperature represents product quality, i.e. bulk density, colour, flavour, activity as well as moisture content.

Spray dryers can be controlled either manually or automatically. Manual control is applied to small plants (Laboratory, pilot- plants or small industrial sizes). Manual control can be applied to large industrial units, but the demands of continuous operation on operating personnel, the maintenance of constant product quality over lengthy durations of productions makes automatic control (semi or full) a virtual necessity.

Control is accomplished by maintaining a set outlet temperature through varying (a) the feed rate to the dryer, hereafter denoted control system A, or (b) inlet drying air temperature, hereafter denoted control system B. Control system A is the more widely used of the two systems. By applying automatic control to the outlet air temperature, product moisture can be held within very narrow limits.

CONTROL SYSTEM 'A':-

1. Outlet temperature control by feed rate regulation.

2. Inlet temperature control by air heater regulation.

The control system is illustrated in figure-I. The system consists of two control loops of quick response. Quick response loops are the desired control characteristics to prevent adverse drying conditions.

The air temperature in the exhaust duct is measured and transmitted to the temperature indicating controller (TIC) which counteracts any temperature deviation

from the desired set points by varying the feed rate. The temperature of air to the dryer air disperser is measured and transmitted to a temperature indicating controller. Any deviation from the desired inlet air temperature is corrected by control of fuel and combustion air to the burner (oil and gas fired air heaters), steam pressure in a steam air heater, or power input to an electric air heater.

In the event of failure in the feed system (pipe or atomizer blockage, pump damage. pump control failure) where feed supply to the atomizer is drastically reduced or ceases, a safety system can be installed to prevent the outlet air temperature rising above a known safety level, since the system can be potentially dangerous for many products in as much that feed failure can lead to rapid rise in outlet air temperature as the air heater continues to function. A built in safety system can shut down the air heater once a certain outlet air temperature is reached or water can be passed to nozzles positioned as safety measure, for example, in the dryer root.

Some safety systems switch feed over to water at the feed pump and operate on a two temperature level safety system. For a partial blockage of the feed system, the outlet air temperature will rise more slowly and on reaching the first level (say 300 ° F- 500°), feed supply is stopped and switched over to water. If the blockage is minor, the water flow may dislodge the blockage and after a short time when the normal outlet temperature has been restored, so can the feed supply. If the blockage cannot be removed by water, or water cannot pass to the atomizer (in case of pump failure), the outlet air temperature will continue to rise to the secondary safe level after which the chamber is flooded by quench nozzles or the air heater is shut down or a combination of both. To draw attention to rise on outlet air temperatures, alarms can sound 20-40 °F. (10-20° C) before any unsafe temperature level is reached.

The use of two level safety system gives the opportunity of restoring dryer conditions on water by using water to flush out a blocked feed or enable feed system failures to be rectified. If feed system difficulties can be overcome by a short operation on water feed, time will be saved by not having to shut down and restart the dryer.

CONTROL SYSTEM 'B':-

1. Outlet temperature control by air heater regulation.

2. Feed rate held constant.

The control system is shown in figure 2 and is used particularly for dryers with nozzle atomization where wide variations in feed rate cannot be handled. The outlet air temperature is measured and transmitted to a temperature indicating controller (TIC). To compensate for any deviation from the desired outlet air temperature, the heat input to the dryer is adjusted by the controller through regulation to the combustion rate in the gas or oil air heater (if fitted) or steam pressure at the steam-air heater (if fitted).

From a theoretical view point, this is an inherently safe and acceptable as any increase in outlet temperature brings about a decrease in heat input to the dryer. From a practical view point however, the system has operational disadvantages of lengthy control large due to time lags in the heater control circuit. These time lags can increase outlet air temperature fluctuations. The system has inability to handle effectively variations in feed solids, but it can be improved by outlet temperatures cascaded on the inlet temperature controller which controls the heater.

Safety systems similar to these used in control system A are used. When using a two level safety system, as the outlet air temperature reaches first level, water is flushed in dryer and on reaching the second safety level, the heater is automatically shut down.

FEED SYSTEM CONTROLS

Systems for Rotary Atomizers

Control system A is adopted with direct feeding from a suitable positive displacement pump with variable speed control, a centrifugal pump throttled by a control valve, or a gravity feed constant heat tank with a control valve in the outlet pipe. Control system B is rarely considered.

Systems for Nozzle Atomizers

Both control systems are applicable but control system B is preferred. Control system B can be applied in two ways with the feed pump on a fixed manual control setting. The outlet temperature controller can be cascaded on to the inlet temperature controller as shown in figure 3, or linked directly to the heater. Pressure safety systems are incorporated to shut down the dryer if excessive pressure build up in the feed system due blocked nozzle(s). Control system A can be applied in two ways. The outlet temperature controller sets the pressure control loop in the feed system or is linked directly to the feed pump. It is usual for each nozzle in a multi nozzle assembly to be brought in manually during start up as the inlet temperature rises.

INTER LOCKS

Interlocks are closely connected with the control and operation of dryer. Interlocks are installed to ensure safe start up, operation and shut down of the dryer. Some examples of typical interlocks are as follows:-

For Prevention of Drying Chamber Damage:-

An interlock ensures that an exhaust fan cannot be started before the supply fan. This is installed if there is a change of chamber collapse under the low negative pressure conditions caused by an exhaust fan operating alone. The interlock is usually over ridden when a chamber door is open. This allows the exhaust fan to operate alone for shut down and cleaning purposes. For example, for an "air sweep" chamber cleaning operation. An alternative system for prevention involves a vacuum switch mounted at the chamber ceiling in a powder free area. The switch is normally set to shut down the exhaust fan if chamber pressure reaches -4 in w.g. (-100 mm W.G.)

For Prevention of Wet Chamber Wall

An interlock ensures that feed cannot be passed to the rotary atomizer when not running. Furthermore the interlock will cause the feed to cease an atomizer failure.

For Prevention of Heater Damage

An interlock ensures that the burner cannot be ignited unless the storage pump, burner fuel pump, combustion fan, and dryer fans are in operation. For indirect heaters, a differential pressure switch can be installed to check the correct air flow, and linked to the combustion and supply fans.

Precaution Against Burnt Product:-

An interlock ensures that the main dryer fans cannot be started unless the necessary cooling fans are in operation. The fans cool potential hot areas in the chamber where build-up and scorching of product can take place.

Full Automation of Spray Dryer and Feed Pretreatment:-

The full automation of the spray dryer *as* described above will maintain a uniform product quality as long as input feed compositions do not vary widely during operation. To reduce variations in feed solid concentration, attention must be paid to pretreatment section that supplies the spray dryer. The maintenance of constant feed solids to the spray dryer is best achieved by coupling the pretreatment section to the spray dryer and applying control system analysis to the two parts as one unit.

The coupling of an evaporator (pretreatment section) to the spray dryer has been achieved within the dairy industry. Notable advantages achieved, apart from control of feed conditions to the dryer include the elimination of intermediate feed tanks and great precision in the dosing of additives. Feed concentrate does not come into contact with ambient air.

The control parameter is the total solids in the feed concentrate leaving the evaporator and is based upon the continuous measurement of density, or continuous weighing. Systems are based upon hydrometer measurement, refractometers or electronic sensors but all have disadvantages to various degrees in accuracy, reliability or unsuitability to certain products. Continuous weighing techniques of a given volume, however, have been successfully applied. One of such measuring equipments is known as U-tube equipment.

The milk or steam supply at the evaporator is controlled by signals from the U-tube transmitter. Four possible control arrangements are shown in figure 5. System A has the evaporator as the dominating unit. (The evaporator is termed the **master** spray

dryer is termed the slave). Systems B-D are inverse with the spray dryer playing the dominant role in the control.

In system A, signal from the total solids detector (i.e. U-tube equipment) control the input of raw feed to the evaporator. The steam pressure is held at a fixed setting. The variations in the amount of concentrate due to deposit formation in the evaporator are compensated by to the spray dryer inlet temperature.

In system B, the spray dryer inlet and outlet temperatures are fixed. The total solids in the concentrate are kept at the required value through alterations of feed input. The evaporative capacity of evaporator is changed through alteration to the steam pressure supplied to the thermo-compression stage which itself is controlled by a level controller in the last effect of the evaporator.

In system C, steam pressure regulation is governed by the solid content passing in the feed passing to the spray dryer. The raw feed input to the evaporator is governed by level control on the last effect of the evaporator.

In system D, steam is added to the finisher stage and is independent of steam supply to the main evaporator stages. The total solids control the steam pressure to the finishers, and the level controller regulates raw feed input to the evaporator. This system has faster response characteristics.

Cleaning-in-place (C.I.P.) can be built into the control system to operate automatically on evaporator shut down. There are considerable advantages in establishing a fully programmed C.I.P. system for the spray dryer too. Full benefit of evaporator and spray dryer automation is achieved only when other sections of the factory are under automatic control, but the time is fast approaching when instrumentation for a whole factory incorporating spray drying plant is centralized, and the control room linked to those already established and publicized in the modern oil refining industry. Electronic instrumentation is now being applied more widely to spray dryers. More extensive usage appears inevitable with computers for process control of complete plants that include a spray drying stage.

Factors affecting bulk density of powder

Bulk Density – “ Mass of powder which occupies fixed volume” (mass per unit volume) it is also termed as packing density or apperent density, unit= gm/ml

Dairy Process Engineering

This property is important because :

1. It influence packaging, transportation cost and storage space. It is functionally important. Low B.D powder requires larger velocity to pack so total volume during transportation will be more per unit wt. So transportation cost increase, so mfr desires heavy powder
2. Functional property also influenced by this basic property .

e.g reconstitution is rapid by lighter powder as water can easily entre inside particle.

-roller dried have low BD than spray dried so spray dried is heavier. In roller dried BD mainly depends on fitness of milling and grinding range 0.3-0.5 gm/ml. Irregular shape particles will make avoids of air and so BD LESS.

Spray dried has BD higher: - because uniform shape so close packing of particles and loss void(free)space. partical density is less in case of spray dried.particle density of individiuil particle, it depends on

I. Nature of milk

II. Amount of enterupted air

I. Whole milk 1.032 g/ml, skim milk 1.0362-1.04 g/ml this affect particle density

II. There is a void of air and air particles in spray dried while roller dried particle is compact so it has more particle density

There is less void left in between the particle of spray dried as small particle will fit in void of big particle so particle density are different

I. Nature of milk

II. Particle density

III. Void volume left

Instant powder

Random fusing of particle gives irregular shape so more void left and agglomerates are porous in nature (rewet powder). Straight thr' may so slight higher bulk density than conventional. So in straight thr' we can use higher TS temperature history of particle different

In the first stage of drying the particle size is decided and final shape decided in second stage depending on temperature difference. So higher TS can be used to have high bulk density.

Depending on temperature difference of inlet air and drying particle temperature which decide how quick the crust is form. If skim forms rapidly, moisture within the particle is gradually escaping. The vapour pressure developed inside the crust. As vapour goes out, its place will be taken by air. As high ts , amount of vapour escape is less so less volume will left for air entrapment. So high bulk density.

If vapour pressure inside the particle is very high and cause bulging effect.(expansion of particle size)so powder become higher so less B.D. B.D. of spray dried=0.05-0.8gm/ml

Rewetted powder process statting of powder itself. So its B.D.is expected lower bulk density then that of powder from which it is made.

During manufacturing of straight the powder we are removing the fines and thus it tends to decrease bulk density as it fines are present, they will be occupied in the gap in between the particle having irregular shape.

Measurement of bulk density

Bulk density in four terms

1. Fixed weight is taken and volume occupied is to be found out = gm/ml without tapping.

This is poured bulk density as render size of particle- poured bulk density varies widely

2. Loose B.D. = tapping for 10 times.
3. Tapped B.D. = tapping for 100 times.
4. Tapped to extreme density = tapping is done for 1250 times.

Dairy Process Engineering

Normally 3rd type of tapping is done for more reliable and consistent B.D. no. Of tapping should be specified.

- Feed composition- high protein and low fat = (whipping)
- So foaming ability is more is SM
- Nature composition –more denatured WP –test foaming as WP give good whipping
- Feed concentration –high TS =less foaming and more viscosity also = less ent-air
- Feed temperature – high temp. low foaming
- Preheating- denaturation of WP = high denaturation – less foaming
- A.Tk – effect on viscosity- affect the amount of air to be incorporate. More air incorporated= more occluded air in powder unless de-aeration is done
- A.Tk=more viscosity =high air =low B.D.
- Type of atomizer- nozzle atomizer=less entrapped air than disc type, but disc type dcan use high concentrated milk so effect of type is compensated.
- A new atomizer- steam hustling ('S' vanes) reduces chances of air incorporation.
- Speed / pressure
- Higher the air in feed = higher air in the product= low B.D.
- Feed viscosity= coarse particle= larger size
 - o Better flow ability
 - o Lower outlet air temp.
 - o More moisture
 - o More interstitial air
- Outlet temp – lower temp =higher moisture

- Fine returns – to increase dispersibility and facilitate agglomeration high fines = more agglomeration
- B.D. is affected by two – main factors

1) P.D, 2) Interstitial air

EFFECT OF PARAMETERS ON B.D:

- conventional spray drying process 11% Ts
- outlet = 90°C gives 0.39 gm/ml B.D
- sp.vol = 2.54 ml/g
- same process – but 34% Ts

thus high Ts = more BD BD sp.vol

0.55 1.81

0.66 1.51

0.46 2.19

-Same process Ts =47

-Same process outlet =113°C

-Thus outlet temp increase =B.D decrease

Straight through process

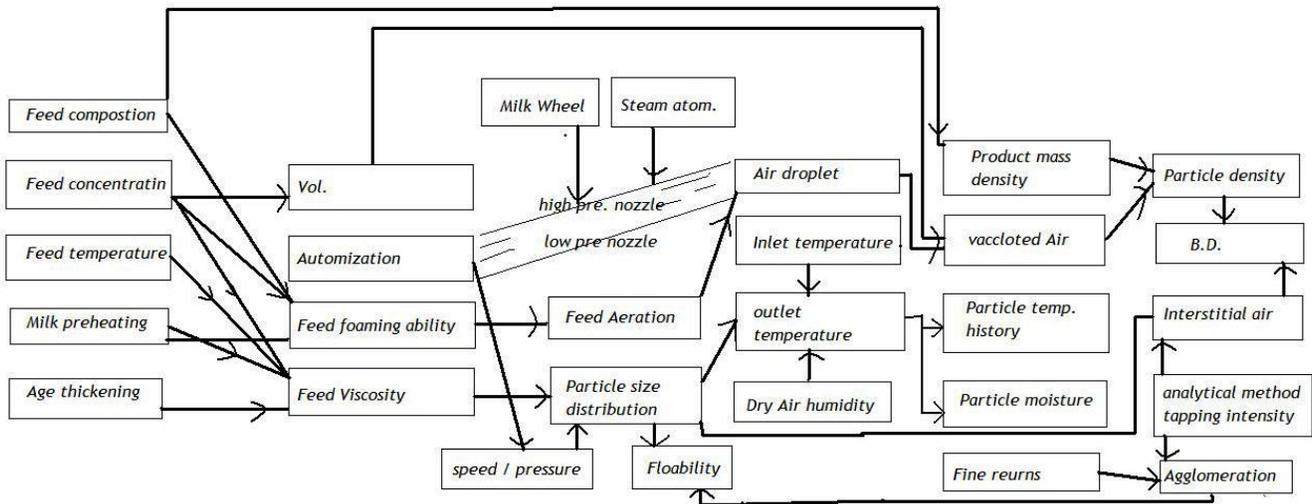
BD sp.vol

0.63 1.60

0.33 3.0

Rewet process - low B.D large particles

Limit – packaging is costly



Lesson 15

Theory of Solid Gas Separation, Cyclone Separators, Bag Filters etc.

Introduction:

15.1 Powder Separation System

As the drying air will contain a small proportion of powder (10-30%) when it leaves the chamber, it is necessary for economic reasons, but also because of pollution problems, to clean the drying air by separating the powder particles. This powder fraction is usually referred to as the fines, as they normally represent the smallest particles.

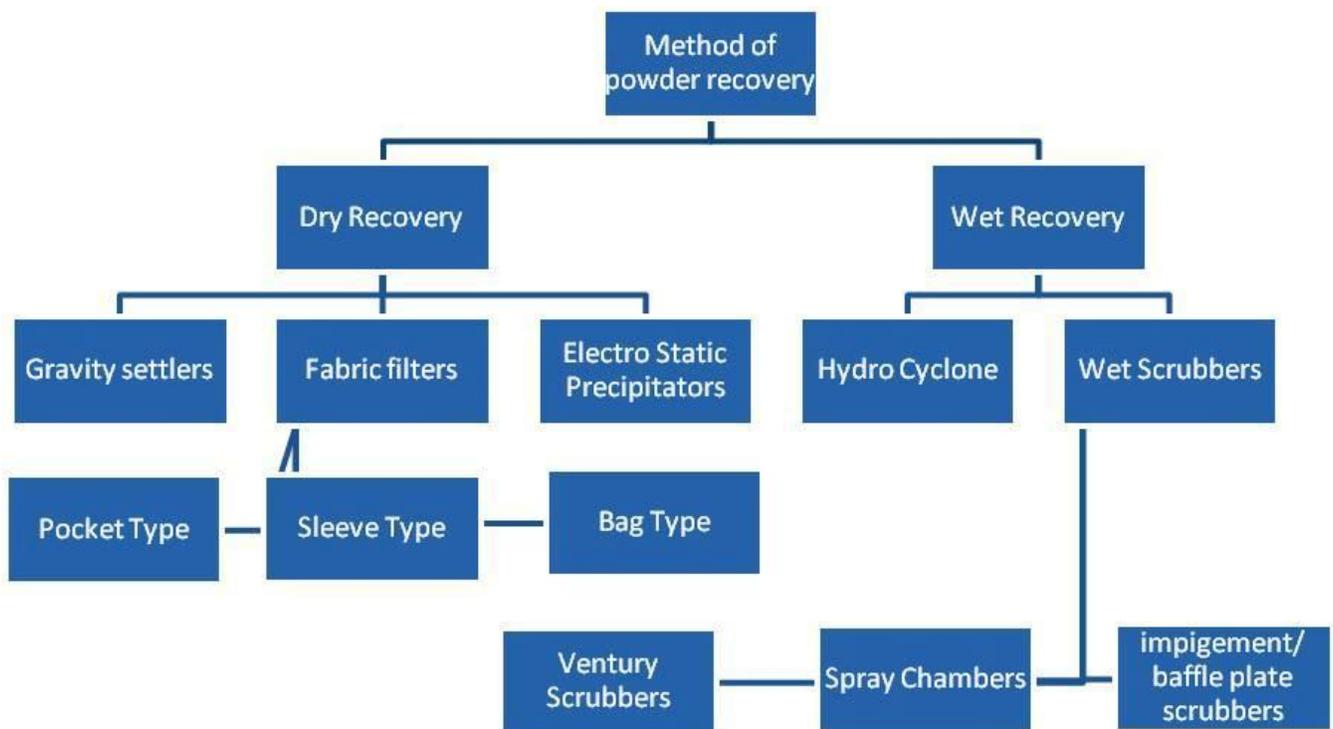


Fig. 15.1 Classification of method of powder recovery

The most used separators in the milk powder industry are:

- Cyclone
- Bag filter
- Wet scrubber

15.2 Cyclone

The cyclone has some advantages, such as high efficiency, it is easy to maintain and easy to clean.

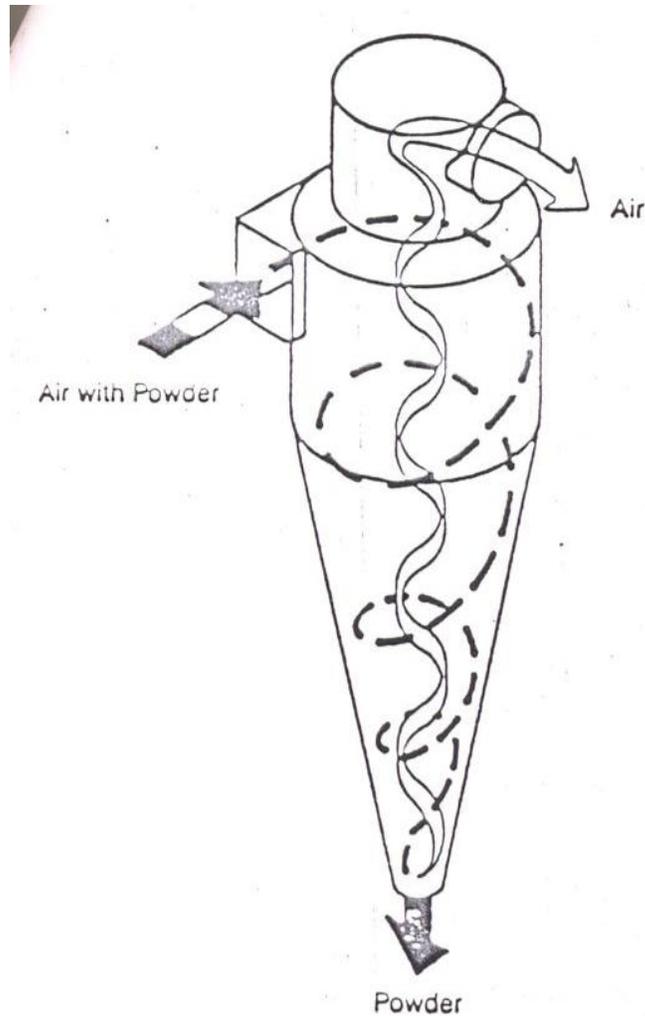


Fig. 15.2.1 Cyclone separator

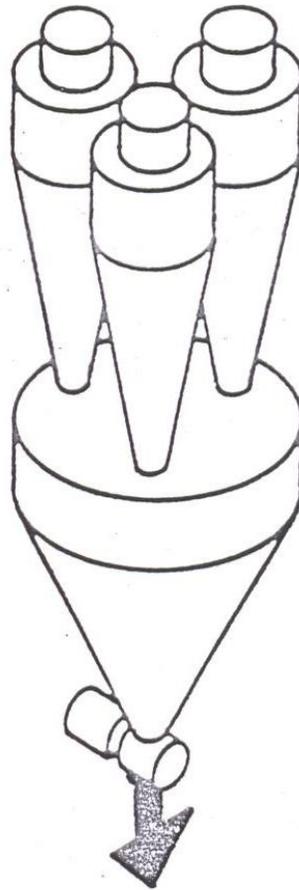


Fig. 15.2.2 Battery of cyclone separator with central hopper

The operation theory is based on a vortex motion where the centrifugal force is acting on each particle and therefore causes the particles to move away from the cyclone axis towards the inner cyclone wall. However, the movement in the radial direction is the result of two opposing forces where the centrifugal force acts to move the particle to the wall, while the drag force of the air acts to carry the particles into the axis. As the centrifugal force is predominant, separation takes place.

Powder and air pass tangentially into the cyclone at equal velocities. Powder and air swirl in a spiral form down to the base of the cyclone separating the powder out to the cyclone wall. Powder leaves the bottom of the cyclone via a locking device. The clean air spirals upwards along the center axis of the cyclone and passes out at the top. (Fig. 15.2.1).

The centrifugal force each particle is exposed to can be seen in this equation:

$$C = mV_t^2/r$$

Where:

C= centrifugal force

m= mass of particle

V_t = tangential air velocity

r= radial distance to the wall from any given point

From this equation it can be concluded that the higher particle mass, the better efficiency. The shorter way the particle has to travel the better efficiency, and the closer the particle is to the wall the better efficiency, because the velocity is highest and the radial distance is short. However, time is required for the particles to travel to the cyclone wall, so a sufficient air residence time should be taken into consideration when designing a cyclone. From above equation it seems evident that small cyclones (diameter less than 1m) will have the highest efficiency, a fact generally accepted.

However, the big capacity dryers are require many cyclones (Fig. 15.2.2). As each cyclone has to have an outlet for powder in form of a rotary valve, pneumatic valve or flap valve, this means that there is a big risk of air leaks which will reduce the cyclone efficiency. The small cyclones can also be connected to one central hopper, and only one valve is then necessary. This means however, that unless there is exactly the same pressure drop over each cyclone, air and powder will pass from one cyclone to another via the bottom outlet. This will result in decreased efficiency and increased powder loss. Cleaning the many small cyclones is a problem, as it is a time consuming job, and with the many corners there is a risk of a bacterial infection. For above reasons the cyclones have become bigger and bigger and are now constructed with diameters of 2.5-3 m, each handling 25,000-30,000 kg of air/h.

When designing a cyclone various key figures should be taken into account in order to obtain the highest efficiency. This is achieved if

Cyclone diameter : Exit duct diameter = 3:1

Cyclone diameter : exit duct diameter = 10:1

Air through-put (velocity V_0 and increased pressure drops will also increase the efficiency, but the energy requirement will increase simultaneously, so in general the upper limit is 175-200 mm WG for skim milk powder. 140-160 mm WG is the maximum for whole milk in order to avoid deposits and final blocking. In most cases rotary valves are used as air lock and product discharge at the bottom of the cyclone.

In order to know a cyclone's efficiency the following terms have to be defined:

- a) The critical particle diameter
- b) The cut size
- c) The overall cyclone efficiency

- a) The critical particle diameter is defined as the particle size that will be completely removed from the air flow (100% collection efficiency).
- b) The cut size is defined as the size for which 50% collection is obtained and is a much better value for starting the efficiency of cyclones.
- c) The overall cyclone efficiency is obtained when handling a product of definite size distribution.

Another method of learning the cyclone efficiency is by a simple powder loss measurement after the cyclone. A very small fraction of the out-going air is passed through a high-efficient mini cyclone or through micro dust filters. The amount of powder collected is directly proportional to the powder loss, which will mainly due to

- Feed with low solids or feed containing air
- High outlet air temperature
- Low particle density (as a result of the above, for example)
- Leaking product outlet from old non-adjusted rotary valves
- Blocked cyclone

- Change in drying parameter resulting in decrease of mean particle size

15.3 Bag Filters

Average powder loss from a normal high-efficient cyclone should not exceed 0.5% when spray drying skimmilk. However, local authorities may conclude that 0.5% is too high due to pollution, thus requiring a final cleaning of the air. This is usually done in bag filters consisting of numerous bags or filters arranged so that each bag receives almost equal quantities of air. The direction of the air is from outside in through the filter material to the inner part of the bag from where the cleaned air enters an exhaust manifold. With a correct selection of filter material high efficiencies can be obtained and collection of 1 micron particles is reported from the manufacturers. The collected powder is automatically shaken off by blowing compressed air through the filter bags from the inner side. The powder is collected at the bottom via a rotary valve. (Fig. 15.3).

The bag filter may also replace the cyclones, a solution often chosen in dryers for whey protein powder or egg white. To prevent condensation, especially on the conical part of the filter housing, warm air, water circulation or heat tracing is established. Powder loss of 15-20 mg/Nm³ is reported.

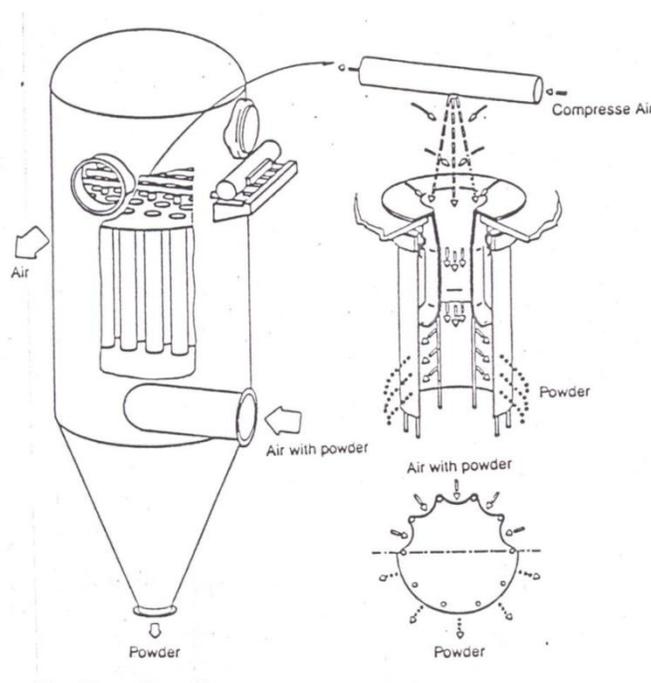


Fig. 15.3 Bag Filters

Fabrics filters consist of woven fabrics of tubular shape which are held over certain frames. Among the various designs available the commonest is bag filters. It consists of freely suspended tubes which are open at both the ends and mounted inclined or vertical. Dust laden air enters from the top and escapes from the pores. Where as solid particles leaves from the bottom. The sleeve type needs internal wire frame for supports .It is mounted inverted .Air enters from the bottom opening and is filtered on the inner side of the sleeve .Pocket type is mounted with opening on the top . Air, enters from the sides and gets filtered on outer surface and leaves through the inside of the tube while the dust is collected on outer surface. For large capacity plants large numbers of sleeves/pockets might be mounted in a chamber. Continuous build up dust layer on the fabric surface results in increase in pressure drop and thus in drop of capacity. To avoid this, the dust is continuously dislodged by mechanical sacking or by reverse air pulsations. The advantages of fabric filters are :

- a. High collection efficiency for smallest size particles. For particles up to 1 micron size it provides 99% collection efficiency. However , it can remove a substantial quantity of particles as small as 0.01 micron size
- b. Moderate pressure drop of the order of 7-15 cm of water gauge.
- c. Dry recover , and
- d. Absences of corrosion and rusting problem.

However the disadvantages of the system are :

- a. Large size of the unit
- b. Difficult maintenance and need for frequent replacement
- c. Plugging of fabric pores by hygroscopic materials

15.4 Wet Scrubbers

The wet scrubber has now been known for many years in the chemical industry. It is based on the venturi scrubber principle. When introduced in the dairy industry, it proved especially efficient, i.e. an efficiency very close to 100%. The outlet separator is designed according to the well-known cyclone principles, however with a modified outlet, resulting in a

minimum liquid level, thereby minimizing bacteria growth, and a design ensuring de-aerating thus avoiding from building.

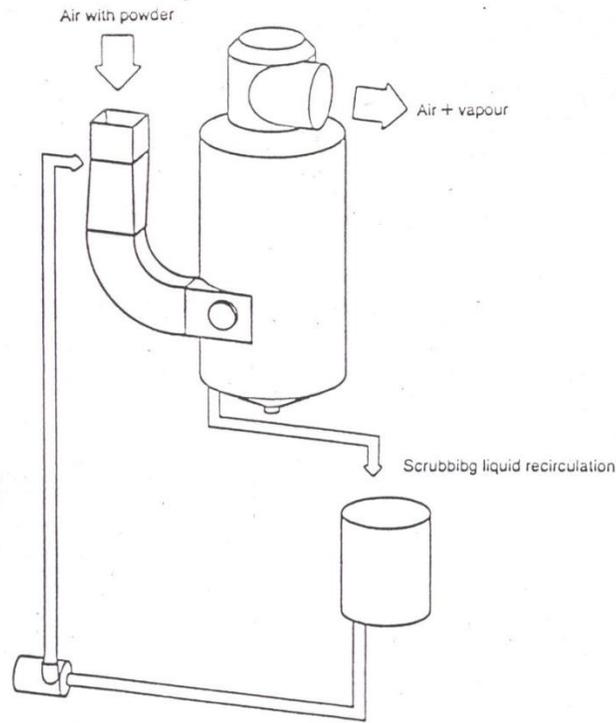


Fig.15.4.1 Sanitary wet scrubber

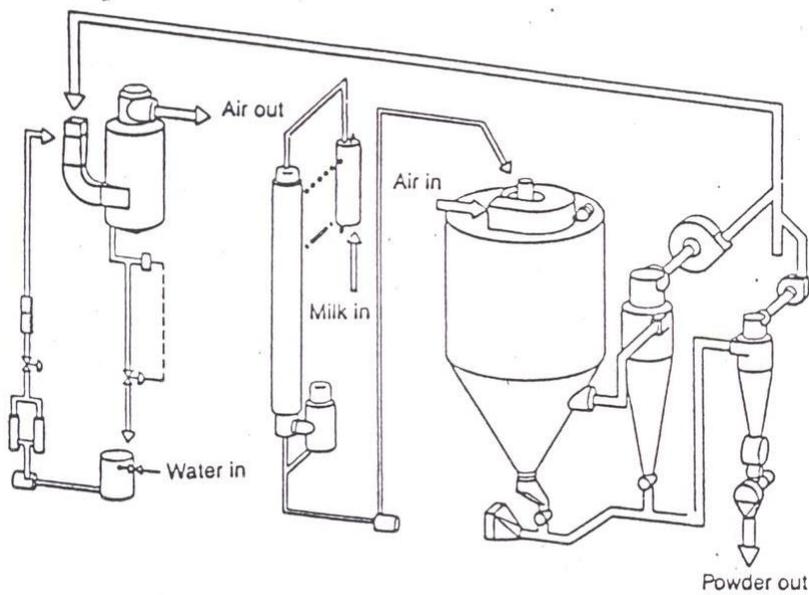


Fig. 15.4.2 Wet scrubber recycled with water

The outlet air from the spray dryer containing powder particles is accelerated to a high velocity in the venturi inlet, where also the liquid is injected through full-cone nozzles. Due to different velocities between the air/particles and the liquid droplets, they will collide, and the powder will dissolve in the liquid droplets. Passing through the subsequent diffuser this process will continue simultaneously with a certain pressure recovery of the air/droplet mix. (Fig. 15.4.1 and 15.4.2). Passing through the separator, air and liquid are separated again. The air leaves through the centre duct and the liquid through the bottom outlet for further processing or recycling depending on what system is selected.

Table:15.4.1 Some of the general advantages and disadvantages of wet scrubbers are:

Advantage	Disadvantages
1.Ability to recover solids as well as liquids.	1.May create liquid disposal problem if the same is hot reused.
2.Ability to handle high temperature, high humidity gas streams.	2.Product is collected wet which subsequent drying.
3.Initial cost is usually low.	3.Pressure drop is higher. Thus operating cost is more.
4.Small space requirement.	4. Severe corrosion and maintenance problem.

15.5 Electrostatic (ES) Precipitators

The device works on the principle that if one or more of the materials in a mixture can be imparted surface charge, on or before entering the electrostatic field, those charged grains will be repelled from one electrode and attracted towards other depending upon the polarity of the electrode. Thus in ES precipitator, strong electric field is created with the help of rectifier and transformer unit and dust laden air flows, that chamber. Powder particles develop negative polarity by combination with air ions. These particles move towards positively charged collecting plates where from they fall in separate chute after getting neutralized. High D.C voltage of the order of 50,000 volt is used.

The advantages of ES precipitator are:

- i. High collection efficiency above 99% for particles upto 0.01 micron size,

- ii. Low pressure drop,
- iii. Low maintenance cost.

The disadvantages of the unit are:

- i. High initial cost.
- ii. Higher energy consumption and difficult operation,
- iii. Ionization of air and production of ozone.

Because of these disadvantages ES precipitators are not frequently used in dairy plants. They are preferred in chemical industries, especially those dealing with hazardous chemicals where near complete trapping of even the finest particles is essential.



Lesson 16

Care and Maintenance of Spray and Drum Dryers

Introduction

16.1 Care and maintenance of drum dryers

The success of uniform drying depends on the application of a uniform film thickness on the drum surface. The main points to be considered for proper operation of drum dryers are:

- (i) Drums must be properly aligned and have identical characteristics of speed, heat transfer, wear etc.
- (ii) Knives must be reground regularly (after every 100 h) and be uniform sharpness.
- (iii) Drums must be kept smooth.
- (iv) Condensate must be continuously discharged from the drum
- (v) Drum must be vented of air for better heat utilization from steam.
- (vi) Uniform level of milk in the reservoir must be maintained
- (vii) There must be close control of temperature and time of drying
- (viii) Accurate control of feed device is required so that milk is evenly spread between the rolls. The maximum concentration at which the film can be spread evenly is about 30% solids.
- (ix) Preheating of milk is advantageous, but temperature should not exceed 71 °C
- (x) The dried product must be scraped off carefully.

16.2 Care and maintenance of spray dryers

The success of uniform drying in spray dryer depends on the care and maintenance of different parts of it. The main points to be considered for proper care and maintenance are as follows:

- (i) Atomizer is a heart of spray drying plant, clean the nozzles of pressure atomizer regularly
- (ii) The drive mechanism of disc type of atomizer should be properly lubricated
- (iii) The filter pads for inlet air for conveying the powder should be cleaned at regular time intervals
- (iv) The rotary valve for discharge of powder should be checked properly and it should not get blocked
- (v) Avoid powder deposits on hot surfaces to avoid fire explosion.
- (vi) Use magnetic hammers or vacuum to avoid powder deposition on inner wall of spray drying chamber
- (vii) Thermostats should be placed in the air inlet and outlet duct that sounds alarm and cuts off the air heating system if the air inlet and/or outlet temperature exceeds a certain predetermined value.
- (viii) A fire extinguishing system should be provided consisting of sprinklers in the chamber ceiling.
- (ix) The dryer can be equipped with fire detectors to prevent fire.
- (x) The spray dryer should be provided with powder recovery systems from outlet air like bag filter, cyclone separator, wet scrubbers etc.
- (xi) The spray dryer should be provided with heat recovery systems.
- (xii) All cyclone separators and bag filters should be cleaned properly at regular time intervals.

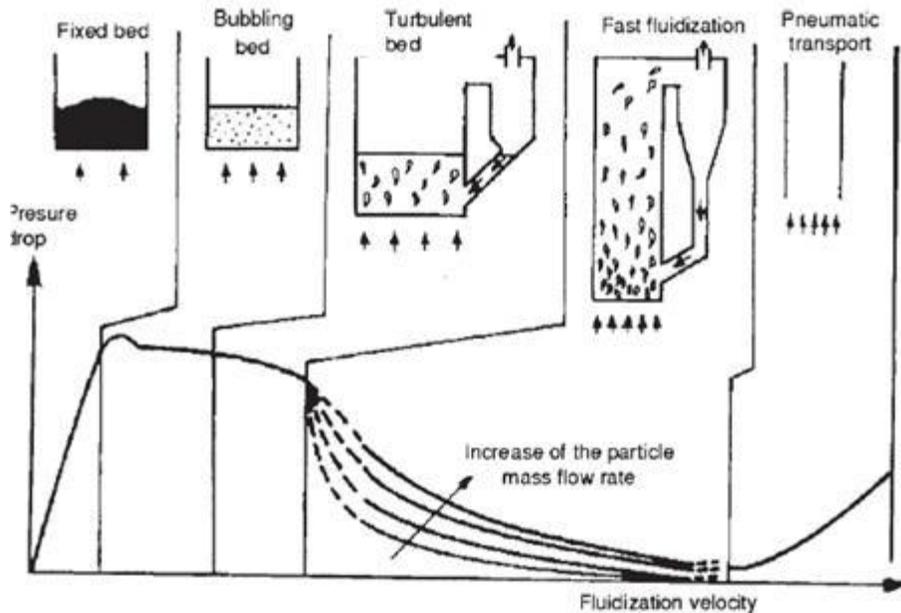
(xiii) Other parts of the spray dryers should be followed with preventive maintenance.



Lesson 17

Mechanisms of Fluidization, Characteristics of Gas Fluidization Systems, Minimum Porosity, Bed Weight, Pressure Drop in Fluidized Bed.

Most powder-like products produced by spray drying or grinding are dusty, exhibit poor flow characteristics and are difficult to rehydrate. It is well known, however, that agglomeration in most instances will improve the redispersion characteristics of a powder. Added benefits of agglomerated powders are that they exhibit improved flowability and are non-dusting. All of these characteristics account for their increased demand in recent years. Depending on the application or industry where the process is being used, agglomeration is sometimes referred to as granulation or instantizing.



Fluidization Regimes

Fluidization of fixed bed takes place in distinct stages of air velocity and trans bed pressure drop. Initially, the air cannot escape the bed, and the bed remains stagnant. As the pressure drop across the bed keeps increasing, the bed slowly expands in its height. After a certain peak, the air finds paths to escape and there is a slight dip in the pressure drop. At this stage we can call it as the beginning of the fluidization of the

bed, but the flow is smooth and the particles are not showing much movement. On further increase in the velocity and flow rate of air, the bed expands further and the particles are separate from each neighbouring particle and there significant turbulence among the particles and air flow. Any further increase in the air velocity, will make the particles to be carried away by the air and passes into the region of Pneumatic transport.

Mechanism of Fluidization:

Fluidized bed drying is generally used in combination with spray and roller drying, as a final drying procedure to bring the moisture of the powder down to the level required for storage stability. Fluidized bed drying is an integral part of instantization. It is also used for production of lactose and granular powders. The fluidized bed method is not only used for drying but also used for cooling any material which can be made to flow.

The powdered products are made to flow through a permeable support on which material rests, when gas is passed. The packing of the bed of material will become less dense. i.e. the bed will start to expand when a certain velocity is reached. At still greater velocities the particles in the bed will begin to be in turbulent motion. All particles of the product are thoroughly mixed in the turbulent layer and they dry therefore at a uniform rate. A further increase in the stream of gas finally leads to a velocity at which the particles float, which occurs when the upward force equals the force of gravity acting on the particles. Beyond this velocity it is impossible to maintain a fluidized bed and the particles are carried away in the gas stream (pneumatic conveying). A fluidized bed therefore maintained at air velocities which lie between those at which the bed starts to expand and those at which the particles float. The velocity at which the bed starts to expand is reached when the pressure drop on passing through the bed equals the force of gravity acting on the whole mass of the bed. Fig. 17.1 shows perforated plate for directional air flow, Fig. 17.2 shows animation of fluidized bed dryer and Fig. 17.3 shows animation of vibro fluidized bed dryer

Force of gravity acting on the bed:

$$\Delta P = H_0 \cdot g (\rho_k - \rho_A) (1 - \psi_0)$$

Where,

H_0 = depth of the bed of material at rest

ρ_k = density of the individual particles

ρ_A = density of the air

ψ_0 = porosity of the bed at rest (usually $\psi_0 = 0.4$)

The pressure drop of the gas on passing through the bed is:

$$\Delta P = 64 (\mu_1 / \psi^2) \{ (1/Re) + (\xi_\infty/64) \} (H_0/d^*) (\rho_{A/2}) v^2$$

μ_1 = factor due to increase in length of the path, $\mu_1 = 0.75$ for beds

Re = Reynold's number, composed of d^* and $V\dot{\epsilon} = v/\dot{\epsilon}_0$

ξ = resistance coefficient for turbulent flow

v = velocity of gas based on the cross section of empty tower

d^* = the hydraulic diameter of the pores

The above equation is valid for laminar, transition and turbulent flow. Combining the two equations yields the velocity at which the bed starts to expand.

Types of fluidized bed dryer:

Particles of a moist product can be put into turbulent motion using only air provided their surfaces are not stuck together by moisture or thermoplasticity. In such a case fluidized bed drying can be carried out in a relatively simple installation.

If particles stick together initially, stable fluidized beds can be produced by using mechanical stirrer to break up particle agglomerates. Another possibility of forced mixing, which at the same time, also provides forced transport is the much employed vibration fluidized bed drier. The dryer is based on a vibrating conveyor trough which can be up to 10 m long and up to 1 m wide. Eccentric motors produce the vibration of the drier which may be supported on helical or leaf springs. The direction of the vibration can be changed by rotating the motor and the amplitude by changing its eccentricity.

To ensure a uniform distribution of air over the whole area of the air permeable base plate the resistance offered by the plate to the air flow should be in the range of 1000 to 2000 Pa, depending on the type of product and the depth of the bed. The perforations occupy usually between 1.5 and 5 % of the area of the plate, and the depth of the bed, which can be

adjusted by means of an overflow weir, is usually between 50 and 300 mm. The vibration fluidized bed has the advantage of forced conveyance in a given direction, fluidization even at low air velocities and a residence time of the product which can be at least partially controlled.



Lesson 18

Application of Fluidized Bed in Drying

Fluid bed processing involves drying, cooling, agglomeration, granulation, and coating of particulate materials. It is ideal for a wide range of both heat sensitive and non-heat sensitive products. Uniform processing conditions are achieved by passing a gas (usually air) through a product layer under controlled velocity conditions to create a fluidized state. In fluid bed drying, the fluidization gas supplies heat, but the gas flow need to be the only source.

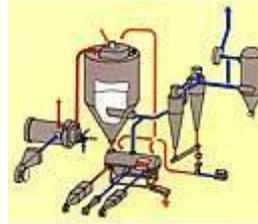
Fluid bed drying offers important advantages over other methods of drying particulate materials. Particle fluidization gives easy material transport, high rates of drying at high thermal efficiency while preventing overheating of individual particles. Fluid bed drying is suitable for powders, granules, agglomerates and pellets with average particle size normally between 50 and 5,000 microns. Very fine, light powders or highly elongated particles may require vibration for successful fluid bed drying.

In fluid bed cooling, cold gas (usually ambient conditioned air) is used. Conditioning of the gas may be required to achieve sufficient product cooling in an economically sized plant and to prevent pick up of volatiles (usually moisture). Heat may also be removed by cooling surfaces immersed in the fluidized layer. Agglomeration and granulation may be performed in a number of ways depending upon the feed to be processed and the product properties to be achieved. Fluid bed coating of powder involves the spraying of a liquid on to the fluidized layer under strictly controlled conditions.

Application of fluidization in drying:

Conventional Two-Stage Dryer

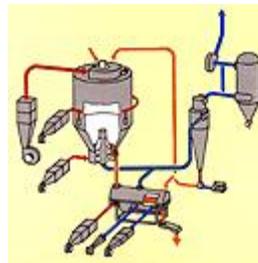
Powder discharged from the drying chamber can be further dried and cooled in a vibrating fluid bed, Vibro-Fluidizer. This two-stage drying concept achieves better overall heat economy and is suitable for many food and dairy products. When non-agglomerated powders of non-fat products are dried, a pneumatic transport system can replace the fluid bed.



A spray dryer layout featuring either a rotary atomizer or spray nozzle atomizer.

Compact Dryer

Atomization is created by either a rotary atomizer or spray nozzle atomizer. The location of the fluid bed within the drying chamber permits drying to be achieved at lower temperature levels resulting in higher thermal efficiencies and cooler conditions for powder handling. The plant can be equipped with pneumatic transport system for many powders or with an external vibrating fluid bed for agglomerated powders.



A space saving spray dryer with integrated fluid bed

. Fluidized Spray Dryer - FSD

Agglomerated powders are obtained in systems based upon the integrated fluid bed or belt and a multi-stage concept where moist powder, produced during the first drying stage, forms agglomerates, which are after-dried and cooled in the following stages.

Fluidized Spray Dryer / Multi-Stage Dryer

The Fluidized Spray Dryer and the Multi Stage Dryer combine spray drying and fluid bed drying technologies and offer excellent product flexibility, thermal efficiency.

Pressure nozzles or a rotary atomizer spray the feed down towards the fluid bed where agglomeration incorporating finer, recycled material takes place. Exhaust air outlet is let through the roof



Microphoto:
Skimmed Milk

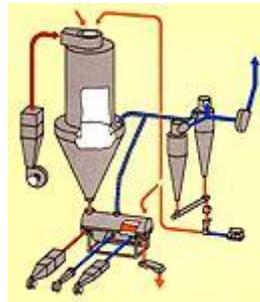
Microphoto: Skimmed Milk

causing further agglomeration in the spray zone.

Sticky products can be dried successfully, and the concept is ideal for drying heat sensitive products, and improved aroma retention is accomplished.

Tall Form Dryer (TFD)

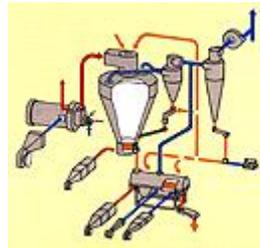
The atomized droplets dry while gently falling down the tower. Further drying and cooling are carried out in a vibrating fluid bed located under the tower. The tall form dryer is suited for both non-fat and fat-containing products, producing non-agglomerated and agglomerated free-flowing powders.



A tower spray dryer with a top mounted nozzle assembly featuring a fines return capability.

Multi-Stage Dryer (MSD)

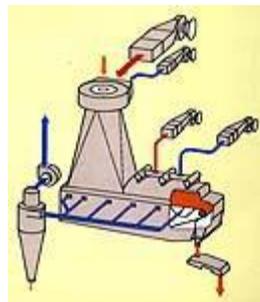
The spray is created by a spray nozzle atomizer. Operational flexibility enables production of a wide range of physical properties. The process produces non-dusty, free flowing agglomerated powders with high flavor retention. It operates with low outlet-temperatures, achieving high thermal efficiency. Dry ingredients for additional flavor or nutrient fortification can be added within the system to further promote capabilities and improve formulation efficiencies. This design concept is successful for drying high fats, hygroscopic, and sticky products that are difficult to handle in more conventional designs.



A spray dryer with integrated fluid bed.

FILTERMAT Dryer

The FILTERMAT Spray Dryer is frequently used in food and dairy applications. It operates at a low outlet temperature, achieving high thermal efficiency. It is the recommended system for drying high fat, sugar-based, hydrolyzed, and fermented products.



	A spray dryer with an integrated belt
--	--



Lesson 19

Batch Fluidization, Fluidized bed Dryer

Introduction

Typically, equipment designs are complicated, probably reflecting the fact that agglomeration actually is a complicated process. Despite the complexity of the process, however, it is possible to carry out agglomeration by means of comparatively simple equipment, which involves the use of a fluidized bed for the re-wetting and particle contact phase.

Advantages of fluidized bed system for agglomeration

- There is sufficient agitation in the bed to obtain a satisfactory distribution of the binder liquid on the particle surfaces and to prevent lump formation.
- Agglomerate characteristics can be influenced by varying operating parameters such as the fluidizing velocity, re-wet binder rate and temperature levels.
- The system can accept some degree of variation of the feed rate of powder and liquid as the product level in the fluid bed is always constant, controlled by an overflow weir. Thus, the re-wetting section will not be emptied of powder. Even during a complete interruption of powder flow, the fluidized material will remain in the re-wet section as a stabilizing factor in the process.
- By using fluid bed drying and cooling of the formed agglomerates, it is possible to combine the entire agglomeration process into one continuously operating unit.
- Start-up, shut-down and operation of the fluid bed agglomerator are greatly simplified due to the stabilizing effect of the powder volume in the re-wet zone.

Proper implementation of a fluid bed agglomeration system requires detailed knowledge of the fluidization technology. Fluidization velocities, bed heights, air flow patterns, residence time distribution and the mechanical design of vibrating equipment must be known.

There are two basic types of fluid bed designs according to the solids flow pattern in the dryer.

- (i) The back-mix flow design for feeds that requires a degree of drying before fluidization is established.
- (ii) The plug flow design for feeds those are directly fluidizable on entering the fluid bed.

19.1 Back-mix flow fluid beds:

These are applied for feeds that are non-fluidizable in their original state, but become fluidizable after a short time in the dryer, e.g. after removal of surface volatiles from the particles. The condition of the fluidizing material is kept well below this fluidization point. Proper fluidization is obtained by distributing the feed over the bed surface and designing the fluid bed to allow total mixing (back-mix flow) within its confines. The product temperature and moisture are uniform through out the fluidized layer.

19.2 Plug flow fluid bed:

These are applied for feeds that are directly fluidizable. Plug flow of solids is obtained by designing the fluid bed with baffles to limit solids mixing in the horizontal direction. The volatile content and temperature vary uniformly as solids pass through the bed, and the plug flow enables the solids to come close to equilibrium with the incoming gas.

19.3 Vibrating fluid bed dryer (VFBD):

For beds of particles, which are difficult, to fluidize due to strong poly dispersity, particle size, or particle-to-particle adhesive forces (stickiness) it is worth considering a batch or continuous vibrated bed dryer. An application of nearly vertical sinusoidal mechanical vibration (half-amplitude 3-5 mm; frequency 10-50 Hz) allows 'pseudo-fluidization' of the bed with rather low airflow rates. In this case, the requirements of hydrodynamics and heat/mass transfer are effectively coupled. Vibrated bed dryers can also be used to reduce attrition by gentle processing. Most vibrated fluidized bed dryers are continuous units.

This design is known as vibro-fluidizer, which is basically of plug flow type. It is specially applied for drying and cooling the products that fluidize poorly due to a broad particle size distribution, highly irregular particle shape or require relatively low fluidization velocities to prevent attrition. The vibro-fluidizer operates with a shallow powder layer of less

than 200 mm. This gives a much lower product residence time per unit bed area than non-vibrating beds, which can have powder layers up to 1500 mm. Fig. 19.1 shows Schematic diagram of vibro fluidizer, while fig. 19.2 shows vibro fluidizer animation and fig. 19.3 shows animated multi purpose rewet agglomeration two stage spray drying plant

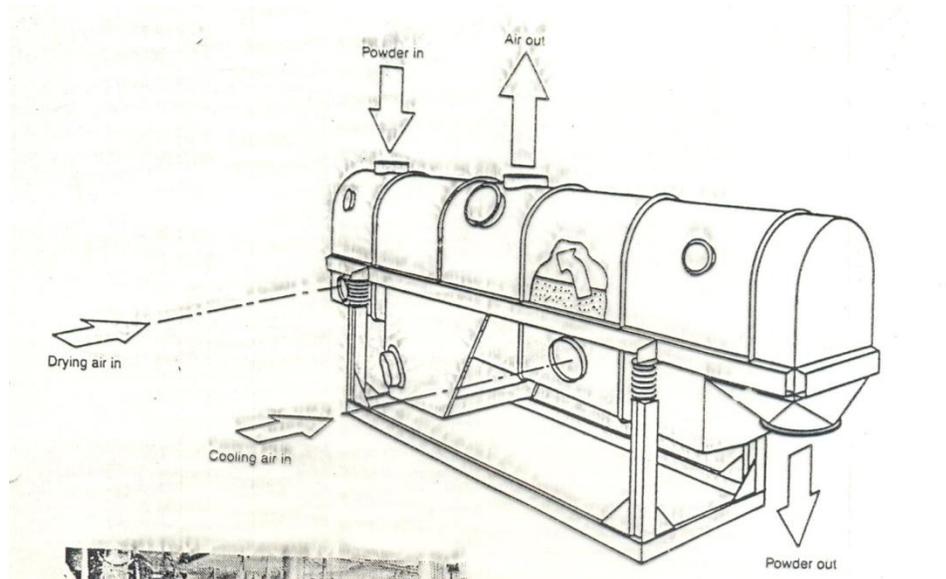
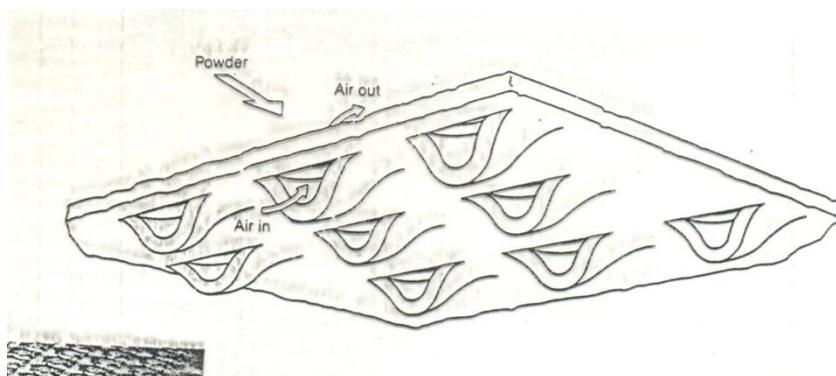


Fig. 19.1 Schematic diagram of vibro fluidizer



19.4 Schematic diagram of perforated plate of fluidized bed

During agglomeration process fine particles are returned from the cyclone separator, which is animated in the Fig. 19.4

19.4 Contact fluidizers

This is a rectangular fluid bed dryer incorporating back-mix and mix flow sections. A rotary distributor disperses the wet feed evenly over the back-mix section equipped with contact

heating surfaces immersed in the fluidized layer, The heating surfaces provide a significant portion of the required energy, and therefore, it is possible to reduce both the temperature and the flow of the gas through the system. This is particularly important for heat sensitive products. Subsequent plug flow sections are used for post drying and cooling, if required.

19.5 Batch fluidized bed dryer:

Batch fluidized bed dryers are used for low through out, multi product applications. Drying air is heated directly or indirectly usually to a fixed temperature. The drying air flow rate is also usually fixed. However, it is possible to start drying at a higher inlet gas temperature and flow rate and lower it since the product moisture content falls below the critical value. Mechanical agitators or vibration may be needed if the material is difficult to fluidize.

19.6 Multi-tier fluid beds:

These fluid beds consist of two or more stacked fluid beds. The upper tier (back-mix or plug flow) is for pre drying and the lower tier (plug flow) for the post drying. The drying gas travels counter-current to the solids. The gas leaving the lower tier contains sensible heat, which is transferred to the upper tier. Furthermore, each fluid bed may be provided with immersed heating surfaces. These designs result in a low gas throughput and high thermal efficiency, which are of great importance in closed cycle drying systems.

19.7 Continuous fluidized bed dryer

In this type of dryer, the bed temperature is uniform and is equal to the product and exhaust gas temperatures. However, due to inherent product residence time distribution, product moisture content will sway the range from inlet moisture content to lower value. One advantage of the perfect mixing dryer is that the feed falls in to a bed of relatively dry material and so is easy to fluidize.

19.8 Mechanically agitated fluidized bed dryer

Several designs of such dryers are in use today. For drying of pastes or sludges one variant uses a cylindrical vessel with a fast spinning agitator the bottom on to which the feed drops by gravity for dispersion into an upward spiral of hot drying gas. Other versions use a high rpm chopper that disperse the feed in to hot air. More commonly, slowly rotating

agitators (or rakes) are used to facilitate fluidization in the feed zone where highly wet feed is fed into a continuous plug-flow dryer.

19.9 Centrifugal fluidized bed dryers:

To intensify heat and mass transfer rates for rapid drying of surface-wet particles, a centrifugal-type device may be used so that the drag force due to the fluidizing gas can be balanced with an ‘artificial gravity’ generated by rotating the bed on a vertical axis. The rotating fluidized bed equipment is complex and the decrease in drying times for most material is normally not high enough or essential enough to justify the cost and complexity.



Module- 4 Mechanization in manufacture of indigenous dairy products

Lesson- 20

Butter making machines

20.1 Introduction

Generally the extra fat of milk is best preserved by converting it either into butter or ghee. In this chapter different types of the butter making equipments are described.

20.2 BATCH BUTTER CHURNS:

20.2.1 Rotating churns

The rotating butter churn was introduced in the nineteenth century and gradually from farm butter making it was adopted for the factory butter making by the butter industry. The rotating churns consisted mainly of a barrel rotated on an axis with shelves of various kinds to increase the agitation effect. The first combined churn and butter worker was introduced in USA in 1890. The combined churn and butter worker was of short barrel type.

20.2.2 Batch method using rotating churns

The use of batch churn for butter manufacture is on decreasing trend because of increase in popularity of improved designs of continuous butter making machines. In India, however, the butter produced by organized dairies is made by batch churns, except a few leading dairies.

The capacity of batch churns varies from 100 to 3000 Kg of cream per batch. The shape is mostly cylindrical with front opening, cone with cylinder, single cones and double cone etc. The churn is short in length and large in diameter. Baffles are fitted internally to improve agitation. In some designs, ribbed rollers are fitted through which butter grains pass. The fittings like air vent, sight glass, butter milk outlet, opening for cream inlet, and outlet for butter are mounted on barrel. Butter does not adhere on the wood, while the metal churns, the inside surface is roughened (sand or lead shot blasting) to allow film of moisture on the surface between the metal and the butter.

The degree of mixing depends on the amount of cream in the churn and on the rate of revolution. Too low a rate will not give sufficient turbulence and with too high a speed there is the danger that the centrifugal force ($m \omega^2 R$) will exceed the gravitational force (mg) and that the cream will stick to the periphery and rotate there with drum. The best condition for churning i.e. maximum turbulence, are achieved when the force of gravity just exceeds the centrifugal force.

$$\text{i.e. } m\omega^2 R < mg$$

$$(2\pi n)^2 R < g$$

$$\text{Or } n < [g/R]^{1/2} \cdot 1/2\pi \approx 1/(2\sqrt{R})$$

The energy consumption is about 7 - 11 kWh per 1000 kg of butter of which about 90% is used in churning and 10% in working. The lower values are for the cream with a higher fat content.

1. Loading the cream

Pasteurized cream with 35 - 40 percent fat, properly aged is pumped into the churn. Cream is filled to 40 - 45% of the volume of the churn. The cream may be ripened.

2. Churning

The churn can be operated at different speeds. The range of speed depends on the size and shape of the churn. The cream is churned at the churning speed (60 - 100 rpm). The cream is well whipped by the corners, edges and other irregularities in the churn. Chilled water is sprayed over the churn during churning operation. It takes about 35 - 40 minutes for the formation of butter granules of peanut size.

3. Buttermilk draining

The churn is stopped and buttermilk is drained off. Equal quantity of pasteurized wash water is added.

4. Washing

The churn is started again. The wash water is drained off after some time. Two or three washings are generally given.

5. Working

The wash water is drained off and salt is added. The churn is then operated at lower speed (25 - 50 rpm) for working as compared to that at churning. After 3 – 5 min., sample is taken and moisture is adjusted by adding required quantity of water. The working is carried out till desired body and texture is attained. Applying vacuum of 5 m of water gauge during working gives close texture by reducing the content of air.

6. Unloading and packing

The butter is unloaded in trolleys and then packed for sale. Different types of packing machines are employed for the required size of packages.

Care of churns:

1. Driving gear should be filled with lubricating oil and every alternate year replace it.
2. Never change the speed while the churn is running.
3. Solid foundation is necessary.
4. Gaskets to be maintained leak proof.
5. Proper roughness inside of the churn should be maintained.
6. Proper cleaning of the churn after the operation is over.

20.3 Continuous churns

Continuous butter making was first introduced in 1889 following successful development of centrifugal separation of cream from milk by a continuous process. The machine developed was first exhibited in England in 1889. The machine was known as butter extractor. The separated cream was beaten with great violence and thus converted into butter granules, which was discharged along with the buttermilk.

20.3.1 Continuous butter making

Different continuous butter making machines which are used in dairy industry can be classified into three categories according to the churning principle involved as under:-

1. Machines operating on Fritz process or floatation churning, where accelerated churning and working takes place. Few examples of this type are known as Westfalia Separator (West Germany), Contimab (France), HMT (India) and Masek (Czechoslovakia).
2. Machines operating on concentration of normal cream followed by phase inversion, cooling and mechanical treatment. Machines with commercial names as Alfa (West Germany) and Alfa-Laval (Sweden) fall under this category.
3. Machines operating on concentration of normal cream de-emulsification and re-emulsification into butter are available with commercial names of Gold'n Flow Process (USA), New Way Process (Australia) and Creamery Package Process (USA).

The important steps in butter making by these three processes are outlined below. One representative machine from each of the three processes is described briefly here.

20.3.2 The Fritz Process

The first prototype of modern machine developed by Fritz was demonstrated in the year 1940. Only this process has managed to consolidate its place in the Western Europe and countries like India. This is probably because its close similarity with ordinary batch method and the ease with which it can be applied practically. It contains three main parts, viz. Churning cylinder, draining and washing cylinder and worker. Capacity is up to 10000 kg/h.

1. Preparation of cream

For smooth operation of the churn, the cream must be of uniform quality. The properties like fat content, temperature, age, pH, previous treatments it has undergone and like are controlled.

2. Churning the cream

The cream delivered by a cream pump, enters the butter shaft through cream inlet. From this, it goes into the churning cylinder. The butter shaft is driven by a variable speed V-belt drive. In this cylinder, is a four-armed beater running at 250 – 2800 rpm with a wall clearance of 2-3mm. The speed can be varied as required. The pockets in the churning cylinder impart extra turbulence to the film of cream thereby enhancing the butter making action and improving the yield. Butter granules are formed within a 3-5 seconds. The cylinder is cooled by cold water circulation during the operation. Second churning cylinder rotates at 10-25 rpm or stationary cylinder with paddle-bearing shafts rotates at 34 rpm it is also cooled.

3. Butter milk separation and draining

The mixture of buttermilk and butter granules proceed into the adjoining section known as separating cylinder with its welded in ribs. The next unit is the buttermilk draining cylinder. This cylinder is perforated and provided with beater studs. Buttermilk gets separated and drained through holes.

4. Washing the granules

The butter granules enter the washing section which is also perforated and has provision for washing spray. The grains which by now reach the finished stage are washed here.

5. Working and texturizing

The washed butter grains fall into twin worm butter worker (two contra rotating screws). They are inclined and forces butter through number of perforated plates arranged in series which gives the fine dispersion of water. The process is assisted by mixing vanes, situated between plates. The butter worker can be operated at either of two fixed speed of approximately 65 and 30 rpm.. In this section, there are provisions for salt and colour addition, moisture corrections etc. The butter comes out in the form of a continuous stream, its shape depending upon that of the outlet spout.

20.3.3 Concentration and phase Inversion Process

Machines operating on the principle of concentration and phase inversion were introduced after the discovery of Wendt (1932) of high fat cream. He found that normal cream could be

re separated to a rich cream with fat content as high as the minimum permissible fat content in butter. Butter formation in the cooling of concentrated cream was observed by Mohr (1931). The Alfa process was developed in Germany and Sweden. The Alfa-Laval (Sweden) butter making process consists of the following major steps (McDowell, 1953).

1. Pasteurization and concentration

Normal cream of 30 – 35 percent fat is pasteurized at 90°C. It then passes through a cream concentrator where the fat content is raised to 80 – 84 percent.

2. Cooling and phase inversion

The high fat content cream is delivered by the concentrator into the balance tank, which is mechanically stirred continuously. The prepared cream is then drawn and is forced through the transmutator. This consists of a bank of three stainless steel jacketed cylinder provided with mechanically driven rotors. There is an annular space about 0.5 to 0.6 cm wide between the inner cylinder and the rotor. The rotors are fitted with soft metal ribs set in spiral fashion and of such thickness as to scrape lightly the internal surface of the cylinder. The direction of rotation of the rotors is related to the direction of spiral ribbing so as to aid the forward movement of the contents in the annular space. Brine is circulated through the jackets. The cream is kept moving over the cooled surfaces of the cylinders by the revolving rotors. The combined cooling and mechanical action causes butter formation to take place. The butter leaves the transmutator in a semi liquid state, but solidifies rapidly. A plate type transmutator is now available.

The Alfa process is not suitable for acid cream as it clogs the concentrator bowl. It involves some difficulties in control of moisture content of butter (McDowell, 1953).

20.3.4 Concentration, De-emulsification and Re-emulsification Process

The main steps of Gold'n Flow butter making method are described below (McDowell, 1953).

1. Destabilization

Freshly separated cream of 30 – 40 percent is taken and air is incorporated in it. After this, the cream passes through a destabilizing pump containing perforated rotor blades turning at about 3000 rpm.. Better destabilization is obtained by using two pumps in series. The cream is preheated to 60°C in a vertical centrifugal heater. The preheating is employed to

bring the cream to adequate temperature and to complete destabilization. Fat globule membrane is disrupted and weakened by the pump and the destabilization is completed by subsequent heating. Fat then moves as a continuous mass which is free of globular fat.

2. Concentration

After destabilization cream is concentrated to 85 – 90 percent by a special separator which discharges skim milk, sludge and concentrated cream.

3. Pasteurization

The concentrated cream is pasteurized in a vacreator at 88 - 90°C and subsequently cooled to 38 – 43°C.

4. Standardization

The liquid butter fat in which small droplets of cream are dispersed is constantly stirred and standardized for moisture, salt and fat.

5. De-emulsification and Texturisation

The standardized mixture is cooled to 4 - 6°C in a chiller. The chiller consists of two horizontal cylinders, installed side by side, and cooled by direct expansion of NH₃. Each cylinder is equipped with an agitator provided with scrapper blades. The moisture is finely disturbed by means of vigorous mechanical treatment.

The required consistency is obtained in the butter by treatment in the texturator. While passing through the texturator, temperature increases by about 2°C, which indicates further crystallization of butterfat. Butter comes out at 4 - 6°C.

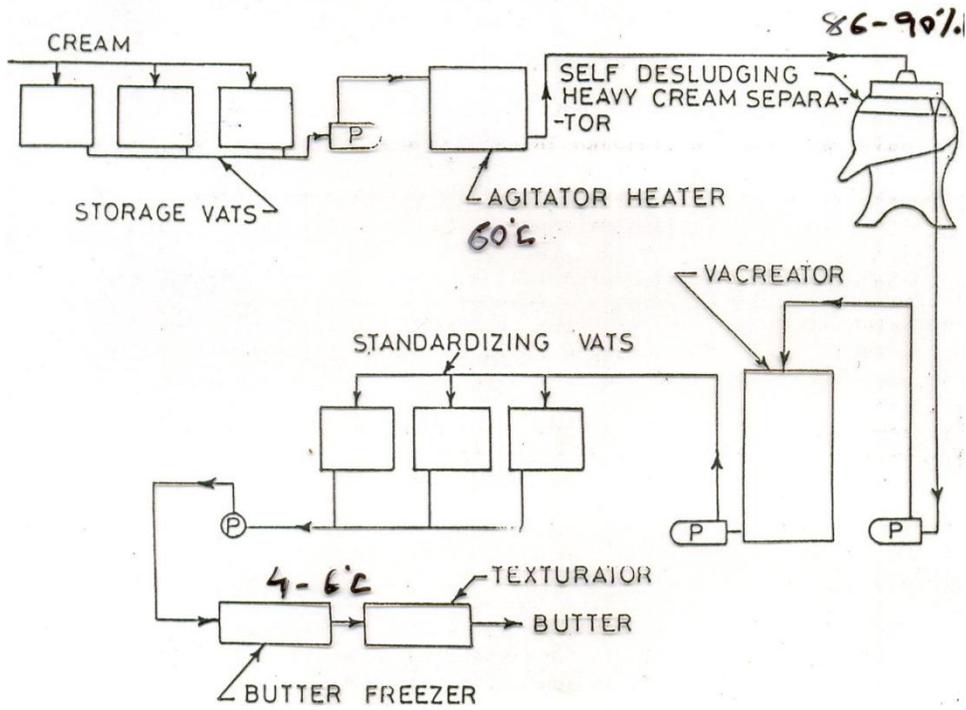


Fig.20.4 Gold'n Flow Process - Continuous Butter Churn



Lesson- 21

Ghee making machines

21.1 Introduction

Generally the extra fat of milk is best preserved by converting it either into butter or ghee. In this chapter different types of the ghee making equipments are described.

21.2 Ghee making Equipments

Steps for ghee making

1. Concentration of milk fat
2. Breaking of fat in water emulsion to bring fat in continuous phase.
3. Development of typical ghee flavour.
4. Control of moisture
5. Removal of ghee residue

Concentration can be done by centrifugal separation and heating the cream. Alternatively, cream can be churned into butter and then heated. Ghee flavour is developed when the fat is heated with milk solids at high temperatures.

21.2.1 Batch Method

It contains

1. steam heated butter melting vat
2. Pre-stratification tank (optional)
3. Ghee kettle for clarification
4. Ghee settling tank

5. Storage tanks

6. Filling machine

21.2.2 Ghee kettle (Boiler):

It is made up of a steam jacketed S.S. pan with agitator. Steam jacket may be of more than one compartment. At the bottom outlet valve for removal of ghee is present or a hollow S.S. tube at the centre of the bottom of vessel is present or a simple pan tilting device may be present for ghee removal. For better operational controls the steam controlling mechanism and steam pressure and temperature gauges are also provided. Raw material is either unsalted melted butter or a cream. In some cases pre-stratification method may also be present.

21. 3 Continuous ghee making equipments

Continuous ghee making equipment consists of receiving cum heating vat, pressurized SSHE coupled with vapour separator and a pump. The raw material is melted in the vat and then pumped to balance tank. It then enters in to SSHE and vapour separator where the flashed vapour is separated out. The product then goes to second stage where flavour development is completed. If cream is used then the third stage is necessary. Ghee residue is removed by standard filtering and clarifying devices.

Advantages are

- a) it handles large volume
- b) automation is possible
- c) high fat recovery and
- d) CIP is possible.
- e) High heat transfer coefficient, hence compact design
- f) No foaming problem
- g) Less scale formation

Lesson- 22

Ice-cream making equipment

22.1 INTRODUCTION

Ice cream is a frozen dairy product. In ice cream making refrigeration system and air incorporation system is required. The type of freezer play an important role in freezing of ice cream mix and subsequently on the quality of the product. There are batch and continuous type of ice cream freezers available in the market which are described here.

22.2 ICE CREAM FREEZER

The function of the freezer are

- (a) to freeze a portion of the water of the mix to get a smooth product,
- (b) to incorporate a predetermined amount of air uniformly into the mix to get proper overrun, n.

Fast freezing is essential for a smooth product because ice crystals that are formed quickly are smaller than those formed slowly. Therefore, it is desirable to freeze and draw from the freezer in as short a time as possible.

Failure to provide adequate refrigeration during freezing or hardening, results in formation of large ice-crystals in ice cream. Also, since freezing continues after the ice cream is placed in the hardening rooms; the ice crystals formed during the hardening period are larger because they form more slowly than in the freezer. For this reason, it is desirable to freeze the ice cream as stiff as possible and yet have it liquid enough to draw out of the freezer.

Following factors influencing the freezing time

Mechanical factors :

- 1) Type and make of freezer

- 2) Condition of the freezer wall and blades
- 3) Speed of the dasher
- 4) Temperature and flow rate of the refrigerant
- 5) Overrun desired and
- 6) Feed rate

Characteristics of the mix influencing the freezing time are:

- (1) Composition of mix
- (2) Freezing point of mix and method of processing the mix

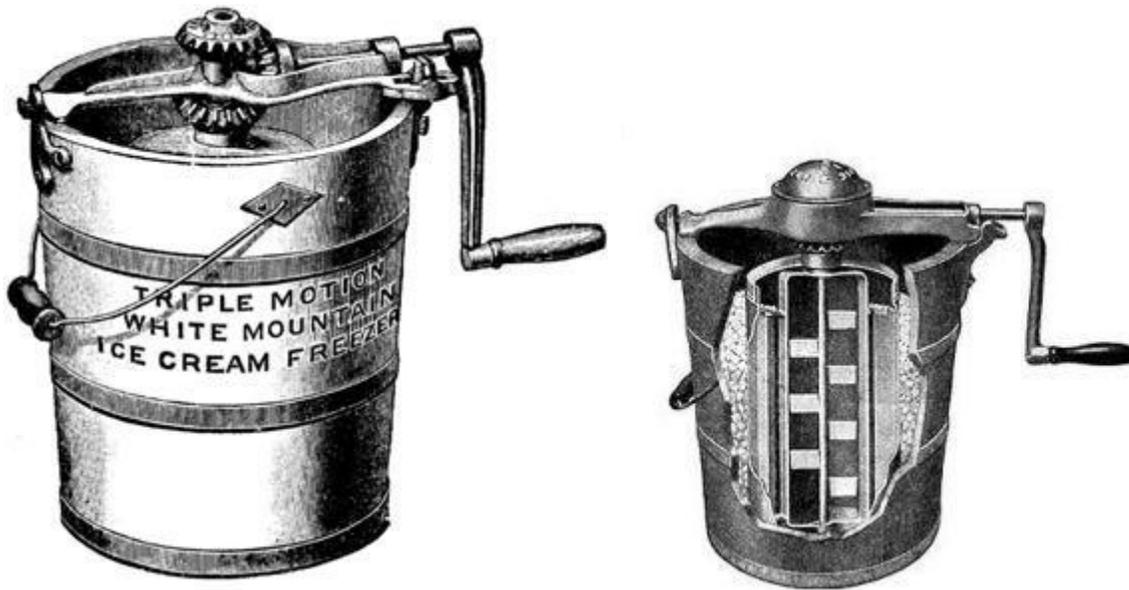
Freezers are of two basic types: the batch and continuous freezers.

22.2.1 Batch Freezers

BATCH ICE-CREAM FREEZER

Tub Freezer:

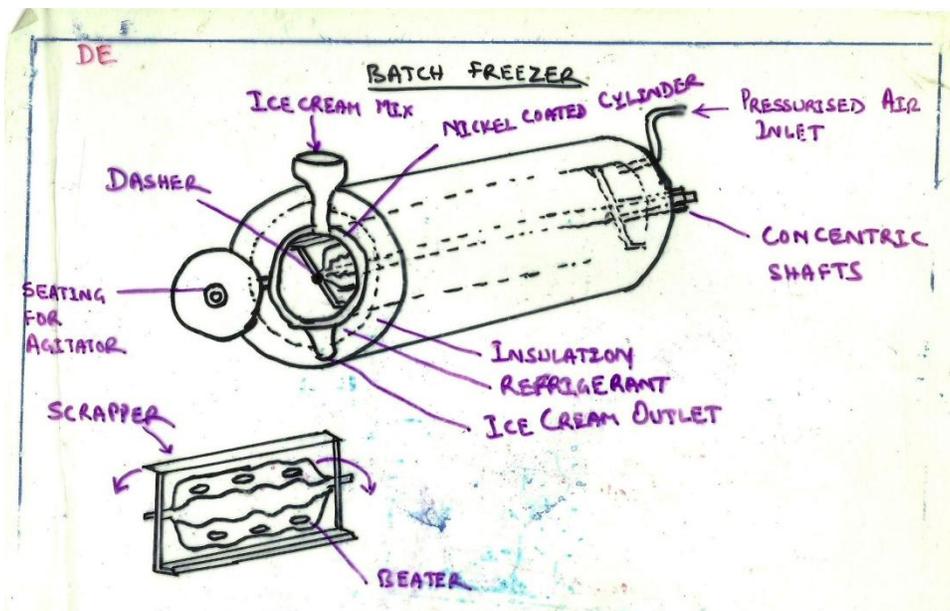
It has a vertical can, surrounded by Ice & Salt mixture. The can is rotated with mix filled to $\frac{1}{2}$ and rotated with handle and bevel gear. The dasher is stationary, while the can will be rotating when handle is rotated. The salt keeps the ice melting point low. This type of batch freezer is now not in common use. However, some of the traditional Indian dairy products like Kulfi is being frozen by this kind of a device.



Horizontal Batch Freezer :

- It has refrigerated drum or cylinder which is stationary, with direct expansion of refrigerant in the coils surrounding the cylinder. The cylinder itself can be of SS or Brass with Nickel coating, to take advantage of good thermal conductivity of the Copper alloy, at the same time to prevent it from coming in contact with the product.
- The cylinder has a front openable door , which in its inner side has bush arrangement to hold a horizontal shaft. The door even when closed, the cylinder has an opening at the top to pour ice cream mix, and another opening at bottom to draw frozen ice cream.
- Dasher which is a combination of Beater and Scrapper has the following functions:
 - a) To scrape the frozen film from cylinder wall, so that ice crystals do not grow beyond 40μ
 - b) Beat the mix to incorporate air to the maximum extent possible
 - c) Mix any fruit & flavouring material uniformly
 - d) Eject the finished ice cream rapidly
 - e) It is important to have the dasher in proper alignment and the blades must be sharp.
 - f) The beater and scrapper rotate in opposite direction to avoid slug type movement of the entire semifrozen mix.
 - g) The Dasher rpm is usually 150 to 250.
- The sequence of operations involves:

- i) Fill the mixture one third to half the volume of the cylinder
- ii) Start freezing the mix , with switching ON both the refrigeration system and beater
- iii) Time to time check the stage of freezing and over run by taking the sample and weighting, as well as keeping a watch on the Ammeter reading of the Dasher motor. The power consumed will increase with the progress of freezing
- iv) After required freezing is achieved (approx. half the moisture to be in frozen condition), continue beating to incorporate air further till required over run is achieved (which is maximum 100% for batch freezer).
- v) The freezing is generally over in 5 to 7 minutes, and over run takes little more time, if the composition is suitable.



22.2.2 CONTINUOUS ICE CREAM FREEZER

Advantages: 1) Large scale production capacity 2) uniform and smoother ice cream quality 3) More efficient controls 4) Shorter aging time is possible 5) Less tendency towards sandiness

Disadvantages: 1) High initial cost 2) Not suitable for small scale production

Construction:

- The volume of the cylinder is comparatively reduced, by having more solid dasher and mix passing as a thinner layer, as compared to batch process
- The freezing chamber is supplied with mix from tank by two pumps in some designs, where the first pump is a metering pump, designed to feed mix at a controlled rate. The outlet of this pump leads to a second pump through a pipe, which has provision to allow controlled quantity of air. The second pump being larger in capacity (approx. three times), it handles

both incoming air and the mix. The second pump, then, leads the mixture of air and ice cream mix, in to the freezing chamber at about 5 to 6 kg/ cm².

- Other designs single large pump with air entry on suction like along with mix.
- Both horizontal and vertical models are available.
 - In a continuous freezer, about 30 second time is taken for partial freezing the mix.
 - The ice crystal size is reduced to 45-55 µm and the air cell wall thickness to 100-150 µm.
 - For cooling, evaporating coolants in the temperature range of -20 to -30°C are used in the cooling jacket.

Refrigeration Unit:

- Cooling is by Direct expansion using R502 refrigerant (Cattabriga)
- Semihermetic compressor, with oil sum heating element is provided.
- Condenser is water cooled, along with a safety valve in case of high pressure being developed.
- Cooling water is regulated
- Liquid refrigerant line with provided with Ceramic filter, sight glass, solenoid valve
- The expansion valve is Thermostatic type
- Two hours after oil heater is switched ON, the compressor is to be switched on. This removes the refrigerant in the oil.
- Controls include switches for Beater, compressor. When the beater motor current consumption exceeds a limit, the controls activate a solenoid, which allows hot gas from compressor immediately below the expansion valve. This control can be operated manually also. This limiting value can be adjusted by a Rheostat.

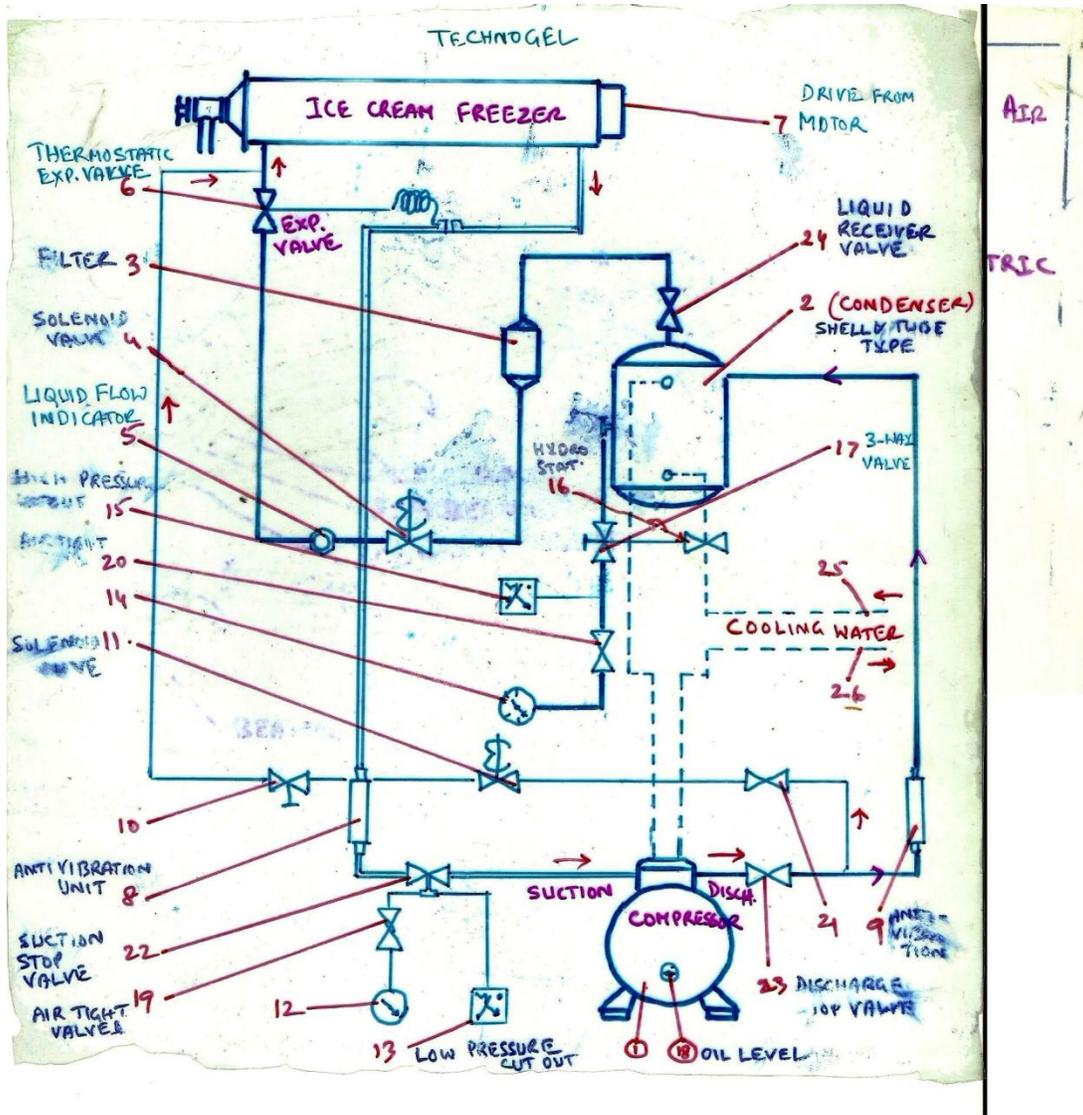


Fig.22.2 Continuous Ice Cream Freezer

22.3 Pumps

Pumps of ice-cream freezers are usually of the rotary type with the capability to pump against pressure of 7-14 kg/cm² (690-1380 kPa) with reasonable volumetric efficiency. There are two general pumping arrangements, both designed as a part of the overrun system. The first employ a pump (or a pair of pumps or compound pump) to pump or meter the mix into the freezing cylinder, plus a hold-back valve at the ice cream discharge port. The hold-back valve may be spring loaded with manual adjustment, it may have an air operator with adjustable air pressure supplying the operating power. The hold-back valve permits imposing a pressure on the cylinder during freezing which compresses the air admitted with the mix for overrun. Cylinder pressure of 3.5-4.0 atmospheres keeps the volume of air in the freezing

cylinder sufficiently small so that it does not significantly lower the internal heat transfer out from and through the mix. That pressure is sufficient for proper air dispersion and small air cell size. Higher pressures may be imposed on the cylinder, but in most cases, the improvement of heat transfer and air cell size is not great enough to offset the disadvantages of increased pumping cost.

22.4 Controls and Automation

All continuous ice cream freezers have control for operation which include on-off switches for pump and dasher motors, and for air compressor motors (when these are part of the freezer), for solenoid valves on hot gas defrost lines, air lines and refrigerant supply lines, speed regulation of pumps, refrigeration supply and back pressure, pressure gauges for the refrigeration system and cylinder or air pressure and dasher motor ammeter, wattmeter or motor load indicator. In addition more sophisticated machines may have a viscosity meter and controller, and a programmable controller or micro-processor to operate and control most functions of the ice cream freezer.

The modern ice cream freezer consists of a micro-processor programmed to control all the function of operation including overrun, viscosity of product, cylinder pressure, all operating steps such as start up, routine or emergency shutdown, resumption of operation after an automatic shutdown when the reason for shutdown has been corrected. Preparation for cleaning and the valve and pump by pass is required for automatic cleaning. The micro-processor shows the time of day, mix flow rate, percentage of overrun, product rate, hours of operation, accumulated production in that time interval, the program step in operation, and various warnings. In case of an impending freeze-up, the warning is displayed and corrective action is taken. If a freeze-up should occur, the micro processor automatically causes defrosting of the cylinder and operation to be resumed when conditions are satisfactory. The display can be in one or more of several common languages.

The micro-processor programmed operation assures that all functions are performed in the proper sequences, and under the conditions envisioned by the designer of the freezer. This is especially beneficial to the ice-cream maker in preventing damage to the freezer in emergency situations, thus avoiding the incidental unplanned down time in production.

22.5 Adding Ingredients and Flavours

Flavouring materials are added after the mix has been made. Pieces of fruit and purees should not be added to the mix prior to freezing in continuous freezers, as they tend to settle out in the tank with subsequent poor distribution in the frozen ice cream. The ingredient feeders often referred to as fruit feeders have a hopper for the ingredient, an auger or other means for metering or proportioning the fruit, a rotator or plunger for inserting the ingredient.



Lesson- 23

Cheese making equipment

23.1 Introduction

Cheese is protein rich food. It is coming under western dairy products. Now a days the paneer and cheese is consumed by the Indian people. So the Indian dairy is manufacturing this products. In the following text details of cheese making equipments are described.

23.2 Cheese Making Equipment

Cheese is a concentrated milk product of great importance. It commonly includes the steps

- (a) Setting the milk to develop some acidity,
- (b) Coagulation by an enzyme to facilitate cutting,
- (c) Cutting the coagulum for easy expulsion of whey,
- (d) Cooking or heat treatment to shrink the curd and drain the whey,
- (e) Consolidation and shaping,
- (f) Curing or maturing the green cheese for short or long periods of time.

The traditional process of cheese making consists of

1. Standardization, clarification and pasteurization of milk to get uniform quality of cheese.
2. Homogenization of milk to help in greater access of lipase enzyme to fat, allowing faster fat hydrolysis necessary to secure blue cheese flavour, wherever necessary.
3. Formation of coagulum involving use of favourable starter culture (0.5 to 1.0%) at 30 to 31° C for development of acidity (0.01 to 0.02%) and to assist curd formation by rennet added at the rate of 165 ml/ 1000 kg milk in about 30 min.

4. Careful cutting of the curd into uniform size to promote whey removal.
5. Raising temperature of curd to 35° C in about 30 min and holding for about 45 min to firm the curd and removal of whey.
6. Dipping or whey drainage and retaining maximum solids.
7. Cheddaring, a characteristic step for cheddar cheese, by cutting the curd into slabs, turning every 15 min and piling every 30 min to get 3 to 4 high piles of curd to develop proper body in the curd when acidity of whey is 0.5% lactic acid (pH about 5.2).
8. Milling the curd into pieces to help in filling into hoops for pressing.
9. Salting to get about 1.5% of salt in finished cheese for flavour development and stoppage of acid production.
10. Pressing hoops for about 12 to 16 h for removal of whey and getting final desired moisture content in cheese, and cheese blocks waxed to cover external surfaces.
11. Curing under controlled conditions of temperature and humidity to develop characteristic body and flavour in cheese.

23.2.1 Equipment

The cheese equipment consists of cheese vats, cheese knives, agitator, curd strainers, curd mill, cheese hoop and press.

Cheese vat : The cheese vat used for coagulation and cooking are made of either SS or with SS lining rectangular design. The vats are jacketed, allowing space for circulation of water between the inner and outer container. A steam pipe is fitted at the bottom in between outer and inner tank for uniform distribution of heat to the inner tank. The outer tank may be MS construction. The inner tank should not have any sharp corners and the welded joints should be properly ground and polished for effective cleaning. Fittings such as jacket drain valve, overflow connection, SS gate valve to draw whey with longitudinal central ridge to allow whey to flow towards whey valve with steam and water inlet connections are fixed on the vat. The vats are supported suitable on adjustable legs.

Agitator : The agitator is used for moving the curd after cutting, fork type motor driven agitator which reciprocates back and forth from one end of the vat to the other end is generally used in large vats. The stroke of this agitator is adjustable between two stops. A paddle type agitator or wooden rake is used in small units.

Cheese knives: Uniformity in the size of the pieces is the aim of proper cutting. For this purpose, two kinds of knives are used. One knife cuts the curd into horizontal layers and the other vertically across these layers from top to bottom, slicing them into small cubes. The blades are thin wire which gives effective cutting. In some the blades are thin and sharp of metal construction, cuts the curd with least possible breaking. The distance between the blades usually varies from 6 to 17 mm.

The curd is cut first with horizontal knife lengthwise of the vat, then crosswise with vertical knife and finally lengthwise with the same knife. The knives may be of SS construction or tinned brass.

Gate Strainer: Whey is removed from the vat through a gate strainer which holds back the curd. It is semicircular in design with perforation which can be fitted to the vat outlet.

Curd mill: The mill, spike-toothed or circular blade type cuts the curd into small pieces of uniform size and should do it without crushing or squeezing the milk fat from the curd. The mill could be hand operated or motor driven. If power curd mill is used, it should not be run too rapidly to prevent uneven curd cutting which will result in poor cheese texture.

Cheese hoop: Different designs and capacities of hoops are available, to give shape to the curd and compact the same. They are round or rectangular (Wilson type) with followers.

Cheese press: The cheese press is used to press the cheese in the hoops. The loaded cheese hoops are placed in the press and pressure applied. The hand operated cheese press consists of a frame having two or three vertical columns, pressing plates fitted to sleeves moving on the vertical columns, a simple or compound lever attachment or hand wheel with spindles and proportional weights for applying pressure. The press could be vertical or horizontal, mechanical or hydraulic type depending upon whether the force is applied by mechanical action or hydraulic pressure. The pressure on the cheese should be uniform and there should not be any buckling of the hoops during pressing.

23.3 Mechanization in cheese making

Mechanization is a system in which most of the stages in cheese making are carried out by machinery instead of manual labour. The present day cheese making systems involve handling milk ranging from 2,50,000 to 10,00,000 l/day. With increasing cost of labour and conventional horizontal vats it is very difficult for cheese makers to cut the coagulum and handle the curd as required for the conventional cheddar process. When the volume of milk increases it is logical to reduce manual work and drudgery. The adaptation of mechanical principles in cheese making has grown with the trend of automation in dairy industry. Mechanization in the major stages of making cheese is given below.

1. Curd making:

Use of banks of rectangular jacketed cheese vats of about 15000 l capacity using built in swinging stirring units to stir curd-whey mixture after cutting coagulum manually is an accepted practice. Mechanical cutting is now widely used and nylon thread is replacing SS wire in many cases. Vats are fitted with pneumatic or hydraulic tilting gears for emptying the contents.

Besides horizontal enclosed cheese processing tanks, totally enclosed round ended vertical cheese vats with built-in-stirring units usually made of two frame assemblies with angle of the blade in the knife agitator frame is so designed that the assembly acts as cutting knife in one direction and as agitator in the opposite direction. The knives have rotary or linear movement depending on the type of vats. The vertical vats economise space. In enclosed vats many operations like filling, adding starter, renneting, cutting, stirring, scalding and emptying are controlled automatically.

2. Curd/whey separation and texturing of curd:

For the separation of curd pieces from whey various devices are used, viz., troughs with perforated linings, vibrating mesh separator to separate fine particles of curd from whey, rotating screens or simple screens.

The curd conditioning is done by (a) pumping or gravity flow of curd/whey mixture, (b) transfer of curd pieces by vibrating belt or conveyor belt. The stretching and squeezing are affected by belts running at different speeds.

The curd is converted into fibrous slab in cheddar towers where the curd is forced down by the pressure of the succeeding curd into a square bottom cross section, or in a cheddar box with regular turning through 90° every 15 min. milled, salted and filled in moulds and carried on long moving belts.

3. Hooping, moulding and pressing:

The milling of cheddared curd is done by power driven mill and the use of block shaped perforated SS or light non-corrodible plastic moulds. The feeding of the milled curd is done by vibrations, and automatic weighing machine.

The pneumatic, hydraulic or mechanical spring press has replaced the lever type of presses. The demand of close textured cheese has led to the technique of vacuum pressing of cheese. This system sucks out air between the curd particles and eliminates open texture in cheese. The press consists of a chamber of rectangular cross-section fitted with piston at the bottom for compression and extrusion of the pressed curd at the top. The top removable lid can be replaced by cutters to get blocks.. The height of the extruded curd is adjusted to get required size of the block. Vacuum is applied on all the sides of the curd block (about 80 kPa). This is followed after about 10 min, a pre-pressing pressure of about 3,400 kPa for 10 min, raised to about 9,500 kPa leads to a final pressure of 480 kPa on the cheese. The press time varies. Normally, it is 1.5 h under vacuum and 6.5 h under normal pressure.

For brine salting multitier crates are used for lifting, immersing and taking back of small cheese blocks from brine bath. For retail use cheese blocks are cut by using mechanical cutters from variously shaped blocks and film packed with suitable materials.

Several mechanical cheese making systems are available for cheddar, hard and semi-hard varieties and soft cheese.

23.4 Continuous cheese making

In this system milk is fed at one end of the machine and continuously converted to coagulum, curd and cheese during the passage through the machine. Basically the process consists of application of heat to cold renneted milk in such a manner that curd is formed continuously and then cut for removal of whey and finally ending with cheese.

Lesson 24

Packaging Machines for Milk

Introduction:

The Form Fill Seal(FFS) machines are a genre of filling equipment that can fill in a flexible packing material. The product should be free flowing type, either liquid or even granular. The equipment may be controlled electro-pneumatically or mechanically.

The process involves certain steps, which will take place cyclically in auto operation.

There is option for variation in size and quantity of the product packed. To a large extent, the market milk is now being sold by packing in these machines.

The following are the operations that go cyclically.

1. Forming of tube of packing material from film in rolled state
2. Simultaneous operation of filling and sealing
3. Movement of film to form next package
4. Simultaneous separation of filled and sealed packet while filling of next packet.

Sequence of Operation:

With reference to the fig. the film roll is loaded at the backside of the filling machine on a sliding platform. The film edge is passed over end of role contact lever, dancer roller, UV tube and brought to the front side over to forming plates. The forming plates rolled the flat film in to tube a certain band of overlap. Within the tube is the fluid filling pipe enveloped. The tube then passes over to vertical seal jaws that are engaged and disengaged with the help of an air operated piston, or in machines by mechanical means. In between the jaws, the overlapped

part of the film tube passes. The set of jaws have one stationary and one moving jaw. The moving jaw has a nichrome rod, supplied with variable voltage such that the heat is generated when the current passes intermittently. During the period when the current does not pass, when the jaws are disengaged, the cooling water being circulated in the moving jaw, cools it and prevents continuous over heating of the sealing rod. The film is supported by Teflon cloth and rubber cushion, as well as protected by Teflon cloth from sealing rod. This arrangement prevents electricity passing on to the film and other parts, while allowing only the heat to pass on to the film and partly melting and fusing the vertical joint.

Lower down the film tube, there are a pair of nip rollers giving a holding and pulling down action, when the jaws are disengaged, making the film to move to seal the next portion of vertical overlap.

Further lower down the film tube is engaged by horizontal jaws, at a sufficiently below the lower edge of fluid filling pipe. This arrangement allows the formation of lower seal of the packet, while the fluid is being filled to a known quantity. The quantity of flow is controlled by a valve operated by a rod which is lifted by a solenoid coil position at the top of machine, just at the feeding line from the over head tank carrying the fluid to be filled. While filling is taking place, a pair of flat blades operated by spring keeps the film perfectly flat at horizontal edge so that there is no folds and horizontal seal is perfect.

When the filling of fluid and the horizontal sealing is complete, the horizontal jaws (as well as vertical jaws) get disengaged, and the nip rollers start rolling to bring the next length of film tube to be filled for next packet. While the second packet is being filled, the first packet already filled will be getting the horizontal seal of top portion of the filled packet. When the next time the jaws open, the first packet drops down by its own weight and weakened connection to the rest of the tube.

The above cycle of operation is repeated when the controls are in automatic operation, while single action takes place when in manual operation during initial adjustment of time and temperature combination for obtaining proper seal.

Controls:

The Form Fill Seal Machine has various controls for the following operations.

1. Adjusting the temperature of sealing rod by controlling the electric supply, to match to the thickness of the film to be sealed.
2. Adjusting the timing for the jaws to be engaged and simultaneously filling operations to take place, with a known quantity of fluid.
3. Adjusting the quantity of fluid to be filled when jaws are engaged
4. Adjusting the timing for the jaws to be engaged and allow time for movement of film to the required length of package.

The other useful instrumentation are the end of film indicator (gives audio signal), so that the new film roll can be changed easily, fine adjustments for the quantity of fluid filled in few grams range, fine adjustment of timings, etc.

The equipment will require water for cooling the jaws at a fixed flow rate and of low temperature. Also, compressed air is required which is at required pressure and free of condensed moisture.

Fig. 24.1 Film feed circuit



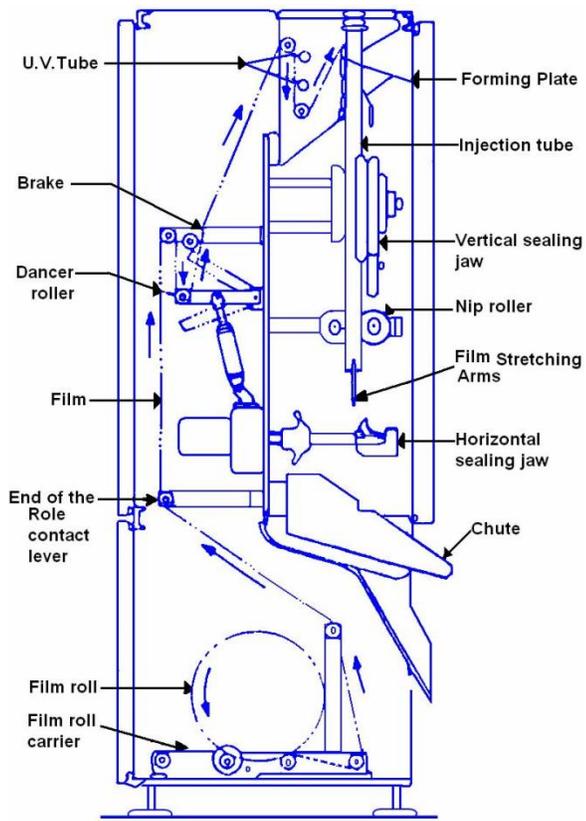


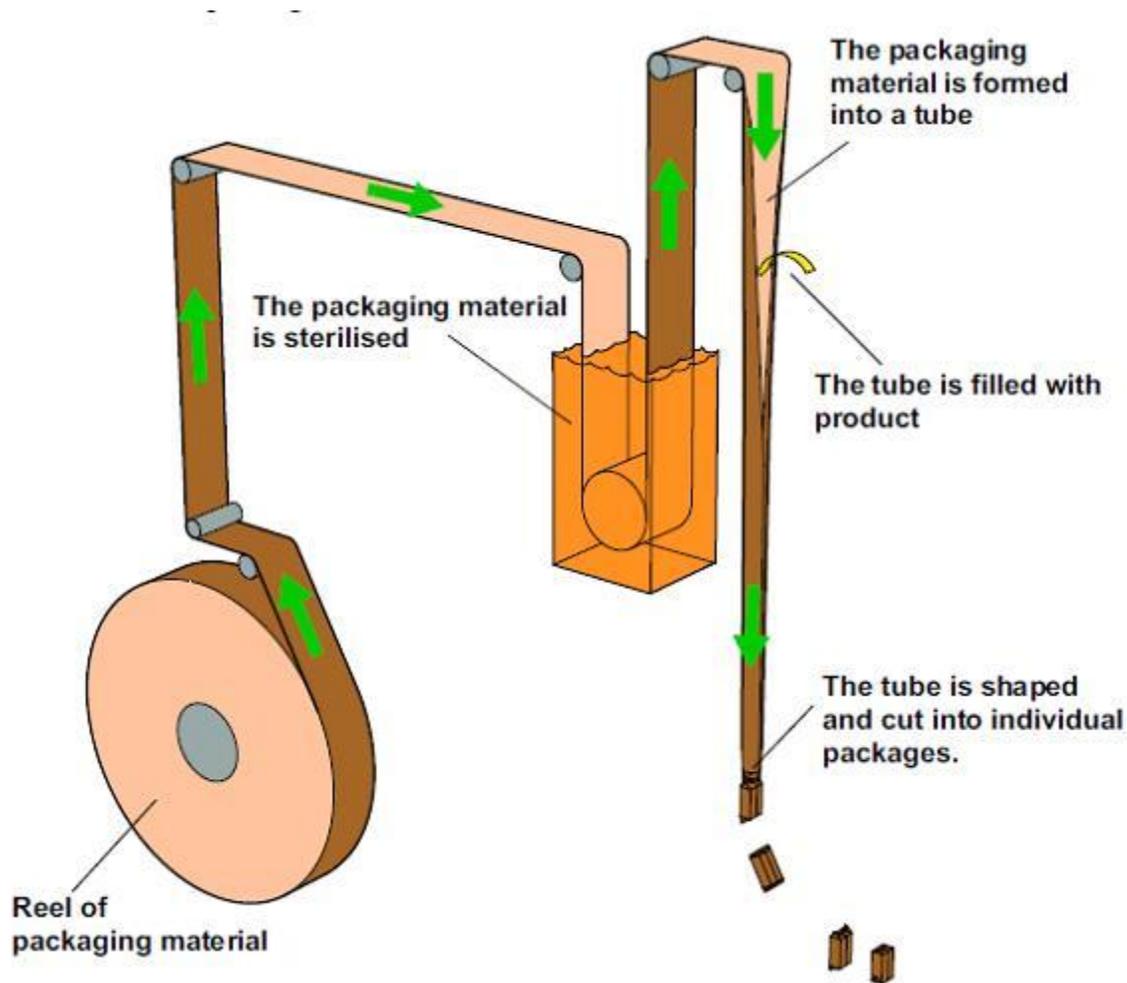
Fig .2 Film feed Circuit



UHT milk packing machine

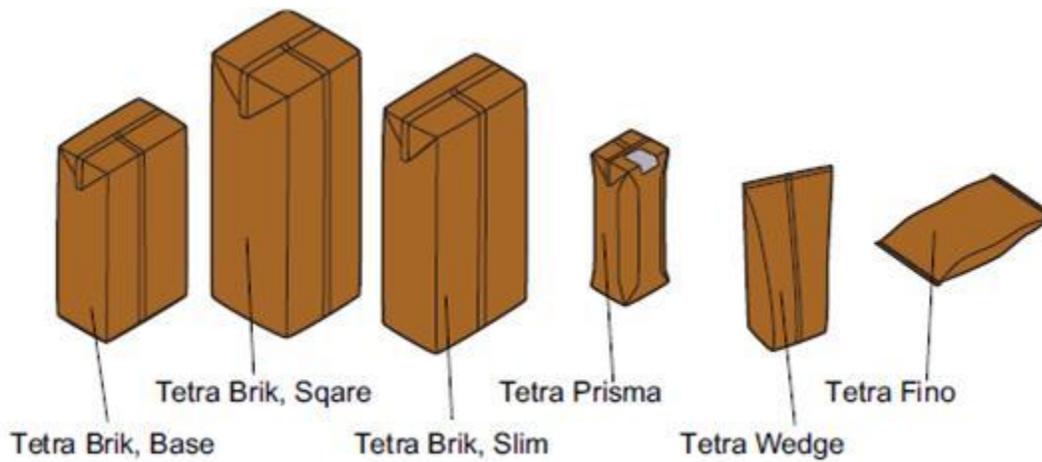
Introduction

The UHT milk packing machine is different than the usual FFS machine in that the packaging material is multi layered, and the filling is done in an absolutely aseptic condition. The filling room is kept in a positive pressure, and the air inlet is through HEPA filters. Starting out from a reel of packaging material, the Tetra Brick Aseptic (TBA) filling machine produces filled packages. The packaging material is first sterilized and then formed into a tube. The tube is filled with product and then shaped and cut into individual packages.



The package

There is a range of Aseptic packages , all deriving their origin from the same forming technique. In India, the commonly available Aseptic packaging machine is from Tetrapak company.



Package terminology

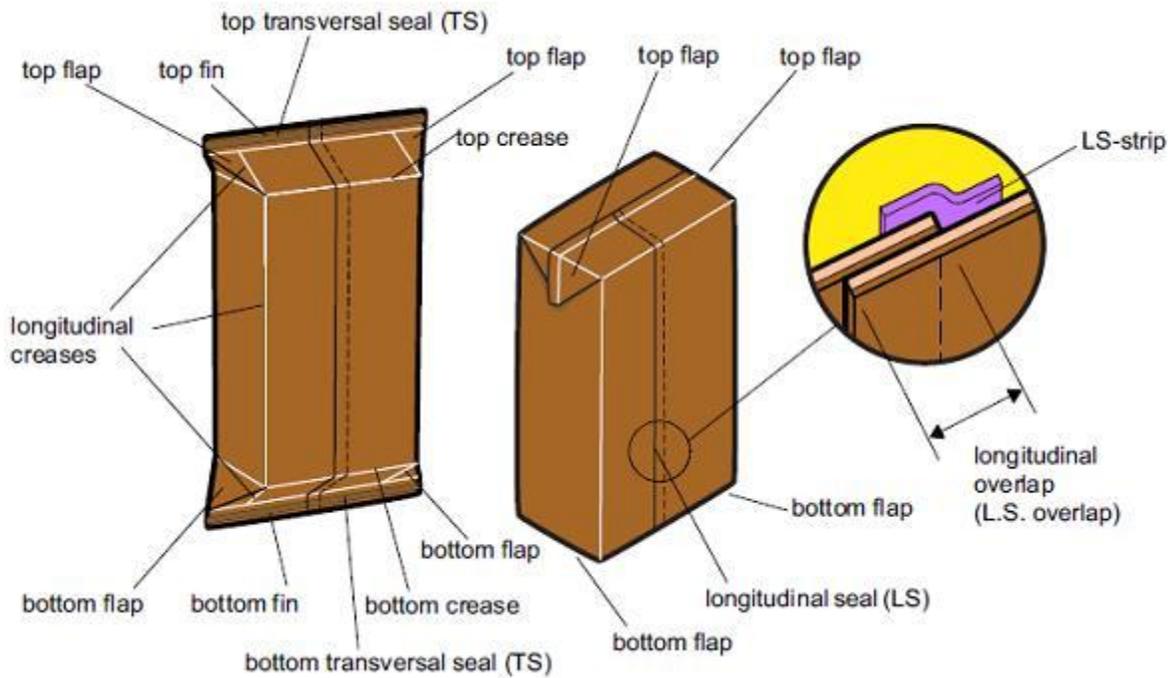
Creases are the folding instructions on the packaging material, to ensure the Creases package's final shape. The creases are pressed into the material by the creasing tools in the converting process.

The longitudinal seal (LS) is accomplished when forming the packaging material seals into a tube. It seals the package along the side. A strip of laminated plastic, the LS-strip, covers the seal on the inside. The area of the overlap joint is called the longitudinal overlap.

The transversal seal (TS) is made when the tube is filled with product. It seals the package at top and bottom. The sealing takes place below the product level in the tube.

The fins are the areas, at top and bottom of the package, where it is sealed and Fins cut.

The flaps would be the corners of the package, if you flattened it out. When Flaps shaping the package, the flaps are folded down and in, and then sealed to the package body.



Machine introduction

Tetra Brik filling machines are built from so called modules or main groups with similar functions in the various machines. The machines may also have different additional equipment and accessories.

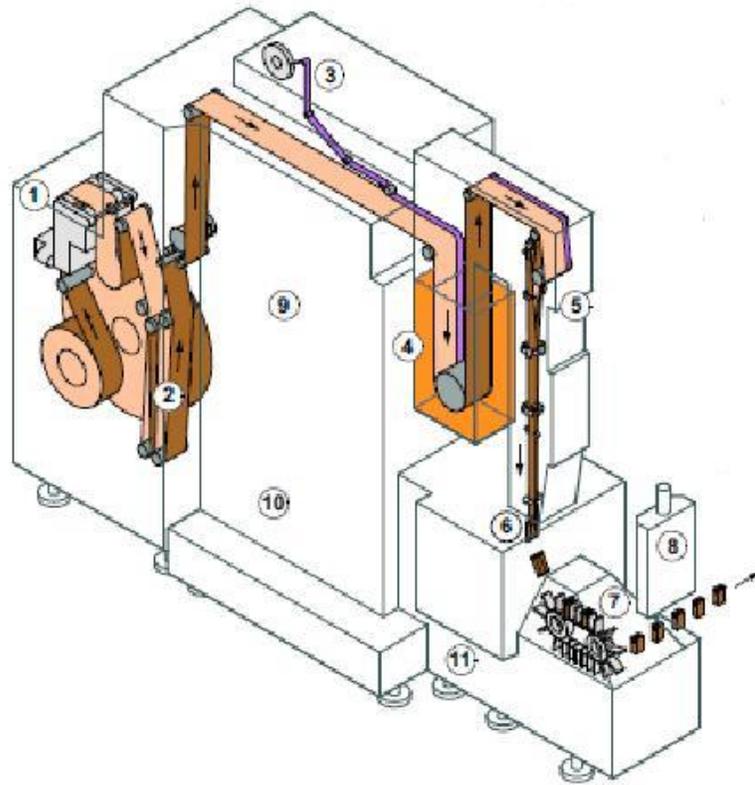
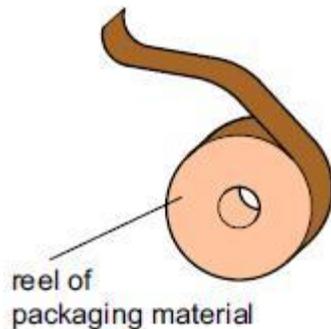


Fig: Tetra Brik Aseptic (TBA)filling machine.



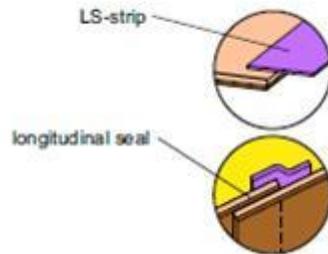
1 . ASU Automatic splicing unit(ASU): The automatic splicing unit splices reels of packaging material. This means that production can continue uninterrupted when one reel of packaging material comes to an end.

2. During splicing though, the packaging material has to remain still in the splicing head. The magazine provides the necessary supply of material so that the machine does not have to stop.

PullTab unit

The PullTab unit is additional equipment, providing the packaging material with a PullTab opening before it enters the peroxide bath. The PullTab opening is created by punching a hole in the packaging material. The hole is

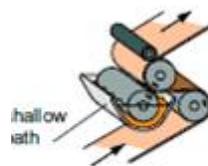
sealed with plastic on the inside and aluminium on the outside.



3.

Strip applicator: The strip applicator

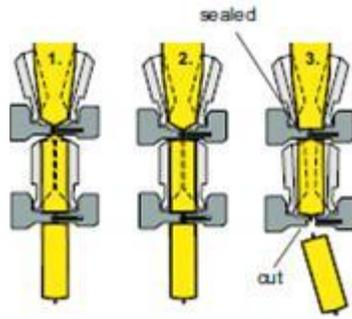
applies a plastic strip, the LS-strip, along one edge of the packaging material. The strip is applied on the inside of the packaging material and is intended to prevent product from being soaked into the raw paper edge of the longitudinal seal. The strip will also support the seal. Only half of the LS-strip is sealed to this edge of the packaging material. The other half will be sealed to the other edge later, when the packaging material is formed into a tube.



. Peroxide bath: The packaging material will be sterilized in

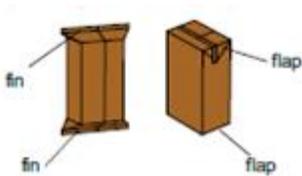
the peroxide bath. In machines with deep baths, as shown in the example, the packaging material will be immersed into warm peroxide and both sides will be sterilized. In machines with shallow baths the inside of the packaging material will merely be covered with cold peroxide and the sterilization will be finished in the tube heater.

5. Aseptic chamber: The packaging material will be dried with heated air. In machines with deep baths, as shown in the example, an aseptic environment around the sterilized packaging material is maintained with an overpressure of heat-sterilized air. This takes place in the aseptic chamber. Machines with shallow baths, which have no aseptic chamber, heat-sterilized air will be blown into the tight tube. This way a sterile area is maintained where the tube is to be filled with product. The packaging material will be formed into a tube and sealed longitudinally. Finally, the tube will be filled with product.



Jaw system: In the jaw system the tube is sealed transversally and cut into separate packages. The sealing is made by induction heating, using the aluminum in the packaging material to melt the plastic. It is important that the package design, with the creases, appear in accordance with the jaws.

This is controlled and corrected by the jaw system.



7. Final folder: In the final final shape. The fins are sealed. Hot air is used to on the package material is heated and the flaps are pressed against the sides and the bottom of the package. When the plastic gets cool the flap is sealed.

folder the separate package gets its folded and the flaps are folded and seal the flaps. The plastic outer coating

8. Operator panel: The operator panel allows the operator to communicate with the machine. It is used to start and stop or make the machine take any other action.

9. Electrical cabinet: In the electrical cabinet a great part of the electrical components are included, such as:

- Temperature regulators
- Control system
- Contactors
- Induction Heating unit, etc.

10. Service unit: The service unit includes parts and supply systems needed for the machine function, for example:

- Water and air system
- Lubrication and hydraulic oil system
- Pneumatic and peroxide systems

11. Drive system: The drive system includes motor, gear and cam. These parts run the jaw system and also the final folder on certain machines.



Lesson 25

Packaging Machines for Milk Products

Introduction:

The wide varieties of milk products packaging makes the choice of packing machines. The requirement of each product is different, as well as the size and shape. Some of them are to be stored at low temperatures, while others are kept in ambient temperatures. The packing material also different, and the information to be given on packages may be a legal requirement in most of the cases. Some products are further processed while in the packaging itself, like sterilization, curd setting etc. The packaging machine working principle will also depend on the physical nature of the product, like liquid, solid, semi solid.

Cheese packing

Specific Applications

When packaging food products those are sensitive to spoilage or loss of freshness, it is important to seal the product in containers that allow a tight seal. It is typical to evacuate the chamber to a target vacuum level, thus removing air and oxygen. Higher vacuum levels remove more air, but require larger vacuum systems, higher attainable vacuum levels, and more time for the evacuation process. The target vacuum level is a function of the product being packaged and is determined by the packager and/or government regulations. Speed is an important factor in many packaging operations, and machine manufacturers are often rated on how many packs per hour their machine can perform, while meeting a set of specifications. Higher speed usually means higher vacuum system capacities, and/or a secondary vacuum system to “pre-evacuate” the vacuum packaging chamber. Sometimes, purge gases are introduced during the packaging operation to help displace air and oxygen, retard spoilage, and further enhance shelf life and appearance. Appearance is vitally important in the packaging industry.

Machine Types

Chamber Packaging Machines

Chamber machines are typically used to seal meats and cheeses in film pouches. In appearance, they have a base and a swinging top cover (sort of like a Xerox machine). The product is placed into the machine, and the swing lid is closed. Where the lid and top of the machine meet, a seal is formed. At this point vacuum evacuation begins and the rest of the sealing process occurs under vacuum. When the lid is lifted, the product is fully packaged and ready to remove.

Small Chamber Machine (Desk Model)

Chamber up to 50 liters, rotary vane pump 3 to 25 m³/hr.

DoubleChamber (Mobile)

Two chambers, each up to 150 liters, rotary vane pump 40 to 300 m³/hr

Big Chamber Machine (Non Mobile)

Chamber up to 400 liters, pump combination rotary vane pump 340 to 1000 m³/hr. Booster pumps 500 to 2000 m³/hr

RotatingChamber Machine (Non Mobile)

Multiple rotating chambers (step evacuation) rotary vane pump 160 to 630 m³/hr

Multiple rotating chambers (step evacuation) rotary vane pump 160 to 630 m³/hr and booster pump 500 to 2000 m³/hr

TraySealing Machine

With Tray type machines, the user purchases a tray (Styrofoam, plastic, etc), loads the product onto the trays and places them into the machine. At this point the chamber is evacuated to achieve a "skin pack". These machines are typically used by small packagers.

InertGas-Flushed Packaging (Snorkel Machines)

MAP (Modified Atmosphere Packaging) involves packaging the food product in an gas atmosphere other than standard room air to achieve specific goals not otherwise possible. Common atmospheres include:

Nitrogen

80% Nitrogen- 20% CO₂ mixture

Saturated oxygen greater than 80%.

The machine pulls a vacuum and reduces oxygen content down to 0.3 to 1% to remove Anabolic Bacteria. When this occurs, meat becomes purple. Back flushing with the appropriate gas maintains product color for an attractive and appetizing appearance. All machines that use a chamber can be fitted with gas flush option, and approximately 25% of machines on the market do so.



Fig. 25.1 Different types ofcheeses



Fig. 25.2 Different types ofwrapped cheeses



Fig. 25.3 Cheeses packingmachine

ChamberPackaging Machines

SmallChamber

PackagingMachines

(desktopand portable)



Fig. 25.4 Chamber packingmachine (small size)

Mid SizeChamber

PackagingMachines

Forhigher production rates



Fig. 25.5 Chamber packing machine (medium size)

Large, fully Automatic

Chamber Packaging

Machines for High



Fig. 25.6 Chamber packing machine (large size, automatic)

Fig. 25.7

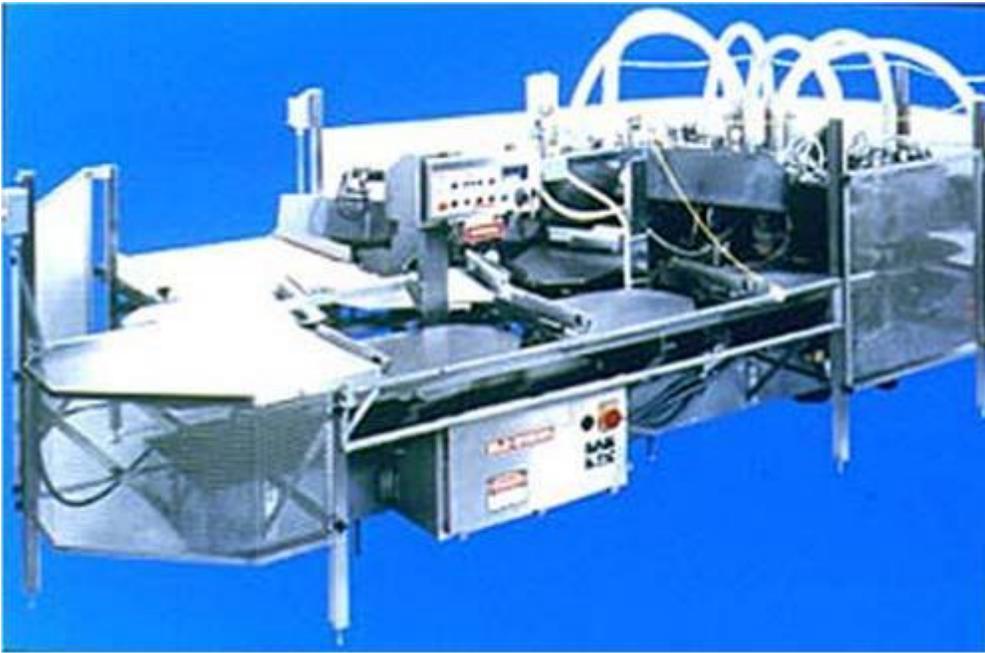


Fig. 25.8 High speed rotary chamber machine

Vacuum Packaging:

Key factors in vacuum packaging of food products include consistent vacuum levels, fast pump down times and low maintenance. Rietschle pumps are capable of operating cooler than our competition's models, due to our superior design. Cooler operation contributes to reduced oil breakdown, less oil misting, reduced maintenance and better pump life. Bush claims our cooler operation is a disadvantage, saying that we will condense water vapor inside the pump. That is pure marketing spin on their part. All our oil-lubricated rotary vane pumps come with adjustable gas ballast valves that eliminate the likelihood of any condensation in the pump. It is a non-issue. General Volume and Pressure Requirements: 5 to 1535 CFM, usually at 1 Torr. Pumps are usually rated @ 1 Torr when purchased. After use, and due to pressure drop for piping lines, 2 to 3 Torr will still produce a good pack. Often, end users cannot reach 2 to 3 Torr even after the OEM service tech visits, and they may believe their pump is undersized for machine. Offer to work on these projects if ROI is good. Many user customers can speed up cycle time for their machines by putting a larger volume pump on the machine. Our VC Product line, with its many sizes and increased volume for same HP, is perfect for this purpose. Some users have old, worn, or undersized pumps that cannot attain the ultimate required vacuum or have cycle times that are longer than standard. Look for these opportunities to sell new pumps with more CFM per HP than our competitors. Busch parts prices are higher than ours and in some cases, double! Busch does not include some parts in their standard rebuild kits and these required parts must be purchased as adders. This can be a Rietschle advantage, especially if the customer is feeling he has been gouged. (You might even want to suggest this). Some customers buy "pirate" non-OEM parts from other sources, but they can have genuine Rietschle parts at a reasonable price. Busch requires serial numbers before they will sell any parts; this is an inconvenience to most users. We will provide test units with special terms for large projects. Please inquire with the Rietschle Inc. Sales Department for assistance, terms & conditions.

Lesson 26

Ultra-filtration

Introduction

Membrane processing is used in the dairy industry for non-thermal processing , to retain most of the nutrients and is mainly used for manufacture of health and functional foods, through concentration and fraction of various components. This involves, Ultra Filtration, Reverse Osmosis, Micro Filtration and Electrodialysis.

USES OF MEMBRANE FILTRATION:

1. Changing pattern of milk consumption is stressing on individual use of its components.
2. Whey which has high BOD value is being efficiently concentrated form protein . Then, the lactose in the permeate solution can also be handled by RO.
3. It saved energy in transportation, due to concentration.
4. Cheaper method of drying. Pumping is involved, as against evaporation of moisture.
5. Possibility of incorporating whey proteins into cheese.
6. Pollution due to whey is controlled, as whey contains lactose.
7. Milk also can be concentrated without damage to protein or changing flavour unlike in concentration and drying.
8. Other industrial uses, like water purification, fractionation & concentration in Food and Pharmaceuticals, recovery of various components of waste for further use.

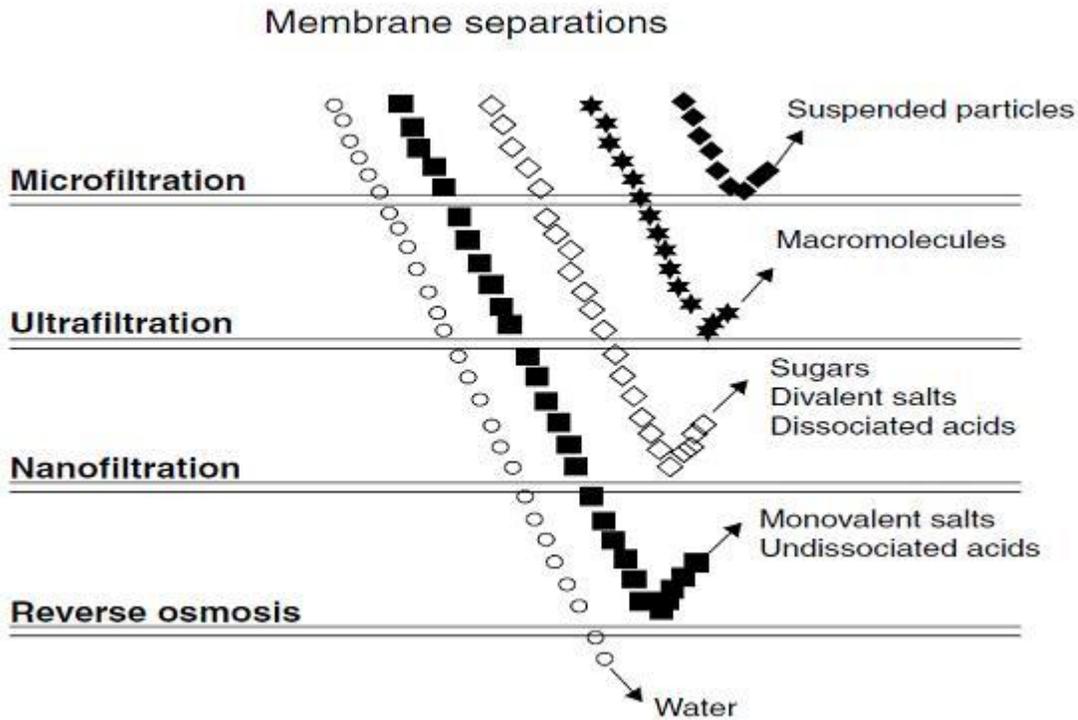
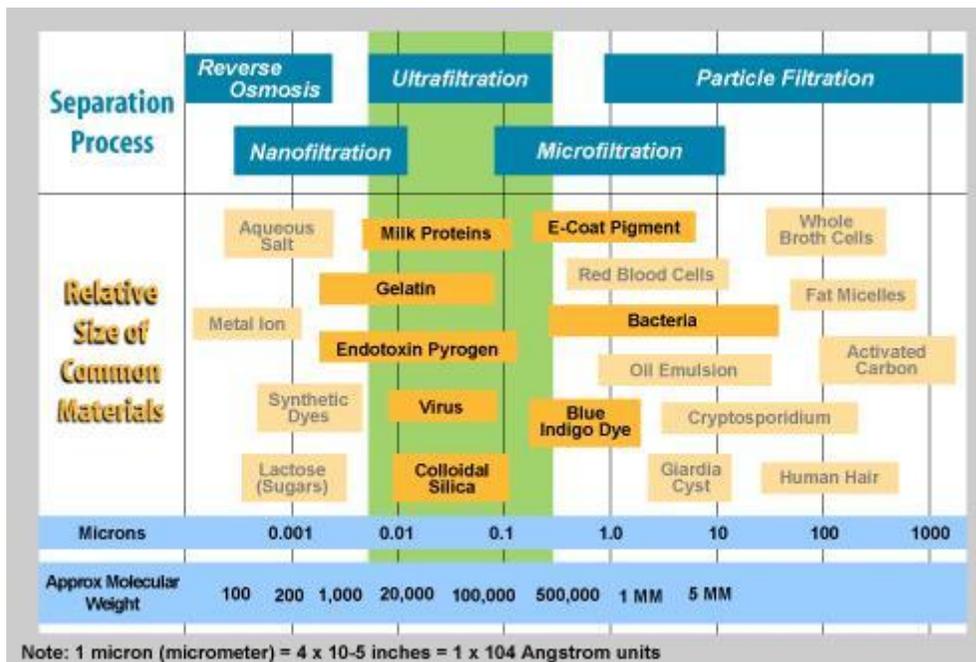


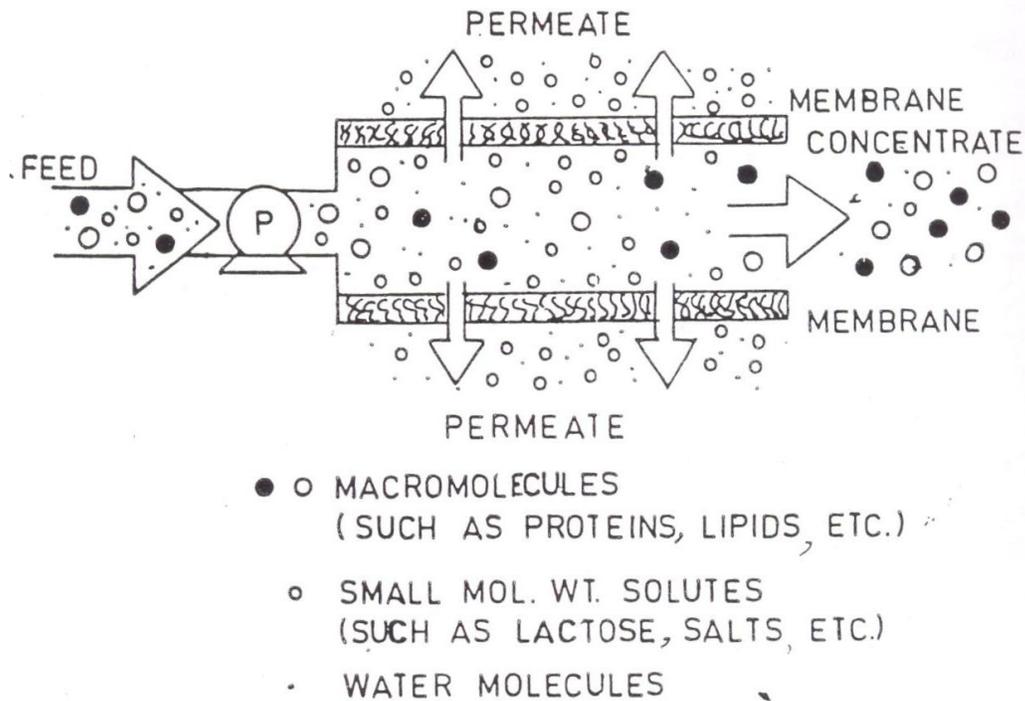
Fig. 26.1 Types of Membrane Separations

The various membrane processes have different range of conditions under which they operate as well as the basic principle of drive. However, the heart of the membrane process is the membrane itself. The over view of the various membranes are shown below:



(table of operating prerssure to be given here)

The membrane processing has certain basic terminology, that is common across the various ranges of membrane processes. The important terms are given below:



Membrane : A membrane can be defined as a phase which acts as a barrier to flow of molecular or ionic species between other phases that it separates. It is either dry solid, a solvent swollen gel, or a liquid that is immobilized.

Semipermeable membrane: A membrane which allows some molecules to pass and retains other according to their size.

Composite membrane or thin film : Thin filtering layer built on to the support layer and the two layers are of different materials.

Asymmetric Membrane: Chemically of the same material throughout but physically is of different structure on its two sides.

Membrane cut off: Molecular weight above which 100 % (in practice 95%) of a solute is retained by the membrane.

Permeate: The filtrate, the liquid passing through the membrane.

Concentration Factor: The volume reduction achieved by concentration.

Initial volume of feed Final conc. of component retained

----- OR -----

Final volume of concentrate Initial conc. of component retained

Retention Factor: It specifies the ability of a membrane to retain that molecule.

$$C_f - C_p$$

$R = \frac{C_f - C_p}{C_f}$ where, C_f = Conc. of molecule in feed

$C_f C_p = \text{“ “ permeate}$

In Batch process where the concentrations are continually changing, R varies and then the realistic value can be,

$$\ln(C/C_0) = R \ln(V_0/V) \text{ where, } C_0 = \text{Initial concentration at } V_0$$

C = Conc. at any other volume V

Separation Factor (s) a measure of performance of the membrane in separating solvent and solute.

$$S = C_f / C_p \text{ and } R = 1 - (1/S)$$

S is a concept more appropriate to water purification than milk concentration.

Concentration Polarization : Increase in concentration of solids in the direction towards the membrane due to the extraction of permeate through the membrane.

The rediffusion of concentrated solids back into the feed is governed by Fick's law. This law describes molecular diffusion .

$$J_{AB} = -D_{AB} (dc_A / dz)$$

Where J_{AB} = Molar flux of component A in the direction of Z of mixture of AB (kg mol of A/m² s)

D_{AB} = Molecular diffusivity of component A in component B (m² / s)

c_A = Concentration of component A (kg mol / m³)

z = distance (m)

Flux: Rate of extraction of permeate, measured in litres/sq. h

The flux or the flow rate in the membrane under laminar flow is governed by Hagen Poiseuille equation. This equation relates the pressure drop, path geometry and viscosity of fluid flowing through membrane under laminar condition.

QUOTE

Where Q is average velocity, ΔP is pressure drop, D is diameter of μ , η is viscosity, L is length of the pipe

Microfiltration (MF) :

Microfiltration is the oldest membrane technology, having been used several decades before the first industrial use of reverse osmosis. However, subsequent development of the technology has been slow. MF is a pressure-driven employing pressures considerably lower than others especially Reverse Osmosis. In fact the distinction between UF and MF is somewhat arbitrary and there is no distinction on purely theoretical grounds. The distinction lies in the size ranges of the materials which are separated. UF is considered to involve the processing of dissolved macromolecules, while MF involves separation of dispersed particles such as colloids, fat globules or cells. MF can be considered to fall between UF and conventional filtration, although there is overlap at both ends of the spectrum

Ultra Filtration(UF):

Ultra filtration can be defined as a pressure driven membrane process that can be used in the separation and concentration of substances having a molecular weight between $10^3 - 10^6$ Dalton.

UF is a process where the high molecular weight component, such as protein, and suspended solids are rejected, while all low molecular weight component pass through the membrane freely. There is consequently no rejection of mono and disaccharides, salts, amino acids, organics, inorganic acids or sodium hydroxide.

Characteristics:

Membrane	Asymmetrical
Thickness	150 – 250 μm
Thin film	1 μm
Pore size	0.2 – 0.02 μm
Rejection of	Macro molecules, proteins, polysaccharides, vira
Membrane materials	Ceramic, PSO, PVDC, CA, thin film
Membrane module	Tubular, hollow fibre, spiral wound, plate-and-frame
Operating pressure	1-10 bar
Mechanism of membrane retention	Molecular screening
Typical flux	30 – 300 lit/m ² h

Membrane modules:1. Tubular module:

- 18 x12.5 mm perforated stainless steel tubes
- Tubes assembled in a shell-and-tube like construction and connected in series.
- A replaceable membrane insert tube is fitted inside each of the perforated stainless steel pressure support tubes.
- Permeate is collected on the outside of the tube bundle in the stainless steel shroud.

In tubular module with ceramic membrane, the filter element is a ceramic filter. The thin walls of the channels are made of fine-grained ceramic and constitute the membrane. The support material is coarse grained ceramic.

2. Hollow fibre:

- Cartridges each having bundles of 45 to over 3000 hollow-fibre elements.
- The fibres are oriented in parallel.
- Fibers are potted in a resin at their ends and enclosed in the permeate-collecting-tube of epoxy.
- The membrane has an inner diameter ranging from 0.5 to 2.7 mm.
- The active membrane surface is on the inside of the hollow fibre.
- The outside of the hollow-fibre wall, has a rough structure and acts as a supporting structure for the membrane.
- The feed stream flows through the inside of these fibres, and permeate is collected outside and removed at the top of the tube.

3. Spiral wound

- Contains one or more membrane envelopes, each of which contains two layers of membrane separated by a porous permeate conductive material.
- *Permeate channel spacer* allows the permeate passing through the membrane to flow freely.
- The two layers of membrane with the permeate channel spacer between them are sealed with adhesive at two edges and one end to form the membrane envelope.
- The open end of the envelope is connected and sealed to a perforated permeate collecting tube.
- The feed channel spacer is placed in contact with one side of each membrane envelope.

4. Plate and frame design

- It consist of membranes sandwiched between membrane support plates arranged in stacks.
- The feed material is forced through very narrow channels that may be configured for parallel flow or as a combination of parallel and serial channels.

Polymers used in membrane manufacturing:

- Cellulose Acetate
- Polyamide membranes
- Polysulfone membranes

- Ceramic membranes

Fouling of membrane:

Fouling is termed as decline in flux when all operating parameters like pressure, flow rate, temperature and feed concentrations are kept constant. It can be avoided by:

- Ø Pretreatment of feed.
- Ø Maintain minimum axial velocity.
- Ø Dynamic pressure of flow should be higher.
- Ø For proteinaceous feed, pH far away from iso- electric point is maintained.

Terms:

1. Rejection = $1 - (\text{solute conc. in Permeate} / \text{solute conc. in Retentate})$
2. Volume concentration ratio (VCR) = Initial feed volume / Retentate volume
3. Weight concentration ratio (WCR) = Initial feed weight / Retentate weight
4. Volume reduction % = $\{1 - (1 / \text{VCR})\} \times 100$
5. Flux: The quantity of permeate liquid(Kg or L) per membrane area unit(sq. m) and time unit ♥.
6. Transmembrane Pressure: Pressure gradient between Retentate side and permeate side.
7. Retentate: Fraction of feed stream not passing through the membrane.
8. Permeate: Fraction of feed stream passing through the membrane.
9. Hold up volume: volume of concentrate remaining in the module.
10. Concentration polarization (CP): A higher concentration of retained solute species adjacent to the membrane surface than in the bulk stream.

U.F. membrane preparation methods:

- Phase inversion
- Thermal inversion
- Dynamic membrane
- Ultrathin composite membranes
- Track – etched membranes

Disadvantages:

- As the surface of membrane is not smooth, building of scale leads to idle environment for bacterial growth.
- The voids provide space for growth of micro-organisms.
- Disassembly of the UF equipment for manual cleaning is not practical due to high surface area involved.

- Membrane materials like cellulose acetate have high sensitivity to several cleaning and sanitizing solutions.

Applications:

1. Separation and fractionation of individual milk proteins from lactose and minerals.
2. Enzyme recovery in various operations like lactose hydrolysis using lactase.
3. Fractionation of cheese whey
4. Pre – concentration of milk for cheese manufacturing.
5. Sugar refining
6. Vegetable protein processing. e.g. soy proteins
7. Concentration of egg white
8. Animal products industry. e.g. gelatin
9. Biotechnology applications
10. Fruit juices & other beverages.



Lesson 27

Reverse Osmosis

Introduction

Reverse Osmosis (RO) is the tightest possible membrane process in liquid/liquid separation. Water is in principle the only material passing through the membrane; essentially all dissolved and suspended material is rejected. The more open types of RO membranes are sometimes confused with nanofiltration (NF). Reverse osmosis is a process which separates small molecules and ions (molecular weight less than 1000; molecular size less than 0.001µm) from the solvents.

It is a pressure driven membrane system essentially used for dewatering of fluid foods.

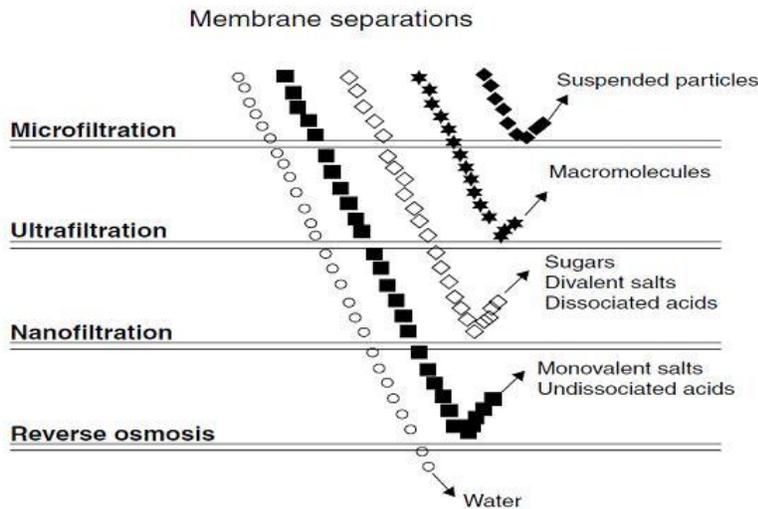


Fig. 27.1 Principle of RO (a)

Characteristics:

Membrane	Asymmetrical
Thickness	150 µm
Thin film	1 µm
Pore size	<0.002 µm

Rejection of	High molecular weight component, low molecular weight component, NaCl, glucose, amino acids
Membrane materials	CA, thin film
Membrane module	Tubular, spiral wound plate-and-frame
Operating pressure	15-150 bar
Mechanism of membrane retention	Diffusive transport
Typical flux	3 – 30 lit/m ² h

Osmotic Pressure of Foods at Room Temperature

Food	Concentration	Osmotic pressure (psi)
Apple juice	15% total solids	300
Coffee extract	28% total solids	500
Grape juice	16% total solids	300
Lactic acid	1% w/v	80
Lactose	5% w/v	55
Orange juice	11% total solids	230
Perilla anthocyanins	10.6% total solids	330
Skimmilk	9% total solids	100
Sodium chloride	1% w/v	125
Sweet potato waste	22% total solids	870
Whey	6% total solids	100

Materials for membrane

manufacturing:

- Cellulose acetate
- Polymers
(polysulphones, polyamides, PVC, polystyrene, polycarbonates, polyethers).
- Composite or ceramic membranes (porous carbon, zirconium oxide, alumina).

Terms:

- The pressure difference across the membrane (the trans-membrane pressure) is found using:

$$P = \frac{P_f + P_r}{2} - P_p$$

where P (Pa) is trans-membrane pressure, P_f (Pa) is pressure of the feed (inlet), P_r (Pa) is pressure of the retentate (outlet) (high molecular weight fraction) and P_p (Pa) is pressure of the permeate (low molecular weight fraction).

- Water flux is measured as:

$$J = kA(\Delta P - \Delta \Pi)$$

where J (kg /h) is flux, K (kg m⁻² h⁻¹ Pa⁻¹) is mass transfer coefficient, A (m²) is area of the membrane, ΔP (Pa) is applied pressure and $\Delta \Pi$ (Pa) is change in osmotic pressure.

- Osmotic pressure $\Pi = MRT$

where T (°K) is absolute temperature, R is universal gas constant, M is molar concentration and $\Delta \Pi$ (Pa) is osmotic pressure.

Advantages:

1. The removal of water is accomplished without a change in phase or state of the solvent.
2. The process can be operated at ambient or up to 50°C temperature. Thus thermal degradation of nutrients is minimum.
3. There is negligible loss of volatiles and eating quality.
4. Complicated heat transfer or heat generating equipments are not required.
5. Lower labour and operating costs.

Limitations:

1. Variation in the product flow rate when changes occur in the concentration of feed liquor
2. Higher capital costs than evaporation
3. A maximum concentration to 30% total solids
4. Fouling of the membranes (deposition of polymers), which reduces the operating time between membrane cleaning.

Applications:

1. Concentration of milk, whey & UF permeate.
2. Preparation of indigenous dairy products like khoa, chakka etc.
3. Concentration and purification of fruit juices, enzymes, fermentation liquors and vegetable oils.

4. Concentration of wheat starch, citric acid, egg white, coffee, syrups, natural extracts and flavours.
5. Clarification of wine and beer.
6. Demineralization and purification of water from boreholes or rivers or by desalination of sea water.



Lesson 28

Electrodialysis

Introduction

- Ø Electro Dialysis (ED) is a membrane process, during which ions are transported through semi permeable membrane, under the influence of an electric potential.
- Ø Electrodialysis is an electrically driven membrane separation process that is capable of separating, concentrating, and purifying selected ions from aqueous solutions (as well as some organic solvents).

History:

- The history of electrodialysis goes back to the development of the first multi cell stack.
- However, modern electrodialysis became a practical reality with the development of the first reliable ion-exchange membranes having both good electrolyte conductivity and ion-permselectivity.
- Electrodialysis was first commercially exploited for the desalination of brackish water by Ionics Inc.
- In the early 1980's a completely new area for the application of electrodialysis was opened up with the introduction of bipolar membranes for the recovery of acids and bases from the corresponding salt.

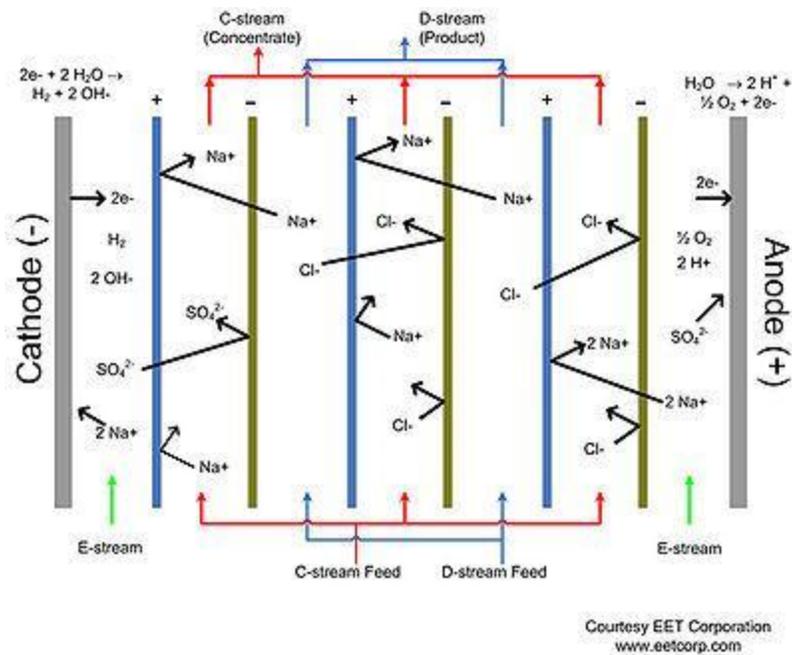


Fig. 28.1ED by Ion Permeable Membranes

Principle:

Ø Electro dialysis stack includes following components:

- Diluate Feed Stream (D)
- Concentrate Stream(C)
- Electrode Stream (E)
- Cell compartment formed by ion exchange membrane.
- Electrodes

Ø Potential difference created between electrodes attracts oppositely charged ions.

Ø Cations (positively charged ions) are attracted toward cathode (-) and Anions (negatively charged ions) are attracted toward anode (+).

Ø Anion exchange membrane (positively charged) allows anions to pass through but checks cations.

Ø Similarly, cation exchange membrane (negatively charged) allows cation to pass through but checks anion.

Ø Equal amount of cations and anions get collected in C stream (transferred from D stream). Overall charge balance is maintained.

Ø The overall result of the electro dialysis process is an ion concentration increase in the concentrate stream with a depletion of ions in the diluate solution feed stream.

Materials and specifications:

1. Ionic mobility: The ionic mobility is directly proportioned to specific conductivity and inversely proportioned to number of molecules in solution. $\sim 3-6 \times 10^2$ mm/sec.
2. Membranes: Electro dialysis membranes are comprised of polymer chains - styrene-divinyl benzene made anionic with quaternary ammonium groups and made cationic with sulphonic groups.
3. Operating voltage: 1-2 V is applied across each pair of membranes.
4. Membrane arrangement:
 - a. Anion and cation exchange membranes are arranged alternately in parallel between an anode and a cathode.
 - b. Distance between membranes is 1 mm or less.
 - c. A plate and frame arrangement similar to a plate heat exchanger or a plate filter is used.

2. Electrodialysis using Bipolar Membranes

A bipolar membrane in an electric field generates hydrogen ion on one side and hydroxyl ion on the other side. Therefore electro dialysis with bipolar membrane can be used to produce acid and base from salt.

Current efficiency:

Current efficiency is a measure of how effective ions are transported across the ion exchange membranes for a given applied current. Current efficiency is generally a function of feed concentration

$$\xi = \frac{zFQ_f(C_{inlet}^d - C_{outlet}^d)}{NI}$$

Where,

ξ = current utilization efficiency

z = charge of the ion

F = Faraday constant, 96,485 Amp-s/mol

Q_f = diluate flow rate, L/s

C_{inlet}^d = diluate ED cell inlet concentration, mol/L

C_{outlet}^d = diluate ED cell outlet concentration, mol/L

N = number of cell pairs

I = current, Amps.

Advantages:

- ED system separates without phase change, which results in relatively low energy consumption.
- When brackish water is desalted by ED system, the product water needs only limited pre-treatment. Typically only chlorination for disinfection is required.
- As ED system removes only ionized species, it is particularly suitable for separating non-ionized from ionized components.
- Osmotic pressure is not a factor in ED system, so the pressure can be used for concentrating salt solutions to 20% or higher.

Limitations:

- Organic matter, colloids and SiO_2 are not removed by ED system.
- Feed water pre-treatment is necessary to prevent ED stacks fouling.
- Elaborate controls are required, and keeping them at optimum condition can be difficult.
- Selection of materials of construction for membranes and stack is important to ensure compatibility with the feed stream.

Applications:

1. Removal of salts from food.
2. demineralization of milk products and whey for infant formula and special dietary products.
3. Concentrate salts, acids and bases.
4. Adjustment of pH in food and wine.
5. Large scale brackish and seawater desalination.

6. Drinking water production
7. Pre-demineralization (for process water, chemical manufacturing, boiler makeup)
8. Glycol desalting
9. Glycerin purification



Lesson 29

Materials for Membrane Construction

Introduction

The selection of membranes offered by the various suppliers in the business may appear to be confusing since many materials may be used to make membranes, and they are provided under an array of trade names. In reality, relatively few materials are actually used in quantity, and only a few basic membrane types form the bulk of the membranes being sold and used.

Different materials for membrane construction

Following materials are used for the membrane construction:

1. **Cellulose Acetate:**

- Contains 38 – 40 % by weight of acetyl group.
- Membranes are strong and flexible.
- Used for RO, NF and UF applications.
- Advantages
 - o Low price
 - o Less prone to fouling due to its hydrophilic nature.
- Limitations
 - o Low resistance to pH change.
 - o Maximum operating temperature is 35°C.
 - o Low resistance to chemicals normally used for cleaning and sanitization (e.g. chlorine)

- o Can be eaten by microorganisms.

2. **Synthetic polymers :**

a. **Polysulphones:**

- Used for UF and MF membrane since 1975.
- Advantages:
 - o Exceptional temperature and pH resistance
- These membranes do not tolerate oil, grease, fat and polar solvents.
- Aromatic polysulphones are used as they are resistant to oxidation, dimensionally stable and resistant to acids, alkali, salt solutions and detergents even at elevated temperatures or moderate pressure.

b. **Polyvinylidene fluoride:**

- These are resistant to hydrocarbons and oxidizing environments.
- These have excellent abrasion resistance and good resistance against temperature and chemicals.

c. **Polyacrylonitrile**

d. **Polytetrafluoroethylene:**

It has extraordinary chemical resistance and can be used in a wide range of temperature.

e. **Aliphatic and aromatic polyamides**

3. **Composite membranes:**

- Made to replace cellulose acetate RO membranes.
- The main advantage is the combination of relatively high flux and very high salt rejection.
- They also have good temperature and pH resistance.

- They do not tolerate oxidizing environments.
- Composite membranes are made in two-layer and three-layer designs, the precise composition of which is proprietary.
- Around 1980, FilmTec marketed the two-layer design which immediately became the industry standard for water desalination.
- In the mid-1980s Desalination Systems, Inc. (DSI) began making composite membranes with a three-layer design.
- The three-layer design is available for RO and NF, and it is still the best choice for treating a vast array of difficult process streams.

4. **Others:**

1. **ABS** :Useful material in water desalination systems.
2. **Delrin**: Also called POM; it is an excellent material. Its biggest weakness is limited resistance in low pH environments.
3. **PE** Polyethylene has good chemical stability but very limited temperature stability.
4. **PP** Polypropylene is chemically a very resistant polymer. The temperature stability is limited, and it has a tendency to creep.
5. **PVC** PVC is mostly used for low pressure piping. It is inexpensive, but has severe temperature limitations. It can only be used for un-demanding applications, such as the desalination of ground water.
6. **C-PVC** Chlorinated PVC has significantly better temperature stability than ordinary PVC. The present political lobbying against the PVC industry may preclude it from being an acceptable construction material in the future.
7. **PVDF** An excellent but rather expensive material. It has good heat stability and is chemically almost as resistant as Teflon.
8. **FRP** Glass fiber reinforced polyester is widely used for housings. It has become the standard in water desalination in spite of its obvious shortcomings. Corrosion resistance is its prime advantage, closely followed by low price.

9. **Epoxy** A very special type made only in Germany by Membratec. The housings are thin walled, but can nevertheless tolerate very high pressure.

Membrane structure:

Membranes have a tight top layer facing the product to be treated. This layer is also called the skin layer. It is thin, typically <0.1 micron. The membrane itself is 150 - 250 micron, the bulk of the membrane simply providing structural support for the skin layer.

Pore size differs for different types of processes:

MF – 5 – 0.1 micron

UF – 0.1 – 0.01 micron

NF, RO – 0.001 micron (theoretical)

Selection of membrane materials:

	Composite	CA	PSO	PVDF	PAN	SiO ₂	Cellulose
3 < pH < 8	✓	✓	✓	✓	✓	✓	✓
pH<3 or pH>8	✓	✗	✓	✓	✓	✓	✓
Temp >35°C	✓	✗	✓	✓	✓	✓	✓
Humic acid	(✓)	✓	✗	✗	(✓)	✗	✓
Proteins	✓	(✓)	✓	(✓)	(✓)	✓	✓
Polysaccharides	(✓)	✗	✓	✗	(✓)	✓	✗
Textile waste	✓	✗	✓	(✓)	✓	✗	✗
Aliphatic hydrocarbon	✗	✗	✗	(✓)	✓	✓	✓
Aromatic hydrocarbon	✗	✗	✗	✓	✗	✓	(✓)
Oxidizers	✗	(✓)	✓	✓	(✓)	✓	(✓)
Ketones, Esters	✗	✗	✗	✓	✗	✓	(✓)
Alcohol	✓	✗	✓	✓	✓	✓	✓

✓ means high resistance

(✓) means either that the information is based on theory or that practical results have proved to be dubious

✗ means high resistance

	Reverse Osmosis	Nanofiltration	Ultrafiltration	Micro filtration
Membrane	Asymmetrical	Asymmetrical	Asymmetrical	Symmetrical Asymmetrical
Thickness Thin film	150 μm 1 μm	150 μm 1 μm	150 - 250 μm 1 μm	10-150 μm
Pore size	<0.002 μm	<0.002 μm	0.2 - 0.02 μm	4 - 0.02 μm
Rejection of	HMWC, LMWC sodium chloride glucose amino acids	HMWC mono-, di- and oligosaccharides polyvalent neg. ions,	Macro molecules, proteins, polysaccharides vira	Particles, clay bacteria
Membrane material(s)	CA Thin film	CA Thin film	Ceramic PSO, PVDF, CA Thin film	Ceramic PP, PSO, PVDF
Membrane Module	Tubular, spiral wound, plate-and-frame	Tubular, spiral wound, plate-and-frame	Tubular, hollow fiber, spiral wound, plate-and-frame	Tubular, hollow fiber
Operating pressure	15-150 bar	5-35 bar	1-10 bar	<2 bar



Lesson 30

Ultra Filtration of Milk

Introduction

Membrane filtration is a separation process which separates a liquid into two streams by means of a semi-permeable membrane. The two streams are referred to as retentate and permeate. By using membranes with different pore sizes, it is possible to separate specific components of milk and whey. Depending on the application in question, the specified components are either concentrated or removed/reduced.

Ultra filtration of milk

- Commercial membranes of UF have nominal weight cut-offs at 20,000 – 25,000.
- The protein and fat are retained in the retentate. Lactose, minerals and vitamins are fractioned between the retentate and the permeate.
- Minerals such as Ca, Mg, P and citrate are partly bounded to protein in milk and partly in solution. During UF, the former portion is retained and concentrated and the latter part passes to the retentate.
- Rejection coefficient of the components in whole milk:

Total solids – 54%

Protein – 93 %

Fat – 100 %

Lactose – 0 %

Ash – 29 %

NPN – 62 %

- If during UF, if flux reduces to almost zero because of increase in protein concentration, diafiltration is followed.
- UF milk is useful in formulating reduced- or no-lactose dairy products.

1. Milk Protein Standardization and Fractionation

- UF milk fractionated components can be used to stand the nutritional value of consumer milk or to prepare standardized milk powders, overcoming natural variations in milk composition.
- Increasing the protein content by ultrafiltration makes the milk whiter, and more viscous, the sensory quality more similar to that of higher fat milks.
- An MF/UF process can be used to fractionate non-fat milk into value-added protein ingredients. Resulting ingredients include native casein concentrates (from the retentate), pure milk serum proteins (from the permeate) and individual milk protein isolates that have application as emulsifiers, fortifying proteins and gelling agents.

2. Fermented Dairy Products

- UF can be used to standardize protein and total solids in milk for use in fermented dairy foods such as cream cheese, yogurt and cottage cheese.
- Fermented products made with UF milk have superior quality and sensory characteristics compared to products made from milk concentrated by conventional methods.
- Membrane filtration helps control quality attributes such as consistency, post-processing acidification and extent of syneresis.
- However, using membrane-processed milk often requires an adjustment in starter culture selection and fermentation conditions.

3. Cheesemaking

- The cheese industry uses membrane concentrated milk to elevate the solids level of cheesemilk.
- Future applications for membrane processing may include the manufacture of fresh, soft, hard and semi-hard cheese varieties.

- UF concentrated milk, with its fat and protein content concentrated to 3.5X, and a portion of the lactose, ash and water removed, possesses the ideal composition for the potential manufacture of fresh cheeses like ricotta or brine cheeses like Feta.
- Replacing 10-15% of the cheese milk volume with UF milk creates the opportunity to boost total solids, therefore increasing cheese throughput in factory by as much as 18%— subsequently reducing production costs.
- Using concentrated milk could also reduce rennet and starter culture requirements, depending on the application.
- In addition, using UF milk could reduce a cheese plant's wastewater processing costs.

4. **Cream**

Scurlock in 1986 used UF as the 1st stage in the preparation of protein enriched whipping creams. Whole milk concentrated 2 to 5 fold by UF was separated conventionally to produce protein enriched creams with fat 25 – 45 % (w/w).

5. **Skim milk retentate powder**

- Ultra filtered skim milk retentate is spray dried to obtain S.M. retentate powder with 50 – 65 % protein. It shows lower bacterial counts and acidity and an excellent flavour.
- A standardization of the protein levels with WMP with 32 – 35 % protein and skim milk powders with 38 – 41 % protein can be done by using UF skim milk and whey retentates and permeates.

6. **Low lactose milk powder:**

- It is developed by using low lactose milk powder, lactose content of which can be reduced by 86 %.
- Lactose was replaced by malto-dextrin.
- Na and K salts are added to compensate the loss of milk salts.

7. **Skim milk based concentrates:**

- In-container sterilized milk concentrates are prepared from UF skim milk.

· Such concentrates with edible carbohydrates have TS of 40 % and shelf life over 1 year.

8. Sweetened condensed milk

UF concentrates are used in making of SCM. Such product has reduced sandiness in the texture.

9. Ice – cream

UF can be used to prepare ice cream by using UF skim milk or UF reconstituted skim milk. Ice cream doesn't shows any change in viscosity, specific gravity and overrun but gives improved creamy body and texture.

10. Non – fat dairy coffee whiteners

Retentates obtained by UF of skim milk are freeze – dried. The product is comparable to commercial non – dairy coffee creamer and has acceptable dispersibility.

11. Whey protein quarg

Concentrate obtained by UF of mixture of 80 % whey and 20 % skim milk is heated to obtain firm coagulum. It is also suitable for sweet desserts and puddings.



Lesson 31

Effect of Milk Constituents on Operation of Membrane Process

Introduction

The dairy industry has used membrane processing to clarify, concentrate and fractionate a variety of dairy products. Applying membrane technology to whey processing allowed the production of refined proteins and commercial usage and thus transformed a waste byproduct from cheese production into a valuable product. In addition to whey processing, membrane technology is also used for fluid milk processing with clear advantages. Further, specific milk components can be obtained without causing a phase change to the fluid milk by the addition of heat as in evaporation.

Membrane filtration technologies, such as ultrafiltration and reverse osmosis, are capable of the molecular fractionation of fluids. Milk is ideally suited for processing by membrane filtration because it is a fluid consisting largely of water, lactose, butterfat, and protein molecules. Separation at the molecular level means that butterfat, lactose, and protein can be isolated from one other.

Component in Milk Average Dimension (nm)

Water 0.2

Lactose 0.5

Casein Proteins 2.0-4.0

Fat 1,000-10,000

Reverse osmosis

RO appears to be a promising method for concentrating whey with significant savings in the total energy and overall cost. It has been suggested that RO can be used as a pre-

concentration step for UF permeate to 20 percent, which would reduce the cost of transportation. The UF permeate containing approximately 4 per cent lactose and 1 per cent minerals can be concentrated to 18 per cent total solids by RO. From economic point of view, 2 fold concentration (i.e. 50 per cent volume reduction) of paneer whey and 2.5 fold concentration (i.e. 60 per cent volume reduction) of cow and buffalo cheese Whey.

UF

Fractionation of whey into protein rich and lactose containing streams is one of the most successful industrial applications of UF. Protein content of raw whey can be increased from an initial value of 0.6 per cent to over 20 per cent in the UF step. When whey is concentrated about 20 times by UF, a dry matter content of 18-20 per cent is attainable. It is suggested when UF of whey be carried out for deproteinization for lactose manufacture. Whey protein concentrates (WPC) are powders made by drying of retentate from ultrafiltration of whey. They are described in terms of protein content, percent protein in dry matter, ranging from 35 to 85 per cent. To make 35% protein product the liquid whey is concentrated to about 6-fold to an approximate total dry solids content of 9%.

Milk protein concentrate using ultrafiltration

- concentrating both casein and whey proteins
- Ratio similar to milk

MPC Composition

Components (% wt/wt) NFDM MPC-56 MPC 75 MPC 80

Protein 35 56 75 80

Water 4 5 5 5

Fat 1 1.2 1.5 1.7

Lactose 51.3 31.7 10.9 5.5

Minerals 7.7 8.0 7.2 7.4

Microfiltration

MF can be used to remove large particles: casein fines, micro-organisms or microbial spores, fat globules, somatic cells, phospholipoproteins, particles, etc. from whey. MF separation process uses porous membranes with a cut off pore sizes in the Region of micron(10-6m) allowing passage of whey proteins but retaining fat globules, microorganisms and somatic cells. Whey usually contains small quantities of fat (in the form of small globules of

0.2 to 1micron) and casein (as fine particulates of 5 to 100micron).Centrifugal separation of whey does not completely remove the fat and casein fines. Thus, when the whey is ultrafiltered, these components can prevent the attainment of high purity, as well as having detrimental effects on the functional properties of WPC. MF can effectively remove substantial quantities of these undesirable components. Fat: protein ratios of 0.07 to 0.25 in whey can be reduced to 0.001 to 0.003 by MF. In addition some of the precipitated salts may be removed, and there is a considerable reduction in the microbial load. It is reported that 30 to 80 per cent residual lipids can be removed from cheddar cheese whey using MF. There is a 1.8 fold increase in the rate of UF of whey proteins when the lipids are removed by MF. When MF is performed on sweet whey as an intermediate step within the UF process, a fat content below 0.4 per cent in 85 per cent WPC powder can be achieved

Microfiltration of buttermilk

	Fresh buttermilk	MF permeates 0.8 μ m			MF retentates 0.8 μ m		
		7°C	25°C	50°C	7°C	25°C	50°C
Protein (% DM)	30.33	25.91 ^a	28.69 ^a	29.87 ^a	32.59 ^a	35.84 ^b	37.36 ^b
Lipids (% DM)	8.41	4.81 ^a	5.22 ^a	6.05 ^b	9.02 ^a	18.43 ^b	13.56 ^{a,b}
PPL (% DM) ¹	2.10	1.95	1.23	1.75	1.94	4.48	3.94
% of PPL ²							
PE	32.4	29.2	37.4	33.1	39.7	30.8	34.0
PI	20.9	13.9	16.3	17.7	16.0	16.1	20.8
PC	30.5	46.2	33.3	36.0	30.4	37.1	31.0
SM	16.2	10.7	13.0	13.1	13.9	16.0	14.2

Factors affecting membrane performance fouling

Concentration polarisation

- Differential solute conc between membrane surface and bulk stream
- Reversibly affected by operation parameters

Fouling

- Formation of deposits
- Irreversibly affected by operation parameters

Membrane fouling

Two types

- Surface (temporary) fouling
- Pore (permanent) foul

Implications

- Higher energy consumption
- Frequent need for cleaning
- Affects membrane durability

Dairy Process Engineering

- Effect on properties and quality of concentrate
- Overall economy of the membrane process

Surface (temporary) fouling

- Foulant appears an evenly deposited layer on the membrane surface
- Can be easily removed by cleaning solution
- Permeation rate of membrane can be regenerated by cleaning
- Most common type of fouling in UF plant

Pore (permanent) fouling

- Particulate matter diffuses into the membrane
- Could be caused by the poor quality of the cleaning water
- Uneven distribution of the foulant and compression of the separation zone
- Flux cannot be regenerated by cleaning
- Determines the lifetime of the membrane



Lesson 32

Membrane for Electro Dialysis

Introduction

Electrodialysis is an electromembrane process in which ions are transported through ion permeable membranes from one solution to another under the influence of a potential gradient.

Different types of membranes:

1. Ion Permeable Membranes

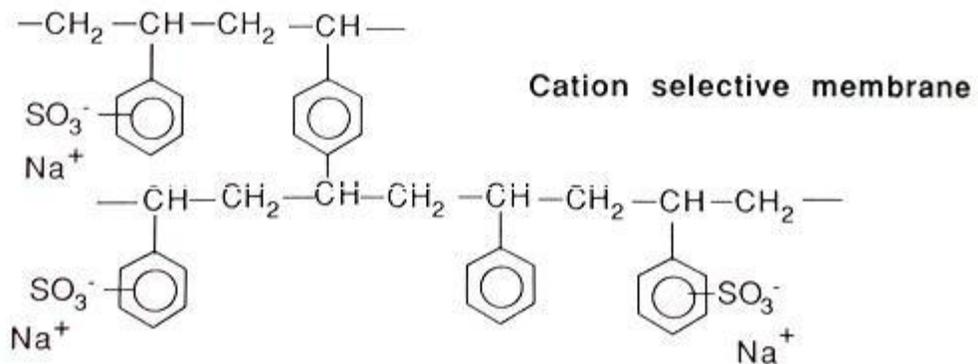
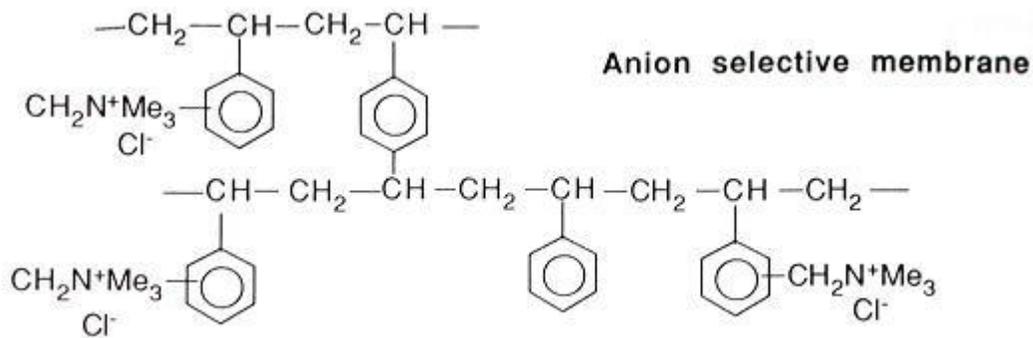
Membranes for electrodialysis are typically hydrocarbon films with ion exchange functional groups attached to the polymer chains. Hydrocarbon membranes are usually categorized as homogeneous or heterogeneous.

For heterogeneous membranes, the film-forming polymer is usually polyethylene or polyvinylidene fluoride, but other polymers could also be used. These membranes are thick, opaque and mechanically strong, but they tend to have higher resistance than homogeneous membranes.

Typical homogeneous membranes have a polymer matrix of styrene cross linked with divinylbenzene (DVB) and ion exchange functional groups of sulfonic acid or quaternary amines.

- They are essentially sheets of ion-exchange resins.
- They also contain other polymers to improve mechanical strength and flexibility.
- The resin component of a cation-exchange membrane would have negatively charged groups (e.g., -SO_3^-) chemically attached to the polymer chains (e.g., styrene/divinylbenzene copolymers).

- Attachment of positive fixed charges (e.g., $-NR_3^+$ or $C_5H_5N^+R$ where commonly $R = CH_3$) to the polymer chains forms anion permeable membranes, which are selective to transport of negative ions.
- Ion-exchange polymers such as poly(styrene sulfonic acid) are water soluble, so crosslinking is needed to prevent dissolution of ion permeable membranes. Divinylbenzene is used to cross link polystyrene chains.
- The degree of cross-linking and the fixed-charge density affect the membrane's properties in opposite ways. Higher crosslinking improves selectivity and membrane stability by reducing swelling, but it increases electrical resistance.
- High charge density reduces resistance and increases selectivity, but it promotes swelling and thus necessitates higher crosslinking.
- A compromise between selectivity, electrical resistance, and dimensional stability is achieved by proper adjustment of crosslinking and fixed-charge densities.



Method of preparation of ion permeable membranes:

- Cation exchange membranes are made by adding a sulfonic acid functional group to the benzene ring of the styrene group, usually by treatment with concentrated sulfuric acid, sulfur trioxide or chlorosulfonic acid.
- Anion exchange groups can also be added to the benzene ring, but a key reagent for that procedure, chloromethyl methyl ether, is a dangerous carcinogen. That danger is avoided by replacement of styrene with chloromethylstyrene and treatment of the polymer with trimethylamine to form a quaternary amine functional group. Alternative monomers for anion membranes include vinylpyridine or methylvinylpyridine, both of which are quaternized with methyl iodide after polymerization.
- Ion permeable membranes are also made by swelling existing films with styrene and DVB, which can then be post-treated to add functional groups, or by grafting of ion exchange functional groups directly onto the polymer matrix of existing films.

2. **Bipolar Membranes**

- Bipolar membranes consist of an anion-permeable membrane and a cation permeable membrane laminated together.
- Multiple bipolar membranes along with other ion permeable membranes can be placed between a single pair of electrodes in an electro dialysis stack for the production of acid and base from a neutral salt.
- When this composite structure is oriented such that the cation-exchange layer faces the anode it is possible, by imposing a potential field across the membrane, to split water into proton and hydroxyl ions. This results in the production of acidic and basic solutions at the surfaces of the bipolar membranes.
- Potential drop of only 0.8 V is necessary for modern bipolar membrane performance.

REFERENCES

Ahmed, T. 1985. Dairy Plant System Engineering. Kitab Mahal, K.L. Agencies Pvt. Ltd., New Delhi.

Ahmed, T. 1990. Dairy Plant System Engineering and Management. Kitab Mahal, K.L. Agencies Pvt. Ltd., New Delhi.

Anantakrishnan, C.P. and Simha, N. N. 1987. Technology and Engineering of Dairy Plant Operations. Laxmi Publ., Delhi.

Brennan. 1969. Food Engineering Operations. Elsevier Publ. Co., Amsterdam, New York.

Farrall, A. W. 1963. Engineering for Dairy and Food Products. John Wiley and Sons, New York.

Gardner, A. W. 1971. Industrial drying. Leonard Hill Publ., London.

Kessler. 1981. Food Engineering and Dairy Technology. V. A. Kessler Publ., Freising, Germany.

Masters, K. 1972. Spray drying: an introduction to principles, operational practice, and applications. Leonard Hill Publ., London.

Robinson, R. K. 1993. Modern Dairy Technology. Chapman & Hall, UK.

Spicer, A. 1974. Advances in Pre-concentration and Dehydration of Foods. John Wiley & Sons. New York.

***** 😊 *****

This Book Download From e-course of ICAR
**Visit for Other Agriculture books, News,
Recruitment, Information, and Events at**
WWW.AGRIMOON.COM

Give FeedBack & Suggestion at info@agrmoon.com

DISCLAIMER:

The information on this website does not warrant or assume any legal liability or responsibility for the accuracy, completeness or usefulness of the courseware contents.

The contents are provided free for noncommercial purpose such as teaching, training, research, extension and self learning.

***** 😊 *****

Connect With Us:

