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MODULE MAV 405
DAIRY ENGINEERING

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SADC-UNIVERSITY OF ZIMBABWE REGIONAL POSTGRADUATE PROGRAMME IN DAIRY SCIENCE AND TECHNOLOGY

MODULE MAV 405

Dairy Engineering

January 2010

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Chapter 1

SEPARATION AND CONCENTRATION

1.1 Sedimentation

Sedimentation is defined as the separation of particulate materials (insoluble solids) from a fluid stream by use of gravitational force. The particles are usually solids and the liquid can either be liquid or gas.

When a suspension or slurry is left to settle, the particles of greater density tend to settle at the bottom. As the particles settle a layer referred to as supernatant (A) is formed with solid particles settling down into subsequent layers B, C, D.

1.1.1 Terminal Settling Velocity (TSV)

When a particle falls through a viscous medium accelerating under the influence of the act of gravitational field it will attain a constant settling velocity after a certain period of time when the drag force exerted on it by the liquid balances the force due to gravity. This velocity is called terminal velocity.

Factors that influence sedimentation under gravity are:

- Wall interference
- Particle interaction
- Viscosity of the medium that particles are passing through
- Particle density and sizes

1.1.2 Stokes Equation

This equation gives a fundamental relationship for streamline settling velocity of spherical particles of mean diameter d.

$$TSV(Vt) = d^2(\rho_p - \rho_l)g/18\mu$$

where; TSV is the sedimentation velocity of every particle

d(m) is particle diameter

$\rho_{p\ (kg/m^3)}$ is particle density

$\rho_l\ (kg/m^3)$ is density of liquid

The larger the particle diameter the greater the TSV
The larger the density difference between the particle and the fluid the greater the TSV
The thinner the liquid (less viscous) the greater the TSV

However, the rate of separation is slow and may not be ideal in the food industry.

1.2 Centrifugation

This is a unit operation involving the separation of materials by the application of a centrifugal force.

The main areas of application of centrifugation in the food industry are:

i) Separation of immiscible liquids i.e. milk and cream, oil and water

ii) Centrifugal clarification – used for removal of small quantities of solids from liquids. The solids should be below 5%.

iii) Desludging – solids should be greater than 5%

Centrifugal force is generated when materials are rotated and the size of the force is dependant on the radius and speed of rotation and the density of the centrifuged material. When immiscible liquids are being separated the denser liquid moves to the bowl wall and the lighter liquid is displaced to an inner annulus.

1.2.1 Rate of separation

The centrifugal force (Fc) acting on an object of mass m rotating on a circular path of radius r at an angular velocity ω is expressed as:

$Fc = mr\omega^2$

For a fixed speed of rotation the Fc is not constant but changes with the radius from the axis of rotation.

Consider a particle suspended in a liquid retained in a container spinning about its own axis. At a given distance r the centrifugal terminal settling velocity can be expressed as;

$v = d^2(\rho_p – \rho_l)r\omega^2 /18\mu$

where; v is the sedimentation velocity of every particle in the centrifuge

d(m) is particle diameter

ρ_p (kg/m^3) is particle density

ρ_l (kg/m^3) is density of liquid

μ (kg/m, s) is viscosity of fluid medium

r (m) distance of particle from axis of rotation

ω (rad/s) angular velocity

1.2.2 Equipment

There are three groups of centrifuges:

- separation of immiscible liquids (liquid-liquid centrifuges)
- clarification of liquids by removal of small amounts of solids (centrifugal clarifiers)
- removal of solids(desludging or dewatering centrifuges)

1.2. 3 Clarification and cream separation

Centrifugal separation is common in the dairy industry. It is used for:

- clarification – removal of solid impurities from milk prior to pasteurisation
- skimming – separation of cream from skim milk
- whey separation – separation of fat from whey
- bactofuge
- treatment –separation of bacteria from milk
- quarg separation – separation of quarg curd from whey
- butter oil purification – separation of serum phase from a anhydrous milk fat

Chapter 2

MEMBRANE CONCENTRATION (HYPERFILTRATION AND ULTRAFILTRATION)

Reverse osmosis (RO) (or hyperfiltration) and ultrafiltration (UF) are unit operations in which water and some solutes are selectively removed through a semi-permeable membrane. In both cases the driving force is the pressure applied to the feed liquid.

Reverse osmosis is used to separate water from low molecular-weight solutes e.g. salts and monosaccharides which have a high osmotic pressure. A high pressure 5 to 10 times that used in UF is necessary to overcome this (hence reverse osmosis). Reverse osmosis is used to:

- concentrate whey from cheese manufacture, either as a pre-concentration prior to drying for use in the manufacture of ice cream
- concentrate and purify fruit juices, enzymes, fermentation liquors and vegetable oils
- concentrate wheat starch, citric acid, egg white, milk, coffee, syrups, natural extracts and flavours
- to clarify wine and beer
- demineralise and purify water from boreholes or rivers

2.1 Advantages

Concentrating fluids by removal of water at low temperatures in the dairy and fruit juice industry competes with vacuum evaporation and freeze concentration. Membrane concentration has the following advantages over concentration by evaporation:

- negligible loss of volatiles or change to nutritional or eating quality since the food is not heated
- no change in phase in contrast with boiling in evaporators and therefore energy is used more efficiently
- simple installation with lower labour and operating costs
- no need for steam boilers

2.2 Limitations

Membrane concentration has the following limitations:

- variation in product flow rate when changes occur in the concentration of feed liquor
- higher capital costs than evaporation
- maximum concentration to 30% total solids
- fouling of membranes which reduces the operating time between membrane cleaning

Membranes reject solutes with specific ranges of molecular weight. Molecular weight cut-off points are used to characterise membranes. Cut-off points of RO membranes range from molecular weights of 100 Da at 4000 – 7000 kPa to 500 Da at 2500 – 4000 kPa.

UF membranes have a higher porosity and retain only large molecules e.g proteins which have a lower osmotic pressure. Smaller solutes are passed across the membrane with the water. Ultrafiltration therefore operates at lower pressure (50 – 1000 kPa) Applications of UF are:

- concentrate milk prior to the manufacture of dairy products
- concentrate whey to 20% solids
- removal of lactose and salts
- concentration of sucrose and tomato paste
- separation and concentration of enzymes, other proteins or pectin
- removal of protein hazes from honey and syrups
- treatment of process water to remove bacteria and contaminants(greater than 0.003 micrometres in diameter)
- pre-treatment for reverse osmosis membranes to prevent fouling by suspended organic materials and colloidal materials

Microfiltration (MF) is similar to UF in using lower pressures than RO but is distinguished by the larger range of particle sizes that are separated (0.01 – 2 μm). UF is used to separate macromolecules whereas MF separates dispersed particles such as colloids, fat globules or cells. MF falls between UF and conventional filtration.

Chapter 3

HOMOGENISATION

The tendency of milk fat to sediment upwards in milk and form a creamline on the surface is an undesirable property in the manufacture of certain dairy products e.g. chocolate milk, coffee cream and sterile milk. Homogenisation prevents sedimentation of fat.

Homogenisation means fat globules are subjected to mechanical treatment which breaks them down into smaller globules uniformly dispersed in the milk. The mean diameter of the fat globules is reduced by a factor of 10 in this treatment. The sedimentation velocity of the small fat particles is extremely low, so the homogenised milk is stable.

Homogenisation may either be total or partial. In total homogenisation, the whole body of the milk is processed and since the fat content is low in this case there is no coalescence of fat and the resulting product shows little or no tendency of creamlining. Only the cream fraction is treated in partial homogenisation. In this case the fat content is high, so the globules coalesce.

Advantages of homogenisation:

- Uniform distribution of fat, no creamline
- Whiter, more appetising colour
- Faster coagulation in the manufacture of rennet cheese
- Reduced sensitivity to oxidation
- More full-bodied flavour

Disadvantages of homogenisation:

- The milk cannot be effectively separated
- Sensitivity to light-it quickly gets a corrosive, metallic taste
- Sensitivity to lipase attack
- Low thermal stability of proteins

3.1 The Homogeniser

Principal components of a homogeniser are a high-pressure pump and a back pressure device, the homogeniser head. The pump is driven by a powerful electric motor through a crankshaft and connecting rod transmission which converts the rotary motion of the motor into the reciprocating motion of the pump pistons.

The pistons run in cylinders bored in a high-pressure block. Piston rings are provided to prevent oil from leaking into the product. Water can be supplied to the space between rings to cool the pistons. Steam or condensate can also be supplied to prevent reinfection in aseptic processing, i.e. when the homogeniser is treating sterile milk.

3.1.1 The homogeniser head

The pump boosts the pressure of the milk from about 80 – 220 kPa at the inlet to the homogenising pressure of between 10 000 and 20 000 kPa depending on the product. The homogenisation pressure is set with a lever and the set pressure can be read off from high-pressure manometer.

The milk is fed at high pressure into the space between the outer ring and the core. In the fine gap the high pressure is converted into kinetic energy, so that the milk attains a very high velocity (200 – 300 m/s) in the narrow, ring-shaped gap. On leaving the gap, the milk impacts at high velocity on the inside of the homogeniser ring and is forced to change direction.

The resulting homogenising effect is produced by three collaborating factors:

- Passage through the narrow gap in the homogeniser head at high velocity subjects the fat globules to very powerful shearing forces, which deform, elongate and shatter the spherical globules.
- The acceleration of the liquid in the gap is accompanied by a pressure drop, possibly to below the vapour pressure of fat. This creates cavitation phenomena, in which the globules are subjected to very implosive forces.
- Further shattering takes place when the fat globules impact in the homogeniser ring at high velocity.

The effect can be enhanced by two-stage homogenisation, with two homogeniser heads in tandem. The back pressure from the second stage to the first can be adjusted to produce the desired total degree of homogenisation.

Chapter 4

PASTEURISATION

Pasteurisation is a relatively mild heat treatment, in which food is heated to below 100°C. The primary purpose of heat treatment is to kill all micro-organisms capable of causing disease in human beings. Pasteurised milk must be free from pathogens. The secondary purpose of pasteurisation is to destroy as much as possible micro-organisms which may spoil the taste and shelf life to safeguard product quality. This requires more intensive heat treatment than is necessary to kill the pathogenic bacteria. Minimal changes are caused to the sensory characteristics or nutritive value of the food.

4.1 Limiting factors of heat treatment

Intensive heat treatment has adverse effect on the appearance, taste and nutritional value of the milk. High temperatures denature proteins in milk and harsh heating changes taste, first cooked flavour and then burnt flavour. Time and temperature combination must be optimised so that both microbiological effects and quality aspects are taken into account.

4.2 Time and temperature combination

Heat treatment entails heating the milk to a certain temperature and holding it at that temperature for certain period of time before it is cooled again to ensure destruction of all pathogenic micro-organisms.

The combination of temperature and holding time is very important because it determines the intensity of the heat treatment. The figure below shows the lethal effect curves for coli bacteria and tubercle bacilli. These curves show that coli bacteria are killed if milk is heated to 70 °C and held at that temperature for one second, while at a temperature of 65°C it takes a hold of 10 seconds to kill coli bacteria. These two combinations have the same lethal effect.

Tubercle bacilli are more resistant to heat treatment than coli bacteria. It takes a hold of 20 seconds at 70 °C or about 2 minutes at 65 °C to ensure that they are all destroyed.

4.3 HTST Pasteurisation

HTST stands for high temperature short time. The actual time and temperature combination varies with the type of product treated.

The HTST process for milk involves heating to 72 - 75°C with a 15 second hold before it is cooled again. The enzyme phosphatase, which is present in the milk, is destroyed by this time and temperature combination. The phosphatase test is used to check that the milk has been properly pasteurised. The test result must be negative, that is there must be no detectable phosphatise activity.

Cream and cultured milk products are pasteurised by heating to a temperature above 80°C with a hold of 3 – 5 seconds. This is more intensive than the treatment used for milk and is sufficient to inactivate the enzyme peroxidise. The peroxidise test is used to check the results of pasteurising cream and cultured products. The test result must be negative, i.e. there must no detectable peroxidise activity in the product.

4.4 UHT Treatment

UHT stands for ultra-high temperature and the technique is also known as ultra-pasteurisation. The milk is heated in two stages, first to 75 °C and then under pressure to about 140 °C for 4 s. After this the milk is quickly cooled and packed under aseptic conditions.

The intensity of the UHT treatment is sufficient to destroy practically all heat resistant bacterial spores. UHT-treated milk can therefore keep for a very long time.

4.5 Pasteurisation of packaged foods

Some liquid foods are heat treated in containers. Hot water is usually used if the food is in glass, to reduce the risk of thermal shock to the container. Maximum temperature difference between the container and water is 20°C for heating and 10°C for cooling. Metal or plastic containers are heat treated using steam-air mixtures or hot water as there is little risk of thermal shock. Hot water pasteurisers may be batch or continuous in operation. Batch equipment consists of a water bath in which crates of packaged food are heated to a pre-set temperature and held for the required length of time. Cold water is then pumped in to cool the product.

Continuous equipment consists of a long narrow trough fitted with a conveyor belt to carry containers through heating and cooling stages.

A second design consists of a tunnel divided into a number of heating zones. Very fine water sprays heat the containers as they pass through each zone on a conveyor, to give incremental rises in temperature until pasteurisation is achieved. Water sprays then cool the containers as they continue through the tunnel. Energy and water can be saved by re-circulating water between pre-heat sprays, where it is cooled by incoming food and cooling zones where it is heated by the hot products.

4.6 Pasteurisation of unpackaged liquids

Open boiling pans are used for small-scale batch pasteurisation of some liquid foods. Large scale pasteurisation of low viscosity liquids (e.g. milk, milk products, and fruit juices) usually employs plate heat exchangers. Food is pumped from a balance tank to a regeneration section, where it is preheated by food which has already been pasteurised. It is then heated to pasteurising temperature in a heating section and held for the time required to achieve pasteurisation in a holding tube. If the pasteurisation temperature is not reached, a flow diversion valve automatically returns the food to the balance tank to be re-pasteurised. The pasteurised product is then cooled in the regeneration section and then further cooled by cold water and if necessary chilled water in a cooling section. The regeneration of heat leads to substantial savings in energy and up to 97% of the heat can be recovered.

Advantages of heat exchangers over in-bottle processing include:

- More uniform heating
- Simpler equipment and lower maintenance costs
- Lower space requirements and labour costs
- Greater flexibility for different products
- Greater control over pasteurisation conditions

Chapter 5

STERILISATION

Sterilisation means subjecting a product to powerful heat treatment at a sufficiently high temperature and for a sufficiently long time to destroy microbial and enzyme activity. Sterilised products have excellent keeping properties and can be stored for long periods at relatively high temperatures. Sterilised foods have a shelf life in excess of six months at ambient temperatures. Common sterilised dairy products are milk, coffee cream, ice cream mixes and chocolate flavoured milk.

5.1 Methods of treatment

Three alternative methods can be used to sterilise milk: one-stage, two-stage or continuous sterilisation.

5.1.1 One-stage sterilisation

The milk is preheated to about 80 °C and then filled into clean, heated bottles. The bottles are capped, placed in an autoclave and sterilised at 110 – 120 °C for 10 – 40 minutes.

5.1.2 Two-stage sterilisation

The milk is pre-sterilised at 130 – 140 °C for 2 to 20 seconds. This treatment can take place in a shell-and –tube or plate heat exchanger by indirect heating or direct steam injection into the milk. After being cooled to about 80 °C, the milk is filled into clean heated bottles which are capped, placed in an autoclave and sterilised. This last stage of treatment is not quite so intense as in one-stage sterilisation. Its main purpose is to eliminate the risk of re-infection after the first stage.

5.1.3 Continuous sterilisation

The milk is treated either ready-bottled in continuously working autoclaves or in a closed continuous process line under aseptic conditions. Sterilisation in a continuous autoclave can take place in either one or two stages. The milk bottles are conveyed slowly through successive heating and cooling zones in an autoclave. These zones are dimensioned to correspond to the required temperatures and dwell times in the various stages of heat treatment.

Closed piping systems are now being used in modern continuous sterilisation processes. The milk is preheated, sterilised, homogenised, cooled and packed. Sterilisation takes place at 140 – 150 °C for 2-5 s, either by indirect heating or direct steam injection. All parts of the system down stream of the actual sterilising section are of aseptic design; this eliminates the risk of re-infection and therefore the need for after-sterilisation.

Sterilisation in a process line of this type is generally known as UHT (Ultra-high temperature) treatment. By international definition UHT milk is milk that has been sterilised at a temperature of at least 130 °C for a period of one second or more in a continuous flow and then packed under aseptic conditions.

Chapter 6

EVAPORATION

Evaporation is the partial removal of water from liquid foods by boiling off water vapour. The evaporation process involves simultaneous heat and mass transfer. Evaporation preserves food by reduction in water activity, pre-concentrates foods (e.g. fruit juice, milk, coffee) prior to drying freezing or sterilisation hence weight and volume, saves energy in subsequent operations, and reduces storage, transport and distribution costs. In the dairy industry evaporation is used to concentrate products such as skim milk, whey and milk for condensation.

The operation is conducted at the boiling point of the solution and where the solution is heat sensitive the boiling point is lowered by reducing the operation pressure.

The rate of evaporation is determined by the rate of heat transfer into the food and the rate of mass transfer of vapour from the food.

6.1 Heat and mass balances

The degree of concentration, energy use and processing times are calculated from heat and mass balances.

6.1.1 Mass balance

i) Overall Mass balance

Mf = Mp + Mv

Where;
Mf = mass flow rate of feed
Mp = mass flow rate of product
Mv = evaporative capacity

ii) Solids balance

XfMf= XpMp

Where;
Xf = solid fraction in the feed
Xp = solid fraction in the product

iii) Liquid balance

Mf (1-Xf) = Mp (1-Xp) + Mv

6.1.2 Heat Balance

Assuming negligible heat losses from the evaporator

$$Q = M_s\lambda_s = M_fC_p (T_b - T_f) + M_v\lambda_v$$

Where
C = specific heat capacity of the feed
Λs = latent heat of condensing steam
λv = latent heat of vaporisation of water
T is temperature.

This implies:
Heat supplied by steam = sensible heat + latent heat of vaporisation.

In sizing the heat exchanger to support the necessary overall rate of heat transfer the following equation applies:

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

Where
Q = heat transfer rate
U = overall heat transfer coefficient.

6.2 The Evaporator

An evaporator consists of a heat exchanger to maintain the liquid food at the boiling point and component for continuous removal vapour.

The most common type of evaporator in the dairy industry is the falling film evaporator, see fig. The tubes are vertical and the product forms a thin film on the inside of the tubes while the steam surrounds them. Evaporation in this type of evaporator takes place as follows.

The product is preheated at a slight pressure to a temperature somewhat above the temperature of generation in the evaporator. From the preheater the product is led into the upper section of the evaporator, see fig.

By means of a specially shaped nozzle, the product is distributed over a spreader plate. Since the product is somewhat superheated, it expands as soon as it leaves the nozzle, whereupon part of the water is immediately vaporised. The steam formed presses the product outwards against the inside of tubes in a thin film that runs down along the walls of the tubes. The water content of the film evaporates rapidly as the product passes through the tubes. A steam separator is fitted under the evaporator to separate the steam from the concentrated product.

The dwell time in the evaporator is very short, about 1 minute, as only a small amount of the product is treated at the same time. This is of great importance for the concentration of dairy products which are sensitive to heat treatment.

6.3 Heat Conservation in Evaporator Systems

6.3.1 Vapour recompression

Mechanically compressing vapour from the evaporator increases pressure and the resulting high pressure steam is returned to the calandria and reused as a heating medium. Increase in pressure causes an increase in condensing temperature of the steam

6.3.2 Feed pre-heating

This involves the use of hot vapours exhausted to heat the incoming feed liquor or condensed vapour is used to raise steam in a boiler.

6.3.3 Multiple-Effect Evaporation

Vapour removed from an evaporator contains heat and this heat is wasted if the vapour is discarded. The reuse of this heat reduces the operating cost of the plant.

If an evaporator is fed with steam at 399 K with a total heat of 2714 kJ/kg and it is evaporating water at 373 K, the total heat contained by the vapour produced is 2675 kJ/kg. Condensing this vapour results in great wastage of heat and makes very poor use of steam. The vapour produced can be passed to the calandria of a similar evaporator provided $T_2 < T_1$ so that an adequate temperature difference is maintained. The boiling temperature of liquor in the second effect (T2) can be reduced by applying a vacuum.

If two evaporators are connected in series the second of them can operate at a greater vacuum (and thus a lower boiling temperature) than the first. The steam generated from the product in the first effect can be used as the heating medium in the second effect which works at a higher vacuum (lower temperature). Thus for a primary steam input of 1.2 kg, 2kg of water can be evaporated from the product , even taking into account heat losses.

Similarly it is possible to connect three or four evaporators in series. Although this improves the steam economy, the equipment becomes more expensive and more complicated to run. Evaporators with up to seven effects are being used in the dairy industry.

6.3.3.1 Tripple Effect Evaporator

Let the temperatures and pressures in each effect be - T_1, T_2, T_3 and P_1, P_2, P_3 respectively.

The heat transmitted per unit time across each effect is:

Effect1 $Q_1 = U_1A_1\Delta T_1$ where $\Delta T_1 = (Ts - T_1)$
Effect1 $Q_2 = U_2A_2\Delta T_2$ where $\Delta T_2 = (T_1 - T_2)$
Effect1 $Q_3 = U_3A_3\Delta T_3$ where $\Delta T_3 = (T_2 - T_3)$

Assuming the heat required to heat the feed from T_f to T_1 to be negligible, Q_1 transferred across A_1 appears as latent heat in the vapour V_1 and is used as steam in the second effect, therefore

$$Q_1 = Q_2 = Q_3$$

$U_1A_1\Delta T_1 = U_2A_2\Delta T_2 = U_3A_3\Delta T_3$

If $A_1 = A_2 = A_3$ then

$U_1\Delta T_1 = U_2\Delta T_2 = U_3\Delta T_3$

6.3.3.2 Specific steam consumption (s.s.c)

Definition

$$S.S.C = \frac{\text{amount of steam used for heating}}{\text{Amount of water evaporated}}$$

The latent heat required to evaporate 1 kg of water in 1, is approximately equal to the heat obtained in condensing 1 kg of steam at Ts. Thus 1 kg of steam fed to 1 evaporates 1 kg of water in 1 and 1 kg of steam from 1 evaporates about 1 kg of steam in 2. Therefore for a single, double, triple, quadruple effect evaporator s.s.c = 1, 0.5, 0.33, 0.25 respectively.

6.4 Comparison of Forward Feed and Backward Feed Evaporators

6.4.1 Forward Feed Evaporator

In the food industry and in biotechnology a forward feed system is commonly used. In this system the product or feed enters the first effect at the highest temperature. The product, partially concentrated in the 1st effect, is fed to the second effect which has a lower temperature. In this way, the medium flows through the evaporator with increasing concentration and decreasing temperature, using the vapour of each effect as the heating medium for the next effect. The combination of lowest temperature and highest viscosity in the subsequent effects is beneficial to heat sensitive products such as enzymes and proteins.

6.4.2 Backward Feed Evaporator

The diluted product is fed to the last effect, which is at the lowest evaporation temperature and then transferred through successive effects to the 1st. The steam and vapour travel still in the direction 1, 2, 3. The concentrate is collected from the first effect, which is at the highest temperature. The backward feed system has the advantage that the concentrated product evaporates in the first effect at the highest temperature but lowest viscosity (because of the high temperature) which improves the heat transfer considerably.

6.5 Types of Evaporators

There are many different types of evaporators. These are a) natural circulation evaporators, b) Falling film evaporators and c) plate evaporators.

6.5.1 Natural circulation evaporator

-based on natural circulation of the product, which is caused by difference in density generated by heating. The liquid to be evaporated boils in the vertical tubes. The rising bubbles cause circulation of the liquid, thus facilitating the separation of liquid and vapour at the top of the heating tubes. The remaining liquid recirculates to the evaporation section so that only part of the total evaporation occurs in one pass. A pump may be installed in the circulation channel inorder to attain sufficient circulation. Running the evaporator under pressure (by use of pump) suppresses bubble formation which causes heavy fouling.

Advantages

- relatively cheap, easy to operate and therefore frequently applied
- good heat transfer at high temperature differences

Disadvantages

- Has poorly defined residence time, high steam consumption

6.5.2 Falling Film Evaporator

Consists of a large number of long tubes (3-15m length) surrounded by a steam jacket. The liquid product enters the tubes at the top and distributes itself over the heating surfaces as a thin film.

As the liquid flows downwards, its linear velocity increases considerably (up to 200 m/s at the end of 12m tubes. This is caused by the vapour evolved from the liquid, flowing in the same direction. Due to this mechanism falling film evaporators are well suited for concentrating viscous products or those that are very heat sensitive. Heat sensitive (enzymes) solutions, as well as clear forming, or corrosive products can be treated, even at low pressures. The residence times are very short (typically 5-30s)

6.5.3 Plate evaporators

Differ from other types of evaporators in having a relatively large evaporation surface in a small volume. Metal plates are supported by a frame.

During the evaporation process, the steam flows through the channels formed by the free space between the two plates. It alternately climbs and falls parallel to the concentrate in co-current or counter current mode. The concentrate and vapour are fed to a liquid/vapour separator which is outside the evaporator. Plate evaporators are frequently applied in the dairy and fermentation industry because of their small construction volume and flexibility. Despite the high capital investment, this type of evaporator has very high rates of heat transfer, short residence times and high energy efficiencies. It is compact, capable of high throughputs and easily dismantled for maintenance and inspection. More suitable for heat sensitive foods of high viscosity (0.3-0.4 Ns/m2

Chapter 7

HEAT EXCHANGE

7.1 Principles of heat transfer

Heating and cooling of products and apparatus are widely applied in the food industry. Heat exchangers contain a flowing medium that is used to remove or add heat while the product also flows through the heat exchanger. The flow can be laminar or turbulent on both sides. However, the non-product side is usually operated under turbulent conditions because this provides a larger heat transfer coefficient.

Heating and cooling are very common unit operations in the dairy industry. Milk is heated by means of a heat transfer medium such as low pressure steam or hot water. Milk is cooled by a cooling medium which may be cold water, ice water, brine solution or an alcohol solution such as glycol, depending on desired temperature after cooling. In this case heat is transferred from the milk to the cooling medium.

7.2 Regenerative heating and cooling

To save heating and refrigeration energy, the heat content of pasteurised milk is used to warm the cold milk. This process takes place in a heat exchanger and is called regenerative heat exchange. In practical operating conditions as much as 94% of the heat content of the pasteurised milk can be recycled in this way. The incoming milk is regeneratively heated from say, 4 °C to 68 °C, heated with hot water from 68 to 73 °C, held at that temperature for the required number of seconds, then cooled regeneratively from 73 °C to 9 °C and finally chilled with ice water from 9 to 4 °C.

This implies that the result of regenerative heat exchange is that heating and refrigeration calories are supplied for the final heating step (68 to 73 °C) and the final chilling step (9 to 4 °C). This saves a great deal of energy.

7.3 The heat exchanger

A heat exchanger is an apparatus used to transfer heat by the indirect method. Factors that influence heat transfer in a heat exchanger can be divided into three main categories:

1. External process data (specific heats of milk and heating or cooling medium, flow rates, temperature difference of milk and heating or cooling medium)

2. Design of the heat exchanger

The amount of heat transfer can be calculated by the formula $Q = U\ A\ \Delta t_m$

Q = amount of heat transferred
U = overall heat transfer coefficient

A = heat transfer area between media
Δtm = mean differential temperature

3. Physical properties of the product and the heating or cooling medium

7.4 Basic Equations and Engineering Calculations

7.4.1 Countercurrent flow heat exchanger

Fig. 2 shows a scheme of a countercurrent flow heat exchanger. The two flows are separated by a wall. In this section the equations will be derived to calculate the temperature profiles in the heat exchanger. For the heat flux Q" ($J.m^{-2}. s^{-1}$) between the two media, the following equation is valid.

$Q" = U (T_1 – T_2)$, where

$1/U = (1/\alpha_1 + d_w/\lambda_w + 1/\alpha_2)$ $(J^{-1}m^2 s K)$

In which:

U = overall heat transfer coefficient
$_{Dw}$ = wall thickness
α_1 = heat transfer coefficient on side 1
α_2 = heat transfer coefficient on side 2
λ_w = heat conductivity of the wall
T_1 = temperature side 1 of the wall
T_2 = temperature side 2 of the wall

The following assumptions have been made:

- The value of U is constant along the heat exchanger
- The heat capacity and density of the two media are independent of the temperature
- There are no phase transitions
- Heat losses to the surroundings are negligible
- The wall thickness is assumed to be small and the inner and outer surface can be assumed to be the same.

$Q = UA_t (T_1\text{-}T_2) \ln$ $(J.s^{-1})$

In which $(T_1\text{-}T_2) \ln$ is the logarithmic average temperature difference given by:

$(T_1\text{-}T_2) \ln = [(T_{1i} – T_{2o}) – (T_{1o}\text{-}T_{2i})]/ \ln \{(T_{1i} – T_{2o})/ (T_{1o} – T_{2i})\}$ [K]

The logarithmic average temperature difference is a measure of the average temperature difference in the heat exchanger. It is a rather complicated formular because the temperature difference is not the same for all positions for most cases. These two equations give the basis for heat exchanger design.

7.4.2 Cocurrent type heat exchanger

The equations for heat transfer can be derived in a way analogous to the countercurrent type.

The equations become;

$$Q = U\, A_t\, (T_1 - T_2)\ln$$

With the logarithmic average temperature difference for this type being:

$$(T_1 - T_2)\ln = [(T_{1o} - T_{2o}) - (T_{1i} - T_{2i})] / \ln\{(T_{1o} - T_{2o})/(T_{1i} - T_{2i})\} \quad [K]$$

Countercurrent flow is the most efficient flow and this design is usually selected. However, other criteria have to be met such as large surface area per apparatus. Frequently this leads to a series of pipes in one apparatus. It may be favourable to to use a larger number of smaller diameter pipes because this increases the surface area and the larger flow velocity increases the heat transfer coefficient.

7.5 Heat Transfer Coefficient Calculations

The total heat transfer coefficient is a function of the resistance of the two media and the wall. In heat transfer operations a fouling layer can build up on the wall, particularly with food products and high temperatures. Components in the food product can react or degrade and deposit on the wall. The rate of deposition is also determined by the liquid flow velocities and material properties of the heat exchanger. These fouling layers can contribute significantly to heat transfer resistance.

Values for the heat conductivity of the wall can be found in data books. Thickness and composition of the fouling layers are unknown. Therefore the heat conductivity of these layers must be determined experimentally or estimated by common sense.

The literature gives relations to determine the liquid side heat transfer coefficients. For forced convection in circular pipes the following relation is valid at Re > 10 000:

$$Nu = 0.023 Re^{0.8}\, Pr^{0.33} \{\eta/\eta_w\}^{0.14}$$

In which:

Nu =Nusselt number = $\alpha d\, \lambda^{-1}$
Pr = Prandtl number = $\eta C p \lambda^{-1}$
$Re = \rho D\, v/\mu$
D = pipe diameter
η = medium viscosity at average temperature
η_w = medium viscosity at wall temperature

7.6 Types of heat exchangers

Heat exchangers of many different designs are found in the dairy industry. Examples are plate, spiral, lamella and shell-and-tube heat exchangers and the plate heat exchanger is most commonly used for heating dairy products.

7.6.1 Shell-and-tube heat exchangers

Its heat transfer surface consists of a number of tubes through which the product flows. The heating medium flows through the space inside the shell and outside the tubes

7.6.2 Lamella heat exchangers

It is usually a variant of the shell-and –tube heat exchanger in which the round tubes are replaced by flat lamella (fib.). The lamellae are profiled steel plates welded together to form closed channels for the product with space for the heating medium to flow in between. The lamella bundle is placed inside a cylindrical shell. The product is introduced at one end of the cylinder, flows through the lamellae and leaves at the other end. A lamella heat exchanger can be arranged with the heating medium in concurrent or counter current flow

7.6.3 Plate heat exchangers

The plate heat exchanger (PHE) is used to heat treat almost all dairy products. It consists of a pack of stainless steel plates clamped in a frame. The frame has sections in which different stages of treatment such as pre-heating, final heating, holding and cooling take place. The heating medium may be vacuum steam or hot water and the cooling medium may be cold water, ice water or brine depending on the desired product outlet temperature.

The product is introduced through a corner hole into the first channel of the section and flows vertically through the channel. It leaves at the other end through a separately gasketed corner passage which conducts it past the next channel into the channel after that. The arrangement of the corner passages is such that the product flows through alternate channels in the plate pack. The heating or cooling medium is introduced at the other end of the section and passes in the same way through alternate interpolate channels. Each product channel thus has channels for heating or cooling medium on both sides of it. The system of alternating product and heating/cooling medium channels is illustrated schematically in fig.

Chapter 8

DEHYDRATION

This is the application of heat under controlled conditions to remove the majority of water present by evaporation or by sublimation in the case of freeze drying.

The water in the liquid product (milk) is removed so that the product acquires a solid form. The water content of the milk powder ranges from 2.5 to 4 %. No bacterial growth occurs at this low water content. The main purpose of dehydration is to extend the shelf life of foods by reducing the water activity. Reduction in weight and volume lowers the cost of transport and storage of product.

The design and operation of the dehydration equipment aim to minimise changes to the eating quality and nutritional value of the food. This is achieved by selection of appropriate drying conditions for individual foods.

Skim milk powder has a shelf life of about three years whilst whole milk powder has shelf life of about 6 months. Fat in whole milk powder is oxidised during storage and the consequent gradual deterioration in taste will eventually render the powder unfit for human consumption.

Commercial methods of drying are based on heat being supplied to the product. The water is then evaporated and is removed as steam. The residue is the milk powder. Roll drying and spray drying are the two principal methods used for drying in the dairy industry.

8.1 Categories of drying

There are four categories of drying operations in the food industry.

- Air drying under atmospheric pressure
- Contact drying under atmospheric pressure
- Vacuum drying
- Freeze drying

8.1.1 Drum drying

A drum drier consists of a slowly revolving internally heated steel drum on which a film of solids are deposited and dried. Pressurised steam is used to heat the drum to 120 - 170°C. Drying is achieved by direct contact heating. This technique is used to dry liquids and dilute slurry feeds.

A thin layer of food (milk) is distributed uniformly onto rotating, steam heated rolls by dipping, spraying or spreading. On coming into contact with the hot roll surface, the water in the milk is evaporated and removed by a flow of air.Before the drum has completed one revolution(within 20s -3min) the dried food is scraped off by a doctor blade which contacts the drum surface uniformly along its length. The high temperature of the heating surfaces causes protein to be converted to a form which is not easily soluble and causes brown discolouration of the product. Roll drying is therefore not used for producing powder satisfying strict demands on solubility, appearance, taste and aroma.

However, intense heat treatment increases the water-binding properties of the powder and this characteristic is useful in the fields such as the precooked foods industry.

Driers may have a single drum, double drums or twin drums. Single drum driers are widely used as they have greater flexibility, larger proportion of the drum area is available for drying, and there is easier access for maintenance and no risk of metal objects falling between the drums.

Drum driers have high drying rates and high energy efficiencies and are suitable for slurries in which particles are too large for spray drying.

8.1.1.1Advantages of drum driers

It is not necessary to heat large volumes of air before drying begins and the thermal efficiency is therefore higher

Drying may be done in the absence of oxygen to protect food components that can easily be oxidised.

8.1.1.2 Limitations of drum driers

They can only be used to dry liquids of foods in slurry form

They are operated atmospheric pressure in most cases so the boiling temperature is above 100°C and this causes heat damage to the product. However, the problem can be overcome by use of vacuum drum driers.

8.1.2 Spray drying

Spray drying is carried out in two stages. The pre-treated milk is first concentrated by evaporation to a DS content of 45 – 55%. The concentrate is then fed into a drying tower for final drying and this process occurs in three stages:

- dispersion of the concentrate into very fine droplets
- mixing of the finely-dispersed concentrate into a stream of hot air (150 - 300°C) which quickly evaporates the water
- separation of the dry milk particles from the drying air

Evaporation is a necessary production stage for high quality powder. If prior concentration is not done, the powder particles will be very small and will have high air content, poor wettability and a short shelf life. Furthermore, this process becomes uneconomical.

Falling-film evaporators are used for concentration and this is carried out in two or more stages to a DS content of 45 – 55%.

8.1.2.1 Design of the spray drier

A spray drying plant consists of the following components and systems:

- a unit designed for supplying large quantities of hot air
- a milk atomiser
- a mixing chamber in which hot air is intimately mixed with the milk droplets
- a drying chamber
- powder discharge equipment
- a system in which the milk particles are effectively separated from the drying air
- a powder conveying and cooling system
- packaging equipment.

A high-pressure pump is used to pump milk into the tower and the milk is directed into the milk atomiser. The design of the atomising equipment depends on the particle size and thus properties required of the dried product. Stationary nozzles or rotating disc atomisers can be used. Very small milk droplets are sprayed into the mixing chamber, where they are mixed with the hot air.

A fan is used to draw air through a filter and is delivered through a heater, where the air temperature is raised to 150 -250 ˚C. Heating reduces the relative humidity of the air and thus improves its capacity to absorb water from milk.

The atomised milk is intimately mixed in the mixing chamber with hot air and water is evaporated from the milk. Heat applied to the milk powder is very modest since the heat of the hot air is continually consumed in evaporating water.

The milk powder produced settles in the drying chamber and is discharged at the bottom. Cooling air is used to convey the powder to the packaging section. The cooling air is drawn by a fan. After cooling powder and cooling air flow into a battery of cyclones, where the powder is separated out the air before packaging.

Rapid drying (1-10s) takes place because of the very large surface area of the droplets. The feed rate is controlled to produce an outlet air temperature of 90 - 100°C, which corresponds to a wet bulb temperature of 40 - 50°C hence little heat damage to food .

8.1.2.2 Advantages

- rapid drying
- large scale continuous production
- low labour costs
- relatively simple operation and maintenance

8.1.2.3 Limitations

- high capital costs

- requirement for a relatively high –feed moisture content so that food can be pumped to the atomiser(this results in higher energy costs to remove moisture and higher volatile losses.

8.1.3 Heat balances

Heat in = Heat out

Heat losses due to radiation are ignored in our calculations.

Heat in

weight of air in x Ca(Tai – Td)
weight of air in x Ha x Cv (Tai –Td)
Ha =mass of water vapour/mass of drying air
weight of solids in the feed x Cs (Tf –Td)
weight of water in the feed xCw(Tf-Td)

Assume no losses in solids i.e. all that goes in comes out

Heat out

weight of dry air in x Ca(Tao-Td)
weight of dry air in x Ha x Cv (Tao-Td)
weight of water evaporated[Cw(Te-Td)+Le + Cv(Tao-Te)]
Le = Latent heat of evaporation
Te = temperature at which water is evaporating
weight of water in the product x Cw (Tp-Td)
weight of solids in the product x Cs (Tp-Td)
heat losses due to radiation

Chapter 9

REFRIGERATION

This is a heat transfer operation using various refrigerants to effect cooling. Reduction in temperature of foods slows the biochemical and microbiological changes that would otherwise take place during storage and hence extend shelf life of fresh and processed foods. Preservation by lowering temperature of foods has important benefits in maintaining their sensory characteristics and nutritional value to produce high quality products.

9.1 The principles of refrigeration

The cooling process is in the form of a closed circuit in which the refrigerant is changed by reducing its pressure (expansion) and by increasing its pressure (compression) respectively from it's gaseous to its liquid form. The main components of the cooling plant are

- The evaporator
- The compressor
- The condenser
- The throttling valve

The surface of the refrigerant is under low pressure in the evaporator. Heat from the surrounding space is absorbed by the refrigerant, which causes part of the refrigerant to vaporise continuously. The vapour is continuously extracted from the evaporator by the compressor. Thus the pressure at the surface of the refrigerant and also its vaporisation temperature are maintained at a constant level.

The vaporised refrigerant is compressed to a higher pressure in the compressor. The hot refrigerant gas is then forced from the compressor to the condenser for cooling. The vaporisation temperature and condensation temperature will both be increased as a result of the pressure of the refrigerant vapour having been increased by the compressor. Where ammonia is used, for example, the operating vaporisation temperature is about -20 °C, which corresponds to a vaporisation pressure of 200 kPa.

The pressure of the gas is raised to about 1000 kPa in the compressor, which corresponds to a vaporisation temperature of +25 °C, and then the ammonia gas will condense. This occurs in the condenser by cooling the gas with water or air. The heat absorbed by the refrigerant in the evaporator is released in the condenser.

The condensate must then be returned to the evaporator. The liquid is passed through the throttling valve in order to reduce pressure and pressure of the condensate. The throttling valve is set so that there is precise reduction in pressure.

Chapter 10

PACKAGING

Packaging is a means of protecting materials (processed/unprocessed) by use of containers designed to isolate contents from external influences. Good packaging must protect contents from re-contamination/re-infection and spillage.

Most processed items are consumed/utilised far away from their production points. Packaging should aid both in storage and distribution of commodities without loss. Packaging serves as a material handling tool.

Factors which cause deterioration of food during storage are:

- Climatic influences (UV light, moisture vapour, oxygen, temperature changes)
- Contamination (by micro-organisms, insects or soils)
- Mechanical forces (damage caused by impact, vibration, compression or abrasion)
- Pilferage, tampering or adulteration

Packaging provides a barrier between the food and the environment. It controls light transmission, rate of transfer of heat, moisture and gases, and movement of micro-organisms or insects.

10.1 Functions of packaging

a) To contain the product: Should hold the contents and keep them secure until they are used. In order to contain the product, the physical barrier it provides must be of the right mechanical strength i.e. not torn or punctured during handling, transportation, storage or in-trade.

b) Protective function against mechanical and environmental hazards encountered during distribution and use.

   - Mechanical hazards – transportation, stacking, sampling, storage –stack loads
   - Climatic hazards - atmospheric humidity, temperature, rain, light
   - Biological hazards - insects, moulds, mites attack, bacteria, rodents

c) Communication: to identify contents and assist in selling the product. Some packages inform the user about the method of opening and/using the contents.

d) Marketing tools: for sale, advertising and merchandising but should avoid deceptive information

e) Convenient item to customers: beer, bottle and can

10.2 Factors considered when choosing a packaging material

a) The product characteristics
   - Physical state (liquid, solid, gas etc)
   - Flow characteristics (viscous, free flow, sticky)
   - If solid consider state of division e-g, blocks, granular, powder, hard/soft, fragile(e.g. eggs)

b) Bulk density, esp. for powders

c) Sensitivity to moisture, oxygen, light and microbial decay

d) Corrosion resistance of package (if metal) and nature of product e.g. acid materials aid corrosion

e) Mechanical strength of packaging material: The package should have corrosion and vibrational resistance and be suitable for various stress conditions of pressure, temperature and impacts

f) Suitability for contact with packed item: Package should be non-toxic, sanitary and compatible with packed item

g) Costs for maintenance and replacement should be low. It must also be easily disposable, re-usable or have another use

h) Availability – readily available

i) Distributive system –distance, storage, handling

Rigid containers

- Good mechanical strength
- Good gas and water impermeability
- Good resistance to insects and microbes
- Impervious to light

Flexible containers

- items can be packed into small convenient economic packs
- light in weight
- can be laminated easily

Glass containers

Advantages:

- It is chemically inert with respect to food items and it does not corrode like metals

- Impermeable to gases, oil and water
- Transparent and therefore can be used for product display
- Have smooth surfaces which make them easy to clean and sterilise
- Versatile i.e. a wide range of products can be packed in glass
- They can do multi-trip ie they can be re-used

Disadvantages:

- Create weight and volume problems (they are heavy)
- They are mechanically brittle (vulnerable to mechanical damage)
- They have low thermal shock resistance

Good quality, tasty market milk products in consumer-oriented packaging are the strongest selling point for the dairy. Packaging must sell the product, be convenient, easy to open, pleasant to handle and decorative on the table and above all must protect and maintain the quality of the product.

Glass bottles have been the only packaging material for milk for more than half a century. However, they were relatively heavy. The need for washing caused great problems to the dairies and the grocery trade. Milk packed in glass has disappeared from many markets.

Plastic-paper laminates or simply plastic alone have brought great opportunities for development into the area of packaging. Market milk packaging uses thermoplastics, which are characterised by the fact that they soften and melt under the effect of heat. The thermoplastic polyethylene is used as a plastic surface coating. One important quality characteristics of polyethylene is its density. Low Density (LD) polyethylene forms an effective barrier to vapour odours. Imperviousness to gas increases with higher density; the plastic is then stiffer and less pliable. LD polyethylene is generally used in the market milk packagings.

Chapter 11

CLEANING DAIRY EQUIPMENT

Cleaning and disinfection of equipment are essential in food processing plants if the food materials are to be produced under hygienic conditions. Equipment must be cleaned and disinfected before or after use. Residual food materials and dirt deposits must be physically removed or dislodged by brushing or by a combination of high turbulent fluids (water jets). Addition of detergents and conditioners to assist in the wetting of surfaces can be used to enhance their removal. This must be followed by a clean water rinse. Disinfection can be obtained by the use of steam, hot water or chemical disinfectants

Thorough cleaning and disinfection of equipment are an important part of dairy operations. Milk is a perfect nutrient substrate in which bacteria can multiply quickly hence faulty hygiene can have serious consequences. Dirty surfaces of tanks, pipes and other process equipment are a source of contamination. A single mistake in cleaning may lead to spoilage of very large quantities of the product.

11.1 Theory of cleaning

Chemists are devising more and more effective detergents to improve cleaning. Mechanisation and automation of cleaning operations is becoming more common because of labour shortages and economic pressures.

The degree of cleanness is defined by the following terms:

- Physical cleanness -removal of visible dirt from the surfaces
- Chemical cleanness - removal of visible dirt, microscopic residues which can detected by taste or smell but not visible to the naked eye.
- Bacteriological cleanness – attained by disinfection
- Sterile cleanness - destruction of all micro-organisms

In dairy cleaning operations the objective is to ensure chemical and bacteriological cleanness. The equipment surfaces are first thoroughly cleaned with chemical detergents and then disinfected.

11.2 Disinfection

This is the destruction of micro-organisms which might infect dairy products and impair their quality. In dairy, disinfection means killing micro-organisms by heating the equipment with water at 90 °C or by using chemical detergents. If there is need to destroy of bacteria, the equipment must be sterilised. There are three classes of chemical detergents namely, acid, base and neutral. The most widely used being neutral disinfectants.

Certain micro-organisms may develop immunity to a disinfectant after some time. This can be solved by using strong enough solutions or change of type of disinfectant used occasionally to avoid this kind of phenomenon.

11.3 Cleaning procedures

The cleaning cycle in a dairy consists of the following steps:

a) Recovery of product residue by scraping, drainage, displacement with water or expulsion with compressed air. Product residues should be recovered from production line at the end of a run to minimise product losses and facilitate cleaning

b) Prerinsing with water to remove loose dirt. Should be done immediately after the end of the production run. Otherwise the milk residues will dry out and stick to the surfaces which will be more difficult to clean. Milk fat residues are easily flushed out if the water is warm but the temperature must not exceed 60 °C to avoid protein coagulation.

c) Cleaning with detergent. To ensure satisfactory results with a detergent solution the following variables must be controlled;

- Concentration of detergent solution
- Temperature of detergent solution
- Mechanical effect on the cleaned surfaces
- Duration of cleaning

d) Postrinsing with clean water: The surface must be flushed with water to remove all traces of the detergent, as any detergent leftin the system is liable to contaminate the milk. The system must be thoroughly drained after rinsing. The final rinse water must be acidified to a pH which is less than 5 to avoid overnight growth of bacteria in the residual rinsing water in the system.

e) Disinfection by heating or with chemicals, in the latter case the cycle is completed with a final rinse. The bacteriological cleaning effect can be improved by disinfection which leaves the equipment totally free from bacteria. Dairy equipment can be disinfected by; thermal disinfection (boiling, hot water, steam) or chemical disinfection (chlorine, acids, hydrogen peroxide etc.)

Each step requires a certain length of time to achieve an acceptable result.

11.4 Cleaning in place (CIP)

Manual cleaning in many dairies is being replaced by mechanised and in most cases automated cleaning. Manual cleaning (dismantling and cleaning) is time-consuming, expensive and often unsatisfactory in terms of bacteriological cleanness. Dismantling and re-assembly can easily result in mechanical damage to equipment parts resulting in high maintenance costs since cleaning is a regular process. The manual cleaning of the inside of large equipment can be a difficult task and to avert these disadvantages the technique of CIP is used. CIP is capable of achieving the highest standard of hygiene required for a process plant and is more economical.

CIP means that rinsing water and detergent solutions are circulated through tanks, piping and process lines. In other words CIP is defined as circulation of cleaning fluids through machines and other items of equipment interconnected to form a cleaning circuit. Large tanks are cleaned by spraying the detergent on the upper surfaces and the detergent is allowed to run down the walls by gravity. Tank cleaning requires the use of large volumes of detergent. The scouring effect of high-velocity liquids dislodges deposits of dirt in pipes, heat exchangers, pumps, valves, separators, etc.

11.5 Make-up of CIP circuits

The dairy installations are divided into a number of circuits for cleaning purposes. These circuits can be cleaned at different times. The following factors are used to determine the type of equipment in the same circuit:

- the product residue deposits must be of the same kind so that the same detergent and disinfectant solutions can be used.
- the equipment surfaces to be cleaned must be of the same materials or of materials compatible with the same detergent and disinfectant solutions.
- all components in the circuit must be available for cleaning at the same time

11.6 Compatible materials and system design

All surfaces of the equipment must be reached by the detergent solution (no dead ends). Machines and pipes must also be installed in such a way that they are easy to empty and drain. Any pockets of residual water provide sites for rapid multiplication of bacteria and risks infecting the product.

Process equipment materials such as stainless steel, plastics, and elastomers should not transmit any odour or flavour to the product. They should also withstand contact with detergents and disinfectants at the temperatures used for cleaning. Stainless steel is the universal material for product-wetted surfaces in modern dairies, metallic contamination is rare. It can however be attacked by nitric acid and chlorine solutions.

Elastomers (e.g. rubber gaskets) can be attacked by chlorine and oxidising agents and this causes them to blacken or crack and release particles of rubber into milk.

Plastics in process equipment may present a contamination hazard. Constituents of some plastics can be dissolved out by the fat in milk. Detergent solutions can have the same effect. Plastic materials for dairy use must therefore satisfy certain criteria in terms of composition and stability.

11.7 Steps in CIP

a) Initial wash – water rinse to remove the gross dirt due to soil or residual food. During rinsing detergents are used to remove/strip films from inner surfaces. For the pipeline advantage is taken of turbulent flow to help in the initial rinsing of the surfaces. For large plant items in the line which are uneconomic to fill with water they are fitted with stationery or rotating jets designed to reach every part of the inside surface.

b) Supply caustic and acid based detergents alternately. This supply must be maintained at the right titre strength, at the required temperature, delivered at the required turbulence and held for the required time (4Ts). The 4Ts result in effective scouring effect. The CIP process can be easily automated saving on labour costs. During this process water conditioners may be added to prevent the precipitation of residues on the surfaces.

c) Final water rinse

d) Disinfection using steam or hot water

Chapter 12

PROCESS PLANT LAYOUT

Basically plant layout involves the arrangement of physical facilities (building, machinery and land). This is done to optimise:

- The flow of materials
- Inter-relationships amongst personnel
- Information flow - this varies from plant to plant

If the arrangement is done optimally then the plant will operate efficiently and economically.

When one is designing a process plant outlay the main objective to keep in view is to get all the inputs into, through and out of the entire plant or each facility within the shortest time possible and at an acceptable cost.

In terms of machinery layout you can adopt;

a) A linear system

b) L-shaped layout

c) U-shaped layout

d) S-shaped layout

12.1 Specific considerations during designing and layout of facilities

a) It should facilitate the manufacturing process. The layout should be designed in such a way that the manufacturing process be carried out in the most efficient, economic and technically acceptable way.

b) The layout should minimise material handling. The spacing between equipment should be close enough. The handling should be mechanical where possible and the movement of material should be towards storage and exit points.

c) Should maintain flexibility of arrangement in that if there is need for more production or expansion it can be done.

d) The outlay should maintain a high turnover of work in process i.e. the material line should be as straight as possible or at times inclined to take advantage of free flow under gravity. Should reduce in process storage of materials to a minimum to reduce the manufacturing time

e) The design outlay should hold down investments in equipment

f) Make economic use of building i.e. the flow area should be utilised very efficiently i.e. there should be minimum spacing between the machines after the necessary allowances for the movement of men /women and materials have been done.

g) Should provide for employee convenience, safety and comfort during their work and this requires light, heat and ventilation. There should be provision for the removal of dust and moist from the plant.

12.2 Importance of designing an efficient plant layout for food processing

a) Improves throughput or turnover

b) Provides flexibility for expansion and full utilisation of installed plant capacity

c) Results in economic utilisation of the building

d) Provides an effective supervision of personnel

e) Caters for workers' convenience, safety and comfort during process operation

f) Improves hygienic handling of produce and reduces wastage of materials

Chapter 13

WASTE MANAGEMENT AND DISPOSAL

Solid waste and liquid effluents are produced in large quantities in food processing plants. They arise due to cleaning and preparation of raw materials, spillages and cleaning of equipment and floors and change-over to different productions.

The nature of wastes varies according to the type of food being processed. Meat and dairy processing effluents contain a higher proportion of fats and proteins whereas fruit and vegetable processing produces effluents that have high concentrations of sugars, starch and solid matter such as peelings.

In large processing plants or those located in unpopulated areas, effluent treatment can be done on-site in purpose-built facilities. Effluent from most food factories is treated by municipal authorities or private water utilities. The cost of effluent treatment is steadily increasing and it's becoming a major cost to food business. It is possible to reduce treatment costs by separating concentrated waste streams from more dilute ones.

Means of reducing polluting potential and waste treatment charges include:

a) Recycling water
b) Recovering fats and oils by aeration flotation for sale as a by-product
c) Storing concentrated effluents and blending them over a period of time with dilute wastes to produce consistent moderately dilute effluent
d) Removing solids using screens and discharging them as solid waste to commercial waste disposal companies or for composting.
e) Flocculating suspended solids using a chemical coagulant or removing suspended solids directly by sedimentation, filtration or centrifugation and disposing of them as solid waste
f) Treating effluents using a biological method such as trickling filters, activated sludge processes, lagoons, spray irrigation or anaerobic digesters
g) Fermenting waste materials to produce more valuable products (e.g. organic acids, vitamins)
h) Solid wastes, packaging and office waste materials are collected by municipalities or private waste management and recycling companies. They are usually disposed of in landfill sites and the steadily increasing costs of collection have stimulated incentives and opportunities for recycling and re-use.

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