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Module on

Unit operations in food processing

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Text

All food processing involves a combination of procedures to achieve the intended changes to the raw materials. These are conveniently categorized as unit operations, each of which has a specific, identifiable and predictable effect on a food. Unit operations are grouped together to form a process. The combination and sequence of operations determines the nature of the final product.

1. Cleaning

Cleaning is the unit operation in which contaminating materials are removed from the food and separated to leave the surface of the food in a suitable condition for further processing. All food raw materials are cleaned before processing. The purpose is obviously to remove contaminants, which range from innocuous to dangerous. It is important to note that removal of contaminants is essential for protection of process equipment as well as the final consumer. For example, it is essential to remove sand, stones or metallic particles from wheat prior to milling to avoid damaging the machinery. Peeling fruits and vegetables, skinning meat or descaling fish may also be considered as cleaning operations. There are a number of cleaning methods available, classified into dry and wet methods, but a combination would usually be employed for any specific material.

1.1. Dry cleaning methods

The main dry cleaning methods are based on screens, aspiration or magnetic separations. Dry methods are generally less expensive than wet methods and the effluent is cheaper to dispose of, but they tend to be less effective in terms of cleaning efficiency.

Screens are essentially size separators based on perforated beds or wire mesh. Larger contaminants are removed from smaller food items: e.g. straw from cereal grains, or pods and twigs from peas. This is termed 'scalping'. Alternatively, 'dedusting' is the removal of smaller particles, e.g. sand or dust, from larger food units.

Aspiration exploits the differences in aerodynamic properties of the food and the contaminants. It is widely used in the cleaning of cereals, but is also incorporated into equipment for cleaning peas and beans. The principle is to feed the raw material into a carefully controlled upward air stream. Denser material will fall, while lighter material will be blown away depending on the terminal velocity.

Magnetic cleaning is the removal of ferrous metal using permanent or electromagnets. Metal particles, derived from the growing field or picked up during transport or preliminary operations, constitute a hazard both to the consumer and to processing machinery, for example cereal mills. Metal detectors are frequently employed prior to sensitive processing equipment as well as to protect consumers at the end of processing lines.

Electrostatic cleaning can be used in a limited number of cases where the surface charge on raw materials differs from contaminating particles. The principle can be used to distinguish grains from other seeds of similar geometry but different surface charge; and it has also been described for cleaning tea.

1.2. Wet Cleaning Methods

Wet methods are necessary if large quantities of soil are to be removed; and they are essential if detergents are used. However, they are expensive, as large quantities of high purity water are required and the same quantity of dirty effluent is produced. Treatment and reuse of water can reduce costs. Employing the countercurrent principle can reduce water requirements and effluent volumes if accurately controlled. Sanitising chemicals such as chlorine, citric acid and ozone are commonly used in wash waters, especially in association with peeling and size reduction, where reducing enzymic browning may also be an aim. Levels of 100–200 mg l^{-1} chlorine or citric acid may be used.

Soaking is a preliminary stage in cleaning heavily contaminated materials, such as root crops, permitting softening of the soil and partial removal of stones and other contaminants. Metallic or concrete tanks or drums are employed; and these may be fitted with devices for agitating the water, including stirrers, paddles or mechanisms for rotating the entire drum.

Spray washing is very widely used for many types of food raw material. Efficiency depends on the volume and temperature of the water and time of exposure. As a general rule, small volumes of high pressure water give the most efficient dirt removal, but this is limited by product damage, especially to more delicate produce. With larger food pieces, it may be necessary to rotate the unit so that the whole surface is presented to the spray. The two most common designs are drum washers and belt washers.

Flotation washing employs buoyancy differences between food units and contaminants. For instance sound fruit generally floats, while contaminating soil, stones or rotten fruits sink in water.

Hence fluming fruit in water over a series of weirs gives very effective cleaning of fruit, peas and beans.

Froth flotation is carried out to separate peas from contaminating weed seeds and exploits surfactant effects. The peas are dipped in an oil/detergent emulsion and air is blown through the bed. This forms foam which washes away the contaminating material and the cleaned peas can be spray washed.

2. Peeling

Peeling of fruits and vegetables is frequently carried out in association with cleaning. Mechanical peeling methods require loosening of the skin using one of the following principles, depending on the structure of the food and the level of peeling required:

– Steam is particularly suited to root crops. The units are exposed to high pressure steam for a fixed time and then the pressure is released causing steam to form under the surface of the skin, hence loosening it such that it can be removed with a water spray.

– Lye (1–2% alkali) solution can be used to soften the skin which can again be removed by water sprays.

– Brine solutions can give a peeling effect but are probably less effective than the above methods.

– Abrasion peeling employs carborundum rollers or rotating the product in a carborundum-lined bowl, followed by washing away the loosened skin.

– Mechanical knives are suitable for peeling citrus fruits.

– Flame peeling is useful for onions, in which the outer layers are burnt off and charred skin is removed by high pressure hot water.

3. Size reduction

Size reduction or 'comminution' is the unit operation in which the average size of solid pieces of food is reduced by the application of grinding, compression or impact forces. When applied to the reduction in size of globules of immiscible liquids (for example oil globules in water) size reduction is more frequently referred to as homogenisation or emulsification.

Different methods of size reduction are classified according to the size range of particles produced:

1. Chopping, cutting, slicing and dicing:

(a) Large to medium (stewing steak, cheese and sliced fruit for canning)

(b) Medium to small (bacon, sliced green beans and diced carrot)

(c) Small to granular (minced or shredded meat, flaked fish or nuts and shredded vegetables).

2. Milling to powders or pastes of increasing fineness (grated products > spices > flours > fruit nectars > powdered sugar > starches > smooth pastes)

3. Emulsification and homogenisation (mayonnaise, milk, essential oils, butter, ice cream and margarine).

3.1. Size reduction of solid foods

In all types of size reduction there are three types of force used to reduce the size of foods:

1. Compression forces

2. Impact forces

3. Shearing (or attrition) forces.

In most size reduction equipment, all three forces are present, but often one is more important than the others. The equipments used to reduce the size of both fibrous foods to smaller pieces or pulps, and dry particulate foods to powders are shown in Table 1.

Table 1: Properties and applications of selected size reduction equipments

Type of equipment	Type(s) of force	Peripheral velocity (m s^{-1})	Typical products
Pin-and-disc mill	Impact	80–160	Sugar, starch, cocoa powder, nutmeg, pepper, roasted nuts, cloves
Wing-beater mill	Impact and shear	50–70	Alginates, pepper, pectin, paprika, dried vegetables
Disc-beater mill	Impact and shear	70–90	Milk powder, lactose, cereals, dried whey
Vertical toothed disc mill	Shear	4–8	Frozen coffee extract, plastic materials Coarse grinding of rye, maize, wheat, fennel, pepper, juniper berry
Cutting Granulator	Impact (and shear)	5–18	Fish meal, pectin, dry fruit and vegetables
Hammer mill	Impact	40–50	Sugar, tapioca, dry vegetables, extracted bones, dried milk, spices, pepper
Ball mill	Impact and shear	-	Food colours
Roller mills	Compression and shear	-	Sugar cane, wheat (fluted rollers) Chocolate refining (smooth rollers)

Size reduction in liquid foods (emulsification and homogenisation)

The terms emulsifiers and homogenisers are often used interchangeably for equipment used to produce emulsions: emulsification is the formation of a stable emulsion by the intimate mixing of two or more immiscible liquids, so that one (the dispersed phase) is formed into very small droplets within the second (the continuous phase). Homogenisation is the reduction in size (to 0.5–30 μm), and hence the increase in number, of solid or liquid particles in the dispersed phase by the application of intense shearing forces. Homogenisation is therefore a more severe operation than emulsification. Both operations are used to change the functional properties or eating quality of foods and have little or no effect on nutritional value or shelf life. Examples of emulsified products include margarine and low-fat spreads, salad cream and mayonnaise, sausagemeat, ice cream and cakes.

Equipment

The five main types of homogeniser are used for size reduction of liquid foods:

1. High-speed mixers

2. Pressure homogenisers

3. Colloid mills

4. Ultrasonic homogenisers

5. Hydroshear homogenisers and microfluidisers.

High-speed mixers

High-speed mixers use turbines or propellers, to pre-mix emulsions of low-viscosity liquids. They operate by a shearing action on the food at the edges and tips of the blades.

Pressure homogenisers

Pressure homogenisers consist of a high-pressure pump, operating at 10 000–70 000 × 10^3 Pa, which is fitted with a homogenising valve on the discharge side. When liquid is pumped through the small adjustable gap (up to 300 μm) between the valve and the valve seat, the high pressure produces a high liquid velocity (80–150 ms^{-1}). There is then an almost instantaneous drop in velocity as the liquid emerges from the valve. These extreme conditions of turbulence produce powerful shearing forces and the droplets in the dispersed phase become disrupted.

Colloid mills

Colloid mills are essentially disc mills with a small clearance (0.05–1.3 mm) between a stationary disc and a vertical disc rotating at 3000–15 000 rpm. They create high shearing forces and are more effective than pressure homogenisers for high-viscosity liquids.

Ultrasonic homogenisers

Ultrasonic homogenisers use high-frequency sound waves (18–30 kHz) to cause alternate cycles of compression and tension in low-viscosity liquids and cavitation of air bubbles, to form emulsions with droplet sizes of 1–2 μm.

Hydroshear homogenisers and microfluidisers

The hydroshear homogeniser is a double-cone shaped chamber which has a tangential feed pipe at the centre and outlet pipes at the end of each cone. The feed liquid enters the chamber at high velocity and is made to spin in increasingly smaller circles and increasing velocity until it reaches the centre and is discharged.

1. Filtration

Filtration is the removal of insoluble solids from a suspension (or 'feed slurry') by passing it through a porous material (or 'filter medium'). The resulting liquor is termed the 'filtrate' and the separated solids are the 'filter cake'. Filtration is used to clarify liquids by the removal of small amounts of solid particles (for example from wine, beer, oils and syrups). When a suspension of particles is passed through a filter, the first particles become trapped in the filter medium and, as a result, reduce the area through which liquid can flow. This increases the resistance to fluid flow and a higher pressure difference is needed to maintain the flow rate of filtrate. The rate of filtration is expressed as follows:

$$\text{Rate of filtration} = \frac{\text{driving force (the pressure difference across the filter)}}{\text{Resistance to flow}}$$

Equipment

Gravity filtration is slow and finds little application in the food industry. Filtration equipment operates either by the application of pressure to the feed side of the filter bed or by the application of a partial vacuum to the opposite side of the filter bed. Filter aids are usually applied to the filter or mixed with the food to improve the formation of filter cake.

Pressure filters

Two commonly used pressure filters are the batch plate-and-frame filter press and the shell-and-leaf pressure filter.

Vacuum filters

Vacuum filters are limited by the cost of vacuum generation to a pressure difference of about 100×10^3 Pa. However, cake is removed at atmospheric pressure and these types of filter are therefore able to operate continuously. Two common types of vacuum filter are the rotary drum filter and rotary disc filter.

2. Mixing and forming

Mixing (or blending) is a unit operation in which a uniform mixture is obtained from two or more components, by dispersing one within the other(s). The larger component is sometimes called the continuous phase and the smaller component the dispersed phase by analogy with emulsions, but these terms do not imply emulsification when used in this context. Mixing has no preservative effect and is intended solely as a processing aid or to alter the eating quality of foods. It has very wide applications in many food industries where it is used to combine ingredients to achieve different functional properties or sensory characteristics. Examples include texture development in doughs and ice cream, control of sugar crystallisation and aeration of batters and some chocolate products. In some foods, adequate mixing is necessary to ensure that the proportion of each component complies with legislative standards (for example mixed vegetables, mixed nuts, sausages and other meat products). Extruders and some types of size reduction equipment also have a mixing action.

Forming is a size enlargement operation in which foods that have a high viscosity or a dough-like texture are moulded into a variety of shapes and sizes, often immediately after a mixing operation. It is used as a processing aid to increase the variety and convenience of baked goods, confectionery and snackfoods. It has no direct effect on the shelf life or nutritional value of foods. Close control over the size of formed pieces is critical (for example to ensure uniform rates of heat transfer to the centre of baked foods, to control the weight pieces of food, and to ensure the uniformity of smaller foods and hence to control fill weights). Extrusion also has a forming function.

3. Pasteurisation

Pasteurisation is a relatively mild heat treatment, in which food is heated to below 100ºC. In low acid foods (pH > 4.5, for example milk) it is used to minimise possible health hazards from pathogenic micro-organisms and to extend the shelf life of foods for several days. In acidic foods (pH < 4.5, for example bottled fruit) it is used to extend the shelf life for several months by destruction of spoilage micro-organisms (yeasts or moulds) and/or enzyme inactivation. In both types of food, minimal changes are caused to the sensory characteristics or nutritive value. Processing containers of food, either which have a naturally low pH (for example fruit pieces) or in which the pH is artificially lowered (for example pickles) is similar to canning. It is often termed pasteurisation to indicate the mild heat treatment employed. Some liquid foods (for example beers and fruit juices) are pasteurised after filling into containers. Hot water is normally used if the food is packaged in glass, to reduce the risk of thermal shock to the container (fracture caused by rapid changes in temperature). Maximum temperature differences between the container and water are 20ºC for heating and 10ºC for cooling. Metal or plastic containers are processed using steam–air mixtures or hot water as there is little risk of thermal shock. In all cases the food is cooled to approximately

40ºC to evaporate surface water and therefore to minimise external corrosion to the container or cap, and to accelerate setting of label adhesives. Swept surface heat exchangers or open boiling pans are used for small-scale batch pasteurisation of some liquid foods. However, the large scale pasteurisation of low viscosity liquids (for example milk, milk products, fruit juices, liquid egg, beers and wines) usually employs plate heat exchangers.

4. Heat sterilization

Heat sterilization is the unit operation in which foods are heated at a sufficiently high temperature and for a sufficiently long time to destroy microbial and enzyme activity. As a result, sterilized foods have a shelf life in excess of six months at ambient temperatures. The severe heat treatment during the older process of in-container sterilization (canning) may produce substantial changes in nutritional and sensory qualities of foods. Developments in processing technology therefore aim to reduce the damage to nutrients and sensory components, by either reducing the time of processing in containers or processing foods before packaging (aseptic processing). In heat sterilization it is important to ensure that the food is adequately heat treated and to reduce post processing contamination. The food should then be cooled quickly and it may require refrigerated storage or be stable at ambient temperature. The heating process can be either batch or continuous. In all thermal processes, the aim should be to heat and cool the product as quickly as possible. This has economic implications and may also lead to an improvement in quality. Heat or energy (J) is transferred from a high to a low temperature, the rate of heat transfer being proportional to the temperature difference. Therefore, high temperature driving forces will promote heat transfer. The heating medium is usually saturated steam or hot water. For temperatures above 100^{o}C, steam and hot water are above atmospheric pressure. Cooling is achieved using either mains water, chilled water, brine or glycol solution. Regeneration is used in continuous processes to further reduce energy utilization.

5. Evaporation and distillation

In common with other unit operations that are intended to separate components of foods, evaporation and distillation aim to separate specific components to increase the value of the food. In both types of operation, separation is achieved by exploiting differences in the vapour pressure (volatility) of the components and using heat to remove one or more from the bulk of the food.

8.1. Evaporation

Evaporation, or concentration by boiling, is the partial removal of water from liquid foods by boiling off water vapour. It increases the solids content of a food and hence preserves it by a reduction in water activity. Evaporation is used to pre-concentrate foods (for example fruit juice, milk and coffee) prior to drying, freezing or sterilization and hence to reduce their weight and volume. This saves energy in subsequent operations and reduces storage, transport and distribution costs. There is also greater convenience for the consumer (for example fruit drinks for dilution, concentrated soups, tomato or garlic pastes, sugar) or for the manufacturer (for example liquid pectin, fruit concentrates for use in ice cream or baked goods). Changes to food quality that result from the relatively severe heat treatment are minimised by the design and operation of the equipment. Evaporation is more expensive in energy consumption than other methods of concentration (membrane concentration and freeze concentration) but a higher degree of concentration can be achieved. If evaporation is carried out in open pans at atmospheric pressure, the initial temperature at which the solution boils will be some degrees above 100°C, depending on the solids content of the liquid. As the solution becomes more concentrated, the evaporation temperature will rise.

5.1. Distillation

Although common in the chemical industry, distillation in food processing is mostly confined to the production of alcoholic spirits and separation of volatile flavour and aroma compounds (for example, production of essential oils by steam distillation). When a food that contains components having different degrees of volatility is heated, those that have a higher vapour pressure (more volatile components) are separated first. These are termed the 'distillate' and components that have a lower volatility are termed 'bottoms' or residues. Although batch distillation (in 'pot stills') remains in use in some whisky and other spirit distilleries, most industrial distillation operations use more economical continuous distillation columns. Feed liquor flows continuously through the column and as it is heated, volatiles are produced and separated at the top of the column as distillate and the residue is separated at the base. In order to enhance the separation of these components and equilibrium conditions between the liquid and vapour phases, a proportion of the distillate is added back to the top of the column (reflux) and a portion of the bottoms is vapourised in a reboiler and added to the bottom of the column. Columns are filled with either a packing material (typically ceramic, plastic or metal rings) or fitted with perforated trays, both of which increase the contact between liquid and vapour phases.

5.2. Dehydration

Dehydration (or drying) is defined as 'the application of heat under controlled conditions to remove the majority of the water normally present in a food by evaporation' (or in the case of freeze drying by sublimation). This definition excludes other unit operations which remove water from foods (for example mechanical separations and membrane concentration, evaporation and baking) as these normally removes much less water than dehydration. Dehydration is the oldest method of food preservation practised by man. For thousands of years he has dried and/or smoked meat, fish, fruits and vegetables, to sustain him during out of season periods in the year. Today the dehydration section of the food industry is large and extends to all countries of the globe. Drying facilities range from simple sun or hot air driers to high capacity, sophisticated spray drying or freeze drying installations. A very large range of dehydrated foods is available and makes a significant contribution to the convenience food market.

The main reason for drying a food is to extend its shelf life beyond that of the fresh material, without the need for refrigerated transport and storage. This goal is achieved by reducing the available moisture, or water activity to a level which inhibits the growth and development of spoilage and pathogenic microorganisms, reducing the activity of enzymes and the rate at which undesirable chemical changes occur. Appropriate packaging is necessary to maintain the low water activity (a_w) during storage and distribution. Drying also reduces the weight of the food product. Shrinkage, which occurs often during drying, reduces the volume of the product. These changes in weight and volume can lead to substantial savings in transport and storage costs and, in some cases, the costs of packaging. However, dehydration is an energy intensive process and the cost of supplying this energy can be relatively high, compared to other methods of preservation.

Dehydration is usually described as a simultaneous heat and mass transfer operation. Sensible and latent heat must be transferred to the food to cause the water to evaporate. Placing the food in a current of heated air is the most widely used method of supplying heat. The heat is transferred by convection from the air to the surface of the food and by conduction within the food. Alternatively, the food may be placed in contact with a heated surface. The heat is transferred by conduction to the surface of the food in contact with the heated surface and within the food. There is limited use of radiant, microwave and radio frequency energy in dehydration. Freeze drying involves freezing the food and removal of the ice by sublimation. This is usually achieved by applying heat, by conduction or radiation, in a very low pressure environment. In osmotic drying food pieces are immersed in a hypertonic solution. Water moves from the food into the solution, under the influence of osmotic pressure. Examples of commercially important dried foods are coffee, milk, raisins, sultanas and other fruits, pasta, flours (including bakery mixes), beans, pulses, nuts, breakfast cereals, tea and spices. Examples of important dried ingredients that are used by manufacturers include egg powder, flavourings and colourings, lactose, sucrose or fructose powder, enzymes and yeasts.

5.3. Baking and roasting

Baking is the unit operation in which heated air is used to alter the eating quality of foods. Baking is a term commonly applied to the production of cereal-based products such as bread, biscuits, cakes, pizzas, etc., and in its English usage baking is generally applied to the production of fermented bread. Baking is at heart a process: the conversion of some relatively unpalatable ingredients (starch, gluten, bran, in the case of most cereals) into the aerated, open cell sponge structure we know as bread has taken millennia to develop.

Baking involves simultaneous heat and mass transfer; heat is transferred into the food from hot surfaces and air in the oven and moisture is transferred from the food to air that surrounds it and then removed from the oven. In an oven, heat is supplied to the surface of the food by a combination of infrared radiation from the oven walls, by convection from circulating air and by conduction through the pan or tray on which the food is placed. Infrared radiation is absorbed into the food and converted to heat. Air, other gases and moisture vapour in the oven transfer heat by convection. The heat is converted to conductive heat at the surface of the food. A boundary film of air acts as a resistance to heat transfer into the food and to movement of water vapour from the food. The thickness of the boundary layer is determined mostly by the velocity of the air and the surface properties of the food and in part controls the rates of heat and mass transfer. Convection currents promote uniform heat distribution throughout the oven, and many commercial designs are fitted with fans to supplement natural convection currents and to reduce the thickness of boundary films. This increases heat transfer coefficients and improves the efficiency of energy utilization.

Heat passes through the food by conduction in most cases, although convection currents are established during the initial heating of cake batters. The low thermal conductivity of foods causes low rates of conductive heat transfer and is an important influence on baking time. Conduction of heat through baking pans or trays increases the temperature difference at the base of the food and increases the rate of baking compared to the surface crust. The size of the pieces of food is an important factor in baking time as it determines the distance that heat must travel to bake the centre of the food adequately.

6. Frying

Frying is a unit operation which is mainly used to alter the eating quality of a food. A secondary consideration is the preservative effect that results from thermal destruction of micro-organisms and enzymes, and a reduction in water activity at the surface of the food (or throughout the food, if it is fried in thin slices). The shelf life of fried foods is mostly determined by the moisture content after frying: foods that retain a moist interior (for example doughnuts, fish and poultry products which may also be breaded or battered, have a relatively short shelf life, owing to moisture and oil migration during storage. These foods are important in catering applications and are produced on a commercial scale for distribution to retail stores, preserved by chilling and/or gas packing. Foods that are more thoroughly dried by frying, for example potato crisps (potato chips in the USA), maize and other potato snack foods, have a shelf life of up to 12 months at ambient temperature. The quality is maintained by adequate barrier properties of packaging materials and correct storage conditions. During frying when food is placed in hot oil, the surface temperature rises rapidly and water is vaporized as steam. The surface then begins to dry out in a similar way to that described during baking and roasting. The plane of evaporation moves inside the food, and a crust is formed. The surface temperature of the food then rises to that of the hot oil, and the internal temperature rises more slowly towards 100ºC. The rate of heat transfer is controlled by the temperature difference between the oil and the food and by the surface heat transfer coefficient. The rate of heat penetration into the food is controlled by the thermal conductivity of the food

7. Chilling

Chilling is the unit operation in which the temperature of a food is reduced to between -1ºC and 8ºC. It is used to reduce the rate of biochemical and microbiological changes, and hence to extend the shelf life of fresh and processed foods. It causes minimal changes to sensory characteristics and nutritional properties of foods and, as a result, chilled foods are perceived by consumers as being convenient, easy to prepare, high quality and ‘healthy’, ‘natural’ and ‘fresh’. Since the 1980s there has been substantial product development and strong growth in the chilled food market, particularly for sandwiches, desserts, ready meals, prepared salads, pizza and fresh pasta.

Chilling is often used in combination with other unit operations (for example fermentation or pasteurization) to extend the shelf life of mildly processed foods. There is a greater preservative effect when chilling is combined with control of the composition of the storage atmosphere than that found using either unit operation alone. However, not all foods can be chilled and tropical, subtropical and some temperate fruits, for example, suffer from chilling injury at 3–10ºC above their freezing point.

Chilled foods are grouped into three categories according to their storage temperature range as follows:

1. -1ºC to +1ºC (fresh fish, meats, sausages and ground meats, smoked meats and breaded fish).

2. 0ºC to +5ºC (pasteurized canned meat, milk, cream, yoghurt, prepared salads, sandwiches, baked goods, fresh pasta, fresh soups and sauces, pizzas, pastries and unbaked dough).

3. 0ºC to +8ºC (fully cooked meats and fish pies, cooked or uncooked cured meats, butter, margarine, hard cheese, cooked rice, fruit juices and soft fruits).

11. Freezing

Freezing is the unit operation in which the temperature of a food is reduced below its freezing point and a proportion of the water undergoes a change in state to form ice crystals. The immobilisation of water to ice and the resulting concentration of dissolved solutes in unfrozen water lower the water activity (aw) of the food. Preservation is achieved by a combination of low temperatures, reduced water activity and, in some foods, pre-treatment by blanching. There are only small changes to nutritional or sensory qualities of foods when correct freezing and storage procedures are followed.

The major groups of commercially frozen foods are as follows:

• Fruits (strawberries, oranges, raspberries, blackcurrants) either whole or pureed, or as juice concentrates

•Vegetables (peas, green beans, sweetcorn, spinach, sprouts and potatoes)

• Fish fillets and seafoods (cod, plaice, shrimps and crab meat) including fish fingers, fish cakes or prepared dishes with an accompanying sauce

• Meats (beef, lamb, poultry) as carcasses, boxed joints or cubes, and meat products (sausages, beefburgers, reformed steaks)

• Baked goods (bread, cakes, fruit and meat pies)

• Prepared foods (pizzas, desserts, ice cream, complete meals and cook–freeze dishes).

During freezing, sensible heat is first removed to lower the temperature of a food to the freezing point. In fresh foods, heat produced by respiration is also removed. This is termed the heat load, and is important in determining the correct size of freezing equipment for a particular production rate. Most foods contain a large proportion of water, which has a high specific heat (4200 J kg^{-1} K^{-1}) and a high latent heat of crystallisation (335 kJ kg^{-1}). A substantial amount of energy is therefore needed to remove latent heat, form ice crystals and hence to freeze foods. The latent heat of other components of the food (for example fats) must also be removed before they can solidify but in most foods these other components are present in smaller amounts and removal of a relatively small amount of heat is needed for crystallization to take place. Energy for freezing is supplied as electrical energy, which is used to compress gases (refrigerants) in mechanical freezing equipment or to compress and cool cryogens.

12. Freeze Drying (Sublimation Drying, Lyophilisation) of Solid Foods

This method of drying foods was first used in industry in the 1950s. The process involves three stages: (a) freezing the food material, (b) subliming the ice (primary drying) and (c) removal of the small amount of water bound to the solids (secondary drying or desorption). Freezing may be carried out by any of the conventional methods including blast, immersion, plate or liquid gas freezing. Blast freezing in refrigerated air is most often used. It is important to freeze as much of the water as possible. This can be difficult in the case of material with high soluble solids content, such as concentrated fruit juice. As the water freezes in such a material, the soluble solids content of remaining liquid increases, and so its freezing point is lowered. At least 95% of the water present in the food should be converted to ice, to attain successful freeze drying. Ice will sublime when the water vapour pressure in the immediate surroundings is less than the vapour pressure of ice at the prevailing temperature. This condition could be attained by blowing dry, refrigerated air across the frozen material. However, this method has proved to be uneconomic on a large scale. On an industrial scale, the vapour pressure gradient is achieved by reducing the total pressure surrounding the frozen food to a value lower than the ice vapour pressure. The vapour pressure of ice at -20^{o}C is about 135 Pa, absolute. Industrial freeze drying is carried out in vacuum chambers operated at pressures in the range 13.5–270.0 Pa, absolute. The main components of a batch freeze drier are a well sealed vacuum chamber fitted with heated shelves, a refrigerated condenser and a vacuum pump or pumps. The refrigerated condenser removes the water vapour formed by sublimation. The water vapour freezes on to the condenser, thus maintaining the low water vapour pressure in the chamber. The vacuum pump(s) remove the non condensable gases. The heated shelves supply the heat of sublimation. Heat may be applied from above the frozen food by radiation or from below by conduction or from both directions.

13. Extrusion

Extrusion is a process which combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming. Extruders are classified according to the method of operation (cold extruders or extruder-cookers) and the method of construction (single- or twin-screw extruders). The principles of operation are similar in all types: raw materials are fed into the extruder barrel and the screw(s) then convey the food along it. Further down the barrel, smaller flights restrict the volume and increase the resistance to movement of the food. As a result, it fills the barrel and the spaces between the screw flights and becomes compressed. As it moves further along the barrel, the screw kneads the material into a semi-solid, plasticised mass. If the food is heated above 100ºC the process is known as extrusion cooking (or hot extrusion). Here, frictional heat and any additional heating that is used cause the temperature to rise rapidly. The food is then passed to the section of the barrel having the smallest flights, where pressure and shearing is further increased. Finally, it is forced through one or more restricted openings (dies) at the discharge end of the barrel. As the food emerges under pressure from the die, it expands to the final shape and cools rapidly as moisture is flashed off as steam. A variety of shapes, including rods, spheres, doughnuts, tubes, strips, squirls or shells can be formed. Typical products include a wide variety of low density, expanded snackfoods and ready-to-eat (RTE) puffed cereals. Developments using combined supercritical fluid technology with extruders to produce a new range of puffed products, pasta and confectionery. Extruded products may be subsequently processed further by drying, frying or packaging. Cold extrusion, in which the temperature of the food remains at ambient is used to mix and shape foods such as pasta and meat products. Low pressure extrusion, at temperatures below 100ºC, is used to produce, for example, liquorice, fish pastes, surimi and pet foods.

14. Coating or enrobing

Coatings of batter or breadcrumbs are applied to fish, meats or vegetables, chocolate or compound coatings are applied to biscuits, cakes, confectionery and coatings of salt, sugar, flavourings or colourants are also applied to snackfoods, baked goods and confectionery. In each case, the aim is to improve the appearance and eating quality of foods, and to increase their variety. In some cases coatings also provide a barrier to the movement of moisture and gases, or protect the food against mechanical damage. Coatings are also applied to foods:

- To improve appearance
- To modify the texture

- To enhance flavours
- To improve convenience
- To increase variety and add value to basic products.

Coating operations have a minimal effect on the nutritional quality of foods, except in terms of the ingredients added to food in the coatings.

Methods of coating particles of food to encapsulate flavours or other ingredients are

There are three main methods of coating foods. The selection of an appropriate method depends on the type of coating material to be used and the intended effect of coating. The main methods are:

1. Enrobing with chocolate, compound coatings, glazes or batters
2. Dusting with spices, breadcrumbs, flour, sugar, flavourings, colourings, salt, etc.
3. Pan coating with sugar or sugarless coatings.

15. Packaging

Packaging is an important part of all food processing operations and with some (for example canning and MAP), it is integral to the operation itself. There have been substantial developments in both materials and packaging systems over the last ten years, which have been instrumental in both reducing packaging costs and the development of novel and minimally processed foods. Packaging may be defined in terms of its protective role as in 'packaging is a means of achieving safe delivery of products in sound condition to the final user at a minimum cost' or it can be defined in business terms as 'a techno-economic function for optimizing the costs of delivering goods whilst maximizing sales and profits'.

The functions of packaging are:

• Containment – to hold the contents and keep them secure until they are used

• Protection – against mechanical and environmental hazards encountered during distribution and use

• Communication – to identify the contents and assist in selling the product. Shipping containers should also inform the carrier about the destination and any special handling or storage instructions. Some packages inform the user about method of opening and/or using the contents

• Machinability – to have good performance on production lines for high speed filling, closing and collating (1000 packs per min or more), without too many stoppages

• Convenience – throughout the production, storage and distribution system, including easy opening, dispensing and/or after-use retail containers for consumers (Paine, 1991).

The main marketing considerations for a package are:

• The brand image and style of presentation required for the food

• Flexibility to change the size and design of the containers

• Compatibility with methods of handling and distribution, and with the requirements of retailers.

The package should be aesthetically pleasing, have a functional size and shape, retain the food in a convenient form for the customer without leakage, possibly act as a dispenser which opens easily and recloses securely, and be suitable for easy disposal, recycling or re-use. The package design should also meet any legislative requirements concerning labelling of foods.

16. Materials handling

Efficient materials handling is 'the organized movement of materials in the correct quantities, to and from the correct place, accomplished with a minimum of time, labour, wastage and expenditure, and with maximum safety'. When establishing methods for materials handling, a systems approach that covers raw materials and ingredients, in-process stock and distribution of finished products to consumers is needed. This creates optimum flows of materials, in the correct sequence throughout the production process, and avoids bottlenecks or shortages. This area is known as production planning. In summary, correct production planning should ensure that:

- Raw materials, ingredients and packaging materials are scheduled to arrive at the factory at the correct time, in the correct quantities and in the required condition
- Storage facilities are sufficient for the anticipated stocks of materials and are suitable to maintain the quality of materials for the required time
- Handling equipment has sufficient capacity to move materials in the required amounts
- Staff levels are adequate to handle the required amounts of materials

• Processing and packaging equipment is selected to provide the required production throughput finished product warehousing is sufficient to accommodate stock levels, taking into account both production and sales volumes

• Distribution vehicles are sufficient in number and capacity, and journeys are scheduled to optimise fuel consumption and drivers' time, particularly minimising journeys with empty vehicles.

16.1. Handling equipment for raw materials and ingredients

The bulk movement of particulate, powdered and liquid food ingredients by road or rail tanker, and storage in large silos, has been common practice in large plants for many years. More recent advances in microelectronics are now applied to monitoring and control of storage silos (fill-level, humidity and temperature) and multi-ingredient batch weighing and metering systems, using PLC based logic controllers. Additionally, within the last few years increasing use has been made of large (1 tonne or more) intermediate bulk containers (IBCs) for movement of foods. Examples include 'Combi' bins and woven polypropylene bags which are used to both ship ingredients and to move food within a production line. Large bulk packaging made from eight-layer corrugated outer card and an inner food grade membrane is increasingly replacing metal drums as shipping containers.

Mechanised handling systems for fresh crops and other raw materials for processing have developed from, for example, the pea viners and combine harvesters that have been in common use for several decades. Mobile crop washing, destoning and grading equipment, gentle-flow box tippers that transport and unload crops with minimal damage, and automatic cascade fillers for large boxes and 'jumbo' bags are now routinely used to produce washed and graded crops for processors and retailers. Batch weighing and metering systems are an integral part of ingredient or raw materials handling and there are a number of different systems: for example, sensors can be used to detect the loss in weight from a storage tank or silo as it is emptied and calculate the weight of ingredient used. Alternatively sensors on a mixing vessel can detect the increase in weight as different ingredients are added. The information from sensors is used by PLCs to control pumps, create pre-programmed recipe formulations and record data for production costing and stock control.

16.2. Handling equipment for processing

The pattern of movement of materials during processing should be as simple as possible to avoid the risk of contamination of processed foods by raw foods. Cross-contamination is a major concern for all food processors, but especially for those that produce 'high-risk' foods. There is no single 'model' layout for plant and equipment, but five patterns are commonly used:

1. Straight line – for relatively simple processes containing few pieces of equipment.

2. Serpentine (or 'zig-zag') – where the production line is increased for a given floor area by 'bending back' on itself.

3. U-shaped – used when a process is required to place the finished product in the same general area as the starting point.

4. Circular – used when a part-processed or finished product is required in exactly the same place where it started.

5. Odd-angle – where there is no recognisable pattern, but where short flow lines are needed between a group of related operations, where handling is mechanised or where space limitations will not permit another layout.