Dairy and Food Engineering

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Dairy and Food Engineering

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Module 1. Dairy Development in India

Lesson 1. Dairy development in India

1.1 RISE OF COOPERATIVES IN INDIA:

The India District Co-operative Milk Producers' Union was registered on December 14, 1946 as a response to exploitation of marginal milk producers by traders or agents of existing dairies in the small town named Anand (in Kaira District of Gujarat). Milk Producers had to travel long distances to deliver milk to the only dairy, the Polson Dairy in Anand. Often milk went sour as producers had to physically carry the milk in individual containers, especially in the summer season. These agents arbitrarily decided the prices depending on the production and the season. Milk is a commodity that has to be collected twice a day from each cow/buffalo. In winter, the producer was either left with surplus / unsold milk or had to sell it at very low prices. Moreover, the government at that time had given monopoly rights to Polson Dairy (around that time Polson was the most well-known butter brand in the country) to collect milk from Anand and supply it to Bombay city in turn. India ranked nowhere amongst milk producing countries in the world because of its limitations in 1946 British Raj.

Angered by the unfair and manipulative trade practices, the farmers of Kaira District approached Sardar Vallabhbhai Patel under the leadership of the local farmer leader Tribhuvandas Patel. Sardar Patel advised the farmers to form a Cooperative and supply milk directly to the Bombay Milk Scheme instead of selling it to Polson. He sent Sh. Morarji Desai to organize the farmers. In 1946, the farmers of the area went on a milk strike refusing to be further oppressed. Thus, the Kaira District Cooperative was established to collect and process milk in the District of Kaira in 1946. Milk collection was also decentralized, as most producers were marginal farmers who were in a position to deliver 1-2 litres of milk per day. Village level cooperatives were established to organize the marginal milk producers in each of these villages.

The Cooperative was further developed and managed by Dr. V Kurien along with Shri H M Dalaya. The first modern dairy of the Kaira Union was established at Anand. Indigenous research and development and technology development at the Cooperative had led to the successful production of skimmed milk powder from buffalo milk – the first time on a commercial scale anywhere in the world. The success of the dairy co-operative movement spread rapidly in Gujarat. Within a short span five other district unions – Mehsana, Banaskantha, Baroda, Sabarkantha and Surat were organized. In order to combine forces and expand the market while saving on advertising and avoid a situation where milk cooperatives would compete against each other it was decided to set up an apex marketing body of dairy cooperative unions in Gujarat. Thus, in 1973, the Gujarat Co-operative Milk Marketing Federation was established. The Kaira District Co-operative Milk Producers' Union Ltd. which had established the brand name Amul in 1955 decided to hand over the brand name to GCMMF (AMUL).

Dr. Verghese Kurien, the World Food Prize and the Magsaysay Award winner, was the architect of India's White Revolution, which helped India emerge as the largest milk producer in the world. Impressed with the development of dairy cooperatives in Kaira District and its success, Shri Lal Bahadur Shastri, the then Prime Minister of India during his visit to Anand in 1964, asked Dr. V Kurien to replicate the Anand type dairy cooperatives all over India. Thus, the National Dairy Developed Board was formed and Operation Flood Programme was launched for replication of the Amul Model all over India.

1.2 ACHIEVEMENTS OF CO-OPERATIVE MOVEMENT IN INDIA:

1. The phenomenal growth of milk production in India – from 20 million MT to 100 million MT in a span of just 40 years.

2. Encouraged Indian dairy farmers to keep more animals, which has resulted in the 500 million cattle & buffalo population in the country – the largest in the World.

3. The dairy cooperative movement has assembled a large base of more than 13 million milk producer families.

4. The dairy cooperative movement has spread across the length and breadth of the country, covering more than 125,000 villages of 180 Districts in 22 States.

5. The dairy cooperatives have been able to maintain democratic structure at least at the grass-root level with the management committee of the village level unit elected from among the members in majority of the villages.

6. Bridged the social divide of caste, creed, race, religion & language at the villages, by offering open and voluntary membership.

7. Propagated the concepts of scientific animal husbandry & efficiency of operations, which has resulted in low cost of production & processing of milk.

8. The movement has been successful because of a well-developed procurement system & supportive federal structures at District & State levels.

9. Dairy Cooperatives have always been proactive in building large processing capacities, which has further propelled growth of milk production.

10. The dairy cooperatives are among those few institutions in India, which still cherish a strong Cooperative identity, values and purpose.

11. The dairy cooperatives have removed the poor farmers of India from the shackles of agents & middlemen and provided an assured market for their produce.

12. Dairy cooperatives have been able to create a market perception of honesty & transparency with their clean management.

1.3 NATIONAL DAIRY DEVELOPMENT BOARD (NDDB):

The National Dairy Development Board is an institution of national importance setup by an Act of Parliament of India. The main office is located in Anand, Gujarat with regional offices throughout the country. NDDB's subsidiaries include Mother Dairy, Delhi.

It was founded by Dr. Verghese Kurien and Dr. Amrita Patel is the current Chairman of the National Dairy Development Board, Anand.

The National Dairy Development Board (NDDB) was created in 1965, fulfilling the desire of the then Prime Minister of India - the late Lal Bahadur Shastri - to extend the success of the Kaira Cooperative Milk Producers' Union (Amul) to other parts of India.

That success combined the wisdom and energy of farmers with professional management to successfully capture liquid milk and milk product markets while supporting farmer investment with inputs and services. The major success of this mission was achieved through the World Bank financed Operation Flood, which lasted for 26 years from 1970 to 1996 and was responsible for making India the world's largest producers of milk.

NDDB has now integrated 96,000 dairy co-operatives in what it calls the Anand Pattern, linking the village society to the state federations in a three-tier structure.

NDDB launched its Perspective Plan 2010 with four thrust areas: Quality Assurance, Productivity Enhancement, Institution Building and National Information Network.

In addition, NDDB also promotes other commodity-based cooperatives, allied industries and veterinary biologicals on an intensive and nation-wide basis.

1.4 OPERATION FLOOD/ WHITE REVOLUTION:

Operation Flood was a rural development programme started by India's National Dairy Development Board (NDDB) in 1970. One of the largest of its kind, the programme objective was to create a nationwide milk grid.

It resulted in making India the largest producer of milk and milk products, and hence is also called the White Revolution of India.

A 'National Milk Grid', links milk producers throughout India with consumers in over 700 towns and cities, reducing seasonal and regional price variations while ensuring that the producer gets a major share of the price consumers pay. Objectives of Operation Flood's included:

- Increase milk production ("a flood of milk")
- Augment rural incomes
- Fair prices for consumers

1.4.1 Operation Flood was implemented in three phases:

PHASE I

Phase I (1970–1980) was financed by the sale of skimmed milk powder and butter oil donated by the European Union (then the European Economic Community) through the World Food Programme. NDDB planned the programme and negotiated the details of EEC assistance.

During its first phase, Operation Flood linked 18 of India's premier milk-sheds with consumers in India's major metropolitan cities: Delhi, Mumbai, Kolkata and Chennai. Thus, establishing mother dairies in four metros.

Operation flood, also referred to as "White Revolution" is a gigantic project propounded by Government of India for developing dairy industry in the country. The Operation Flood – 1 originally meant to be completed in 1975, actually spanned the period of about nine years from 1970–79, at a total cost of Rs.116 crores.

PHASE II

Operation Flood Phase II (1981–1985) increased the milk-sheds from 18 to 136; 290 urban markets expanded the outlets for milk. By the end of 1985, a self-sustaining system of 43,000 village cooperatives with 4,250,000 milk producers were covered. Domestic milk powder production increased from 22,000 tons in the pre-project year to 140,000 tons by 1989, all of the increase coming from dairies set up under Operation Flood. In this way EEC gifts and World Bank loan helped promote self-reliance. Direct marketing of milk by producers' cooperatives increased by several million litres a day.

PHASE III

Phase III (1985–1996) enabled dairy cooperatives to expand and strengthen the infrastructure required to procure and market increasing volumes of milk. Veterinary first-aid health care services, feed and artificial insemination services for cooperative members were extended, along with intensified member education.

Operation Flood's Phase III consolidated India's dairy cooperative movement, adding 30,000 new dairy cooperatives to the 42,000 existing societies organized during Phase II. Milk-sheds peaked to 173 in 1988-89 with the numbers of women members and Women's Dairy Cooperative Societies increasing significantly.

Phase III gave increased emphasis to research and development in animal health and animal nutrition. Innovations like vaccine for Theileriosis, bypassing protein feed and urea-molasses mineral blocks, all contributed to the enhanced productivity of milch animals.

Module 2. Engineering, thermal and chemical properties of milk and milk products.

Lesson 2. Engineering properties of milk and milk products

2.1 INTRODUCTION

Rheology is the study of the flow and deformation of matter. It is often used interchangeably with texture, which refers to the flow, deformation, and disintegration of a sample under force. In short, texture relates to solid foods, and viscosity - the tendency to resist flow - relates to fluid foods. Food can exhibit both solid and liquid characteristics, and rheology can identify the properties of such foods. Rheological studies are performed as a quality control method in dairy plants and as a technique for scientists to study the structure of the product.

Fluids will flow under the influence of forces, whereas solids will stretch, buckle or break. An ideal solid is represented by the Hooke solid, and the ideal liquid by the Newtonian liquid. Both are structureless (there are no atoms), isotropic (they have the same properties in all directions) and follow their respective laws exactly. Many materials can exert both types of properties, depending upon the environmental conditions and stresses they are subjected to. For example butter at 20 °C is regarded as a solid, although if the shearing force is sufficiently high, it can be made to flow or if its temperature is raised to above 50 ℃, it will melt and behave like a fluid.

Some of the rheological properties are also used for assessing and monitoring the quality of products such as cream, dahi, butter and cheese.

2.1.1 VISCOSITY

The dynamic viscosity μ is a parameter related to the inner friction of a liquid or fluid. It is reduced when temperature is increased. Due to the friction of the fat (emulsified in milk) and the dispersed protein, the viscosity of milk is twice as high as that of water. It increases with the protein coagulation and increasing fat content.

The dimension of the dynamic viscosity is Ns/m^2 or Pa-s; an old term is the centipoises cP (10^{-3} Pa-s). The value for milk at 5°C is a function of the fat content and ranges from 2.96 X 10^{-3} Pa-s (skimmed milk) and 3.25 X 10^{-3} Pa-s (whole milk); at 20°C we observe a range of 1.79 X 10^{-3} Pa-s and 2.13 X 10^{-3} Pa-s.

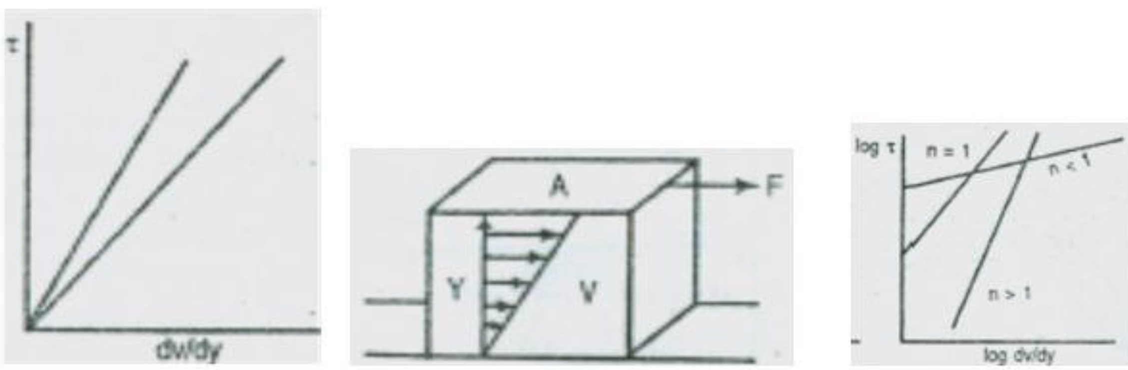
The viscosity of a fluid is the internal friction within the fluid. When a fluid is subjected to a shearing force (F) over a surface area (A), it will undergo a deformation known as flow (Fig. 2.1).

The shear stress is force/area. The rate of deformation termed as the shear rate is determined by the velocity gradient. For Newtonian fluids, there is a direct relationship between the shear stress (τ) and the rate of shear (dv/ dy). The ratio of the shear stress to shear rate is known as the dynamic viscosity or coefficient of viscosity (μ).

$$\mu = \tau/(dv/dy) = (\text{Shear stress}/\ \text{Shear rate}) = (Nm^{-2}/\ s^{-1}) = Nsm^{-2}$$

Viscosity data are often plotted as shear stress against shear rate, either in ordinary or logarithmic co-ordinates (Fig.2.l). Such plots are known as rheograms.

The two common units for viscosity measurements arc the poise (p) in cgs and the Poiseuille (PI) in SI. One Poiseuille is the dynamic viscosity of a fluid which, when subjected to a shear stress of 1 N m^{-2} gives a shear rate of 1 s^{-1}. The viscosity of water at 20℃ is 1.002 X 10^{-3} Nsm^{-2} or 1.002 cp.



(a) Deformation of a fluid

(b) Rheogram on ordinary co-ordinates

(c) Rheogram on logarithmic co-ordinates

Fig. 2.1 Deformation and rheograms of fluid

Milk, skim milk, cheese, whey and whey permeate are usually considered to be Newtonian fluids. The viscosity of all fluids is temperature dependent. The viscosity of liquids, pastes, suspensions and emulsions decrease with increase in temperature between 2-10 % for each ℃. Therefore, it is important to control the temperature accurately when measuring the viscosity and temperature should always be quoted with the results.

Occasionally, it is more appropriate to the term kinematic viscosity which is dynamic viscosity/density. Kinematic viscosity is measured directly by the Ostwald capillary flow type viscometer. The viscosity of solutions increases as the concentration increases in a non-linear fashion. At high concentrations, small additional changes in the concentration will lead to rapid changes in the viscosity. This could result in reduced flow rates, higher pressure drops, decreased turbulence and severe fouling in heating operations. In concentration

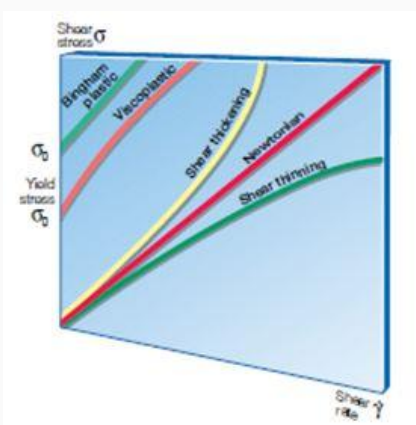
processes, the extent of concentration may well be limited by viscosity considerations. There is often a transition from Newtonian to non-Newtonian conditions as concentration proceeds.

Homogenisation and heat treatment both tend to increase the viscosity slightly, with homogenisation giving the milk a creamier mouth feel. The effect of homogenisation becomes more pronounced as the fat content increases.

The viscosity of milk products increases as the concentration increases. The viscosity of evaporated whole milk will depend upon the degree of forewarming, homogenisation conditions, the type of stabilizer used and the extent of the final temperature in-container heat treatment.

Viscosity is one of the main factors which limits the extent of concentration for ultrafiltration and reverse osmosis processes. The protein fraction makes the main contribution to the viscosity. Freshly separated cream has a fairly low viscosity. When cream is homogenised at fairly high pressures, usually after heat treatment, there is a significant increase in viscosity. Filling into cartons using piston filler will reduce the viscosity, probably due to shear breakdown but the viscosity then increases during cold storage. Cream cooled very quickly and stored at a uniform low temperature often shows a dilatant character.

Flow curves and viscosity curves for Newtonian and non-Newtonian fluids are shown in Fig.2.2 and Fig.2.3.



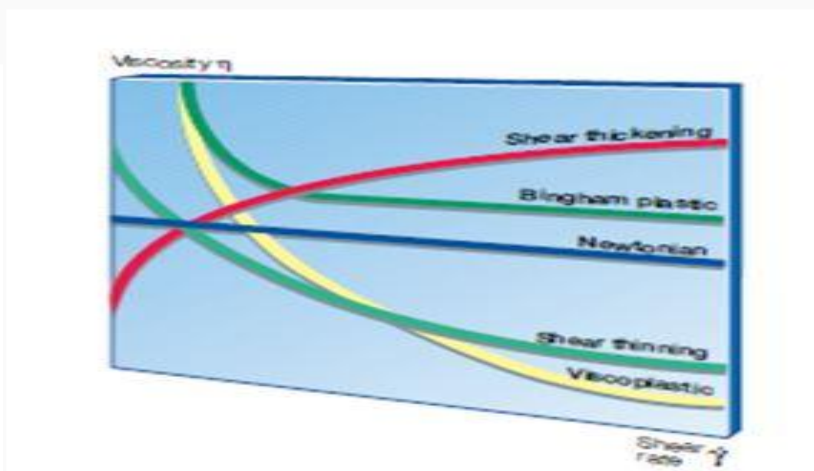
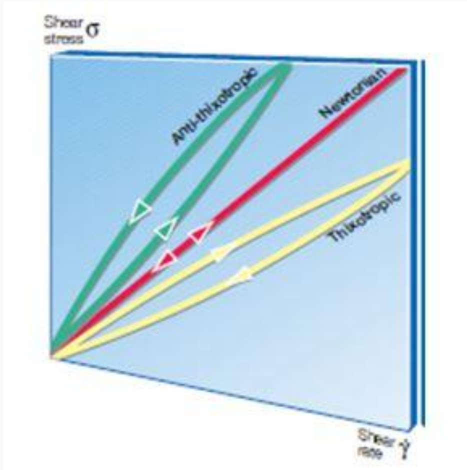


Fig. 2.2 Flow curves for Newtonian and non-Newtonian fluids **Fig. 2.3 Viscosity curves for Newtonian and non-Newtonian fluids**



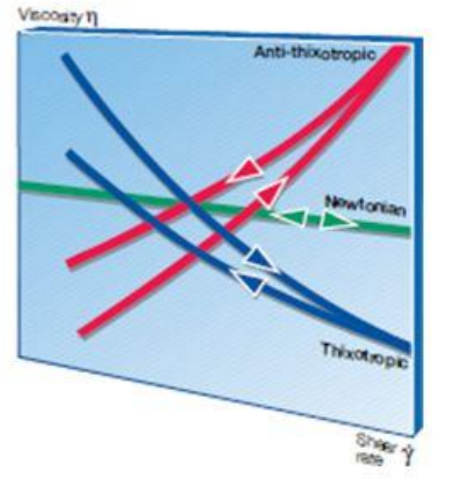


Fig. 2.4 Flow curves for time dependant non-Newtonian fluids **Fig. 2.5 Viscosity curves for time dependant non-Newtonian fluids**

2.1.2 Newtonian fluids

Newtonian fluids are those having a constant viscosity dependent on temperature but independent of the applied shear rate. One can also say that Newtonian fluids have direct proportionality between shear stress and shear rate in laminar flow.

A Newtonian fluid can therefore be defined by a single viscosity value at a specified temperature. Water, mineral and vegetable oils and pure sucrose solutions are examples of Newtonian fluids. Low-concentration liquids in general, such as whole milk and skimmilk, may for practical purposes be characterised as Newtonian fluids.

2.1.3 Non-Newtonian fluids

Materials which cannot be defined by a single viscosity value at a specified temperature are called non-Newtonian. The viscosity of these materials must always be stated together with a corresponding temperature and shear rate. If the shear rate is changed the viscosity will also change. Generally speaking, high concentration and low temperature induce or increase non-Newtonian behaviour.

Apart from being shear rate dependent, the viscosity of non-Newtonian fluids may also be time dependent, in which case the viscosity is a function not only of the magnitude of the shear rate but also of the duration and, in most cases, of the frequency of successive applications of shear. Non- Newtonian materials that are time independent are defined as shear thinning, shear thickening or plastic. Non-Newtonian materials that are time dependent are defined as thixotropic, rheopectic or anti-thixotropic. Flow curves and viscosity curves for time dependant non-Newtonian fluids are shown in Fig.2.4 and Fig.2.5.

2.1.4 Shear thinning flow behaviour

The viscosity of a shear thinning fluid (sometimes also denoted pseudoplastic fluid) decreases with increasing shear rate. Many liquid food systems belong to this category of fluids. The shear rate dependency of the viscosity can differ substantially between different products, and also for a given liquid, depending on temperature and concentration. The reason for shear thinning flow behaviour is that an increased shear rate deforms and/or rearranges particles, resulting in lower flow resistance and consequently lower viscosity.

Typical examples of shear thinning fluids are cream, juice concentrates, shampoo and salad dressings. It should be noted that although sucrose solutions show Newtonian behaviour independent of concentration, fruit juice concentrates are always significantly non-Newtonian. This property is found in certain complex solutions, such as lava, ketchup, whipped cream, blood, paint, and nail polish.

2.1.5 Shear thickening flow behaviour

The viscosity of a shear thickening fluid increases with increasing shear rate.

This type of flow behaviour is generally found among suspensions of very high concentration. A shear thickening fluid exhibits dilatant flow behaviour, i.e. the solvent acts as a lubricant between suspended particles at low shear rates but is squeezed out at higher shear rates, resulting in denser packing of the particles. Typical examples of shear thickening systems are wet sand and concentrated starch suspensions. Other examples are silly putty, Corn Starch and Water (Oobleck) and Silica and poly(ethylene glycol).

2.1.6 Plastic flow behaviour

A fluid which exhibits a yield stress is called a plastic fluid. The practical result of this type of flow behaviour is that a significant force must be applied before the material starts to flow like a liquid (often referred to as the ketchup effect). If the force applied is smaller than the force corresponding to the yield stress, the material stores the deformation energy, i.e. shows elastic properties, and hence behaves as a solid. Once the yield stress is exceeded, the liquid can flow like a Newtonian liquid and be described as a Bingham plastic liquid, or it can flow like a shear thinning liquid and be described as a viscoplastic liquid.

Typical plastic fluids are quarg, tomato paste, toothpaste, hand cream, certain ketchups and greases.

2.1.7 Thixotropic flow behaviour

A thixotropic fluid can be described as a shear thinning system where the viscosity decreases not only with increasing shear rate but also with time at a constant shear rate. Thixotropic flow behaviour is normally studied in a loop test. In this test the material is subjected to increasing shear rates followed by the same shear rates in decreasing order. The time-dependent thixotropic flow behaviour is seen from the difference between the ascending and descending viscosity and shear stress curves. To recover its structure, the material must rest for a certain period of time which is characteristic for the specific material. This type of flow behaviour is shown by all gel forming systems. Typical examples of thixotropic fluids are yoghurt, mayonnaise, margarine, ice cream and brush paint.

2.1.8 Rheopectic flow behaviour

A rheopectic fluid can be described as a thixotropic fluid but with the important difference that the structure of the fluid will only recover completely if subjected to a small shear rate. This means that a rheopectic fluid will not rebuild its structure at rest.

2.1.9 Anti-thixotropic flow behaviour

An anti-thixotropic fluid can be described as a shear thickening system, i.e. one where the viscosity increases with increasing shear rate, but also with time at a constant shear rate. As with thixotropic fluids, the flow behaviour is illustrated by a loop test. This type of flow behaviour is very uncommon among foodstuffs.

2.2 ELECTRICAL PROPERTIES

2.2.1 Electrical Conductance

Electrical resistance and conductance provide a measure of the ability of material to transport an electric current, resistance usually being preferred for solids and conductance for liquids.

Most dairy products are poor conductors of electricity. Milk has values ranging from 0.004 to 0.0055 mho/cm. There is little difference between varieties, as the major contribution arises from potassium and chloride ions. Increasing the concentration of milk solids would increase the specific conductance, but the relationship is not so straight forward. The conductance of concentrated skim milk is about 0.0078 mho/cm at 28% total solids, above this value it decreases; this is explained by the extremely complex salt-balance between the colloidal and soluble phases.

The presence of fat tends to decrease the specific conductance, the specific conductance of milk fat being less than 10^{-16} mho/cm. The development of acidity occurring during many fermentation has also been observed to increase the conductivity. Mastitic milk also has an increased conductivity due to its raised content of sodium and chloride ions. The electrical conductivity increases with increase in temperature.

It has been suggested that conductivity measurements may be useful for monitoring processes where such changes occur. The conductivity of dairy products will be important in ohmic heating processes.

2.2.2 Electrical Conductivity

Due to their ion content, milk is conducting an electrical current. This conductivity K has the dimension Siemens per meter [1 S/m = I / Ω.m] or is given more often in Siemens per cm. The specific conductivity of milk is low (4.10-5.5.10 S/cm at 25°C). It is controlled mainly by the levels of sodium and chloride ions; an increase in ions results in a conductivity increase. Udder diseases can be detected by an increase in conductivity of raw milk. The specific conductivity decreases with increasing fat content and thus is suitable for fat content determinations in automated processes.

Lesson 3. Thermal properties of milk and milk products

3 INTRODUCTION

Milk and milk products undergo heating and cooling in dairy. Milk and other liquid foods are sometimes dehydrated to form powders. Cooling, cooking, baking, pasteurization, freezing and dehydration, all involve heat transfer. Design of such processes requires knowledge of the thermal properties of the materials involved. In this chapter, we will try to learn the thermal properties of milk and milk products.

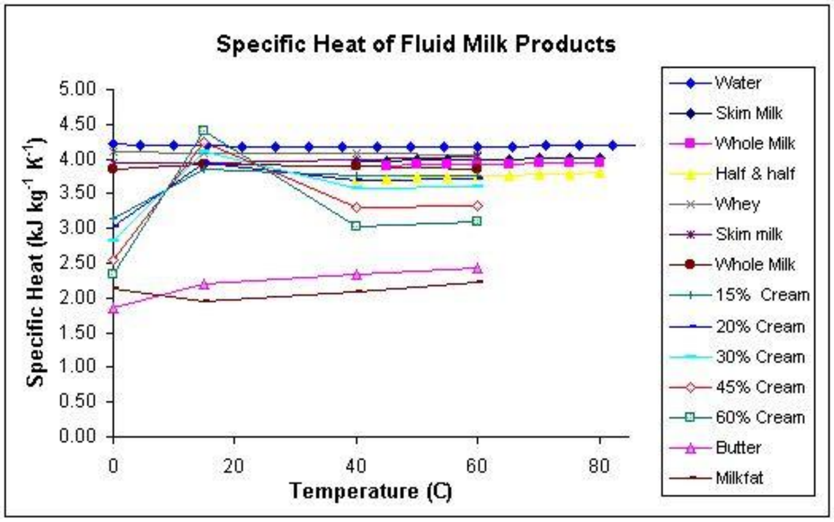
3.1 Specific Heat

The specific heat is the amount of heat required to raise a unit mass through a unit temperature rise. The specific heat of most substances is slightly temperature dependent: this can be overcome by using an average specific heat value for the temperature range being considered.

The specific heat of milk usually ranges between 0.92 to 0.93 kcal $kg^{-1}C^{-1}$. Milk has highest specific heat (0.938 kcal $kg^{-1}C^{-1}$) at 15°C, however an average value of 0.93 kcal $kg^{-1}C^{-1}$ or 3.93 kJ $kg^{-1}K^{-1}$is used if temperature is not specified as

1 kJ $kg^{-1}K^{-1}$ = kcal $kg^{-1}C^{-1}$.

Relationship between the specific heat and temperature for fluid milk products is shown in figure no. 3.1.



[1] Holman (1976)

[2] Fernandez - Martin and Montes(1972)

[3] ASHRAE (1982)

Figure 3.1 Relationship between the specific heat and temperature for fluid milk products

The different components in foods have different specific heat values so it should be possible to estimate the specific heat of a food from knowledge of its composition. Water has the greatest influence on the specific heat.

$c = m_w c_w + m_s w_s$

where c = specific heat, m = mass fraction, water (w) and solids (s).

For dairy products consisting water (w), fat (f), and solids-not- fat (snf), the specific heat can be given as : .

$c = (0.5\ m_f + 0.3 m_{snf} + m_w)\ 4.18\ (kJ\ kg^{-1}\ K^{-1})$

Kessler (1981) has recommended the equation:

$c = 4.18\ m_w + 1.4\ m_c + 1.6\ m_p + 1.7\ m_f + 0.8\ m_a$

(water) (carbohydrate) (protein) (fat) (ash)

If the chemical composition is known, the specific heat can be estimated accurately. Values for frozen products can be obtained by substituting the specific heat of ice in the respective equations. This however assumes that all the water is in the frozen form.

The specific heat of milk concentrates in the temperature range 40-80℃ and total solids range (8 - 30%) can be calculated as:

$c = [m_w + (0.328 + 0.0027\ \theta)\ m_s]\ 4.18$

3.2 Specific heat capacity

The specific heat capacity c is the quantity of heat which is required to heat 1 kg of material by 1 ℃; the units are J/ kg OK (an old term is kcal/kg grad). 1 J/kg ℃ = 2.389 X 10 kcal/kg grd. For water we have c = 4186.8, for all other materials c >4186.8 J/kg ℃. The specific heat content of milk depends on temperature and is lower at 40°C than at 15 ℃. The reason for this is that at 15 ℃ some fatty acids are still crystalline, so that additional heat is required for melting them.

Table 3.1 shows some values for c. Compared to milk, heating of butter requires only half as much heat. Values for the specific heat content are required for energy calculations for the thermal processing of milk (heating/cooling).

Table 3.1 Specific heat c

	Skim milk	Full cream milk	Cream 20 % fat	Butter
J/kg ℃	3977.5	3935.6	3516.9	2219.5

3.3 Latent Heat

Heat absorbed or released as the result of a phase change is called latent heat. There is no temperature change during a phase change, thus there is no change in the kinetic energy of the particles in the material. The energy released comes from the potential energy stored in the bonds between the particles. The major changes involved with dairy products are: the transition from water to ice (freezing), removal of water during evaporation and concentration, and the phase changes involved in the fat fraction when products are cooled below 50°C (crystallisation).

At atmospheric pressure, water boils at 100 ℃ and the latent heat of vaporisation is 2257 kJ kg-1. As the pressure is reduced, the boiling point decreases, and the latent heat value increases. At a pressure of 0.073 bar (absolute), the latent heat value is increased to 2407 kJ kg-l.

The latent heat of fusion for pure water is 335 kJ kg^{-1}. Unfortunately the situation for foods is more complex. The presence of solids depresses the freezing point, with most foods starting to freeze at about -10 ℃. This results in a concentration effect and a further depression of the freezing temperature. Therefore, the food does not freeze at a constant temperature: rather as freezing proceeds the temperature falls as most of the ice is converted to water: hence there is a concept of unfrozen water.

Most of the water freezes over the temperature range -1 ℃ to -100 ℃, and by -15°C, more than 90% of the water is frozen. The freezing point of milk is of considerable interest, because it is also used to detect any dilution of the milk. Most foods contain substantial quantities of solids, whereas only the water contributes to the latent heat value. On this basis, Lamb suggested the following equation to determine the latent heat value of food.

$L = m_w \times 335$ (kJ kg^{-1})

3.4 Thermal Conductivity

The following equation is given by Lamb to evaluate the thermal conductivity of a food from its moisture content:

$k = 0.0801 + 0.568\ m_w$

where m_w = fractional moisture content

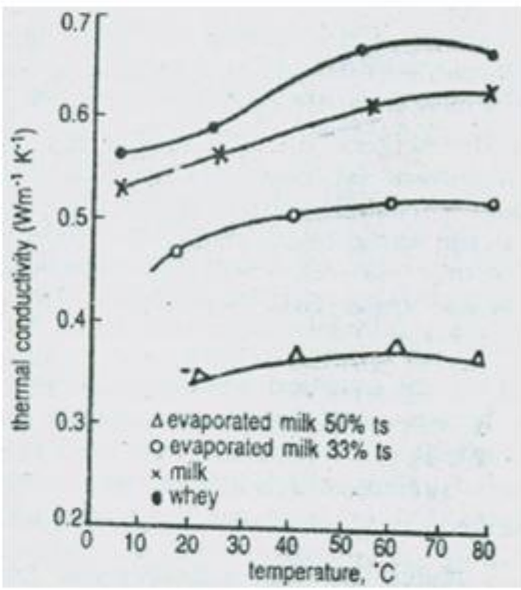
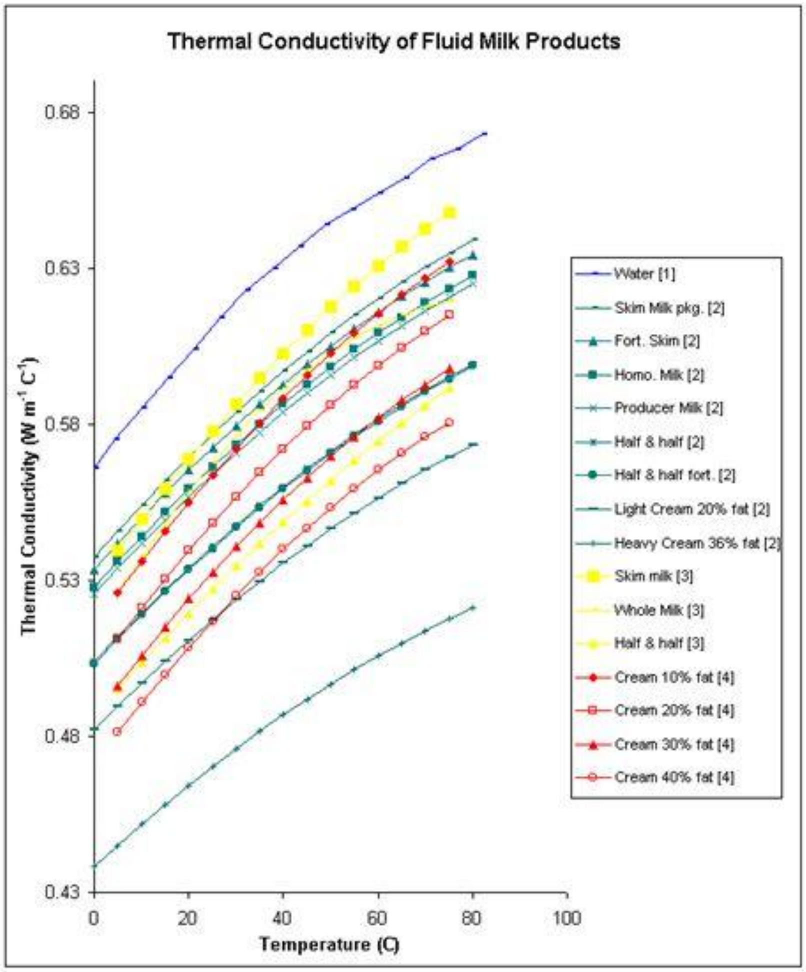


Figure 3.2 shows the changes in thermal conductivity with temperature for some dairy products. The thermal conductivity increases as the temperature increases. It decreases as the concentration level increases and for a given temperature and concentration, the higher the fat content the lower the thermal conductivity.
At 30°C, the thermal conductivity of cow milk is 0.486 and 0.569 kcal/h-m^2 (°C/m) for buffalo milk (1 kcal/h-m^2 (°C/m) = 1.163 Wm^{-1}K^{-1})

Figure 3.2 Relationship between the thermal conductivity and temperature for dairy products



[1] Holman (1976) [3] Fernandez - Martin and Montes (1972)

[2] Riedel (1949) [4] Fernandez - Martin and Montes (1977)

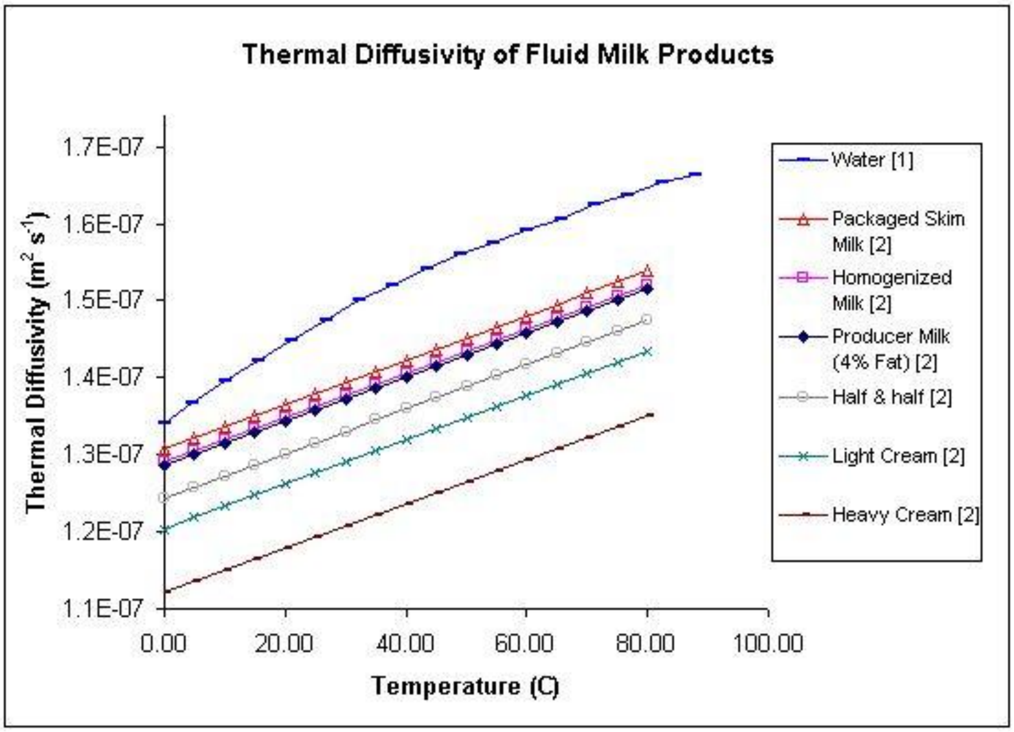
Figure 3.3 Relationship between the thermal conductivity and temperature for fluid milk products

3.5 Thermal Diffusivity

The thermal diffusivity (k/ρc) is an extremely useful property in unsteady-state heat transfer problems; because it is a measure of how quickly temperature changes with time, during heating and cooling processes. It is extensively used in unsteady-state heat transfer problems in a dimensionless form known as the Fourier number

$F_o = at/r^2$

Where, t = heating time, a = thermal diffusivity, r= characteristic dimension of food.



[1] Holman (1976)

[2] Martens (1980)

Figure 3.4 Relationship between the thermal conductivity and temperature for fluid milk products

Lesson 4. Chemical properties of milk and milk products-I

4. INTRODUCTION

The physico-chemical properties of milk and milk products affect most of the unit operations used during their processing. These operations include fluid flow, heat transfer processes, mixing and churning, emulsification and homogenisation. Some of the rheological properties are also used for assessing and monitoring the quality of products such as cream. dahi, butter and cheese.

Raw milk is extremely variable in its composition and most dairy products can be produced in a variety of ways from this milk. There are two approaches to obtain, data for physical properties. The first is to use data available in the literature; the second is to determine the values experimentally.

4.1 DENSITY

Density is defined as the mass of substance divided by the volume occupied. Its unit in SI is the kilogram per cubic meter (kg m^{-3}). At 5°C water has a density of 1.00 g/ml or 10^3 kg m^{-3}.

The addition of solids, e.g. minerals, sugar, protein will increase the density, whereas oil and fat will decrease the density. The density of fluid is usually measured with a hydrometer. The density is temperature dependent, so temperature should always be recorded. The density of milk usually falls within the range of 1028 - 1035 kg m^{-3} depending on the composition. It is generally measured with a special hydrometer known as a lactometer and the result can be used to estimate total solids.

The densities of the solid constituents are regarded as fat (930), water (1000), and milk solids-not-fat (l035 kg m^{-3}). Fat contents range between 1 and 10 per cent and the total solids determination is based on the following equation.

$T = 0.25\ \rho + 1.2.2\ F + 0.72$………………………………………………….. (1)

where T=total solids [w/w], ρ = 1000 (density in g/ml). F=fat percentage.

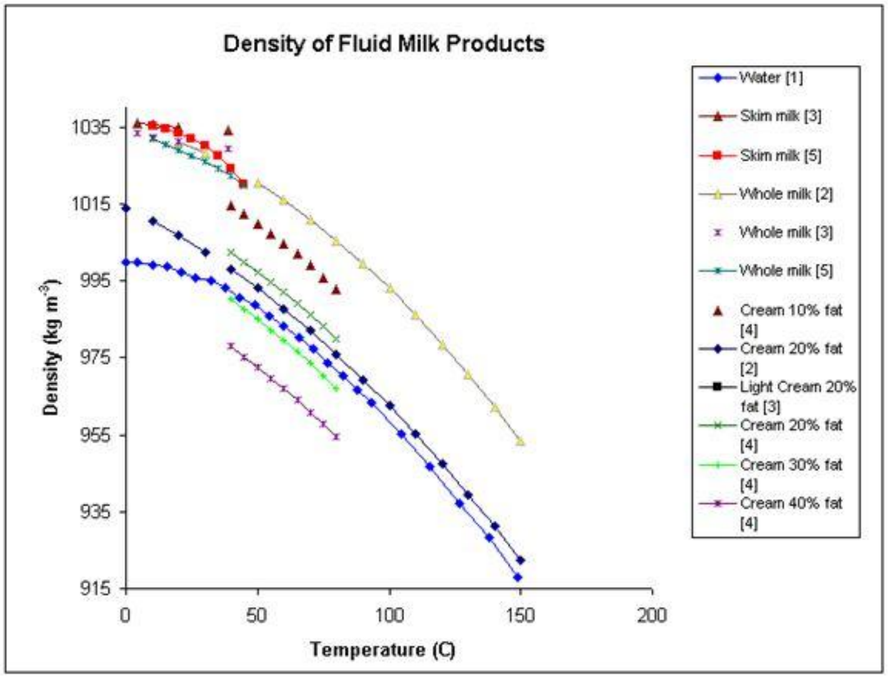
Fat is determined separately usually by the Gerber method.

Kessler (1981) presents relationship for the density of whole milk and cream over the temperature range 0 - 150°C.

Whole milk; $\rho = 1033.7 - 0.2308\ \theta - 2.46 \times 10^{-3}\theta^2$ ……………………………(2)

Cream (20 % fat) ; $\rho = 1013.8 - 0.3179\ \theta - 1.95 \times 10^{-3}\theta^2$ ……………………(3)

where θ = temperature, ℃.



[1] Holman (1976)

[2] Kessler (1981)

[3] USDA (1965)

[4] Phipps (1969)

[5] Short (1955)

Density is useful for monitoring changes occurring during processing. e.g. evaporation, or for checking whether extraneous water has entered the product. When dealing with solids, it is necessary to differentiate between solid density and bulk density, particularly with particulate matter and powder. The solid or particle density is mass of solid/volume of solid, and it will take into account the presence of air within the solid. For particulate matter, it can be determined either by flotation using liquids of known specific gravity or by using a density bottle.

The density of milk varies between 1.027 and 1.035 g/cm^3 as a function of the type and quantity of the dispersed particles (emulsified, colloidal or soluble). With increasing fat content, the density decreases; density increases with an increasing protein, lactose and mineral content. Density is influenced by temperature, average values for densities at 20°C and 1.013 bar (standard atmospheric pressure) in g/cm^3 are:

Whole milk	1.027-1.032	Cream	1.0035-1
Whey	1.025-1.027	Skimmed milk	1.033-1.036
Buttermilk (heat serum)	1.0214		

Density is technologically important when calculating the raw milk quantity, when determining adulterations, for automatic fat standardization, for the determination of water in buttermilk and when manufacturing concentrates for longlife products.

A rapid method for the determination of density in milk uses the lactodensitometer.

The solid density is important in separation processes. e.g. centrifugation of cheese fines, cyclone operation and the pneumatic or hydraulic transport of powders and particulate matter.

Bulk density is an important property, particularly for the transportation and storage of bulk particulate material e.g. fruit, grain, powders. It is the mass of material divided by the total volume occupied.

In most cases, it is important to have a high bulk density. The bulk density of milk powder is affected by processing condition. The bulk density increases as the total solids increases. The particle density increases as the total solids increase indicating that less air is incorporated into the particles at higher total solids. Injection of air or nitrogen into the product immediately before atomisation may reduce the bulk density and agglomeration achieved by a re-wetting process substantially decreases the bulk density.

The method of atomisation will also affect the bulk density. Early designs of atomiser wheel produced powder 0.45 - 0.55 g/ml, whereas later designs typified by the vaned wheel produced bulk densities of ·0.55- 0.65 g/ml; later designs have used steam to occlude air from the fluid. Jet nozzles can produce powders with bulk densities as high as 0.83 g/ml.

The porosity is the fraction of the total volume which is occupied by air between particles. It does not take into account air within the particles.

Porosity = $(\rho_s - \rho_b) / \rho_s$

where ρ_s = solid density and ρ_b = bulk-density

The density of whole milk powder ranges from 43 to 51 per cent.

4.2 Boiling and Freezing Point

The boiling point for milk is 100.2 ℃, slightly higher than for pure water. The boiling point of both cow and buffalo milk ranges from 100.2 ℃ to 101℃ with an average of 100.5 ℃. The boiling point ranges slightly with the percentage of solids present in milk.

The freezing point of cow milk and buffalo milk ranges from – 0.535 ℃ to – 0.59 ℃ with an average of – 0.553℃ depending on the lactose, proteins and mineral content.

The average freezing point of raw milk is at -0.526 ℃; of pasteurized milk in the range -0.517 to -0.521 ℃. This is influenced (see also the boiling point) by the dissolved lactose and the similarly dissolved ions of the milk salt and a few other compounds with a relatively low molecular mass.

This relationship permits to detect adulteration with water or with additives e.g. salts, disinfectants or neutralizing agents.

The freezing point of raw milk has a lower value of -0.515 ℃, values of < -0.5 ℃ indicate adulteration with water. Values of > -0.62℃ indicate adulteration with salts.

The freezing point can be modified by gassing/ degassing of milk, lactose splitting or pH modification.

The presence of dissolved substances elevates the boiling point of a solution.

Dissolved substances lower the freezing point of a solution, since milk is a solution containing salts and sugars its freezing point is lower than that of water.

The fortification of milk with milk powder or lactose lowers the freezing point.

Lesson 5. Chemical properties of milk and milk products-II

5. INTRODUCTION

The physico-chemical properties of milk and milk products affect most of the unit operations used during their processing. These operations include fluid flow, heat transfer processes, mixing and churning, emulsification and homogenisation. Some of the rheological properties are also used for assessing and monitoring the quality of products such as cream. dahi, butter and cheese.

Raw milk is extremely variable in its composition and most dairy products can be produced in a variety of ways from this milk. There are two approaches to obtain, data for physical properties. The first is to use data available in the literature; the second is to determine the values experimentally.

5.1 Refractive Index

The refractive index of milk is sometimes used to indicate adulteration especially watering. The refraction of light by a solution depends upon the individual molecular substance present and upon their concentrations. The total refraction is sum of the individual refractions of the constituents present in the solution. The refractive index of the milk then is the refractive index of the solvent plus the indices of the solutes. The freezing point determination is more reliable than the refractive index for detecting added water. The average refractive index of cow milk has been found to be 1.3461 and that of buffalo milk 1.3477 at 40℃.

5.2 Acidity and pH

The natural or apparent acidity of fresh milk is caused by the presence of casein, acid-phosphates, citrates etc. in milk. Thus higher the solids-not-fat the higher the natural acidity. The natural acidity of cow milk varies from 0.13 - 0.14 percent and that of buffalo milk from 0.14 – 0.15 percent. Developed or real acidity is due to lactic acid formed as a result of bacterial action on milk lactose. The titrable acidity is usually expressed as percent of lactic acid and for stored milk is equal to the sum of natural acidity and developed acidity.

As milk is slightly acidic, its pH is lower than 7 which is the value for neutrality. The pH of fresh cow milk varies from 6.6 to 6.7 and that of buffalo milk from 6.7 to 6.8 Skimming and dilution with water raise the pH of milk while sterilization usually lowers it.

Soxhlet-Henkel value (potential acidity or titrable acidity). The acid reaction as it occurs in milk and dairy products is often expressed in terms of the Soxhlet-Henkel value (SH, SHV), The SH value indicates how many cm^3 of a caustic solution with a concentration c (NaOH) of 25 mol per cm^3 (N/4) are required to neutralize 100 cm^3. As an indicator, about 1 cm^3 of a 2% alcoholic phenolphthalein solution is added. Absolutely fresh milk from healthy cows has an SH value of 6.4-7.0. Part of this is due to acidic salts, e.g., NaHC03, and the free organic acids (mainly citric acid); the balance is due to casein, which reacts to NaOH like an acid. The increase of the SH value after milk coagulation is due to the formation of lactic acid by the corresponding bacteria, especially lactic acid bacteria.

SH values in raw milk < 5.0 indicate mastitis, defects in feeding or negative microbial influences, resulting in reduced lab coagulation or taste defects in milk. SH values of 8.0- 9.0 result in a noticeable sour taste, at SH values> 10 protein coagulation during heating of the milk occurs.

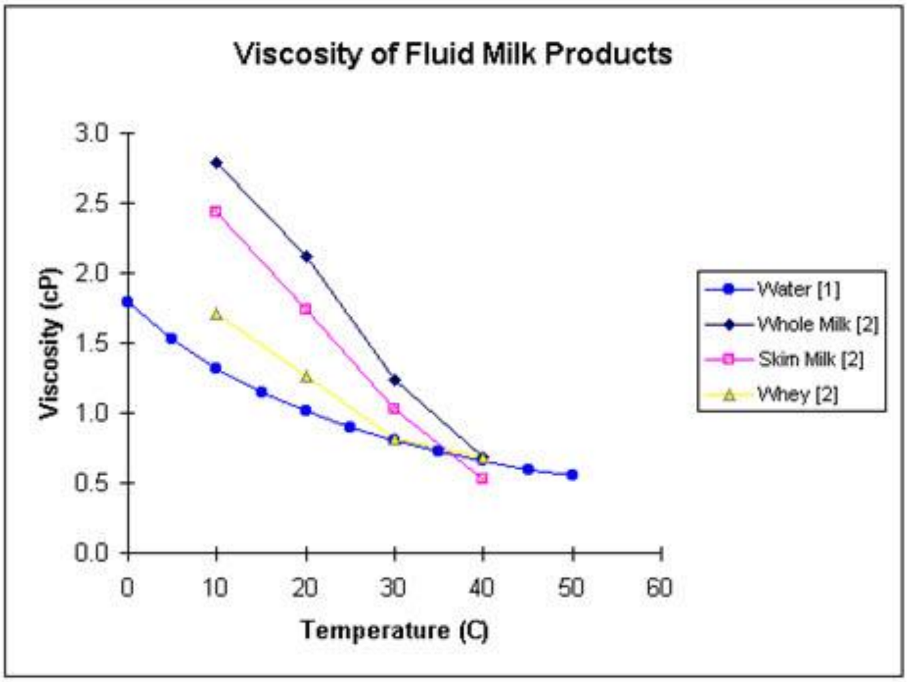
SH values of 10-12 will not necessarily lead to heat precipitation, because due to breeding activities a higher value can be obtained. Then the acidity has to be determined by the pH value, as the SH analysis cannot determine the dissociated part of the acid precisely.

As the dissociated part of the acid cannot be determined precisely by SH analysis (and nondissociated acidic parts can also be neutralized too), we call this the probable potential acidity. This determination becomes more imprecise the lower the percentage of titrable serum becomes (e.g., cream with a high fat content).

Other acidity determinations by titration result in Thorner degrees and the Domic grade. Sometimes acidity is given as g lactic acid per 100 cm^3 milk or % lactic acid

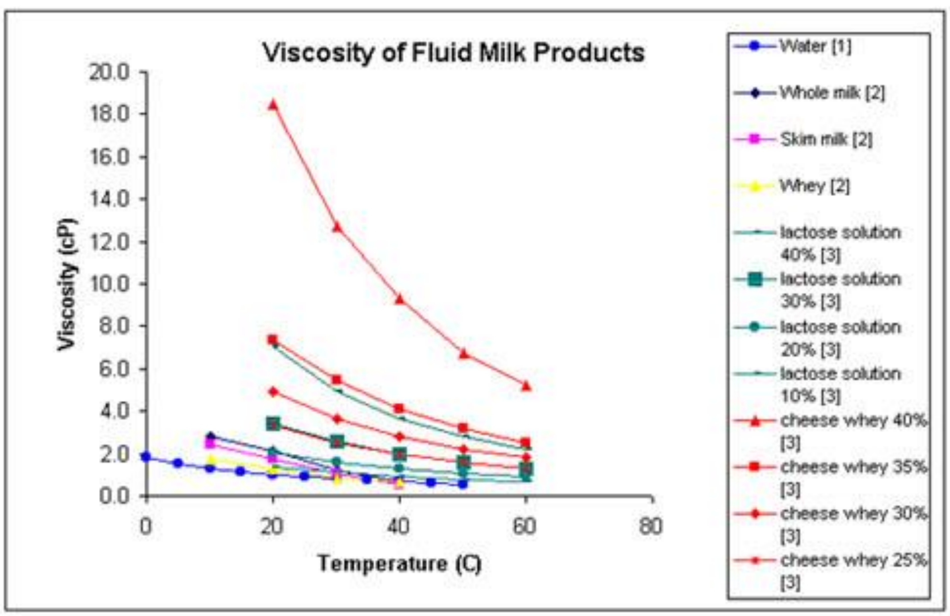
5.3 Viscosity

The dynamic viscosity μ is a parameter related to the inner friction of a liquid or fluid. It is reduced when temperature is increased. Due to the friction of the fat (emulsified in milk) and the dispersed protein, the viscosity of milk is twice as high as that of water. It increases with the protein coagulation and increasing fat content. The dimension of the dynamic viscosity is Ns/m or Pa-s; an old term is the centipoises cP (10^{-3} Pa-s). The value for milk at 5°C is a function of the fat content and ranges from 2.96 X 10^{-3} Pa- s (skimmed milk) and 3.25 X 10^{-3} Pa-s (whole milk); at 20°C we observe a range of 1.79 X 10^{-3} Pa-s and 2.13 X 10^{-3} Pa-s.



[1] Lange (1967)

[2] Kessler (1981)



[1] Lange (1967)

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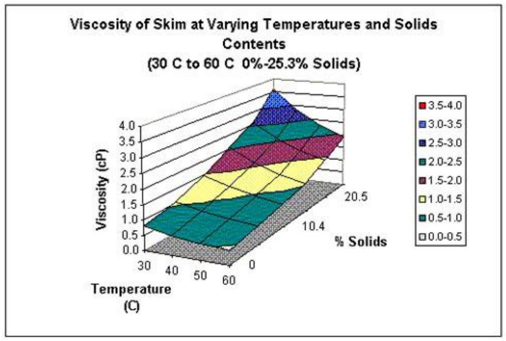
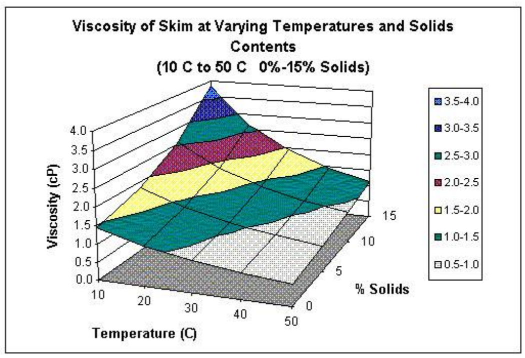


Kubota et al. (1980)

Temperature C / % Solids

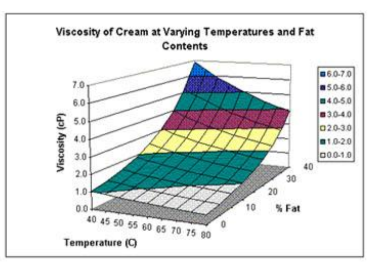
Temperature C	0	5	10.4	17	20.5	25.3
30	0.8	1.0	1.5	2.1	2.6	3.6
40	0.7	0.9	1.2	1.6	2.1	2.8
50	0.5	0.7	1.0	1.3	1.7	2.3
60	0.5	0.6	0.8	1.0	1.4	1.9



Kubota

Temperature C / % Solids

Temperature C	0	5	10	15
10	1.441	1.830	2.564	3.829
20	1.104	1.378	1.862	2.654
30	0.875	1.076	1.408	1.927
40	0.714	0.866	1.103	1.456
50	0.597	0.716	0.889	1.138



Phipps (1969)

Temperature C / % Solids

Temperature C	0	5	10	15	20	25	30	35	40
40	1.045	1.243	1.516	1.884	2.379	3.048	3.959	5.207	6.932
45	0.956	1.138	1.389	1.728	2.184	2.801	3.642	4.796	6.393
50	0.877	1.045	1.277	1.589	2.011	2.581	3.360	4.429	5.911
55	0.806	0.962	1.176	1.465	1.856	2.385	3.108	4.102	5.480
60	0.744	0.888	1.086	1.355	1.717	2.209	2.882	3.808	5.094
65	0.687	0.821	1.006	1.255	1.593	2.051	2.679	3.543	4.746
70	0.637	0.761	0.933	1.166	1.481	1.909	2.496	3.305	4.432
75	0.591	0.708	0.868	1.085	1.380	1.781	2.330	3.089	4.148
80	0.550	0.659	0.809	1.012	1.288	1.664	2.180	2.894	3.890

5.4 Surface Tension

Surface tension σ [N/m] is often given in dyne/cm (1 dyne/cm = 10 N/m); it is the work *W* required to recreate a new liquid surface *A* of 1cm. In other terms, the surface tension corresponds to a force *F* which is oriented parallel to the surface, in relation to 1cm of length *l*, against which work is to be done when the surface is increased.

$$\sigma = \frac{W}{A} \text{ or } F$$

The surface tension, which causes the contraction of a liquid surface, acts as an inter- face tension between phase layers (liquid/air, liquid/liquid, liquid/solid). Each phase has its own surface tension, which depends upon the characteristics of the ingredient. In cleaning processes e.g., the surface tension of the area to be cleaned is reduced, which results in complete wetting of the surface despite the higher surface tension of the water. The surface tension of water is 72.8 dyne/cm at 20°C. Milk and dairy products have a lower value due to fat and protein. Surface tensions for milk and dairy products (all data in dyne/cm) are:

Raw milk	49 – 51	Standardized milk	51
Skimmed milk	52 – 53	Cream	42 – 45
Buttermilk	39 – 40	Lab whey	51 - 52

Module 3. Unit operation of various dairy and food processing systems, process flow charts for product manufacture.

Lesson 6. Unit operation of various dairy and food processing systems-I

6. INTRODUCTION

The study of process engineering is an attempt to combine all forms of physical processing into a small number of basic operations, which are called unit operations. Food processes may seem bewildering in their diversity, but careful analysis will show that these complicated and differing processes can be broken down into a small number of unit operations. For example, heating, there are innumerable instances occur in every food industry. There are many reasons for heating and cooling - for example, pasteurization of milk, baking of bread, freezing of meat and frying of potato slices in oils. But in process engineering, the prime considerations shall be the extent of the heating or cooling that is required the conditions under which this must be accomplished. Thus, this physical process qualifies to be called a unit operation.

Various unit operations common to many food products include heating/cooling (heat exchange), materials handling, cleaning, concentrating, controlling, disintegrating, drying, evaporating, fermentation, forming, mixing, packaging, pumping and separating.

6.1 Material handling

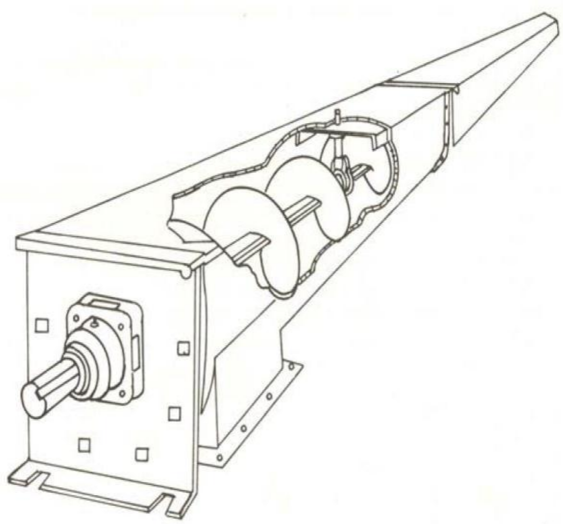
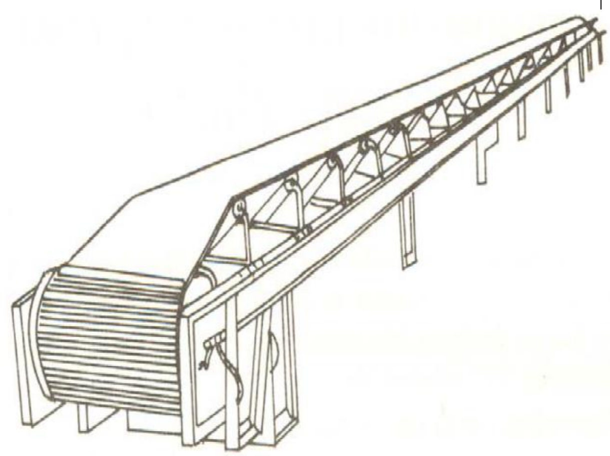
Materials handling includes variety of operations such as mechanical harvesting on the farm, transportation of live cattle, refrigerated transportation of perishable produce and pneumatic conveying of flour from rail cargo to bakery storage bins.

Throughout such operations it is very important to minimize product losses, to maintain raw material quality (e.g., vitamin content and physical appearance), to maintain sanitary conditions, to minimize bacterial growth and to maintain timing of all transfers and deliveries so that holdup time can be minimized, which can be uneconomical as well as harmful to the quality of the product.

The movement of produce from farm to processing area may lead to change it into many different forms. For example, Grapes are transferred by tractor/ truck/ trailer to juice plants/ wineries, where they are graded, washed and further processed. There is a limit to the size the trucks/trailers may be and the length of time the fruit may be held since fruits and vegetables are alive, respire and can lead to rise in the temperature of a batch to the point where spoilage may occur.

Handling of sugar and flour is also a challenging work. When dry sugar reaches processing plants, via truck trailers or rail, it is moved to storage tanks via a pneumatic conveying system. The sugar has a tendency to cake if the storage time, temperature and humidity are not maintained. Improper movement of sugar may also lead to dusting and buildup of static electricity, which may cause an explosion, as the sugar particles are highly combustible. The same is the case with the flour industry. Proper method of material handling has the additional advantages of preventing loss of desirable volatile compounds from the spices, irritation to personnel and flavor exchange between different spices.

The wide variety of screw conveyors, bucket conveyors, belt conveyors and vibratory conveyors in food plants are required for conveying and handling of variety of food materials.

	
Screw Conveyor	**Belt Conveyor**

The material handling is intended to achieve following major objectives:

(1) Acceptable product quality

(2) Proper sanitation

(3) Minimum holding time

(4) Minimum loss of product and

(5) Minimum bacterial growth

6.2 Pumping

One of the most common unit operations in the food industry is the moving of liquids from one location or processing step to another by pumping. There are many kinds of pumps available depending upon the nature of the food to be pumped. One common type is a rotary gear pump, where the inner gears rotates and sucks food into the pump housing and subsequently squeezes food out of the pump housing. For motives of mechanical efficiency, with such pump, close clearances between the gears and housing are necessary. Although such pump is effective for moving liquids and pastes, it may crush the chunk-type foods, reducing them to purees. A single screw pump is best suitable for pumping food with large suspended pieces without disintegration. Such pumps are also known as progressing cavity pumps and can be selected for large clearances of the cavities between the rotating center rotor and the housing. The food is gently pushed from large clearance to large clearance by the screw like action of the turning rotor. Food pieces such as corn kernels, grapes and even small shrimp can easily be pumped without any physical damage that would have been ground up in the gear-type pump. Centrifugal pumps are generally used for moving the liquids to the plate heat exchangers to avoid excessive pressure buildup within plates.

An essential feature for all food pumps is ease of disassembly for thorough cleaning. Today's sanitary stainless steel pumps in many cases can be disassembled in minutes with a single tool.

6.3 Cleaning

All the foods are naturally available/ grown in open environment. This leads to compulsion in cleaning all foods before consumption. It may vary from simple removal of dirt from fruits and vegetables with an abrasive brush to the complex removal of bacteria from milk by microfiltration. Grains are also cleaned of stones by passing through screening with or without vibrations before they are used.

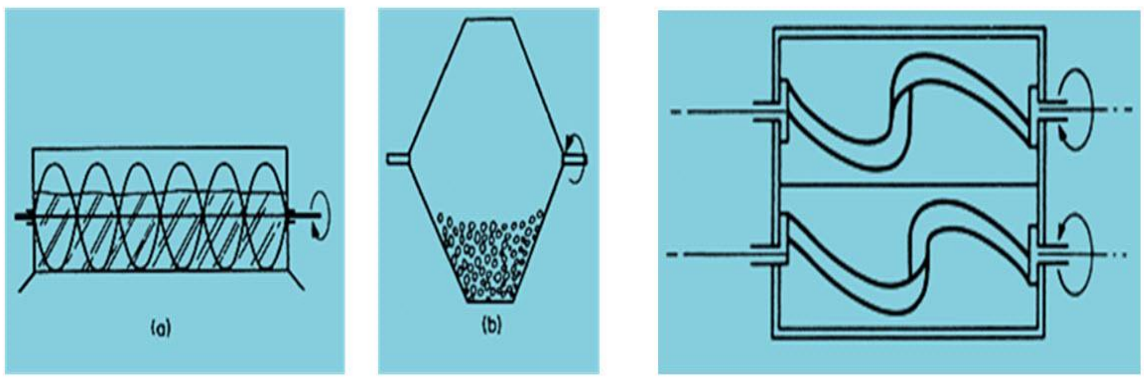
Cleaning can be done using water, steam, pressurized air, brushes, vacuum, magnetic attraction of metal contaminants, mechanical separation and other techniques, depending on the characteristic of the product and dust/dirt. The purity of water used in the soft drink bottling industry must exceed many of the standards found adequate for drinking water. If a high degree of carbonation is to be achieved, then the water used in making the drink must be remarkably free of dust particles, colloidal particles and certain inorganic salts, as these minimize carbon dioxide solubility and promote excessive escape of gas bubbles. To adequately purify this water treatment with controlled chemical flocculation of suspended matter, sand filtration, carbon purification, microfiltration and de-aeration may be employed. This is no longer the unit operation of cleaning but a total cleaning process.

Some cleaning methods are defined by surface characteristics of the product. For example, pineapples have an asymmetric surface, high-pressure water jets are used for removing the dirt from the grooves below the eyes of the fruit. Similarly, different food materials require special cleaning equipment and methods. For the cleaning of equipment, walls and floors of the plant, the chemical and physical properties of both the surface to be cleaned and the type of soil must be taken into consideration. Many types of soil can be removed with mild alkaline detergents, but strong alkali may be required for more tenacious deposits and heavy deposits of fats and oils or built up protein deposits. Some hard soils of salts, formed during heating, will require strong acids to efficiently clean the heating surface.

6.4 Mixing

One may wish to mix solids with solids, liquids with liquids, liquids with solids, gases with liquids and so on. Like pumps, there are many kinds of mixers available depending on the materials to be mixed.

For simple mixing of dry ingredients such as the components that make up a baking powder, a conical blender is suitable. The tumbling action in the bowl continued for 10-20 min makes the mixture is homogenous. If we want to prepare a dry cake mix, we must cut the shortening into the flour, sugar and other dry ingredients in order to produce a fluffy homogeneous dry mix. We may use a ribbon blender, which is a horizontal trough with one of several types of mixing elements rotating within it. The efficiency of mixing depends on the choice of the mixing element. These types of ribbon like elements suitable for cutting in shortening. For mixing solids into liquids, a propeller mounted within a stainless steel vat is most desirable. There are many types of propellers, turbines and paddles available for such kind of mixing.



Mixers (a) ribbon blender, (b) double-cone mixer (c) Kneader

All types of mixers do almost similar work on the material being mixed and cause some elevation in temperature. It is generally desirable to control the temperature rise. However, to work on heavy viscous materials special mixers are also chosen. Such mixers may have arms that knead dough, or paddles and arms that work butter. These working mixers are designed with precise geometries to maximize efficiency and minimize energy requirements to achieve the optimum mixing/working operation. Some mixers are designed to beat air into a product while it is being mixed. The scraper-beater found in ice cream freezers is an example (Fig. ANIMATION TO BE DEVELOPED). During freezing of ice-cream mix in the freezer cylinder, the beating element, or dasher, turns within the bowl. It not only keeps on scraping the mix from the cylinder surface to speed up freezing and make product more uniform, but it also incorporates air into the mix being frozen to give the ice-cream with desired volume rise or overrun and smooth texture.

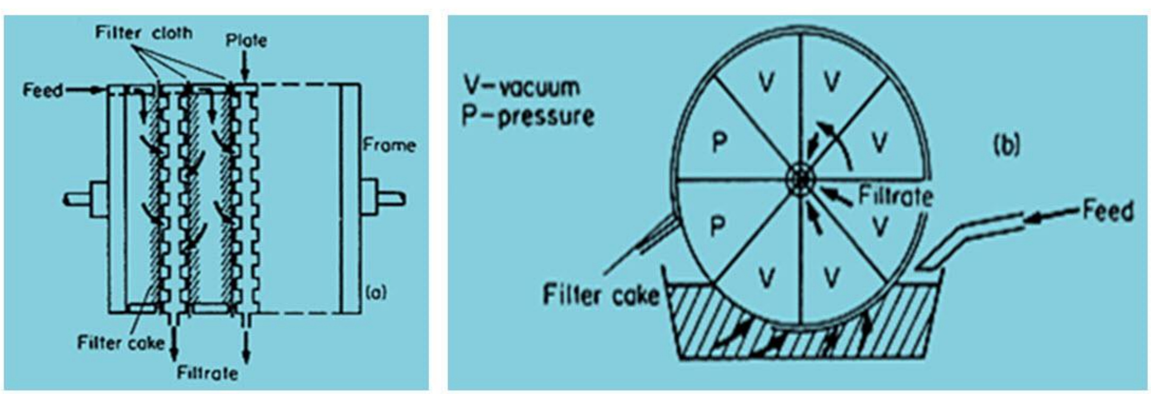
6.5 Separating

Separation can involve separating a solid from a solid, as in the peeling of potatoes or the shelling of nuts; separating a solid from a liquid, as in the many types of filtration; or a liquid from a solid, as in pressing juice from a fruit. It might involve the separation of a liquid from a liquid, as in centrifuging oil from water, or removing a gas from a solid or a liquid, as in vacuum removal of air from canned food in vacuum canning.

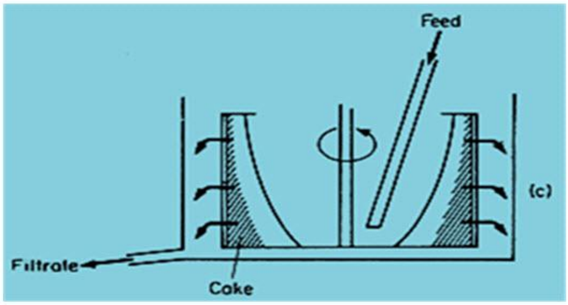
One of the most common forms of separating in the food industry is the hand sorting and grading of individual units as in case of vegetables and fruits. However, mechanical and electronic sorting devices have been developed because of the high cost of labor. Difference in color can be detected with a photocell and off-colored products are rejected. This can be done at massive speeds with automatic rejection of discolored or moldy nuts or kernels of grain that flow past the photocell. In case of manufacturing of peanut butter from peanuts, each peanut individually passes through a light beam that activates a jet of air due to change in reflection and blows off the discolored peanuts from the main stream. Light shining through eggs can detect blood spots and automatically reject such eggs. By passing fruits or vegetables over different size screens, holes or slits, automatic separation according to size is easily accomplished.

The skins of fruits and vegetables can be separated using a lye peeler. Fruits such as peaches, apricots etc. are passed through a heated lye solution where the skin of fruits is softened. Soft skin can be easily slipped from the fruit by gentle action of mechanical fingers or by jets of water. Density difference of the fruit and skin can then be used to float away the removed skin.

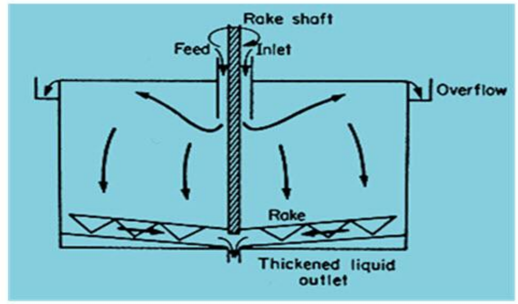
To extract corn oil from corn kernels, the germ portion of the corn first is separated from the rest of the kernel by milling; then the oil is separated from the germ by applying high pressure to the germ in an oil press. Similarly, pressure is used to squeeze oil out of peanuts, soybeans and cottonseeds. The traces of oil can be separated from the pressed cake by the use of fat solvents. The separation of the oil from the solvent can be achieved by distillation apparatus.



(a) Plate and frame press **(b) Rotary vacuum filter**



(c) Centrifugal filter



(d) Continuous-sedimentation plant

Salt from sea water or sugar from sugar cane juice can be separated by crystallization. Here, evaporation of some of the water makes the solution super saturated and forms crystals. Since crystals are quite pure, this may also be considered as purification process. The crystals are then separated from the suspending liquid by centrifugation. Newer methods of separation include several techniques involving manufactured membranes with porosities or permeabilities capable of fractionating the colloidal and macromolecular size level. Ultra filtration uses membranes of such porosity that water and low-molecular-weight salts, acids and bases pass through the membrane but larger protein and sugar molecules are retained. This selective permeation process may also be carried out at ambient temperatures to avoid the damage to heat sensitive food constituents that is common with water evaporation at high temperatures. Further, removal of acids and salts with the water prevents their concentration, which would otherwise be detrimental to sensitive retained solids.

6.6 Size Reduction

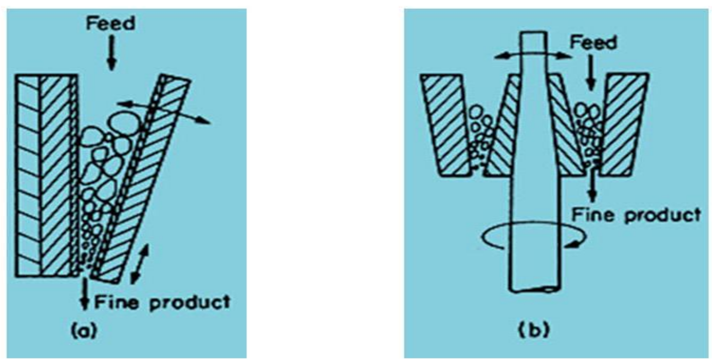
The term size reduction means particles of solids are cut or broken into smaller pieces. Throughout the process industries solids are reduced in size and shape by different methods for different purposes. Size reduction is carried out by mechanical means without any change in chemical properties of the materials. Here, the chunks of large particles are crushed or reduced to workable size. In this process uniformity in size and shape of the individual particles of the resultant product is desirable, but difficult to attain. Reduced size leads to increased reactivity of solids, helps separation of unwanted ingredients and reduces the bulk of fibrous materials for easier handling.

The equipment mostly used for size reduction of agricultural products are crushers and grinders. Usually the performance of any milling equipment is compared with respect to an ideal operation as standard. Amount of power required to create smaller particles and desired uniformity of size are the parameters for the efficient of operation. The ground product consists of a mixture of various particle sizes irrespective of uniformity of feed size. In some equipment there is a provision to control the magnitude of the largest particles like the hammer mill, but the fine size is beyond control. In some size reducing machine fines are minimized but they can’t be eliminated.

There are many methods of size reduction, but only four of them are commonly used: (1) compression, (2) impact, (3) attrition or rubbing and (4) cutting. A nutcracker, a hammer, a file and a pair of scissors exemplify these four types of action. In general, compression is used for coarse reduction of hard solids, to give relatively few fines; impact gives coarse, medium, or fine products; attrition yields very fine products from soft, nonabrasive materials. Cutting gives a definite particle size and sometimes a definite shape, with few or no fines.

6.6.1 Crushing

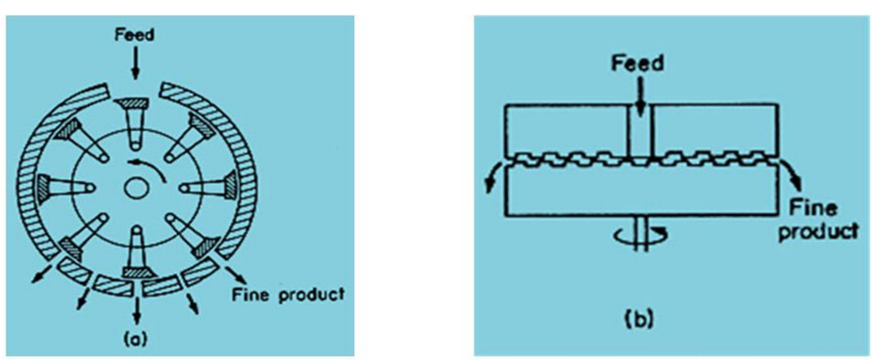
When an external force is applied on a material in excess of its strength, the material fails because of its rupture in many directions. The particles produced after crushing are irregular in shape and size. Food grain flour, grits and meal, ground feed for livestock are made by crushing process. Crushing is also used to extract oil from oilseeds and juice from sugarcane.



Crushers: (a) jaw, (b) gyratory

6.6.2 Impact

When a material is subjected to sudden blow of force in excess of its strength, it fails, like cracking of nut with the help of a hammer. Operation of hammer mill is an example of dynamic force application by impact method.



Grinders: (a) hammer mill, (b) plate mill

6.6.3 Cutting

In this method, size reduction is accomplished by forcing a knife through the material, where minimum deformation and rupture of the material is achieved. An ideal knife is of excellent sharpness and as thin as practicable. The size of vegetables and fruits are reduced by cutting by knives.

6.6.4 Shearing

It combines cutting and crushing and consist of units like a knife and a bar. In an ideal shearing unit the clearance between the bar and the knife should be as small as practicable and the knife as sharp and thin as possible.

Lesson 7. Unit operation of various dairy and food processing systems-II

7.1 Heat Exchanging

Heat exchanging is one of the most important unit operations of any food industry. Every industry must able be to control the temperature of products at every stage in the process. Heating and cooling are therefore very common heat transfer operations in the dairy/ food plant

7.1.1 Heating

We heat foods for many different reasons among them the major reasons are to cook the food for better palatability and tenderness, to destroy microorganisms and to preserve it. For example, baking of bread, pasteurization of milk and canning of vegetables. Others are heated to drive off moisture and develop flavors, as during the roasting of coffee and toasting of cereals. Some food ingredients, such as soybean meal, are heated to inactivate natural toxic substances.

Heating of foods is carried out by conduction, convection, radiation, or combination of these. Most foods are heat sensitive and prolonged heating causes loss of nutritional values, formation of dark colors and burnt flavours. Rapid heating can destroy microorganisms faster than it causes undesirable chemical reactions. Since microorganisms are more sensitive to rapid heating than are chemical reactions, hence, it is desirable to heat and cool foods rapidly to maintain optimal quality. Rapid heating is achieved by giving maximum contact with the heating source. This may be accomplished by dividing the food into thin layers in contact with heated plates as in the plate-type heat exchanger used to pasteurize milk. The milk flows across one side of the plates while hot water or steam heats the other side. Such plate heat exchangers can be used for rapid cooling with cold water or brine instead of hot water. But the limitation with plate heat exchanger is that it can only be used with liquid foods. A jacketed tank or kettle with steam/ hot water circulated in the jacket is another way of heating liquid foods. It can also be used to heat foods with suspended solids like vegetable soup. The soup is kept moving with an agitator for uniform heating and to avoid burning onto the kettle wall.

For in-can or in-bottle sterilization of foods, they must be heated to temperatures higher than the boiling point of water to sterilize nonacid foods and to achieve that large pressure cookers or retorts are used. High pressure is used to obtain the high temperature needed using pressure cookers of heavy construction to withstand this pressure. Another type of retort employs mechanical agitation for better convection of heat within individual cans, where the outside of the cans are heated by conduction from steam. For roasting coffee beans or nuts, many kinds of heaters are being used. In one type, the beans or nuts move from overhead hoppers into cylindrical vessels that turn and keep the beans in constant motion for even heating. These vessels may be heated from within by circulating heated air or with radiant heat from the vessel walls and the exterior by contact with hot air, gas flame or steam. In some instances this type of roaster is replaced with tunnel ovens in which the coffee beans or nuts pass on moving belts or are vibrated beneath radiating infrared rods or bulbs. Whatever the method, precise control of temperature is essential for proper roasting. Foods may be heated or cooked using toasters, direct injection of steam, direct contact with flame, electronic energy as in microwave cookers and so on; all of these methods are currently used in the food industry. Processes such as baking, frying, most food concentration, food dehydration and various kinds of package closure all employ the unit operation of heating.

7.1.2 Cooling

While heating is the addition of heat energy to foods, cooling is the removal of heat energy. This may be done to the level where food is chilled to refrigeraton temperature, or beyond the freezing point. Primarily, food is refrigerated and frozen to enhance its keeping quality. But there are some foods that owe their entire character to the frozen state. A prime example is ice cream. A mixture of milk and cream are cooled by passing them in thin layers through heat exchangers by allowing the liquids to run down over the surface of a hinged leaf cooler. Within the leaves are pipes through which cold water or refrigerant is pumped. Liquid egg, apple slices and other fruits in 13.6 kg cans are commonly frozen solid in an air-blast freezer or sharp freezer room maintained at about -26°C. The cans are kept with certain space allowing the cold air to be circulated by fans/blowers, between them to speed up the freezing operation. Such products are mainly sent to bakeries for use after thawing.

There are many kinds of commercial air-blast freezers designed to freeze peas, beans and other vegetables as individual pieces. In one type, the peas are loaded on trays that are automatically moved upward through a cold air blast. After freezing, the peas are removed from the trays and conveyed under cold air to packaging equipment. The trays return to initial position under the pea hopper to receive next batch and the cycle is repeated.

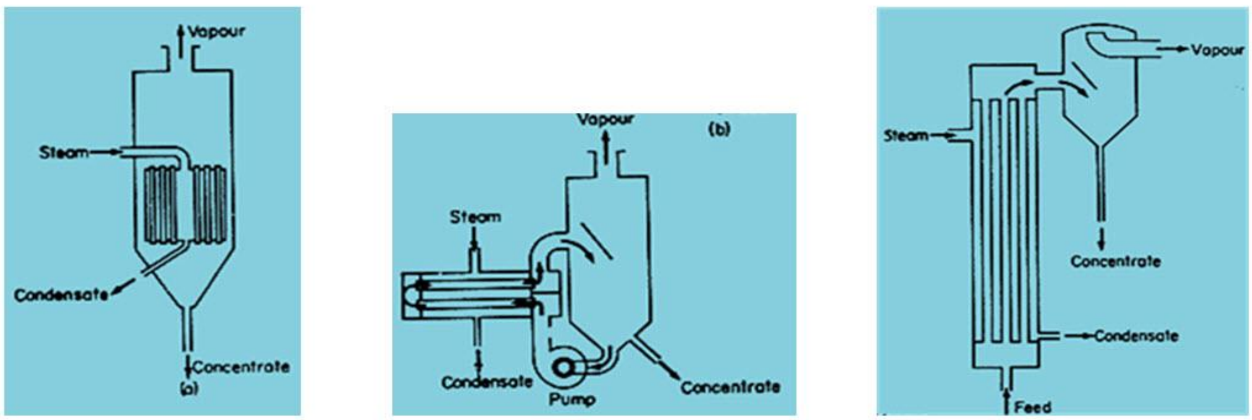
Freezing of canned or packaged foods may be done by direct immersion in a refrigerant. Here the cans may be agitated as they pass through the refrigerant within a cylindrical shell or tube, to increase the rate of heat transfer. The value of quick freezing to food quality has led to the use of liquid nitrogen with its extremely low temperature of -196°C.Many food plants have installed large liquid nitrogen tanks and pump liquid-nitrogen to freezers where it is sprayed directly onto foods to be frozen. Delicate products such as mushrooms/strawberries are frozen this way.

7.2 Evaporating

In food industry, evaporation is used principally to concentrate liquid foods by the removal of water and also to increase the shelf life of the food to certain extent. It is also used to remove undesirable volatiles and to recover desirable food volatiles.

The simplest and natural evaporation is the evaporation of sea water due to heat of sun and production of salt as a residue. Grapes and other fruits can be dried using sun drying. Another simple form of evaporation occurs when water and sugar is boiled in a heated kettle to make sugar syrup, as is common in candy-making. However, this requires considerable energy in the form of heat for a long period of time, which may cause damage to products which are heat sensitive, such as milk or orange juice.

The boiling point of all liquids is depressed as pressure decreases and this is the key to modern evaporation processes. If a heated kettle is enclosed and connected to a vacuum pump, one has a simple vacuum evaporator. Such evaporators are generally used to remove water from sugar cane juice in the early stages of crystalline sugar production.



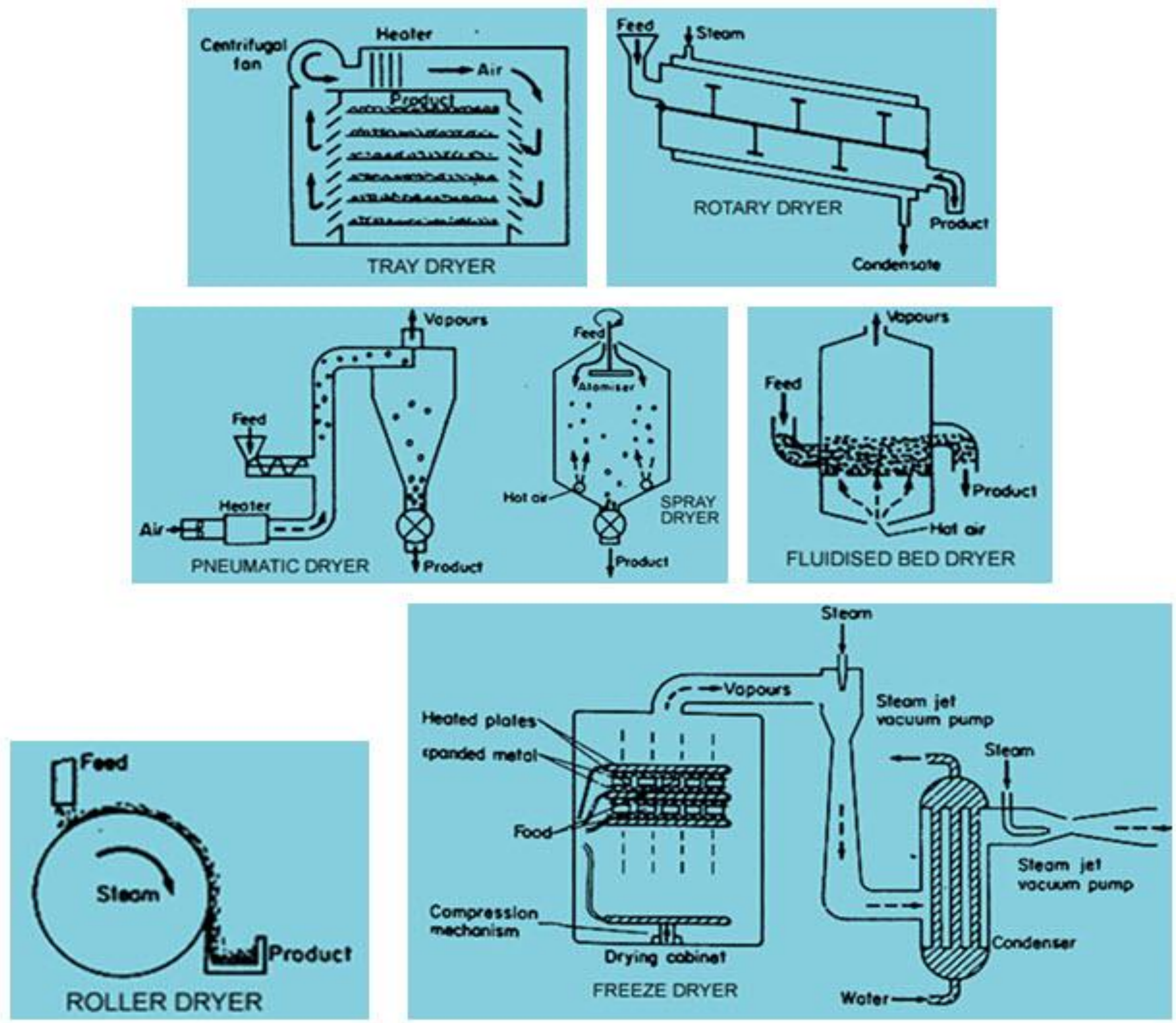
Evaporators (a) basket type (b) forced circulation (c) long tube

The level of vacuum in the evaporator is kept amplified gradually in subsequent stages through which the liquid food passes. Irrespective of design, major objective of vacuum evaporators is to remove water at temperatures low enough to avoid heat damage to the food. In multiple stage evaporators, we can easily remove water at 50°C and some are designed to boil off water at temperatures as low as 21°C. Milk is generally evaporated to a total solids content of 40%, before it is dried, to avoid nutritional damage, energy loss and physical damage.

7.3 Drying

In drying, the major objective is to remove as much water as possible with minimum damage to the food. In case of evaporation foods are concentrated two to threefold whereas, driers will take foods very close to nil moisture or in many cases less than 2% or 3% water. Driers are installed to prepare well-known products such as dried milk powder and instant coffee. Although food has traditionally been dried to preserve it for longer time as well as to reduce its bulk, some foods are dried as convenience items and for their novelty appeal; an example is freeze-dried fruits for cereals.

Foods in liquid form such as milk and chunk forms like shrimp or steak may be dried. It is generally much easier to dry liquid foods because these are easier to subdivide (both as a spray or a film) and in a subdivided form, the moisture can be removed more quickly. Subdivision of a liquid to increase the surface area is the principle behind the widely used spray drier. Liquid foods like milk, coffee or egg yolk is first concentrated to desired level and then pumped into the top of the large drying chamber, where the liquid is atomized by a spray nozzle or equivalent device. The chamber is incorporated with the hot air from the entry points kept in the drying chamber depending upon the product to be dried. The hot air in contact with the fine droplets of food dries the droplets and dehydrated particles are collected at the bottom of the drying chamber. The moisture removed with hot air during drying is exhausted separately.



Different type of Dryers

Drying food by making a thin film is commonly done on a drum or roller drier. The single or double drums are heated from within by steam on which the layer of food applied that loses the moisture immediately. The dried food is then mechanically scraped from the drum with long knives. Mashed potatoes, tomato puree and several milk products are preferably dried this way.

Small pieces of food such as peas and diced onions can be dried by passing them through a long tunnel dryer. However, overheating and shrinkage may result into poor quality products in the case of heat sensitive foods such as chunk foods where a milder method like vacuum freeze-drying is employed. There are many kinds of vacuum freeze-driers where, all types of food pieces are first frozen and then dehydrated under vacuum from the frozen state. Under the conditions of high vacuum ice portion of food directly sublimates. This is very gentle kind of drying protects majority of food quality attributes such as texture, color, flavor and nutrients. Freeze-drying can be easily done for solid or particulate foods without any restriction. Several Direct Vat Set Starter cultures, brewed coffee and nutritional and fresh like juice products are dehydrated by freeze-drying.

7.4 Forming

Foods are most often formed into specific shapes for convenience and attractiveness. For example, hamburger patties are formed by gently compacting ground beef into a disk shape in various types of patty-making machines, which apply controlled pressure to the beef within an appropriate form. Pressure is controlled to avoid the hamburger become overly tough or loose after cooking. Uniform pressure is essential or patties will vary in weight. Pressure extrusion through dies of various shapes forms dough into spaghetti and other pasta shapes for subsequent oven drying.

In the ice-cream industry, besides extrusion, frozen ice-cream is formed by filling in mold in which chocolate and nuts may be added followed by cooling and hardening. Some confectionaries and food tablets may be formed from powdered ingredients by the application of intense pressure in specially designed tableting machines. Sometimes, as in the case of malted milk tablets, an edible binding agent is required to hold the malted milk powder together. When the powders are high in certain sugars or other thermoplastic food constituents, an additional binding agent is not required. Here high pressure during tablet forming produces heat, melting some of the sugar or other thermoplastic material, which on cooling helps fuse the powdered mass together. This is one way to form fruit juice tablets from dehydrated fruit juice crystals. Some tablet-forming machines also may employ additional heat beyond that generated by pressure. The table butter and cheese are packed in the form of cubes or blocks by this operation only.

7.5 Fermentation

Fermentation is a process in which microorganisms generate energy by oxidizing carbohydrates and related compounds. It has been used since ancient times as important method of food preservation. Vegetables, fruits, cereals, milk and other food materials have been treated in special ways in order to promote the growth of beneficial microorganisms while inhibiting the growth of deteriorating and pathogenic microorganisms. Fermentation preserves the food and it also enhances the digestibility, taste, aroma, texture and nutritional value of the product. The fermentation end products like lactic acid, acetic acid, alcohols, antimicrobial substances, etc. provide the preservation effect to the fermented products. Besides lowering the pH, organic acids are also toxic for many microorganisms. It is also important that the fermentable carbohydrates are completely utilized by the fermenting microorganisms and thereby made unavailable for the undesirable microorganisms. In some products the addition of salt also increases the shelf life of the products by lowering the water activity. The natural habitats of lactic acid bacteria, yeast and molds are most often plant materials. However, the type of organisms can vary considerably depending on type of plant, climatic conditions and available nutrients in the raw material. During some fermentations (e.g., fermentation of plant material such as cabbage, cucumbers, olives, soya beans and coffee), several different types of microorganisms are required at various stages of the fermentation process. In other fermentations (e.g., production of yogurt and beer), only a few different microorganisms are required.

7.6 Packaging

The major objectives of food packaging include containment for shipping, dispensing and unitizing into appropriate sizes and improving the usefulness of the product. The primary goal of packaging is to protect the product from microbial contamination, physical dirt, insect invasion, light, moisture pickup, flavor pickup, moisture loss, flavor loss and physical abuse.

Foods are packaged in metal cans, glass and plastic bottles, paper and paperboard, a wide variety of plastic and metallic films or combinations of these. Continuous automatic machines sometimes at speeds of more than 1000 units per minute are used for packaging. Many food products were earlier being filled into rigid metal and glass containers are now being replaced with flexible and formable materials. Filling and capping machines are being joined by more sophisticated systems. Much of the consumer milk supply is now packaged in multi-layer paper cartons. Containers are automatically formed from stacked paper flats, volumetrically filled and sealed by passing the upper flaps through heated jaws, which melt the plastic coating and thus provide sealability. In recent years, paperboard cartons coated with special plastics which have good barrier to oxygen are widely used for orange juice and similar products.

Other machines form pouches from rolls of plastic/ aluminium laminate film, fill them and seal them. This is the way many popular snack food items are packaged. Still more complete systems form the container from roll stock film, fill the container to exact weight, draw a vacuum on the package to remove oxygen, back flush the package with inert nitrogen gas, seal the package and finally stack the packages into cardboard cartons. In this way, some dessert powders and dehydrated soups are commonly packaged.

The container-forming step is not restricted to the use of paper laminates or films of various materials. Some food-packaging machines handles plastic resins in granular form followed by melting and blow-molding or otherwise forming rigid or semi rigid containers for immediate filling and sealing. Main advantages of this system are the savings of storage space for various empty containers in food plants and the in-line production of virtually sterile containers, since the heat to melt the plastic resins also kills microorganisms.

Lesson-8: Unit operation of various dairy and food processing systems-II

Assignment

Answer the following.

1. Write about the plate heat exchanger.

2. Write in short about tunnel drying.

3. Write down objectives of packaging

Lesson 9 Process flow charts for dairy and food product manufacture

Flow chart for manufacture of Cheddar cheese from buffalo milk

Milk

↓

Standardization
(Casein: Fat= 0.68:1.0)

↓

Pasteurization
(63°C / 30 min or 72°C / 15 S)

↓

Ripening of Milk
(31°C, increase in acidity ~ 0.01%, 30 min)

← **Starter: Mesophillic** (*Str. Cremoris* & /or *Str. Lactis* @ 1.25%)

↓

Renneting of Milk
(31°C / 30 min, Fromase: 2.5-3.0 g / 100 L, Dilution about 30X)

↓

Cutting of Curd
(Cube size: ~ 1 cm, Whey acidity (W.A.) ~ 0.10%, Curd healing: 5-10 min)

↓

Stirring
(Enough whey to float the curd)

↓

Cooking / Scalding
(Temp. rise: 31°C→36.5°C, ~ 30 min)

↓

Draining of Curd
(1 / 2 of the vat content)

↓

Add Salt (NaCl)
(@ 1.75% w / v of the whey drained)

↓

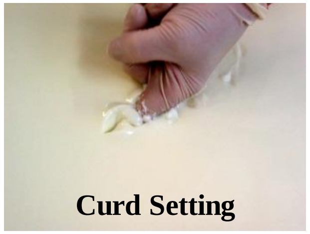
Cooking of the curd continued
(Temp.: 36.5°C, time ~ 40 min)

↓

Setting of Curd & Draining of Whey

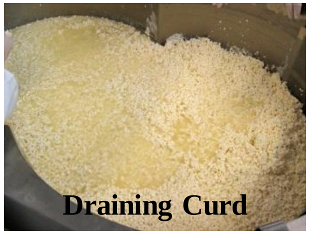
↓


Milk Vat


Curd Setting

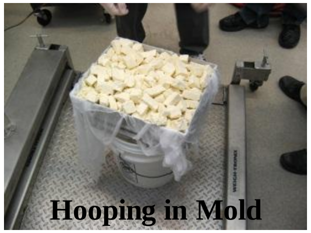

Cooking Curd


Curd Cutting


Draining Curd

Packing: 45 min
W.A. ~ 0.17-0.18%
Turning: every 15 min

Piling
Two Pile: 30-45 min
W.A. ~ 0.25%
Three Pile: 30-45 min
W.A. ~ 0.30%



Cheddaring
(Time ~ 2 h, Final W.A.: 0.40-0.45 %, curd structure: "Chicken Breast")

Milling the curd
(Curd strips ~ 5 / 8" X 2")

Hooping the curd

Initial pressing
(Time ~ 30 min)

Dressing & final pressing
(Overnight, 12-16 h)

De-hooping, Weighing and Coding

Drying for rind formation
(Temp. 10-15°C, RH- 50%)

Paraffining
(Paraffin + Microcrystalline wax, 1:1; Temp. ~ 110-115°C; Deeping: 3-5 S)

Cold curing
(Temp.: 5-6°C,
RH- 75%,
Period: 3-12 months)

Warm curing
(Temp.: 10-15°C,
RH > 85% <93%,
Period: 6-18 wk.)

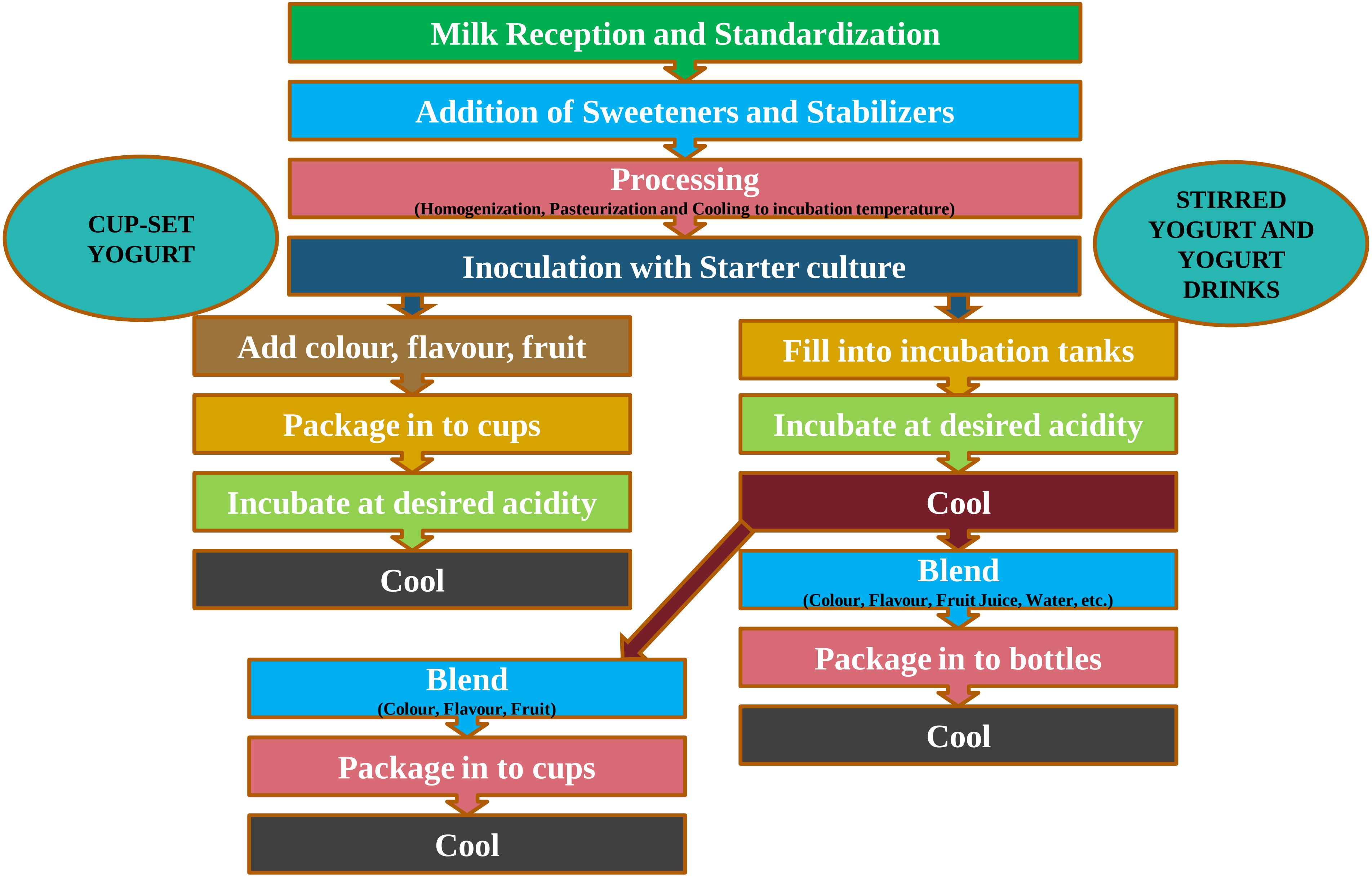
Ripening of cheese

Grading the cheese

Storage and/or Marketing

Flow chart for manufacture of Cheddar cheese from buffalo milk

Source: (Prateek Kumar, 1995)



Flow Chart for Yoghurt Manufacture

Flow chart for Chocolate Manufacture

Harvesting of Cocoa fruits
(Colour of ripe fruits - 4 to 6 months after flowering)

↓

Ripening of fruits
(1-2 days)

↓

Peeling and separation of beans and pulp

↓

Sorting
(bad beans, hollow beans, sprouting)

↓

Fermentation of beans
(box, heap, basket, tray – 1.5 to 10 days)

↓

Soaking of beans
(2 hrs.)

↓

Washing of beans
(2 hrs for 4 t wet beans in 250 kg machine)

↓

Drying
(Sun drying :1 week, Mechanical,: 20-44 hrs, 45-80 ^{o}C)

↓

Fermented and Dried beans

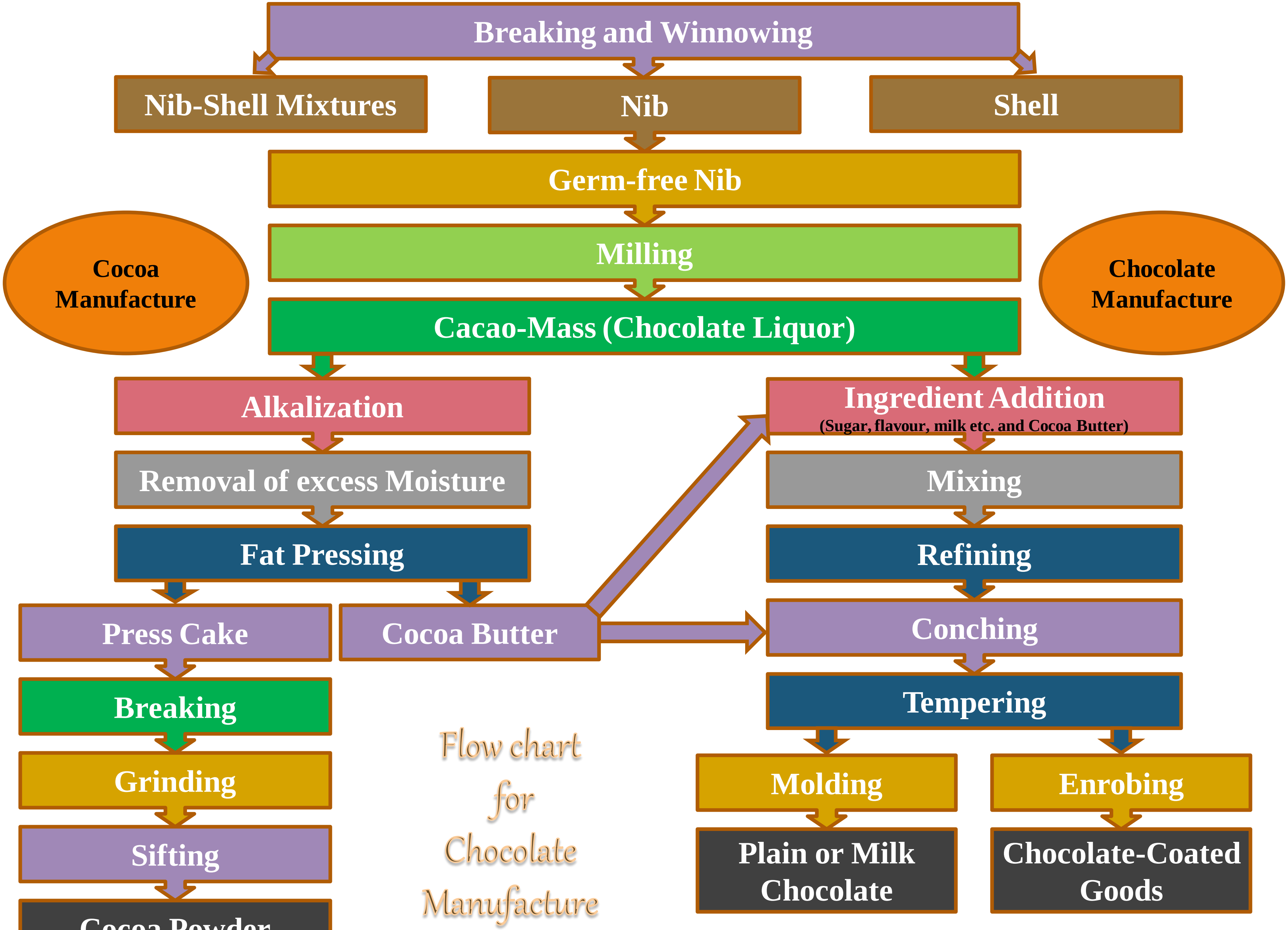
↓

Cleaning and Sorting the beans

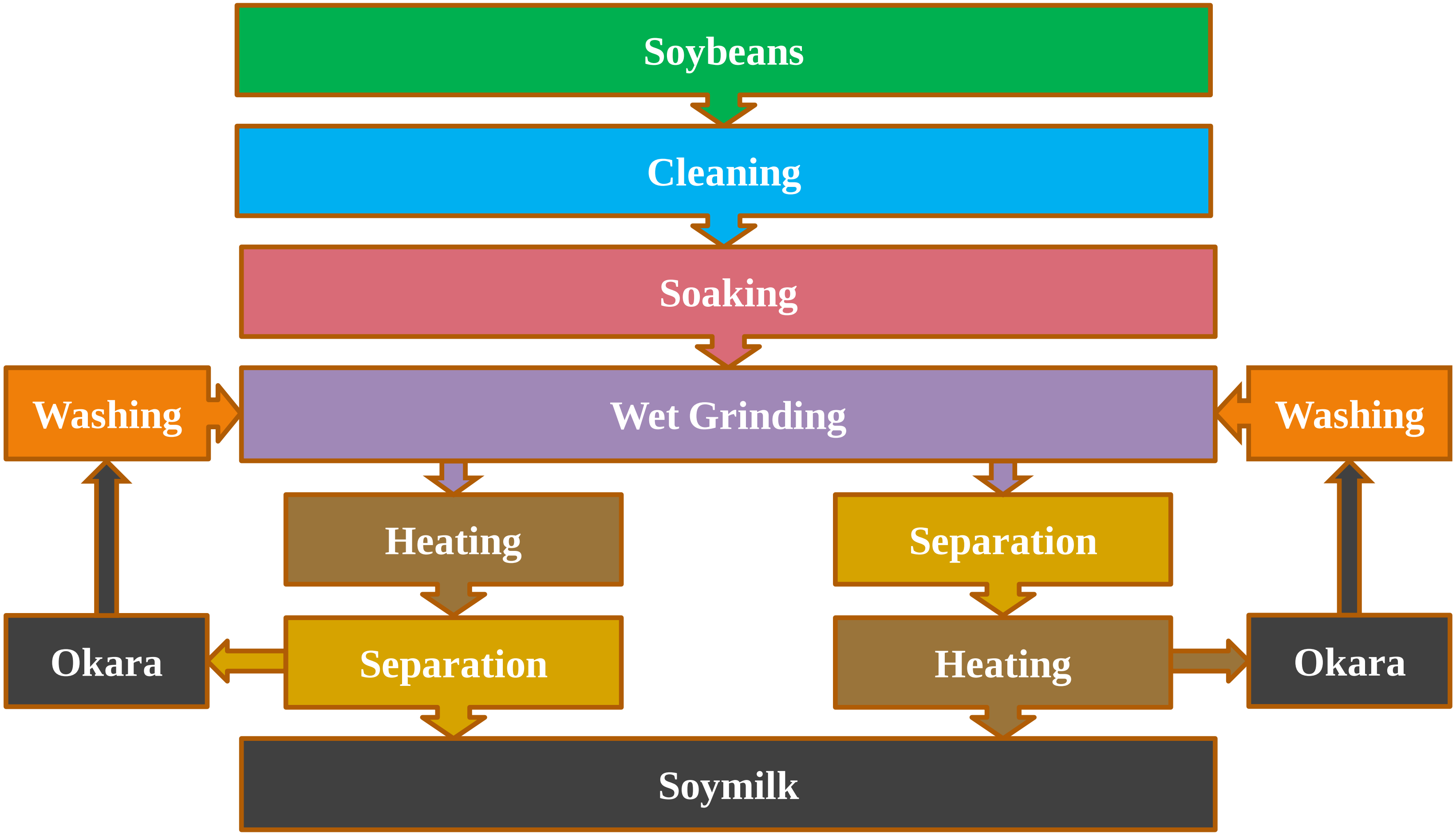
↓

Roasting of beans

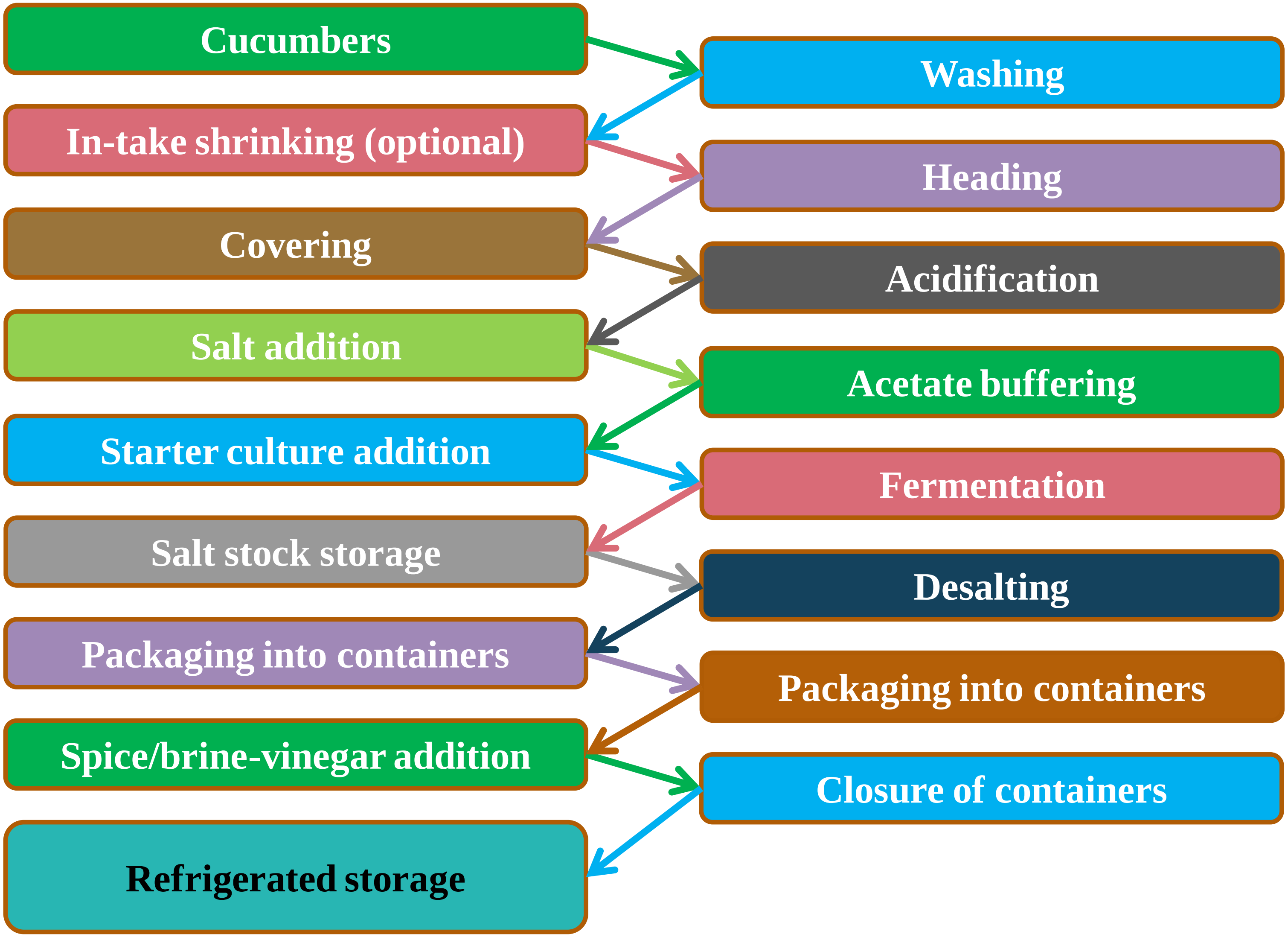
↓


Breaking and Winnowing
Nib-Shell Mixtures
Nib
Shell
Germ-free Nib
Milling
Cocoa Manufacture
Chocolate Manufacture
Cacao-Mass (Chocolate Liquor)
Alkalization
Removal of excess Moisture
Fat Pressing
Press Cake
Cocoa Butter
Breaking
Grinding
Sifting
Cocoa Powder
Ingredient Addition
(Sugar, flavour, milk etc. and Cocoa Butter)
Mixing
Refining
Conching
Tempering
Molding
Enrobing
Plain or Milk Chocolate
Chocolate-Coated Goods
Flow chart for Chocolate Manufacture

Flow Chart for Bread Making



Flow Chart for Preparation of Soymilk



Flow Chart for the Production of Pickles

Module 4. Working principles of equipment for receiving, pasteurization sterilization, homogenization, filling & packaging, butter manufacture.

Lesson10. Milk Reception and Homogenization

10.1 Milk Reception

Milk may be received at the dairy plants for processing either in cans direct from producers or in tanks from a milk chilling centres. The first stage of the process of reception involves emptying the cans over the tip-tank or weigh-tank, if milk is received in cans. This process may be carried out entirely by hand, by a mechanical inverter, or by a "hand-assisted" method. Drainage of the can is important and it is generally considered that for cans of 40 ℓ capacity, a drainage time of at least 30 seconds should be allowed.


Fig 10.1: Milk Weighing Tank

Where weigh-tanks are installed, after the weight of the consignment has been recorded, the contents are discharged into a tank immediately below it from which the milk is pumped through a cooler to a storage tank. Where milk is measured volumetrically, the cans are tipped directly into the tip-tank, from which milk is pumped to the cooler. Where a higher throughput is required, the procedure must be mechanized.

Most raw milk is nowadays delivered to the dairy plant through milk transport tankers, either trucks or trailers varying from approximately 7,500 to 25,000 ℓ in capacity. The receiving operation is divided into three phases: (a) preparing to unload (b) unloading and (c) weighing.

Preparing to unload normally involves agitating the milk. Inspecting for off-flavors (generally odours) and connecting the unloading hose to the tanker outlet. Sampling is always preceded by agitation.

The product is then transferred from the tanker to a receiving or storage tank with the help of a centrifugal or rotary pump. The receiving tanks may be mounted on scales or load cells to permit full tank loads to be weighed. Alternatively, the milk may be pumped through a meter for volumetric measurement. Modern dairy plants use air-operated valves to control flow in the receiving operation and CIP system for tankers, tanks and pipelines.

Most plants make at least spot checks of the incoming product volume using the following methods: (a) weighing or measuring the tankers, (b) weighing in receiving or storage tanks, (c) metering and (d) liquid-level measurement in the storage tank.

The milk that comes directly from the farmers is paid on the basis of measurement in the farm bulk tank, using a graduated dip stick. The use of receiving tanks on scales or load cells adds extra equipment and accordingly, capital and operating costs. Two receiving tanks are required for an efficient operation so that one can be filled as the other is emptying.

In the weighing-tank method, the milk is pumped from the tanker into a special weighing tank, with load cells built into the feet. The cells supply an electric signal that is always proportional to the weight of the tank. The weight of the contents in the tank can be recorded when all the milk has been delivered. After this, the milk is pumped to a silo/storage tank. This system is subject to wind load errors and is thus limited to enclosed tanks. Milk in the storage tank may also be measured with a liquid-level gauge. Maximum accuracy of gauges of this type has been reported under field conditions, but more recent applications combining silo-type tanks, diaphragm-type pressure sensors and multi-range manometers provide improved performance.

Sanitary meters are used in a number of plants. Measurement is by determining volumetric displacement, mass flow rate or velocity. Variations in air content, temperature, flow rate, back pressure and meter position influence the meter reading. Since air in the product is included in the total, back-pressure control is essential for milk receiving applications. Filtering system should be employed, with meters which have moving parts to protect the meter and permit greater accuracy. All the weighing or measuring system should be calibrated frequently to ensure continued accuracy. A print-out device may be used with load cells, scales or meters to automatically record weight or volume of the product.

10.1.1 Milk Transport Tanks:-

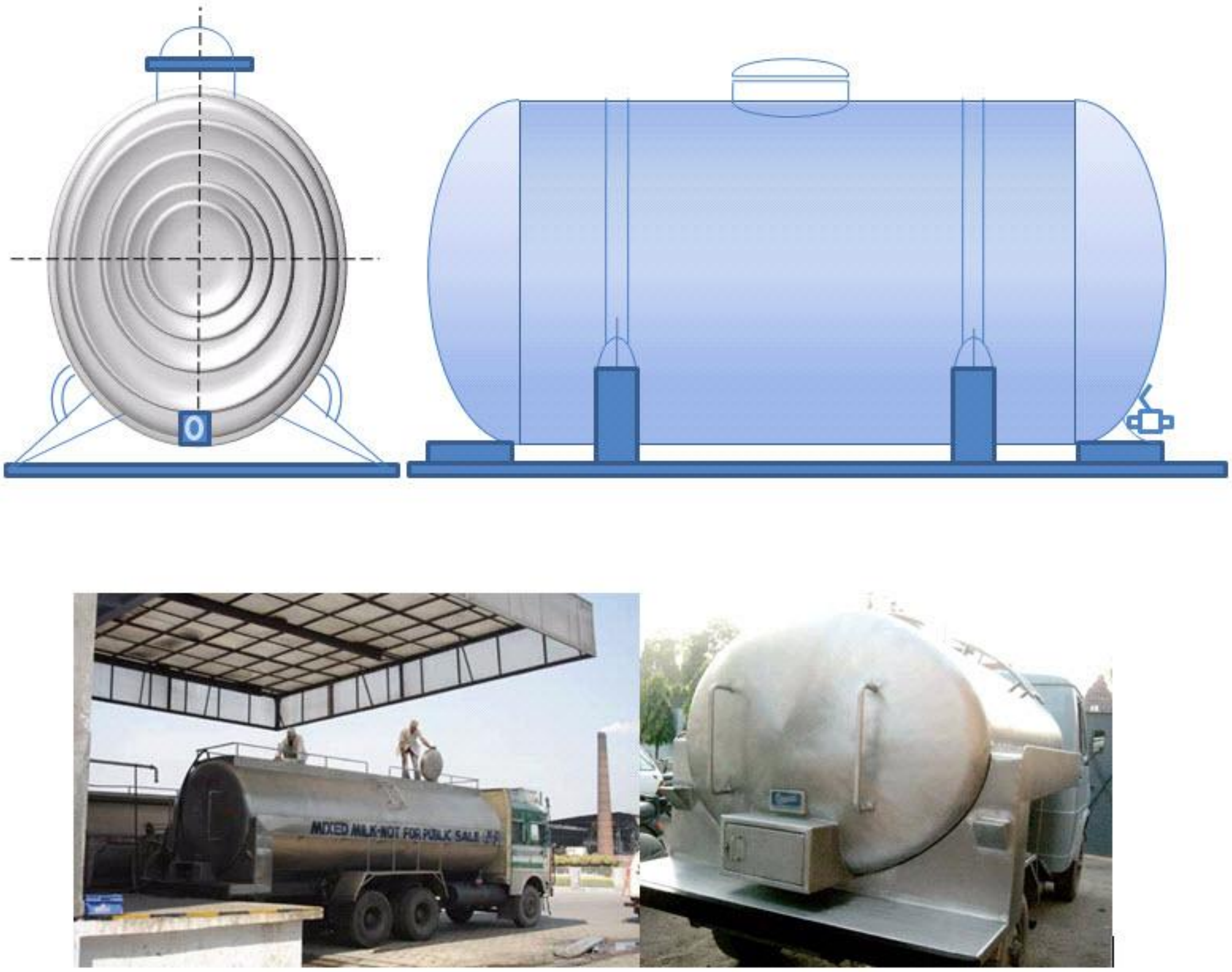


Fig 10.2: Milk transport tank

Handling the milk in cans is slow and laborious when the larger quantities are to be handled. Road truck/ trailers or rail tankers are convenient options in such cases.

- Capacity: 500 to 12000 ltr.
- The size and the type depend upon.
    - Amount of milk to be transported
    - Road condition
    - Comparative cost

10.1.1.1 Difference between Truck and Trailer

Truck	Trailer
Easy to travel in tighter places	Suitable for long distances and wide roads.
Carry less	Pull more.

10.1.1.2 Construction of Milk Transport Tank

The milk transport tanks are generally having the similar type of construction, with some modifications based upon requirements and convenience.

- **Material of construction:**

Inner shell- Stainless Steel (18% chromium, 8% Nickel)

- Smooth welding
- Polished surface
- Rounded corners & edges

Insulation- cork, plastic, foam, mineral wool.

Outer jacket—ordinary carbon steel, Aluminum, S.S,

Ordinary carbon steel	Stainless Steel
Low cost	High cost
High maintenance	High demand • Long life • Low maintenance • Excellent appearance • Some tanks may have two compartments for,

Different milks can be transported at once

Low agitation

Distribute load over Axle.

- **Accessories or mountings:**

- Manhole, air vent and cover assembly required for inspection
- Sanitary cover is having sanitary rubber gasket and locking device.
- Air vent → to “breath” → prevent pressure and vacuum during loading or unloading.
- Outlet valve with covered cabinet which can be sealed properly.
- Ladder- to climb on tank for cleaning or inspection
- Hoses - Rubber or translucent Plastic, Puncture & collapse resistant, sanitary cap/Plug at dead end.

10.1.2 Milk Storage Tanks

Storage tanks are used on dairy plants for the storage of raw, pasteurized or processed products, often in very large volumes. Milk is stored up to 72 hrs. between reception and processing in this most important part of any dairy plant, during this period the milk is also held below the temperature 7 ^{o}C or below.

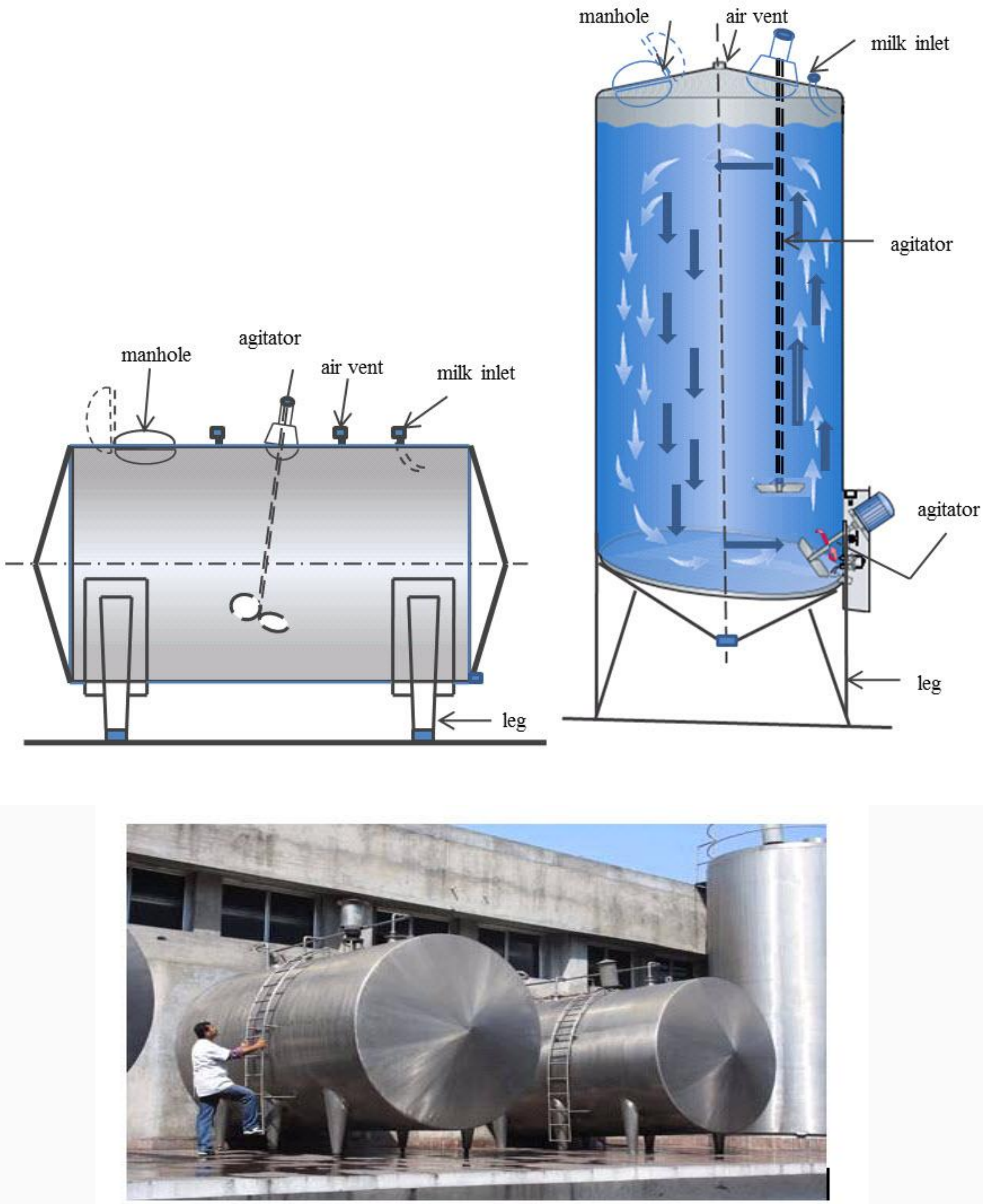


Fig 10.3: Cylindrical milk storage tanks in a horizontal and vertical design

The design and construction of the tanks should be such that it provides ease of CIP as well as sanitizing. The major constructional and design features are as follows:

- Smooth surface inside made up of 18:8 type Stainless Steel (18% chromium, 8% nickel)

- May be horizontal, vertical, Oval or cylindrical

Horizontal	Vertical
Less head required	High Head required
More floor space required	Less floor space required

- Capacity- up to 2,00,000 ℓ
- Fitted on Adjustable legs (Ball feet)
- Construction :-
- Inner S.S shell (18:8 type s.s.)
- Outer jacket (mild steel or s.s)
- Insulation (5-7.5 cm thick)
- Minimum contact of metals between inner & outer shell inorder to reduce heat transfer/ heat loss
- Accessories or mountings:
    - Man hole - with diameter 450mm.

-Inside outside Swing type door where weight of products aids in the sealing.

- Foam free inlet but better to fill from below to achieve better CIP and less foaming.
- Head Space: 15 cm for viewing ports and lights and also for CIP systems.
- Air vent: At the top of the tank which prevent vacuum or pressure during loading or unloading respectively. It should have screen to prevent entry of dust and design should be such that no water shall penetrate.
- Sampling valve is kept on man hole door.
- Thermometer probe is inserted in to s.s. well which is welded inside.
- Plug type valve for sanitary design and full opening area.
- Agitator is provided to mix product for standardization, cooling etc.

- Horizontal agitator requires: - oil free bearings

  - Rotary seals

- Vertical agitator requires step bearings at bottom due to length

10.1.3 Silo Tank:-

Silo tanks are used to handle larger quantities of product in a limited ground area. Normally its capacity ranges from 50,000 to 1,00,000 ltrs.

- Tanks can be kept outside to reduce the building cost.
- Silo walls have double wall construction with a minimum 70 mm thick insulation of mineral wool.
- Outer shell can be made up of stainless steel but to reduce the cost mild steel with anti-corrosion paint can be used.
- In order to make complete drainage easy, the bottom of tank slop is downwards with an inclination of about 6^{o} towards outlets.
- Agitator:-Electrodes to stop-start agitators as per level, as well as to control overflow are provided
    - Are provided to avoid cream separation at the top during storage
    - One or two agigators can be installed based upon the size of silo.
    - Agitator must not be started before level of milk is above it to avoid splashing and whipping.
- Temperature and level indicators are provided on control panel.

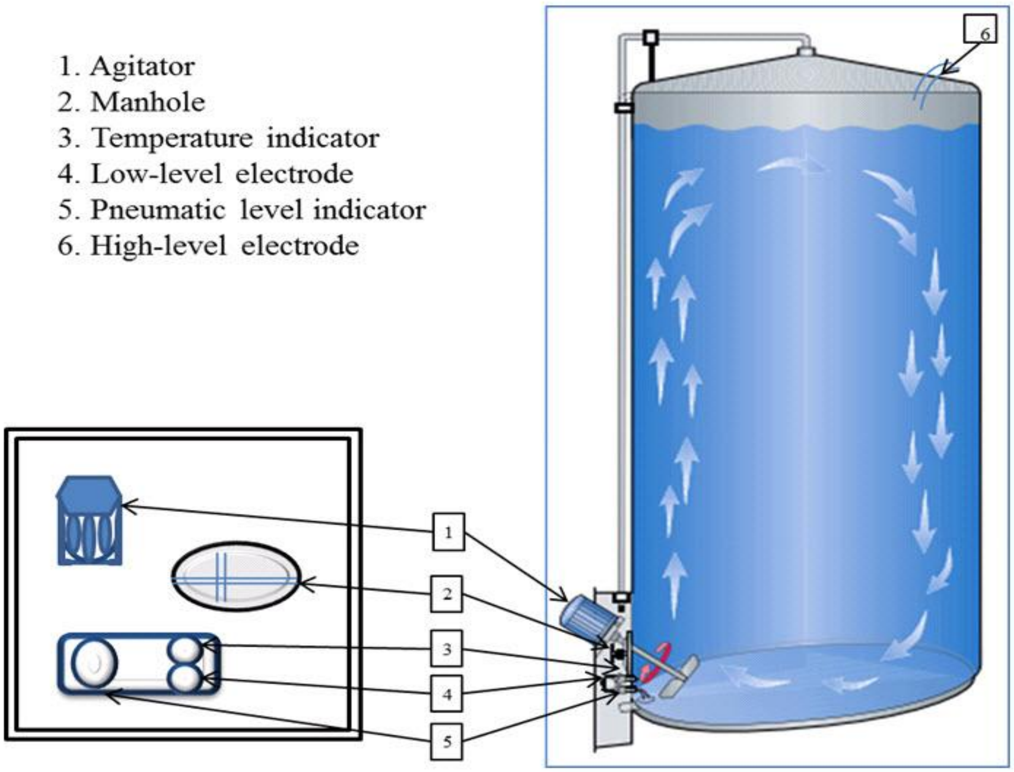


Fig 10.4: Silo tank with control panel

10.2 Homogenization

Milk is an oil-in-water emulsion with the fat globules dispersed in a continuous serum phase. If raw milk is allowed to stand, the fat would rise and form a cream layer. Homogenization is a mechanical treatment of the fat globules achieved by passing milk under high pressure through a thin slit, which results in stability of milk due to a decrease in the average diameter and an increase in number and surface area, of the fat globules. Three factors contribute to this enhanced stability of homogenized milk: a decrease in the mean diameter of the fat globules (a factor in Stokes Law), a decrease in the size distribution of the fat globules (causing the speed of rise to be similar for the majority of globules such that they don't tend to cluster during creaming) and an increase in density of the globules (bringing them closer to the continuous phase) owing to the adsorption of a protein membrane.

10.2.1 Homogenization Mechanism

Auguste Gaulin's patent in 1899 consisted of a 3 piston pump in which product was forced through one or more hair like tubes under pressure. It was discovered that the size of fat globules produced were 500 to 600 times smaller than tubes. There have been over 100 patents since, all designed to produce smaller average particle size with expenditure of as little energy as possible. The homogenizer consists of a 3 cylinder positive piston pump and homogenizing valve. The pump is turned by electric motor through connecting rods and crankshaft. To understand the mechanism, consider a conventional homogenizing valve processing an emulsion such as milk at a flow rate of 20,000 ℓ/hr. at 14 MPa (2100 psig). As it first enters the valve, liquid velocity is about 4 to 6 m/s. It then moves into the gap between the valve and the valve seat and its velocity is increased to 120 m/s in about 0.2 ms. The liquid then moves across the face of the valve seat (the land) and exits in about 50 µs. The homogenization phenomena is completed before the fluid leaves the area between the valve and the seat, and therefore emulsification is initiated and completed in less than 50 µs. The whole process occurs between 2 pieces of steel in a steel valve assembly. The product may then pass through a second stage valve similar to the first stage. While most of the fat globule reduction takes place in the first stage, there is a tendency for clumping or clustering of the reduced fat globules. The second stage valve permits the separation of those clusters into individual fat globules.

It is most likely that a combination of two theories, turbulence and cavitation, explains the reduction in size of the fat globules during the homogenization process.

10.2.1.1 Turbulence

Energy, dissipating in the liquid going through the homogenizer valve, generates intense turbulent eddies of the same size as the average globule diameter. Globules are thus torn apart by these eddie currents reducing their average size.

10.2.1.2 Cavitation

Considerable pressure drop with charge of velocity of fluid. Increased pressure increases velocity. Liquid cavitates because its vapour pressure is attained. Cavitation generates further eddies that would produce disruption of the fat globules. The high velocity gives liquid a high kinetic energy which is disrupted in a very short period of time.. Dissipation of this energy leads to a high energy density (energy per volume and time). Resulting diameter is a function of energy density. In summary, the homogenization variables are:

- type of valve
- pressure
- single or two-stage
- fat content
- surfactant type and content
- viscosity
- temperature

Also to be considered are the droplet diameter (the smaller, the more difficult to disrupt), and the log diameter which decreases linearly with log P and levels off at high pressures.

10.2.2 The homogeniser

High-pressure homogenisers are generally needed when high-efficiency homogenisation is required.

The product enters the pump block and is pressurised by the piston pump. The pressure that is achieved is determined by the back-pressure given by the distance between the forcer and seat in the homogenisation device.

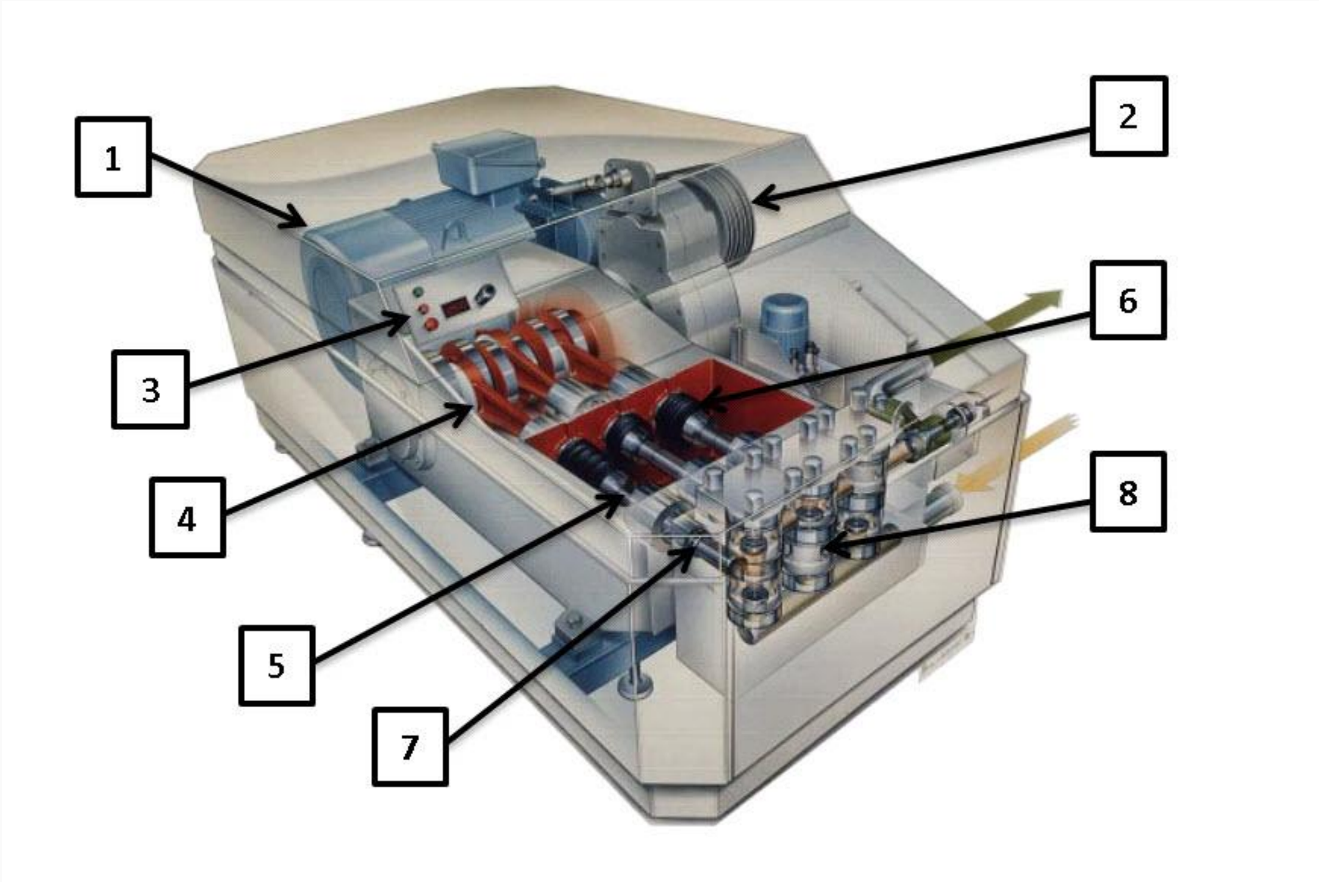


Fig 10.5: The homogeniser is a large high-pressure pump with a homogenising device.

1 Main drive motor

2 V-belt transmission

3 Pressure indication

4 Crankcase

5 Piston

6 Piston seal cartridge

7 Solid stainless steel pump block

8 Homogenising valve assembly

10.2.2.1 The high-pressure pump

The piston pump is driven by a powerful electric motor [1] in figure 10.5, through a crankshaft and connecting-rod transmission which converts the rotary motion of the motor to the reciprocating motion of the pump pistons. The pistons [5], run in cylinders in a high-pressure block. They are made of highly resistant materials. The machine is fitted with double piston seals. Water is supplied to the space between the seals to cool the pistons.

10.2.2.2 The homogenisation device

Figures 10.6 shows the homogenisation and hydraulic system. The piston pump boosts the pressure of the milk from about 300 kPa (3 bar) at the inlet to a homogenisation pressure of 10 – 25 MPa (100 – 250 bar) depending on the product. The inlet pressure to the first stage before the device (the homogenisation pressure) is automatically kept constant. The oil pressure on the hydraulic piston and the homogenisation pressure on the forcer balance each other. The homogeniser is equipped with one common oil tank, whether it has one or two stages. However, in two-stage homogenisation there are two oil systems, each with its own pump. A new homogenisation pressure is set by changing the oil pressure. The pressure can be read on the high-pressure gauge.

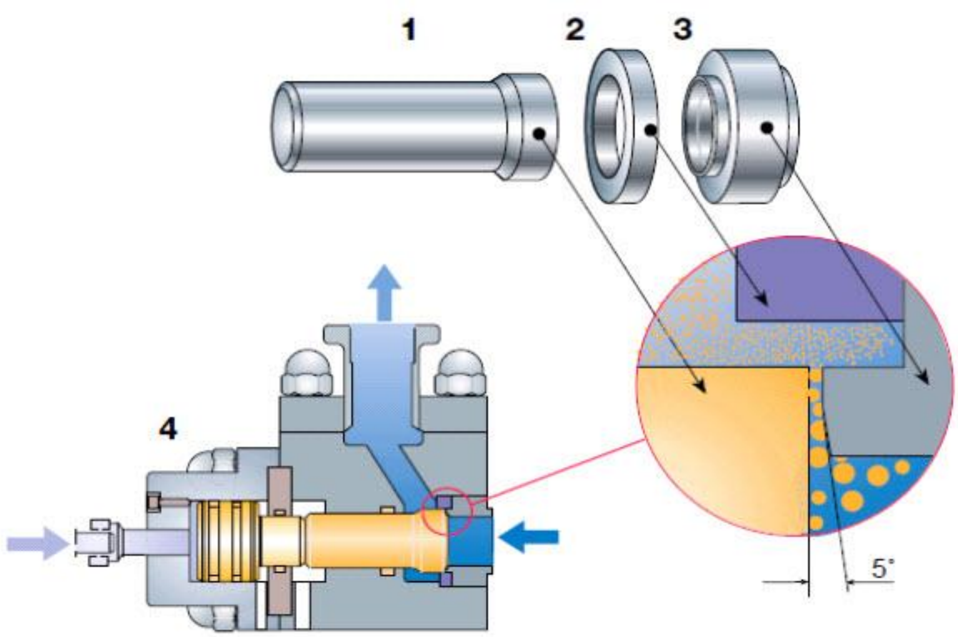


Fig 10.6: The components of a single stage homogenisation device.

1 Forcer

2 Impact ring

3 Seat

4 Hydraulic actuator

Homogenisation always takes place in the first stage. The second stage basically serves two purposes:

• Supplying a constant and controlled back-pressure to the first stage, giving best possible conditions for homogenisation;

• Breaking up clusters formed directly after homogenisation.

The parts in the homogenisation device are precision ground. The impact ring is attached to the seat in such a way that the inner surface is perpendicular to the outlet of the gap. The seat has a 5° angle to make the product accelerate in a controlled way, thereby reducing the rapid wear and tear that would otherwise occur.

Milk is supplied at high pressure to the space between the seat and forcer. The width of the gap is approximately 0.1 mm or 100 times the size of the fat globules in homogenised milk. The velocity of the liquid is normally 100 – 400 m/s in the narrow annular gap, and homogenisation takes place in 10 – 15 µs. During this time all the pressure energy delivered by the piston pump is converted to kinetic energy. Part of this energy is converted back to pressure again after the device. The other part is released as heat; every 40 bar in pressure drop over the device gives a temperature rise of 1°C. Less than 1% of the energy is utilised for homogenisation, but nevertheless high pressure homogenisation is the most efficient method available.

10.2.3 Effects of Homogenization:

10.2.3.1 Fat globule

The table shows the major changes occurs in the fat globules during the homogenization process.

	No Homogenization	15 MPa (2500 psi)
Av. diam. (µ m)	3.3	0.4
Max. diam. (µ m)	10	2

Surf. area (m^2/ml of milk)	0.08	0.75
Number of globules (per µm-3)	0.02	12

10.2.3.2 Surface layer

The milk fat globule has a native membrane, picked up at the time of secretion, made of amphiphilic molecules with both hydrophilic and hydrophobic nature. This membrane lowers the interfacial tension resulting in a more stable emulsion. During homogenization, there is a tremendous increase in surface area and the native milk fat globule membrane (MFGM) is lost. However, there are many amphiphilic molecules present from the milk plasma that readily adsorb: casein micelles (partly spread) and whey proteins. The interfacial tension of raw milk is 1-2 mN/m, immediately after homogenization it is unstable at 15 mN/m, and shortly becomes stable (3-4 mN/m) as a result of the adsorption of protein. The transport of proteins is not by diffusion but mainly by convection. Rapid coverage is achieved in less than 10 s but is subject to some rearrangement.

10.2.3.3 Advantages of Homogenization:

- Smaller fat globules leading to no cream-line formation,
- Whiter and more appetizing colour,
- Reduced sensitivity to fat oxidation,
- More full-bodied flavour, better mouthfeel,
- Better stability of cultured milk products.

10.2.3.4 Disadvantages of Homogenization:

- Homogenised milk cannot be efficiently separated.
- Somewhat increased sensitivity to light – sunlight and fluorescent tubes – can result in "Sunlight flavour" (see also chapter 8, Pasteurised milk products).
- Reduced heat stability, especially in case of single-stage homogenisation, high fat content and other factors contributing to fat clumping.
- The milk will not be suitable for production of semi-hard or hard cheeses because the coagulum will be too soft and difficult to dewater.

Lesson 11. Pasteurization of Milk

11. Introduction

The process of pasteurization was named after Louis Pasteur, who discovered method of inactivating spoilage organisms in wine by applying heat at temperatures below its boiling point. The process was later applied to milk and remains the most important operation in the processing of milk.

11.1 Definition (FSSAI, 2006):

The terms ―Pasteurisation, ―Pasteurised and similar terms shall be taken to refer to the process of heating every particle of milk of different classes to at least 63^0C and holding at such temperature continuously for at least 30 minutes or heating it to at least 71.5^0C and holding at such temperature continuously for at least 15 seconds or an approved temperature time combination that will serve to give a negative Phosphatase Test.

All pasteurised milk of different classes shall be cooled immediately to a temperature of 10^0C, or less

11.2 Purpose:

There are two distinct purposes for the process of milk pasteurization:

11.2.1 Public Health Aspect - to make milk and milk products safe for human consumption by destroying all bacteria that may be harmful to health (pathogens)

11.2.2 Keeping Quality Aspect - to improve the keeping quality of milk and milk products. Pasteurization can destroy some undesirable enzymes and many spoilage bacteria. Shelf life can be 7, 10, 14 or up to 16 days. The extent of microorganism inactivation depends on the combination of temperature and holding time. Minimum temperature and time requirements for milk pasteurization are based on thermal death time studies for the most heat resistant pathogen found in milk, *Coxiella Burnetii*.

11.3 Methods of Pasteurization

There are two basic methods, batch and continuous.

11.3.1 Batch method

The milk or milk products is heated and cooled in one, two or some times more than that tanks. The process involves heating every particle of milk atleast to the temperature of 63 ^{o}C for 30 min, and cooled rapidly to below 10 ^{o}C.

The parts of a typical batch pasteurizer are following:

- Insulated outer casing
- Insulated hinged cover
- Stainless steel inner vessel
- Agitator and its motor
- Outlet cock and heating water distribution pipe.

This system is well suited for small-scale operation, where less than 3000 to 5000 litres of milk are available. The vat may be rectangular, but a vertical, cylindrical design is preferred for practical reasons. The vat normally consists of an inner vessel, surrounded by an insulated outer casting, thus forming a jacket, through which hot water or steam is passed (Figure 11.1). After the milk has reached the required temperature (63.0°C), it is usually held at that temperature for a certain fixed period (30 minutes). Thereafter, it is cooled as quickly as possible either by circulating refrigerant/chilled water or through plate/surface chiller. Cooling the milk after pasteurization by circulating a refrigerant – in most cases cold water through the jacket or the vat may take much time. Therefore, a separate small capacity surface, tubular or plate cooler may be used to rapidly cool the milk to the required temperature. This system also has the advantage that the vat will be available sooner for the pasteurization of another batch of milk.

Batch pasteurizers have a small heating surface area relative to their contents. Heat transfer is greatly improved by agitating the milk. Agitators of different design are used for this purpose. They may even consist of double-walled paddles or other devices with internal steam or water circulation. Care must be taken to avoid foam formation during filling of vat. It is very difficult to heat the milk and foam together uniformly and consequently microorganisms present in the foam may survive pasteurization. If the inlet valve is at the bottom of the vat, foam formation can easily be prevented. A lid or cover on top of the vat promotes a uniform temperature of the contents and prevents skin formation on the milk

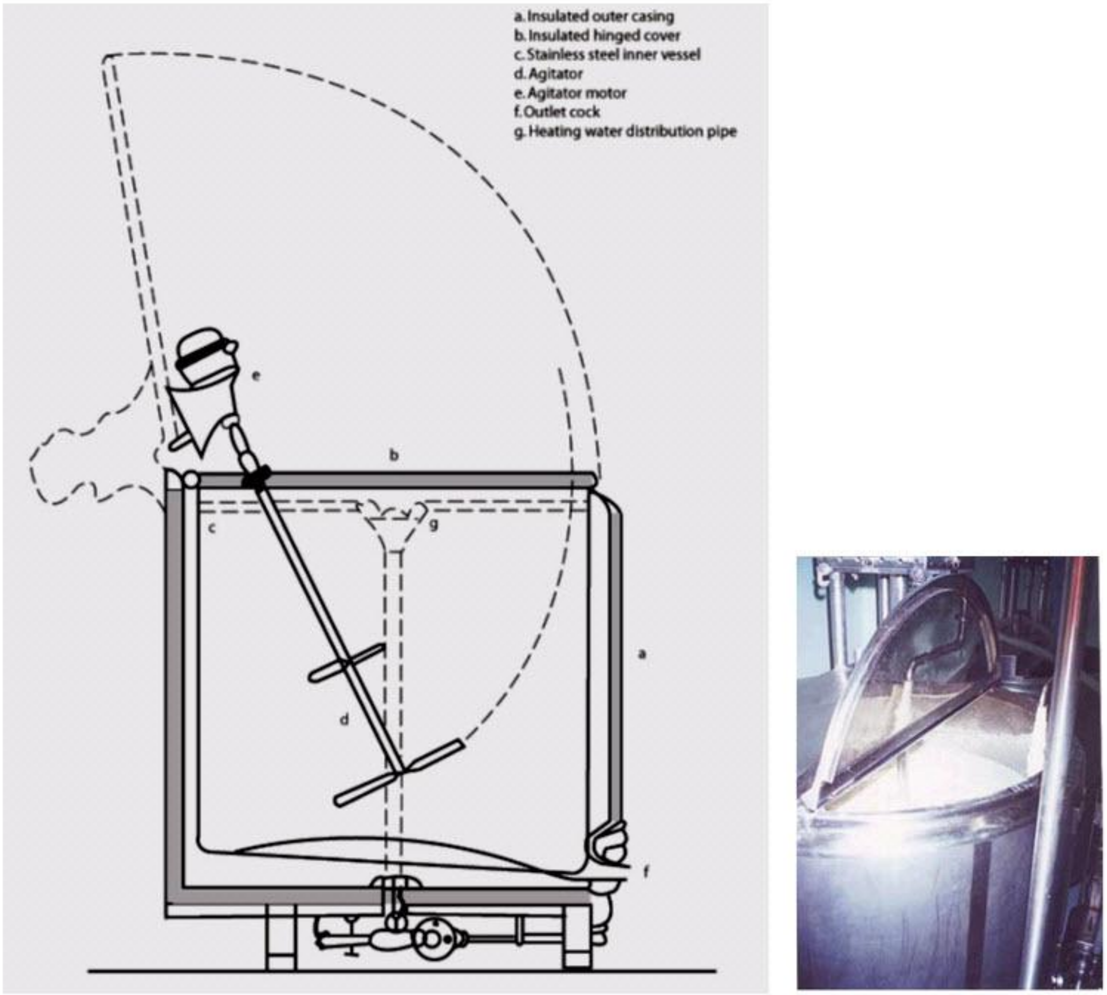


Fig 11.1: Batch Pasteurizer

11.3.2 Continuous Method

Continuous method has several advantages over the batch method, the most important being time and energy saving. For continuous processing, a high temperature short time (HTST) pasteurizer is used. The heat treatment is accomplished using a plate heat exchanger. This piece of equipment consists of a stack of corrugated stainless steel plates clamped together in a frame. There are several flow patterns that can be used. Gaskets are used to define the boundaries of the channels and to prevent leakage. The heating medium can be vacuum steam or hot water.

Cold raw milk at 4° C in a constant level tank is drawn into the regenerator section of pasteurizer. Here it is warmed to approximately 57°C - 68°C by heat given up by hot pasteurized milk flowing in a counter current direction on the opposite side of thin, stainless steel plates. The raw milk, still under suction, passes through a positive displacement timing pump which delivers it under positive pressure through the rest of the HTST system.

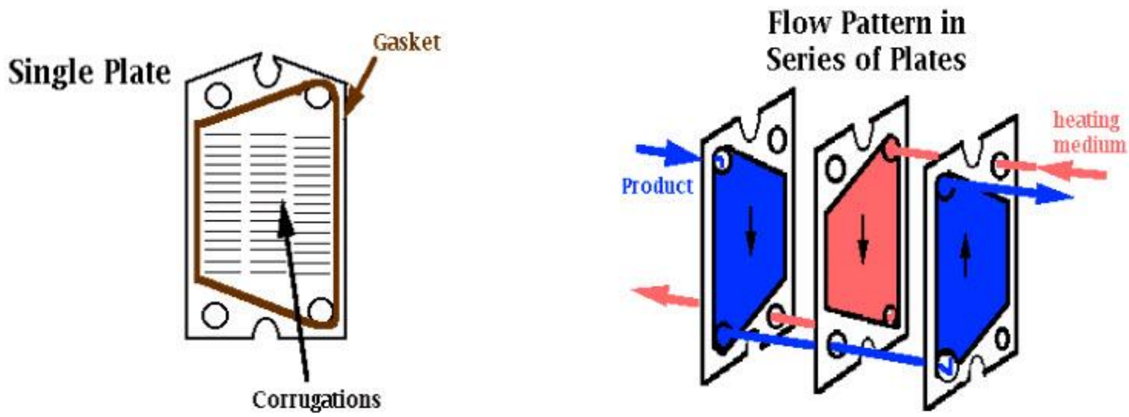


Fig 11.2: HTST Milk Flow Overview

The raw milk is forced through the heater section where hot water on opposite sides of the plates heat milk to a temperature of at least 72° C. The milk, at pasteurization temperature and under pressure, flows through the holding tube where it is held for at least 16 sec. The maximum velocity is governed by the speed of the timing pump, diameter and length of the holding tube and surface friction. After passing temperature sensors of an indicating thermometer and a recorder-controller at the end of the holding tube, milk passes into the flow diversion valve (FDV). The FDV assumes a forward-flow position if the milk passes the recorder-controller at the pre-set cut-in temperature (>72° C). The FDV remains in normal position which is in diverted-flow if milk has not achieved pre-set cut-in temperature. The improperly heated milk flows through the diverted flow line of the FDV back to the raw milk constant level tank.

Properly heated milk flows through the forward flow part of the FDV to the pasteurized milk regenerator section where it gives up heat to the raw product and in turn is cooled to approximately 32° C - 9° C. The warm milk passes through the cooling section where it is cooled to 4° C or below by coolant on the opposite sides of the thin, stainless steel plates. The cold, pasteurized milk passes through a vacuum breaker at least 12 inches above the highest raw milk in the HTST system then on to storage tank filler for packaging.

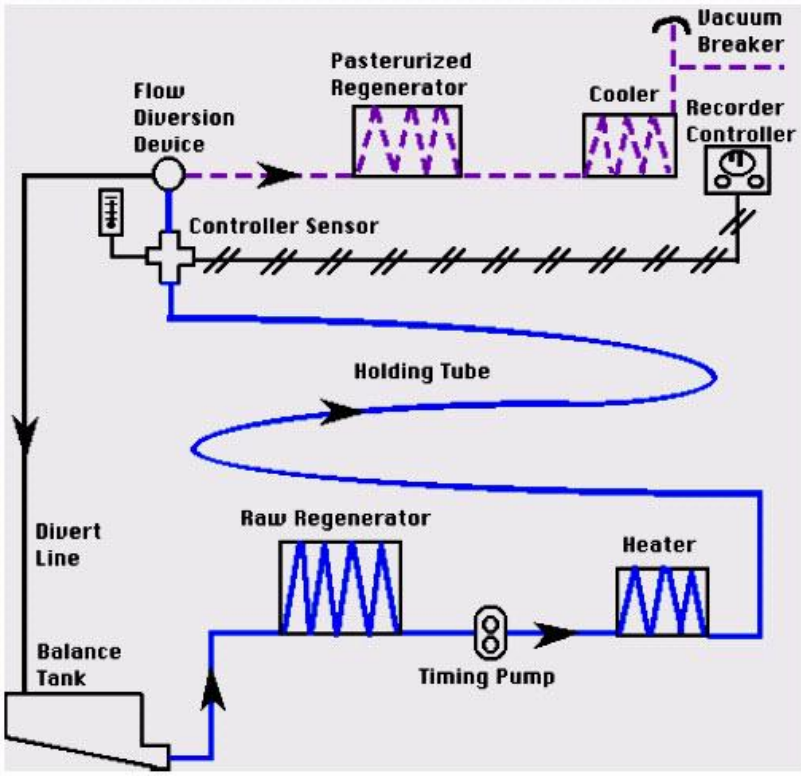


Fig 11.3: Basic Flow- HTST Pasteurization

11.3.2.1 Holding Time

When fluids move through a pipe, either of two distinct types of flow can be observed. The first is known as turbulent flow which occurs at high velocity and in which eddies are present moving in all directions and at all angles to the normal line of flow. The second type is streamline, or laminar flow which occurs at low velocities and shows no eddy currents. The Reynolds number, is used to predict whether laminar or turbulent flow will exist in a pipe:

Re < 2100 laminar

Re > 4000 fully developed turbulent flow

There is an impact of these flow patterns on holding time calculations and the assessment of proper holding tube lengths. The holding time is determined by timing the interval for an added trace substance (salt) to pass through the holder. The time interval of the fastest particle of milk is desired. Thus the results found with water are converted to the milk flow time by formulation since a pump may not deliver the same amount of milk as it does water.

11.3.2.2 Pressure Differential

For continuous pasteurizing, it is important to maintain a higher pressure on the pasteurized side of the heat exchanger. By keeping the pasteurized milk at least 1 psi higher than raw milk in regenerator, it prevents contamination of pasteurized milk with raw milk in event that a pin-hole leak develops in thin stainless steel plates. This pressure differential is maintained using a timing pump in simple systems, and differential pressure controllers and back pressure flow regulators at the chilled pasteurization outlet in more complex systems. The position of the timing pump is crucial so that there is suction on the raw regenerator side and pushes milk under pressure through pasteurized regenerator. There are several other factors involved in maintaining the pressure differential:

- The balance tank overflow level must be less than the level of lowest milk passage in the regenerator
- Properly installed booster pump is all that is permitted between balance tank and raw regenerator
- No pump after pasteurized milk outlet to vacuum breaker
- There must be greater than a 12 inch vertical rise to the vacuum breaker
- The raw regenerator drains freely to balance tank at shut-down

11.3.2.3 Basic Component Equipment of HTST Pasteurizer

11.3.2.3.1 Balance Tank

The balance or constant level tank provides a constant supply of milk. It is equipped with a float valve assembly which controls the liquid level nearly constant ensuring uniform head pressure on the product leaving the tank. The overflow level must always be below the level of lowest milk passage in regenerator. It, therefore, helps to maintain a higher pressure on the pasteurized side of the heat exchanger. The balance tank also prevents air from entering the pasteurizer by placing the top of the outlet pipe lower than the lowest point in the tank and creating downward slopes of at least 2%. The balance tank provides a means for recirculation of diverted or pasteurized milk.

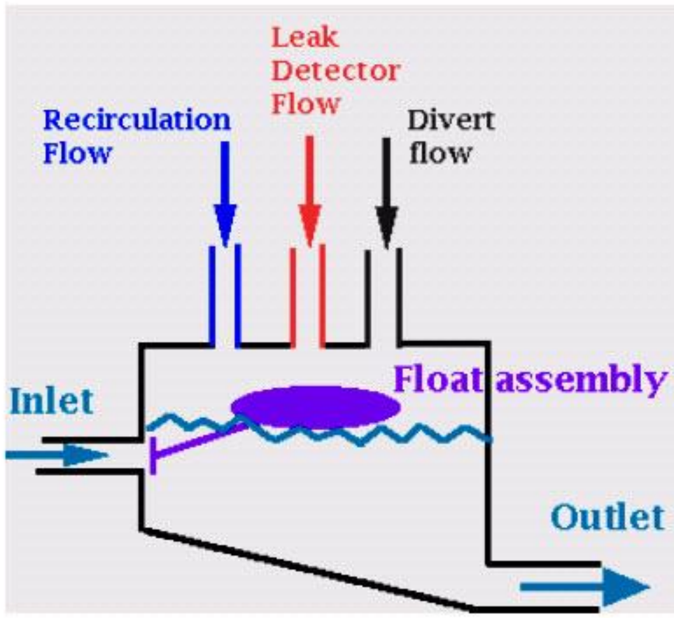


Fig 11.4: Milk Balance Tank/ Flow Control Unit

11.3.2.3.2 Regenerator

Heating and cooling energy can be saved by using a regenerator which utilizes the heat content of the pasteurized milk to warm the incoming cold milk. Its efficiency may be calculated as follows:

% regeneration = temp. increase due to regenerator/total temp. increase

For example: Cold milk entering system at 4° C, after regeneration at 65° C, and final temperature of 72° C would have an 89.7% regeneration:

65 – 4

-------- = 89.7

72 - 4

11.3.2.3.3 Timing pump

The timing pump draws product through the raw regenerator and pushes milk under pressure through pasteurized regenerator. It governs the rate of flow through the holding tube. It must be a positive displacement pump equipped with variable speed drive that can be legally sealed at the maximum rate to give minimum holding time in holding tubes. It also must be interwired so it only operates when FDV is fully forward or fully diverted, and must be "fail-safe". A centrifugal pump with magnetic flow meter and controller may also be used.

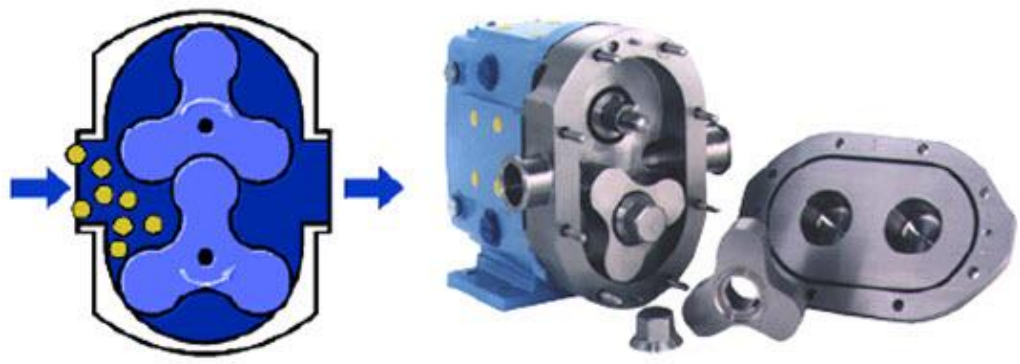


Fig 11.5: Timing Pump

11.3.2.3.4 Holding tube

Must slope upwards 1/4"/ft. in direction of flow to eliminate air entrapment so nothing flows faster at air pocket restrictions.

Fig 11.6 Holding Tubes

11.3.2.3.5 Indicating thermometer

The indicating thermometer is considered the most accurate temperature measurement. It is the official temperature to which the safety thermal limit recorder (STLR) is adjusted. The probe should sit as close as possible to STLR probe and be located not greater than 18 inches upstream of the flow diversion device.

11.3.2.3.6 Safety Thermal Limit Recorder-controller (STLR)

The STLR records the temperature of the milk and the time of day. It monitors, controls and records the position of the flow diversion Valve (FDV) and supplies power to the FDV during forward flow. There are both pneumatic and electronic types of controllers. The operator is responsible for recording the date, shift, equipment, ID, product and amount, indicating thermometer temperature, cleansing cycles, cut in and cut out temperatures, any connects for unusual circumstances, and his/her signature.

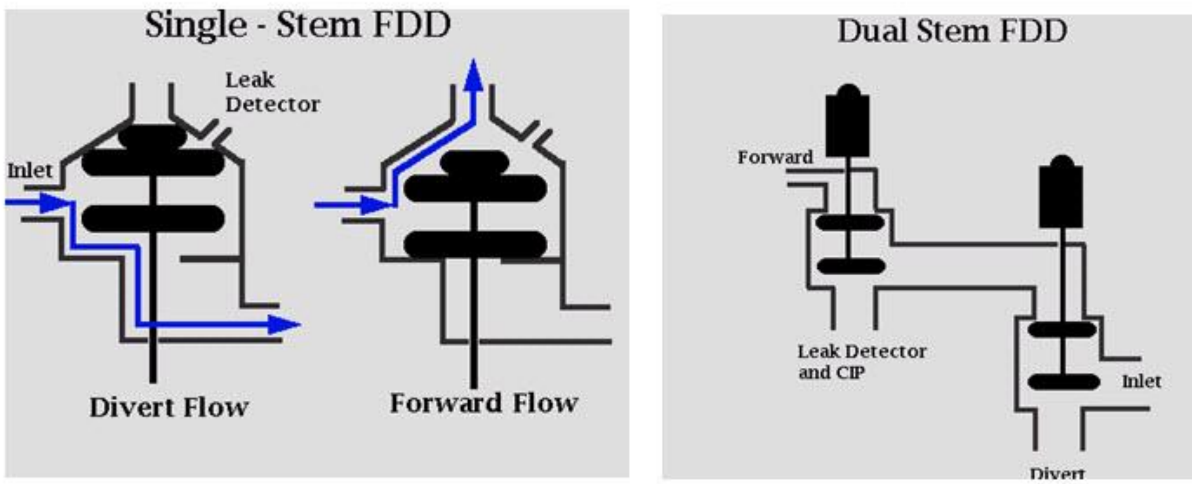
Fig 11.7: Safety Thermal Limit Recorder-controller

11.3.2.3.7 Flow Diversion Valve (FDV)

Also called the flow diversion Device (FDD), it is located at the downstream end of the upward sloping holding tube. It is essentially a 3-way valve, which, at temperatures greater than 72° C,opens to forward flow. This step requires power. At temperatures less than 72° C, the valve recloses to the normal position and diverts the milk back to the balance tank. It is important to note that the FDV operates on the measured temperature, not time, at the end of the holding period. There are two types of FDV:

single stem - an older valve system that has the disadvantage that it can't be cleaned in place.

dual stem - consists of 2 valves in series for additional fail safe systems. This FDV can be cleaned in place and is more suited for automation.



11.3.2.3.8 Vacuum Breaker

At the pasteurized product discharge is a vacuum breaker which breaks to atmospheric pressure. It must be located greater than 12 inches above the highest point of raw product in system. It ensures that nothing downstream is creating suction on the pasteurized side.

11.3.2.4 Auxiliary Equipment

11.3.2.4.1 Booster Pump

It is centrifugal "stuffing" pump which supplies raw milk to the raw regenerator for the balance tank. It must be used in conjunction with pressure differential controlling device and shall operate only when timing pump is operating, proper pressures are achieved in regenerator, and system is in forward flow.

11.3.2.4.2 Automated Public Health Controllers

These systems are used for time and temperature control of HTST systems. There are concerns that with sequential control, the critical control points (CCP's) are not monitored all the time; if during the sequence it got held up, the CCP's would not be monitored. With operator control, changes can be made to the program which might affect CCP's; the system is not easily sealed. No computer program can be written completely error free in large systems; as complexity increases, so too do errors. This gives rise to a need for specific regulations or computer controlled CCP's of public health significance:

1. Dedicated computer - no other assignments, monitor all CCP's at least once/sec

2. Not under control of any other computer system or override system, i.e., network

3. Separate computer on each pasteurizer

4. I/O bus for outputs only, to other computers no inputs from other computers

5. On loss of power - public health computers should revert to fail safe position (e.g. divert)

6. Last state switches during power up must be fail safe position

7. Programs in ROM - tapes/disks not acceptable

8. Inputs must be sealed, modem must be sealed, program sealed

9. No operator override switches

10. Proper calibration procedure during that printing - Public health computer must not leave public health control for > 1 sec and upon return must complete 1 full cycle before returning to printing

11. FDV position must be monitored and temperature in holding tube recorded during change in FDV position

12. Download from ROM to RAM upon startup

13. Integrated with CIP computer which can be programmed e.g., FDV, booster pump controllable by CIP computer when in CIP made only.

Lesson 12. Filling and Packaging of Milk

12. Introduction

Most food consumed is far removed in time and space from the point of its production. Packaging is a necessary aid for the storage and distribution of food. Food is packaged for four primary reasons: (a) to protect the product from contamination. by micro- organisms, macro-organisms and filth ; (b) to retard or to prevent either losses or gain of moisture; (c) to shield the product from oxygen and light and (d) to facilitate handling.

The package may also serve as a processing aid. It is a convenient item for the consumer and is a marketing tool. The sales appeal and product identification aspects of packaging are particularly important to the sales and marketing branches of food companies. Certain packages have obvious economic benefits, such as prevention of spills, ease of transporting, prevention of contamination, reduction of labour cost and so on.

The quality of products as they reach the consumer depends on the condition of the raw material, on method and severity of processing and on conditions of storage. The chemical, physical and biological mechanisms of food deterioration are sensitive to various environmental factors and the most pertinent barrier property of the package varies with each product.

12.1 Packaging Materials Used For Fluid Milk

A container of good quality must prevent post-processing contamination from bacterial sources. It should be such that all indirect or direct chemical change in the milk should be prevented. The package should be of such materials that their constituents do not get transmitted into milk. It should also be resistant to the cleaning materials used in the dairy. It may either be used once (single-use) or may be returned to the processing factory for reuse.

12.1.1 Single-use Packaging Materials

These are also classified as flexible packaging. They, as the name suggests, are used to package milk once and are discarded after removing the product. The consumer is responsible for disposing off the packages. They have been in the news in recent times due to the difficulty in their disposal and their role in environmental pollution.

12.1.1.1Plastic pouches:

Flexible plastic material can be made into pouch packs. As they are not self-supporting, they generally need some secondary packaging. The advantages offered by the plastic packages are:

- Good barrier properties
- Visibility of the contents
- Light weight (thus reducing the cost of transportation)
- Single-service, thus eliminating the need for return, washing and sanitation
- Easy to carry
- Economical and
- Can be made more attractive.

The most commonly used plastic material for pouches is polyethylene (PE). There are several types of polyethylene available and are characterized by their density. These are low density (LDPE – 0.91-0.925 g/cm^3), medium density (MDPE – 0.926-0.941 g/cm^3) and high density (HDPE – 0.942-0.970 g/cm^3). The material has good moisture barrier properties, but poor oxygen barrier characters. HDPE is the least permeable to moisture. PE is suitable both for rigid and flexible packaging, though for some applications, it must be combined with an oxygen barrier.

Flexible pouches are also made from a derivative of polyvinyl chloride (PVC) in the plasticised form (PPVC). It contains plasticisers to render it flexible and stabilizers to prevent thermal and UV light degradation of the product. However, there has been some controversy regarding its toxicity owing to the high chloride content and additives present.

The use of plastic pouches eliminates noise in the milk bottling plants and during delivery, and also reduces water pollution caused by milk residues and detergents used in the bottle washing process. However, they have the disadvantage of poor recyclability and hence, their disposal is a problem.

12.1.1.2 Carton:

The history of the beverage carton is closely associated to the development of milk distribution. The first carton was patented in 1915 in the USA as a 'foldedblank box'. Cartons generally have a square or rectangular cross-section. Tetrahydral and other shapes are also seen, though rarely. These are manufactured by well-developed systems. They are high-technology packaging formats and need well-trained operators to ensure efficient filling of the product. The serving size is also important while designing the package. A 200- or 250 ml single serve packet may be marketed with a straw and if a multiserve (say, one litre), some sort of reclosable feature should be provided. These kinds of packaging materials are normally used for long-life products that need not be refrigerated during storage.

The form-and-fill types of cartons are normally used for liquid milk. They are normally received as rolls of heat-sealable packaging material. The material is laminated paper, consisting of duplex kraft paper coated with PE inside and wax outside. A sandwiched layer of thin aluminium foil between an outer kraft paper and inner PE coating is also prevalent.

The advantages of carton packaging are as follow:

- Lightweight and compact shape, thus increasing distribution efficiency
- Made from renewable raw material (wooden fibre)
- Hygienic
- One way containers, so no need for cleaning before or after filling operation, hence decreasing water and detergent usage
- Recyclable
- Easy to dispose

The distinct disadvantage also is the felling of trees for making the raw material. However, it is a renewable source and can be regenerated with the help of strict laws and effective management. In the forests of Scandinavia and North America, from where the raw material is procured, for every tree cut, three new trees have to be planted.

Paper and paper-based Materials: Several kinds of paper-based materials are used in the form of wrappers, cartons, boxes, bags and cups, while boards are used as cartons and boxes. These materials are made of bleached or unbleached kraft paper, grease-proof paper, vegetable parchment paper, glassine paper, wax-coated paper, plastic-coated paper, straight or corrugated paper boards, solid fibre boards, liner boards and box boards. While boxes and cartons are used generally for packaging products other than fluid milk, they may sometimes be useful in constructing the outer casing material (secondary packaging) for long distance transportation of flexible pouches.

12.1.2 Multiple-use Packaging Materials

Of the possible pack types, bottles are the most commonly used multiuse packages. They can be made of glass and plastic. Metal bottles have also recently emerged for specialist markets, but they are rare and expensive.

12.1.2.1 Glass:

Glass containers come in the form of bottles, jars, jugs and tumblers. They may be plain and transparent or coloured and opaque. While the plain glass bottle provides the advantage of direct viewing of the product contained in it, it has the disadvantage of exposing the milk to ultra violet rays that deteriorate it. Glass has many virtues, but also has several disadvantages that limit its use as a packaging material for milk.

Advantages of glass:

- Strong, inert material
- Good closure and decorative options
- Raw materials easily available
- Recycling possible
- Excellent gas and water barrier properties
- Quality image
- Product compatibility
- Good internal pressure resistance
- Reuse opportunity

Disadvantages of glass:

- Heavy
- Brittle

Despite its disadvantages, the older generation of consumers still thinks of glass as the best option for packaging milk.

12.1.2.2 Plastic:

Plastic bottles for milk generally are made with ribs to add strength. This additional tenacity is needed for withstanding the vacuum on filling machines, for resisting the lateral forces that act within the pack and during transit. Plastic bottles for milk are common in the developed countries and are yet to catch up in India. Plastic has the distinct disadvantage of making recycling difficult. Plastic bottles may be manufactured from PVC, HDPE or polyethylene terephthalate (PET). Of these, the first two are generally considered together because of the type of moulding machines they are made on and the type of bottle that can be made. They have the following disadvantages:

- Poor oxygen barrier properties in polyethylene
- Less clarity than PET, though not very apparent
- PVC is brittle (specially at low temperatures) and breaks on impact

PET occurs in three physical forms (amorphous, orientated and crystalline), which are exploited to manufacture a wide range of packaging materials. PET bottles are made in two steps. The first is to make a 'perform', which is in the shape of a test tube with the actual neck of the bottle at the end that is open. The second step involves the stretching and moulding of this into the finished shape of the bottle.

The advantages are:

- Light, strong and impact resistant
- Can be made temperature-stable by suitable heat treatment

12.1.3 Materials used for bulk supply

Milk is packaged for bulk and institutional supplies in cans made of stainless steel or aluminium and of capacity of 20 L or 40 L. These are robust and offer excellent product protection. However, there is little opportunity to differentiate one product from the other and branding/labelling is the only alternative. PET containers are also used in the western countries, but they require some form of separate strap or handle. Milk is also sold to cafes and caterers in the western countries in large 22 or 40 litre packs in the form of bag-in-box. The short life of fluid milk allows the bag to be produced from PE in two layers, each of 50 micrometers thickness.

12.2 Processes for Packaging Fluid Milk

12.2.1 Processes for single-use packaging

The pouch-filling machine is an integral part of a modern fluid milk plant. Several types of plastic materials are used in forming the pouches. The material generally comes in the form of rolls, which are loaded onto the machine. The layer of plastic is folded vertically and sealed. A horizontal sealer seals the bottom of the pouch. Simultaneously, milk from an overhead float tank is siphoned into the formed cylinder. It is then again horizontally sealed at the top and cut off to form a pouch filled with milk. These machines come with adjustable filling heads capable of filling several volumes of milk as the need be.

12.2.2 Processes for Multiple-use Packaging

The filling of milk in glass bottles was an important operation in the fluid milk factory till recent times when the sachet-packing systems gained popularity for several reasons. However, inspite of the weight of the bottle and the problems regarding the return and cleaning of bottles before refilling, it has several advantages such as ease of cleaning and ease of visual detection of spoilage and impurities.

The bottle-filling process is a cycle of events that follow one another. Clean bottles are filled in the bottle-filling machine and capped (generally with aluminium foil caps). The filled bottles are stacked in crates and sent for cold storage/refrigeration. The crates of empty bottles, after selling the product are returned to the factory. The crates are emptied and cleaned separately. The bottles go to the bottle washer, where the broken/chipped bottles are discarded and the clean, disinfected bottles are returned to the bottle-filling machine. Bottles require the following properties: The shape of the bottle should be such that it facilitates easy cleaning and allows brushes and jets (of water and detergents) to act on the entire inner surface. The neck of the bottle should be joined to the body smoothly with no sharp and protruding angle. The base should be concave so that the sediments and residues collect in the center of the bottle rather than on the periphery, thus making cleaning easier.

The resistance of the bottle to shocks is influenced by shape, consistency of quality and the thickness of the glass. The bottles should also be able to resist the high internal pressures and temperatures created during in-bottle sterilization. Optical defects such as irregularities in the composition of glass, presence of air bubbles, deformations and coarseness in the surface or extraneous matter in the glass also decrease the resistance to mechanical and thermal shocks. The capacity of the bottle should be constant and consistent and should match with the capacity of the filling machine. The most common volumes in the market are one litre, 500 ml and 200 ml.

12.2.3 Processes for Bulk Supply

The milk for bulk supply is generally processed and filled in containers manually. These may be cans of PET containers. Bulk milk is also sometimes supplied in small tankers or vans fitted with SS tanks. In the modern dairying countries where the bag-in-box-type of containers is used, the bags, which have a separate bung with a flexible tube attached, are supplied to the producers. The dairy owners use semi-automatic filling machines to fill directly into the box. When delivered to the caterers the filled box fits into a custom-built refrigeration unit with a prefitted, simple on-off tap. The tube on the bag is fed around the tap and cut off to open the bag and permit the product to be dispensed.

12.2.4 Processes for Long-life Milk

Long-life milk is that milk from which most of the spoilage bacteria are removed so that the milk could be stored for a longer period than normal milk. Specific processes such as bactofugation, microfiltration, ultra-pasteurization and ultra-high-temperature (UHT) processing help to increase the shelf life of milk. Bactofugation is a method by which the bacteria in the milk are removed by centrifugation. This uses the theory that bacteria have higher density than milk and thus will separate out into the outer orbit during centrifugation and can be removed after the process. The bacteria-rich portion is separately sterilized and added to the centrifugally sterilized bulk of the milk. Any packaging systems for fluid milk packaging may be employed to pack and market the product. However, the packaging system has to be clean and the seals preferably hermetic, in order to avoid recontamination during packaging and storage.

Microfiltration is a non-thermal, pre-pasteurization step that can extend the shelf life of milk up to 45 days. The microfiltration process uses a ceramic filter membrane to remove spoilage bacteria from milk, thus extending shelf life. Because it is a non-thermal process, milk is less susceptible to heat-related sensory defects with a 90-day shelf life. Packaging systems that prevail for fluid milk packaging may be used to pack and sell the product.

Aseptic packaging is a technology wherein the product and package are separately sterilized, and the product is then filled into the package and the package sealed in a sterile environment. The product is commercially sterile (meaning that any pathogenic or other spoilage microorganisms have been destroyed) and shelf stable (does not require refrigeration or freezing). Containers for aseptic filling have traditionally been aluminum cans, high-barrier pouches and multi-layer, foil barrier boxes. Aseptic packaging using flexible materials is also employed where extended shelf life is required. Many aseptic packaging systems are based on form-fill-seal. That is, the processor procures the packaging material in the form of rolls or stacks and they are formed (shaped) during the filling process.

Plastic materials used in aseptic packaging of milk products are polyethylene, polypropylene, polystyrene as tubes, bottles or plastic film laminates with paperboard or aluminum in the form of cartons. High-pressure steam is used to sterilize product lines and hydrogen peroxide with heat of UV radiation for container materials. The popular commercial systems available for aseptic packaging of milk are Tetra Pak, Tetra Brick, Brick Pack, Combi Block, Pure Pak, Hind Pak, etc. Tetra Pak/ Tetra Brick packs are used to pack UHT-treated milk into pre-sterilized package in aseptic conditions. The first aseptic carton was the 'Tetra Classic'. It was made from a roll of packaging material that had been sterilized in hydrogen peroxide, formed into a tube, filled with liquid, sealed transversely and cut into tetrahedronshaped containers. Tetra Pak uses paperboard laminated with 10m LDPE from outside and 70-75m LDPE from inside. The Tetra Brick uses aluminum foil of 7- 9m in addition to above laminates. The machinery needed for this system is very expensive.

Ultra-pasteurized products are produced under slightly less extreme conditions than aseptic processing. However, heat processing and clean packaging still play important roles. Ultra-pasteurized milk beverages are usually packaged in barrier-coated paperboard cartons, or HDPE or PET bottles. To prevent light degradation, PET bottles, which are clear as compared to HDPE bottles that are opaque, can be tinted and/or covered with full-body labels. A window in the label allows consumers to see the product. Ultra-pasteurized bottles include a hermetic foil seal on the bottle mouth. This prevents contamination and enables the product to achieve a 90-day refrigerated shelf life. Some processors who want to obtain a slightly longer shelf life than the standard 14 days, but do not want to ultra-pasteurize the milk, may opt for an intermediate thermal process referred to as higher-heat-shorter-time. The shorter heat exposure can leave the milk free from the sensory defects associated with aseptic and ultra-pasteurization temperatures. The refrigerated shelf life for such products is about 30 days.

12.3 Machinery involved in packaging fluid Milk

12.3.1 Machinery for single-use packaging

The machinery for single-use packaging involves a pouch-filling machine besides the normal milk handling equipments that are necessary. The available machines normally pack one litre, 500 ml and 200 ml capacity pouches. The packaging material coming out of a roll is suitably sterilized before it is shaped into a chute and sealed vertically to form a pipe. It is then sealed horizontally and a preset quantity of milk is filled from an overhead tank. The pouch is then again sealed horizontally to contain the milk before being cut and stacked manually into crates. The crates are stored in the cold room till marketing.

12.3.2 Machinery for Multiple-use Packaging

Bottles, being reusable are returned to the dairy every morning and evening after the market supply and are washed and sterilized in bottle-washers before filling. The most common among bottles being glass, we shall be discussing here, the processes dealing with glass bottle-washing and filling only. The bottle washing operation takes care of pre-rinsing, washing, rinsing and sanitizing the bottles. The clean bottles are then passed onto the filling machine where they are filled to preset volumes before capping, crating, cold storage and distribution.

12.3.3 Machinery for Bulk Supply

Bulk supply to hotels, cafes, hospitals and other institutions is generally done in cans in India. These are filled manually and therefore, the process does not require the elaborate machinery that is needed for retail packaging of milk. They can be filled directly from the outlet point of the pasteurizer or from a holding tank provided after the pasteurizing equipment.

In the case of bag-in-box type of packages that are used in the western countries, the purchase of a filling machine depends on several factors. These include (a) whether the packing is to be retailed as per volume or weight, (b) the product needs to be aseptically packaged or not, (c) the process needs to be fully automatic or not, among others.

12.3.4 Machinery for Long-life Milk

The machinery needed for filling and packaging long-life milk is very expensive. Ultra-High-Temperature (UHT) processing and packaging of milk are employed to increase its shelf life.

12.4 Packaging In Single-Service Pouches

The sequence of operations when packaging into single-service pouches includes forming the container, filling and sealing, storage of the packaged product and dispatch to wholesale and retail outlets. The parts of the packaging machine are enclosed in a stainless steel (SS) cabinet. All parts are made of SS or treated aluminium protected by a coat of weatherproof paint. Plastic sachets are pillow-shaped and made of low-density polyethylene film (LDPE). The packaging material may come in a roll of single or double film or as a flat tube. The material should be coloured to reduce light transmission. Heat-sealable film rolls are mounted inside the compartment at the rear bottom. The film is sterilized by exposing to ultra violet rays just before use. The film is shaped and heat-sealed into a tube by a vertical electrode. The flat tube type comes pre-shaped as a tube and so there will be no longitudinal seam.

After vertical sealing, the film is then moved downwards by a set of rubber rollers. It then comes to contact with the horizontal electrode. A simultaneous seal is made at the bottom of each packet and across the top of the preceding packet. The transverse seals are thus made above milk level. This also separates one pouch from the other. Injection of milk into the pouch takes place between the strokes of the horizontal electrode. The milk is kept in a small balance tank above the packaging machine, where the level is kept constant by means of a float. A timer-controlled pneumatically operated valve is used to dispense constant quantities of milk. The heat generated by both the sealing valves is removed by circulating soft water. After the packaging operation, the machine should be washed and cleaned. A general set of instructions for washing is given below.

- Bring the machine to manual operation.
- Switch off the horizontal seal and liquid injection systems.
- Empty the product from the balance tank into a can.
- Flush the balance tank with water and drain.
- Clean by circulating 1% caustic soda at 80° C.
- Drain alkali and flush with sufficient quantity of water.
- Cool machine and switch off.

The following is the daily maintenance schedule of a pouch-filling machine.

- Clean parts of the machine with a soft brush and warm liquid soap solution.
- Wash with clean water.
- Dry with air blower.
- Lubricate parts that need it.
- Check horizontal and vertical electrodes for deposition of milk solids. Do not use sharp materials for removing these.
- Elements should be replaced in case of burns or physical damages.

Lesson 13. Working principles of equipment for sterilization of milk

13. Introduction

We know milk is a highly perishable commodity. Its myriad nutrients makes it extremely favourable medium for the growth of microorganisms. It is, therefore, essential that milk is subjected to certain processing treatments for enhancing its keeping quality and ensuring safety to consumers.

Thermal processing is the most prevalent preservation process employed in the dairy and food industry. Starting from pasteurization, which is a mild heat processing technology, in-bottle/in-package sterilization emerged as a means of extending shelf life of milk for several weeks at room temperature. Considerable changes in nutritional and sensory quality due to severity of heat treatment in this process restrict its application to only special milks. Ultra-high-temperature processing, a relatively new processing know-how, became popular as it uses very high temperature (140^{o}C) for short time (2 sec) to sterilize milk. Such a time-temperature combination ensures minimal change in the product quality. Sterilized milk is then packaged in sterile container under aseptic conditions to prevent post-processing contamination. The product thus obtained has very long storage life.

13.1 Sterilization

13.1.1 Definition

Sterilized milk refers to a product obtained by heating milk in a container in a commercial cooker/ retort to temperatures of 110-130^{o}C for 10-30 min. The process is also referred as in-container sterilization. Sterilized milk is generally intended for prolonged storage at room temperature (up to 6 months). The major objective of heat sterilization is to destroy microbial and enzymatic activity. The length of time and magnitude of temperature employed during processing depend on the type of the product, number and heat resistance of microorganisms and enzymes present in milk. The heat resistance of microorganisms or enzymes is generally evaluated in terms of D-value or Z-value. Sterilization load or heat load for sterilization is generally expressed in terms of F_0 value.

13.1.2 Theoretical Basis

Clostridium botulinum is considered as the index organism for assessing thermal sterility in foods. Under anaerobic conditions, inside a sealed container, it can produce botulin, a toxin, which can be 65% fatal to humans. Therefore, destruction of this organism is a minimum requirement of heat sterilization. As milk is a low acid (pH>4.5) food, it is recommended to achieve 12 decimal reductions for *C. botulinum*. This can be achieved by heating the product at 121^{o}C for 3 min (F_0 = 3). However, this minimum treatment may produce milk that is safe but not necessarily commercially sterile. This is so because there are more heat-resistant spores present in milk. There is *B. stearothermophilus* or *B. sporothermodurans*. These spores are not pathogenic. Their presence may require heat treatment equivalent to two (2) or more decimal reductions. This may correspond to an F_0 value of 8. Target spoilage rates should be less than one survivor in every 10,000 containers.

13.1.3 Types of Sterilization Plants

Sterilizing retorts are either batch type or continuous in operation. Batch type sterilizers may be either vertical or horizontal. Horizontal retorts are easier to load or unload. They have facilities for agitating containers/cages. However, they require more floor space. Typically such horizontal retorts contain concentric cages. Cans are loaded horizontally into the annular space between the cages. When cages are full, the retort is sealed. The cages are supported by guide rails, which slowly rotate them. This stirring of the contents in cans facilitate proper heating. Continuous retorts are generally equipped with better controls. They cause very gradual change in pressure inside the cans. Thus products are heated more uniformly. Can seams are also subjected to less strain in comparison to batch process.

13.1.4 Continuous sterilizers:

They are mainly of three types: (a) cooker-coolers; (b) hydrostatic sterilizers; and (c) rotary sterilizers. Cooker-coolers carry cans on a conveyor which passes through three sections of a tunnel. These sections are maintained at different pressures for preheating, sterilization and cooling. The hydrostatic sterilizer consists of a chamber equipped with provision for steam injection. The chamber that is partially full of water is connected to two water columns (12 to 18 meter tall, barometric leg) which are used to adjust pressure in the chamber. If the height of the water columns is changed, the steam pressure is changed and therefore the maximum attainable temperature changes. For example, to get a temperature of 116^{o}C, a difference in height between the two water columns should be 10.7 m while for attaining 121^{o}C temperature in the chamber, the water column difference should be 13.7 m. A conveyor with provision to accommodate cans of different sizes moves through the steam chamber carrying the food cans. The heating time could be regulated by varying the speed of the conveyor. Hydrostatic sterilizers are very flexible and suitable for large capacity plants. However, size of the structure and high capital costs are the major disadvantages of this system.

Continuous rotary sterilizer consists of several horizontal inter linked cylinders which allow for preheating, heating, precooling and cooling in upto four continuous stages. The vessel has a spiral track on the inner wall. A spoke or reel within the centre of the cooker causes the cans to roll along the spiral track. Rotary valves used to interconnect the shells, maintain pressure in the heating and cooling sections. Sealed cans are introduced directly from the sealing machines. The contents inside the cans are mixed as cans travel along the helix and therefore enhance heat transfer and ensure less heat damage to the product. Cans coming out of the cooker are directly taken to labelling and palletizing machine. Rotary sterilizers are particularly suitable for processing of milk and milk based products, which are extremely heat sensitive and susceptible to browning.

13.1.5 Description of the Canning Process

Basic operations in conventional retorting/canning process include: preparation of the raw material, filling of the container, exhausting, sealing of container, sterilization, cooling of the cans, labelling and storage. The preparation of raw materials refers to washing, peeling, cutting, blanching, precooking, etc. in case of fruits, vegetables, meat, etc; and preheating, mixing, homogenization, etc; in case of milk. Filling of containers can be carried out either manually or mechanically. Correct and accurate filling is important from economic standpoint as well as for prevention of entrapment of large volume of air/ gas inside the can, which might decrease the intensity of heat treatment. Exhausting is an essential operation in the canning process and involves removal of air/ oxygen from the container before it is closed. Removal of air ensures minimum of strain on the can seams or pouch seals through expansion of air during heat processing. Removal of oxygen is essential to prevent internal corrosion of the container through oxidation and creation of vacuum inside the container while cooling. Absence of oxygen inside the container also delays oxidative deterioration of the product besides destruction of ascorbic acid. After exhaustion, containers are sealed. Depending on the type of containers (metal cans, glass bottles, flexible pouches); sealing machines are chosen. Glass jars are normally vacuum-sealed while tins are closed with a double sealing on the seal side and may also be vacuum-sealed. Flexible retortable pouches are sealed by fusion of two thermoplastic materials through application of heat by heated plates or jaws. Product in the closed containers is heated in the sterilizer in an atmosphere of saturated steam or hot water or air-steam mixture. The sterilizing action of steam depends on its latent heat of vaporization as it condenses on the surface of the can.

Saturated steam condenses readily and is therefore an efficient sterilizing medium. Displacement of all air present in the retort by steam before the sterilizer is brought to operating temperature is a very essential step. This is also known as venting. The purpose of this processing step is to maintain uniform steam-air mixture in the sterilizer and prevent under processing. Sterilization temperature – time combination in retorts may vary from 110 – 130^{o}C for 10-30 min. Sterilized containers are then cooled and brought to room temperature for labelling and storage. Turbidity test developed by Aschaffenburg is conducted to ensure sterility of the product. This is an indirect test and it measures denatured whey proteins. Complete denaturation indicates that the milk is adequately sterilized.

13.2 UHT (Ultra High Temperature) Processing

13.2.1 Definition

UHT milk can be defined as a product obtained by heating milk in a continuous flow to a temperature in excess of 125^{o}C for not less than two seconds and immediately packaging in sterile packages under aseptic conditions. In India, UHT milk is generally processed at 140^{o}C for 2 seconds.

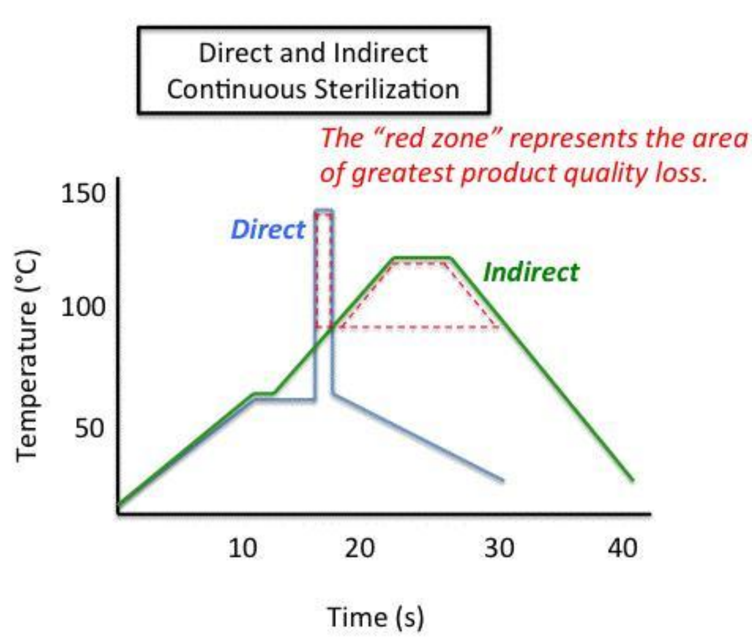
13.2.2 Theoretical Basis

Heating of milk results in death of microorganisms. While some bacteria are destroyed by pasteurization (71.7ºC/15 sec) only, some survive this thermal treatment. *Bacillus subtilis* and *Bacillus stearothermophillus* spores are very heat resistant. Of the two, *Bacillus stearothermophillus* spores are most heat resistant. It is therefore, considered index organism for evaluating performance of UHT processing. Heating of milk at higher temperatures also result in undesirable changes in chemical quality. Browning reactions are particularly important. Higher thermal load results in more browning and therefore loss of flavour and quality. In the temperature range of 100-120ºC, time required for death of almost all *B. stearothermophillus* spores are more. This may therefore result in more browning in the product.

However, if milk is treated in the UHT range i.e. 135-150ºC for only few seconds, almost all spores may get killed and browning would be minimum. Loss of nutrients and total quality also will be minimum. A product processed in this temperature range will be thus microbiologically safe and yet superior in terms of overall quality.

13.2.3 Types of Sterilization Plants

There are two types of UHT plants: Direct type and Indirect type. In direct type plants, heating is done by mixing product and steam. In indirect type plant, product is heated by steam or hot water without the two coming in direct contact. Heating in direct type plant is very rapid particularly between 80-140ºC and total heat load is less. Changes in the product quality are therefore minimum. In indirect plant, rise in temperature is very gradual. Therefore, heat load on the product is more. Changes in chemical quality are comparatively more in indirect type than in direct type plants.

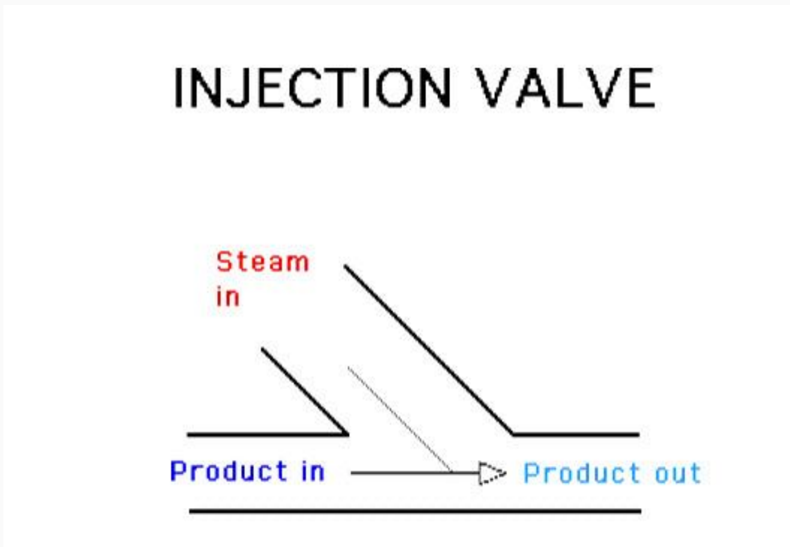


13.2.3.1 Direct Heating Plant:

There are two types of direct heating plants (a) Injection type and (b) Infusion type.

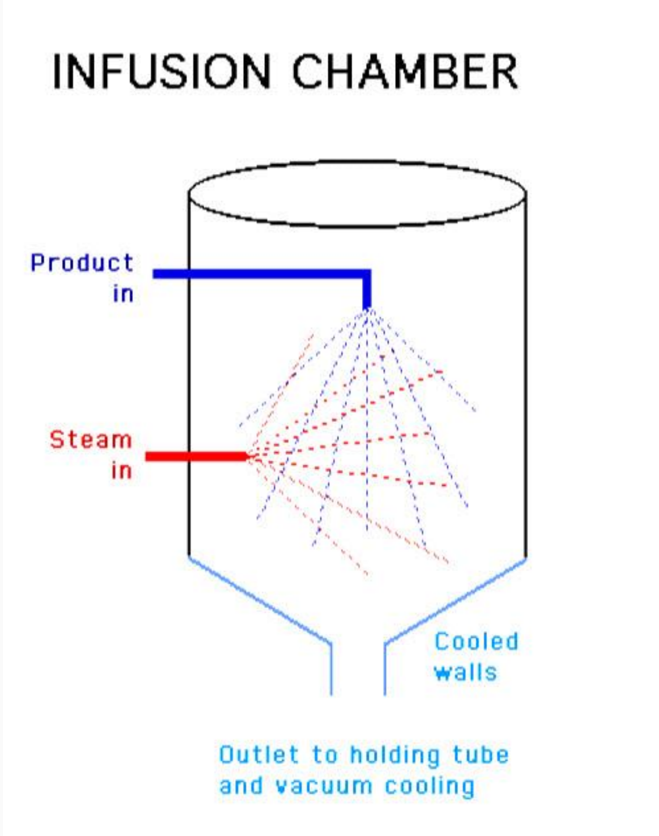
13.2.3.1.1 Injection type:

Processing is through steam-into-milk arrangement. Steam injector is the heart of this plant. Preheated milk at 80-90^{o}C enters the injector nozzles from one side. Steam at slightly higher pressure enters the injector from the other side. As the steam mixes with milk, steam condenses and the product is rapidly heated. Rapid condensation of steam prevents entry of air in holding tube. Air in holding tubes results in improper heating. Backpressure is maintained on the discharge side. Backpressure ensures that product does not boil in holding tube. Boiling may result in fouling and improper heating of milk. Several designs of injector are available.



13.2.3.1.2 Infusion type:

In this system, milk is heated by milk-into-steam arrangement. The processing unit consists of a chamber filled with pressurized steam. Milk enters the chamber from the top. There are two alternative arrangements for distribution of milk. In the first type, milk flows to a hemispherical bowl with loose circular disc closing the top. When the bowl is full, milk overflows and falls in droplets through the steam environment. In an alternative arrangement, milk flows through a series of parallel and horizontal distribution tubes. These tubes have slits along the bottom and milk flows like a thin film through the chamber. As milk reaches the bottom of the chamber, it is heated to desired temperature. This system is particularly suitable for thicker liquids and for liquids suspended with smaller chunks.



13.2.3.2 Advantages and Disadvantages of Direct Heating System:

During processing in direct type heating systems condensing of steam coming into product contact results in dilution of the product. To remove this excess of water from the product, cooling is done in an expansion cooling vessel. In expansion vessel, along with the evaporating water incondensable gases and undesirable flavour volatiles produced during heating are also removed. The product therefore tastes better. Steam injection induces formation of casein aggregates, which give “chalky” or “astringent” mouthfeel to the product. Aseptic homogenizer, which can safely homogenize the product after final heating section, is generally preferred with direct heating systems to overcome such defects in the product. Rate of heating is very high (takes less than 1 sec to attain sterilization temperature).

Thick/viscous liquid can also be easily processed. Deposit formation is minimum, hence plant can be operated for longer time without cleaning. Undesirable flavours are removed during flash cooling. Oxygen is removed during cooling, hence oxidized flavour defects are delayed during storage. Cost of processing per unit volume of milk is high. Requires additional equipment (vacuum expansion chamber and aseptic homogenizer) – cost of plant is twice that of indirect type plant. Heat energy requirement is very high. Water and electricity (25-50% more than indirect type) consumption are high. Requires culinary steam and hence special boiler. Creates greater noise during operation.

13.2.3.3 Indirect Type Heating System:

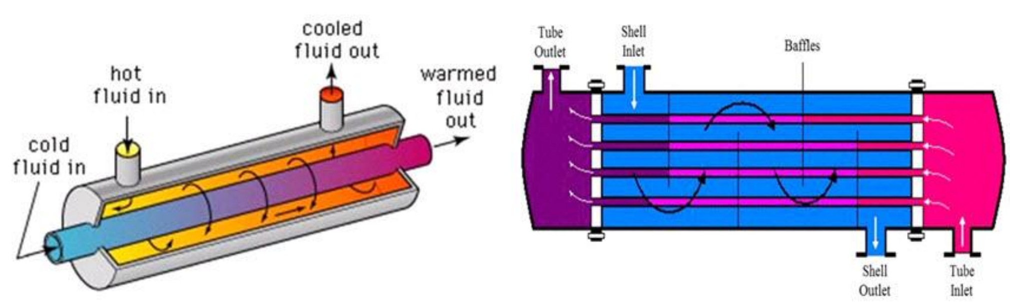
There are three types of indirect heating systems: (a) Plate heat exchangers (b) Tubular heat exchanger (c) Scraped surface heat exchanger.

13.2.3.3.1 Plate heat exchanger:

This resembles plate heat exchanger of HTST plants. Several rectangular stainless steel plates with corrugations are arranged in sequence. These plates are then mechanically tightened to hold together. Corrugations on the plates induce turbulence and therefore result in high heat transfer. High temperature processing generates high internal pressure. The gaskets are therefore made of heat resistant materials such as medium nitrile rubber or resin cured butyl rubber. A major advantage of this plant is therefore simple design and comparatively less cost. If deposit formation is more, plates can be removed and manually cleaned.

13.2.3.3.2 Tubular heat exchanger:

There are two types of tubular heat exchangers – (a) concentric tube, (b) shell and tube type. Concentric tube type heat exchangers comprise two or three stainless steel tube lengths put one inside another. Spacer is placed in each inner tube space to maintain them concentric. Several such multiple tubes are bound together and placed into an outer cylindrical housing. Two tube heat exchangers are used for simple cooling and heating. In triple tube heat exchanger, available heat transfer area is doubled. It is generally used in final cooling section. It is also suitable for processing of thick liquids, which generally reduces heat transfer rate. Product flows through the middle annular space. Heating or cooling medium passes through inner tube and outer annular space. In shell and tube type heat exchangers, 5-7 straight lengths of smaller tubes (10-15 mm internal diameter) are assembled in an outer tube. The smaller tubes are connected to large outer tube at both ends by a manifold. Product passes through the smaller tubes.

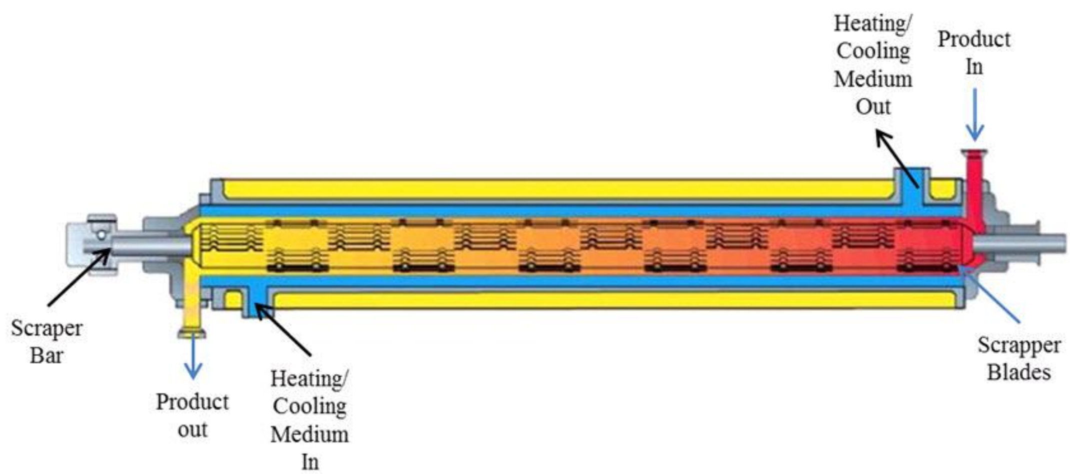


Concentric Tube type Heat Exchanger　　Shell and Tube type Heat Exchanger

Heating or cooling medium passes through the space around them in a counter current flow. Tubular heat exchangers are mechanically very strong and can withstand even very high internal pressure generated during homogenization (200- 300 bar). Therefore the need for acquiring an aseptic homogenizer to be placed after heating section is totally eliminated. Instead, the high pressure reciprocating pump of an ordinary homogenizer can be placed before the sterile section. The homogenizing valve can be put at any point on the downstream side (even after final heating section). The problem of product contamination arises from the homogenization pump and not the valve. Therefore, with tubular heat exchangers, the product can be homogenized before sterilization, after sterilization or on both the occasions. Fat rich products like cream require homogenization after final heating to prevent re-association of fat globules due to high temperature processing after homogenization.

13.2.3.3.3 Scraped Surface Heat Exchanger (SSHE):

It is a very specialized type of heat exchanger. It consists of a jacketed cylinder. A shaft passes along the axis of the cylinder. The shaft is supported by bearings at both ends of the cylinder. The shaft also carries several scrapper blades. As shaft rotates, scrapper blades provide turbulence and physically remove the product from the surface of the wall. The colder product subsequently replaces the heated product and the cycle continues.



Scraped Surface Heat Exchanger

SSHE is used only for heating very thick liquids. SSHE units are very expensive and have poor energy conversion efficiency. The cost of processing is therefore very high.

13.2.3.4 Advantages and Disadvantages of Indirect Heating System:

It is simple in design and requires less pumps and controls. It can regenerate 90% of the thermal energy requirement. It does not require aseptic homogenizer, which is very costly. It does not require culinary steam and therefore special type of boiler. The indirect type plant is less noisy. It requires low initial capital and operational cost is also comparatively less. In indirect type heat exchanger, rate of heat transfer is low. More heat load results in less acceptable product quality. Deposit formation is more and therefore plant requires frequent cleaning. For removal of dissolved oxygen from milk, additional equipment 'deaerator' is required.

13.2.4 Aseptic Packaging

Aseptic packaging can be defined as the process in which UHT processed or sterilized milk is filled in pre-sterilized containers under aseptic/sterile environment. This ensures that there is no post processing contamination of the milk so that the product has longer shelf life. Since aseptic packaging systems are complex, great care is needed to prevent contamination. Before the start of product packaging, trial runs are routinely conducted with sterile water. Critical parts of the filling machine and carton forming systems are thoroughly checked. The seal integrity of the package and overall microbial quality of the packaging material are monitored properly. Generally, for a good processing plant permissible spoilage rate is one in every 5000 sterilized, filled and sealed package of one litre carton.

13.2.4.1 Types of Sterilizing Medium

Sterilizing mediums to be used in aseptic packaging systems could be broadly classified under two categories: physical sterilization mediums and chemical sterilization mediums.

- **Physical sterilization mediums:**
  - **Dry heat/ superheated steam (300^{o}C)**
  - **Ultraviolet radiation (UV rays, 250 nm wavelength)**
  - **Ionizing radiations (gamma rays, 2.5 M rad intensity)**
- **Chemical Sterilization Mediums**
  - **Ethylene oxide**
  - **Hydrogen Peroxide (H_2O_2)**

13.2.4.2 Type of Packaging Materials

- **Metal container:**

Cans made of tin plate or drawn aluminium are generally used for packaging of condensed milk, viscous liquids and chunk-in-gravy type of products. These are expensive and unsuitable for low cost products like liquid milk.

- **Laminates/cartons:**

Different layers of flexible films of different materials viz. paper, polyethylene and aluminum foil are co-extruded to form a laminate. These materials have specific properties viz. water vapour transmission, burst strength, etc; and hence when co-extruded form an ideal packaging film.

- **Plastic films:**

Black and transparent polyethylene films are co-extruded for packaging of UHT processed milk intended for 2-3 weeks shelf life.

Lesson 14. Working Principles of Butter Manufacturing

14. Introduction

Butter is essentially the fat of the milk. It is usually made from sweet cream and is salted. However, traditionally it is being made from cream that had been allowed to stand and sour naturally. The cream is then skimmed from the top of the milk and poured into a wooden tub. Butter making is done by hand in butter churns. The natural souring process is, however, a very sensitive one and infection by foreign micro-organisms often spoiled the result.

Today's commercial butter making is a product of the knowledge and experience gained over the years in such matters as hygiene, bacterial acidifying and heat treatment, as well as the rapid technical development that has led to the advanced machinery now used.

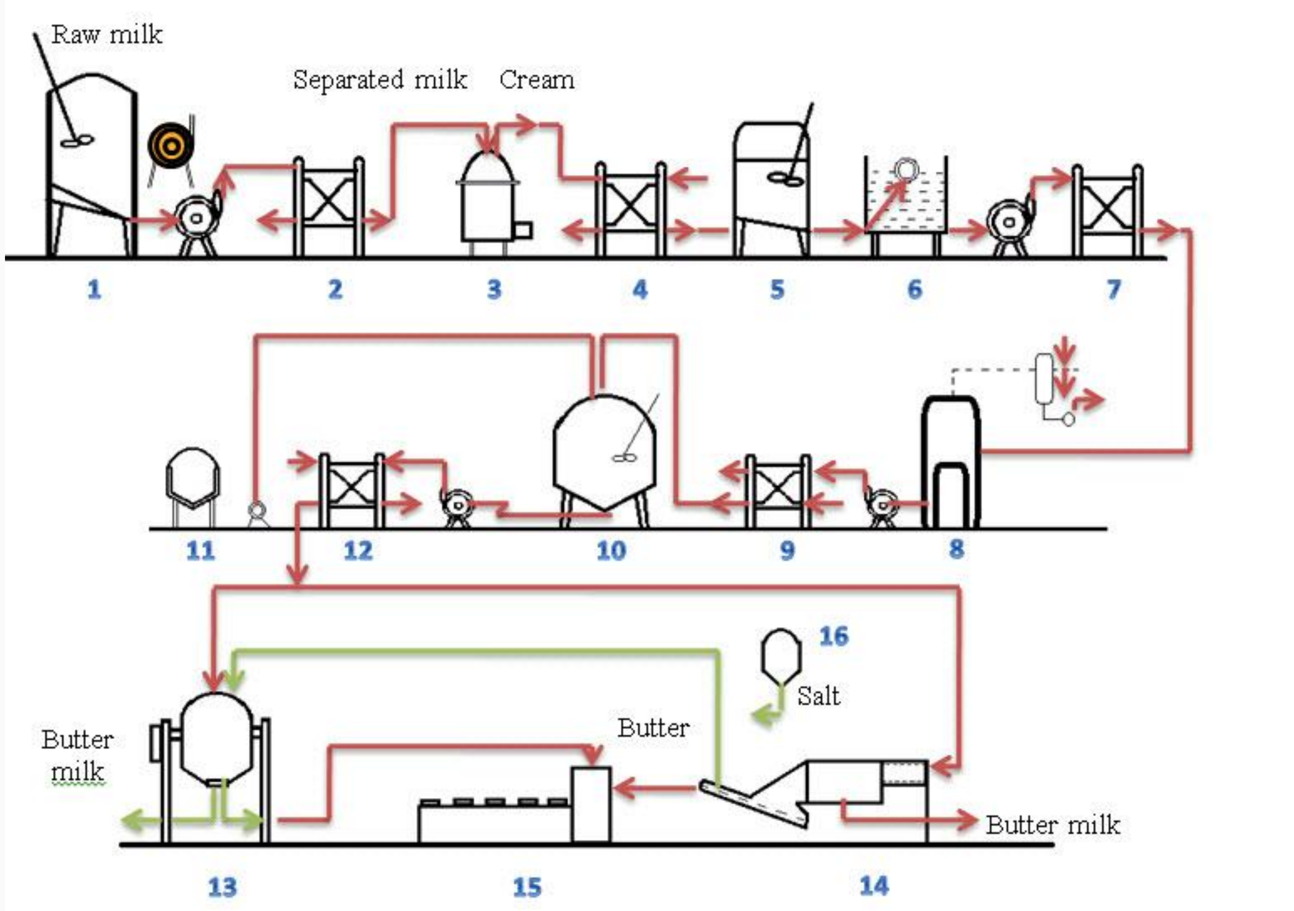
The principal constituents of a salted butter are fat (80 - 82%), water (15.6 - 17.6%), salt (about 2-3%) and residual curd (about 1.5 %). In butter making the oil-in-water emulsion of cream is converted by the process of churning into the water-in-oil emulsion of butter. The consistency should be smooth so that the butter is easy to spread and melts readily on the tongue.

14.1 Important Steps in Butter Making

Figure 14.1 presents a flow diagram of butter making starting with the raw milk delivered to the plant.

The severe heat treatments to cream should be avoided to retard the migration of copper from the milk serum into milk fat and ultimately to control development of rancid flavour and to increase the shelf-life of butter.

The plate heat exchanger design should avoid high pressure differentials, as the high shear rate associated with this could result in premature damage to the milk fat globules. This damaged cream would be unstable and liable to cause problems on subsequent handling prior to butter making. Cream may also be damaged by incorrect sizing of pumps, particularly centrifugal pumps. It is recommended that the cream for butter making be handled by positive displacement pumps. Care is needed to avoid excessive shear forces which would create too many small fat globules. This would result in higher losses of fat in the buttermilk. Any rubber components in the plant for cream handling or butter making must be of a fat resistant type, e.g. nitrile rubber. Rubber compounds, that are not fat resistant, break down after several days of contact, and will contaminate the product.



1. milk storage tank 2. preheater 3. separator 4. cream cooler 5. cream storage tank 6. balance tank 7, heater 8. de-gassing 9. cooler 10. cream ripening tank 11. starter culture 12. heat exchanger 13. butter churn (batch process) 14. continuous butter making machine 15. butter packing 16. salt container

Fig.14.1 Flow diagram of butter manufacture

14.1.1 Churning

The purpose of churning is to destroy the 5 to 10 nm thick fat globule membrane in which the butter fat exists partly as a liquid. Liquid fat should leave the fat globules and coalesce to form fat agglomerates or butter granules. For agglomeration of fat globules into butter granules to take place, it is necessary that part of the fat be in crystalline form. The rapid motion of the fat globules in relation to each other, aided by collisions with surfaces and by high turbulence causes the fat crystals to penetrate the membranes as these become progressively thinner. Free fat finally emerges from the porous parts of the membrane and fat agglomeration takes place.

Agglomeration is difficult at too low temperature when the proportion of liquid fat is too low and equally difficult at too high a temperature when all the fat is in liquid form.

14.2 Batch Butter Churns:

14.2.1 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.

14.2.2 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.

i.e.: $m\omega^2 R < mg$

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

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.

i) <u>Loading the cream</u>

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.

ii) 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.

iii) Buttermilk draining

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

iv) Washing

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

v) 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.

vi) 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:

a) Driving gear should be filled with lubricating oil and every alternate year replace it.

b) Never change the speed while the churn is running.

c) Solid foundation is necessary for churn and driving gear

d) Gaskets to be maintained leak proof.

e) Proper roughness inside of the churn should be maintained.

f) Proper cleaning of the churn after the operation is over.

14.3 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.

14.3.1 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.

14.3.2 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.

i) <u>Preparation of cream</u>

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.

ii) <u>Churning the cream</u>

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.

iii) 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.

iv) 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.

v) 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.

14.3.3 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).

i) 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.

ii) 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.

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).

14.3.4 Concentration, De-emulsification and Re-emulsification Process

The main steps of Gold'n Flow butter making method are described below (McDowell, 1953).

i) 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.

ii) Concentration

After destabilization cream is concentrated to 85 – 90 percent by a special separator which discharges skim milk, sludge and concentrated cream.

iii) Pasteurization

The concentrated cream is pasteurized in a vacreator at 88 - 90°C and subsequently cooled to 38 – 43°C.

iv) Standardization

The liquid butter fat in which small droplets of cream are dispersed is constantly stirred and standardized for moisture, salt and fat.

v) 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 NH_3. 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.

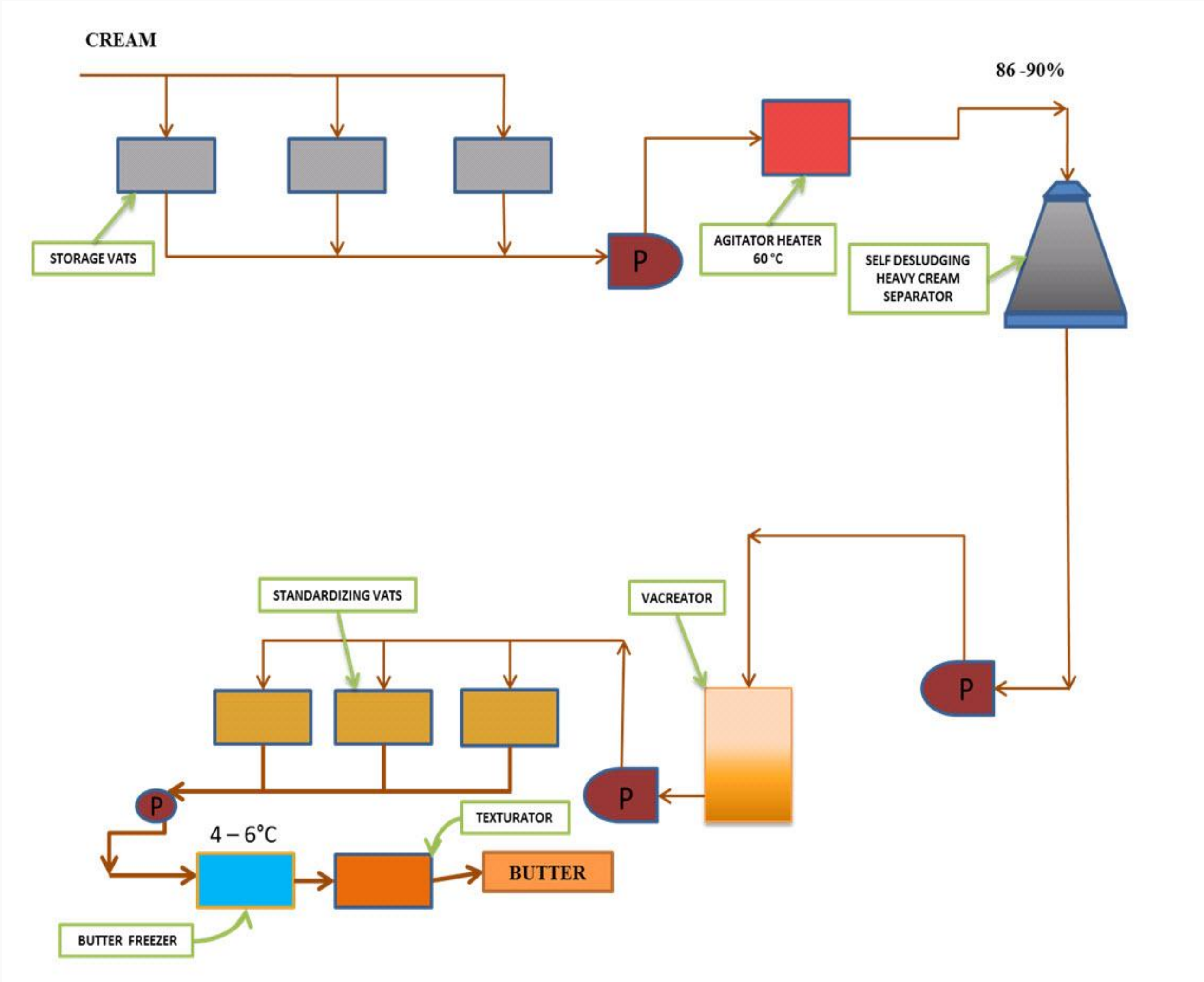


Fig.20.4 Gold'n Flow Process - Continuous Butter Churn

Module 5. Dairy plant design and layout, composition and proximate analysis of food products

Lesson 15. Dairy plant design and layout-I

15. Introduction

In the dairy plants, there are number of unit operations being carried out to convert raw milk into value added finished products. They employ all sorts of resources like raw materials, plant utilities (water, air, electricity, refrigeration, steam and waste treatment etc.), plant-machinery and human resource. All these resources are accommodated in one or more buildings located in campus in order to boost the economy of interactions between these housings and various resources. Thus, a good planning is required to help smooth flow of resources for effective operations that provide hygienic atmosphere during production in one hand and economy of operations and value addition on the other.

In India, the organized dairy sector processes less than 15% of total milk production whereas the rest is either consumed at home or used in unorganized sectors like sweet makers. Especially during lean period the capacity utilization of the plant goes down hence milk remains underutilized. Operation of unnecessary large size plants and equipment becomes uneconomical due to more operational expenses along with other overhead expenses. Thus, illogically designed dairy plants fetch higher investment and working capital. Hence, various factors that are relevant to design and layout of dairy plant must be looked into.

15.1 Classification of dairy plant

Looking to the unit operations and product profile, dairy plants could be categorized as liquid milk processing plants, products manufacturing plants or combination of these two (i.e. Composite Dairy Plants).

15.1.1 Liquid milk Processing Plant:

In such plant raw milk is received at the dock, chilled, processed (pasteurized) and packed for sale. These plants directly procure milk from recognized milk sheds or other sources. Such plants have little value addition but with high liquidity of money, as the payment for raw milk is done after 7 or 10 days, whereas realization is either in advance or on the same day. Furthermore, the realization money is circulated on daily basis creating an advantage for low requirement of working capital.

15.1.2 Product Manufacturing Dairy Plants:

Raw milk is converted into value added milk and milk products by engaging suitable technologies and using proper equipment. Manufacture of these products improves the viability of the overall milk business. Other benefit lies in the conversion of perishable milk into products with long shelf life, which are suitable for distant marketing.

15.1.3 Composite Dairy Plant:

Most of the dairy plants do have facilities for processing and packaging of milk and milk products. This benefits the dairy plant in terms of high liquidity of cash together with the advantage of better shelf life and value added products. Such milk plants are more viable and sustainable.

15.2 Planning considerations for dairy plant

Planning for dairy plant should consider following aspects:

a) Projecting of milk business with respect to milk procurement and marketing;
b) Market research for product demand;
c) Accessibility & requirement of land, topography to suit disposal of waste and communication;
d) Investigation of water requirement and availability; and
e) Permissions from municipal, pollution and aviation authorities.

Based upon above factors, taking into full consideration the selection of plant location, design and layout, dairy plant of desired capacity could be designed.

15.3 Site location

The main criterion of functional importance is the minimum cost for procurement, production and distribution. Other vital factors which should favour, the location include topography, shape and size of site, availability of water, power/ fuel and climatic conditions. Yet, due to increased pollution and industrialization, all sites are not permitted for industrial work. Some incentives are being provided by some states or central government for development of certain industries on specified locations, that also requires to be looked into. These are some of the points that need to be analyzed thoughtfully for finding out the best location.

15.4 Estimation of capacity

Selection of facilities and equipment for optimum handling of the various resources involved in the manufacturing of products are the key factors for successful design. Hence, the first step would be the estimation of the capacity of a dairy and earmark production of various products with capacity. Other requirements like equipment, utilities, structure and manpower can be estimated accordingly. Generally following main factors are taken into consideration:

a) Milk shed area and its potentiality,
b) Future probability of expansion,
c) Nearby dairy plant, its distance and expansion possibilities,
d) Connectivity of villages, possibilities for milk procurement and expected development,
e) Productivity of animals and future aspects affecting milk production,
f) Allied occupation of farmers and extent of their sustainability,

g) Social tendencies for milk business,
h) Government policies for boosting milk production,
i) Change in life style, purchasing power of consumers and nutritional awareness among people.

15.5 Selection of plant equipment

Some of the important points for deciding equipment are detailed below:

a) Select the production technology,
b) Calculate the number of equipment required, with their capacities,
c) Finalize the production line according to the multiple uses of processes and requirement of products having provision to get maximum benefits. Some plants have process sequence, whereas others are specific to products.
d) Study the cleaning and sanitary provision to allow maintenance, cleaning, disinfection, monitoring and inspection.
e) The construction material should be non-reactive, non-toxic, non-corrosive and of food grade quality especially that coming in direct contact with the milk. It should be able to withstand processes like heating and cooling. Materials for heat exchanger should be good heat conductors.
f) Wherever necessary, equipment should have provision for controlling and monitoring of temperatures, humidity, airflow and other parameters which else would be considered as harmful to food safety.
g) Space requirement for equipment should be calculated.
h) Utility requirements associated with the product and equipment.
i) Spacing between adjacent equipment and service pipelines to facilitate maintenance.
j) Develop flow diagram for identification of operation sequence and material flow.
k) Consider the housing requirement for each product and equipment. Some products need to be manufactured in controlled atmosphere and need proper building, whereas others manufactured within the equipment kept in open. Similarly some of the equipment requires proper housing and others need open air for their efficient operation.

In dairy industry there are lots of examples to witness the above situations. For examples, ammonia condenser used in the refrigeration plant needs to be kept in open for maximum dissipation of heat, whereas milk vats need to be placed in the sanitary place with complete enclosure. While visiting a dairy plant one can have notice of such aspects.

a) Find out economy of material handling by using natural or gravity flow.

b) Find out operation economy by proper location of section or equipment. In other words, we should not place openings of low temperature or cold room directly facing to west if frequent openings are to be in the second half of the day. Similarly, openings or doors of high hygiene production area should not open towards the unhygienic area, without safety measure like air curtain or anti-room.

After giving full considerations to above aspects, next planning step would be to design establishment for production and other facilities, which is detailed in the next lecture.

Lesson-15: Dairy Plant Design and Layout-I

Assignment

Answer the following	
1	What is expected from a good design of establishment, Give main five objectives?
2	Name main Factors which influence dairy plant capacity
3.	Write any five major factors for selection of dairy equipment.

Lesson 16. Dairy plant design and layout-II

16.1 Design of establishment

Manufacturing norms for Milk and milk products are covered under Essential Commodity Act like Prevention of Food Adulteration (FPA) and Milk and Milk Product Order (MMPO). After globalization under World Trade Organization (WTO) agreement, the manufacturing conditions can be looked with more stringent CODEX Food hygiene guidelines. Now with implementation of Food Safety and standards bill 2006 all food produces including milk products will have to meet its guidelines.

Depending upon the nature of the operations, and the risks associated with them, premises, equipment and facilities should be located, designed and constructed to ensure that:

a) Contamination is minimized to safe level;

b) Permits appropriate maintenance, cleaning and disinfections and minimize airborne contamination;

c) Surfaces and materials, particularly those in contact with food, are non-toxic and if necessary suitable for easy cleaning.

d) Where appropriate, suitable facilities are available for temperature, humidity and other controls; and

e) Effective protection against pest access and harborage.

Attention to good hygienic design and construction, appropriate location, and the provision of adequate facilities, is necessary to enable hazards to be effectively controlled. In this context, each aspect of dairy is discussed below:

16.1.1 Location

Suitable location for the establishment and equipment should include following considerations:

16.1.1.1 Establishments

- To prevent potential sources of contamination to food.
- No food establishment should be located in the hazard prone site.

- Location should be away from environmentally polluted area that can contaminate food, such as, flooded, waste and infestations of pest prone area

16.1.1.2 Equipment

- Equipment should be properly located to permit adequate maintenance and cleaning.
- The location facilitates good hygienic practices and effective monitoring.

16.1.2 Premises and rooms

Suitable consideration should be given depending upon requirement and nature of equipment:

16.1.2.1 Design and layout:

Where appropriate /applicable, the internal design and layout of food establishments should permit good food hygienic practices including protection against cross-contamination during manufacturing and storage.

16.1.2.2 Internal structure and fittings:

Structures within dairy establishment should be soundly built of durable materials and be easy to maintain, clean and /or disinfect. To achieve this, the surfaces of wall, ceiling and floor should be impervious and of non- food toxic materials. The surfaces should be smooth and allow proper removing of water, dirt and germs. The material of facilities or fittings coming in the direct contact of milk should be non-reactive type.

16.1.2.3 Temporary /mobile premises and vending machines:

- Premises and structures like stalls, mobile sales and street vending points as temporary housing should be sited, designed and constructed to avoid, as far as reasonably practicable, contaminating food and harboring pests.

16.1.3 Equipment and containers

The design and construction of equipment and containers handling milk and milk products should be given adequate consideration for cleaning, disinfecting and preventing food contamination. The contact surfaces should be made of materials with no toxic effect in the intended use of food. Design of equipment should facilitate easy movement and capability of disassembling to allow maintenance, cleaning, disinfecting, monitoring and inspecting pest. Other important requirement of processing equipment is to withstand processing condition without affecting food safety aspect. The equipment should have provision and capability for monitoring and control of process parameters. Containers for waste, by-products and inedible or dangerous substances should have specific identification, safe design and placement at appropriate location. Required safeguard should be made to prevent cross contamination from these containers or their contents.

16.1.4 Design of facilities

Dairy plant has to be provided with required facilities for water supply, drainage/waste disposal, cleaning system, personal hygiene, toilets, humidity, air and temperature control, lighting and storage of various materials. These are discussed below:

16.1.4.1 Water supply:

An adequate and potable water supply with appropriate storage, distribution and temperature control, should be available whenever necessary to ensure the safety and suitability of food. Supply and storage line for non-potable water should be separate with proper identification. This requires proper selection of source of supply, pumping, storage and treatment units.

16.1.4.2 Drainage and disposal system:

Adequate sanitary condition in and around plant can be maintained by proper arrangement for types of drains with cleaning and dis-infection arrangement. Slope of floor and drains is of equal importance to let-out the spillage and washings.

16.1.4.3 Cleaning:

Cleaning of plant premises and equipment should have provision in the planning stage itself. Proper clearance and facilities need to be considered.

When manual cleaning is either not possible or less effective, then alternative methods like cleaning –in-place should be employed.

16.1.4.4 Facilities for personnel hygiene:

In order to prevent cross contamination from machine and materials to man and vice versa, required arrangements should be thought for necessary equipment, space and water supply. Good dairy plants have provisions of cloth changing and hand washing and drying. Other requirement relates to minimizing human contact with product. For this, most of the works are done by equipment and tools like trolley and shovel etc.

16.1.4.5 Temperature control:

Most of the dairy operations are temperature dependent. Heating, cooling or holding at certain temperature is required to obtain product of good microbial quality, flavor and texture. For this steam supply unit, refrigeration unit and temperature recording, monitoring and controlling mechanism are provided.

16.1.4.6 Air supply system:

Adequate air supply system should include compressor, inter-cooler, oil separator, air filters and drier /humidity controller. Air pipeline is provided to meet operation requirements of agitation, oxidation, control and / or conveying function. If air comes in direct contact of product, then its proper hygienic quality should be ensured.

16.1.4.7 Lighting:

Design should consider availability of adequate natural light. However provision of artificial light needs to be made according to the requirement of operation. A minimum illumination requirement in lumen per square meter for functions like reception, processing, cleaning is approximately 500 to 600, monitoring places like weighing, equipment with gauges, filling & inspection, laboratory and accounting is approx. 1000 and for common places like corridor and utility section is 200 to 300.

16.1.4.8 Storage:

Adequate facilities should be provided for the storage of food, ingredients and non-food chemicals (e.g. cleaning materials, lubricant fuels).Appropriate, food storage facilities should be designed and constructed to permit adequate cleaning and maintenance, avoid pest access and harborage, enable food to be effectively protected from contamination, and provide proper environment that minimizes the deterioration. Storage of edible, non-edible and hazardous materials should be separate.

16.1.5 Space consideration

Space requirement for facilities and equipment varies from make to make and model to model for a given capacity. Functional areas or rooms in a plant must not be crowded or sized far larger than necessary. Therefore, the structure and civil arrangement is made precisely, One has to either select specific model /make process /product line or has to approximate the requirements. In the first type of arrangement, selected supplier may be requested to detail the space requirement.

However, the planning of a dairy is done in advance before selection of particular equipment /model or manufactures; hence, for effective planning, one has to depend on certain guidelines, which are given below for general purpose:

1. For a medium size milk plant, the area should be 2 to 3 sq. m per 100 L of milk, whereas for small plant of less than 10000 L per day, space requirement will be approximately 6 to 7 sq. m per 100 L milk.
2. Approximately 75000 L milk can be stored in 200 sq. m area cold store.
3. Approx. 50 kg ghee or butter can be stored per sq. m area.
4. 750 kg milk powder in 25 kg bags would require approx. one sq. m storage space.
5. Dry storage area should constitute approx. 25% of the total plant area.
6. Refrigeration and steam boilers each requires approx. one fifth sq. m per 100 L milk

7. Processing area should be five times the size of equipments
8. At-least one meter space is considered good between two equipments.
9. If floor area available is insufficient, then vertical type of storage tanks /vessels should be preferred. Now for storage of chilled water, insulated silos are becoming popular, which requires less space and can be installed outside of plant. Similarly, milk storage tank can be kept outside of the constructed building.
10. While considering the requirement of hardening room, a minimum of five days production would be required.
11. Milk reception, storage tank and product sections require approximately10% of the plant area. CIP, laboratory, personal hygiene and rest room etc. require approx. 2 to 3 %, whereas processing, packaging and cold store would require 15 to 20% of the plant area.

16.2 Plant layout

Dairy functions and equipments require number of considerations. Therefore, best match of these considerations would give optimum layout to allow smooth plant operations without hindrance and cross contamination at economical cost. While finalizing the layout plan, future expansion of facilities and product line also need to be kept in mind. The ideal layout permits production of new product or modification in production system at the least possible expense and interruption in production schedule.

Good plant layout has short pipeline, least number of bends. As far as possible, sequencing of equipment should follow the process layout. Plant machinery should be placed apart at sufficient distance to allow movement for cleaning, operation and monitoring. Minimum holding of product during production is another aspect of consideration. Least possible stock of intermediary or in-process and finished item should be present on the production floor. The premises should allow use of the material handling equipment. Development of good layout should fulfill following objectives:

a) Improve or facilitate production operation,

b) Minimize material handling,

c) Have flexibility of operation for alterations and expansions,

d) Minimize investment in equipment,

e) Economize use of floor area,

f) Make labour utilization effective,

g) Make effective utilization of by-products,

h) Provide convenience and comfort for employees,

i) Ensure proper cleaning, operation and monitoring of processes, and

j) Prevent cross contamination.

The above points can be planned according to the type of layout. In multipurpose production system, product layout is preferred, whereas specialized production needs process oriented layout. Depending upon the requirement and nature of production, each function should have their optimized layout.

Lesson 17. Composition of food products

17. Introduction

The primary food nutrients contributing to the total dietary energy intake are protein, carbohydrate and fat, which provide 4, 4 and 9 kcal per gram of food respectively. Metabolism of these nutrients produces the chemical energy that powers muscular contraction, allows brain cells to function and permits the synthesis of compounds the body needs from simpler compounds in the diet. The breakdown of digestible carbohydrates yields carbon dioxide and water, which are eliminated through the respiratory system. Whereas, metabolism of fats and proteins involve the liver to safely convert intermediate metabolic compounds that are further metabolized or eliminated through the urinary system.

17.1 Carbohydrates

17.1.1 Fiber

Carbohydrates are the structural and storage organelles of plants. The structural carbohydrates in plants are complex compounds of repeating five carbon sugars called pentosans or repeating six carbon sugars called glucans. Hemicellulose and cellulose are non-digestible carbohydrates and together with another complex non-carbohydrate compound known as lignin which forms dietary fiber that can't be softened appreciably by hydration or heating, thus they generally impart a rough mouth feel to food products.

Another plant component is pectin which is soluble in hot water but non-digestible, forms a component of cell walls of plants and causes the softening of vegetables when cooked due to change in the pectin molecular structure. Commercial pectin preparations are used for manufacturing jams, jellies and preserves as they are very good gelling agents.

Some plant seeds, secretions from the bark, or the stem and leaves of aquatic plants contain soluble complex carbohydrates called gums. Gums can be dissolved in water to produce viscous solutions and they forms gels at specific concentrations, or in the presence of specific ions or sugar. Due to wide applicability of gums, they provide tools to food technologists to modify and customize the body, mouth feel and texture of the modern foods.

17.1.2 Sugars

The simple sugars are the primary products of photosynthesis as well as the finished product of the complete digestion of carbohydrates. Simple sugars are sweet soluble carbohydrates and cannot be further broken down. The end products of digestion of complex carbohydrates in the digestive tract, are quickly absorbed from the intestines into the blood circulatory system, that provide rapid energy to some individuals, but it could also be unfavourable to diabetics who are susceptible to hyper/hypoglycemic fluctuations with intakes of simple sugars. Refined sugars are the common carbohydrate sweeteners such as cane sugar, corn syrup and high fructose corn syrup. The consumption of these sugars in excess with minimal intake of the other dietary nutrients increase the susceptibility of tooth decay by promoting the growth of certain bacteria. These health issues must be taken into consideration by a food technologist before choosing the carbohydrate for food formulations.

17.1.3 Starch

Starch, a complex molecule consisting of a long chain of repeating units of the simple sugar, glucose is a storage carbohydrate in grains and root crops. As plants also utilize starch for respiration, it is easily digestible by humans. It is also recommended to provide the majority of dietary calories. It plays a significant role in determining the texture of foods in addition to supplying calories.

Starch, in native form, is available as granules in a cellular matrix of grains and storage roots or tubers of plants. A purified starch can be easily separated from other components by macerating the root or milling the grain releases these granules. Wheat flour is a mixture of starch along with the other components of the grain, whereas corn starch is a pure starch. Within the starch granule, there are two types of polymers, amylose, a straight chain polymer and amylopectin, a branched chain polymer. These large complex molecules are tightly coiled within the granule. Heating of starch in presence of water allows the granules to absorb water, swell and release the amylase and amylopectin into solution. These hydrated polymer molecules in the solution forms the gelatinized starch, where intact starch granules are not visible. The gelatinization process is manifested by an increase in viscosity. Different starches will have different gelatinization temperature and different viscosities at different concentrations. When starch is gelatinized at an appropriate concentration and allowed to cool, it forms a gel that possesses the ability of starch to bind water and to impart firmness to food products.

Amylose and amylopectin are present in different starches in different proportions and provide different characteristics on gelatinization. Gelatinized amylose solutions are clear and form firm gels with a tendency to release free water from the gel matrix on cooling, whereas amylopectin on gelatinization gives opaque solutions that do not form firm gels on cooling. Amylose has a higher gelatinization temperature than amylopectin.

Most natural starches consist of one or more of the other polymer. For example, waxy maize starch contains practically all amylopectin, whereas regular corn starch has more amylose than amylopectin.

This process of conversion of gelatinized starch from a soluble to an insoluble form is called retrogradation. It is a reversible process that may be reversed by heating. In low moisture cooked starchy products, for example, retrogradation in bread leads to stiffening of the structure or staling, making the product hard and dry. With decreasing moisture content and reduced temperature, the rate of starch retrogradation increases. In frozen foods, water is immobilized by freezing and so there is little movement from entrapment within the starch molecular network. The retrogradation in frozen foods can be minimized if both freezing and thawing processes are carried out rapidly. When starchy foods are stored under refrigeration, they are most susceptible to retrogradation due to the time of holding at low temperature just above the freezing point is the critical period for development of retrograded starch. When starch is used in a food formulation its retrogradation can irreversibly alter the desirable product quality attributes. Amylose due to its straight molecular structure is more susceptible to retrogradation compared to amylopectin. Nowadays commercially available modified starches, which are designed to alter the gelatinization temperature, viscosity enhancing properties and retrogradation tendency of natural starches are boon for the food technologists to formulate newer products with improved functionalities.

17.2 Fats and oils

Fats or oils consist of three long chain fatty acids associated with a glycerol molecule and are also called triglycerides. They have a similar chemical structure, but different types of fatty acids in the molecule that alters its physical state at room temperature. When the fatty acids are highly saturated, each carbon atom in the molecule has its full complement of hydrogen atoms. Fats made up of saturated fatty acids are stable against reacting with oxygen and hence are less prone to oxidative rancidity. On the other hand, oils are made up of unsaturated fatty acids, i.e., they do not have their full complement of hydrogen atoms in the molecule which may easily react with oxygen to produce compounds which impart a rancid odour or flavor. Physiologically, in animals, saturated fats tend to be present in leaf fat or adipose tissue while unsaturated fats form a component of cellular membranes. The degree of saturation of such fats depends upon the source animal. Amongst all fats, red meat contains the highest level of saturated fatty acids while fish has the least amount of saturated fats followed by poultry. Plant-derived oils, such as peanut, canola, corn, soybean and cottonseed are highly unsaturated, whereas, tropical plant oils such as cocoa, coconut and palm oil contain highly saturated fats.

In the human body, saturated fats cannot be dehydrogenated into unsaturated compounds, hence the necessity for highly unsaturated fats to form cellular membranes must be met by dietary intake of such compounds. These highly unsaturated fats are known as polyunsaturated fats and considered as essential dietary nutrients. No major physiological function is performed by saturated fats except to serve as a source of dietary calories. Fats have nearly double the caloric equivalent of the same weight of carbohydrates or proteins. Thus, the products having high fat are also high in calories, which can be reduced by formulating low fat products. The melting point of fat used in a food formulation affects the texture, appearance and flavour of the product depending on how the components blend, how the product holds water and fat as it undergoes the mechanical and thermal processes. As fat is an excellent carrier for colour and flavours, the success of a food formulation mainly depends upon the choice of fat. The type of fat in the product formulation will also decide the packaging options for adequate storage to prevent development of oxidative rancidity.

17.3 Proteins

Proteins are the structural component of animal tissue. The muscles which contract and relax for body movement are composed of the proteins namely, actin and myosin. The connective tissue that separates muscle bundles is collagen which also forms the matrix so that calcium and phosphorus are deposited in bones.

Proteins consist of a long chain of amino acids or nitrogen-containing organic compounds. There are 22 known amino acids in proteins. The type and number of amino acids in a protein decides its protein type. Plant and animal proteins diverge in the distribution of different types of amino acids in the molecule. Animal proteins most closely resemble the amino acid profile of human tissue protein, so they are best for human growth and maintenance. Plant proteins, may contain a low level of some of the essential amino acids and so more of it must be consumed in the diet to fulfil the requirement for growth and maintenance of healthy tissue. Some proteins such as gelatin have no nutritive value as they lack one or more of the other essential amino acids.

Proteins get metabolized, for energy and thus contribute to dietary calories. Proteins on digestion produce free amino acids. Commercial proteolytic enzymes from microbial sources may also digest proteins in vitro to alter their solubility, gelled product textural attributes, or to impart a characteristic flavour. Proteins are generally bland in flavour. However, with the decrease in the amino acid chain length, the flavour becomes more distinct. Hydrolysed proteins with a high fraction of free amino acids have a very strong flavour and odour, while some may have even a bitter flavour. A careful formulation and processing of foods containing animal muscle and plant based protein foods is required to get a stable solid matrix with the ability of proteins to bind water and fat. Proteins and carbohydrates have the same caloric equivalent; therefore, they may be exchanged in the food formulations to get reduced cost. A number of commercial protein products and protein hydrolysates are available to food scientists for different product formulations.

17.4 Other food components

Food components though present in low concentrations, define a characteristic colour and flavour of foods.

17.4.1 Acids

After the basic chief nutrients, acids exist at the next higher level. They are intermediates in plant metabolism; and even certain plants have the capacity to accumulate specific acids at enough high levels to impart a distinctive flavour and mouth feel.

Acids impart a sour flavour and its intensity depends upon the pH and the fraction of un-dissociated acid. Generally, strong acids give a harsh mouth feel on swallowing. The different interactions of the un-dissociated acid molecules with other food components such as carbohydrates may control or enhance the sourness perception. Commonly, sugars tone down sourness, whereas mineral salts exaggerate the sensation. Gums tend to minimize the harshness of the acid, by coating the linings of the throat, but they also prolong the sourness sensation after swallowing. Lactic acid has a slightly bitter after taste, while tartaric acid leaves a slight scratchy feeling in the throat after swallowing the product. Citric acid is best used in a formulation with a small amount of sugar to give a smooth non-tenacious sourness sensation after swallowing.

Acids may be naturally present in the product or they may be an added ingredient. Citric acid is the most common plant acid, primarily available in citrus fruits viz.; lactic acid in fermented dairy products, malic acid in apples and tartaric acid in grapes. Most of these acids are produced commercially by fermentation and are available in pure form for use in food formulations.

17.4.2 Pigments

Plants synthesize pigments to produce the various colours of plant products. The most widely distributed pigment is chlorophyll, the green pigment in plants. It is water soluble and is unstable with heat, particularly at low pH. Degradation of chlorophyll leads to bleaching out of green colour and transformation into brown colour. Hence during processing of products care must be taken or else green colour may change to brown.

The next most widely distributed water-soluble pigments are the anthocyanins, whose colours ranges from pink to deep blue. It is pH dependent, being red at the low end and as pH increases, it intensifies to blue. Anthocyanins also change colour to brown when they degrade during storage or during heat treatment of the product. The degraded pigments tend to agglomerate with surrounding degradation products to precipitate slightly at the bottom of the container. The presence of oxygen along with the elevated storage temperature tends to accelerate the degradation of anthocyanins, while the presence of sugar tends to slow down its rate. Anthocyanins do not have an attractive colour at near neutral pH and so they are mostly used as a colourant in frozen sliced fruit and shelf stable juices or beverages.

The natural fat-soluble colours are available in yellow, orange and red. These compounds include carotene, which is a precursor of vitamin A and a group of similar compounds, called carotenoids. These fat soluble colours are heat stable, although during storage slow loss of colour can occur in conditions which promote oxidation. Natural plant derived water and fat soluble colour pigments are commercially available to be used as food colorants. Meat pigments are normally not intensified by addition of artificial colorants although on some processed meat products, addition of coloured spices such as paprika, turmeric and annatto enhances the colour. Myoglobin, a meat pigment varies in concentration in the meat with the age and species of the animal. Raw meats, when stored in absence of O_2 changes colour to dull red with a purplish hue and when exposed to O_2 turns deep red. Oxidized pigments turn to brown met-myoglobin, when cooked it becomes grey and addition of nitrite produces a stable pink colour, which is the characteristic colour of cured meats.

17.4.3 Micronutrients

The micronutrients needed for meeting dietary requirements are normally not taken into consideration in food product development, except when formulating analogues using ingredients that do not contain the micronutrients. Flavour compounds when volatile, are responsible for the aroma of food and when non-volatile they contribute to the taste sensation. Non-volatile compounds are high molecular weight alcohols (e.g. tannins). Whereas volatile compounds have low molecular weight and may be lost during processing. A group of compounds called carbonyls is an important component which participates in flavour development during heating which usually result in roasted flavours. The flavour of, roasted nuts, roasted beef and coffee and cocoa may be attributed to the reactions involving these carbonyls. Although these compounds may be naturally present, formulations may be developed where these compounds are added to intensify the desired flavour or colour effect.

Lesson 18. Proximate analysis of food products

Foods are classified as animal, vegetable, and mineral, and are divided into subgroups according to their source or method of manufacture, factors which are intimately correlated with their chemical composition.

18. Introduction:

Definition: "Estimation of the main components of a food using procedures that allows a reasonably rapid and acceptable measurement of various food fractions without the need for sophisticated equipment or chemicals."

Original Terminology	Alternative Terminology
Moisture	Loss on Drying
Ash	Mineral elements
Crude Fat	Fat
	Ether extract
Crude Protein	Protein
Nitrogen free extractives	Carbohydrates
	Available Carbohydrates
Crude Fibre	Unavailable Carbohydrates
	Fibre
	Neutral Detergent Fibre
	Dietary Fibre
	Non-Starch Polysaccharides

18.1 Moisture

Water, the simplest of all constituents of foods, is one of the great concern to producer, consumer and chemist. The weight of food has little significance unless the water content is taken into consideration. The accurate determination of moisture poses many challenges as the difficulty of separating all the water from the food sample, results in underestimation of moisture content. Whereas, harsher conditions to remove all moisture from a food may result into decomposition of the product, along with/or a loss in sample mass. Most of the methods for the estimation of water in food depends on the loss in weight on heating. An exposure to the air of the drying oven causes the oxidation of certain oils and other constituents. A weight gain of such constituents offsets the weight loss due to moisture. To remove this error, the drying should be performed in vacuum. The loss in weight on heating is not entirely because of water but also due to small amount of volatile substance evident to smell present in foods. Most of the spices however contain notable quantities of volatile oil that pass off with the water.

Analytical methods of moisture determination can be classified in two ways:

A) Direct methods: Moisture analysis normally involves removing water from the food samples by drying, distillation, extraction and measuring its quantity by weighing, titration and so forth, e.g., oven drying, vacuum drying, freeze drying, distillation method, Karl Fischer method, chemical desiccation, thermo-gravimetric analysis and gas chromatography.

B) Indirect methods: The indirect methods must be calibrated against standard moisture values that have been precisely determined using direct methods, e.g., refractometry, infrared absorption, near infrared reflectance spectroscopy, microwave absorption, dielectric capacitance, mass spectrometry, NMR spectroscopy, neutron scattering method, etc.

18.1.1 Air-Oven Drying Method

It is one of the most common and widely used methods for routine moisture determination. The ovens should be thermally regulated to 0.5˚C and have minimal temperature variations (<3˚C) within the oven. The main criterion of food for moisture determination by air-oven drying is that sample should be thermally stable and should not contain significant amount of volatile compounds.

18.1.2 Vacuum Oven Drying Method

It is the standard and most accurate drying method for moisture analysis of foods. The AOAC methods generally recommend that moisture content of food can be determined by heating foods at 98 to 102 ^{0}C at a pressure of 25-100 mm Hg for 2-6 h. Lower temperatures (60-70 ^{0}C) can be used for heat sensitive/ sugary food products to prevent decomposition of sugar used in products like jam, confectionery etc.

18.1.3 Distillation Method

Two types of distillation procedures exist for moisture determination;

(a) Direct distillation and (b) Reflux distillation.

18.1.3.1 Direct Distillation

In this method, a food is heated in a liquid immiscible in water and has a high boiling point (e.g., mineral oil). The water in the food like spices and herbs distils directly from this liquid, condenses and collects in a graduated tubes; the volume of the water removed is then measured.

18.1.3.2 Reflux Distillation

It makes use of the azeotropic properties of solvent mixtures. During heating, water and an immiscible solvent (toluene or xylene) distil off together at a constant ratio and frequently at a temperature lower than the boiling point of either component. For example, the boiling points of water and toluene are 100˚C and 110.6˚C, respectively, but the boiling point of the binary mixture is 85˚C; the distillation ratio of the mixture is 20% water and 80% toluene. As water is denser than toluene, the water is again collected in a suitable measuring apparatus where it separates and has its volume measured.

18.1.4 Karl Fischer Titration Method

The Karl Fischer (KF) titration has become a standard method for the moisture analysis in liquids and solids due to its selectivity, high precision and speed. The method is particularly suitable for food where heating methods give erratic results. It has been approved for dried vegetables, oils and fats, cocoa products and liquid molasses. This method is based on the quantitative reaction of water with an anhydrous solution of sulphur dioxide and iodine dissolved in pyridine and an alcohol. The Karl Fischer reagent consists of iodine, pyridine, SO_2 and methanol. The titration is conducted either by volumetric method (where the end point is brown colour, determined visually) or by colorimetric titration, where the end point is determined by a potentiometer. Food samples may be directly introduced into the reaction vessel if the water is easily accessible to the reagent. In solid foods where water is not accessible, the water is frequently extracted into anhydrous methanol and then estimated.

18.1.5 Refractometry

The refractive index is a ratio of the sine of the angle of incidence made by a ray in air to the sine of the angle of refraction made by the ray in the material being tested. The refractive index increases as the moisture content decreases. By measuring the refractive index of a solution, the moisture content can be rapidly determined using an appropriate calibration curve. Refractometry is best suited for high sugar products *viz*., fruit products, syrups and honey. For solid or semi-solid foods, the sample can be homogenized with an anhydrous solvent (e.g., isopropanol) and then the refractive index of the solution can be measured using a refractometer. The moisture content of the sample may be calculated using the calibration curve (produced by measuring refractive index of solutions containing the same solvents with known amounts of added water) and the mass of food homogenized in the solvent.

18.2 Total Ash

Ash refers to the inorganic residue remaining after total incineration of organic matter. The ash content is an indicator of product quality and the nutritional value of food products.

When a high ash figure suggests the presence of an inorganic adulterant, it is advisable to determine the acid insoluble ash.

18.2.1 Dry Ashing

Dry ashing is the most standard method for determining the ash content of a food sample. The sample is commonly ignited at 550-600°C to oxidize all organic materials without flaming. The inorganic residue that does not volatilize at that temperature is called ash. The ash content is determined from the loss of weight, which occurs from complete oxidation of sample.

18.2.2 Wet Ashing

Wet ashing is usually used for the elemental analysis. Wet ashing commonly employs concentrated nitric acid and perchloric acid or nitric acid and sulphuric acid to oxidize the organic matter of the food sample. These acids are partially removed by volatilization and the soluble minerals remain dissolved in nitric acid. Any silica present is dehydrated and made insoluble.

However, great care must be taken when using perchloric acid, because it can be explosive on contact with water.

18.2.3 Acid Insoluble Ash

The acid insoluble ash is a measure of the sandy matter and maxima are prescribed for herbs and spices. Acid insoluble ash is determined by dissolving ash in dilute hydrochloric acid (10% w/w), the liquid filtered through an ashless filter paper and thoroughly washed with hot water. The filter paper is then ignited in the original dish, cooled and weighed.

18.2.4 Sulphated Ash

This involves moistening the ash with concentrated sulphuric acid and igniting gently to constant weight. The sulphated ash gives a more reliable ash figure for sample containing varying amount of volatile inorganic substances that may be lost at the ignition temperature used.

18.3 Crude Fiber

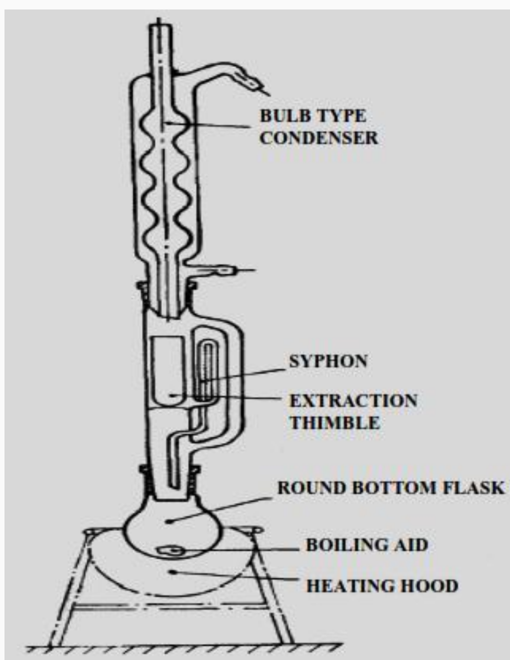
The crude fibre representing the cell wall material left after boiling with dilute acid and alkali in the process, is a mixture of cellulose, lignin and pentosans, together with sand, silica and other mineral matter locked in the tissues and little nitrogenous matter after grinding and defatting, boiling with sulphuric acid solution, and separation and washing of the insoluble residue. This residue is boiled with sodium hydroxide solution, separated, washed, and dried and the insoluble residue is then weighed. The loss in mass on incineration is also noted.

18.4 Fat

The oils and fats from oilseeds and fruits as well as from animal fatty tissues correspond quite closely with those extracted by diethyl ether. Practically, all the sterols and phosphorus containing organic compounds notably the lecithins are extracted with the glycerides. Essential oil and resins are the chief constituents of the ether extract of certain spices. Similarly, pepper contains nitrogenous ether soluble substance, piperine (alkaloids). Other solvents *viz.*, chloroform, carbon tetrachloride, carbon disulphide and petroleum distillates of lower or higher boiling points dissolve fats and oils and can be used but the yield and composition of the extract differ somewhat with the solvent. Free fat can be extracted by the less polar solvents such as petroleum ether and diethyl ether, whereas the bound fat requires more polar solvents *viz.*, alcohols for their extraction. The bound fat may be broken down by hydrolysis or other chemical treatment to yield free fat. Hence, the amount of extracted fat found in food products will depend on the method of analysis used.

18.4.1 Direct Solvent Extraction Method

The free fat content can be conveniently determined in foods by extracting the dried and ground material with petroleum ether or diethyl ether in Soxhlet extraction apparatus (Fig. 18.1). Extraction in the presence of alcohols causes the release of lipoidal substances bound to proteins and carbohydrates *viz.*, phospholipids and glycolipids. Hence, maximum extraction is obtained by a mixture of polar and non-polar solvents. This procedure co-extracts water and water soluble substances. Hence, the residue after solvent removal and the addition of anhydrous sodium sulphate needs to be extracted with petroleum ether.



18.4.2 Solubilization Extraction Method

Bound fat can be made free if the food sample is dissolved completely prior to extraction with polar solvents. Dissolution of the food can be achieved by acid or alkaline hydrolysis. In acid hydrolysis method, the sample is heated on a steam bath with dilute HCl and boiled for 30 min. The sample solution is filtered through a wet filter paper and washed with hot water. The filter paper is then oven dried and placed directly into a Soxhlet apparatus and extracted with ethyl or petroleum ether or dichloromethane. In alkali hydrolysis method (Rose Gottlieb method), the material is treated with ammonia and alcohol in cold and the fat is extracted with diethyl ether petroleum ether mixture. The alcohol precipitates the protein, which dissolves in the ammonia; the fat can then be extracted with ether. Petroleum ether is then added as it reduces the proportion of water and hence all non-fatty substances.

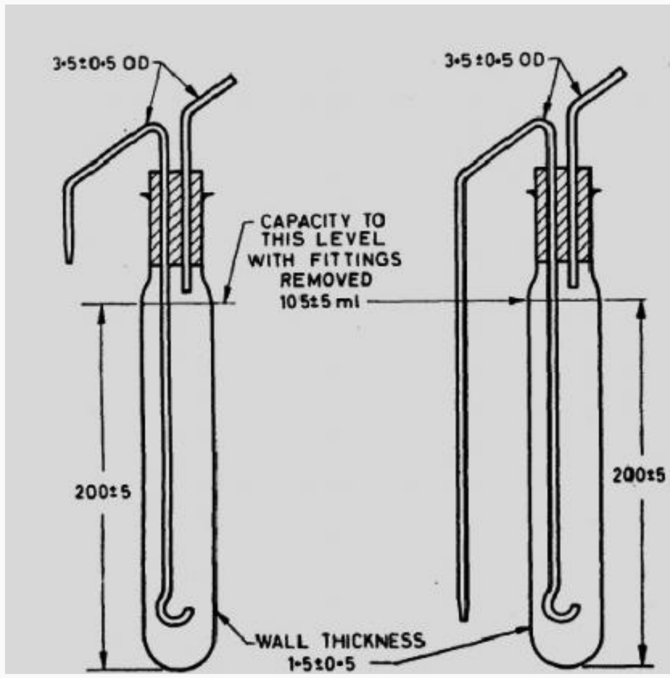


Fig. 18.2: Rose Gottlieb method

18.4.3 Volumetric Method

These involve dissolving the sample in sulphuric acid and centrifuging out the fat in specially calibrated glass vessels (butyrometers). The Gerber method is commonly employed for the routine determination of fat in milk and dairy products.

18.5 Protein

All natural foods contain protein, although trace amounts are found in honey and maple sugar. The quantification of total protein in food and food products can be performed directly or by determining total nitrogen from conversion of crude protein using a suitable conversion factor. The protein content is calculated from the total nitrogen determined by either Kjeldahl method or Dumas/Pregl-Dimas method. Amides (abundant in young shoots), ammonium salts, nitrates, lecithin, nucleic acid, purines of tea, coffee, cocoa and meat extracts in addition to protein contain nitrogen in varying proportions.

Although small, these compounds thus add error to the calculated protein estimate. However, the protein calculated by factor is a valuable figure, not only because it represents approximately the true protein present but also because it is an index of the content of other groups. The protein content can also be determined directly by formal titration, UV spectrophotometry, Lowry method, Dye binding method, IR spectrophotometry, NMR spectroscopy, turbidimetry, refractometry, etc.

18.5.1 Direct Method

Since foods contain mixtures of proteins, the methods for the direct determination of proteins need to be calibrated against a reference standard for nitrogen, e.g. Kjeldahl method.

18.5.1.1 Formal Titration Method

When formaldehyde is added to neutralized aqueous solution containing protein, the $-NH_2$ group of protein converts to methylene-amino group ($-N=CH_2-$) with the release of proton. This may be titrated.

18.5.1.2 Spectrophotometric Method

The Lowry method is based on the amplification of the biuret reaction

(Complex of cupric ions with protein) by subsequent reduction of the Folin phenol reagent (mixed acids of phosphomolybdic and phosphotungstic) by tyrosine and tryptophan. This redox reaction is accompanied by the formationof a blue colour (λ_{abs}745 – 750 nm), which is highly pH dependant (10-10.5).

18.5.2 Indirect Method

18.5.2.1 Kjeldahl Method

It has wide acceptance for the determination of protein in food products. The method follows three steps:

Digestion – Decomposition of organic matter by heating in the presence of concentrated sulphuric acid, the end product is ammonium sulphate solution.

Distillation – Ammonium sulphate is converted into gaseous ammonia by addition of an excess base, followed by boiling and condensation of the ammonia in a receiving solution (acid).

Titration – Quantification of the unreacted acid in the collecting vessel. The rate of digestion and the completeness of the breakdown of nitrogenous compounds to ammonium sulphate mainly depend upon the heat input, amount of boiling point elevator of acid (alkali sulphate), addition of catalyst (mercury, copper sulphate, titanium dioxide), oxidant (hydrogen peroxide), reflux rate of sulphuric acid and length of digestion. Ammonia is liberated from the acid digestion mixture by distillation in the presence of alkali (50% NaOH). A total recovery of ammonia from the digest can be obtained within 5 to 20 min by direct distillation and about 10 min by steam distillation.

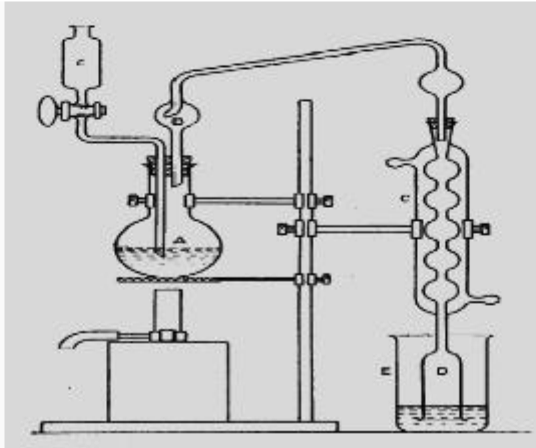


Fig. 18.3: Kjeldahl Nitrogen distillation assembly

18.5.2.2 Dumas Combustion Method

The protein content of foods can be estimated by the determination of elemental nitrogen using instruments based on the Dumas principle. In these instruments, the nitrogen containing constituents of the sample are combusted at high temperature about 100^{0}C in the presence of oxygen to oxides of nitrogen (NO_x) and then reduced over copper or tungsten to gaseous nitrogen which is measured by gas solid chromatograph using thermal conductivity detector. This method offers significant advantage over Kjeldahl method i.e., shorter analysis time (3-4 min), but these instruments appear to have limited usefulness for some food products because they can only deal with very less amount of sample.

Module 6. Deterioration in products and their controls

Lesson 19. Deterioration in Food Products and Physical deterioration.

19.0 Introduction

Foods undergo deterioration of varying degrees in terms of their sensory characteristics, nutritional value, safety, and aesthetic appeal. Most foods, from the time they are harvested, slaughtered, or manufactured, undergo progressive deterioration, depending upon the food.

Definitions:

Food Deterioration: A series of continuous degradative changes occurring in a food item which may affect the product's wholesomeness, result in a reduction of its quality, and/or alter its serviceability.

Wholesomeness: Wholesomeness is a term that refers to freedom from pathogenic or otherwise harmful microorganisms.

or

A characteristic possessed by a food product that is conducive to good health and well being of the consumer.

Spoilage: Spoilage is a term which we often hear in conjunction with deterioration. It is often used as a synonym for deterioration. However, it needs to make distinction between these two terms. We define food spoilage as an arbitrary end point of the deterioration process which denotes that a food item is unwholesome and, therefore, is no longer suitable for human consumption.

(1) Spoilage is a benchmark--a signal to denote that a food item is unwholesome and is no longer suitable for human consumption.

(2) It can occur anywhere during the deterioration process. The point of spoilage depends upon such factors as type of food (milk vs beef), storage environment (low-temperature storage vs. High-temperature), and method of preservation (canning vs. Freeze dehydration).

Unwholesome: Unwholesome food is food procured, packed, or held under unsanitary conditions that renders it injurious to the health of the consumer, or food or food containers having naturally occurring or added harmful substances, or food found to be filthy, putrid, decomposed, or produced from a diseased animal or an animal that died other than by slaughter.

Off-condition: Off-condition is any variation from the expected appearance, feel, smell, or taste characteristics of a product when it was initially produced or processed for resale. (A product is considered unwholesome if any off condition affects it in such a way that the product may be injurious to the health of the consumer.)

Quality: Quality is a term that refers to the degree of excellence or grade of a Product.

Serviceability: Serviceability is a term that refers to the usefulness of a food item. Reduced serviceability in a product may result in the use of additional processing methods to return the food item to its original state.

Food Deterioration

Major causes of food deterioration include:

1. Growth and activities of micro-organisms, mainly bacteria, yeasts and moulds;
2. Activities of natural food enzymes;
3. Insects, parasites and rodents;
4. Temperature, both heat and cold;
5. Moisture and dryness;
6. Air and in particular oxygen;
7. Light;
8. Time.

These causes are not isolated in nature. High temperature, moisture, and air will all affect the multiplication and activities of bacteria, as well as the chemical and enzymatic activities of the food. Bacteria, insects, and light can all be operating simultaneously to deteriorate food in the field or in a warehouse.

At any one time, many forms of deterioration may be in progress, depending upon the food and environmental conditions.

Preservation techniques are designed to counteract or slow the changes which cause deterioration by:

Physical Deterioration

Chemical Degradation

Biological Changes

19.1 Physical Deterioration

19.1.1 Moisture absorption

A physical change that causes food deterioration is excessive moisture. The gross changes in foods from excessive moisture are part of everyday experience. Dried, dehydrated, and freeze-dried foods are especially susceptible to this form of deterioration. These types of food are very hygroscopic (readily taking up and retaining moisture)

One of the major undesirable physical changes in food powders is caking due to absorption of moisture as a consequence of an inadequate barrier provided by the package. It may occur due to poor selection of packaging material or failure of the package integrity during storage. This may lead to other forms of deterioration, such as bacterial growth and chemical reactions such as oxidation, as well as surface defects like mottling, crystallization, and stickiness.

In a moisture-proof package, food materials such as fruits and vegetables can give off moisture from respiration and transpiration, which gets trapped within the package and supports the growth of microorganisms.

Anti-caking agents can be added to powders in order to inhibit caking and improve flowability. Studies in onion powders showed that at ambient temperature, caking does not occur at water activities of less than about 0.4. At higher activities, however, (a_w> 0.45) the anti-caking agents are completely ineffective. It appears that while they reduce inter-particle attraction and interfere with the continuity of liquid bridges, they are unable to cover moisture sorption sites.

19.1.2 Temperature

19.1.2.1. Low Temperature

(A) Freezing of many foods will cause undesirable changes, such as the destruction of emulsions and texture.

Emulsified products, such as salad dressing and mustard, contain a fat/oil and water mixture which does not combine without special processing or additives. If these types of products are frozen, the emulsion will be destroyed and the fat and water will separate into distinct layers.

Fruits and vegetables that are allowed to freeze and then thaw will have their texture disrupted. Skin's cracks leave the food susceptible to attack by microorganisms. The texture of canned fruits and vegetables becomes softened and mushy due to uncontrolled freezing, also called as chilling injury.

(B) Many fruits and vegetables, like other living systems, have optimum temperature requirements after harvest. Several fruits and vegetables when held at common refrigeration temperatures of about 41ºF (5ºC) are weakened or killed and various deteriorative processes like off-color development, surface pitting, and various forms of decay occur.

Bananas, lemons, squash, and tomatoes are some products that need to be held at temperatures no lower than 50ºF (10ºC) for maximum quality retention. This provides an exception to the inaccurate generalization that cold storage preserves all foods, and the colder the better.

19.1.2.2. High Temperature

There is a moderate temperature range over which much of the food is handled, i.e 50º-100ºF (10º-38ºC)Within this range, for every 18ºF (10ºC) rise in temperature, the rate of chemical reaction is approximately doubled, in terms of many enzymatic as well as non enzymatic reactions. Excessive heat treatment results into denaturation of proteins, breakage of emulsions, drying out of foods by moisture removal, and destruction of vitamins.

(A) Excessive heat treatment in green vegetables causes loss of integrity of cell walls and membranes with release of acids and enzymes. This results in the softening of texture as well as the development of off-colors and off-flavors.

(B) The consequences of excessive heat on muscle tissue leads to denaturation and clumping of proteins, and enzyme inactivation. This results in a toughening of the texture, loss of water holding capacity, cooked or caramel flavors, and development of off-colors.

19.1.3. Dehydration

Dehydration, is another form of physical change that causes food deterioration. It can be defined as the loss of water from the food product.

Foods, especially fresh, chilled, and frozen, are subject to dehydration. Foods contain a substantial amount of water. Meat products contain 70 to 75 % water, whereas fresh fruits and vegetables contain from 80 to 95 % water. Since water vapor is continually seeking to go from an area of high concentration to an area of low concentration, improper storage conditions and improper packaging will lead to dehydration. Dehydration results when the humidity is too low in a storage area.

The signs of dehydration include dryness or shriveling on the surface of the food item, development of off-colors, with usually a darkening effect.

In frozen foods, the dehydration is known as freezer burn, whereas in fresh fruits and vegetables, it is known as wilt.

19.1.4. Mechanical Damage

When any food item receives mechanical damage, not only is the appearance of the item affected but the damaged food tissue also becomes more susceptible to other forms of deterioration. Such foods become more susceptible to invasion by microorganisms, for the damaged area serves as a port of entry. The cell walls of foods are also destroyed by mechanical abrasion, and the inherent enzymes in the food product are liberated from the cells. Once liberated, the enzymes begin the process of deterioration or, more specifically, autolysis. The notable changes would be a softening in the texture, development of off-colors, and development of off-flavors.

19.1.4.1 Freezer Burn

Freezer burn is a deteriorative condition commonly found in frozen foods, especially poultry, water foods, and red meats. This condition is a physical change in the food item that results in no loss of wholesomeness.

Abnormal Characteristics

The abnormal characteristics that are exhibited by a freezer-burned product include an abnormal color, usually white or pale amber. The surface of the product will be dry and shriveled, and usually a buildup of frost on the surface of the product, the texture similar to that of a dry sponge.

Cause of Freezer Burn

Freezer burn is caused by the evaporation (sublimation) of moisture from the surface of the food item which results in the product having a bleached, unattractive appearance and adverse effects on the palatability.

(A) Dehydration

In a freezer, the relative humidity is low because the cold dense air is not capable of holding much moisture. The moisture content of the food may vary from 65 to 90%, depending upon the type of food. This uneven concentration of moisture makes frozen foods very susceptible to moisture loss, hence the products which are improperly wrapped and packaged will be susceptible to dehydration resulting in a freezer burn.

(B) Colour change

The frost formed on the outside of the product leads to excessive loss of moisture hence resulting in a colour change in the product. The small holes formed on the product are more susceptible to the oxidative process; there is an increased area of exposure to oxygen.

Control of Freezer Burn

Freezer burn may be prevented by a skintight covering or an ice glaze for the food product, which may be obtained by the use of water impermeable films, dip coatings, or spray coatings.

19.1.5. Light

Light, causes food deterioration, by fading of color in many food items. Some vitamins are destroyed by light, notably riboflavin, vitamin A, and vitamin C. Milk in bottles exposed to the sun develops "sunlight" flavor due to light induced fat oxidation and changes in the protein.

Sensitive foods often can be protected from light by impervious packaging or by incorporating compounds into glass and transparent films that screen out specific wavelengths.

One of the most common problem due to light is the greening of potatoes. This condition is also referred to as sunburn. It is the result of the exposure of the potatoes to sunlight during growth or after digging, and to artificial light during display for sale. After exposing for two days or longer to either natural or artificial light, a green pigment develops. The skin and the flesh are affected. Chlorophyll and an alkaloid called solanine are produced due to exposure to light. Chlorophyll is tasteless and harmless, whereas the green tubers acquire a bitter, pungent taste due to solanine and if eaten in quantity, they may be poisonous.

19.1.6. Time

Another major cause of food deterioration is that of time or the aging process. After slaughter, harvest, or food manufacture, there is a time when the quality of food is at its peak, but this is only a transitory period. The growth of microorganisms, destruction by insects, action of food enzymes, non-enzymatic interaction of food constituents, loss of flavor, effects of heat, cold, moisture, oxygen, and light, all progress with time. The longer the time, the greater the destructive influences.

It is true that certain cheeses, sausages, wines, and other fermented foods are improved with aging up to a point. However, for the vast majority of foods, quality decreases with time, and the major goal of food handling and preservation practices is to capture and maintain freshness. The storage life of foods is determined to a great extent by type of food, method of processing, method of packaging, and storage environment. This is the rationale behind the frequencies of cyclic inspections of food items.

Lesson 20. Bio-Chemical Deterioration in Food Products

20.1 CHEMICAL DEGRADATION

20.1.1 Enzymatic Reactions

Mostly in fruits and vegetables this phenomenon occurs as a result of certain enzyme catalyzing reactions on components in the food. Enzymes which are endogenous to plant tissues can have undesirable or desirable consequences.

Examples involving endogenous enzymes include:

a) The post-harvest senescence and spoilage of fruit and vegetables;

b) Oxidation of phenolic substances in plant tissues by phenolase (leading to browning);

c) Sugar - starch conversion in plant tissues by amylases;

d) Post-harvest demethylation of pectic substances in plant tissues (resulting into softening of plant tissues during ripening, and firming of plant tissues during processing).

The major factors useful in controlling enzyme activity are:

- temperature,
- water activity,
- pH,
- chemicals which can inhibit enzyme action,
- alteration of substrates,
- alteration of products and
- pre-processing control .

There are three common types of chemical deterioration of foods:

20.1.1.1. Oxidative Rancidity

It occurs in fatty foods with high levels of unsaturation due to breakdown of fats and oils resulting into production of off-flavors and off odour.

Lipid oxidation rate and course of reaction is influenced by light, local oxygen concentration, high temperature, the presence of catalysts (generally transition metals such as iron and copper) and water activity. Control of these factors can significantly reduce the extent of lipid oxidation in foods.

20.1.1.2 Non-enzymatic Browning

This occurs when sugars and amino acids present in the food go through a series of reactions producing a brown colour in the food.

This is referred to as Maillard Reaction. The development of a brown colour and the accompanying flavour in the baking of bread, brewing of beer and roasting of coffee are desirable attributes of this reaction. However it is highly undesirable when it develops in dried milk during storage. Caramelization occurs in products which are high in sugar due to direct or excessive exposure to heat. Some of its examples include syrups, candied fruits, jams and jellies. There is also the oxidation of ascorbic acid on exposure to oxygen that may occur in foods high in this nutrient.

20.1.1.3 Enzymatic Degradation

A typical example is an unappealing brown discoloration, which is seen when peeled ripe bananas or sliced apples, pears or some vegetables are exposed to the air. Enzymatic spoilage also causes the production of off-odours and off-flavours in foods such as meats and meat products. In order to prevent this type of spoilage, the enzyme in the food has to be inactivated before storage.

Effects of Enzyme Action

(A) The ripening process of the banana makes it sweeter, softer, less astringent in taste, and more odorous. This occurs due to hydrolysis (degradation) of the starch (essentially tasteless and insoluble in the water of the banana) to simple water-soluble sugars.

(B) Over-riped tomato gets softened due to hydrolysis of the pectins to their simpler carbohydrate building blocks. Pectin is a water-soluble carbohydrate found in ripe fruits and has strong gelling properties which are used in cooking.

(C) Proteins in foods like cheese, meat, and fish may be hydrolyzed to simpler compounds by the enzymes naturally present. Such chemical changes are often manifested as changes in taste, odor, texture, and so forth.

(D) When freshly harvested products are processed for eating, the normal cellular organization of the tissues may be disrupted, as a result of which the residual enzymes may initiate degradative changes at a very rapid rate. One of the most common examples of such changes is the rapid darkening of freshly peeled potatoes, apples, peaches, and pears. Other oxidizing enzymes induce the common and sometimes intense "hay" flavor of vegetables such as lima beans, corn, and broccoli if they are not cooked soon enough after harvesting.

20.1.2 Effect on Nutritional quality

The four major factors which affect nutrient degradation and can be controlled to varying extents by packaging are light, oxygen concentration, temperature and water activity

20.1.2.1 Vitamins:

Ascorbic acid is the most sensitive vitamin in foods, and its stability varies markedly as a function of environmental conditions such as pH, concentration of trace metal ions and oxygen. The nature of the packaging material can significantly affect the stability of ascorbic acid in foods. The effectiveness of the material as a barrier to moisture and oxygen as well as the chemical nature of the surface exposed to the food are important factors.

The problems of ascorbic acid instability in aseptically packaged fruit juices have been encountered because of oxygen permeability of the package and the oxygen dependence of the ascorbic acid degradation reaction.

Due to the preferential oxidation of metallic tin, citrus juices packaged in cans with a tin contact surface exhibit greater stability of ascorbic acid than those in enameled cans or glass containers. The aerobic and anaerobic degradation reactions of ascorbic acid in reduced-moisture foods have been shown to be increasing in an exponential fashion over the water activity range of 0.1-0.8.

20.2 Biological Changes

20.2.1 Microbiological

The microorganisms that are principally involved in food deterioration are bacteria, molds, and yeasts. There are thousands of genera and species of microorganisms associated in one way or another with food products. Not all cause food spoilage, and many types are used in preserving foods, such as the lactic-acid-producing organisms of cheese, sauerkraut, and some types of sausage. Other microorganisms are used for alcohol production as in wine or beer making, or for flavor production in other foods.

Microorganism multiplication on or in foods is a major cause of food deterioration. The microorganisms attack virtually all food constituents. Some of them may lead to ferment sugars and hydrolyze starches and cellulose, whereas others hydrolyze fats and produce rancidity, still others digest proteins and produce putrid and ammonia-like odors.

Some produces acid and make food sour, while others produce gas and make food foamy. Some form pigments, and a few produce toxins giving rise to food borne illnesses.

When food is contaminated under natural conditions, several types of organisms will be present together. Such mixed organisms contribute to a complex of simultaneous or sequential changes which may include acid, gas, putrefaction, and discoloration.

Foods are frequently classified on the basis of their stability as non-perishable, semi-perishable and perishable. Hermetically sealed and heat processed (e.g. canned) foods are generally regarded as non-perishable. Spoilage may also take place when the canned food is stored at unusually high temperatures: thermophilic spore-forming bacteria may multiply, causing undesirable changes such as flat sour spoilage.

Majority of foods (e.g. meat and fish, milk, eggs and most fresh fruits and vegetables) are classified as perishable unless they have been processed in some way. Often, the only form of processing which such foods receive is to be packaged and kept under controlled temperature conditions.

Low moisture content foods such as dried fruit and vegetables and frozen foods are classified as semi-perishable.

Table 20.1 Major modes of deterioration, perishables.

Perishables	**Mode of deterioration** (assuming an intact package)	**Critical environmental factors**
Fluid milk and dairy products	Bacterial growth, oxidized flavour, hydrolytic rancidity	Oxygen, temperature
Cheese	Rancidity, browning, lactose crystallization, undesirable mold growth	Temperature, relative humidity
Ice cream	Graininess cause by ice or lactose crystallization, texture	Fluctuating temperature (below freezing)
Fresh red meat	Bacterial growth, loss of red colour	Oxygen, temperature, light
Fresh poultry	Bacterial growth, off- odour	Oxygen, temperature, light
Fresh fish	Bacterial growth, off- odour	Temperature
Fresh fruits and vegetables	Respiration compositional changes, nutrient loss, wilting, brushing, microbial growth	temperature, relative humidity, light, oxygen, physical handling
Frozen fish, meats,	Rancidity, protein denaturation, colour	Oxygen, temperature,

poultry	change(freezer bum), toughening	temperature Fluctuations
Frozen fruits and vegetables	Loss of nutrients, yeast growth, loss of texture, flavour, odor, colour and formation of package ice	Oxygen, temperature, temperature Fluctuations
Frozen concentrated juices	Loss of cloudiness, yeast growth, loss of vitamins and loss of flavour or colour	Oxygen, temperature, temperature Fluctuations
Frozen convenience foods	Rancidity in meat portion, weeping and curding of sauces, loss of colour, loss of flavour, package ice	Oxygen, temperature, temperature Fluctuations

Table 20.2 Major modes of deterioration, semi perishables

Semi Perishables	**Mode Of Deterioration** (Assuming An Intact Package)	**Critical Environmental Factors**
Fresh bakery products	Staling, microbial growth, moisture loss causing hardening, oxidative rancidity	Oxygen, temperature, humidity
Breakfast cereals	Rancidity, loss of crispness, nutrient loss, breakage	Relative humidity, temperature, rough handling
pasta	Texture change, staling, vitamin and protein quality loss, breakage	Relative humidity, temperature, light, oxygen, rough handling
Fried snack foods	Rancidity, loss of crispness, breakage	Oxygen, light, temperature, Relative humidity, physical handling
Dehydrated foods	Browning, rancidity, loss of colour, loss of texture, loss of nutrients	Relative humidity, temperature, light, oxygen

Nonfat dry milk	Flavour deterioration, loss of solubilization, caking, nutrient loss	Relative humidity, temperature
Coffee	Rancidity, loss of flavour and odor	Oxygen, temperature, lights, relative humidity
Tea	loss of flavour, absorption of foreign odors	Oxygen, temperature, lights, humidity
Canned fruits and vegetables	Loss of flavour, texture, colour and nutrients	Temperatures

The species of micro-organisms which cause the spoilage of particular foods are influenced by two factors: a) the nature of the foods and b) their surroundings. These factors are referred to as intrinsic and extrinsic parameters.

The intrinsic parameters are an inherent part of the food:

- pH,
- water activity,
- nutrient content,
- antimicrobial constituents and
- biological structures.

The extrinsic parameters of foods are those properties of the storage environment that affect both the foods and their microorganisms:

- temperature,
- relative humidity and
- gas compositions of the surrounding atmosphere.

The protection of packaged food from contamination or attack by micro-organisms depends on the mechanical integrity of the package (e.g. the absence of breaks and seal imperfections), and on the resistance of the package to penetration by micro-organisms.

Extensive studies on a variety of plastic films and metal foils have shown that microorganisms (including mounds, yeasts and bacteria) cannot penetrate these materials in the absence of pinholes.

20.2.1.1 Bacteria

Bacteria are unicellular microorganisms of many forms, spherical, cocci, rod shaped bacilli and spiral shaped spirilla. Some bacteria produce spores which are remarkably resistant to heat, chemicals, and other adverse conditions. Bacterial spores are far more resistant than yeast or mold spores, and more resistant to most processing conditions than natural food enzymes. Most of the bacteria are in the order of one to a few microns in cell length and somewhat smaller than this in diameter. (A micron is one-thousandth of a millimeter (0.001 mm) or about 0.00004 inch.) All bacteria can penetrate the smallest of openings, and many can pass through the natural pores of an egg shell once the natural bloom of the shell is worn or washed away.

20.2.1.2 Molds

Molds are larger than bacteria and yeast and more complex in structure. They grow by a network of hair-like fibers called mycelia and send up fruiting bodies that produce mold spores referred to as conidia. The blackness of bread mold and the blue-colored veins of blue cheese are due to the conidia. The mycelia are a micron or so in thickness and, like bacteria, can penetrate the smallest opening; or in the case of weakened skin or shell can digest the skin and make their own route of penetration.

20.2.1.3 Yeasts

Yeasts are somewhat larger than bacteria, of the order of 20 microns in individual cell length and about half this size in diameter. However, yeasts are smaller than molds. They are associated with nearly all types of food products. Foods such as fresh vegetables, meat, poultry, and cheese often contain yeasts, but in these foods, bacteria outgrow the yeasts. When bacterial inhibitors are added, yeasts can dominate. Some yeasts are found in foods such as honey, molasses, sugar, and fruit. Salt-tolerant yeasts grow as films on brine food and on salted food and ham.

20.2.2 Macrobiological

20.2.2.1 Insect Pests

Even though warm humid environments promote insect growth, most insects will not breed if the temperature exceeds about 35 C° or falls below 10 C°. They can't reproduce satisfactorily unless the moisture content of their food is greater than about 11%.

The main categories of foods subject to pest attack are cereal grains and products derived from cereal grains, legumes, dairy products such as cheese and milk powders, dried fruits, dried and smoked meats and nuts.

The presence of insects and insect excrete in packaged foods may render products unsaleable, causing considerable economic loss, as well as reduction in nutritional quality, production of off-flavours and acceleration of decay processes due to creation of higher temperatures and moisture levels.

Early stages of infestation are often difficult to detect; however, infestation can generally be spotted not only by the presence of the insects themselves but also by the products of their activities such as webbing, clumped food particles and holes in packaging materials.

Unless plastic films are laminated with foil or paper, most of the insects are able to penetrate them quite easily. As the rate of penetration is directly related to film thickness hence, thicker films are more resistant than thinner films, and oriented films tend to be more effective than cast films.

Generally, the penetration varies depending on the basic resin from which the film is made, on the combination of materials, on the package structure, and of the species and stage of insects involved. The relative resistance to insect penetration of some flexible packaging materials is as follows:

- excellent resistance: polycarbonate; poly-ethylene-terephthalate;
- good resistance: cellulose acetate; polyamide; polyethylene (0.254 mm); polypropylene (biaxially oriented); poly-vinyl-chloride (unplasticised);
- fair resistance: acrylonitrile; poly-tetra-fluoro-ethylene; polyethylene (0.123 mm);
- Poor resistance: regenerated cellulose; corrugated paper board; Kraft paper; polyethylene (0.0254 - 0.100 mm); paper/foil/polyethylene laminate pouch; poly-vinylchloride (plasticized).

Some simple methods for obtaining insect resistance of packaging materials are as following:

- select a film and a film thickness that are inherently resistant to insect penetration;
- use shrink film over-wraps to provide an additional barrier;
- Seal carton flaps completely.

20.2.2.2 Rodents

Rats and mice carry disease-producing organisms on their feet and/or in their intestinal tracts and are known to harbour salmonella of serotypes frequently associated with food-borne infections in humans. In addition to the public health consequences of rodent populations in close proximity to humans, these animals also compete intensively with humans for food.

Rats and mice gnaw to reach sources of food and drink. Their incisor teeth are so strong that rats have been known to gnaw through lead pipes and unhardened concrete, as well as sacks, wood and flexible packaging materials.

Proper sanitation in food processing and storage areas is the most effective weapon to fight against rodents, since all packaging materials apart from metal and glass containers can be attacked by rats and mice.

Lesson 21. Control of Deteriorations in Food Products

21.1Control by Heating

Chemical reactions catalyzed by enzymes can be stopped by destroying or removing the enzymes. The method is simply heating or cooking food. All enzymes are proteins, and proteins are easily changed or denatured by heating. The temperature required to inactivate most enzymes are in the range of 60º-80ºC (140º-176ºF), although some enzymes are destroyed below 60ºC (140ºF) and some require heating to temperature above 80ºC (176ºF) before they lose their catalytic properties.

21.2Control by Freezing

Many foods are preserved by freezing. However, freezing does not destroy most enzymes. Many frozen foods can deteriorate enzymatically, even though the rates of the reactions may be slow. Vegetables are the worst offenders, hence in order to preserve peas, green beans, corn, and so forth, by freezing, it is first necessary to heat them briefly to almost 100ºC (212ºF) before they are frozen to prevent deterioration in frozen storage. Cold storage can be combined with storage in an environment with added of carbon dioxide, sulphur dioxide, etc. according to the nature of product to be preserved.

21.3 Control Techniques for Fruit

Generally, fruits do not require heat treatment such as blanching, as many of them are adversely altered in flavor when heated. However, enzymatic darkening often occurs in frozen fruits such as sliced peaches. To counteract this, they are often packed with sugar syrups containing ascorbic acid or similar oxidation inhibitors (antioxidants). Along with proper packaging, this diminishes greatly the amount of atmospheric oxygen reaching the fruit, which is necessary for the darkening reactions.

Once fruit is harvested, any natural resistance to the action of spoiling micro-organisms is lost. Changes in enzymatic systems of the fruit also occur on harvest which may also accelerate the activity of spoilage organisms.

Means that are commonly used to prevent spoilage of fruits must include:

- Care to prevent cutting or bruising of the fruit during picking or handling;
- Refrigeration to minimize growth of micro-organisms and reduce enzyme activity;
- Packaging or storage to control respiration rate and ripening;
- Use of preservatives to kill micro-organisms on the fruit.

A principal economic loss occurring during transportation and/or storage of produce such as fresh fruit is the degradation which occurs between the field and the ultimate destination due to the effect of respiration. Methods to reduce such degradation are as follows:

- Refrigerate the produce to reduce the rate of respiration;
- Vacuum cooling;
- Reduce the oxygen content of the environment in which the produce is kept to a value not above 5% of the atmosphere but above the value at which anaerobic respiration would begin. When the oxygen concentration is reduced within 60 minutes the deterioration is in practice negligible.
- Storage in controlled atmosphere where carbon dioxide and oxygen levels are monitored, increasing concentration of CO_2 and lowering that of oxygen according to fruit species. Excellent results can be obtained for pomace fruit; in particular the storage period for apples has been extended. Application of this combined procedure requires airtight storage rooms.

21.4 Chemical preservation is combined with acidification of food medium (lowering pH); and using combined chemical preservatives.

21.5 Deterioration control by drying/dehydration

Fresh fruits and vegetables are preserved with the procedure (freeze-drying) that combines the advantages of drying (reduction of volume and weight by 50%) with those of freezing (maintaining vitamins and to a large extent organoleptic properties).

A significant advantage of this process is the short drying time and the finished products after defreezing and rehydration/reconstitution are of a better quality compared with products obtained by dehydration alone. Vitamin C content in the product is maintained in the cold storage of dried/dehydrated vegetables at -8° C for more than one year, at a relative humidity of 70-75 %.

21.6 Preservation by lactic fermentation

Natural acidification can be combined with cold storage for pickles in order to prolong storage time or shelf-life.

21.7 Combined preservation procedures

Even though a lot of progress has been made in the area of preservation techniques, no single procedure when applied alone can be considered wholly satisfactory from a microbiological, physico-chemical and organoleptic point of view; even if to a great extent the food value is assured.

Starting with this consideration, the actual tendency in food preservation is to study the application of combined preservation procedures, aiming at the realization of maximum efficiency from a microbiological and biological point of view, with reduction to a minimum of organoleptical degradation and decrease in food value.

The principles of combined preservation procedures for microbiological preservation are:

- Avoid or reduce secondary (undesirable) effects in efficient procedures
- Avoid qualitative degradation appearing during storage of products preserved
- Increase efficiency of preservation procedures by supplementary means;
- Combine preservation procedures in order to obtain maximum efficiency, by specific action on various types of micro-organisms present;
- Establish combined factors that act simultaneously on bacterial cells.

Other than these, there are lot many methods to control deterioration of food, such as, salting, sugaring, pickling, concentration, irradiation, sterilization, solar drying, high pressure processing, control of water activity and pH, smoking, fermentation, use of chemicals such as acidulants, edible films and coating, etc.

These preservation procedures have two main characteristics as far as being applied to all food products is concerned:

- Some of them are applied only to one or some categories of foods; others can be used across the board a wider application (cold storage, freezing, drying/dehydration, sterilization, etc.);
- Some guarantee food preservation on their own while others require combination with other procedures, either as principal or as auxiliary processes in order to assure preservation (for example smoking has to be preceded by salting).

Module 7. Physical, chemical and biological methods of food preservation

Lesson 22. Introduction / History Of Physical, Chemical And Biological Methods Of Food Preservation

Introduction:

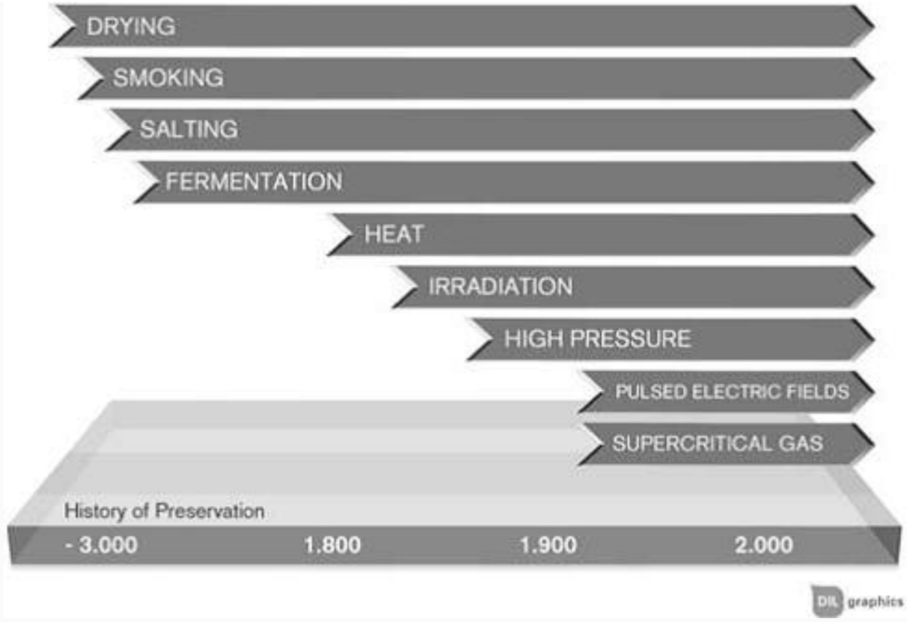
Food Preservation:

- Methods of treating foods to delay the deterioration of the food.
- Changing raw products into more stable forms that can be stored for longer periods of time.
- Allows any food to be available any time of the year in any area of the world.

Methods of preservation used to extend shelf life includes:

- Removal of moistur
- Temperature control
- pH control
- Use of chemical preservatives
- Irradiation

22. Historical Methods of Food Preservation:



(Heinz & Buckow, 2009)

- Primitive and tedious methods

– **Drying:** Used to preserve fruit, vegetables, meats, and fish. Mainly used in the south – warmer climate. Causes the loss of many natural vitamins and texture.

– **Salting:** Used extensively for pork, beef, and fish. Costly due to high price of salt. Done mainly in cool weather followed by smoking.

– **Sugaring:** Used to preserve fruits for the winter. Jams and jellies. Expensive because sugar was scarce commodity in early America.

– **Pickling:** Fermenting, used to preserve vegetables. Use of mild salt and vinegar brine. It increases the salt content and reduces the vitamin content of the food. Oldest form of food preservation.

– **Cold storage:** Used extensively in the northern U.S. Root cellars were used to store vegetables at 30-40°F. Root cellars were replaced by ice boxes in the mid 1800's.

22.1 Food Preservation Shift:

- During the late 18th century, there was a great demand for better preservation methods for naval expeditions.
- Food preservation methods used were not effective enough for long term use; hence better methods were needed for safer food consumption.
- Nicolas Appert worked on his process for years before opening a factory in 1795. He preserved many foods like: Meats, Gravies, Fish, Vegetables – peas, onions, asparagus, spinach, etc. Fruits – currants, cherries, nectarines, etc. Milk, eggs, and cream.

- **Louis Pasteur:** Louis Pasteur believed that particles in the air cause contamination. He found out that heating wines quickly to 130°F after completion of fermentation processes would kill microbes, and unpleasant flavours. This process is now known as pasteurization, and is widely used in beer, milk, wine and vinegar making. This method helped to set precautions to avoid spoilage of food products. It opened the door for microbial research, especially in the food industry.

22.2 Preservation Methods Today:

Physical	**Chemical**	**Biological**
Chilling and cooling Freezing Blanching/Cooking Pasteurization Canning Freezing Drying/Dehydration Separation/Filtration Concentration Irradiation Modified/Controlled Atmospheric Packaging	Preservatives e.g benzoates, nitrites Sugar Salt Spices Additives e.g. antioxidants	Fermentation: Alcoholic Acetic Lactic

22.2.1 PHYSICAL METHODS OF PRESERVATION:

Methods of preserving an array of local products for use throughout the year have been based on traditional methods. More sophisticated techniques such as irradiation may also extend shelf life mainly by the destruction of enzymes and the inactivation of microorganisms.

22.2.1.1 Chilling and cooling

Chilling may be referred to as the process that lowers the food temperature to a safe storage temperature between 0° and 5°C, whereas cooling is a more general term applied to the lowering of a food temperature.

Chilled foods can potentially present a greater risk to public safety than frozen foods. Keeping products at a low temperature reduces the rate of microbiological and chemical deterioration of the food. In most processed chilled foods, it is the microbial growth that limits the shelf life; even the slow growth rates that occur under chilled conditions will eventually result in microbial levels that can affect the food or present a potential hazard. This microbial growth can result in the spoilage of the food (it may go putrid or cloudy or show the effects of fermentation), but pathogens, if present, may have the potential to grow and may show no noticeable signs of change in the food.

The relationship between the temperature of food (for example, in preservation and storage) and its shelf life is evident in several food operations.

22.2.1.2 Freezing

Freezing of food does not render it sterile, although it can reduce the levels of some susceptible microorganisms that is not significant in the context of the overall microbial quality of the food. Once a frozen food is defrosted, those viable microorganisms present will grow and multiply.

Rapid freezing in blast freezers is desirable to prevent the formation of large ice crystals that will tend to adversely affect the texture of the food by disrupting cell integrity in fruits and vegetables or degrading the muscle proteins of meat, fish and poultry.

Apart from enzymatic activity, there are many other chemical and physical changes which may limit the shelf life of frozen food; examples include fat oxidation and surface drying, both of which may occur over a period of months, depending on the food.

Damage to tissue may also result from ice crystals, particularly in the case where slow freezing occurred, for example, in a domestic freezer. In commercial freezers, where temperatures of -40°C and below are maintained, freezing of the product takes place quickly, and the shelf-life is even longer.

It is important to avoid repeated freezing and thawing as this damages the food resulting in a greater chance for microbial repair and growth. **(Richard Coles et al.,2001)**

22.2.2 HEAT PRESERVATION:

Microorganisms and enzymes are the major causes of undesirable changes in foodstuffs. They both are susceptible to heat, and appropriate heating regimes can reduce, inhibit or destroy their activity.

The degree of heat treatment required to produce a product of acceptable stability will depend on the nature of the food, its associated enzymes, the number and types of microorganisms, the conditions under which the processed food is stored and other preservation techniques used.

22.2.2.1. Blanching

Blanching is a process designed to inactivate enzymes and is usually applied immediately prior to other thermal preservation processes either using high temperatures (e.g. thermal processing) or low temperatures (e.g. freezing).

It does not reduce the microbial population on the surface of foods, but it reduces the numbers of organisms of lower heat resistance, such as yeasts, molds and certain bacteria (e.g. Listeria, Salmonella, E. coli). Without a blanching step, the shelf life of, frozen vegetables would be substantially reduced as a result of chemical breakdown during storage.

In thermal processing of fruits and vegetables, the objective of blanching is to prevent further enzymatic breakdown of the foods if delays occur prior to processing the foods. It is mainly used for vegetables by heating the food with steam or hot water to 180-190 ^{0}F and cooling in ice water, which prevents bacteria from growing.

During hot water blanching, some soluble constituents are leached out: water-soluble flavours, vitamins (vitamin C) and sugars. With potatoes this may be an advantage as leaching out of sugars makes the potatoes less prone to turning brown.

Blanching is a delicate processing step. Time, temperature and the other conditions must be carefully monitored. Sodium bicarbonate is added to the blanching water when okra, green peas and some other green vegetables are blanched. The chemical raises the pH of the blanching water and prevents the fresh green colour of chlorophyll being changed into pheophytin which is unattractive brownish-green.

If products are over-blanched (boiled for too long) they will stick together on the drying trays and they are likely to have a poor flavour.

Green beans, carrots, okra, turnip and cabbage should always be blanched. The producer can choose whether or not potatoes need blanching. Blanching is not needed for onions, leeks, tomatoes and sweet peppers. Tomatoes are dipped into hot water for one minute when they need to be peeled but this is not blanching.

As a rule fruit is not blanched.

- **Benefits of Blanching:**
- It helps clean the material and reduce the amount of micro-organisms present on the surface;
- It preserves the natural colour in the dried products;

- It shortens the soaking and/or cooking time during reconstitution.
- Destroys enzymes in the food

22.2.2.2 Pasteurization

This is a heating regime (generally below 105°C) that primarily aims to achieve commercial sterility by virtue of additional factors that contribute towards preserving the food.

The actual degree of heat process required for an effective pasteurization will vary depending on the nature of the food and the types and numbers of microorganisms present. Milk is the most widely consumed pasteurized food, and the process was first introduced commercially in the UK during the 1930s, when a treatment of 63°C for 30 min was used. Modern milk pasteurization uses an equivalent process of 72°C for 15 s.

Pasteurization is used extensively in the production of many different types of food, including fruit products, pickled vegetables, jams and chilled ready meals. Food may be pasteurized in a sealed container (analogous to a canned food) or in a continuous process (analogous to an aseptic filling operation). It is important to note that pasteurized foods are not sterile and will usually rely on other preservative mechanisms to ensure their extended stability for the desired length of time.

Once the food product is exposed to temperatures of 60-70°C, microbial growth stops, and enzyme inactivation starts. As the temperature is increased (80 - 90°C), the vegetative forms of microorganisms are destroyed and the rate of enzyme inactivation increases. Heat processing of acid products, such as fruits and fruit juices, is usually done at higher temperatures (100°C), for short times (10-15 seconds).

Heat processing requirements - dependent on product acidity

Acidity class	**pH value**	**Food item**	**Heat and processing requirements**
Low acid	6.0	Peas, carrots, beets, potatoes, asparagus, poultry, meat, sea foods, milk etc.	High temperature processing 116-121°C (240-250°F)
	5.0	Tomato soup	
Medium acid	4.5	Tomatoes, pears, apricots, peaches	Boiling water processing 100°C (212°F)

Acid	3.7	Jams, sauces, fruits, Sauerkraut, apple,	Temperature of 93-100° C, (200-212° F)
High acid	3.0	Pickles	

Source: Desrosier and Desrosier (1977)

22.2.2.3. Canning

Canning gained popularity after the Civil War. English immigrant, William Underwood, introduced canning to America. John L. Mason invented his famous canning jar in 1858. It revolutionized the way people all over the world ate. United States consume more than 200 million cans of food and drink each day!

Can retorting or processing is a term that is still widely used in the food industry to describe a wide range of thermal processes where the food is heated within the pack to achieve a commercially sterile packaged food. The heating takes place in retorts that are basically batch-type or continuous hot water and/or steam-heated pressure cookers.

Different types of canning:

- Boiling water canning
- Pressure canning
- Pickling
- Jams & Jellies

Safe canning is determined by:

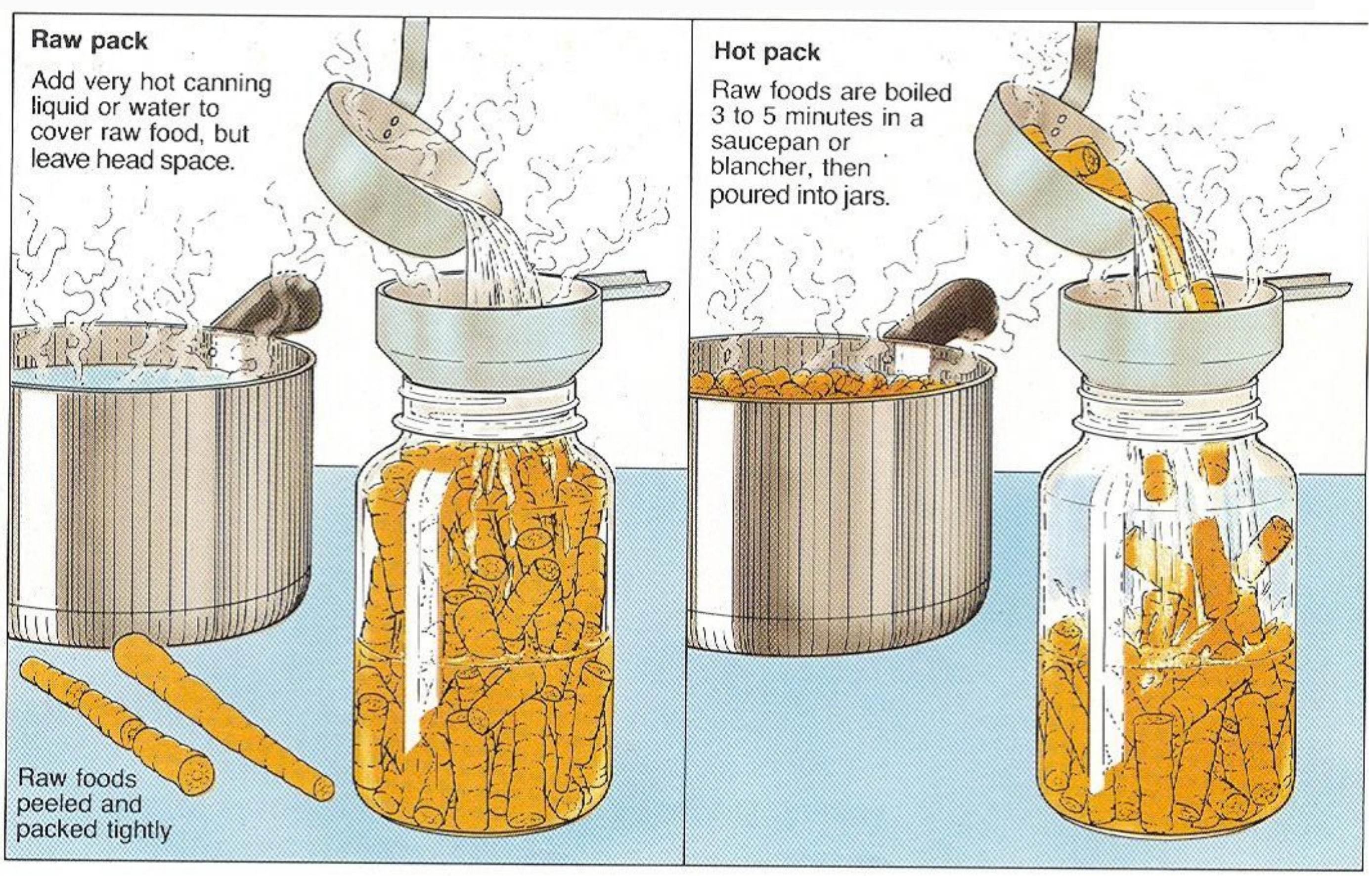
- Processing temperature
- Processing time
- Sealed lid
- Acid level
- Container & size
- Preparation method
- Consistency of food
- Altitude

The principle of food canning is that no microbial growth occurs in the food under normal storage conditions at ambient temperature until the package is opened (Department of Health, 1994). Once the package is opened, the effects of canning will be lost, the food will need to be regarded as perishable and its shelf life will depend on the nature of the food itself.

The most heat-resistant pathogen that might survive the canning process of low-acid foods is C. botulinum. This bacterium can form heat-resistant spores under adverse conditions, that germinate in the absence of oxygen and produce a highly potent toxin, causing a lethal condition known as botulism which can cause death within seven days.

A metal can is the ideal package from a processor's view because, relative to other packaging media, it offers the possibility of high production speeds, as well as good pack size flexibility, and the high compression strength of cans enables them to withstand physical abuse during processing and distribution.

There is evidence that cans do not create a hermetic (gas-tight) seal while they are hot, because of the expansion of the metal in the double seams. Good practice in canneries avoids manual handling of hot and wet cans to reduce the risk of post-process introduction of microbial contaminants into the container.



<table>
<tr><th>Disadvantages:</th><th>Disadvantages:</th></tr>
<tr><td>Floating food</td><td rowspan="3">Texture Loss</td></tr>
<tr><td>Air bubbles</td></tr>
<tr><td>Discoloration over time</td></tr>
</table>

Lesson 23. Physical methods of food preservation-I

23. DRYING/DEHYDRATION:

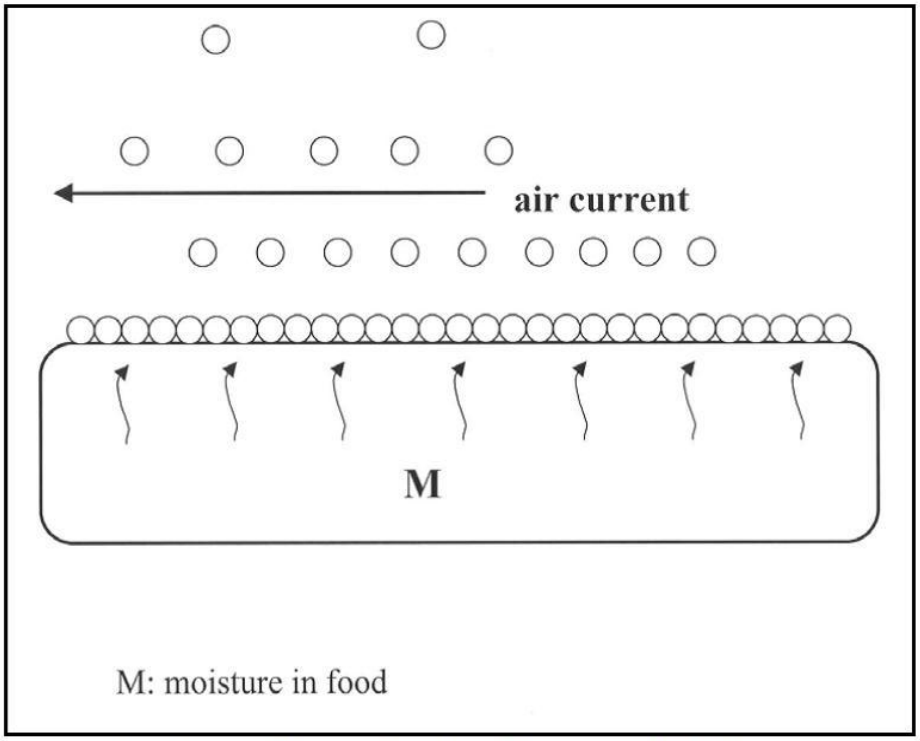
Drying or dehydration involves the removal of water from the food by controlled processes, which may be done by

- Evaporation due to heating of the product.
- Osmotic dehydration.
- Sublimation, or freeze drying.

There are two distinct stages in this process.

- In the first stage, surface water removal depends solely on the state of the air surrounding the food, such as its temperature, relative humidity and speed.
- In the second phase of drying, the moisture within the food moves to the surface. As the air is heated, its relative humidity decreases, resulting in more absorption of water.

The rate of drying depends on the time the moisture takes to get to the surface. The heating of the air around a food product causes faster drying.



Adapted from: Technical Manual – Basic Food Processing, FAO, 1985.

Although in case of starchy foods, the shortest drying time may be referred, to as the common change of "case hardening". In such an event, water removal from the surface is much faster than the rate at which water migrates from the interior. The surface, therefore, dries into a hard layer, which actually prevents the migrating water from reaching the surface.

Factors on which the selection of a particular dryer/drying method depends include:

- form of raw material and its properties;
- desired physical form and characteristics of dried product;
- necessary operating conditions;
- operation costs.

Several types of dryers and drying methods, are commercially used to remove moisture from a wide variety of food products including fruit and vegetables. With this method of preservation, retains most of the flavours, giving less bulkiness to the product (reduced shipping costs) with extended shelf life.

There are five basic methods of drying which are as follows:

- Tunnel Dryer
- Solar Dryer

- Spray Dryer
- Vacuum Dryer
- Freeze Drying

23.1 Tunnel Drying:

Many years ago a solar tunnel dryerwas developed at the university of Hohenheim, with the purpose of preserving agricultural products by the means of drying.

With a joint development of the Institute for Agricultural Technology in the Tropics and Subtropics at the University of Hohenheim and Innotechcompany, the solar dryers of this type are now in use in over 75 countries.

This device is employed for the hygienic preservation of foods. It forms a good alternative for seasonal agricultural surplus, deficient transport capabilities for fresh products and insufficient preservability of undried products. At the same time, the quality of goods dried in this way is substantially superior to traditional drying.

Fishermen in Bangladesh uses the solar dryer for the hygienic drying of their catch. Similarly spices are also dried in China etc.

The solar tunnel dryer is 20m long and 2m wide. It can be loaded with between 300 and 500kg of goods to be dried.

23.2 Sun Drying/Solar Drying

Sun drying and solar drying are obvious alternatives for drying due to the abundance of natural sunlight. Although the two terms are sometimes used interchangeably, sun drying refers to the removal of moisture by merely placing the commodity in the sun, e.g., on a barbecue, rack, etc. Sun drying of fruit crops is still practiced for certain fruit such as prunes, figs, apricots, grapes and dates.

The main problems for sun drying are dust, rain and cloudy weather. Therefore, drying areas should be dust-free and whenever there is a threat of a dust storm or rain, the drying trays should be stacked together and placed under cover. In order to produce dust-free and hygienically clean products, fruit and vegetable material should be dried well above ground level so that they are not contaminated by dust, insects, livestock or people. All materials should be dried on trays designed for the said purpose. The most common drying trays have wooden frames with a fitted base of nylon mosquito netting. Mesh made of woven grass can also be used. The trays should be placed on a framework at table height from the ground to allow air to circulate freely around the drying material and also to keep the food product well away from dirt. The material should be stirred/turned over at least once an hour, during the initial period which will help the material dry faster and more evenly, prevent it sticking together and improve the quality of the finished product. At night the trays should be stacked in a ventilated room or covered with canvas. Plastic sheets should NEVER be used for covering individual trays during sun drying.

Dry or nearly dry products can be blown out of the tray by the wind. However, this can be protected by covering the loaded tray with an empty one; this also gives protection against insects and birds.

Limitations of traditional sun drying include the following:

- Intermittent moisture loss as it is largely dependent on the weather.
- Drying rates are usually slow and do not result in high quality products.
- Moisture levels are too high for prolonged storage.
- Insect infestation.

Solar drying, involves capturing and concentrating solar energy for the purpose of removing water. This method has increased its popularity, although commercial solar dryers with high rates of efficiency are often quite expensive.

The advantages of solar drying over sun drying include:

- Faster drying rates as higher air temperatures are generated.
- Lower final moisture content of the finished product.
- Greater protection of the product from rain, dust, pests.
- Low insect and mould infestation due to higher temperatures.

Essentially, there are two types of solar dryers – direct and indirect. Regardless of which type is used, it is important to have information on the seasonal and daily variation of sunshine, humidity, temperature, wind speed and direction during drying. (**Matthew G. Green, 2001**)

Advantages of Drying:

- **Long Shelf Life**– Most microorganisms responsible for food spoilage are unable to grow and multiply in the absence of moisture, also enzymes catalyzing the undesirable changes in foods are limited due to low moisture content, resulting into a longer shelf life of foods.
- **Reduced Weight**– Results in reduced transportation, storage and shipping costs.
- **Convenience** – The production of convenience items with novelty appeal for niche markets makes drying an attractive option.
- **Concentration of nutrients**– The removal of most of the water from a food results in a highly concentrated source of nutrients.

- **No refrigeration is required for dried products** – Savings in energy and storage costs together with the long shelf life provide a lucrative processing alternative for tropical countries.

- **Inexpensive** - The method is simple to carry out and inexpensive, and can be easily employed by grower, farmer, cooperative, etc., as it uses the natural resource/source of heat: sunlight.

Disadvantages of Drying

Disadvantages of drying are few, and mainly relate to oxidation, which usually accompanies drying. This results in losses of micronutrients such as carotene and ascorbic acid, with minimal loss in protein as a result of browning reactions, that reduces consumer appeal. There might also be changes in flavour and texture if drying is not properly controlled, particularly with regard to maximum temperatures.

Shade drying

Shade drying is carried out for products which can lose their colour and/or turn brown if kept in direct sunlight. Products which have naturally vivid colours like herbs, green and red sweet peppers, chilies, green beans and okra give a more attractive end-product when they are dried in the shade. Under dry conditions when there is a good circulation of air, shade drying takes little more time than is normally required for drying in full sunlight.

23.3 Spray drying

The development of spray drying equipment and technique evolved over a period of several decades from the 1870s through the early 1900s. Spray drying comes from an age of World War II, with the sudden need to reduce the transport weight of foods and other materials.

This technique enables the transformation of feed from a fluid state into dried particulate form by spraying the feed into a hot drying medium. It is a continuous particle processing drying operation. The feed can be a solution, suspension, dispersion or emulsion. The dried product can be in the form of powders, granules or agglomerates depending upon the physical and chemical properties of the feed, the dryer design and final powder properties desired **(Michael, 1993).**

Spray drying process mainly involves five steps:

(i) **Concentration:** Feedstock is normally concentrated prior to introduction into the spray dryer.

(ii) **Atomization:** The atomization stage creates the optimum condition for evaporation to a dried product having the desired characteristics.

(iii) **Droplet-air contact:** In the chamber, atomized liquid is brought into contact with hot gas, resulting in the evaporation of 95%+ of the water contained in the droplets in a matter of a few seconds.

(iv) **Droplet drying:** Moisture evaporation takes place in two stages -1) during the first stage, there is sufficient moisture in the drop to replace the liquid evaporated at the surface and evaporation takes place at a relatively constant rate and 2) the second stage begins when there is no longer enough moisture to maintain saturated conditions at the droplet surface, causing a dried shell to form at the surface. Evaporation then depends on the diffusion of moisture through the shell, which is increasing in thickness.

(v) **Separation:** Cyclones, bag filters, and electrostatic precipitators may be used to purify and cool the air so that it can be released to atmosphere. Spray drying process have advantages that can be designed to virtually any capacity required. Feed rates range from a few pounds per hour to over 100 tons per hour. It can be used with both heat-resistant and heat sensitive products. Nearly spherical particles can be produced. **(Keey& Pham, 1976)**

23.4 Vacuum drying

Since evaporation of water takes place more readily at lower pressures, drying under vacuum is faster. This method is more expensive than air-drying and is reserved for specialized products for sublimation from frozen foods.

Although the food structure is better conserved, the equipment and its maintenance are costly. Vacuum dehydration processes are useful for low moisture / high sugar fruits like peaches, pears and apricots.

23.5 Freeze drying

Freeze-drying is a method of preservation that makes use of the physical principle known as sublimation, the process by which a solid passes directly to the gaseous phase without first melting. Freeze-drying is a desirable way of preserving food because at low temperatures (commonly around –10°C to –25°C) chemical reactions take place very slowly and pathogens have difficulty surviving. The food to be preserved by this method is first frozen and then placed into a vacuum chamber. Frozen water in the food then sublimates, leaving the moisture content in the final product of as low as 0.5%.

The steps of Freeze Drying include:

1 **Freezing** of the product.

2 **Vacuuming**– It ensures that the water does not pass through the liquid phase and goes straight to a gas.

3 **Heating the product** – It increases the rate of the reaction.

4 **Condensation** – Condenser plates move the vaporized solvent to a solid state.

Freeze drying of food products gives following advantages:

- Fresh-like flavors of the products
- Label friendly....all natural, no additives, preservatives or artificial flavoring
- Concentrated nutritional values
- Shelf stable
- Enhanced texture
- Vibrant color
- Intense fragrance
- High anti-oxidant values
- Organic compatible
- Superior alternative to drum and spray drying

Lesson 24. Physical Methods Of Food Preservation -II

24. Separation / Filtration

Separation operations are based on the principles that depend on the physical properties of the components of the liquid product and their differences. A separation process such as centrifugation relies on differences in solubility and specific gravity to separate blends of immiscible materials. In case of membranes, separation takes place with the use of difference in size of osmotic pressure of the components of liquid food.

In last two decades, separation processes have emerged in which membranes have played a prominent role in the isolation and enrichment of functional ingredients by concentrating, fractionating and purification of fluids or gases.

Membrane processing can be applied to vegetable protein concentrates and isolates derived from soybean, peas and canola. It permits concentration and separation without the use of heat. They make it possible to standardize the concentrations of specific components, and to decrease the concentration of undesirable components.

Table: Applications of Membranes in Food Industry.

Process	**Application in Food Industry**
Microfiltration	Removal of particles from beverages and dairy products, clarification of alcoholic beverages, waste water management.
Ultrafiltration	Concentration of egg white, blood serum proteins, whey protein concentrate, clarification of dextrose, waste water recovery and use, recovery of by-products from waste water, pre-concentration of dilute sugar solutions and syrup concentration.
Nanofiltration	Desalting of lactose, whey protein concentrates and antibiotics, recycling of caustic cleaning solutions, softening water to reduce scaling on equipment and heat exchange surfaces.
Reverse Osmosis	Production of pure water, concentration of maple sap, recovery of sugar from candy, recovery of oil-seed protein.

(GEA,Technology Watch,2005)

24.1 Concentration

Foods are concentrated for many of the same reasons that they are dehydrated. Concentration can be a form of preservation but this is true only for some foods. Concentration reduces weight and volume and results in immediate economic advantages.

Nearly all liquid foods which are dehydrated are concentrated before drying. This is because in the early stages of water removal, moisture can be more economically removed in highly efficient evaporators than in dehydration equipment. Further, increased viscosity from concentration often is needed to prevent liquids from running off drying surfaces or to facilitate foaming or puffing.

The more common concentrated fruit and vegetable products include items as fruit and vegetable juices and nectars, jams and jellies, tomato paste, many types of fruit purées used by bakers, candy makers and other food manufacturers.

The methods used to concentrate liquid foods depend on the composition of the product, the sensitivity of the components to decompose with heat, and the economics of the process.

Methods of concentration

1. **Solar concentration** - One of the simplest methods of evaporating water. A typical example of this method is production at farm level in developing countries of fruit pastes/leathers (such as apricot or plum pastes).

2. **Open Kettles** - Some foods can be satisfactorily concentrated in open kettles that are heated by steam, as in case of jellies and jams, tomato juices and purées and for certain types of soups. High temperatures and long concentration time should be avoided in order to avoid thickening and burn-on of product to the kettle wall.

3. This type of evaporation is highly recommended for small scale operations in developing countries, widely used for jellies, jams and marmalades.

4. **Flash evaporators-** Flashing is a process which gives rise to vaporization flow rate more significant thanthat obtained during simple evaporation. The industrial applications of flashing are varied. One of the most important concern is the desalination of seawater in multi-stage flash evaporators.

5. **Vacuum evaporators-** Several vacuumised vessels in series are constructed, so that the product moves from one vacuum chamber to the next and thereby becomes progressively more concentrated in stages. In this way maximum use of heat energy is made. Such system is called a multiple effect vacuum evaporator and is a widely used system for concentrated tomato paste.

6. **Freeze Concentration** - This process has been known for many years and has been applied commercially to orange juice. However, high processing costs largely due to losses of juice occlude [unclear] to the ice crystals.

7. **Ultrafiltration and reverse Osmosis-**

   UF is used in a variety of industries mainly due to its low energy requirements, non-thermal nature and simplicity. It is ideal for removal of anti-nutritional factors (i.e. oligosaccharides, phytic acid, and some trypsin inhibitors from vegetable protein processing) to produce purified protein isolates or concentrates with superior functional properties

   Food products concentrated by reverse osmosis are generally more heat labile; they include high priced fruit juices, dairy products and pharmaceuticals. In most reverse osmosis applications, the liquid products are pre-filtered using membranes with larger pore openings, such as ultrafiltration and microfiltration membranes

Limitations:

- Concentration exposes food to 100° C or above for prolonged periods, which can cause major changes in organoleptic and nutritional properties.
- Cooked foods and darkening of colour are two of the more common heat induced results.
- Concentration at a temperature of 100 °C or slightly above will kill many micro-organisms but cannot be depended on to destroy bacterial spores.
- When the food contains acid, such as fruit juices, the micro-organisms kill will be greater but sterility is doubtful.
- When concentration is done under vacuum, many bacterial types not only survive the low temperatures but multiply in the concentrating equipment.

24.2 Irradiation

Food irradiation is one of the food processing technologies available to the food industry to control organisms that cause food-borne diseases and to reduce food losses due to spoilage and deterioration. Food irradiation technology offers some advantages over conventional processes. Each application should be evaluated on its own merit as to whether irradiation provides a technical and economical solution that is better than traditional processing methods.

Applications

For products where irradiation is permitted, commercial applications depend on a number of factors including the demand for the benefits provided, competitiveness with alternative processes and the willingness of consumers to buy irradiated food products. There are a number of applications of food irradiation. For each application it is important to determine the optimum dosage range required to achieve the desired effect. Too high a dosage can produce undesirable changes in texture, colour and taste of foods.

The way in which the radiation dose absorbed is measured differs according to the source of radiation, and various dosimetry techniques exist.

Dose-range needed for effective treatment	kGy*
Inhibition of sprouting in potatoes and onions	0 03—0 1
Sterilization of insects and parasites	0 03—0.2
Killing of insects and parasites	0 05—5
Reducing by 10* the number of vegetative bacteria, moulds, and fungi	1—10
Reducing by 10' the number of dried or frozen vegetative bacteria, fungi, and spores	2—20
Reduction by 10' the number of viruses	10—40
Sterilization of food	20-45
• 1 kGy (Gray) = 100 000 rad (= 1 Joule/kg).	

Irradiation can extend the shelf-life of foods in a number of ways. By reducing the number of spoilage organisms (bacteria, mould, fungi), irradiation can lengthen the shelf life of fruits and vegetables.

Since ionizing radiation interferes with cell division, it can be used as an alternative to chemicals to inhibit sprouting and thereby extend the shelf life of potatoes, onions and garlic. Exposure of fruits and vegetables to ionizing radiation slows their rate of ripening. Strawberries, for example, have been found to be suitable for irradiation. Their shelf-life can be extended three-fold, from 5 to 15 days. Ionising radiation can also be used as an alternative to chemical fumigants for disinfestations of grains, spices, fruits and vegetables.

The Expert Committee concluded that irradiation to an overall dose of 10 kGy (kilograys) presents no toxicological hazard and introduces no special nutritional or microbiological problems, thus establishing the wholesomeness of irradiated foods up to an overall average absorbed dose of 10 kGy. Data were insufficient to formulate conclusions on applications of food irradiation above 10 kGy.

More than 30 countries have given clearances for the use of food irradiation to process some 40 food items and approximately 30 facilities world-wide treat food by irradiation processing. Approvals for additional items are being considered in many countries and many food irradiation facilities are being planned.

24.3 MAP / CAP

MAP and CAP can supplement proper temperature and relative humidity management in maintaining quality and reducing losses of tropical fruits. Its beneficial effects include reduction of respiration rate, inhibition of ethylene production and action, retardation of ripening and maintenance of nutritional quality.

Short term exposure of tropical fruits to O_2 levels below 1% and /or CO_2 levels below 12% can reduce incidence and severity of physiological disorders (such as chilling injury), pathogens and insects.

Controlled Atmosphere Packaging

A defined mix of gases is maintained or controlled over time by some external apparatus or internal chemical reactions. An example of a controlled atmosphere is the Transfresh container (used for ocean transport of fruit) which have a mechanical means of measuring the container atmosphere and adjusting the gas levels to maintain a predetermined mixture of CO_2, O_2 and N_2 during shipment. Placing an oxygen absorbing sachet inside a barrier package is an example of a controlled atmosphere package using a chemical reaction. The sachet absorbs any oxygen that transmits through the package barrier. Sulfur dioxide producing pads used in long term shipment or storage of table grapes to prevent growth of gray mold are another example of controlling package atmosphere.

Modified Atmosphere Packaging

Gas atmosphere is modified by (1) direct injection of gases (often CO_2 or nitrogen) into a package, (2) evacuating air from the package or (3) interaction between package contents and the air in the package causing the package atmosphere to modify over time. With proper packaging, the natural respiration of produce causes O_2 levels to drop and CO_2 levels to rise. Modified atmosphere packages have an atmosphere different from ambient air but, that atmosphere can change over time.

In the case of produce, package atmosphere is affected by the transmission rates of the packaging material and changes in storage temperatures. Higher temperatures lead to higher respiration rates, creating lower O_2 levels in the package atmosphere and higher concentrations of CO_2. Hence, the atmosphere inside the package is modified but not controlled.

Carbon Dioxide (CO_2)

Carbon Dioxide is a natural gas, which is found in small concentrations in the air. It inhibits the increase of most aerobic bacteria and mildew. CO_2 is the most important gas in the packaging of food under modified atmospheres. Higher the CO_2 concentration the longer the durability of the perishable food. However fat and water absorb CO_2 gases very easily and excessive CO_2 concentrations causes quality failures regarding taste, loss of humidity and the concentration of the packaging (so called vacuum effect). If CO_2 is intended to regulate the growth of bacteria and mildew a concentration of at least 20% is recommended.

Nitrogen (N_2)

N_2 is an inert gas that is used to expel air especially Oxygen out of the packaging. It is also used as a filling gas that equalizes the effect of CO_2 absorption by the perishable food. It reduces the vacuum effect and is also a natural component of the air.

Oxygen (O_2)

O_2 is an essential gas for the respiration of all living beings and supports the decay of perishable food. It is the condition for the growth of aerobic micro organisms. In general Oxygen should be excluded for the MAP but in some cases a determined amount of Oxygen brings quite positive results.

- It keeps the natural colour of the perishable food (effect of freshness).
- It makes possible respiration, especially for fruits or vegetables.
- It inhibits the growth of anaerobic micro organisms in several kinds of fish and vegetable.

Lesson 25. Chemical And Biological Methods Of Food Preservation

25. Preservation Using Chemicals

Salt and sugar

Salt and sugar have long been used as effective means of extending shelf life of various products as these solutes bind water, leaving less water available for the growth of microorganisms. Essentially the water activity (aw) of the product is reduced, and since most microorganisms require a high water activity, they areunable to survive.

Salt and sugar in concentrated solutions have high osmotic pressure. When these are sufficient to draw water from microbial cells or prevent normal diffusion of water into these cells, a preservative condition exists**. (Morris *et al.*,2004)**

The critical concentration of sugar in water to prevent microbial growth will vary depending upon the type of micro-organisms and the presence of other food constituents, but usually 70% sucrose in solution will stop growth of all micro-organisms in foods. Less than this concentration may be effective but for short period of time unless the foods contain acid or they are refrigerated.

Salt becomes a preservative when its concentration is increased and levels of about 18% to 25% in solution generally will prevent all growth of micro-organisms in foods. Except in the case of certain briny condiments, however, this level is rarely tolerated in foods.

Acids

Acids such as citric acid, acetic acid (vinegar) and ascorbic acid are also known to confer protection against product deterioration. In these cases, the pH of the product is shifted to being low, that is, more acidic, where very few molds, yeast and bacteria are able to grow and multiply.

Acetic acid is a general preservative inhibiting many species of bacteria, yeasts and to a lesser extent moulds. It is also a product of the lactic-acid fermentation, and its preservative action even at identical pH levels is greater than that of lactic acid. The main application of vinegar (acetic acid) includes products such as pickles, sauces and ketchup.

Other acidulants

- Malic and tartaric (tartric) acids is used in some countries mainly to acidify and preserve fruit sugar preserves, jams, jellies, etc.
- Citric acid is the main acid found naturally in citrus fruits; it is widely used (in carbonated beverages) and as an acidifying agent of foods because of its unique

flavour properties. It has an unlimited acceptable daily intake and is highly soluble in water. It is a less effective antimicrobial agent than other acids.

- Ascorbic acid or vitamin C, its isomer isoascorbic or erythorbic acid and their salts are highly soluble in water and safe to use in foods.

25.1 Preservatives

Chemical food preservatives are those substances which are added in very low quantities (up to 0.2%) and which do not alter the organoleptic and physico-chemical properties of the foods at or only very little.They are used to improve the colour and keeping qualities of the final product for some fruits and vegetables.

Food additives such as benzoate and sorbate are quite commonly used in the fruit drink industry to protect against microbial spoilage, while nitrites are used in meat processing. These chemicals work best at acidic pH ranges and when the products are pasteurized. A combination of heat and chemicals where applicable is usually more effective than either one on its own.

Treatment with preservatives takes place after blanching or, when blanching is not needed, after slicing. The composition and strength of the preservative solution vary for different fruit and vegetables. As a general rule, preservatives are not used for treating onions, garlic, leeks, chilies and herbs.

Preservation of food products containing chemical food preservatives is usually based on the combined or synergistic activity of several additives, intrinsic product parameters (e.g. composition, acidity, water activity) and extrinsic factors (e.g. processing temperature, storage atmosphere and temperature).

This approach minimises undesirable changes in product properties and reduces concentration of additives and extent of processing treatments.

25.2 Lypophilic acid food preservatives

Benzoic acid

Benzoic acid in the form of its sodium salt, constitutes one of the most common chemical food preservative. Sodium benzoate is a common preservative in acid or acidified foods such as fruit juices, syrups, jams and jellies, sauerkraut, pickles, preserves, fruit cocktails, etc. Yeasts are inhibited by benzoate to a greater extent than are moulds and bacteria.

Sorbic acid

Sorbic acid is generally considered non toxic and is metabolized; among other common food preservatives the WHO has set the highest acceptable daily intake (25 mg/kg body weight) for sorbic acid. Sorbic acid and its salts are practically tasteless and odourless in foods, when used at reasonable levels (< 0.3 %) and their antimicrobial activity is generally adequate.

Sorbates

Sorbates are used for mould and yeast inhibition in a variety of foods including fruits and vegetables, fruit juices, pickles, sauerkraut, syrups, jellies, jams, preserves, high moisture dehydrated fruits, etc.

Potassium sorbate

Potassium sorbate, a white, fluffy powder, is very soluble in water (over 50%) and when added to acid foods it is hydrolysed to the acid form. Sodium and calcium sorbates also have preservative activities but their application is limited compared to that for the potassium salt, which is employed because of its stability, general ease of preparation and water solubility.

25.3 Gaseous chemical food preservatives

Sulphur dioxide and sulphites

Sulphur dioxide (SO_2) has been used for many centuries as a fumigant and especially as a wine preservative. It is a colourless, suffocating, pungent-smelling, non-flammable gas and is very soluble in cold water (85 g in 100 ml at 25°C).

The various sulphite salts contain 50-68% active sulphur dioxide. A pH dependent equilibrium is formed in water and the proportion of SO_2 ions increases with decreasing pH values. At pH values less than 4.0 the antimicrobial activity reaches its maximum. The antimicrobial action of sulphur dioxide against yeasts, molds and bacteria is selective, with some species being more resistant than others.

Sulphur dioxide and sulphites are used in the preservation of a variety of food products. In addition to wines these include dehydrated/dried fruits and vegetables, fruit juices, acid pickles, syrups, semi-processed fruit products, etc. In addition to its antimicrobial effects, sulphur dioxide is added to foods for its antioxidant and reducing properties, and to prevent enzymatic and non-enzymatic browning reactions.

Carbon dioxide

Carbon dioxide (CO_2) is a colourless, odourless, non-combustible gas, acidic in odour and flavour. In commercial practice it is sold as a liquid under pressure (58 kg per cm^3) or solidified as dry ice.

Carbon dioxide is used as a solid (dry ice) in many countries as a means of low-temperature storage and transportation of food products. Besides keeping the temperature low, as it sublimes, the gaseous CO_2 inhibits growth of psychrotrophic micro-organisms and prevents spoilage of the food (fruits and vegetables, etc.).

Carbon dioxide is used as a direct additive in the storage of fruits and vegetables. In the controlled/ modified environment storage of fruit and vegetables, the correct combination of O_2 and CO_2 delays respiration and ripening as well as retarding mould and yeast growth. The amount of CO_2 (5-10%) is determined by factors such as nature of product, variety, climate and extent of storage.

Chlorine

The various forms of chlorine constitute the most widely used chemical sanitizer in the food industry. These chlorine forms include chlorine (Cl_2), sodium hypochlorite (NaOCl), calcium hypochlorite ($Ca(ClO)_2$) and chlorine dioxide gas (ClO_2).

These compounds are used as water adjuncts in processes such as product washing, transport, and cooling of heat-sterilised cans; in sanitising solutions for equipment surfaces, etc.

25.4 General rules for chemical preservation

- Chemical food preservatives have to be used only at a dosage level which is needed for a normal preservation and not more.
- "Reconditioning" of chemical preserved food, e.g. a new addition of preservative in order to stop a microbiological deterioration already occurred is not recommended.
- The use of chemical preservatives MUST be strictly limited to those substances which are recognized as being without harmful effects on human beings' health and are accepted by national and international standards and legislation.

25.5 Preservation by Fermentation

- Food fermentation is usually carried out with the use of micro- organisms, producing alcoholic, acetic or lactic acid as end products as a result of their action on simple sugars present. These reactions take place in the absence of oxygen, that is anaerobic, and are responsible for the production of wine, vinegar, yoghurt and pickled vegetables among others. Having pure cultures of the desirable microorganism in the food products being fermented is critical to obtaining clean", characteristic flavours of end products.
- It is a process in which food spoils, but results in the formation of an edible product. Perhaps the best example of such a food is cheese. Fresh milk does not remain in edible condition for a very long period of time. Its pH is such that harmful pathogens begin to grow in it very rapidly. Early humans discovered, however, that the spoilage of milk can be controlled in such a way as to produce a new product, cheese.
- Bread is another food product made by the process of fermentation. The addition of yeasts brings about the fermentation of sugars present in the mixture, resulting in the formation of a product that will remain edible much longer than will the original raw materials used in the bread-making process.

Module 8. Changes undergone by the food components during processing, evaporation, drying, freezing juice extraction, filtration, membrane separation, thermal processing.

Lesson 26. Changes undergone by the food components during Thermal Processing

26.1 INTRODUCTION

Thermal Processing is primarily concerned with the application of heat to destroy (inactivate) microorganisms and enzymes, which can cause spoilage of foods and health hazards to the consumers. Thermal processing involves heating of foods at various time-temperature combinations, which define the three main thermal processes, i.e., blanching, pasteurization and sterilization. The objective of thermal processing is the long-time and safe preservation of sensitive foods, preferably at ambient (room) temperatures. Traditionally, thermal processing has been applied to the canning of foods, packaged in metallic containers, and preserved for long periods (longer than 6 months). Thermal processing includes, in addition to canning, following food processing operations:

- Blanching (heat inactivation of spoilage enzyme in vegetables prior to further processing)
- Pasteurization (inactivation of pathogenic and spoilage microorganisms and enzymes) and
- Sterilization (long-term preservation of foods with minimum heat damage)

Foods are heat processed for five main reasons:

- To eliminate pathogens (organisms that cause disease)
- To eliminate or reduce spoilage organisms
- To extend the shelf life of the food
- To improve palatability of the food
- To develop new products (value addition)

High-temperature processing may have, in addition to preservation, some other desirable effects on foods, like improvement of eating quality (cooking), softening of some hard foods, and destruction of some undesirable components, like the trypsin inhibitor in legumes. Thermal treatments (heating), aimed mainly at improvement of eating and other qualities of foods, like baking, cooking, and frying. The major problem of thermal processing is the significant damage to the nutritional (vitamins, proteins) and organoleptic (sensory) quality (taste, colour, and texture) of foods, particularly those exposed to high temperature for a relatively long time.

26.2 CHANGES IN FOOD COMPONENTS DURING THERMAL PROCESSING

Although thermal processes may cause desirable changes to foods, like cooking and improvement of eating quality of foods, some heat-induced chemical and biochemical changes are undesirable, e.g., non-enzymatic browning, and vitamin, taste, texture, and colour deterioration. Most thermal damage reactions are described by first-order kinetics, similar to the inactivation of microorganisms and enzymes. The rate of thermal damage to food components is much slower than the thermal inactivation of the heat-resistant microorganisms and enzymes.

Important nutritional aspects of the thermal treatment of food are the inactivation of enzyme activities and the elimination/reduction and inactivation of microbial contamination and microbial toxins. These changes in general lead to an increase in the ability to store and use food. Thermal treatment also changes the physico-chemical structure of macronutrients, e.g. starches and proteins, with the generalized effect of a better gastro-intestinal digestion. Regarding the nutritional quality of heat-treated food one should discriminate between the effects on essential nutrients and non-nutrient bioactive components. While some water-soluble vitamins are heat-sensitive, e.g. vitamins C, B1, B2, B6, and folic acid, the lipid-soluble vitamins are not. A decrease in essential nutrients by heat treatment thus reduces the nutritional value of certain foods. Thermal treatment also causes changes in plant cell wall structure and thus modifications of the food matrix. These changes may lead to a marked increase in the bioavailability of bioactive food components, e.g. secondary plant metabolites (phytochemicals). Such effects have been demonstrated for carotenoids, e.g. β-carotene, lycopene, and lutein, but also for other substances like the isoflavonoids. By changing the tertiary structure of proteins thermal treatment may also lead to a change in epitopes responsible for allergenicity of certain foods. However, not all allergens can be inactivated by heat treatment.

However, during thermal treatment new compounds are formed and these compounds may have nutritional relevance. The Maillard reaction products are important for the colour and sensory properties of foods. The major nutritional benefits of thermal treatment of food are:

- Reduction/Elimination of Harmful Components

- Microbial Contamination/Parasites

- Toxins

- Enzyme Inhibitors

- Allergens

- Preservation of Food
- Changes in Food Matrix Structure and Texture

- Improvement of Digestibility

- Increased Bioavailability

- Generation of Beneficial New Compounds

- Aroma

- Antioxidants

For the nutritional quality of foods and the respective impact on health nutrients and bioactive non-nutrients should be considered separately. For the nutrients thermal effects on macronutrients and micronutrients are of importance and since the effects are rather different they will be discussed individually.

26.3 NUTRIENTS: ***MACRONUTRIENTS:***

26.3.1 PROTEINS

Thermal treatment of proteins leads to denaturation and corresponding changes in three-dimensional structure, which in general leads to a better digestibility by the action of proteolytic enzymes in the human digestive system. Protein denaturation, on the other hand, also imposes a greater risk of rapid subsequent microbial contamination under poor hygienic or storage conditions, respectively, imposing the risk of food poisoning. Immunological properties of food proteins may be altered by heat denaturation as has recently been demonstrated with bovine β-lactoglobulin. Further, heat-denatured β-lactoglobulin was less efficiently transported than the native form.

26.3.2 COMPLEX CARBOHYDRATES

During thermal treatment, in the presence of water, starches, e.g. amylose and amylopectin undergo gelatinization and during subsequent cooling retrogradation, both processes greatly affect the digestibility of these compounds. The degree of gelatinization depends on temperature, proportion of water, and time of cooking. Gelatinized starches are digested much more rapidly than raw ones. With retrogradation resistant starches are produced which are poorly degraded by α-amylase and thus generally reach the large intestine, where microbial fermentation takes place. Resistant starches thus may affect the microbial flora composition and the microbial metabolism which may have consequences for gut health by changing for example the short-chain fatty acid patterns. Short-chain fatty acids (SCFA) and particularly butyrate are considered to be important substrates for colonic epithelial cells and relations between butyrate concentration and the risk for colorectal carcinogenesis have been observed. Thus foods which lead to a higher production of butyrate in the colon may have beneficial effects. Therefore the generation of resistant starches by thermal treatment of starchy foods may also be associated with beneficial nutritional and health effects.

26.3.3 FATS

The physicochemical properties of fats are highly affected by temperature. Unsaturated fatty acids (mono-unsaturated fatty acids: MUFA; poly-unsaturated fatty acids: PUFA) are rapidly oxidized in the presence of oxygen and in the absence of food antioxidants. Furthermore MUFA and PUFA may undergo isomerisation with heat treatment. Fat oxidation compounds in foods are nutritionally undesirable and have not been shown to have any beneficial effects.

26.3.4 AMINO ACIDS AND SUGARS

Amino acids either in free or in protein-bound form and sugars undergo Maillard-type reactions during thermal treatment and thus change the nutritional and sensory properties of food. Advanced glycation end products (AGE) in food have been demonstrated to show undesired nutritional and health effects, for example they seem to play a role in cellular signal transduction pathways involved in inflammatory processes, cell proliferation, tumor growth and metastasis.

26.4 ESSENTIAL MICRONUTRIENTS: VITAMIN AND MINERALS

In relation to micronutrients it is known since several decades that particularly the water-soluble vitamins are rapidly degraded by thermal treatment. Thus thermal treatment of foods may cause a nutritionally relevant decrease of heat-labile vitamin content. The magnitude of these thermal processing losses of course depends on the processing variables, e.g. temperature and exposure time. The processing related losses of vitamins are creating nutritional problems only for those vitamins where the recommended dietary intakes in the population or in population subgroups are not achieved, this is of particular importance in specific subgroups with a high requirement, for example folic acid supply in pregnant women. Folic acid is one of the heat labile vitamins and is rapidly destroyed with increasing temperature. Furthermore the bioavailability of folates from natural sources is highly variable and may depend on the food matrix structure and stabilizing factors in the food to reduce folate degradation for example by thermal treatment. Most nutrition societies promote a high consumption of fresh fruit and vegetables and also encourage the use of frozen vegetables which maintain a high level of vitamins if properly processed and stored.

On the other hand the bioavailability of minerals and trace elements may be enhanced by changes in the food matrix upon heat treatment. A recent human dietary intervention study investigating the bioavailability of selenium from various food sources, however, could not find a difference in apparent absorption or retention of selenium from either cooked or salted fish, respectively. In general, information is lacking on the effects of thermal treatment on the bioavailability of essential micronutrients in human nutrition.

26.5 THERMAL EFFECTS ON NON-NUTRIENTS

Non-nutrients are those bioactive compounds in food that do not seem to be essential for avoiding a specific disease or a clinical condition associated with a deficiency for a specific substance, e.g. a nutrient. However, non-nutrients may have important nutritional and biochemical functions by acting for example as antioxidants or having antimicrobial or anticarcinogenic properties. Thus the effects of thermal treatment on these food components are of importance and highly relevant to human health. There are a number of bioactive compounds in food and in the human diet, probably the largest group being the phytochemicals. Phytochemicals are secondary plant metabolites which are present in small and varying amounts in plants. Phytochemicals belong to different chemical classes among them carotenoids, flavonoids, isoflavonoids, phenolic acids, glucosinolates, monoterpenes, phytosterins, and saponins to name the most important and prominent classes.

26.5.1 POLYPHENOLS

Polyphenols are highly reactive compounds and good substrates for various enzymes, including polyphenoloxidases, peroxidases, glycosidases, and esterases. They undergo numerous enzymatic and chemical reactions during postharvest food storage and processing. The effects of thermal treatment on these compounds so far have not been studied in detail: Particularly the interactions between different bioactive compounds present in the same food during thermal treatment. Different polyphenols react differently to thermal treatment as has been shown for example in a study with virgin olive oils. Virgin olive oils contain hydroxytyrosol and tyrosol-like substances and they also contain the lignans 1-acetoxypinoresinol and pinoresinol. The lignans were much less affected by heating to 180°C for 25 hours, microwave heating for 10 minutes or boiling in a pressure cooker for 30 minutes than hydroxytyrosol and tyrosol-like substances. Thus thermal treatment differentially affects bioactive compounds present in the same food and thus very likely changes the nutritional characteristics of that food considerably.

26.5.2 ANTHOCYANINS

Anthocyanins are present in different fruits, particularly in berries, and vegetables. They are water-soluble plant pigments and they occur naturally as glycosides. The large variety of different anthocyanins results from the differences in glycosylation patterns. Some anthocyanins occur also in the acylated form, for example in the skin of red radishes or in purple carrots. Anthocyanidins, the aglycon forms of anthocyanins are chemically labile with respect to pH, temperature and oxidation. Anthocyanins are considered to be potent anti-oxidants, at least *in vitro*. However, several studies have investigated their bioavailability from different foods sources and have generally found a very low bioavailability. Thermal processing and high-pressure treatment was shown recently to have no effects on the stability of different anthocyanins from grape juices, but another study investigating the effects of processing on different strawberry products found a loss of 27–39% after pasteurization of juice or heating of nectar, respectively.

26.5.3 CAROTENOIDS

Carotenoids are also a large group of plant pigments. It is estimated that in nature about 500–600 different carotenoids exist. However, plants used for human nutrition contain only approximately 50 different carotenoids. The major carotenoids in the human diet are α- and β-carotene, lycopene, lutein and zeaxanthin. A general feature of carotenoids is their ability to quench singulett-oxygen and thus act as antioxidants. The main food sources of carotenoids are vegetables and fruits. In recent years the most studied carotenoids have been β-carotene, lycopene, and lutein. The most important dietary sources of lycopene are tomato and tomato products. Furthermore tomato products usually undergo intense processing including thermal treatment during their production. During thermal processing isomerisation of lycopene from *all-trans*-lycopene to *cis*-lycopene isomers occurs depending on the temperature and the time of heating. Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity; despite a decrease in vitamin C content with increased duration of processing at 88°C, lycopene content and total antioxidant activity increased. The bioavailability of lycopene has been shown to be much higher from processed tomato products (tomato paste) as compared to fresh tomato in a human dietary intervention study. These initial findings with tomato products have also been confirmed in a human dietary intervention study using lycopene-rich carrot products. It was found that lycopene uptake from carrots treated for 30 minutes at 130°C was increased 10-fold. A high consumption of tomatoes and tomato products leading to a high supply of lycopene has been shown in several epidemiological studies to be associated with a decreased risk of cancers and in particular of prostate cancer. Thus increasing the bioavailability of lycopene by thermal processing of tomatoes offers a great health benefits.

26.5.4 ISOFLAVONOIDS

Isoflavonoids, an example of bioactive phytochemicals and a group of compounds, are often also designated as phytoestrogens because of their structural similarity to human endogenous which has capacity to bind to human estrogen receptors. The main dietary isoflavonoids are genistein and daidzein and these compounds occur primarily in soy and soy products. Soy foods are traditional foods in Asian countries, particularly in Japan and China, however, in the past years they have become more and more accepted also in the Western world, particularly as a good source of vegetable protein as an alternative to animal protein. Soy protein has specific properties and a health claim in relation to cardiovascular health approved by FDA. The influence of thermal treatment on the stability of soy isoflavones, genistein and daidzein, was studied in model solutions. Rapid degradation of genistein and daidzein was observed at pH 7 and thermal treatment at 120°C for 20 minutes. It should be emphasized, however, that the degradation rates may be different in an intact food matrix as compared to a model system with isolated compounds.

26.6 OTHER THERMAL EFFECTS

The allergenicity of certain food allergens may be affected by thermal processing. Besides the allergens themselves, however, other modifying factors present in food may play an important role with respect to thermal treatment and heat inactivation of allergens. The presence of sugars in fruits may contribute to the thermostability of the allergenic activity of LTP (Lipid Transfer Protein) in heat-processed foods. In some foods, particularly in legumes, natural components such as lectins, amylase, and trypsin inhibitors are present that may adversely affect their nutritional properties. Because of their protein nature, enzyme inhibitors and lectins are inactivated under conditions leading to irreversible protein denaturation. Thus heat treatment may lead to the destruction of these antinutritional factors and thus may improve the nutritional quality of the respective foods.

26.7 CONCLUSION

The nutritional effects of thermal treatment of foods are very diverse. The effects of thermal treatment can be nutritionally beneficial for example by increasing the bioavailability of bioactive components from an altered food matrix. However, also some of these bioactive components, particularly water-soluble vitamins and some heat-sensitive phytochemicals, will be lost during heat treatment of foods. Although the heating of food has a very long history during the evolution of modern man still the knowledge about the nutritional consequences of chemical and physical changes in food induced by thermal processing are scarce. With the modern analytical methods, further understanding of the interactions between the various food components is become possible during thermal treatment and the respective consequences for nutrition and health.

Lesson 27. Changes undergone by the food components during Evaporation, Drying

27.1 INTRODUCTION

The primary objectives of evaporation, as a unit operation in food processing, are to reduce the volume of the product by some significant amount with minimum loss of nutrient components, and to preconcentrate liquid foods such as fruit juice, milk, and coffee before the product enters a dehydration process, thus saving energy in subsequent operations and reducing handling (transport, storage, and distribution) costs. Evaporation increases the solids content of a food and hence preserves it by a reduction in water activity; however, the flavour and colour of a food may be changed during the process. The technical simplicity of evaporation gives it an obvious advantage compared to other methods such as reverse osmosis and freeze concentration.

Drying differs from evaporating in that the former takes the food to nearly total dryness or the equivalence of 97 or 98% solids. The oldest method of drying food is to put the food under a hot sun. This practice probably started thousands of years ago. Although sun drying is still practiced, especially in many third world countries, modern food drying has been modified to a nearly exact science. Drying has multiple objectives:

- To preserve the food from spoilage
- To reduce the weight and bulk of the food
- To make the food enjoy an availability and consumption pleasure similar to that of canned goods
- To develop "new" or "novelty" items such as snacks.

Some well-known products prepared from drying include dried milk powder, instant coffee, fish and shellfish, jerky, dried fruits and dried potato flakes.

Dehydration is the removal of water from a product. The purpose of dehydrating (drying) is usually to improve the shelf life of the product, and thus dehydration is a unit operation of great importance to the food industry. During dehydration moisture content is reduced, the water activity of the product is also reduced. Once the water activity has dropped to about 0.6, the product is generally considered to be shelf stable. Products may be dried for other reasons; for example, to control texture properties such as crispness (biscuits), to standardize composition, and to reduce weight for transport. The most important reason, however, is control of water activity. Drying is expensive, since the energy required to remove water is high. In this chapter we will discuss the effects of evaporation and drying on quality of foods.

27.2 EFFECT OF EVAPORATION ON FOOD QUALITY

Nutritional changes take place during evaporation processing, the extent varying with the type of food, the process, the plant in use, and the degree of control exercised. Many losses are inevitable, particularly if the process involves heating.

- **VITAMINS:** Part of the water-soluble nutrients such as the B vitamins, together with lesser and less-important amounts of mineral salts, protein, and even carbohydrate will be precipitated out. Vitamin C is oxidized in air and accelerated by heat, whereas vitamins A and D and niacin are unaffected.

- **AROMA:** Aroma compounds that are more volatile than water will be lost during evaporation. With some products such as fruit juices, the retention of taste and aroma is important, yet in other foods such as cocoa and milk, the loss of unpleasant volatiles improves the product quality.

- **COLOUR:** The colour of foods darkens, partly due to an increase in the solids content and partly because the reduction in water activity promotes chemical changes like Maillard browning.

As these changes are time and temperature dependent, short residence times and low boiling points produce concentrates with higher qualities. For instance, the Centri-therm mechanical thin-film evaporator produces a concentrate that, when diluted, has sensory and nutritional qualities that are virtually unchanged from those of the feed material.

27.3 EFFECT OF DRYING ON FOOD QUALITY

Dehydration changes food products in several ways, affecting the organoleptic qualities of the product. Dehydration normally requires high temperatures, which can cause chemical reactions such as nonenzymatic browning, caramelization, and denaturation of proteins in the product. Drying also affects the physical parameters of the product, as removal of water causes shrinkage. Due to these changes, rehydration after drying may not restore the original product. Table 27.1 shows the major changes taken place in food during drying.

Table 27.1: Changes Taken Place in Food during Drying

Basis of reaction	Example and consequence
Physical	**Moisture movement:** causing drying and toughening of texture, hydration and softening of texture, aggregation
Chemical	**Oxidation:** causing oxidative rancidity, loss of colour Maillard reactions, causing discolouration, change in texture

Enzymatic	**Polyphenoloxidase:** causing enzymic browning **Lipoxygenase:** causing oxidative rancidity **Lipase:** causing lipolytic rancidity **Protease:** causing gelation and flavour and texture changes
Microbial	**Growth of spoilage organisms:** causing quality deterioration **Growth of toxigenic organisms:** causing food poisoning **Presence of infectious organisms:** causing food poisoning

Many biochemical reactions can be induced by temperature increase in foods during drying: Maillard reactions, vitamin degradation, fat oxidation, denaturation of thermally unstable proteins (resulting in variation of solubility or of the germinating power of grains), enzyme reactions (which can either be promoted or inhibited), and so on. Some of these biochemical reactions generate components suitable, for example, for their sensory properties (flavor development); others may be more or less undesirable for nutritional or potential toxicity reasons (vitamin losses, changes in color, taste or aroma, formation of toxic compounds). All the reactions are linked to the factors like product composition, temperature and water content.

27.3.1 PHYSICAL QUALITY

Physical properties such as colour, texture, density, porosity, and rehydration capacity are affected by the drying method. A tough and woody texture, slow and incomplete rehydration, and loss of the typical fresh food juiciness are the most common defects encountered during drying. The physicochemical basis for these changes is complex, and its understanding requires tedious lab measurements.

27.3.1.1 COLOUR

Colour is a major quality parameter in dehydrated food. During drying, colour may change because of chemical or biochemical reactions. Enzymatic oxidation, Maillard reactions, caramelization, and ascorbic acid browning are some of the chemical reactions that can occur during drying and storage. Discolouration and browning during air drying may be the result of various chemical reactions including pigment destruction.

27.3.1.2 SHRINKAGE, POROSITY, AND BULK DENSITY

One of the most important physical changes that foodstuffs undergo during drying is the reduction of their volume, often called shrinkage. Shrinkage is caused by structural collapse attributable to the loss of water. Changes in shape and size, loss of rehydration capacity, surface cracking, and hardening of food materials are among the most important physical phenomena associated with shrinkage.

Porosity and bulk density are important physical properties in dried foods. These two properties play an important role in rehydration of dried materials and their handling and packaging aspects. The extent of shrinkage influences the resulting changes in porosity during drying. The bulk shrinkage and the porosity changes were related to moisture content of dried foods. Porosity in fruits and vegetables increases during drying, depending on the initial moisture content, composition, and size, as well as the type of drying method employed.

27.3.1.3 CASE HARDENING

Case hardening occurs when rapid drying causes compounds such as sugars to form a hard, fairly impermeable case around the food piece. This phenomenon can cause the rate of dehydration to decrease. Case hardening can occur in high-sugar products such as tropical fruit and many temperate fruit products. Dehydration procedures are designed to minimize the development of case hardening as much as possible.

27.3.2 MICROBIOLOGICAL AND CHEMICAL QUALITY

Dehydrated foods are preserved because their water activity is at a level where no microbiological activity can occur and where deteriorative chemical and biochemical reaction rates are reduced to a minimum. Reducing water activity below 0.7 prevents microbiological spoilage. Most oxidation reactions and enzyme reactions will be inhibited as water activity decreases. However, auto oxidation of lipids could take place at very low water activity values 0.2. The maximal rate of nonenzymatic browning reactions (Maillard reaction) is achieved at intermediate water activity values (0.4 to 0.65). These reactions result in the loss of nutritive value, formation of brown pigments, as well as the formation of off-flavours, especially when the products are stored at high temperatures. Dried products are considered to be more stable at their monolayer moisture content.

27.3.3 NUTRITIONAL QUALITY

Nutritional quality of food can be affected by handling, processing, and packaging. Aside from physical and chemical changes, drying can also cause loss of nutritional value. The major losses of vitamins and other substances take place because of solubility in water, enzymatic oxidation, oxygen and heat sensitivity, and metal ion catalysis during processing. In addition, sugar–amine interactions (Maillard reaction) can occur during drying and storage, causing loss of nutrients. All these losses in food can be reduced by: pretreatments, proper selection of drying methods, new and innovative drying methods, and optimization of drying conditions.

27.3.3.1 CHANGES IN PROTEIN

The biological value of protein is dependent on the method of drying. Prolonged exposures to high temperatures can render the protein less useful in the dietary. Low temperature treatments of protein may increase the digestibility of protein over native material. Milk proteins are partially denatured during drum drying, and these results in a reduction in solubility of the milk powder, aggregation and loss of clotting ability. At high storage temperatures and at moisture contents above approximately 5%, the biological value of milk protein is decreased by Maillard reactions between lysine and lactose. Lysine is heat sensitive and losses in whole milk range from 3-10% in spray drying and 5-40% in drum drying.

27.3.3.2 CHANGES IN LIPID

Rancidity is an important problem in dried foods. The oxidation of fat is greater at higher temperature than at low temperature of dehydration. Protection of fat with antioxidant is an effective control.

Lipid oxidation is responsible for rancidity, development of off flavours, and the loss of fat soluble vitamins and pigments in many foods, especially in dehydrated foods. Factors that affect oxidation rate include moisture content, type of substrate (fatty acid), extent of reaction, oxygen content, temperature, presence of metals, presence of natural antioxidants, enzyme activity, ultraviolet light, protein content, free amino acid content, other chemical reactions. Moisture plays an important part in the rate of oxidation. The elimination of oxygen from foods can reduce oxidation, but the oxygen concentration must be very low to have an effect. The effect of oxygen on lipid oxidation is also closely related to the product porosity. Freeze - dried foods are more susceptible to oxygen because of their high porosity. Air-dried foods tend to have less surface area due to shrinkage and thus are not as affected by oxygen. Minimizing the oxygen level during processing and storage, and addition of antioxidants as well as sequestering agents, has been recommended in the literature to prevent lipid oxidation.

27.3.3.3 CHANGES IN CARBOHYDRATE

Fruits are generally rich sources of carbohydrates, poor sources of proteins and fats. The principal deterioration in fruits is in carbohydrates. Discoloration may be due to enzymatic browning, or to caramelization types of reactions. In the latter instances, the reaction of organic acids and reducing sugars causes discolorations noticed as browning. The addition of sulphur dioxide to tissues is a means of controlling browning. Carbohydrate deterioration is most important in fruit and vegetable tissues being dried. Slow sun drying permits extensive deterioration unless the tissues are protected with sulphates, or suitable agents.

27.3.3.4 CHANGES IN VITAMINS

Vitamins have different solubility in water, and, as drying proceeds, some (e.g., riboflavin) become supersaturated and precipitate from solution. Losses are therefore small. Others, (e.g., ascorbic acid) are soluble until the moisture content of the food falls to very low levels and react with solutes at higher rates as drying proceeds. Vitamin C is also sensitive to heat and oxidation. Short drying times, low temperatures, and low moisture and oxygen levels during storage are necessary to avoid large losses. Thiamin is also heat sensitive, but other water-soluble vitamins are more stable to heat and oxidation, and losses during drying rarely exceed 5—10% (excluding blanching losses).

Oil-soluble nutrients (e.g., essential fatty acids and vitamins A, D, E, and K) are mostly contained within the dry matter of the food and they are therefore concentrated during drying. However, water is a solvent for heavy-metal catalysts that promote oxidation of unsaturated nutrients. As water is removed, the catalysts become more reactive, and the rate of oxidation accelerates. Fat-soluble vitamins are lost by interaction with the peroxides produced by fat oxidation. Losses during storage are reduced by low oxygen concentrations and storage temperatures and by exclusion of light.

27.4 CONCLUSION

Evaporation and drying plays an important role in food preservation despite having some desirable and undesirable changes taken place during both the processes. But these changes can be avoided by employing appropriate process handling of foods during evaporation and drying. More profound knowledge of the changes in the properties of foods that occur with processing is needed for the design of better drying methods that preserve desirable characteristics and minimize or eliminate undesirable ones.

Lesson 28. Changes undergone by the food components during Freezing

28.1 INTRODUCTION

One of the greatest challenges for food technologists is to maintain the quality of food products for an extended period. The principles of low-temperature preservation have been employed for many years. It renders advantageous negative effect of reduced temperature on various chemical and biochemical reactions responsible for food spoilage, as well as on microbial growth and spore germination. Freezing is a well-known long-term preservation process widely used in the food industry. This is because changes in the nutritional or sensory characteristics of foods are small if appropriate freezing and storage procedures are followed. The freezing of foods normally consists of pre-freezing treatments, freezing, frozen storage, and thawing, each of which must be properly conducted to obtain optimum results. A decrease in temperature generally decreases the rate of chemical reactions that are responsible for the deterioration in food quality over time; therefore freezing is frequently used to extend the shelf life of food products. When a product is frozen, the formed ice crystals may cause cell rupture and alterations in the transport properties of cell membranes, which have practical consequences in terms of leaching of cellular substances from tissues as well as water loss, leading normally to disappointing consequences in terms of texture. There is a general acceptance that high freezing rates retain the quality of a food product better than lower freezing rates since evidence tends to show that relatively slow freezing causes large ice crystals to form exclusively in extracellular areas, while high freezing rates produce small uniformly distributed ice crystals. The formation of ice may result in textural changes and disruption of cell compartments that cause the release of chemically reactive components. Furthermore, the removal of water during ice formation concentrates the solutes in an unfrozen matrix, which can affect reaction conditions, such as pH and ionic strength. Therefore in order to extend the shelf life of frozen food products, it is crucial to understand the chemical reactions that can occur in food components that can lead to quality deterioration.

28.2 EFFECT OF FREEZING ON PRINCIPAL CONSTITUENTS OF FOODS

The effect of freezing on the food components is diverse, and some components are affected more than others. For example, protein can be irreversibly denatured by freezing, whereas carbohydrates are generally more stable. Other common chemical changes that can proceed during freezing and frozen storage are lipid oxidation, enzymatic browning, flavour deterioration, and the degradation of pigments and vitamins. The main goal of the freezing process is to extend the shelf life of a raw material or product beyond that achievable at temperatures above the initial freezing point of the material. Therefore, it is important to understand the modifications that can occur during freezing in food components and that can further lead to quality degradation. This chapter focuses on chemical and biochemical reactions that affect the quality of frozen food systems. These reactions and specific examples in food are summarized in Table 28.1.

Changes that occur in foods during freezing, storage and thawing can be both chemical and physical in nature. Various chemical, enzymatic and physical changes are promoted as a result of the concentration of components (concentration effects) in the unfrozen water phase within the frozen foods. For example:

- Chemical changes such as oxidative rancidity or oxidation of flavour components, pigments and vitamins.
- Enzymatic reactions such as enzymatic browning or lipolytic rancidity.
- Meats become tougher due to protein denaturation by chemical effects and cell breakage by ice crystals

In freezing foods, the objective is to promote the formation of tiny ice crystals rather than the formation of fewer but larger ice crystals that cause cellular damage. Ice crystal damage can lead to loss of water from the food product once it is thawed. The drip that is found in thawed strawberries or beef is due in part to ice crystal damage to the cells, leading to leakage of cellular fluids into extracellular spaces, and to the loss of water-holding capacity of food components as a result of concentration effects.

Other undesirable changes include formation of package ice and freeze dehydration which is popularly called freezer burn and can produce unsightly food surfaces and loss of nutrients. "Freezer burn" is a misnomer since the food does not "burn" in the freezer but rather takes on an appearance of having been burned because of the moisture loss that occurs during this freeze dehydration.

28.2.1 WATER

Water is an essential constituent of most foods. It is present in a very wide range, varying, for example, from 4% in milk powder up to 95% in tomato and lettuce. Water may exist as an intracellular or extracellular component in vegetable and animal products, as a dispersing medium or solvent in a variety of products, as the dispersed phase in some emulsified products such as butter and margarine, or as a minor constituent in other foods. The conversion of water into ice during freezing has the advantage of fixing the tissue structure and separating the water fraction in the form of ice crystals in such a way that water is not available as a solvent or cannot take part in deterioration reactions. On the other hand, ice crystals formed during freezing can affect quality parameters such as color, texture, and flavor. Meanwhile, in the remaining unfrozen portion, the concentration of dissolved substances increases, while the water activity of a product decreases. Usually, this part of water is non-freezable and, therefore, not available for chemical reactions or as plasticizers. The water that does not freeze is normally considered to be the critical water content above which deteriorative changes may occur. Critical water is a rather unusual substance having high boiling and low freezing points, high specific heat, high latent heats of fusion and vaporization, high surface tension, high polarity, and unusual density changes. The considerable difference in the densities of water and ice may result in structural damage to foods when they are frozen, being more likely in plant tissue with its rigid structure and poorly aligned cells than in muscle with its pliable consistency and the parallel arrangement of cells.

Table-28.1: Chemical Reaction of Food Components during Freezing that Affect Food Quality

Food Components	**Mechanism of degradation**	**Effect on quality**	**Studies in food**
Protein	Denaturation	Degradation of texture and functional properties	Toughening and functional changes, particularly loss of protein solubility in fish, Loss of protein solubility, emulsifying capacity Loss of water holding capacity of meat for processing
Lipid	Hydrolysis	Release of FFA—known to contribute to unpleasant flavours	Short chain FFA giving rancid odour in dairy product Medium chain FFA caused a ''sweaty'' flavour in mutton Toughening of muscles in frozen Indian sardine
	Oxidation Autoxidation Enzymatic oxidation	Unstable hydroperoxides break down to reactive compounds and interact with other components to produce off flavours, discoloration, and toughening of muscle	Off-flavours shelled oysters Detection of rancid flavour in silver pomfret

		protein	
Carbohydrates	Hydrolysis	Increases the amount of smaller molecular weight components—leads to lower melting temperatures Change of texture	Sucrose hydrolysis Firmness of ice cream decreased as hydrolysis progressed
Colour pigments (a) Chlorophyll	Pheophytinization	Green chlorophyll forms olivebrown pheophytin in the presence of acid or heat	Greenness in Brussels sprouts decreased Stability of green colour in kiwifruit Frozen blanched spinach had a higher amount of pheophytin than fresh
(b) Anthocyanin	Enzymatic reaction Structure of	Glucosidase hydrolyses glycosidic linkages and produces sugars and aglycone compounds Depending on the pH of the food, different forms of	Loss of anthocyanin in raspberry in the late cultivar was more severe than the early cultivars Red colour hue of sour cherry weakened during frozen storage

	anthocyanin depends on pH value	anthocyanin exist, usually from red to blue as pH increases	
(c) Carotenoids	Oxidation	The loss of pigments causes fading of colour and loss of nutritive value	Loss of carotenoid in salmon
Flavour compounds	Enzymatic degradation Lipid oxidation Leaching of components during the blanching process	Change of flavour profile Produces off-flavours Weakens and changes the sensory Perception	Change in the composition of aromatic compounds of strawberries Change in aroma profile of frozen green peas Green and fatty off-flavour notes in frozen trout due to breakdown products of unsaturated FFA Decrease of organic acids in green beans and Padron peppers Change in volatile composition of guava Effect of heat Changes in concentration of odorants during heat treatment

	Effect of heat		
Micronutrients (a) Vitamins (b) Minerals	Oxidation Generally stable Loss mainly through leaching	Loss of nutritional value because of the loss of vitamins	Loss of vitamins C and B6 due to blanching in french fries Oxidation of AA in peas, lima beans, corn and green beans Unchanged mineral composition in artichokes, green beans, and peas after freezing Mineral content of boiled fresh vegetables was not different from frozen vegetables

When water freezes at atmospheric pressure, it expands nearly 9%. The degree of expansion varies considerably owing to the following factors:

- **Moisture content:** Higher moisture contents produce greater changes in volume.
- **Cell arrangement:** Intercellular air spaces, which are common in plant tissue. These spaces can probably accommodate growing crystals, and thereby minimize changes in the specimen exterior dimensions; for example, whole strawberries increase in volume by 3%, whereas coarsely ground strawberries increase by 8.2%, when both are frozen to −20°C

- **Concentration of solutes:** High concentrations reduce the freezing point and do not freeze or expand at commercial freezing temperatures.
- **Freezer temperature:** It determines the amount of unfrozen water and hence the degree of expansion.
- **Crystallized components:** It includes ice, fats, and solutes, which contract when they are cooled; this reduces the volume of food.

28.2.2 PROTEINS

Proteins may undergo changes during freezing and frozen storage, primarily because of denaturation. Denaturation can be defined as a major change in the native structure that does not involve alteration of the amino acid sequences and usually involves the loss of biological activity and significant changes in some physical or functional properties such as solubility. Oxidative processes during storage can also contribute to protein denaturation; oxidizing agents (e.g., enzymes, transition metals) can react with proteins via lipid and nonlipid radicals. For example, the addition of malonaldehyde, a commonly occurring product of lipid oxidation, to trout myosin solutions during storage at −4°C was found to accelerate protein denaturation. Fish protein is particularly sensitive to denaturation where the protein develops cross links between adjacent protein molecules that effectively stop the thawed fish protein to reabsorb water to recreate the pre-frozen gel structure. This denatured protein has a much tougher and rubbery texture than the native protein. The textural changes that occur in fish proteins have been attributed to changes in the myofibrils. The rate at which fish or beef muscle is frozen also influences the degree of protein denaturation. Although rapid freezing generally results in less denaturation than slower freezing, intermediate freezing rates can be more detrimental than slow freezing, as judged by textural changes and the solubility of actomyosin. For example, cod fillets frozen at intermediate rates developed intracellular ice crystals large enough to damage the cellular membranes.

Freezing and frozen storage do not significantly affect the nutritional value of meat and fish proteins. However, on thawing frozen meat and fish, substantial amounts of intra- and extracellular fluids and their associated water-soluble proteins and other nutrients may be lost (the so-called drip loss). The volume of drip loss on thawing of meat and fish is highly variable, usually of the order of 2%–10% of net weight; however, in exceptional circumstances, up to 15% of the weight of the product may be lost. Nevertheless, it was observed for fish that if the product is stored for an appropriate short time and at a sufficiently low temperature, the subsequently thawed fish would rehydrate with the protein returning to its original gel condition. The caseinate micelles of milk, which are quite stable to heat, may also be destabilized by freezing. On frozen storage of milk, the stability of caseinate progressively decreases and this may lead to complete coagulation. Enzymes have also been linked to protein denaturation, as it is known that low temperature decreases the activity of enzymes in tissue, but does not inactivate them.

28.2.3 LIPIDS

Lipids in food exhibit unique physical and chemical properties. Their compositions, crystalline structure, melting properties, and ability to associate with water and other nonlipid molecules are especially important to their functional properties in many foods. During processing, storage, and handling of foods, lipids undergo complex chemical changes and react with other food constituents, producing numerous compounds both desirable and deleterious to food quality. The process of auto oxidation and the resulting deterioration in flavor of fats and fatty foods are often described by the term rancidity. In particular, the unsaturated bonds present in all fats and oils represent active centers that, among other things, may react with oxygen. This reaction leads to the formation of primary, secondary, and tertiary oxidation products that may make the fats or fat-containing foods unsuitable for consumption.

Lipids can degrade in frozen systems by means of hydrolysis and oxidation. Lipid oxidation is indeed one of the major causes of food spoilage. It is of great economic concern to the food industry because it leads to the development of various off flavors and off-odors. In addition, oxidative reactions can decrease the nutritional quality of foods. Lipids in foods can be oxidized by both enzymatic and non enzymatic mechanisms. One of the enzyme that is considered important in lipid oxidation is lipoxygenase, which has recognition for its off-flavor development in vegetable. Lipoxygenase is the main enzyme responsible for pigment bleaching and off-odors in frozen vegetables; if the enzyme is not inactivated before freezing by blanching, it can generate offensive flavors and loss of pigment color. At temperatures below −10°C, both enzymatic and non enzymatic reactions associated with lipid oxidation are decelerated. However, in the range from 0°C to −10°C, decreased oxidative stabilities have been noted. Unless the rate is very slow, the rate of freezing has been found to have little influence on the oxidative stability of frozen products. Instead, storage temperatures play a dominant role in dictating the stability of food products, including muscle foods. The order of time/temperature holding treatments, on the other hand, markedly influences the development of rancidity. The hydrolysis of lipids or lipolysis results in the release of free fatty acids. Freezing can facilitate lipid oxidation, partly because the competing reactions of microbiological spoilage are avoided and partly because of the concentration effects. Thus, lipid oxidation is relatively more important in frozen muscle tissue than in fresh tissue. Lipid degradation can be reduced in frozen foods by lowering the storage temperature, excluding oxygen (e.g., use of vacuum packaging), adding antioxidants (e.g., butylated hydroxytoluene or BHT as well as natural vitamin E), and supplementing the diet of animals with antioxidants.

28.2.4 VITAMINS

Freezing is considered as one of the best food preservation methods when judged on the basis of nutrients retention. However, it is well known that significant amounts of some vitamins can be lost from processing prior to freezing (e.g., peeling and trimming, leaching especially during blanching), chemical degradation, and thawing. The stability of vitamins in foods is generally influenced by pH and the presence of oxygen, light, metals, reducing agents, and heat. It has been reported that for some frozen foods such as strawberries, the total and biologically active ascorbic acid remain at essentially the same level for a year or longer if the foods are stored below −18°C, although vitamin C losses have also been found to occur at temperatures as low as −23°C. The conversion to the partially active dehydroascorbic acid and the totally inactive 2,3-diketogulonic acid increases with increasing storage temperature; complete conversion practically occurs in 8 months at −10°C and in less than 2 months at −2°C. Such findings were instrumental in establishing −18°C as the upper limit for frozen food storage and for using biologically active ascorbic acid as a general indicator of quality deterioration during frozen storage. For peaches and boysenberries, a 10°C rise in the temperature from −18°C to −7°C caused the rate of vitamin C degradation to increase by a factor of 30–70. Vitamin C and thiamine (vitamin B1) have been studied extensively since they are water soluble, highly susceptible to chemical degradation, and present in many foods; they are also required in the diet and are sometimes deficient in the diet. Therefore, it is generally assumed that if these vitamins are retained, all other nutrients would also be well retained.

28.2.5 CARBOHYDRATES AND MINERALS

Carbohydrates occur in plant and animal tissues in many different forms and levels. In animal organisms, the main sugar is glucose and the storage carbohydrate is glycogen; in milk, it is almost exclusively the disaccharide lactose. In plant organisms, approximately 75% of the solid matter is carbohydrate. The total carbohydrate content can be as low as 2% of the fresh weight in some fruits or nuts, more than 30% in starchy vegetables, and over 60% in some pulses and cereals. In plants, the storage carbohydrate is starch, while the structural polysaccharide is cellulose. The nutritive value of carbohydrates is not significantly affected during handling of fresh foods and the subsequent processing and distribution of frozen foods. In general, carbohydrates are susceptible to hydrolysis during frozen storage, which can still occur at temperatures as low as −22°C. Like B vitamins and proteins, carbohydrates are less affected by process and more by loss through drip following a freeze–thaw cycle. Sugar hydrolysis increases the number of solutes in the food matrix, resulting in a reduction in the amount of ice in the product, which may alter certain physical properties; for example, the firmness of ice cream was found to inversely relate to the degree of hydrolysis. Blanching and freezing can cause changes in texture and the pectic composition of certain foods. Both treatments produce a gradual breakdown in the protoplasmic structure organization, with a subsequent loss of turgor pressure, release of pectic substances, and final softening effect.

Minerals present in any form (e.g., chemical compounds, molecular complexes, and free ions) can dramatically affect the color, texture, flavor, and stability of foods. Minerals are chemically stable under typical conditions of handling and processing, and nutrient losses are negligible, provided that losses by physical means (e.g., leaching) are avoided. Nevertheless, no changes were observed in six mineral elements (Ca, Cu, Mg, Mn, Ni, and Zn) between fresh and frozen artichokes, green beans, and peas; boiled fresh vegetables and boiled frozen vegetables also exhibited similar mineral contents.

28.3 CONCLUSION

Freezing is complex process involving physical and chemical changes that might greatly affect the food quality. Further to minimize the changes in food components during freezing it is imperative to to freeze a product quickly to –18°C and store it at the same temperature throughout the cold chain.

Lesson 29. Changes Undergone By Fruit Components During Extraction, Filtration and Membrane Processing

29.1 INTRODUCTION

Fruit and fruit products are very delicate in nature i.e. they are very susceptible to the physicochemical changes taken place after harvesting process. Typical fruit juice manufacturing process mainly involves three steps i.e. extraction, clarification and concentration. Juice extraction can be performed by pressing or by enzymatic treatment followed by decanting. The extracted juice will then be treated according to the characteristics of the final product. For cloudy juices, further clarification might not be necessary or may involve a coarse filtration or a controlled centrifugation to remove only larger insoluble particles. For clear juices, complete depectinization by addition of enzymes, fine filtration, or high speed centrifugation will be required to achieve visual clarity. For a concentrate, the juice is fed to an evaporator to remove water until the desired concentration level is obtained. Other processes used for water removal include reverse osmosis and freeze concentration, which are best suited for heat-sensitive juices. The concentrate is then ready for final processing, packaging, and storage.

29.2 CHANGES IN FRUIT JUICE COMPOENTS DURING PROCESSING

29.2.1 EXTRACTION PROCESSE OF FRUIT JIUCES

Extraction process involves extraction of nutritionally important components from fruit without much change in its chemical and physical state. Once the fruit is delivered for processing, the critical operation of juice extraction begins. In general, juice extraction should be done as rapidly as possible so as to minimize oxidation of the juice by naturally present enzymes. The oxygen absorbed in the juice during extraction operations leads to oxidation of ascorbic acid and many oxidation induced changes in extracted fruit juice like aroma or flavour changes. Pectic substances released during fruit juices extraction causes a considerable increase in their viscosity, thereby impeding filtration and subsequent concentration processes.

29.2.2 CONVENTIONAL FILTRATION PROCESS OF FRUIT JUICES

Raw fruit juice is turbid, viscous, and dark in colour. Apart from lower molecular weight components like sugar, acid, salt, flavour, and aroma compounds, it contains significant amounts of macromolecules (100–1000 ppm) such as polysaccharides (pectin, cellulose, hemicellulose, and starch), haze-forming components (suspended solids (SSs), colloidal particles, proteins, and polyphenol), etc. Hence, the juice needs to be clarified before its commercial use. Clarification involves the removal of such macromolecules. An enzyme treatment of raw juice is usually carried out with enzymes (pectinase and amylase) to reduce the pectic substances and starch content. This enzyme treatment reduces the cloudiness and makes the filtration process easier by lowering its viscosity. The enzyme treatment is followed by the addition of fining agents such as gelatin, bentonite, etc., which are used to enhance the settling of formed flocks. Then, suspended solids, colloidal particles, proteins, etc., are removed by conventional filtration. These conventional methods to clarify fruit juice are labour intensive, time-consuming, and batch operated. The use of additives (fining agents and filter aids) may leave a bitter taste in the juice. Moreover, the solids obtained after filtration, which contain enzymes, filter aids, and fining agents, cannot be reused and cause pollution problems due to their disposal.

29.2.3 MEMBRANE PROCESSING OF FRUIT JIUCES

In this regard, microfiltration (MF) and ultrafiltration (UF) are considered as energy-efficient and valid alternative membrane processes for the clarification of additive-free high-quality fruit juices with natural fresh taste. The objective of UF/MF of fruit juice is to retain high molecular weight pectin and its derivative, proteins, colloids, etc., and to allow low molecular weight solute-like sugars, acid, salt, etc., to permeate through the membrane together with water. These processes are non-thermal and involve no phase change or addition of chemicals. The production of concentrated fruit juices is of interest at the industrial level since it reduces the storage volume, thus reducing the package, transportation, and storage cost, and also facilitates the preservation. The concentration of fruit juices is usually carried out in a multistage vacuum evaporator. However, high-energy consumption, off-flavour formation, colour changes, and reduction of nutritional value due to thermal effects are the main disadvantages of traditional evaporation processes. Alternative techniques to thermal evaporation to obtain stable concentrated juice with its original colour, aroma, nutritional value, and structural characteristics involve freeze concentration (cryoconcentration) and membrane processes. Reverse osmosis (RO) seems to overcome some of the drawbacks associated with thermal evaporation with less energy consumption; however, it is generally used as a pre-concentration technique allowing concentration values of about 25–30 °Bx due to high osmotic pressure limitations. Recently, direct osmosis concentration (DOC), osmotic distillation (OD), and membrane distillation (MD) have been proposed as attractive membrane processes allowing very high concentrations (above 65 °Bx) to be reached under atmospheric pressure and ambient temperatures. Considerable research has been carried out for the clarification and concentration of a variety of fruit juices including apple, mosambi, pineapple, grapefruit, kiwi, passion fruit, etc. There are three primary areas where membranes can be applied in processing of fruit juices:

- **Clarification:** for example, in the production of sparkling clear beverages using microfiltration or ultrafiltration
- **Concentration:** for example, using reverse osmosis to produce fruit juice concentrates of greater than 42° Brix
- **Deacidification:** for example, electrodialysis or nanofiltration to reduce the acidity in citrus juices.

Membrane technology is a novel and emerging separation technology. Membrane-based separation processes have the following advantages:

- Continuous separation processes
- Energy consumption is generally low
- Easily combined with other separation processes
- Operated at room temperature
- Up-scaling is easy
- No additives are required
- No physical or chemical changes required to feed streams

However the following disadvantages are worth noting:

- Concentration polarization
- membrane fouling
- Low membrane life time
- Low selectivity

The ranges of membrane processes can be used based on size of fruit juice components. RO is mainly used to concentrate the fruit juices by dewatering. MF and UF are used for clarification of juices by removing large suspended particles and colloids. Nanofiltration (NF) can be used to clarify and concentrate juice as well as to decolorize the juices. All processes remove the microorganisms to a great extent.

Many changes take place during the membrane processing of fruit juice, but most of them are comparable with respect to the changes during traditional filtration process. Many changes like browning of juices, colour changes, aroma and nutritional losses of fruit juices can be avoided by membrane filtration. Further, membrane process produces the clear juice without haziness along with retention of enzymes like pectinase and polyphenoloxidases (PPO) which otherwise leads to browning of fruit juice during processing.

29.2.3.1 MICROFILTRATION AND ULTRAFILTRATION

Among all membrane filtration processes, microfiltration is the closest to an ordinary filter. Microfiltration (MF) can be used as pre-filtration process to remove the bacteria from fruit juice. The most suitable application of MF and UF in fruit juice processing is removal of pectin from juice with the help of pectic enzyme to avoid clouding of fruit juice. The removal of large suspended particles and colloids are considered as key changes taking place during MF and UF of fruit juice. Advantages of MF and UF over traditional processing include production of clear juice with retention of depectinized enzymes which can be recycled for further use in fruit juice processing.

29.2.3.2 NANOFILTRATION

The mechanism of separation for Nanofiltration (NF) is not fully understood, but possibly works both on size exclusion like MF and UF, and on solution diffusion like RO. NF can be used to clarify and concentrate juice as well as to decolorize juices. Another major change during NF of fruit juice is loss or rejection of polyvalent ions to a much greater extent than monovalent ions.

29.2.3.3 REVERSE OSMOSIS

The main function of RO in fruit juice processing is to removal of water without phase change and thereby energy is used more efficiently. The beneficial effect of using RO for fruit juice processing is lying with minimum heat damage to color, aroma and viscosity characteristics of juice. Further the retention of volatile flavor compounds, better preservation of organoleptic and nutritive properties are main advantages of RO for fruit juice processing.

29.3 CONCLUSION

Membrane processing of fruit juice is considerably increasing field of interest. Membrane processing preserves the fruit juice components with minimal changes in their inherent quality. Furthermore, thermal labile nature of many food components clearly suggests that non thermal membrane technologies would be much better alternative for the food/ agricultural engineers.

Module 9. Plant utilities requirement.

Lesson 30. Compressed Air, Water And Steam

30.1 INTRODUCTION:

Dairy and Food plant have different requirements to run the plant. Different machineries need different engineering services for smooth running. We can classify utilities in major five parts, compressed air, Water, Steam, Refrigeration system and Electricity.

30.2 Compressed Air:

The dairy and Food industry has an extensive requirement for advanced instruments and equipment for automatic control, monitoring and regulation of the different production processes. Compressed air also has other applications such as powering the actuators on some machines, such as filling machines, emptying product from pipes, agitation in storage tanks and, operating compressed air tools in the workshops. Pneumatically controlled automatic systems have proved reliable in industry and are frequently used. The reliability requires compressed air free from impurities, which places demand on the design of the compressed air system.

30.2.1 Requirements of compressed air:

1. Compressed air, used for pneumatic tools, etc should be free from solid particles and as dry as possible. The supply pressure should be approximately 600 kPa.

2. Compressed air which does not come into contact with the product, used for the control of instruments and as source of power to active pneumatic components and valves etc. must be clean, dry, and preferably oil-free which supply at a pressure between 500 and 600 kPa (5 – 6 bar).

3. Compressed air which comes into direct contact with the product should be clean, oil-free, dry, odorless and practically sterile. Such quality of air is used in relatively small quantity. The supply pressure should be between 200 and 300 kPa (2-3 bar).

30.2.2 Compressed Air Production:

Air compressors are used to provide the compressed air. A compressor will usually consumes its purchase price in electricity consumption every year and therefore selecting and efficiently operating the correct type of compressor for the application can substantially reduce operating costs. Installing a control sequencing system on multiple compressors will help the system to respond more efficiently to varying loads. Variable-speed compressors can reduce power with reduced demand.

The Compressed air system consists of intake air filters, compressors, inter-state coolers, air dryers, moisture drain traps, receivers, regulators and piping network. Compressor is the main component of the compressed air system. The performance of the compressed air supply system depends on the type of the compressor, selection of components, and maintenance aspects of the system.

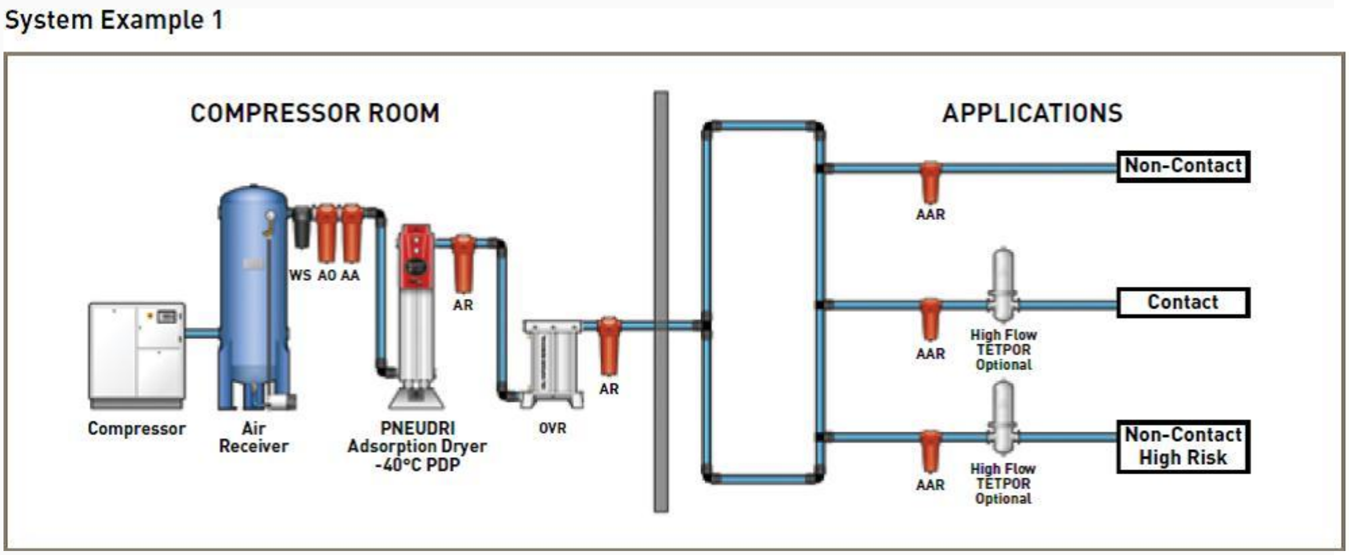


Figure 30.1: Schematic diagram of Compressed air producing unit

30.2.3 Compressor:

Reciprocating kind of compressors is widely used in compressed air generation. Depending upon the engineering aspects there are lubricating or non-lubricating, single or multiple cylinders, water cooled or air cooled. Single cylinder compressor is generally air cooled, while multiple cylinder compressors are water cooled. Water cooled compressors are more efficient than air cooled systems. Two stage compressors are used for high pressure and are characterized by lower discharge temperature. Multistage compressors may have lower specific power consumption compared to single stage compressor operating over the same total pressure difference. Among rotary compressor, screw compressors are widely used in dairy and food industry. Centrifugal compressors are better suited for application requiring very high capacities.

Compressor Performance:

Compressor efficiency can be evaluated as:

$$\text{Isothermal efficiency} = \frac{\text{Isothermal Power}}{\text{Actual Measured Input Power}}$$

$$\text{Volumetric efficiency} = \frac{\text{Free Air Delivered, } m^3/\text{min}}{\text{Compressor Displacement, } m^3/\text{min}}$$

For practical purpose, the most efficient guide in comparing compressor efficiency is the specific power consumption (kW/Volume flow rate).

Capacity of compressor is the rated volume of flow of gas compressed and delivered. The compressor capacity can be evaluated by the following formula,

Considering isothermal compression,

30.2.4 Receiver:

The air receiver should be sized to give large cooling surface and even out the pulsation in air delivery. The minimum size of the receiver should be such that it can store the air equal to one minutes continuous output of the compressor. Another approximation can be to size the receiver volume to be 5% of the rated hourly free air output.

30.2.5 Air Dryer:

Air which has been compressed in a compressor will contain a great deal of water. It will also be hot (about 140 – 150 ^{0}C) and must therefore be cooled. For this purpose, it passes through an after cooler, where most of the water is precipitated by means of cooling with water. The compressed air then continues to a cooler-drier, where further cooling takes place until a dew point of about of 2 ^{0}C is reached.

30.2.6 Traps/ Moisture Separator:

The traps will be installed in air lines at all low points and dead ends to remove condensed moisture.

30.2.7 Piping System:

The piping system will be designed for a maximum allowable pressure drop of 5% from the compressor to the most distinct point of use. The piping system should be arranged in a closed loop to allow more uniform pressure distribution.

Sterile air is obtained by filtering the compressed air in sterile filters. The filter element of these filters consists of chemically pure cotton. Micro-organisms are killed as the air is heated in the compressor. Reinfection occurs in the pipes, and the sterile filters are therefore fitted immediately before the equipment where the air is used.

30.3 Water:

Water is one of the very essential services required for dairy and food plants. The water is necessary for cleaning of equipment and floor, washing operations like can washing, crate washing; preparation of hot water and chilled water as well as for preparation of soft water for boiler feed water. The ratio of water used to milk handled by dairy plants varies from 1 to 2 depending on the types of product manufactured by the plant. It is very important to reduce the water consumption in order to reduce the load on effluent treatment plant of the dairy. The source of water may be from open well, tube well or supply from any other agency. The microbial and chemical quality of water is more important for dairy plant. The hardness of water is concerned to dairy plant as it causes scale deposit in condenser and other heat exchanger. Therefore, it is necessary to treat the water in softening plant to reduce the hardness of water for the equipment requiring soft water. Water having hardness <35 ppm (35 mg/l) is considered as soft water though boiler feed water is treated to get hardness below 5 ppm.

30.3.1 Distribution of water:

The distribution of well water, chilled water and soft water in the food and dairy plants is requiring knowledge of hydraulics and need of such water at different points in the dairy and food plant. Water distribution net work is planned at the time of planning and erection work of the plant. The requirement of quantity of water, pressure, velocity etc. for different equipment is carefully estimated to design an appropriate water supply net work. This involves the estimation of pipe size and various fittings required for the supply of water. Water is distributed in GI pipelines. There are two basic methods for distribution of water.

1. Gravity water distribution

2. Hydro-flow water distribution system

30.3.1.1 Gravity water distribution:

The water from the tube well or open well is pumped to an over head tank constructed for storage and distribution of water. The capacity of the tank and the height varies depending on the requirement of the plant. The rate of discharge of water from any pipeline depends on the velocity of water and the diameter of the pipeline. The available head of water which is decided by the height of water tank as well as major and minor head losses decides the velocity of the water in the pipeline. The size of main pipeline is carefully calculated to supply water in all branches of the pipes.

30.3.1.2 Hydro-flow water distribution system:

The hydro-flow water distribution system consists of a hydro flow air tight tank, centrifugal pumps and underground water sump. The water from the tube well is stored in the big capacity underground sump. This water is pumped in the hydro flow tank which is equipped with a pressure switch to stop the centrifugal pump at some cut out pressure (say 6 bar). The air pressure above the surface of water in the tank gives required head for the supply of water. As the water quantity is reduced from the tank, the pressure of the tank falls (say 3 bar) which activates the pressure switch to start the water pump again to fill the tank. Thus, the pressure head in the hydro-flow tank is maintained between two pressure limits based on the setting of the pressure switch. This method of water distribution can be made complete automatic to start submersible pump based on the level sensors provided in the sump and operation of centrifugal pump to feed water in the hydro-flow tank. In addition to this, this system does not involve heavy construction cost which is required in gravity supply system. A schematic diagram of a hydro flow water supply system is shown in Fig. 30.1

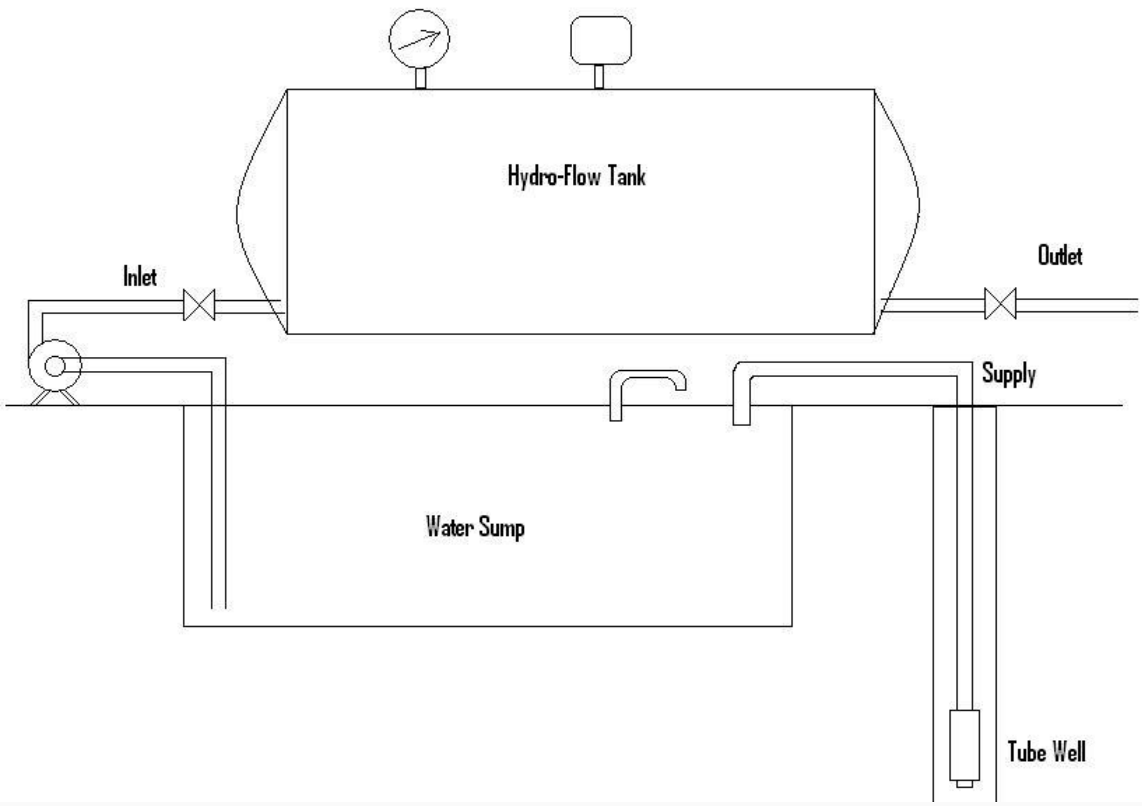


Fig. 30.2_ Hydro Flow Water Distribution System

30.3.2 Measuring water consumption

To understand how to manage water effectively it is essential to understand how much water enters and leaves the factory and where it is being used. There are a number of methods that can help to quantify water use and develop a water model:

1. Install flow meters in strategic areas to directly measure water use.
2. Use a bucket and stopwatch to estimate flow from pipes or hoses.
3. Use manufacturers' data to estimate water use for some equipment and compare with actual water use.
4. Use known operational data to estimate water use (e.g. a 10 kL tank fills every wash cycle). When identifying areas of water use, manual operations as well as equipment should be monitored carefully (e.g. the volume of water used for washing down floors and equipment must be taken into account). It is also a good opportunity to observe staff behavior (e.g. taps left running or hoses left unattended).

30.4 Steam:

Steam is an excellent medium for conveying heat in dairy and food plants. It is the most economical and common source of heat energy, and has been adapted by all the milk processing plants It is used for processing, cleaning and sterilization of process equipments.

30.4.1 Steam Requirement in Dairy:

Considerable quantity of steam is required for processing, heating, cleaning, and sterilization in dairy. Low pressure steam (below 2 kg/cm^2 abs) can be used where temperature up to 115°C is required. Low pressure steam is less expensive because of reduced labor charge, fuel cost and maintenance costs. Low pressure steam requires large pipe size.

30.4.2 Formation of Steam and Its Properties:

Steam is vaporized water, which is formed by adding sufficient heat or reducing pressure. When water is heated vaporization occurs because the vapour pressure of the liquid exceeds the vapour pressure of the surrounding atmosphere.

Consider 1 kg of water at 0 ^{0}C, contained in a closed vessel, is heated slowly. The volume of water will increase slightly with the increase in temperature. On further heating, temperature reaches boiling point, i.e., 100 ^{0}C. When the boiling point is reached, the temperature remains constant and the water evaporates. The vapour will have some particles of water in suspension, and it termed as wet steam. This process will continue till the whole water is converted into wet steam. On further heating, the water particles in suspension will be converted into steam, which is dry or saturated steam. If the dry steam is further heated, its temperature starts rising, and steam is such a state is termed superheated steam.

30.4.2.1 Wet steam: when the steam contains moisture or water particles are suspension, it is called wet steam.

30.4.2.2 Dry saturated steam: when the wet steam is further heated and all the suspended water has evaporated, it is known as dry saturated steam.

30.4.2.3 Superheated steam: when the dry steam is further heated at a constant pressure, thus raising its temperature, it is said to be superheated steam. Since the pressure is constant, the volume of superheated steam increases.

30.4.2.4 Sensible heat of water: It is the amount of heat absorbed by 1 kg water, when heated at constant pressure, from 0 ^{0}C to boiling point or saturation temperature (t_s). the sensible heat is also known as liquid heat or total heat of water, usually denoted by h.

30.4.2.6 Latent heat of vaporization: It is the amount of heat absorbed to evaporate 1 kg of water at its boiling point, without change in temperature, usually denoted by L. Its value depends upon the pressure and is 539 kcal/kg at atmospheric pressure.

30.4.2.7 Total heat or enthalpy of steam: It is the amount of heat absorbed by water from its freezing point to saturation temperature plus the heat absorbed to evaporate water at its boiling point. The total heat or enthalpy of steam is sensible heat + latent heat, denoted by H.

30.4.2.8 Specific volume: It is the volume occupied by the steam per unit mass at a given temperature and pressure, and is expressed in m^3/kg. The value of specific volume decreases with the increase in pressure.

30.4.3 Fuel:

The fuels may be classified as solid, liquid or gaseous fuels. Each of these may be further sub-divided as natural or prepared fuels. The natural solid fuels are wood, peat, lignite or brown coal, bituminous coal, and anthracite coal. The prepared solid fuels are wood charcoal, coke, Briquetted coal and pulverized coal. The liquid fuels are derived from natural petroleum or crude oil with the chief combustible ingredients being carbon and hydrogen. The natural gas consists of marsh gas, methane (CH_4) together with small amount of other gases such as ethane, carbon dioxide, and carbon monoxide.

30.4.4 Steam Boilers:

A steam generator or boiler is a closed pressure vessel used to generate steam. Its function is to transfer the heat produced by combustion of fuel to water and ultimately to generate steam. It consists of the boiler shell, combustion chamber, grate, furnace, heating surface, mountings and accessories. A good steam boiler should produce maximum quantity of steam with the given fuel, economical to install, high efficiency, occupy small space, safe in working, capable of quick starting, meet the load fluctuations, light in weight, easily accessible for inspection and repair, proper arrangement of circulation of water and hot gases. Selection of type of boiler and size of a boiler depends upon the capacity, working pressure, availability of fuel and water, load factor and available space, initial cost, operating cost and maintenance cost.

30.4.4.1 Classification of Boilers

The boilers may be classified according to the Content in the tube: fire tube and water tube, Position of the furnace: internally fired and externally fired, Axis of the shell: vertical and horizontal, Number of tubes: single tube and multi tubular, Method of water and steam circulation: natural and forced circulation, Use: stationary and mobile, Type of fuel: solid, liquid or gaseous fuel.

30.4.4.2 Air Requirement

Adequate supply of oxygen is essential for complete combustion to obtain the maximum amount of heat from the fuel. One kg of carbon requires 8/3 kg oxygen; 1 kg of hydrogen requires 8 kg of oxygen, and 1kg sulfur requires 1 kg of oxygen for its complete combustion**.** The total oxygen requirement for complete combustion of 1 kg of fuels is $\{(8/3)\ C + H_2 + S\}$ kg.

30.4.4.3 Boiler Efficiency

The boiler efficiency can be figured directly from the total fuel burned in a given period and the total water evaporated into steam in the same period. Another method is from data on heat lost up by the stack. It is the ratio of heat actually used in producing the steam to the heat liberated in the furnace. It is also known as the thermal efficiency of the boiler. Boiler efficiency or thermal efficiency is denoted by η.

$$\eta = \frac{\text{fuel energy input} - \text{energy lost up stack}}{\text{fuel energy input}}$$

$$= \frac{\text{heat actually used in producing steam}}{\text{heat librated from fuel}}$$

$$= \frac{\text{We(H}-\text{h1)}}{\text{C}}$$, C is the calorific value of fuel

Lesson 31. Refrigeration Systems

31.1 INTRODUCTION

The American Society of Heating, Air conditioning and Refrigerating Engineers (ASHARE) defines refrigeration as the science of providing and maintaining temperatures below the immediate surrounding temperatures. Thus it is a process of removing heat from a medium. In other words, the term "refrigeration" is used to denote maintenance of a system or body at a temperature lower than that of its surroundings. This enclosed space can be a refrigerator cabin or deep freeze cabin or cold storage, etc. that is being used to store food/ dairy products at low temperature. Refrigeration has very wide applications such as food preservation in domestic as well as in food/dairy industries, ice- manufacturing, ice cream manufacturing, textile industries, etc.

31.2 PRINCIPLE OF REFRIGERATION

The principle of refrigeration is based on second law of thermodynamics. In refrigeration process, since the heat has to be transferred from a low temperature body to a high temperature body some external work has to be done according to the second law of thermodynamics as shown in Fig.31.1. This external work is done by means of compressor.

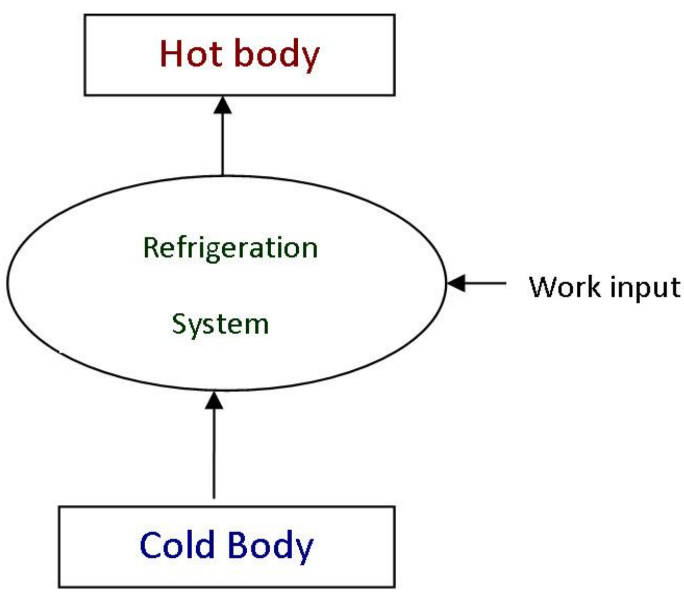


Figure 31.1: Principle of refrigeration system

31.3 Importance of Refrigeration in Dairy Industry:

Refrigeration is a basic requirement for the processing and storage of milk and milk products as majority of dairy products are perishable in nature. The need of refrigeration is indicated below.

1. Chilling of milk at producers' level by employing bulk milk coolers and at milk chilling centres is the first requirement in dairy industry. Immediate cooling of milk to about 2-3 ºC is very important to reduce the multiplications of micro-organisms and to get low bacterial count in the milk and milk products.

2. Processing of milk using either batch pasteurizer or HTST plant requires chilled water or any other cooling medium for cooling of milk.

3. Manufacture of many products requires refrigeration. e.g. butter, ice-cream etc.

4. Storage of milk and milk products requires maintaining low temperature in the cold storages depending on the type of product to be stored. e.g. milk is stored at around 3-4 ºC while ice-cream is stored at -30 ºC temperature.

5. Transportation of many products requires refrigerated vehicles to maintain the quality of products.

6. Low temperature storage is required at distribution of products as well as at the consumers' level.

A refrigeration system is an important and integral part of Dairy Industry. There are numerous types of refrigeration systems depending on different size, design, application, capacity of cooling or low temperature to be maintained, etc. But the principle of refrigeration in all these equipment is mostly common and that is 'vapour compression refrigeration'. The basic major components of refrigeration systems are compressor, condenser, expansion valve and evaporator. Some of the major refrigeration systems used in industry are mentioned as below:

1. Ice Refrigeration

2. Evaporative Refrigeration

3. Refrigeration by Expansion of Air

4. Refrigeration By throttling of the Gas

5. Vapour Compression Refrigeration

6. Vapour Absorption Refrigeration System

7. Steam- Jet Refrigeration System

8. Refrigeration by Using Liquid Gasses
9. Dry ICE Refrigeration

31.4 Unit of Refrigeration:

Capacity of refrigeration system is expressed as ton of refrigeration (TR). A ton of refrigeration is defined as the quantity of heat to be removed in order to form one ton (2000 lbs.) of ice at 0 ºC in 24 hrs, from liquid water at 0 ºC. This is equivalent to 12600 kJ/h or 210 kJ/min or 3.5 kJ/s (3.5 kW).

1 TR = 12600 kJ/h or 210 kJ/min or 3.5 kW

The capacity of refrigeration plant required in any dairy/food plant can be estimated based on the cooling load requirement of the plant.

31.5 Principle of Vapour Compression Refrigeration (VCR) System

Any type of vapour compression refrigeration system has the same principle of working. A fixed quantity of refrigerant, which is any suitable gas, is filled in the closed system of four components, i.e., compressor, condenser, expansion valve and evaporator connected to each other through tubes. When the compressor is run, the refrigerant starts flowing through the system i.e., the system starts it's working. The compressor continuously sucks low pressure, low temperature refrigerant vapors from the evaporator and pump these to condenser at high pressure and high temperature condition. While flowing through the condenser, the high temperature vapors release their heat to atmosphere and condense to high pressure liquid state. After condenser this high-pressure liquid enters the expansion valve where it is throttled to low pressure. It is so constructed that a control quality of refrigerant flows (due to expansion valve) from one necessary steps to another at definite and predetermined pressure. On throttling the pressure and temperature of refrigerant (like ammonia, R-22 etc.) decreases and when this low pressure, low temperature throttled liquid flows through evaporator, it sucks heat and produce cooling. On absorbing heat in evaporator all the low-pressure liquid evaporates to low-pressure, low-temperature vapors, which are again sucked by compressor. In this way all these processes go on continuously and as long as the compressor runs, the system produces cooling around the evaporator. A block diagram of a vapour compression refrigeration system is shown in Fig. 31.2. . The refrigeration system is an enclosed gas tight system of tubes and equipments as shown below.

1 Evaporation

2 Compression

3 Condensation

4 Pressure reduction or Expansion

31.6 Components of the VCR system

31.6.1 Compressor

It is the main component of a Refrigeration System. It may be of many types but a reciprocating compressor is commonly used for different cooling applications in a dairy industry. In this type when an electric motor rotates the main shaft of compressor, a piston reciprocates i.e. moves up and down in the cylinder of compressor. While moving down, the piston sucks the refrigerant vapours coming from the evaporator through suction valve and while moving upward, it compress (increase the pressure of) these vapours and discharge them to condenser through discharge valve. In this way, the basic working of a reciprocating compressor is exactly same as that of a cycle pump.

The purpose of the compressor is to draw low-pressure refrigerant vapour from the evaporator, and compress it so the vapour can be condensed back into a liquid by cooling with air or water. The compressor is the workhorse of a refrigeration system and usually accounts for between 80% and 100% of the system's total energy consumption. It is important, therefore, that the system operates under optimum conditions. The amount of energy used by a compressor is affected by the:

- Type of compressor
- Compressor load
- Temperature difference of the system (i.e. the number of degrees by which the system is required to cool).

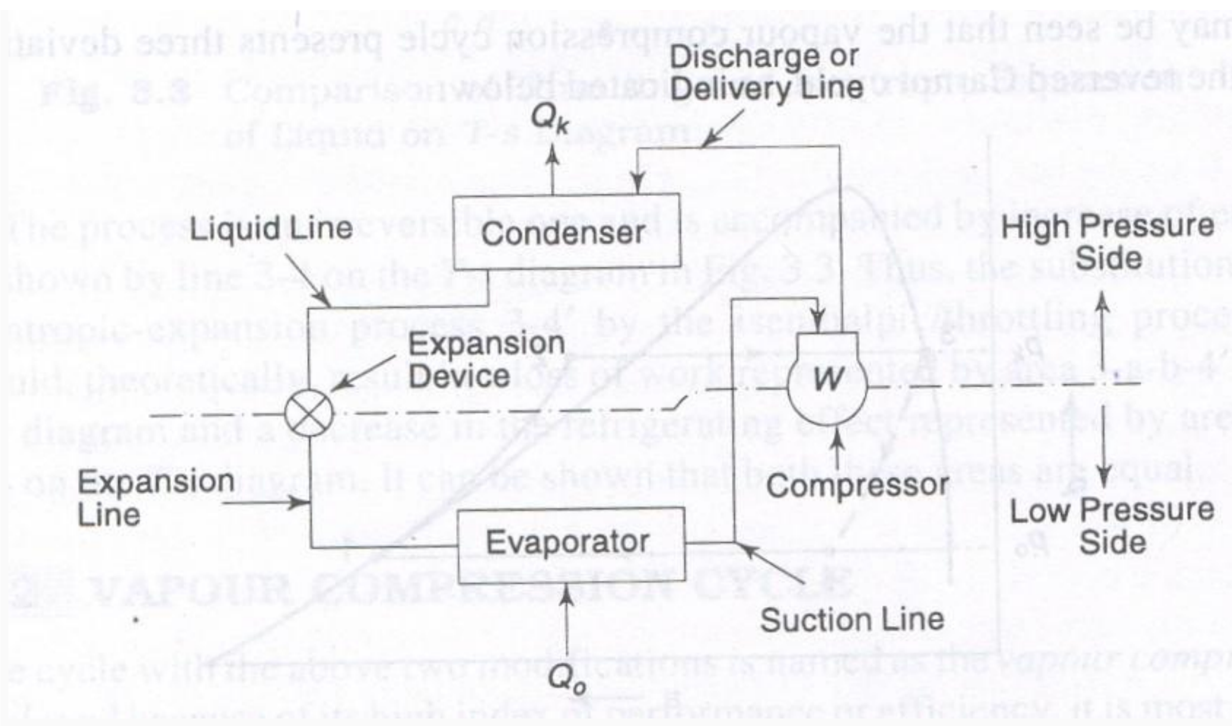


Fig. 31.2 : Block diagram of vapour compression refrigeration system

31.6.2 Condenser

The role of a condenser is to reject heat of compressed refrigerant to atmosphere by providing large area for heat exchange. It is named as condenser because by rejecting latent heat of refrigerant it condenses the refrigerant i.e. converts it from vapour to liquid state. In a Dairy Industry, either shell and tube type or evaporative type, also called as atmospheric condenser is used. Shell and tube type condenser is most satisfactory condenser in case there is no scarcity of cooling water. But its initial cost is high with separate cooling tower. On the other hand, when there is water shortage and cooling tower is being used, then generally the evaporative condenser is more suitable especially in case of large plants.

31.6.3 Evaporator

It is the most required important part of the refrigeration system. The refrigerant from the expansion valve comes in to the evaporator below the temperature required to be maintained in the evaporator and carries the heat from the evaporator.

The evaporators are mostly divided in to different categories as:

1) Flooded Evaporators

2) Dry-expansion Evaporators

a) Natural Convection Evaporators

b) Forced Convection Evaporators

3) Shell and Tube Evaporator

4) Shell and Coil Evaporator

5) Double Pipe Evaporator

6) Plate Evaporator

7) Baudelot-Cooler

31.6.4 Pressure reduction or Expansion:

Expansion valve is one of the basic components of the refrigeration system. The refrigerant is in liquid stage under high pressure in the receiver and it is ready for reuse in the evaporator where much lower pressure is maintained. Some means of retaining of pressure difference is required. This is done by arranging a throttling device in the line between receiver and evaporator. This throttling maintains a higher pressure on one side and allows a lower pressure condition to exist on the other side when flow of refrigerant occurs.

It reduces the pressure of the refrigerant coming from the condenser and temperature also as per the requirement of the system. It also regulates the flow of the refrigerant as per the load on the evaporator. Refrigerant is a the heat transfer medium in vapour compression refrigeration cycle which absorbs the heat through evaporation at the evaporator and rejects the heat absorbed at evaporator plus the heat of work of compression at the condenser. Different devices which are used to perform above functions, are as under:

1. Capillary Tube
2. Pressure Control or Automatic Expansion Valve
3. Thermostatic Expansion Valve
4. High-side float Valve
5. Low-side Float Valve
6. Solenoid Valve

Regarding expansion valve, thermostatic expansion valve is most commonly used in a mid size refrigeration system. In small unit generally capillary tube is preferred because of its low cost, simple working and no maintenance required, etc.

31.7 Primary refrigerant:

The working fluid of vapour compression refrigeration system is known as primary refrigerant which absorbs the heat through evaporation at the evaporator and again becomes liquid on cooling in the condenser. Primary refrigerants include only those working fluids which pass through the cycle of evaporation, compression, condensation and expansion. These refrigerants have very low boiling point. e.g. boiling point of ammonia is -33.3 ^{o} C at atmospheric pressure. There are many refrigerants which as discussed in another lesson.

31.8 Co-efficient of Performance (C.O.P.):

The performance of the refrigeration system is expressed as C.O.P. which is the ratio of refrigerating effect produced to the work of compression. The cooling effect (out put of the system) is produced at the evaporator and the refrigerant is compressed by the compressor using the electrical power (input to the system). The various aspects associated with performance of the system are discussed in some another lesson. Higher C.O.P. is always desirable in order to get more cooling effect with less energy in put

C.O.P. = (Refrigerating effect kJ/h) / (Work Done by compressor kJ/h)

$$C.O.P. = \frac{refrigerationg\ effect,\ kJ/h}{work\ of\ compression,\ kJ/h}$$

31.9Absorption refrigeration

Absorption chillers allow cooling to be produced from heat sources such as clean fossil fuels, incinerated garbage, bio fuels, low-grade steam, hot water, exhaust gas or even solar energy, usually using a lithium bromide and water refrigerant (Broad Air Conditioning 2004). The COP of absorption refrigeration, however, is relatively low compared with vapour compression refrigeration systems with the best absorption chillers generating just over 1 kW of refrigeration for 1 kW of energy. The higher the temperature of the waste heat, therefore, the more effective the refrigeration will be. The advantages of absorption chillers are that they can utilize a waste heat source with lower greenhouse gas emissions compared to conventional vapour compression refrigeration systems. Figure 31.3 shows engineering features of Vapour absorption refrigeration system.

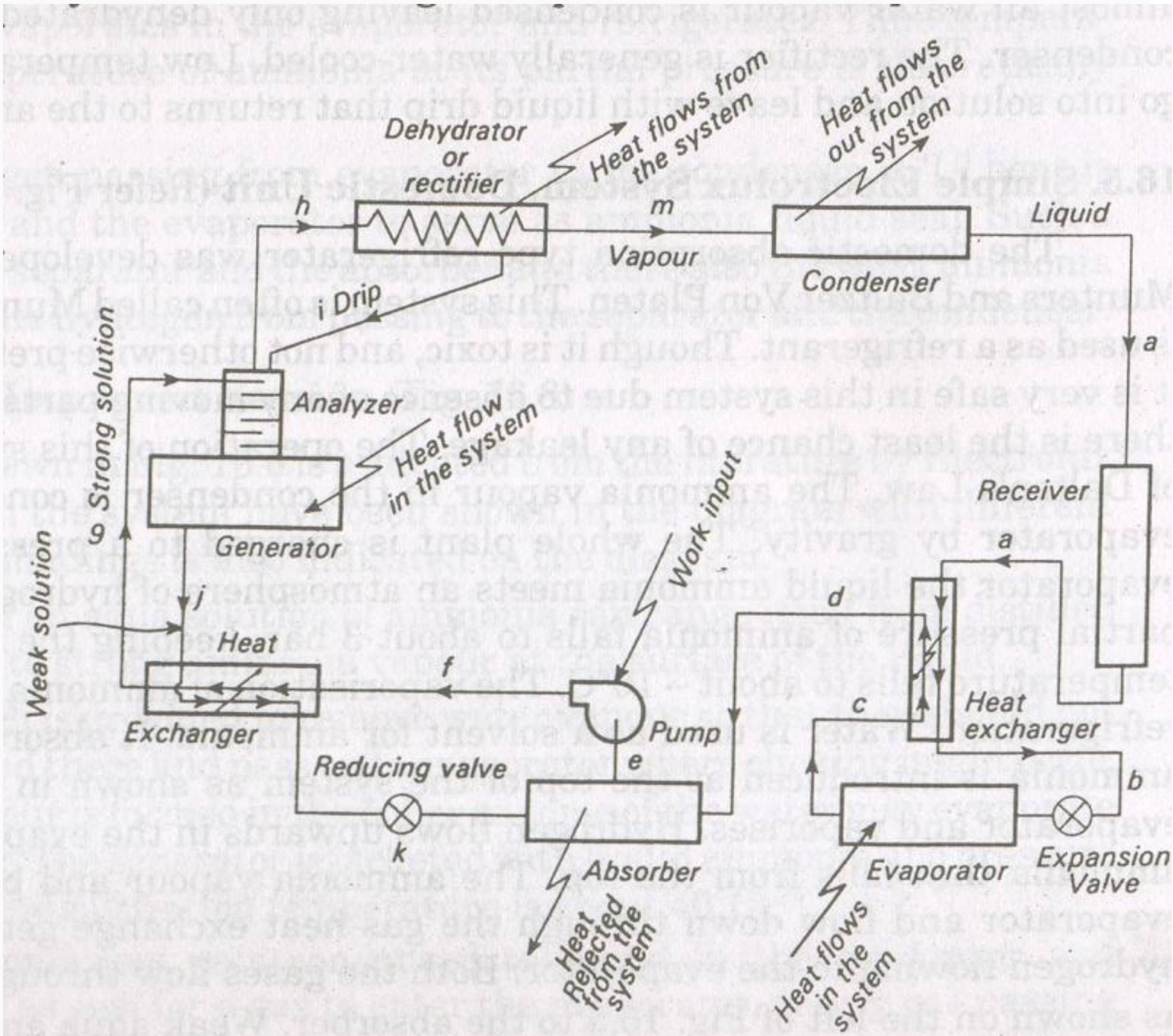


Figure 31.3_ Block Diagram of Vapour Absorption Ammonia System

31.10 Defrosting

Hot gas from the outlet of the refrigeration compressor can be used to defrost freezers, but the control must be accurate. The defrost water may then be used elsewhere in the plant. Once installed and optimized, a hot gas bypass defrost system can ensure frost-free evaporator operation. Once the evaporator is no longer covered in ice its cooling capacity will be increased.

31.11 Reducing load on refrigeration systems

Up to 10% of the power consumption in refrigeration plants can be from heat ingress through doorways in cool rooms. Many plants rely on good operator practice to keep doors closed, but this is not always effective. Automatically closing doors or an alarm system could be considered; and plastic strip curtains or swinging doors are useful at frequently opened entrances. Lights and fans also add to the heat load.

Sensors and timers can be used to ensure that lights are used only when necessary. Variable speed drives, coupled with a programmable controller, can cycle off fans and refrigerant feed during low load times. Cooling water loops using water at ambient temperature have also been used by some dairy processors to pre-cool high-temperature fluids (around 90°C) before chilling, thereby reducing the load on the refrigeration system.

Lesson 32. Electrical Energy And Distribution System

32.1 Introduction

Electric power has become so common place in the dairy industry that modern plants could not operate without this power source. In fact, most plants of significant size have acquired "back-up" electrical power generators to use in case disruptions occur in the primary supply. The electric power represents the most versatile and flexible power source available. In addition, the cost of electric power is very attractive when compared with other sources.

32.2 Electrical Terms and Units

Electricity has its own set of terms and units. These terms and units are entirely different from most physical systems, and it requires careful analysis to relate the terms to applications. The following terms are essential to deal with electrical energy.

Electricity can be defined as the flow of electrons from atom to atom in an electrical conductor. Most materials can be considered conductors, but will vary in the ability to conduct electricity.

Ampere is the unit used to describe the magnitude of electrical current flowing in a conductor. By definition, 1 ampere (A) is 6.06×10^{18} electrons flowing past a given point per second.

Voltage is defined as the force causing current flow in an electrical circuit. The unit of voltage is the volt (V).

Resistance is the term used to describe the degree to which a conductor resists current flow. The ohm (Ω) is the unit of electrical resistance.

Direct current is the type of electrical current flow in a simple electrical circuit. By convention, current is considered to flow from a positive to a negative terminal of a voltage generator.

Alternating current describes the type of voltage generated by an AC (alternating current) generator. Measurement of the actual voltage generated would indicate that the magnitude varies with time and a uniform frequency. The voltage ranges from positive to negative values of equal magnitudes. Most electrical service in the India operates at 50 cycles per second (50 Hz).

Single-phase is the type of electrical current generated by a single set of windings in a generator designed to convert mechanical power to electrical voltage. The rotor in the generator is a magnet that produces magnetic lines as it rotates. These magnetic lines produce a voltage in the iron frame (stator) that holds the windings. The voltage produced becomes the source of alternating current.

Three-phase is the type of electrical current generated by a stator with three sets of windings. Since three AC voltages are generated simultaneously, the voltage can be relatively constant. This type of system has several advantages compared with single-phase electricity.

Watt is the unit used to express electrical power or the rate of work. In a direct current (DC) system, power is the product of voltage and current, whereas computation of power from an alternating current (AC) system requires use of a power factor.

Power factors are ratios of actual power to apparent power from an alternating current system. These factors should be as large as possible to ensure that excessive current is not carried through motors and conductors to achieve power ratings.

Conductors are materials used to transmit electrical energy from source to use. Ratings of conductors are on the basis of resistance to electrical flow.

32.3 Ohm's Law

The most basic relationship in electrical power use is Ohm's 1 law, expressed as

$E_v = IR_E$, where the voltage E_v is equal to the product of current I and resistance R_E.

As might be expected, this relationship illustrates that for a given voltage, the current flow in a system will be inversely proportional to the resistance in the conductor. As indicated earlier, the power generated is the product of voltage and current.

Power = E_vI

Power = I^2R_E

Power = E_v^2/R_E

These relationships can be applied directly to direct current (DC) systems and to alternating current (AC) with slight modifications.

32.4 Electric Circuits

The manner in which conductors are used to connect the electric power source to the point of use is the electrical circuit. There are three basic types of circuits, with the series circuit being the simplest. As indicated by Figure 32.1, this type of circuit is recognized as having the resistances connected in series with the power source. In this type of situation, each resistance would probably represent the points at which the electrical power is used. Often, these points are referred to as electrical loads.

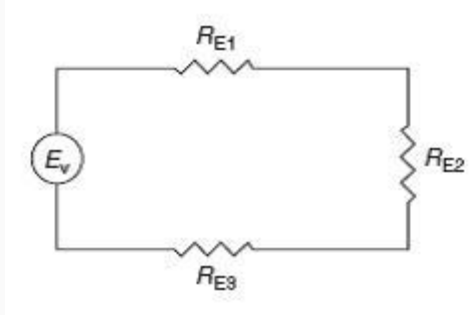


Figure 32.1: Electrical circuit with resistance in series.

Application of Ohm's law to this situation leads to

$E_v = I\ (R_{E1} + R_{E2} + R_{E3})$

indicating that resistances in series are additive. In addition, the voltage is often expressed as the sum of the voltage drop across each resistance in the circuit.

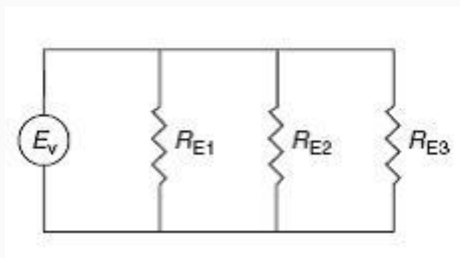


Figure 32.2: Electrical Circuit with resistance in parallel

A parallel electrical circuit has the resistance or loads connected in parallel with the power source, as illustrated in Figure 32.2. When Ohm's law is applied to the parallel circuit, the following relationship applies:

$E_v = I / [1/R_{E1} + 1/R_{E2} + 1/R_{E3}]$

With the inverse of each resistance being additive. The most complex basic electrical circuit has a combination of series and parallel resistances, as illustrated in Figure 32.3.

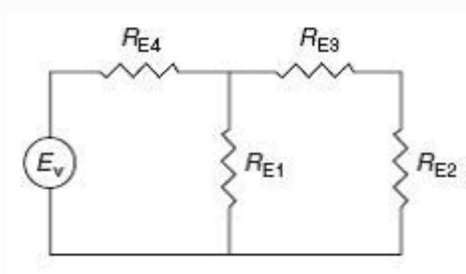


Figure 32.3: Electrical circuit with resistance in series and in parallel

To analyze relationships between voltage and resistances, the combination circuit must be treated in two parts. First, the three resistances (R_{E1}, R_{E2}, R_{E3}) must be resolved as an equivalent R_e.

$$\frac{1}{R_e} = \frac{1}{R_{E1}} + \frac{1}{R_{E2} + R_{E3}}$$

Then the circuit can be analyzed by applying Ohm's law in the following manner:

$E_v = I(R_{E4} + R_e)$

since in the modified circuit, the resistance R_{E4} and R_e are in series.

32.5 Electric Motors

The basic component of an electric energy utilization system is the electric motor. This component converts electrical energy into mechanical energy to be used in operation of processing systems with moving parts.

The majority of the motors used in food processing operations operate with alternating current (AC), and their operation depends on three basic electrical principles. These principles include the electromagnet, formed by winding insulated wire around a soft iron core. Current flow through the wire produces a magnetic field in the iron core; orientation of the field is dependent on the direction of current flow.

The second electrical principle involved in the operation of a motor is electromagnetic induction. This phenomenon occurs when an electric current is induced in a circuit as it moves through a magnetic force field. The induced electric current produces a voltage within the circuit, with magnitude that is a function of the strength of the magnetic field, the speed at which the current moves through the field, and the number of conductor circuits in the magnetic field.

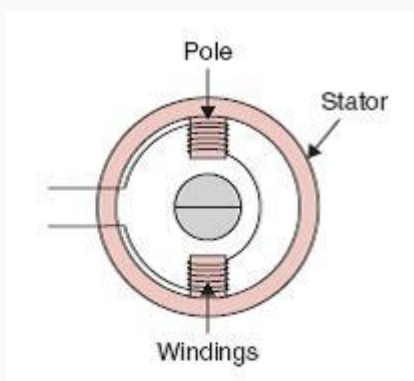


Figure 32.4: Schematic diagram of a stator

The third electrical principle is alternating current. This term refers to a current that changes direction of flow in a consistent manner. Normal electric service in the India is provided at 50 Hz, indicating that the change in current flow direction occurs 50 times per second. An electric motor contains a stator: a housing that has two iron cores wound with insulated copper wire. The two cores or windings are located opposite one another, as illustrated in Figure 32.4, and the leads from the windings are connected to a 50 Hz alternating current source. With this arrangement, the stator becomes an electromagnet with reversing polarity as the current alternates. Another component of an electric motor is the rotor: a rotating drum of iron with copper bars. The rotor is placed between the two poles or windings of the stator (Fig. 32.5). The current flow to the stator and the resulting electromagnetic field produces current flow within the copper bars of the rotor. The current flow within the rotor creates magnetic poles, which in turn react with the magnetic field of the stator to cause rotation of the rotor. Due to the 50 Hz alternating current to the stator, the rotation of the rotor should be 3600 revolutions per minute (rpm), but it typically operates at 3450 rpm. Although there are numerous types of electric motors, they operate on these same basic principles. The most popular motor in the food processing plant is the single-phase, alternating current motor. There are different types of single-phase motors; the differences are related primarily to the starting of the motor.

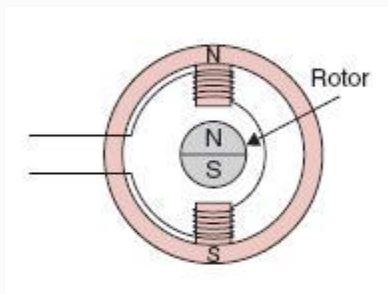


Figure 32.5_ Schematic diagram of stator with rotor

The selection of the proper motor for a given application is of importance when ensuring that efficient conversion of electrical to mechanical energy occurs. The selection process takes into account the type of power supply available, as well as the use of the motor. The type and size of load must be considered, along with the environmental conditions of operation and the available space.

32.6 Electrical Controls

The efficient use of electrical energy and the equipment that is operated by this energy source is related to the opportunity for automatic control. Since the operation of processes and equipment in a food processing plant depends on responses to physical parameters, automatic control involves conversion of the physical parameter into an electrical response or signal. Fortunately, these conversions can be achieved rather easily using a variety of electrical transducers.

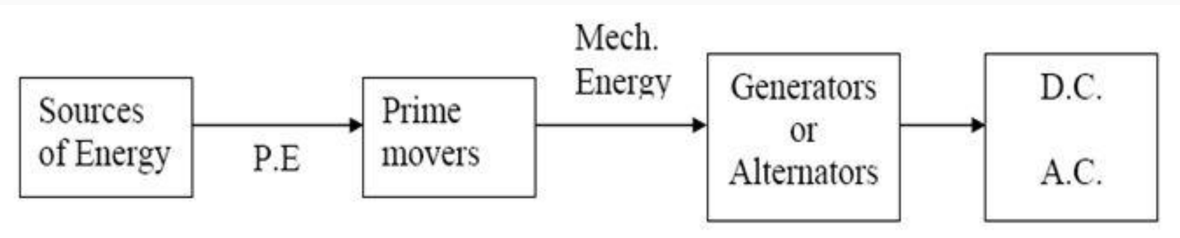
32.7 Electric Lighting: Another primary use of electric power in dairy processing plants is to provide illumination of work spaces.

32.8 Process Controls in Food Processing

A typical food processing factory involves a number of unit operations that are carried out with different processing equipment: pumping, mixing, heating, cooling, freezing, drying, and packaging. Often the processing equipment operates in a continuous mode, which results in higher processing efficiencies than the batch mode. In designing a food processing plant, the processing equipment is arranged in a logical manner so that as raw food enters the plant, it is conveyed from one piece of equipment to the next while undergoing the desired processing.

32.9 Power Generation and Distribution

32.9.1 Generation of electrical Energy



32.9.2 Sub-station

The electrical energy is generated in different types of generating stations located at distant places from the consumer's premises. For example, Some nuclear and coal fired based thermal power generating stations are commissioned far away from the populated area from safety point of view. So, to transfer such a huge quantum of electrical energy from generating stations to the ultimate consumer, number of transformers and other switching equipments are required to step up or step down the voltage. Any station comprising of transformers and switching equipment is known as sub-station. In general the sub-station is of following three types:

1. Pole Mounted Type Sub-station
2. Outdoor Type Sub-station
3. Indoor Type Sub-station

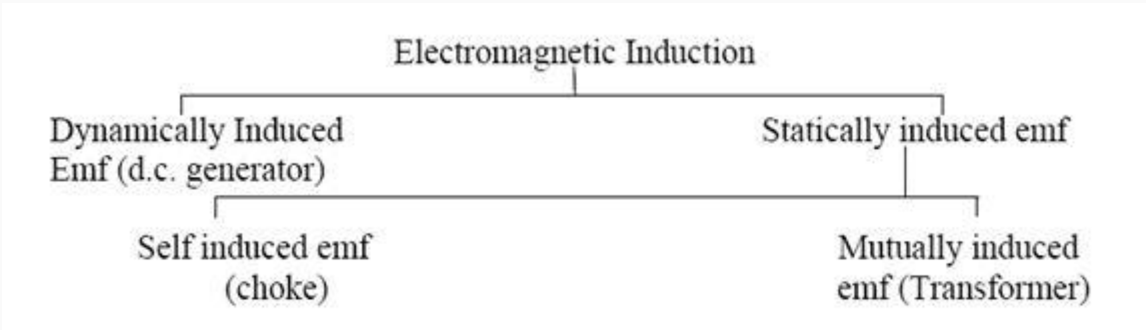
Transmission and Distribution:

High voltage transmission lines are economical which decreases line losses, save copper and increases Efficiency of transmission. Practical working voltage has limit due to increase in cost of switch gear, transformer etc.

32.9.3 Transformer

A transformer is a static electrical device used to transfer electrical power from one circuit to another keeping the supply frequency constant. We can increase or decrease the voltage in the secondary of the transformer with the corresponding changes in current and hence the power transfer will be almost constant if we neglect the losses. This transfer of power and change in secondary voltage will take place due to linkage of common magnetic flux and mutual induction between the two coils as explained below in working principle of transformer.

Working Principle: A transformer works on the principle of Faraday's laws of electro magnetic induction, which states that "whenever a closed circuit coil is placed in an alternating magnetic field, an electro motive force (e.m.f.) will be induced in that coil and magnitude of this induced e.m.f. will depends upon the number of turns in the coil."



When the primary winding of the transformer is connected to A.C. supply, the magnetic flux (F) will be set up and circulate in the laminated magnetic core. This magnetic flux will be alternating in nature as the supply frequency and links with both the windings (Primary and secondary) of the transformer. Now according to faraday's laws of electromagnetic induction an e.m.f. will be induced in the secondary winding due to mutual induction. This induced e=ndF/dt in the secondary winding will depend upon the rate of change of flux and number of turns. If the number of turns in the secondary winding is greater than primary, the transformer will act as step up transformer and vice-versa. Whether a transformer is step up or step down depends upon the transformation ratio (K).

32.10 Distribution Transformer

A distribution transformer is used to step down the 11 kv A.C. supply to 230/440 volts A.C. and are available in different KVA rating depending upon the requirement of the consumers. The main parts of a distribution transformer are, Primary Winding, Secondary Winding, Transformer Oil, Conservator, Breather, Oil Drain Point, Cooling Tubes, Oil Level Indicator, Earth point, Explosion Vent, Tap Changer, etc.

32.11 Distribution System

The system used to distribute the electrical energy to various consumers safely is known as distribution system. Generally 3-phase 4-wire A.C. system is adopted for distribution of electrical energy in industries where as single-phase two-wire system is used in home, offices and commercial purpose. There are three different systems of power distribution system: Single Phase Two wire System, Three Phase Three wire System and Three Phase Four wire System.

32.12 Power Factor

"Cosine of the angle between applied voltage and current drawn in any electrical circuit is known as power factor" and it is denoted by "Cos Φ". When a purely resistive circuit is connected across the A.C. supply, the current drawn from the main supply will be in phase with applied voltage and hence the power factor will be unity. But in case of purely inductive and capacitive circuit, the current drawn will lag behind and lead the applied voltage, by an angle of 90^0 respectively.

32.13 Work, power and energy:

Joule's Law of Electric Heating: The amount of work required to maintain a current of I A through a resistance of R ohm for t second is

Work done = I^2Rt joules = VIt joules (because R=V/I)

= Wt joules (because Watt = VI)

= V^2t /R joules (because I = V/R)

This work is converted into heat

The amount of heat produced = H = Work done /Mechanical equilibrium of heat = W.D./J

Where, J = 4186 joules/kcal = 4200 joules/ kcal

So, H = I^2Rt/4200 kcal = V^2t/4200 R kcal.

In other world: The heat energy evolved in t second is directly proportional to the magnitude of the resistance(R) and square of the current (I)

$H \propto I^2Rt$ so, $H = I^2Rt / J$, J = Joule's constant

Thermal Efficiency:

η = Useful heat / Total heat

$= [m\ s\ (\theta_2 - \theta_1) / (VIt / J)]$

Work: Work is said to be done by a force when it moves the body through a certain distance.

:. W = F x d Nm or jaule

Power: Power is rate of doing work

:. Power= Work/time J/S = Watt

Horse Power (metric): Rate of doing work of 75 kg f m/s

:. 1 hp (metric) = 735.5 J/S (W) & 1 hp (British) = 746 J/S (W)

Energy: It is the capacity to do work. Same unit as work i.e. joule, 1 kwh = 36x10 5J = 860 kcal