UNIT 1 PRINCIPLES OF HEAT AND MASS TRANSFER

Structure

1.0 OBJECTIVES

By the time you have studied this unit, you should be able to:

- define the basic principles and methods of heat transfer;
- explain the role of heat transfer in heat preservation processes;
- identify the type of food for heat processing;
- determine the heat penetration and calculate the process time in a food; and
- identify the factors affecting heat transfer and apply corrective measures to enhance the process of heat transfer.

1.1 INTRODUCTION

Heat transfer is an important operation in the food industry. Whether it is called cooking, baking, drying, sterilizing or freezing, heat transfer is part of processing of almost every food. Heat transfer is a dynamic process in which heat is transferred spontaneously from one body to another cooler body. The rate of heat transfer depends upon the differences in temperature between the bodies, the greater the difference in temperature, the greater will be the rate of heat transfer.

Temperature difference between the source of heat and the receiver of heat is, therefore, the driving force in heat transfer. An increase in the temperature difference increases the driving force and, thus the rate of heat transfer. The heat passing from one body to another travels through some medium, which in general offers resistance to the heat flow. Both these factors, the temperature difference and the resistance to heat flow, affect the rate of heat transfer.

1.2 HEAT TRANSFER SYSTEM

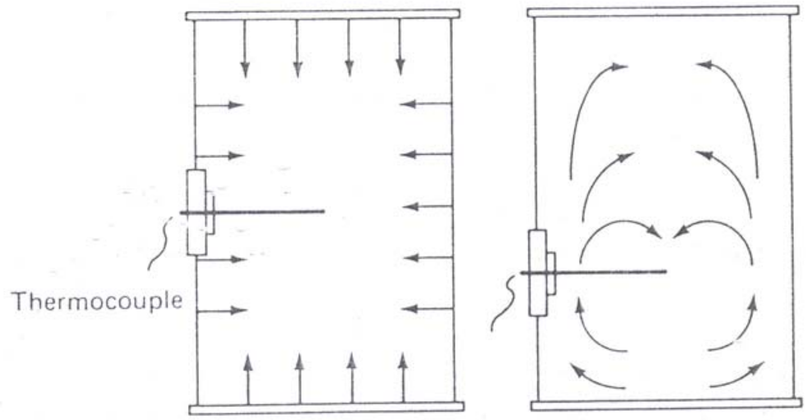
Heat can be transferred from one object to another in three ways: by **conduction,** by **convection** and by **radiation**.

Conduction is the movement of heat by direct transfer of molecular energy within solids. The molecules with greater energy communicating some of this energy to neighbouring molecules with less energy. An example of conduction is the heat transfer through the solid walls of a refrigerated store.

Convection is the transfer of heat by the movement of groups of molecules in a fluid. The groups of molecules may be moved by either density changes or by forced motion of the fluid. An example of convection heating is cooking in a jacketed pan: without a stirrer, density changes cause heat transfer by natural convection; while with a stirrer, the convection is forced.

Radiation is the transfer of heat energy by electromagnetic waves, which transfer heat from one body to another, in the same way as electromagnetic light waves transfer light energy. An example of radiant heat transfer is when a foodstuff is passed below a bank of electric resistance heaters that are red-hot (electric grill).

In general, heat is transferred in solids by conduction and in fluids by conduction and convection (Figure 1.1). Heat transfer by radiation occurs through open space, can often be neglected, and is most significant when temperature differences are substantial. In practice, the three types of heat transfer may occur simultaneously. For calculations it is often best to consider the mechanisms separately, and then to combine them where necessary.



(a) **(b)**

Figure 1.1: Heat transfer in containers by (a) conduction and (b) convection

1.2.1 Conduction

In the case of heat conduction, the equation, heat transfer rate = driving force/resistance, can be applied directly. The driving force is the temperature difference per unit length of heat-transfer path, i.e., temperature gradient. Instead of resistance to heat flow, its reciprocal, **conductance**, is used. This changes the form of the general equation to:

Rate of heat transfer = driving force x conductance, which is:

$$dQ/dt = kA\, dT/dx \qquad (1.1)$$

Where, dQ/dt (JS^{-1})is the rate of heat transfer, the quantity of heat energy transferred per unit of time, A (m^2)is the area of cross-section of the heat flow path, dT/dx ($^0Cm^{-1}$)is the temperature gradient, that is the rate of change of temperature per unit length of path, and k (Jm^{-1} s^{-1} ^0K or Wm^{-1} $^0K^{-1}$)is the thermal conductivity of the medium. Notice the distinction between thermal conductance, which relates to the actual thickness of a given material (k/x) and **thermal conductivity**, which relates only to unit thickness. Eq. (1.1) is known as the **Fourier equation** for heat conduction.

Thermal conductivity does change slightly with temperature, but in many applications it can be regarded as a constant for a given material. Most foodstuffs contain a high proportion of water and as the thermal conductivity of water is about 0.7 J m^{-1} s^{-1}°C^{-1} above 0°C, thermal conductivities of foods are in the range 0.6-0.7 J m^{-1} s^{-1}°C^{-1}. Ice has a substantially higher thermal conductivity than water, about 2.3 J m^{-1} s^{-1}°C^{-1}. The thermal conductivity of frozen foods is, therefore, higher than foods at normal temperatures.

1.2.2 Convection

Convection heat transfer is the transfer of energy by the mass movement of groups of molecules. It is restricted to liquids and gases, as mass molecular movement does not occur at an appreciable speed in solids. It cannot be mathematically predicted as easily as can transfer by conduction or radiation and so its study is largely based on experimental results rather than on theory.

Newton found, experimentally, that the rate of cooling of the surface of a solid, immersed in a colder fluid, was proportional to the difference between the temperature of the surface of the solid and the temperature of the cooling fluid. This is known as **Newton's Law of Cooling**, and it can be expressed by the following equation.

$$q = h_s A(T_a - T_s) \qquad (1.2)$$

Where, h_s is called the surface heat-transfer coefficient, T_a is the temperature of the cooling fluid and T_s is the temperature at the surface of the solid. The surface heat-transfer coefficient can be regarded as the conductance of a hypothetical surface film of the cooling medium of thickness x_f such that

$$h_s = k_f / x_f$$

Where, k_f is the thermal conductivity of the cooling medium. It is useful at this point, however, to appreciate the magnitude of h_s under various common conditions and these are shown in Table 1.1.

Table 1.1: Approximate range of surface heat transfer coefficients

	hs (J m^{-2} s^{-1}°C^{-1})
Boiling liquids	2400-24,000
Condensing liquids	1800-18,000
Still air	6
Moving air (3 m s^{-1})	30
Liquids flowing through pipes	1200-6000

1.2.3 Radiation

Radiation heat transfer is the transfer of heat energy by electromagnetic radiation. Radiation operates independently of the medium through which it occurs and depends upon the relative temperatures, geometric arrangements and surface structures of the materials that are emitting or absorbing heat.

Radiation of wavelength 0.8-400 µm (infrared) is referred to as thermal radiation or heat rays since electro magnetic radiation with this wavelength is most readily absorbed and converted to heat energy. The infrared radiation is used primarily for surface heating as it is transmitted rapidly to the surface. It is used for dehydration of fruits and vegetables, freeze drying, baking, etc.

Radiation can be significant with small temperature differences as, for example, in freeze-drying and in cold stores, but it is generally more important where the temperature differences are greater. Under these circumstances, it is often the most significant mode of heat transfer, for example in bakers' ovens and in radiant driers.

The basic formula for radiant-heat transfer is the **Stefan-Boltzmann Law**

$$q = A\,\sigma \boldsymbol{T}^4 \qquad (1.3)$$

Where, ***T*** is the absolute temperature (measured from the absolute zero of temperature at −273°C, and indicated in Bold type) in degrees Kelvin (K) in the SI system, and (sigma) is the Stefan-Boltzmann constant = 5.73×10^{-8} J m^{-2} $s^{-1}K^{-4}$ The absolute temperatures are calculated by the formula K = (°C+273).

This law gives the radiation emitted by a perfect radiator (a **black body** as this is called though it could be a red-hot wire in actuality). A black body gives the maximum amount of emitted radiation possible at its particular temperature. Real surfaces at a temperature T do not emit as much energy as predicted by Eq. (1.3), but it has been found that many emit a constant fraction of it. For these real bodies, including foods and equipment surfaces, that emit a constant fraction of the radiation from a black body, the equation can be rewritten

$$q = \varepsilon A\,\sigma \boldsymbol{T}^4 \qquad (1.4)$$

Where, ε (epsilon) is called the **emissivity** of the particular body and is a number between 0 and 1. Bodies obeying this equation are called **grey bodies**. Emissivities vary with the temperature ***T*** and with the wavelength of the radiation emitted. For many purposes, it is sufficient to assume that for:

* dull black surfaces (lamp-black or burnt toast, for example), emissivity is approximately 1;
* surfaces such as paper/painted metal/wood and most foods, emissivities are about 0.9;
* rough un-polished metal surfaces, emissivities vary from 0.7 to 0.25;
* polished metal surfaces, emissivities are about or below 0.05.

These values apply at the low and moderate temperatures, which are those encountered in food processing. Just as a black body emits radiation, it also absorbs it and according to the same law, Eq. (1.3). Again grey bodies absorb a fraction of the quantity that a black body would absorb, corresponding this time to their **absorptivity** α (alpha). For grey bodies it can be shown that α = ε. The fraction of the incident radiation that is not absorbed is reflected, and thus, there is a further term used, the **reflectivity**, which is equal to (1 – α).

The radiant energy transferred between two surfaces depends upon their temperatures, the geometric arrangement, and their emissivities. For two parallel surfaces, facing each other and neglecting edge effects, each must intercept the total energy emitted by the other, either absorbing or reflecting it. In this case, the net heat transferred from the hotter to the cooler surface is given by:

$$q = AC\sigma\,(\boldsymbol{T}_1^4 - \boldsymbol{T}_2^4) \qquad (1.5)$$

where $1/C = 1/\varepsilon_1 + 1/\varepsilon_2 - 1$, ε_1 is the emissivity of the surface at temperature T_1 and ε_2 is the emissivity of the surface at temperature T_2.

1.2.4 Overall Heat Transfer Coefficients

It is most convenient to use overall heat transfer coefficients in heat transfer calculations as these combine all of the constituent factors into one, and are based on the overall temperature drop. Radiation coefficients, subject to the limitations discussed in the section on radiation, can be incorporated in the overall coefficient. The radiation coefficients should be combined with the convection coefficient to give a total surface coefficient, as they are in series, and so:

$$h_s = (h_r + h_c) \qquad (1.6)$$

The overall coefficient U for a composite system, consisting of surface film, composite wall, surface film, in series, can then be calculated as:

$$1/U = 1/(h_r + h_c)_1 + x_1/k_1 + x_2/k_2 + \ldots + 1/(h_r + h_c)_2 \qquad (1.7)$$

In Eq. (1.7) often one or two terms are much more important than other terms because of their numerical values. In such a case, the important terms, signifying the low thermal conductance are said to be the **controlling terms**.

1.2.5 Heat Transfer from Condensing Vapours

The rate of heat transfer obtained when a vapour is condensing to a liquid is very often important. In particular, it occurs in the food industry in steam-heated vessels where the steam condenses and gives up its heat; and in distillation and evaporation where the vapours produced must be condensed. In condensation, the latent heat of vaporization is given up at constant temperature, the boiling temperature of the liquid. Two generalized equations have been obtained:

1) For condensation on **vertical tubes or plane surfaces**

$$h_v = 0.94\,[(k^3\rho^2 g/\mu) \times (\lambda/L\Delta T)]^{0.25} \qquad (1.8)$$

Where, λ (lambda) is the latent heat of the condensing liquid in J kg^{-1}, L is the height of the plate or tube and the other symbols have their usual meanings.

2) For condensation on a **horizontal tube**

$$h_h = 0.72\,[(k^3\rho^2 g/\mu) \times (\lambda/D\Delta T)]^{0.25} \qquad (1.9)$$

1.2.6 Heat Transfer to Boiling Liquids

When the presence of a heated surface causes a liquid near it to boil, the intense agitation gives rise to high local coefficients of heat transfer. A considerable amount of experimental work has been carried out on this, but generalized correlations are still not very adequate. It has been found that the apparent coefficient varies considerably with the temperature difference between the heating surface and the liquid. For temperature differences greater than about 20°C, values of *h* decrease, apparently because of blanketing of the heating surface by vapours. Over the range of temperature differences from 1 to 20°C, values of *h* for boiling water increase from 1200 to about 60,000 J m^{-2} s^{-1} $°C^{-1}$. For boiling water under atmospheric pressure, the following equation is approximately true:

$$h = 50(\Delta T)^{2.5} \qquad (1.10)$$

Where, ΔT is the difference between the surface temperature and the temperature of the boiling liquid and it lies between 2 and 20°C. In many applications the high boiling film coefficients are not of much consequence, as resistance in the heat source controls the overall coefficients.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. List the different methods of heat transfer.

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2. What is the relationship of conduction heat transfer rate with temperature difference? What is the name of the equation used for determining the conduction heat transfer rate?

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3. What is the name of the equation used for expressing the radiative flux from an object? How is it related to temperature and properties of the material?

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4. While estimating the rate of heat transfer between two objects, the temperature of one of the objects is doubled. If convection and radiation are the two modes of heat transfer between the two objects, which mode would increase more and why?

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1.3 TYPE OF FOOD FOR HEAT PROCESSING

There are essentially two types of food when we talk of thermal processing:

1. Acid foods
2. Low acid foods

These two categories of foods differ significantly in their behaviour when thermally processed. The acidity of the food, using the pH scale as a measure of acidity, where 1 = very high acid and 4 = very low acid; the dividing line for **acid foods** and **low-acid foods** is pH 4.6. **Acid foods** can be canned at a temperature of 100°C, while **low-acid foods** must be pressure canned (to a temperature of 115°C). The reason for this is that the toxin-producing, potentially lethal organism, *Clostridium botulinum*, will not grow and produce toxins at a pH below 4.6. Many spoilage microorganisms will not grow between pH 1 and 4.6 either. The most common spoilage microorganisms associated with **acid foods** are yeasts and moulds that can tolerate acid environments.

1. Acid foods

High acid foods contain more natural acids. Many fruits are high acid foods and the presence of these natural acids helps prevent growth of some spoilage microorganisms. If the food product has a high enough acid level, boiling-water temperatures are high enough to destroy spoilage organisms. This is a prevention method for the deadly *Clostridium botulinum* bacteria.

2. Low acid foods

Low acid foods, such as vegetables and meat products, contain very little natural acid. They must be processed at higher temperatures than boiling-water to destroy any *Clostridium botulinum* bacteria. Water boils at 100°C, at sea level, and at a lower temperature at higher elevations. Turning up the temperature under the pot or letting the water boil for a longer time does not raise the temperature of the water above its boiling point. To make water boil at a higher temperature, it has to be put under pressure, such as in a pressure canner. When a food is processed at 1.0 kg/cm^2 pressure, the water boils when it gets to 115°C, rather than at 100°C. This is high enough to kill the bacteria that causes botulism poisoning.

Adjust for Altitude to Ensure Safety

The above values of temperatures have been determined for mean sea level. As we move up the mountains, the atmospheric pressure goes down and water boils at lower temperatures as altitude increases. Lower boiling temperatures are less effective for killing bacteria. You must increase either the process time or canner pressure to make up for lower boiling temperatures.

Because altitude affects pressure and the boiling point of liquid, adjustments must be made when canning foods at altitudes of 300 m above sea level or higher. When using the boiling water bath method, processing time must be increased. Add 5 minutes to processing time for altitudes between 300 m and 1500 m above sea level. When using the pressure canner method, pressure must be increased. If using a dial-gauge pressure canner, process foods at 0.8 bar pressure for altitudes between 600 m and 1200 m and at 0.9 bar pressure for altitudes between 1200 m and 1800 m. If using the weight-gauge pressure canner, use 1.0 bar of pressure.

When you mix low-acid and acid foods, assume that the mixture remains low-acid. Although tomatoes used to be considered an acid food, some are now known to have pH values slightly above 4.6, which means they are low-acid. To safely can them as acid foods in a boiling-water canner, you must add lemon juice or citric acid.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. How are acid and low-acid foods distinguished?

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2. How is a thermal process for an acid food different than that for a low-acid food?

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3. What is the method used to raise the boiling point of water in food processing?

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4. What changes are required for thermal processing of foods at high altitudes?

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1.4 HEAT PENETRATION

Heat penetration studies are required to be conducted for verifying the sterilizing temperature of a load (food) meant for moist heat sterilization. These studies are conducted to ensure that the coolest unit within a pre-defined loading pattern (including minimum and maximum loads) will consistently be exposed to sufficient heat lethality (minimum "F").

Heat penetration curve can be drawn by plotting the logarithmic difference between either retort temperature and product temperature (heating curve) or product temperature and cooling medium temperature (cooling curve) versus time. The purpose of a heat-penetration study is to determine the heating and cooling behaviour of a product/package combination in a specific retort system for the establishment of safe thermal processes and evaluating process deviations. The study is designed to adequately and accurately examine all critical factors associated with the product, package and process, which affect heating rates. A goal in conducting these studies is to identify the worst-case temperature response expected to occur in commercial production as influenced by the product, package and process.

Several product, process, package and measurement-related factors can contribute to variations in the time-temperature data gathered during a heat-penetration test. Establishment of a process requires expert judgment and sound experimental data for determining which factors are critical and the effect of changing those factors both within and beyond established critical limits.

A typical heat penetration curve is shown in Figure 1.2. A broken heating curve occurs when a food is initially heated by convective heating but then undergoes a rapid transition to conductive heating (for example in foods, which contain high concentration of starch, which undergoes a sol-to-gel transition).

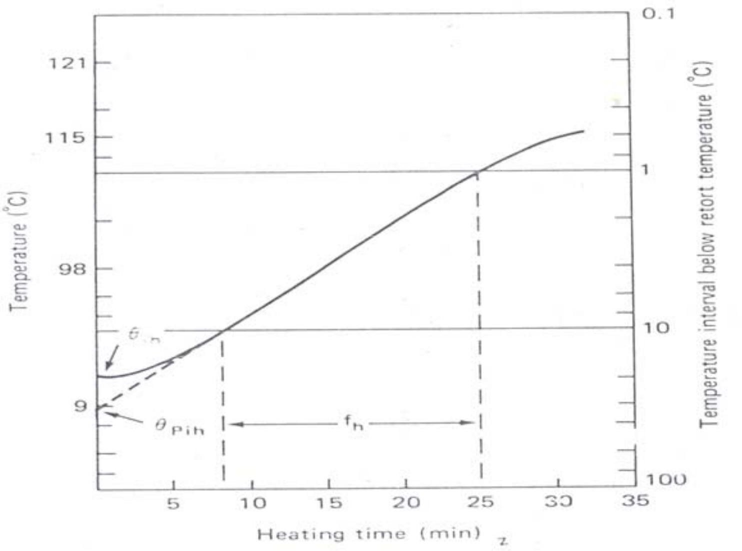

Figure 1.2: Heat penetration curve

There are a number of ways of estimating how effective heat sterilization can be. The thermal death time is the time microbes must be exposed to a particular temperature before they are all dead. Similarly, the thermal death point is the temperature at which all microbes in a sample are killed. Both are very unsatisfactory, since they depend on many factors such as number of microbes present in a sample, analytical conditions and techniques, etc.

1.5 HEAT TRANSFER CHARACTERISTICS OF FOOD

It is necessary to have information on both the heat resistance of microorganisms or enzymes and the rate of heat penetration into the food for determination of process time of a food.

Heat is transferred from steam or pressurized water through the container and into the food. Generally the surface heat transfer coefficient is very high and is not a limiting factor in heat transfer. The following factors influence the rate of heat penetration into a food:

i) Type of product
ii) Size of the container
iii) Agitation of the container
iv) Temperature of the retort
v) Shape of the container. Tall containers promote convection currents in convective heating foods.
vi) Type of container. Heat penetration is faster through metal than through glass or plastics owing to differences in thermal conductivity.

In this section, the objective is to learn as to how the thermal properties of food products affect the heat penetration and the quantity of heat. Two thermal properties of importance are thermal conductivity and thermal diffusivity in determining heat penetration. Specific heat and latent heat are important in determining the quantity of heat required for the process.

I. **Thermal conductivity** is the property indicating the rate at which heat flows through a food product. A product with high thermal conductivity lets the heat flow easily, whereas a material with low thermal conductivity, also known as an insulator, puts resistance to the flow of heat. Fourier's heat conduction equation could be used to derive the units of thermal conductivity, i.e., W/(m°C). It does change slightly with temperature, but in many applications it can be regarded as a constant for a given material. Most foodstuffs contain a high proportion of water and as the thermal conductivity of water is about 0.7 J m^{-1} s^{-1} °C^{-1} above 0°C, thermal conductivities of foods are in the range of 0.6-0.7 J m^{-1} s^{-1} °C^{-1}. Ice has a substantially higher thermal conductivity than water, about 2.3 J m^{-1} s^{-1} °C^{-1}. The thermal conductivity of frozen foods is, therefore, higher than foods at normal temperatures.

Typical thermal conductivities

Metals: k = 50-400 W/m°C
Water: k = 0.597 W/m°C
Air: k = 0.0251 W/m°C
Insulating materials: k = 0.035 - 0.173 W/m°C

For foods it is represented as

$$k = 0.25\ m_c + 0.155\ m_p + 0.16\ m_f + 0.135\ m_a + 0.58\ m_m$$

Where m is mass fraction and subscripts c: carbohydrate, p: protein, f: fat, a: ash and m: moisture.

or

$$k = 0.55p/100 + 0.26(100–p)/l00\ J\ m^{-1}\ s^{-1}\ °C^{-1} \text{ above freezing}$$

$$= 2.4p/100 + 0.26(100\ -p)/l00\ J\ m^{-1}\ s^{-1}\ °C^{-1} \text{ below freezing.}$$

Where p is the percentage of water in the foodstuff.

II. Thermal diffusivity is the actual ability of a food to conduct heat to adjacent molecules. Thermal diffusivity is a derived property that is the ratio of thermal conductivity and the product of density and specific heat. The units of thermal diffusivity, therefore, work out to be m^2/s. Higher value of thermal diffusivity means faster heat penetration and vice versa.

III. Specific heat: The specific heat is an important quantity that determines the amount of energy that must be supplied or withdrawn from a unit mass of material in order to increase or decrease its temperature by one degree. Knowledge of the specific heat of a material is, therefore, important in the design of processes such as chilling, freezing, warming, sterilization and cooking. Specific heat has the units of kJ/(kg.K) in SI system of units.

Specific heat = 4.19p/100 + 0.84(100 – p)/100 kJ kg^{-1} °C^{-1} above freezing
= 2.1 p/100 + 0.84(100 – p)/100 kJ kg^{-1} °C^{-1} below freezing.

p is percentage of water in food stuff

IV. Phase transitions: It is important to determine the temperature at which transitions occur, the enthalpy change associated with a transition, the type of transition involved (exothermic or endothermic), and the quantity of material that undergoes a transition. As an example, we will consider the melting and crystallization of food components. When a material changes its physical state from solid-to-liquid (melting) or from liquid-to-solid (crystallization) it absorbs or gives out heat, respectively. A process that absorbs heat is an endothermic process, whereas a process that evolves heat is an exothermic process. Pure substances usually have very sharp melting or crystallization points and, therefore, all the heat is absorbed or evolved over a narrow range of temperature. Most foods are complex materials and, therefore, do not exhibit sharp transitions from one phase to another. The amount of heat required for the phase change is called the latent heat and has the units of kJ/kg.

$$\text{Latent heat} = 335p/100 \text{ kJ kg}^{-1}$$

This equation and the ones given earlier for thermal conductivity and specific heat represent a considerable over-simplification so they should be used with caution, particularly in the region between −18°C to 0°C. Freezing of foodstuffs occur over a range of temperatures and not at any fixed point.

Some properties of liquids and thermal data for food products are depicted in Tables 1.2 and 1.3, respectively.

Table 1.2: Some properties of liquids

	Thermal conductivity	**Specific heat**	**Density**	**Viscosity**	**Temperature**
	($J\ m^{-1}\ s^{-1}\ °C^{-1}$)	($kJ\ kg^{-1}\ °C^{-1}$)	($kg\ m^{-3}$)	($N\ s\ m^{-2}$)	(°C)
Water	0.57	4.21	1000	1.87×10^{-3}	0
		4.21	987	0.56×10^{-3}	50
	0.68	4.18	958	0.28×10^{-3}	100
Sucrose 20% soln.	0.54	3.8	1070	1.92×10^{-3}	20
				0.59×10^{-3}	80
60% soln.				6.2×10^{-3}	20
				5.4×10^{-3}	80
Sodium chloride 22% soln.	0.54	3.4	1240	2.7×10^{-3}	2
Acetic acid	0.17	2.2	1050	1.2×10^{-3}	20
Ethyl alcohol	0.18	2.3	790	1.2×10^{-3}	20
Glycerine	0.28	2.4	1250	830×10^{-3}	20
Olive oil	0.17	2.0	910	84×10^{-3}	20
Rape-seed oil			900	118×10^{-3}	20
Soya-bean oil			910	40×10^{-3}	30
Tallow			900	18×10^{-3}	65

Milk (whole)	0.56	3.9	1030	2.12×10^{-3}	20
Milk (skim)			1040	1.4×10^{-3}	25
Cream 20% fat			1010	6.2×10^{-3}	3
30% fat			1000	13.8×10^{-3}	3

Table 1.3: Thermal data for some food products

	Freezing point (°C)	Percent water	Specific heat (kJ kg^{-1}°C^{-1})		Latent heat of fusion (kJ kg^{-1})
			Above freezing	Below freezing	
Fruit					
Apples	–2	84	3.60	1.88	280
Bananas	–2	75	3.35	1.76	255
Grapefruit	–2	89	3.81	1.93	293
Peaches	–2	87	3.78	1.93	289
Pineapples	–2	85	3.68	1.88	285
Watermelons	–2	92	4.06	2.01	306
Vegetables					
Asparagus	–1	93	3.93	2.01	310
Beans (green)	–1	89	3.81	1.97	297
Cabbage	–1	92	3.93	1.97	306
Carrots	–1	88	3.60	1.88	293
Corn	–1	76	3.35	1.80	251
Peas	–1	74	3.31	1.76	247
Tomatoes	–1	95	3.98	2.01	310
Water	0	100	4.19	2.05	335

1.6 DEVICES FOR DETERMINATION OF HEAT PENETRATION

There are different types of thermometers available for measuring the temperature in a thermal process and, thereby, permitting the determination of heat penetration.

I. Mercury-in-glass (MIG) thermometer

Each retort system used for the thermal processing is equipped with a MIG thermometer. Aseptic processing systems may have a temperature indicating device other than MIG thermometer as the sole temperature indicator. The MIG thermometer is the reference instrument for all temperature readings, including vent temperature, come-up temperature and process temperature during processing.

It is important that the MIG thermometer be tested/calibrated at the operating temperature of the retort system (i.e., 115°C, 120°C, 125°C etc.) and if possible in the heating medium used in the retort. If the retort is operated at more than one processing temperature or over a wide range of temperatures the MIG thermometer should be checked at all of the temperatures normally used for processing. The MIG thermometers should be tested against a thermometer that can be traced back to a BIS Standard thermometer. The accuracy of the standard thermometer should be checked at least once every 3 years depending upon how it is handled and stored.

II. Temperature recording device

Each retort system is equipped with an accurate temperature-recording device. The recording device provides a continuous record of the temperature in the retort system during thermal processing. Common systems in use are circular or strip charts, which are marked with ink pens, electrical sparks, pressure pins, or which are created by graph plotters at the time temperature readings are received. Electronic temperature monitors and recorders are now available for the purpose and should be utilized for greater accuracy and precision avoiding human errors. A band or ribbon type surface pyrometer is used by processors to monitor container surface temperatures.

III. Temperature sensors

Temperature measurement can be accomplished by essentially five basic methods: (1) liquid-in-glass, (2) resistance thermometry, (3) thermoelectric thermometry, (4) optical/radiation pyrometry, and (5) bi-metal. Investigators are most familiar with the liquid (mercury or alcohol usually) -in-glass and the bi-metal (dial gauge) types. It is possible now that investigators will encounter the use of the optical/radiation pyrometers as well.

i) Resistance thermometry

A resistance thermometer is a temperature-measuring instrument consisting of a sensor (an electrical circuit element whose resistance varies with temperature), a framework on which to support the sensor, a sheath by which the sensor is protected, and wires by which the sensor is connected to a measuring instrument, which is used to indicate the effect of variations in the sensor resistance. Resistance thermometers provide absolute calibration of temperatures in that no reference junctions are involved, and no special extension wires are needed between the sensor and the measuring instrument (as with thermocouples).

The sensors can be of two types: resistance temperature detectors (RTD's) and thermistors. The RTD sensing element is formed of solid conductors (usually in wire form) wound upon an insulating core. The insulating core is usually made of mica or ceramic. The conductors, which are wound in a helical coil to prevent mechanical restraints during thermal expansion, are generally made of platinum; however nickel and copper have been used. Platinum best meets the requirements because being a noble metal, it can be highly refined, it resists contamination, it is mechanically and electrically stable, and the relationship between temperature and resistance is quite linear.

Thermistors (a contraction for "thermally sensitive resistors") are electrical circuit elements formed of solid semi conducting materials such as oxides of nickel, manganese, iron, cobalt, copper, magnesium, titanium, and other metals. The powdered metal is formed under pressure into the desired shape, usually a flat disc. The disc is sintered, leads are attached, and encapsulated in epoxy. The finished thermistor can also be encased in a sheath of plastic, stainless steel, copper or aluminum. Both the RTD and thermistor can be obtained in various configurations.

ii) Thermoelectric thermometry

The thermoelectric thermometer is a temperature measuring instrument consisting of two continuous, dissimilar thermocouple wires extending from a measuring junction to a reference junction with copper connecting wires to a potentiometer. Unlike the resistance types, where power must be supplied to the circuit, the thermocouple circuit generates a measurable low voltage output that is almost directly proportional to the temperature difference between the "hot" junction and the "cold" junction. A unit change in this temperature difference will produce some net change in electromotive force (emf or voltage). Thermoelectric thermometry makes use of the known relationship between a difference in junction temperatures and the resulting emf developed by a thermocouple circuit. The temperature of one junction (reference junction, T1) is held at a constant known value. This is usually accomplished with an ice water (0°C) bath. The temperature of the other junction (measuring junction, T2) is determined by measuring the thermocouple circuit emf and referring to calibration tables for the particular thermocouple materials. The thermocouple junction usually is formed by twisting and fusing the two wires together or they may be butt-welded. The finished element may be used bare or enclosed in a sheath.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Write the full forms of the following abbreviations:

   a) MIG thermometer
   b) RTD sensor

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2. How is a thermocouple used for temperature measurement?

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3. What is a thermistor? How does it differ from a RTD sensor?

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4. How is temperature in Kelvin scale related to temperature in Celsius scale?

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1.7 DETERMINATION OF COLD POINT IN A FOOD CONTAINER

In a study, determination of the cold spot was made using data collected for heat penetration curves at 5 potential cold spot locations in the jars in 18 canner loads (Table 1.4). Two levels of two procedural variations were used in testing for process calculations. Temperature profiles were compared for two fill weights (450g, 480g) and two fill temperatures (direct-fill, and after a 10 minute wait, which had means of 84.4°C and 80.4°C, respectively). Process calculation was accomplished by using thermocouples in each of six jars in different canner loads of each of the three fill methods (standard, low initial temperature, and high-fill weight). These jars were processed to 90.5°C plus an additional 5 minutes. Processing was done in a boiling water canner using the stovetop burners of a household gas range. Data were recorded using Type T copper-constantan thermocouples.

Cold Spot Location

- The cold spot for this product and jar combination was located at the geometric centre of the jar, Table 1.4.

- The D value is the number of minutes it takes the straight line portion of the heat penetration plot to pass through one logarithmic cycle.
- A larger D represents a slower rate of heat penetration.

Table 1.4: Cold spot determination of cranberry salsa in pint jars

Thermocouple height in pint jar	Average D value n = 18	Range	Standard deviation
Centre	54.86[1]	48.5-73.4	5.3
½" Below Center	53.89	48.6-64.7	3.9
1" Below Center	51.94	45.8-64.9	4.8
1½" Below Center	48.98	43.0-60.8	4.7
2" Below Center	47.00	41.4-58.0	4.5

[1]Location of cold spot, as determined by largest individual D value (worst-case scenario)

Heat penetration measures the rate at which a product heats during a thermal process. A temperature sensor or thermocouple measures temperature changes in the slowest heating region of the product or container and temperature is monitored on a recording device. The time/temperature data, and heat resistant data for the target microorganism, are used to calculate the scheduled process.

1.8 CALCULATION OF PROCESS TIME

The time/temperature relationship required for desired reduction of microbial population is based on thermal resistance characteristics of the microorganisms. The translation of this information into a form for use by the operator of a commercial system requires integration with the heating and cooling characteristics of the food product within the container. The methods to be presented lead to the establishment of a processing system operator time to ensure that the impact of the thermal process is equivalent to the desired time/temperature for a given microbial population.

One of the first concepts to be understood when establishing process times is **lethality**. The term lethality can be defined as the integrated influence of time and temperature on a microbial population. Lethality is expressed as time at a reference temperature.

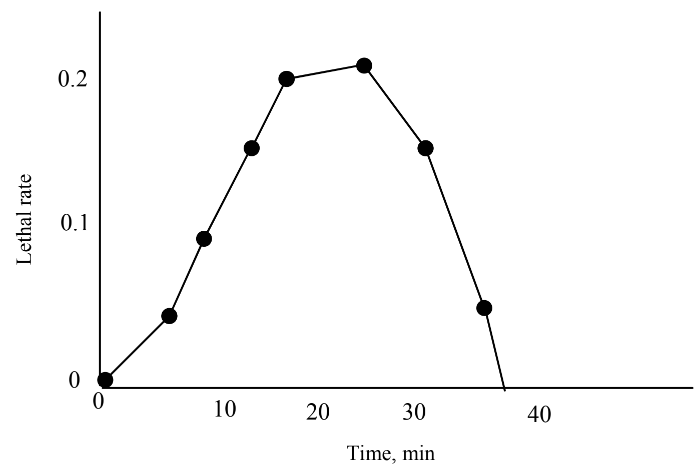

Figure 1.4: Lethal rate curve for typical process in retort

The lethal rate increases gradually with time as the temperature of the product increases. As the product temperature begins to plateau at a magnitude near the heating medium temperature, the lethal rate also plateaus and eventually decreases as the product temperature decreases during cooling. Lethality is expressed in time units for the process accomplished at the heating medium temperature.

The time/temperature relationship representing the process is compared to the process requirement needed to achieve product safety or an established spoilage rate. For example, if the process under consideration is being used to ensure the elimination of *Clostridium botulinum* as a health risk, the lethality for the process must be equal to or greater than the thermal death time for the microbial population.

The D-value or Decimal Reduction Time may be used as a measure. This is defined as the time taken under specified conditions and at a particular temperature to kill 90 per cent of the microbes in a sample. Only 10 per cent or 1/10 of the original number of microbes survive the decimal reduction time: hence its name. D-values can be determined from survivor curves when the log of population is plotted against time.

$$D_{\text{reference temperature}} = \text{Time}/(\text{Log}_a - \text{Log}_b)$$

Where a = the initial population, and b = the survivors after a time interval. F value is a mathematically calculated number that describes the total lethal effect of the process at the slowest heating point in a food container. It is the equivalent, in minutes at a given temperature, of all heat considered with respect to its capacity to destroy spores or vegetative cells of a particular microorganism.

The effectiveness of a canning process is determined from a combination of experimentation and calculation. Processing parameters are expressed in terms of a series of symbols of which D, z, and F are key. When bacterial spores are heated to a lethal temperature as during retorting of canned foods, the death of most species approximates a first order chemical reaction that can be described by a straight line on a semi-logarithmic graph paper. Figure 1.4 shows a hypothetical result from heating a species of spore at 115°C (240°F). In Figure 1.5, one minute is required to reduce the survivors from 10,000 to 1,000 or a 90 per cent reduction (one log reduction). Similarly, one minute is required to reduce the survivors from 1,000 to 100 per gram of food and so on until only 0.01 of a spore is present in 1 gram of food-which really means that there remains only one living spore for each 100 grams of food. This time to reduce the survivors by 90% is the Decimal reduction (D) value or in Figure 1, D_{115} = 1 min. The subscript after the D indicates temperature at which the D value was determined. Many factors affect the D value, such as the species of spore, and the kind of food the spore is suspended in.

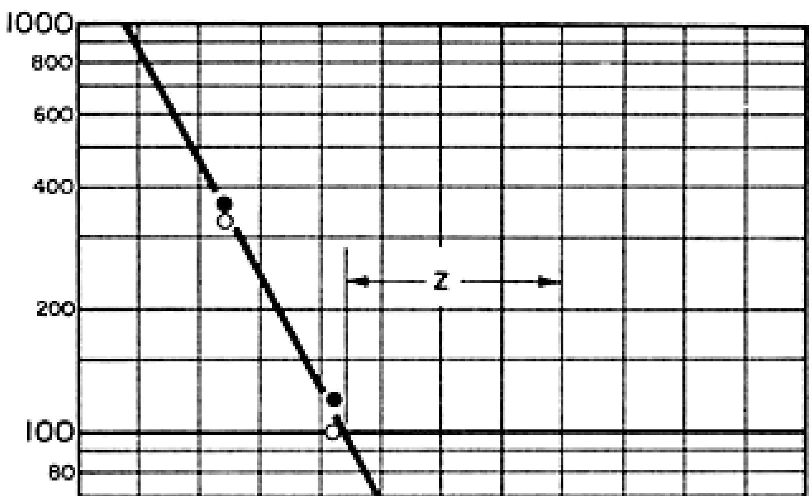

Figure 1.5: Thermal death time curve for *Clostridium botulinum*

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is Decimal Reduction Time (D)? How is it determined?

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2. What is F value and how is it related to D value?

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3. Name the microorganism that is considered in the determination of thermal processing.

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4. What is meant by lethality in food processing? How is it related to various process parameters?

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1.9 FACTORS AFFECTING HEAT PENETRATION

There are many factors, which affect the heat transfer into the food. Generally the surface heat transfer coefficient is very high and is not a limiting factor in heat transfer. The following factors are important which influences the rate of heat penetration into a food:

1. **Type of product:** Liquid or particulate food (for example peas in brine), where natural convection current is established, heat faster than solid food (for example meat pastes and corned beef), where heat is transferred by conduction. The low thermal conductivity of food is a major limitation to heat transfer in conduction heating.

2. **Size of the container:** Heat penetration to the centre is faster in small containers than in large containers.

3. **Agitation of the container:** End-over-end agitation (Figure 1.6) and, to a lesser extent, axial agitation increases the effectiveness of natural convection curie: and thereby increases the rate of heat penetration in viscous or semi-solid foods (for example beans in tomato sauce).

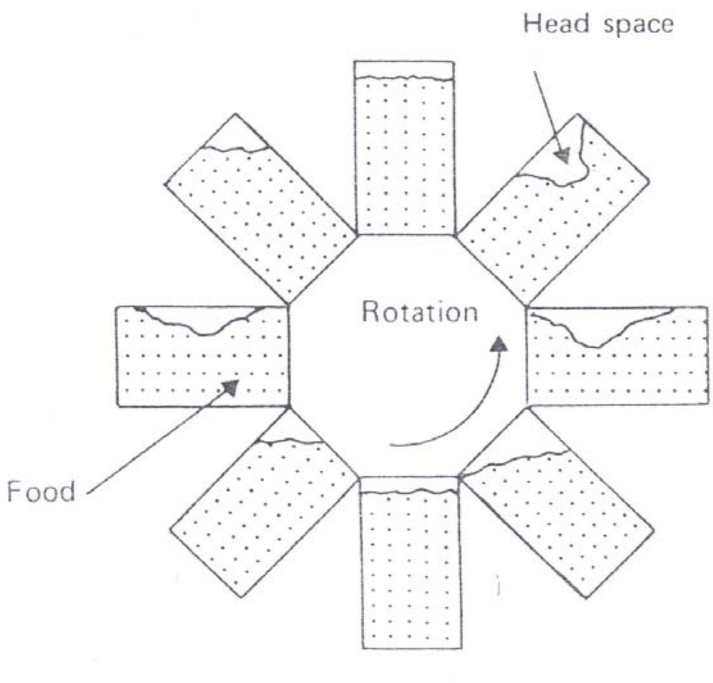

Figure 1.6: End-over-end agitation of containers

4. **Temperature of the retort:** A higher temperature difference between the food and the heating medium causes faster heat penetration.

5. **Shape of the container:** Tall containers promote convection currents in convective heating foods.

6. **Type of container:** Heat penetration is faster through metal than through glass or plastics owing to differences in thermal conductivity.

1.10 LET US SUM UP

We have in this unit learnt the basic concept of heat transfer. Heat is transferred by conduction, convection or radiation modes in a given situation. The methods of temperature measurement include mercury-in-glass (MIG) thermometers, resistance temperature detectors, thermistors, thermocouples and radiation pyrometers. Temperature measurements permit us to evaluate heat penetration rates in the thermal processes so as to determine the process durations to achieve acceptable sterilization levels. These levels differ for acid and less acid foods. If the pH level is below 4.6 the food is classified as an acid food. However, if the pH is equal to or more than 4.6, the foods are low-acid and the process temperatures would have to be more than 100°C. Temperatures more than 100°C are achievable through raising process pressure above that of the ambient. It is important to identify the cold spot in the sterilization process because the heat penetration to that spot will control the overall effectiveness of the process. Decimal reduction time at a given reference temperature is used to fix the process time. Usually, 12 logarithmic cycles are allowed for the microbial population reduction and, thus, the process time F is equal to 12 D. The factors responsible for affecting the temperature distribution and heat penetration rate need to be given due consideration for finalizing the process durations.

1.11 KEY WORDS

Conduction	:	Exchange of molecular energy directly exchanged, from the hotter to the cooler regions.
Convection	:	Transfer of heat by the movement of groups of molecules in a fluid.
Radiation	:	Transfer of heat energy by electromagnetic waves.
Black body	:	It is a body which absorbs all incident light on it.
Grey body	:	Body which partially absorbs and partially reflects incident light falling on it.
Fourier equation	:	It is the general equation guiding conduction heat transfer.
Newton's law of cooling	:	It is the guiding principle behind convective heat transfer.
Radiation pyrometers	:	Measures temperature of a distant / hot object without coming into contact with it.
Decimal reduction time	:	Time required for reducing the microbial population to one tenth of its initial number.
Microbial lethality	:	Time temperature combination to kill all microorganisms including its spores.

1.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answers should include the following points:

1. The different methods of heat transfer are: Conduction, Convection and Radiation.

2. The rate of conduction heat transfer increases as the temperature gradient increases.

   The equation, $dQ/dt = kA\ dT/dx$ is known as **Fourier equation** of heat conduction.

3. The basic formula for radiant-heat transfer is the **Stefan-Boltzmann Law,** $q = \in \sigma \boldsymbol{T}^{4}$.

   As indicated in the equation, the radiative heat flux q, is proportional to the fourth power of temperature. That means for any increase in temperature the flux increases much faster. The emissivity of the object, $\in$, indicates its capacity in relation to a black body to emit thermal radiation. The value of $\in$ is in the range of 0-1; a black body has $\in = 1$ and a perfectly reflective body has $\in = 0$. The σ is Stefan-Boltzmann constant.

4. If the temperature of one of the objects is doubled, it means the temperature difference between the two objects has increased. Since convection is directly proportional to the temperature difference, it will increase in proportion to the temperature difference. On the other hand the radiation heat transfer is proportional to the difference in the fourth power of the temperatures of the two objects, the radiation heat transfer will increase much more steeply. You can therefore, appreciate that the radiation heat transfer increases much faster than the conduction or convection when the temperature difference between two objects increases.

Check Your Progress Exercise 2

Your answers should include the following points:

1. The acid and low-acid foods are distinguished on the basis of pH. The foods with pH less than 4.6 are called acid and the foods with pH more than 4.6 are called low-acid foods.

2. The thermal process for an acid food consists of treating it in a 100°C boiling water bath, whereas the low-acid food must be pressure treated to a temperature of 115°C or higher to kill the spoilage causing microorganisms.

3. To make water boil at a temperature higher than 100°C in food processing, it has to be put under pressure, such as in a pressure canner. When a food

is processed at 1.0 kg/cm^2 pressure, the water boils when it gets to 115°C, rather than at 100°C.

4. At higher altitudes the atmospheric pressure goes down and water boils at lower temperatures. Thus, to make the thermal processing effective, either the process time or canner pressure must be increased to make up for lower boiling temperatures. That means pressure treatment may be required even for acid foods.

Check Your Progress Exercise 3

Your answers should include the following points:

1. a) Mercury-in-Glass (MIG) Thermometer
   b) Resistance temperature detector sensors

2. A thermocouple is made by joining two dissimilar metals. When one of the junctions is at a different temperature than the surrounding temperature, then a small voltage is developed which can then be measured across the two leads at the other junction. When provision is made in the circuit to take care of the reference point such as the freezing point of water, then the resultant voltage is calibrated in terms of temperature difference between the reference point and the temperature of the junction.

3. A thermistor is normally a thermally sensitive material whose electrical resistance changes with temperature. This change in resistance is calibrated in terms of temperature. It differs from a resistance temperature detection (RTD) sensor in terms of its sensitivity. As a result a thermistor is able to sense very small changes in temperature as compared to a RTD sensor.

4. K = (°C + 273), where K and C are units of temperature in Kelvin scale and Celsius scale.

Check Your Progress Exercise 4

Your answers should include the following points:

1. The Decimal Reduction Time or D-value is defined as the time taken to kill 90% of the microbes in a sample under specified conditions and at a particular temperature. D-values are determined from survivor curves when the log of population is plotted against time.

   $$D_{\text{reference temperature}} = \text{Time}/(\text{Log}_a - \text{Log}_b)$$

   Where a = the initial population, and b = the surviving population after a time interval.

2. The F value for a process is the number of minutes required to kill a known population of microorganisms in a given food under specified conditions. This F value is usually set at 12 D values and the resultant microbial population is extremely low such as one microbe in 10,000 cans (say).

3. *Clostridium botulinum* is the reference microorganism, which is used in determining the different parameters related to thermal processing.
4. Lethality is defined as the integrated influence of time and temperature on a microbial population. It is expressed in time units for the process accomplished at the heating medium temperature. For e.g., a thermal process may require 65 min at 115°C of steam temperature for a given food product to achieve full lethality.

1.13 SOME USEFUL BOOKS

1. Henderson, S.M. and Perry, R.L. (1976) Agricultural Process Engineering. AVI Publishing Co. West Port, Connecticut.

2. McCabe, W.L., Smith, J.C. and Harriott, P. (1993) Unit Operations of Chemical Engineering. McGraw Hill, New York.

3. Nielsen, S.S. (1998) Introduction to Food Analysis. Aspen Publications Inc., Maryland.

UNIT 2 HEAT APPLICATION

Structure

2.0 OBJECTIVES

After reading this unit, you should be able to:

- enumerate processes commonly used in processing of fruits and vegetables based on heat application;
- state difference between direct and indirect method of heat transfer;
- identify various types of heat exchangers;
- describe important features of process equipment used for blanching, pasteurization, sterilization and aseptic processing; and
- explain the principle of microwave and ohmic heat transfer.

2.1 INTRODUCTION

We have studied the basic principles of heat transfer in the previous unit. Now, in this unit, we will go through the heat application aspects in relation to processing of fruits and vegetables. The subject shall be of great interest to us as processes based on application of heat form the core of food preservation and processing operations. In fact, thermally processed foods constitute a large part of the industry. As a post-harvest technician or entrepreneur or food technologists, it is essential for us to know about type of heating processes and equipment available so that the twin objectives of preservation and value addition could be achieved effectively and efficiently. Further, understanding of some of the basic thermal processing principles will help in selecting the processing parameters which would ensure maximum retention of sensory and nutritional attributes.

The important conventional as well as new processes such as blanching, pasteurization, sterilization and aseptic processing, microwave, etc., along with associated equipments have been discussed in this unit. In most of these operations, the heat transfer takes place in the form of convection and conduction. Two different principles are used in heat application. In one case, the heating medium is mixed with product to be heated. This is called direct heating and is used: (a) to heat water – steam is injected directly into the water, and (b) application of direct heating in aseptic processing either through injection or infusion. The direct method of heat transfer is efficient for rapid heating. It does, however, involve mixing of the product with the heating medium, and this necessitates strict demand on the quality of the heating medium. Indirect heat transfer is the most commonly used in food processing operations. In this method, a partition is placed between the product and the heating or cooling medium. Heat is then transferred from the medium, through the partition into the product. Most of the heat exchangers in the industry are designed on this principle. General principles governing heat transfer and response of fruits and vegetables to heat energy can be applied to all heat processes but each type of thermal processes has separate objectives. Therefore, the heat application has been delineated in this unit on basis of the objectives of the heat process after introducing heat exchangers.

2.2 HEAT EXCHANGERS

A heat exchanger is a device that transfers heat from one fluid to another without allowing them to mix, i.e., to transfer heat by the indirect method. In food processing, the purpose is to heat or cool a liquid food in bulk.

The heat exchanger has two channels separated by a partition. Hot water flows through one channel and juice through the other. Heat transfer, in connection with food products, follows general law of heat and, therefore, can be calculated by the formula:

$Q = UA\ \Delta T$

Q = Rate of heat transfer (Btu/hr)

U = Overall heat transfer coefficient (Btu hr^{-1} ft^{-2} $^{o}F^{-1}$)

A = Heat transfer area between medium and product (ft^2)

ΔT = Difference in temperature of medium and product (temperature of high medium and temperature of product/ low temperature medium) (^{o}F)

(A true temperature difference is given by logarithm mean difference and is represented by Δ Tm = mean differential temperature.)

From the above equation, it may be said that heat transfer is increased by:

i) Temperature difference between the "warm" and the cold "media". This is known as driving force;

ii) Greater available surface area – this means that a greater quantity of heat can be transferred if the area of the interface between medium and product is increased;

iii) Greater overall heat transfer coefficient (U Value) – more heat can be transferred if the U value is increased. This value is determined by several factors, including the flow rates of the media, the viscosity of the product, the shape of the heat transfer surface area and the material of which the partitions are made.

2.2.1 Practical Application of Principle of Heat Transfer

We know that food products are sensitive to temperature and agitation and this affects the capacity and efficiency of heat exchangers, for example, the higher temperature difference between the product and the heating medium may cause burning of certain food solids. Some of general principles for practical heat exchangers as outlined by Farrall (1976) are:

i) Rapid movement of the film of fluids on both sides of the heat transfer surface is important.

ii) Thorough and certain mixing of the film adjacent to the heat transfer area, with the body of the fluids is essential.

iii) Make use of the counter flow principle where possible, that is having the cold inlet product adjacent to the coldest outlet of the heating medium in a continuous system.

iv) Use as great a temperature difference as possible consistent with accurate temperature control and prevention of bad effects on the product treated.

v) Use as few intermediate cooling fluids or heating fluids as possible.

vi) Use as thin a sheet of heat transfer wall as possible consistent with proper mechanical strength.

vii) Use a heat transfer surface having good heat conductivity.

2.2.2 Types of Heat Exchangers

There are many types of equipment encountered in the food industry. The most important are the plate type, tubular type, scraped surface and vat type. The heating medium is usually either hot water or steam. A brief description is given below so that we may be able to use them effectively.

I. Tubular heat exchanger

The simplest type of tubular exchangers is the double pipe which consists of two concentric tubes with one fluid passing along the centre tube and the second fluid flowing in the annular space created between the tubes. Triple tube type employs three concentric tubes, with the product flowing through the intermediate passage and the heating or cooling medium flowing with counter current system in the other two passages, so that the product is surrounded on both sides. Today the tubular exchangers are not extensively used in food processing industries. The capital cost for these are low.

II. Scraped surface heat exchanger

The scraped surface heat exchanger is designed for heating and cooling of viscous, sticky and lumping products and for crystallization. This consists of a double-pipe exchanger with a central rotating shaft inside the inner pipe. Scraper blades are attached to the shaft and remove any material which builds up on the inner pipe wall. The second fluid flows in the annular space as in a conventional exchanger. The continual scrapping of the heat transfer surface ensures that higher heat transfer coefficients are obtained with highly viscous fluids.

III. Plate heat exchanger

One of the most popular type of heat exchanger is the plate system in which thin corrugated plates are stacked together to provide passage for the product and for the heating and cooling fluid. The advantages are:

i) High heat transfer surface area within a small plant volume.

ii) High heat transfer coefficients due to configuration of the plate surface.

iii) Easily cleanable either by opening it up or by CIP (cleaning in place) method.

iv) Versatile-addition of extra plates to increase surface area, ability to arrange a wide variety of flow patterns and several different fluids can flow through separate sections of the same heat exchanger, for example, allowing heating, cooling and heat recovery to take place in a simple unit.

v) Comparatively low in cost.

IV. Vat or tank heat exchanger

The flooded jacket, vat or tank is the simplest form of heat-exchanger, which is essentially a tank within a tank, with a space between the two that is flooded with water. The vat types of heat-exchangers are mainly used for batch pasteurization. For heating, a steam injection and mixing unit is employed and the agitator is provided for movement of the product over the heat exchanger surface.

Check Your Progress Exercise 1 ✍

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Enlist factors affecting heat transfer.

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2. List the important components of a plate heat exchanger.

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2.3 BLANCHING

As you know that blanching is a heat treatment applied to tissue systems of fruits or vegetables, primarily to inactivate natural food enzymes, prior to canning, freezing or drying. Most blanching operations are accomplished by putting the product in contact with either hot water or steam for an appropriate time. Blanching is not indiscriminate heating. Too little is ineffective, and too much damages the fruits/vegetables. The time is dependent on the objectives of the process, i.e., whether enzymes are to be inactivated or whether partial cooking is desired. It involves: i) heating food to a preset temperature, ii) holding for a preset time, and iii) cool rapidly to ambient temperature. The blanching of vegetables is most often done in hot water or steam containing calcium or magnesium salts to check chlorophyll degradation. Calcium brines or colloidal thickness are used in blanching of fruits for firming them. The blanching is not recommended for frozen fruits after thawing as it results in undesirable changes in texture and flavour. The adequacy of blanching is known through the catalase or the peroxidase test. The peroxidase system is most commonly used and we know that a negative peroxidase test is necessary to prevent the development of undesirable characteristics in the finished product.

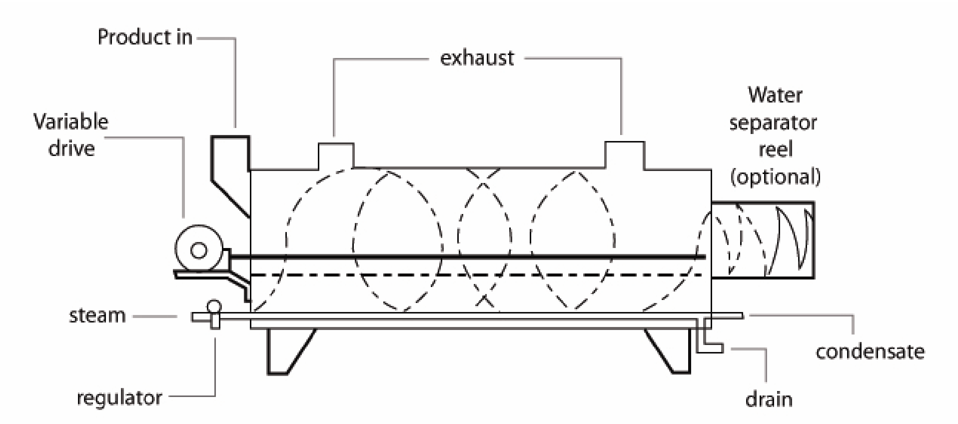
2.3.1 Process Equipment

Rotary hot water and steam blanchers are common process equipment and are shown in Figure 2.1 (a) and (b), respectively. They are available with variable speed drive. The rotary hot water blancher receives the product through a valve just above the drive end. The product is conducted into a spiral unit which conveys it to the opposite end. In the case of the hooded live steam blancher which has a perforated wire belt, the blancher serves as a conveyor making it very adoptable to the system.

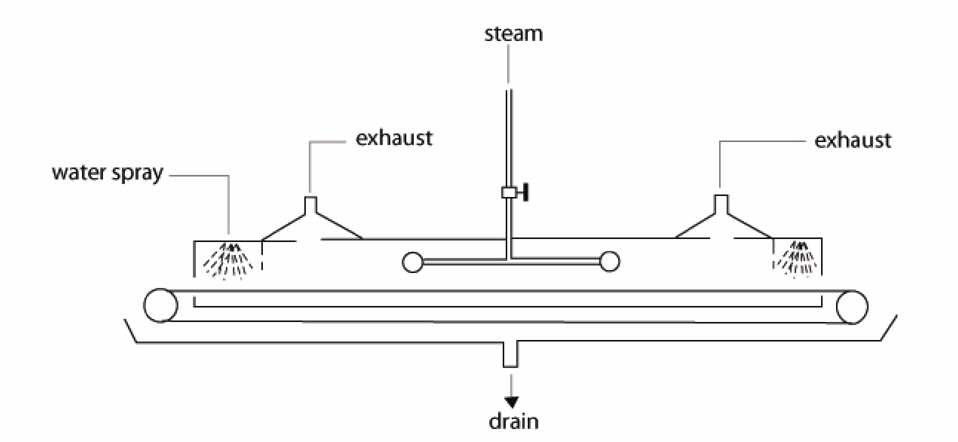
The steam blancher consists of a metal frame with galvanized sheet metal forming the steam chamber. The unit is frequently equipped with both water and steam sprays to increase its versatility as a scolder/blancher. The lower belt of the hooded chamber is pitched to a separate drain outlet for removal of condensate. A typical commercial steam blancher is approximately 20 ft. long, 4 ft. wide and 4 ft. high. A typical water blancher would be around 6 ft. in height with an overall length of 21 ft. In general steam blanching results in greater retention of water-soluble nutrients due to less leaching loss. With leafy vegetables, such as spinach, care must be taken not to overload the belt since upon heating these products tend to wet and mat. Heat transfer through this mat is very slow and under blanching could occur.

The advantages of steam blanchers are: smaller loss of water soluble components, smaller volume of waste, lower disposal charges and easy to clean and sterilize. The disadvantages associated with a steam blanchers are: limited cleaning of food, higher capital cost, uneven blanching, some mass loss in food and poor energy efficiency. At the same time, the advantages of hot water blanchers are lower capital cost and better energy efficiency. The disadvantages are loss of water soluble components, higher cost of water and disposal of effluent and risk of contamination.

A thermal screw may also be used to steam blanch products. Here, the product is conveyed in a trough by a closely fitting helical screw. Steam injected at regular interval is used to heat the product. Similar designs use hot water as the transfer medium, and this reduces abrasion and damage to sensitive products such as mushroom.



(a)



(b)

Figure 2.1: Blanchers. a) Water type rotary blancher; b) steam blancher for leafy products

We should select a size of blancher which will handle the line capacity without being over crowded. Do you know that one of the serious mistakes made by the operator is overloading. As an operator, we have to ensure maintenance of the unit on a regular basis and check that automatic controls are performing well. The use of a check thermometer to ascertain the accuracy of the one installed on the unit is a good practice.

Check Your Progress Exercise 2 ✍

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Draw a diagram of water type rotary blancher.

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2. What are the advantages of steam blancher?

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2.4 PASTEURIZATION

Pasteurization is the term usually applied to preservation of liquid products like pulps or juices by heat. We know that this thermal treatment primarily inactivates the disease causing microorganisms present in the foods. The process i) kills non-spore forming bacteria, ii) inactivates enzymes, and iii) destroys yeasts and moulds. It is suitable for short time preservation because it reduces the number of fermentative microorganisms that contribute to the acidification of juice, at the expense of sugars. The processing details have already been discussed in earlier units and we know that the time-temperature treatment depends on i) the heat resistance of the particular vegetative or pathogenic organism, and ii) the sensitivity of product quality to heat.

2.4.1 Process Equipment

Since pasteurization is normally done at temperature less than 100° C, solid food particles can be pasteurized in the same type of equipment as that used for blanching. A water bath is the simplest pasteurization equipment for acid food products. Packaged food products are placed in steel tanks for heating with hot water. At the end of process cold water is added for cooling. A continuous water bath pasteurizer is used in pickle industry and in fruit processing. The equipment consists of a long tank through which the product moves on a belt.

Continuous water spray equipment is used for pasteurizing fruit juices. In this unit, the product is conveyed on a belt through several temperature zones where water is sprayed onto the containers. The zones are first pre-heat, second pre-heat, pasteurization, pre-cool and final cool. Do remember that glass containers be processed with care to avoid thermal shock.

For fruit, fruit juices, and tomatoes, the continuous, agitating, atmospheric cooker is widely used. Operation of the unit is similar to the continuous, agitating, pressure cooker wherein the cans are screw conveyed through the unit. The unit operates at atmospheric pressure with either steam, hot water, or a combination of steam and hot water as the heating medium. Processing rates of up to 20-250 cans/minute can be achieved.

Pasteurization of unpackaged liquid is commonly done in indirect heat exchanger and High Temperature Short Time (HTST) processing is preferred for high throughputs (Figure 2.2). The nutrient loss is less. This procedure makes use of a plate heat exchanger with three sections for heating, regeneration, and cooling, respectively, a holding tube to pasteurization temperature for the required time and a flow diversion value to ensure that liquid which has not reached the desired temperature is not discharged as finished product. It is important to ensure that rapid cooling occurs in order to prevent quality deterioration and to ensure a uniform residence time. The temperature time treatment for some of the food products is given in Table 2.1.

Table 2.1: Temperature/time treatment in pasteurization

Food Product	Temp (°C)	Time (Seconds)
Milk	72	15
Tomato Juice	118	60
Fruit Juice	88	15
Soft Drink	95	10

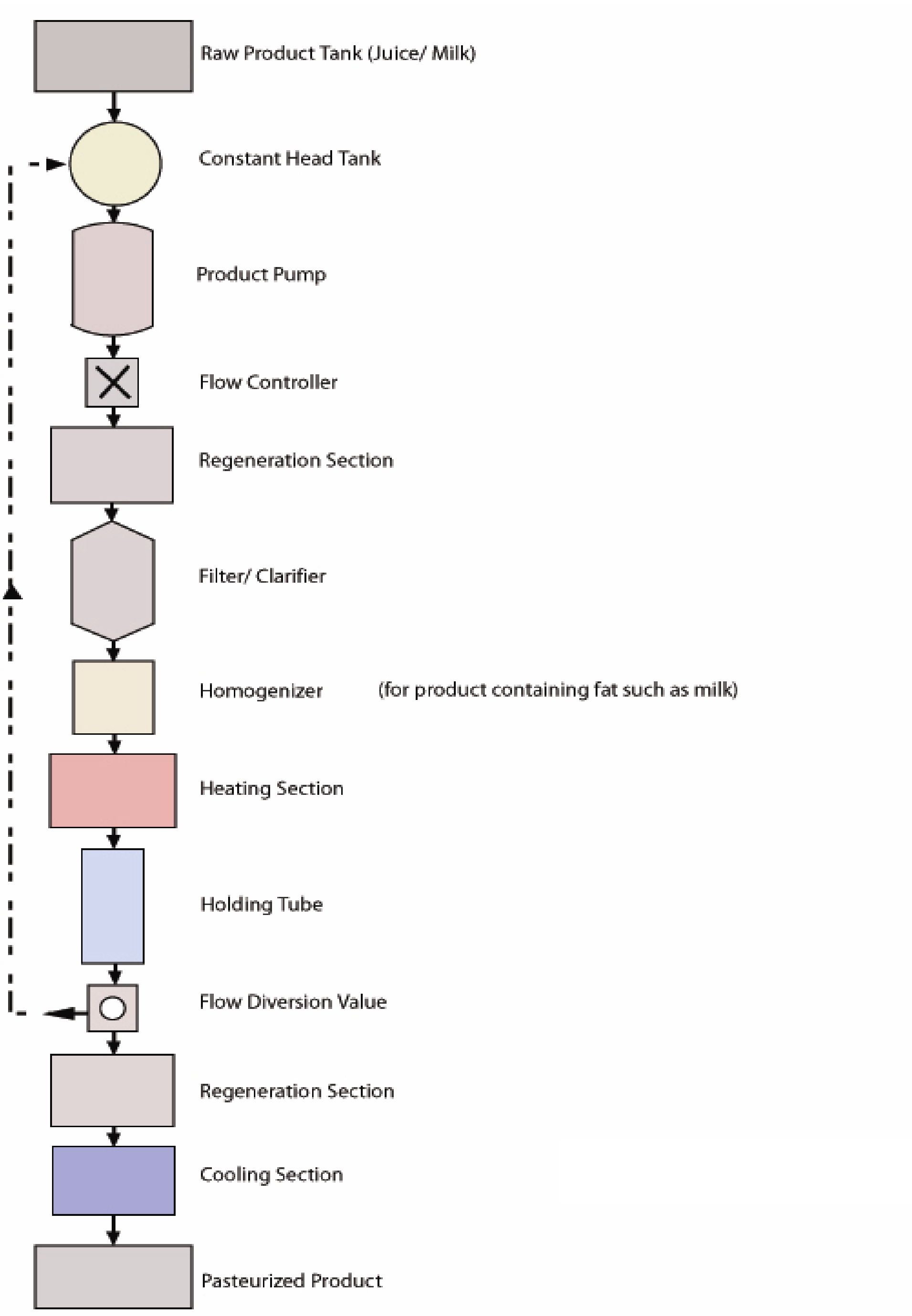

Figure 2.2: Flow diagram of pasteurization process

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Draw a line diagram of HTST pasteurization.

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2. Write pasteurization temperature and time combination for fruit juice and tomato juice.

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2.5 STERILIZATION

Sterilizing a product means exposing it to sufficiently high temperature and for a sufficiently long time that may kill all micro-organisms. In contrast to pasteurization, commercial sterilization is intended to give long shelf life (in excess of six months) to foods by destroying both microbial and enzyme activities. The products that are difficult to sterilize are low in acid and often high in protein and contain spore bearing bacteria. Sometimes severe heat treatment results in substantial changes in nutritional and sensory qualities of food. Therefore, optimum time temperature schedules are to be worked out for each product for better quality and shelf life. Sterilized products have excellent keeping quality.

There are two basic methods for sterilization (i) heating the food after it has been placed in a container (known as "in-container"), and (ii) heating and cooling the food and then packaging it aseptically (aseptic packaging). This subsection deals about sterilization process. The traditional retorting of canned foods is an example of sterilization process.

2.5.1 Process Equipment

The Batch Retort: The batch operated retorts are either horizontal or vertical. The basic feature of a vertical retort is given in Figure 2.3. It consists of a pressure vessel, usually cylindrical and a basket or grate into which individual cans are placed. The various layers of cans are separated by grids which allow thorough circulation of steam. The retort is supplied with steam, cold water and compressed air. Inlets are fitted with globe valves and the outer outlets with gate valves. At the bottom of the retort, a steam spreader is connected to the steam inlet to ensure uniform distribution of stream inside the retort. The drain is fitted to the base of the retort to remove the condensate during heating and cooling cycles. A vent, with a valve, is provided on the body of the retort. It is intended to purge the air flow between the cans during the initial part of the come-up period. The retort instrument packet is fitted with a petcock which acts as a permanent bleeder; mercury in glass thermometer; an additional place for a check thermometer; a temperature-sensing probe connecting to the recording thermometer; and a pressure gauge. An additional petcock and a pressure safety valve are on the lid. The retorts are strong enough to withstand the pressure of air, besides that of steam pressure, i.e., a working pressure of 2.8-3.5 kg/cm^2 (40-50 psig). The retorts should be located in a sufficiently large area to enable easy operation. The floor should be resistant to wear, well-drained, and impervious to water. The free space between the retort should be at least 50 cm.

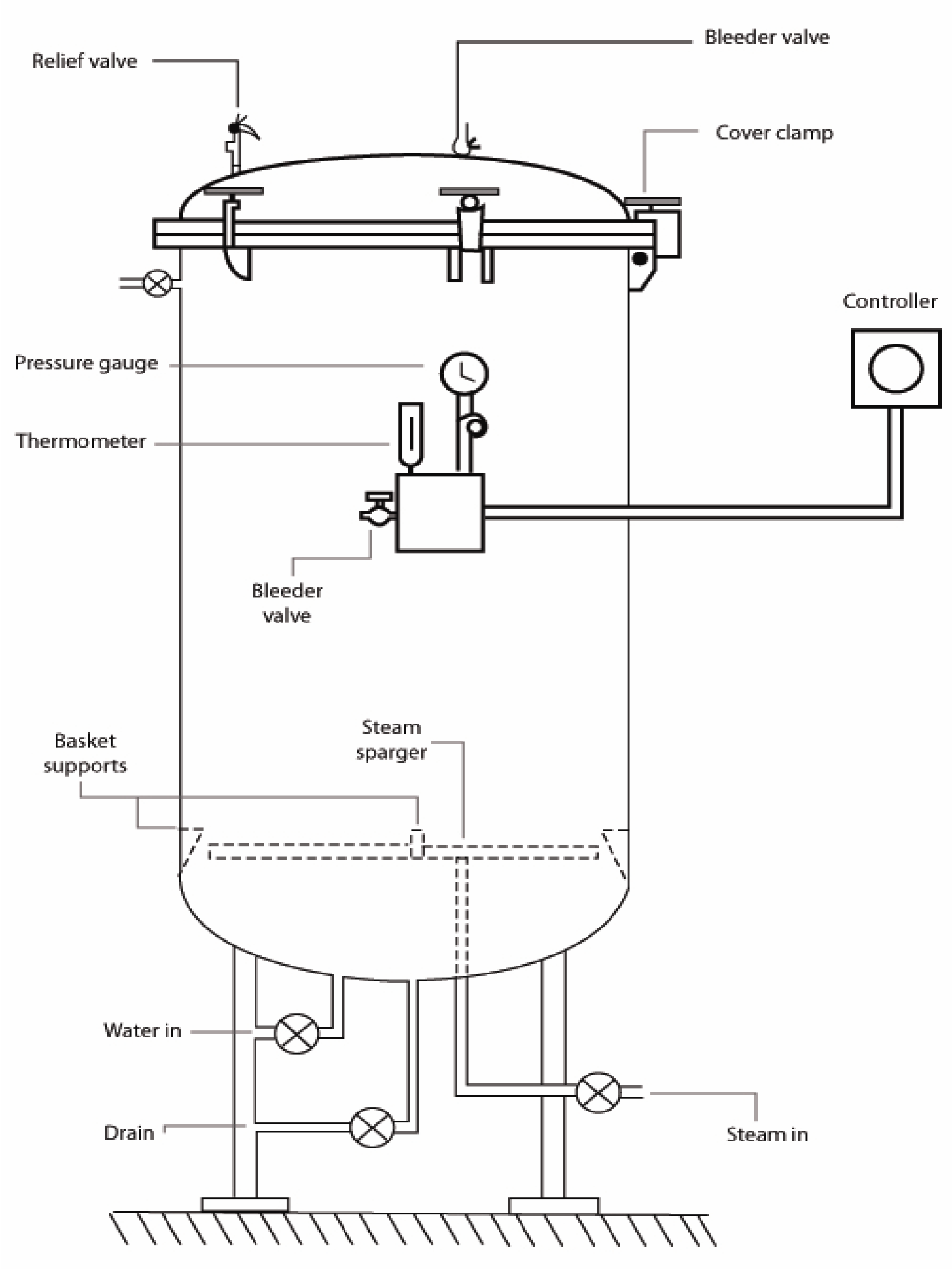

Figure 2.3: Basic layout for a vertical retort

Steam is an excellent heat medium because of its ability to condense on container surface releasing large amounts of latent heat. The main enemy of efficient heating in a closed vessel (e.g. a retort) using saturated steam is the presence of entrapped air especially that trapped in the small spaces between containers in the load. The presence of air reduces the temperature and tends to insulate the cans giving lower rates of heat transfer. This means that in order to bring about efficient and uniform heating, air must be purged, or as it is, referred to in the industry 'venting' from the retort at the start of the process. This is achieved by introducing high velocity steam into the retort. The rotary retorts ensure agitation and give adequate heating and acceptable processing times.

Retort operation is a specialized job. As a technician, you should be well trained in its operation and ensure proper processing. The basic operating procedure is as follows: The cans are placed in a basket which is lowered into the retort and then steam is introduced. Time is allowed for any condensed water to drain away before a drain valve at the base of the retort is closed.

Acidic products, for example canned fruits, require a milder heat treatment and use steam at atmospheric temperature, while the high temperature is required for less acidic foods and need heat to be supplied by steam at pressures greater than atmosphere. The steam is introduced at high speed for venting. After a short period, the vent valve is closed and the retort is brought up to temperature by allowing the steam pressure to rise to a pre-set level. After processing for the required time, the steam flow is stopped and the cooling water flow is started. As the temperature of the can's content rises the vapour pressure inside the can increases. During the heating cycle increase in pressure is balanced by the steam pressure outside the can, however, during the cooling cycle this internal pressure is balanced by admitting compressed air simultaneously. Cooling continues in retort until the temperature falls to about 40°C after which retort is opened and the cans are removed.

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Draw a labelled diagram of a Vertical Retort.

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2. What is venting?

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2.6 ASEPTIC PROCESSING AND PACKAGING

Aseptic processing and packaging is a remarkable technological advancement over traditional retort processing. It is the process by which micro-organisms are prevented from entering into the package during and after packaging. It is achieved by filling a sterilized package with a sterile food product within the confines of a hygienic environment. The packaged product could be stored without the need for refrigeration or preservatives for periods up to one year. Aseptically packaged products include milk, juices, tomato soups, sauces, broths, soy beverages, etc. The production of these products is constantly increasing in the country.

2.6.1 The Aseptic Process

The aseptic process is a technique for processing liquid food products by exposing them to brief intense heating. Sterility is the key word in the process and involves the same principles as discussed with respect to sterilization. Since very high temperatures are employed (125 °C to 145 °C), the process is also referred to as Ultra High Temperature (UHT). The holding time of the product at high temperature is very short (3 to 15 seconds) and therefore, thermal stress on the product is less while ensuring safety. This rapid heating and cooling process also reduces the energy use and nutrient losses associated with conventional sterilization. Processing at high temperature usually requires that the process be based on enzyme inactivation rather than microbial destruction. The process involves:

i) Sterilization of the product in sterile equipment;
ii) Pre-sterilized containers;
iii) Aseptic environment for filling of the sterile product into the sterile package; and
iv) Sterile packaging.

The advantages of the UHT processing are (i) higher quality (ii) increased shelf life (iii) easy adaptability to many size containers from single serving (200 ml.) to thousands of litres of bulk pack, and (iv) cheaper packaging material. The disadvantages are (i) higher cost (ii) sophisticated control and maintenance of plant, and (iii) higher skill level on the part of operators and maintenance personnel.

2.6.2 Process Equipment

UHT plants are often designed with great product flexibility in order to enable processing of a wide range of products in the same plant. Both low acid products (with pH values above 4.5) and high acid products (with pH values below 4.5) can be treated in UHT plant. However, only low acid products require UHT treatment in order to become commercially sterile as spores can grow in a low acid environment. Spores cannot develop in high acid products such as juice and the heat treatment is, therefore, only intended to kill yeasts and moulds. Normal high-temperature pasteurization is sufficient to make high end products commercially sterile. The UHT plants are classified according to the method of heating. The options are consolidated in Table 2.2.

Table 2.2: Types of UHT plants

Sl. No	Type of plant	Options available
1.	Direct Heating (Product and the heating media are in direct contact)	Steam injection (steam into product) Steam infusion (product into steam)
2.	Indirect Heating (Heat transfer surface between the product and the heating media)	▪ Plate, ▪ Tubular and ▪ Scraped surface heat exchangers

i) **Direct Heating:** There are two main methods for aseptic processing by direct methods: by injecting pressurized steam into product or by injecting product into steam (steam infusion). Both systems work on the principle that the steam comes into contact with the product, it will condense and give up some latent heat causing the product to heat up very quickly. The steam has to be of satisfactory quality, i.e., derived from drinking water. Simplified flow sheets for direct steam injection and steam infusion are shown in Figure 2.4 and 2.5, respectively. The basic principle for both systems is to pass the product from a balance tank to a pre-heating and final heating system, usually by a plate heat exchanger at 75-80°C. The product then passes through the main product pump to the steam injection or infusion system. The mixture then flows through a holding tube (2-4 seconds) which enters tangentially into the vacuum chamber. The product passes on an aseptic path – pump, homogenizer, cooler and storage tank – to aseptic package. Steam injection is most suitable for low viscosity homogeneous products such as milk and juice. Steam infusion is for more gentler and sensitive products.

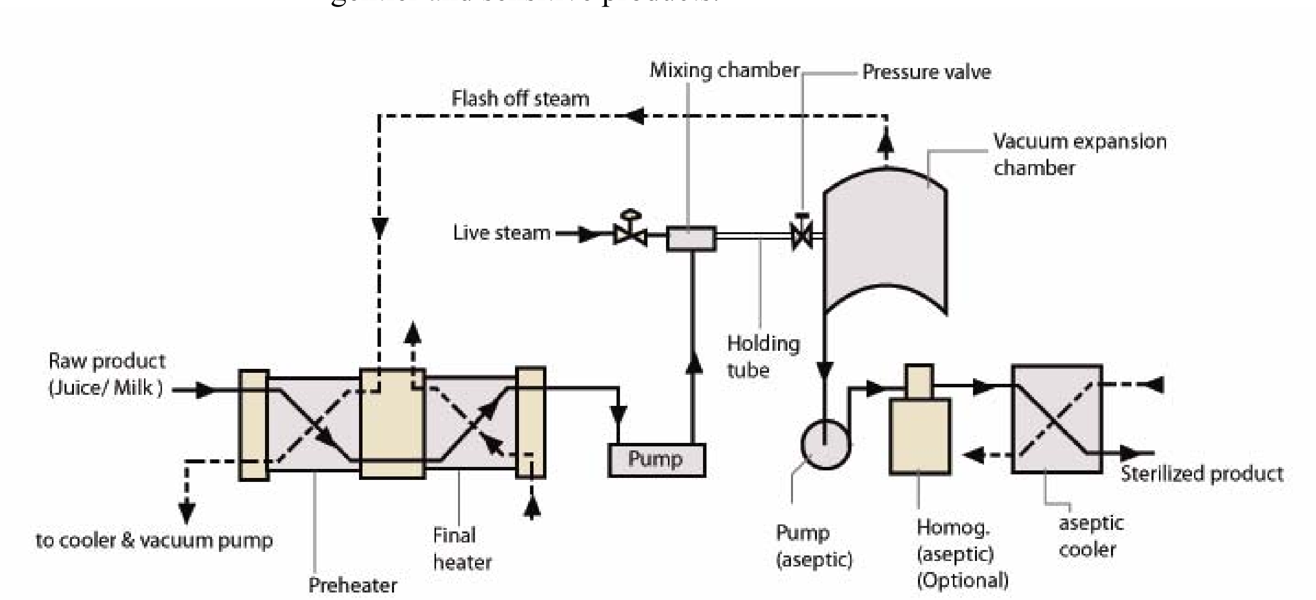

Figure 2.4: Diagram of an ultra-high temperature heating plant using direct heating (steam injection)

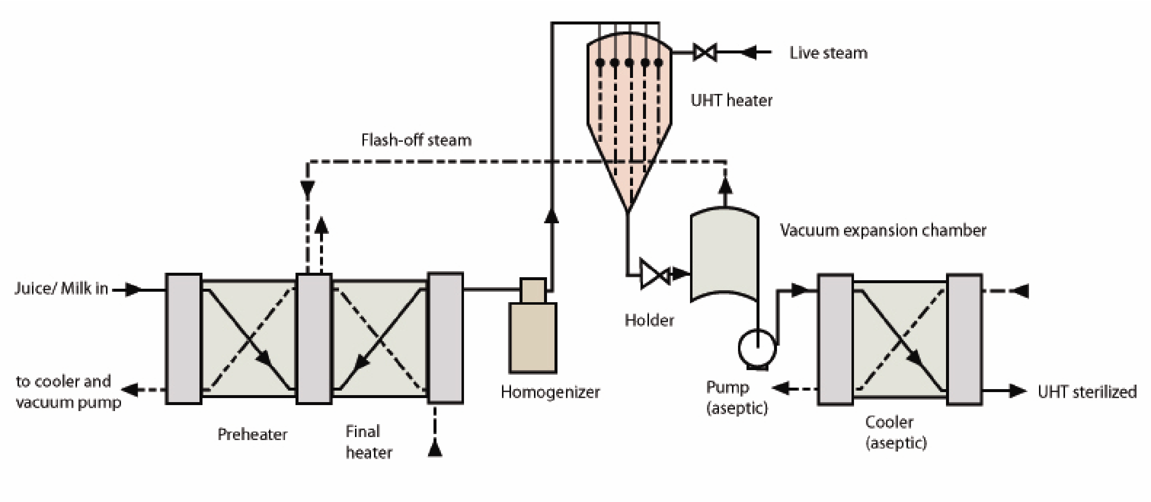

Figure 2.5: Diagram of a UHT plant using direct heating of product in a steam space (steam infusion)

ii) **Indirect UHT Plant:** UHT heating plants using indirect heating method rely on having a heat transfer surface between the product and the heating media. There are three main types of indirect heating system, viz. plate heat exchanger, tubular heat exchanger and scraped surface heat exchanger. Each system has benefits as well as drawbacks depending on the product process requirement. A simplified flow sheet for an indirect UHT plant is shown in Figure 2.6. UHT plants of the indirect heating types are built for capacities up to 30,000 l/h.

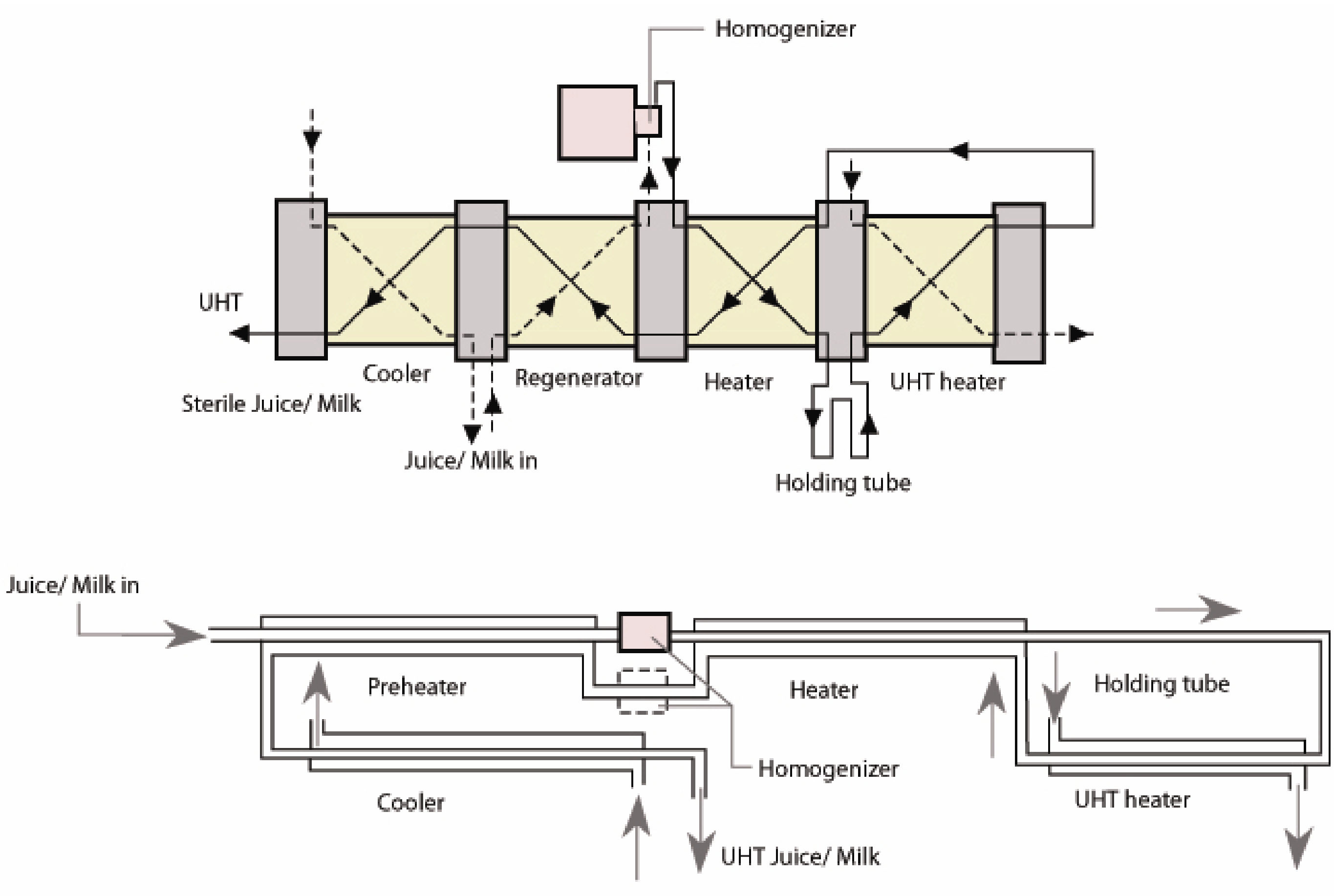

Figure 2.6: Diagrammatic representation of UHT heating plants using indirect heating methods

2.6.3 Aseptic Packages

There are several different forms of packages that are used in aseptic processing such as cans, laminates, flexible pouches, thermoformed plastic containers, tetrapack, etc. Tetrapack, a revolutionary package, is a laminate of three materials: high-quality paperboard, polyethylene and aluminium. Each material plays a critical role in achieving the unique benefits of the aseptic package. Paper (70%) provides stiffness, strength and the efficient brick shape to the package. Polyethylene (24%) on the innermost layer forms the seals that make the package liquid-tight. A protective coating on the exterior keeps the package dry. Aluminium (6%) is the silver material we see on the inside of the aseptic package. This ultra-thin layer of foil forms a barrier against light and oxygen, eliminating the need for refrigeration and preventing spoilage without using preservatives. The aseptic package contains a total of six layers in this order: polyethylene, paper, polyethylene, aluminium foil, polyethylene and polyethylene. The processing steps involved in formation of a package are: sterilization of roll and, formation of package, filling and sealing in sterile environment.

Check Your Progress Exercise 5

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the advantages of UHT Processing?

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2. Draw a line diagram of the direct UHT steam injection plant.

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3. Enlist the packaging materials forming the common aseptic package.

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2.7 HOT PACK OR HOT FILL

The terms Hot Pack or Hot Fill or Hot-Fill-Hold-Cool Process or Flash Pasteurization refer to the filling of previously pasteurized or sterilized foods, while still hot, into clean but not necessarily sterile containers, under clean but not necessarily aseptic conditions. The hermetically sealed containers are then inverted and held for an adequate time (1-3 minutes) to sterilize the lid as well as the containers. The hot-filled containers are then cooled either in a water-spray tunnel or by immersing in a tank containing chlorinated cold water. Rapid cooling is essential to retain the colour, flavour and nutrients. In yet another practice followed in some western countries, the head space is flushed with steam or nitrogen to minimize the residual oxygen. A schematic diagram of hot-fill system is shown in Figure 2.7.

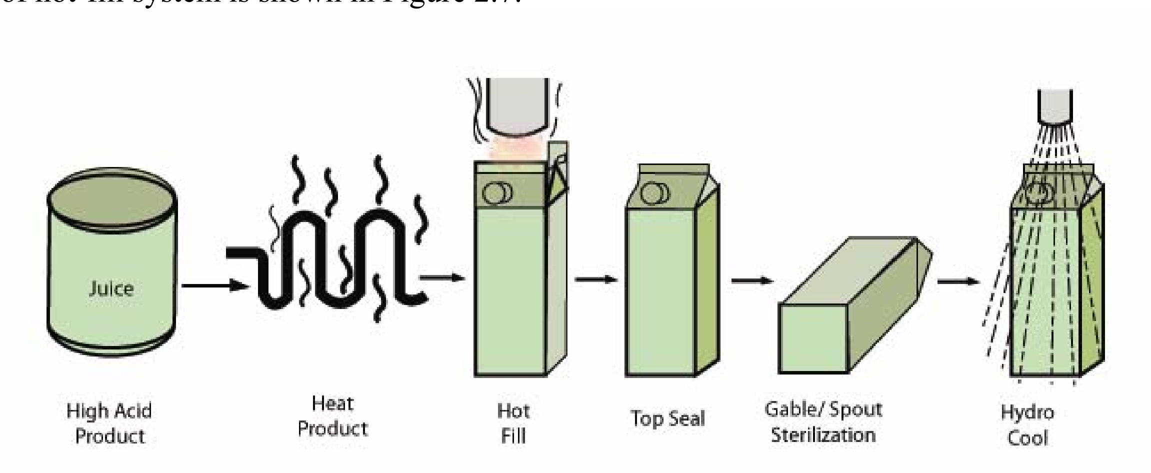

Figure 2.7: Hot-fill system – A schematic diagram

Hot-pack is more effective with acid foods, as at pH below 4.5 *Clostridium botulinum* will not grow or produce toxin. Hot pack with low acid foods (above pH 4.5) is not possible unless the product is recognized as being only pasteurized and will be stored under refrigeration. However, hot pack treatment could be combined with some additional means of preservation such as very high sugar content. The temperature and time for pasteurization and hot filling depend upon the specific product's pH and other food characteristics. It is essential that the definite temperature and time must be adhered for hot pack processing to be effective.

Check Your Progress Exercise 6 ✍

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What do you understand by Hot Pack or Hot Fill Process?

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2. Draw a schematic diagram of hot-fill process.

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2.8 MICROWAVE AND OHMIC HEATING

We are familiar with microwave ovens, their use and popularity is increasing constantly. In microwave heating, a high frequency field is passed through the food, stimulating the vibrational frequencies of chemical bonds to heat the material. Microwave and ohmic heating are known as heat generation methods where heat is generated by the material *in situ* as a result of interaction with an external field.

2.8.1 Microwave Heating

Microwaves are electromagnetic waves of radiant energy, differing from such other electromagnetic radiations as light waves and radio waves primarily in wavelength and frequency. The microwave frequency ranges from 300 MHz. to 300 GHz. corresponding to wavelength in the range of 0.001-1 m, and is positioned somewhat close to FM radio and television broadcasting brands. Microwaves, like light, travel in straight lines. They are reflected by metals, pass through air and many, but not all types of glass, paper and plastic materials, and are absorbed by several food constituents including water.

When microwaves pass into foods, water molecules and other polar molecules tend to align themselves with the electric field. But the electric field reverses 915 or 2450 million times per second (MHz.). The molecules attempting to oscillate at such frequencies generate intermolecular friction which quickly causes the food to heat. In microwave, heat is generated quickly and quite uniformly throughout the mass. .

The use of microwave energy in food processing can be classified into six unit operations: heating, baking and (pre) cooking, tempering, blanching, pasteurization and sterilization, and dehydration.

The most commonly used type of microwave generator is an electronic device called a magnetron. A magnetron is a kind of electron tube within a magnetic field which propagates high frequency radiant energy. The microwave field is transmitted to the oven cavity / tunnel via an antenna placed inside the wave guide. Industrial oven is either a larger version of the domestic oven and is used for batch processing (e.g. tempering) or for continuous processes, taking the form of tunnel with food conveyed on belt inside an enclosure.

A major use of microwave in the food industry is tempering and thawing of frozen foods, especially meat, fish, butter and fruit. Tempering raises the temperature of frozen foods to around – 4°C and thus allows other operations such as cutting to be carried out much faster. Microwave tempering has a number of advantages over conventional methods as it takes minutes rather than days, reduces labour costs and requires a smaller space than the conventional refrigerated storage room. Microwaves have been used for pasteurization of ready meals, further developments are needed to use them in commercial sterilization.

2.8.2 Ohmic Heating

In ohmic heating, an electric current is passed through a food material which then heats as a result of its inherent electrical resistance. The process involves the passage of low frequency alternating current (50 or 60 Hz.) through the product. The electrical energy is transformed into thermal energy. The extent of heating depends on the uniformity of the electrical conduction throughout the product and its residence time in the heater. A typical layout of an aseptic processing system using ohmic heaters is shown in Figure 2.8.

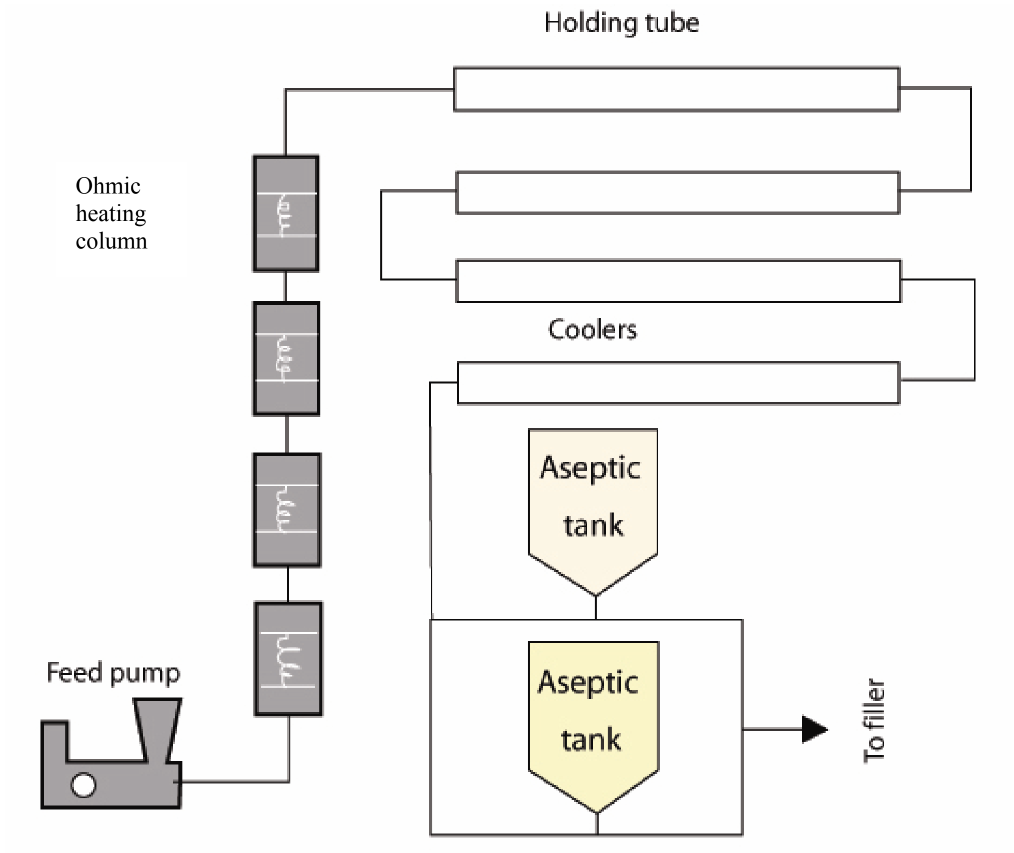

Figure 2.8: Schematic diagram of a continuous-flow ohmic heating process

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Check Your Progress Exercise 7

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. State the principle of microwave heating and its major use in food industry.

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2. What is ohmic heating?

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2.9 LET US SUM UP

The principles of heat transfer are widely used in food processing industries. The common processes based on heat application are blanching, pasteurization, sterilization and aseptic processing. The types of heat exchangers used in these processes may include plate, vat, tubular or scraped surface. Plate heat exchangers are quite common due to various advantages such as high heat transfer surface area within a small plant volume, high heat transfer coefficient, versatility, and low cost.

Rotary hot water and steam blanchers are commonly used equipment for blanching, and size of the blancher should be in proportion to line capacity of the plant. Plate heat exchangers are usually employed for pasteurization of unpackaged liquid. The raw product passes through regeneration, heating, holding and cooling sections. After heating and holding to a stipulated temperature-time combination, the pasteurized product is chilled immediately through regeneration and cooling section. Sterilization is more severe heat treatment employed to have longer shelf life (in excess of six months) of food products and the traditional retorting of canned foods is an example of sterilization process. The entrapped air should be vented from the retort at the start of process for efficient and uniform heating. Aseptic processing and packaging is a technological advancement wherein sterilization is obtained by employing Ultra High Temperature (UHT) (125° C to 145° C) for very short time. The UHT plants could be (i) direct steam injection, (ii) direct steam infusion, and (iii) indirect UHT plant with plate/tubular/scraped surface heat exchanger. Hot pack or hot fill, effective with acid foods, involves filling of previously pasteurized or sterilized foods, while still hot into clean containers.

The new techniques microwave and ohmic heating are known as heat generation methods where heat is generated by the material *in situ* as a result of interaction with an external field.

2.10 KEY WORDS

Aseptic packaging : It is a process by which micro-organisms are prevented from entering into the package during and after packaging. An aseptic process is achieved by filling a sterilized package with a sterile food product within the confines of a hygienic environment.

Blanching : Blanching is a heat treatment applied to tissue systems of fruits or vegetables primarily to

		inactive natural food enzymes prior to canning, freezing and drying.
Commercially sterile	:	The terms are used wherein all pathogenic and toxin forming organisms have been destroyed in the product.
Heat exchanger	:	A device that transfers heat from one fluid to another without allowing them to mix.
Pasteurisation	:	A form of thermal processing, which uses moderate degree of heat treatment generally at temperatures below the boiling point of water, for short time preservation. It inactivates bacteria and disease producing organisms of importance in specific food stuff.
Sterilisation	:	Complete destruction of micro-organisms by powerful heat treatment.
UHT	:	Ultra High Temperature (UHT) is a technique for processing liquid food products by exposing them to intensive heating for a short time.

2.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answer may include the following points:

1. - Temperature difference between heating and cooling media
   - Surface area for heat transfer
   - Heat transfer coefficient

2. Important components of plate heat exchangers: Head frame, guide bar, follower, end support, carrying bar, hinged distance piece, tightening screw device, detachable ratchet spanner, bank of plates, connector grid with inlet and outlet bosses.

Check Your Progress Exercise 2

Your answer may include the following points:

1. Please refer Figure 2.1a.

2. - Smaller loss of water soluble components
   - Smaller volume of waste
   - Lower disposal charges
   - Easy to clean and sterilize

Check Your Progress Exercise3

Your answer may include the following points:

1. Please refer Figure 2.2.
2. Fruit Juice –88°C / 15 seconds
   Tomato Juice –118°C / 60 seconds

Check Your Progress Exercise 4

Your answer may include the following points:

1. Please refer Figure 2.3.

2. - Entrapped air tends to insulate the cans and gives lower rates of heat transfer.
   - Air is purged out from the retort at the start of process for uniform heating. This is achieved by introducing high velocity steam into the retort.

Check Your Progress Exercise 5

Your answer may include the following points:

1. - Higher product quality
   - Increased shelf life
   - Easily adaptable to many size containers

2. Please refer Figure 2.4.

3. The aseptic package laminate consists of (a) paper board, (b) polyethylene, and (c) aluminium.

Check Your Progress Exercise 6

Your answer may include the following points:

1. The process includes rapidly heating the juice in a heat exchanger and filling containers with the hot juice (around 95°C) followed by sealing and inverting, thus pasteurizing the container. It should be followed by rapid cooling.

2. Please refer Figure 2.6.

Check Your Progress Exercise 7

Your answers should include the following points:

1. A magnetron in the oven generates electromagnetic waves (microwave). In the electromagnetic field generated in the oven, there is a rapid reversal of change (at either 915 or 2450 mega hertz). When microwaves penetrate a food, the dipolar molecules of water that are present oscillate about their axes in response to this reversal of change. Heat is generated in the food itself as a result of rapid oscillation.

The major use of microwave in the food industry is tempering and thawing of frozen foods.

2. The ohmic heating is a process where heat is generated in the product by passing an electric current. The heat is produced due to resistance created by the product during passage of current.

2.12 SOME USEFUL BOOKS

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UNIT 3 CANNING OF FRUITS AND VEGETABLES

Structure

3.0 OBJECTIVES

After reading this unit, you should be able to:

- state the principles of canning;
- explain the various unit operations involved in canning;
- describe the canning process of fruits and vegetables; and
- list the cans and types of spoilages of canned products.

3.1 INTRODUCTION

You know there are several methods of preservation of fruits and vegetables and canning is one of them. It is an important method of food preservation by heat. In this process, the foodstuff (fruits & vegetables) are placed in containers, and sterilized by placing them in hot water or steam. Canning is also known as appertizing in honour of its inventor. In 1804, Nicholas Appert, a confectioner in France, invented a process of sealing foods hermetically in containers and sterilizing them by heat. He had also published a book entitled, "The Art of Preserving Animal and Vegetable Substance for Many Years", which is the first known work on modern canning.

Canning is an important process of preservation of fruits and vegetables by application of heat. In this unit, we will discuss canning process for fruits and vegetables. Several unit operations are involved in the canning process. The process discusses the principles and purpose of canning, types and causes of spoilages. Tin cans are used in the canning of fruits and vegetables.

Fruits and vegetables are canned in the season when the raw material is available in plenty and at low price. The canned products are sold round the year and give better returns to the grower. Thus, canning of fruits and vegetables is an important industry.

3.2 CANNING PROCESS FOR FRUITS AND VEGETABLES

Canning is defined as the preservation of foods in the sealed containers and usually implies heat treatment as the principal factor in prevention of spoilage. Mostly the canning is done in tin cans but other containers like glass, plastics, etc. The fruits and vegetables used for canning should be as fresh as possible so that their quality could be retained. Fruits should be mature, firm ripe and free from all defects, while vegetables should be usually tender.

3.2.1 Principles

1. Destruction of spoilage organisms within the sealed containers by application of heat,
2. To improve the texture, flavour and appearance by cooking, and
3. To stop recontamination of food during storage.

You should be careful during heat application that palatability of food is least disturbed while all the microbial load is destroyed.

3.2.2 Process

Canning process includes the following steps or unit operations:

Selection of fruits & vegetables → Sorting & Grading → Washing → Peeling → Cutting → Blanching → Filling → Syruping/Brining → Lidding or Clinching → Exhausting → Seaming → Processing → Cooling → Testing for defects → Storage.

i) Selection of Fruits and Vegetables

We should select the fresh good quality fruits and vegetables for canning because quality of canned product is dependent on the quality of raw material. Fruits should be firm, mature and uniformly ripe. Over-ripe, insect infected and diseased fruits and vegetables should be rejected. Unripe and immature fruits should be rejected because they generally shrivel and toughened on canning. Vegetables should be tender. Fruits and vegetables should be free of dirt.

ii) Sorting and Grading

We should see that any spoiled, blemished, injured fruit or vegetable be discarded. Raw material should be sorted based on maturity and ripeness. Fruit and vegetables should be graded according to size and colour to obtain uniform quality of canned product. Grading can be done by hand or by machines. Screw type and roller type grader are generally used.

Fruits like berries, cherries, grape and plum are graded whole, while peach, pear, apricot, mango, pineapple, etc., are generally graded after cutting into pieces.

iii) Washing

Fruits and vegetables should be washed with water thoroughly. Washing will remove dust, dirt and any sprayed chemical residue. Any microorganism over the surface of the fruits or vegetables are also washed out. Water used for washing may be cold or hot. We may employ chlorine (150ppm) or potassium permanganate (dilute solution) in water to disinfect fruits and vegetables. Fruits and vegetables are generally soaked in water tank before washing by hand. They can be washed by spraying water, which is the most effective method.

iv) Peeling

Washed fruits and vegetables are prepared for canning. The fruits and vegetables are peeled by hand with knife or machine, heat treatment or lye solution. Lye is a solution of caustic soda. For example, peaches and potatoes are scaled in steam or boiling water and put in cold water to soften and loosen or cracking of skin. Later the skin can easily be removed by hand or pressure spray of water.

In case of lye peeling of fruits and vegetables, e.g., peaches, apricots, orange and sweet potatoes are dipped in boiling lye (1-2% caustic soda) for ½ to 2 minutes. Any trace of alkali is removed by washing fruits and vegetables in running cold water; sometimes they are also washed in water containing 0.5 per cent citric acid or hydrochloric acid.

v) Cutting

We should cut the fruits and vegetables depending upon the requirement like slice, dice, finger etc either by knife or by machine. At the same time seed, stone and core are also removed by special coring knife.

vi) Blanching

In blanching operations the prepared fruits and vegetables are kept in boiling water or exposed to steam for 2 to 5 minutes followed by cooling in running cold water. The time and temperature of blanching vary depending on the type of raw material. Inactivation of peroxidase enzyme is used as an index adequacy of blanching. The purposes of blanching are: (1) to inactivate the enzymes, which cause discolouration and off-flavour, (2) to reduce the volume by shrinkage, making their packing easier, (3) to reduce the microbial load on raw materials, (4) to enhance the green colour of vegetables like peas and spinach, (5) to remove undesirable acids and astringent taste of the peel resulting improved flavour, and (6) to remove occluded gases for reducing strain on the seam of can during processing.

vii) Filling

Tin cans are used as containers for canning. The cans can be opened from any end as they are called open top sanitary can. Cans are washed with hot water. Prepared fruits and vegetables are filled into cans either by hand or by machine. Plain cans are used generally, although in case of coloured fruits like black grapes, red plum, strawberries, etc., lacquered cans are employed.

In case of canned fruits the drained weight should not be less than 50% and for berry fruits not less than 40%. Similarly for canned vegetables the drained weight should not be less than 55% but in case of tomatoes limit is the 50%. Therefore, fruits and vegetables are filled about 60 per cent of the filling capacity of a can.

viii) Syruping

A solution of sugar in water is called syrup. Generally the fruits are covered with sugar syrup. Cans are filled with hot (79°–82°C) sugar syrup, leaving a headspace of 0.3 to 0.5cm. Syrup of 10° to 55° Brix (per cent sucrose) is generally used. We can prepare sugar syrup of 20° Brix by dissolving 250 g sugar in one-liter water and of 50^{o}Brix by dissolving one kg of sugar in one litre water. Sometimes citric acid and ascorbic acid are also mixed with the syrup to improve flavour and nutritional value, respectively. The purpose of adding syrup to fruits is (1) to improve taste, (2) to fill up the interspaces in can, and (3) to facilitate further processing.

ix) Brining

Brine is a solution of common salt in water. Brine is used in canning of vegetables. A brine of 1 to 3% salt is used at 79°-82°C, leaving a headspace of 0.3 to 0.5 cm in the can. The objectives of brining are to improve the taste of vegetables and to facilitate further processing by filling the interspaces of vegetables in the can.

x) Lidding or Clinching

Now the filled cans are covered loosely with the lid before exhausting. It has some disadvantages such as spilling of the contents and toppling of the lids. In modern canning, lidding has been replaced by clinching operation. In this case, lid is partially seamed. The lid remains sufficiently loose to permit the escape of gases, air and vapour formed during exhausting operation.

xi) Exhausting

There are respiratory gases and air remain in the cans, which are to be removed before processing. The method of removing these gases is known as exhausting. Containers are exhausted by heating or mechanically. In heat exhausting, the cans are passed through a tank of hot water or exhaust box under steam. The fruit cans are exhausted at 82 to 100°C for 7-10 minutes or until temperature at the centre of the can reaches 74°C. The vegetable cans are exhausted at 90 to 100°C for 7-10 minutes or until temperature at the centre of the can reaches 77°C. The proper exhausting reduces the strain on the seam of the can.

The time and temperature of exhausting vary with the size and contents of can, but it should be sufficient to ensure a vacuum of 12 to 15 inch Hg in processed and cooled can.

xii) Sealing or Seaming

After exhausting, the cans are sealed by double seaming machine and the method is called seaming. In sealing lids on cans, a double seam is created, and the method of sealing or closing is also known as seaming.

xiii) Processing

Process of heating and cooling of canned food to inactivate bacteria and to preserve food is also called as commercial sterilization. Many bacterial spores are heat resistant, which can only be killed either by very high or by very low temperature treatment or prolonged cooking. Such drastic treatment, however, affects the quality of food. Thus, processing time and temperature should be adequate to eliminate all bacterial growth. We must not over-cook the canned foods otherwise it will spoil the flavour, appearance and texture of the product.

All fruits and acid vegetables can be processed satisfactorily at a temperature of 100°C, i.e., in boiling water. The acid present in fruits and acid vegetables retards the growth of bacteria and spores. These bacteria and spores do not thrive in heavy sugar syrups, which are normally used in canning fruits. Vegetables, generally non acidic (except tomato and rhubarb), are processed at a higher temperatures of about 115 to 121°C.

Bacterial spores usually do not grow below pH 4.5 as you have read in previous chapters. We, generally process the canned products having pH less than 4.5 in boiling water but products with pH higher than 4.5 require processing at 115 to 121°C. The higher temperature can be obtained by processing in a retort under a pressure of 0.70 to 1.05 kg/cm^2 (10 to 15 lb/sq. inch). The centre of can should attain these high temperatures.

The temperature and time of processing vary with the size of the can, the larger the can, the greater is the processing time. Fruits and acid vegetables are generally processed in open type cookers, continuous non-agitating cookers and continuous agitating cookers.

The open cookers are galvanized iron tank of desired capacity. Sealed cans are placed in iron crates and immersed in the tank containing boiling water. In continuous cookers, the cans travel in boiling water in crates carried by overhead conveyors. In continuous agitated cookers, the cans are rotated by special mechanical devices to agitate the contents of the cans. Agitation reduces the processing time considerably.

The non-acid vegetables are processed under steam pressure in closed retorts. The sealed cans are placed in the retort, keeping the level of water 2.5 to 5.0 cm above the top of the cans. The cover of the cooker is then screwed down tightly and the cooker is heated by steam to the desired temperature. The period of processing (sterilization) should be counted from the time the water starts boiling or steaming. After heating for the required period, heating is stopped and the petcock or vent is opened. When the pressure comes down to zero the cover is removed and the cans are taken out.

xiv) Cooling

After processing, the cans are cooled rapidly to about 39°C to stop the cooking process. Cooling can be done by several methods such as (1) immersing the hot cans in tank containing cold water, (2) spraying cold water, (3) turning in cold water into the pressure cooker, and (4) exposing the cans to air. Generally the first method is practiced. Cooling water may be kept sterile with 1 or 2 per cent chlorine. If canned products are not cool immediately after processing, the quality is deteriorated, e.g., peaches and pears become dark in colour, tomatoes turn brownish and become bitter in taste, while peas become mashy with a cooked taste.

xv) Testing for Defects

Before the canned products are marketed, we should test them for any defect. The finished cans are tested for leak or imperfect seals. We should tap the top of the can with a short steel rod. A clear ringing sound indicates a perfect seal, while a dull and hollow sound shows a leaky or imperfect seal. Leaky cans should be removed from the lot.

xvi) Storage, labelling and packing

Before storage, the cans should be completely dry, small traces of moisture are likely to induce rusting. They should be stored in a cool and dry place. Storage of cans at high temperature should be avoided, as it shortens the shelf life of the product. The high temperature may lead to hydrogen swell and perforation during extended storage. The basement stores are useful, especially during summer months. The temperature in these stores is lower by about 6° to 8°C, compared to outside temperature. Before dispatch, the cans are labelled and packed either in wooden or cardboard boxes, and are ready for marketing. The cans may be stored for 1 to 2 years depending upon the type of raw materials used and the shelf life of the product.

3.2.3 Tin Containers

The cans are made of thin steel plate of low carbon content, lightly coated on both sides with tin metal. Sometimes discolouration of the product or corrosion of the tin plate takes place. In order to avoid corrosion, these cans are coated inside and or outside with lacquer, the process is known as “lacquering”. There are two types of lacquers used.

1. Acid-resistant-Acid-resistant lacquer is a golden colour enamel, cans coated with it are called R enamel or A.R. cans. The lacquered cans are used for packing fruits having water soluble colour (anthocyanins) for example raspberry, strawberry, red plum, coloured grapes, pomegranate, etc. Fruits having water insoluble colour, for example pineapple, mango, grapefruit, etc., are packed in plain cans only.

2. Sulphur-resistant – This lacquer is also of a golden colour, cans coated with it are called C. enamel or S.R. cans. These cans are used for packing pea, corn, lima beans, etc.

The tin cans are supplied to the canning factory in flattened form, where they are reformed using a machine, reformer, into cylindrical shape. After that, they are flanged by using flanger, which curls the rings outwards at each end. The one end of the cylindrical can is then fixed, before filling it, using a machine known as double seamer. After filling, processing and exhausting the can, the lid is fixed using the same machine.

Table 3.1: Commercial can sizes and capacities

Sl. No.	Trade name of can	Size (mm)	Capacity (in cubic cm)
1.	A1	68 × 102	316
2.	1-1b Jam	78 × 90	356
3.	A1-T	78 × 119	479
4.	A2	87 × 114	579

5.	1-1b Butter	103 × 70	470
6.	A2-1b Jam	103 × 102	721
7.	A2½	103 × 119	848
8.	7-1b Jam	157 × 148	2543
9.	A10	157 × 178	3069

3.2.4 Spoilage in Canned Fruits and Vegetables

Canned products are liable to spoilage for various reasons. Spoilage in canned food may be caused due to two reasons:

A) Spoilage due to physical and chemical changes:

1. Swell – Swell or bulge in cans caused due to the positive internal pressure of gases formed by microbial or chemical action. Hydrogen Swell – This type of swelling is due to the hydrogen gas produced by the action of food acids on the metal of the can. The swelling ranges from flipper – springer, soft swell or hard swell.
2. Overfilling – Overfilling should be avoided.
3. Faulty retort operation – It gives cans look like swells.
4. Under exhausting – It causes severe strain during heat processing.
5. Panelling – It is seen in large sized cans that the body is pushed inward due to high vacuum inside.
6. Rust – Rust is mostly seen under the label and subsequently affects the label. Cans lacquered externally do not rust.
7. Leakage – Cans generally leak due to defective seaming and nail holes.
8. Bursting – Cans may burst due to excess pressure of gases produced by decomposition of the food.
9. Discolouration – This may be due to enzymatic and non – enzymatic browning. Enzymatic discolouration can be avoided by placing the peeled and cut pieces of fruits and vegetables in 2% salt solution.
10. Stack burning – The contents in the can if remain hot for a long time during storage result in stack burning. It may cause discolouration. To avoid stack burning cans should be cooled quickly to about 39^{o}C before storage.

B) Spoilage by microorganisms

The time gap between filling and heat processing may cause microbial spoilage. If cans are not processed properly they may result in spoilage by bacteria and the spoilage is termed as "Under processed" spoilage.

Various spoilages caused due to different microorganisms are:

1. Flat sour – The non-acid vegetables spoiled by Bacillus coagulens and Bacillus sterothermophilus.
2. Thermophilic acid spoilage – Cans swell due to production of carbon dioxide and hydrogen by Clostridium thermosaccharolyticum.

3. Sulphide spoilage – Caused by Clostridium nignificans in low acid foods.

So, we should process cans properly to avoid any type of spoilage.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Define principles of processing.

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2. List the name of unit operations involved in the canning process.

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3. State the differences between processing of fruits and vegetables in a can.

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4. Describe the causes and types of spoilages of canned foods?

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3.3 CANNING OF FRUITS

The fruits are exhausted at 82 to 100°C for 7-10 minutes or until the centre of the can reaches at least 74°C temperature. The types of can, strength of covering sugar syrup and time-temperature for No.2½ and No.10 cans are summarised in Table 3.2.

Table 3.2: Canning time table for fruits and tomatoes

Sl. No.	Fruit	Type of can	Strength of syrup (Degree Brix)	Processing time (min) in boiling water at 100°C	
				No.2½	No. 10
1.	Apple	Plain	Water or light syrup	12	25
2.	Apricot	Plain	55	35	50
3.	Banana	Plain	30+0.2% citric acid	20	–
4.	Blackberry	Fruit lacquered	55	20	30
5.	Cherry (sweet)	Fruit lacquered	40	20	25
6.	Cherry (sour)	Fruit lacquered	45	20	25
7.	Fig	Plain	55	15	35
8.	Grape (coloured)	Fruit lacquered	40	12	15
9.	Grape (white)	Plain	40	12	15
10.	Grape fruit	Plain	60	30to 40	

11.	Guava	Plain	40	20	–
12.	Jack fruit	Plain	50	30	–
13.	Litchi	Plain	40	30	–
14.	Mango	Plain	40	30	–
15.	Mulberry (coloured)	Fruit lacquered	40	12	–
16.	Musk Melon	Plain	40+0.3% Citric acid	30	–
17.	Orange	Plain	50	15 to 20	
18.	Papaya	Plain	45	30	–
19.	Peach	Plain	55	30	50
20.	Pear	Plain	40	35	60
21.	Pineapple	Plain	40	30	60
22.	Plum, red	Fruit lacquered	40	20	30
23.	Raspberry	Fruit lacquered	45	12	25
25.	Strawberry	Fruit lacquered	50	15	20
26.	Tomato	Plain	Only tomato juice in the case of standard pack	30	70
27.	Fruit Cocktail (Fruit salad)	Plain	45	30	90

i) Apple

Apples are generally not canned. However, canned apples available in the large sizes of cans are used in pies. The varieties used for canning are: Golden Delicious, Yellow Newton, Baldwin, Jonathan, and Ambri.

The fruits should be washed in warm dilute hydrochloric acid (0.5%) solution to remove any residue of lead or arsenic sprays. And then washed thoroughly in cold water to remove traces of acid. The apples are peeled by hand or machine and cut into 0.3 to 0.6 cm thick slices. The prepared fruits should be kept in 2 to 3 per cent common salt solution to avoid darkening due to enzyme action. The prepared fruits are blanched in hot water at 71 to 81^{o} C for 3 to 4 minutes and then cooled in water. Blanching removes the air and gases and inactivates enzymes. The blanched fruits are filled into cans, covered with hot water or thin sugar syrup, exhausted, sealed and processed.

ii) Apricot

Apricots are mostly grown in Kashmir, Himachal Pradesh and Uttaranchal, where a great scope exists for their canning. Charmagz and Shakarkand are white sweet varieties which are good for canning. Apricots are either canned whole or halves.

iii) Banana

South Indian varieties of banana, viz. Pachabale, Chandrabale, Nendran, Poovan and Vannan are good for canning. Fully ripe bananas are selected for canning. Fruits are peeled by hand and then cut into long slices of 1 to 2 cm thickness. The slices are filled into cans and covered with a sugar syrup of 25 to 30° Brix containing 0.2 per cent citric acid. Then the cans are exhausted, sealed and processed.

iv) Ber

Umran and *Katha* varieties of *ber* are good for canning. Fully mature fruits are selected for canning. Peel is removed by hand with the help of stainless steel knife or by dipping in 5 per cent boiling hot caustic soda solution for 2 minutes and then washed in running tap water. Second washing is done in water containing 0.1 per cent citric acid in order to remove any traces of caustic soda solution. The fruits are cut into slices. The slices are filled into one lb Jam size can, exhausted; sealed, processed in boiling water for 20 minutes and cooled.

v) Berry Fruits

Among berry fruits, strawberry, loganberry, black berry, raspberry, mulberry and black and red currants are popular for canning. White heart cherry and red cherry having creamy white flesh, are good for canning. Maraschino cherries are canned for mixing with other fruits and for fruit cocktails.

The cherries for canning are generally decolourised during curing in brine for 4-6 weeks. During curing cherries are kept in a brine, which is made up of about 0.75 to 1.0 per cent sulphur dioxide (SO_2) and about 0.4 to 0.6 per cent slaked lime. The cured cherries are washed well in water and dyed with a red dye like Erythrosine, and the colour is fixed with citric acid. These cherries are used for canning.

vi) Citrus Fruits

Generally grape fruit and oranges are canned. Grape fruit varieties Marsh Seedless, Duncan and Foster are good for canning. The fruit is immersed in hot water (93 to 96°C) for 2 to 5 minutes. It softens the peel, which can easily be removed by hand. The peeled fruit is further hand peeled or lye-peeled to remove the white rag portion called albedo. For lye peeling, the whole fruit is immersed in hot lye solution containing 1.5 to 2.0 per cent caustic soda (NaOH) for 20 to 30 seconds. It is then washed with cold water and the segments are separated. The membranes and seeds are removed with the help of knife. The prepared segments are filled into plain cans, and then filled with 60° Brix syrup. The filled cans are exhausted for 25 to 30 minutes at 82 to 87°C, then sealed and processed for 30 to 40 minutes at the same temperature. The cans are cooled immediately after processing.

Satsuma, Mandarin and Unshu (in Japan) are employed for canning. Malta and Sathgudi, which are tight skin, and loose jacket Nagpur and Coorg oranges also yield good canned products.

The peel of loose jacket orange is removed by hand easily. The peel of tight skin oranges is removed and prepared similar to grape fruit. The filled cans are exhausted for 15 to 20 minutes at 82 to 87°C, sealed and pressed for another 15 to 20 minutes at the same temperature in open cooker. After processing, the cans are cooled immediately in cold water.

vii) Grape

Grape varieties such as Thompson Seedless and Muscat are good for canning. Only large sized berries are used for canning. Washed berries are filled into cans and covered with syrup of 20 to 40° Brix. The cans are exhausted, sealed and processed. The coloured grapes should be canned in lacquered cans.

viii) Guava

Fully ripe but firm fruit, with white flesh, are selected for canning. Fruits are peeled by knife or by lye solution as described above. Peeled fruits are cut into halves and seeds are scooped out with a spoon-shaped knife. The prepared fruit should be immersed in 1 to 2 per cent common salt solution. It helps to prevent the fruit from browning. Either halved or quarters are canned. The peel and core with seeds can be used for making guava jelly or guava cheese. Canned guava has a taste and aroma better than those of fresh fruits.

ix) Jack-Fruit

Jackfruit is mostly available in Maharashtra, Bihar, Orissa, Karnataka, Kerala and Tamilnadu. In these states, certain sections of the people use it as an important staple food. All parts of the fruit can be used in one or the other form of food. The green and immature fruit can be canned as a curried vegetable. The ripe fruit with the crisp bulb after seed removal is used for canning in sugar syrup.

The fruit is washed, cut into several large pieces and the bulbs are removed with hand. The fruit contains a white, highly sticky, latex so, a little vegetable oil such as til or gingelly oil, is smeared on the hand and the knife to prevent the latex from sticking on them. The latex is soluble in oil. The bulb after seed removal is canned as a whole, halved or quarter. Generally syrup of 50° Brix having 0.5 to 0.75 per cent citric acid is used for canning of jackfruit bulb.

x) Litchi

Litchis are mostly cultivated in Bihar, Orissa, Uttaranchal and Uttar Pradesh. Tree-ripened fruit is selected for canning. Fruit is washed, skin is removed, and aril is separated from stones. The aril is filled in cans, and aril covered with sugar syrup of about 40^{o} Brix containing 0.5 per cent citric acid. The filled cans are exhausted, sealed and then processed as mentioned earlier. After processing, cans are cooled promptly and thoroughly in running cold water to prevent development of pink colour in the product.

xi) Mango

In India, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Karnataka, Bihar, Maharashtra and West Bengal lead in mango cultivation. Dashehari, Alphonso, Badami, Baneshan, Raspuri, Neelam, Mulgoa and Totapuri or Bangalora are the most important mango varieties for canning. Juicy and fibrous varieties are not suitable for canning.

Fully developed and mature fruits are harvested and ripened. Canning ripe (just ripe but firm) fruits are selected, washed with water and peeled by hand with the help of knife. The pulp is either cut into two broad side (Chick) or quartered or 6 to 8 cm longitudinal slices.

The prepared fruit is placed in two per cent common salt solution to prevent enzymatic browning. The fruit has slightly higher pH than the critical pH of 4.2 so it is necessary to add 0.3 to 0.5 per cent citric acid in the syrup in order to process in open cookers. The trimmings of the slices, pulp adhering to the peel and stone can be used profitably for the preparation of mango juice or beverages and mango jam.

xii) Papaya

Fruit is washed, peeled, seed removed and cut into slices or cubes for canning. The fruit pulp has a high pH value so it is necessary to add 0.5 per cent citric acid in the syrup to reduce the pH below 4.5. Sometimes papaya is canned with other fruits like pineapple, mango, banana, etc., to produce fruit cocktails.

xiii) Peach

There are two types of peaches, one the clingstone, where the pulp adheres to the stone tightly, and the other freestone where the pulp adheres to the stone loosely or freely. Among the clingstone peaches, Tuscan, Palora and Philips Cling are the varieties good for canning. Among the freestone peaches, Elberta, Lovell and J.H. Hale are suitable varieties for canning.

The fruits are cut into two halves and the pits removed. In large canneries, mechanically operated knives are used to cut fruit into halves and to remove the pits. The cut halves are peeled by immersing them in boiling lye solution containing 1 to 2 per cent caustic soda for ½ to 1 minute. The loosened peel is removed by washing with water. The prepared halves are filled in cans, covered with syrup, exhausted and processed in open cooker. Sometimes peach slices are also canned. Peaches are also used as an important constituent of fruit cocktail.

xiv) Pear

Pears are cultivated in Himachal Pradesh, Kashmir, Uttaranchal and hilly areas of South India. Pears are harvested fully mature, firm but green. The fruits are ripened at room temperature (23 – 26^{o} C) and soft fruits are used for canning.

The fruit is peeled with a knife and cut longitudinally into two halves. The core is removed by coring knife. The prepared fruit is placed in 1 to 2 per cent common salt solution to prevent browning. The halves are then filled into cans, covered with hot sugar syrup, exhausted, seamed and processed as usual. The cans should be cooled immediately in cold water to prevent development of pink discolouration of the fruit during storage.

xv) Pineapple

Pineapple is mostly grown in Assam, West Bengal, the West Coast of India, Andhra Pradesh and Karnataka states. Giant Kew and Queen are the two important varieties of pineapple employed for canning.

The fully mature and just ripe fruit is selected for canning. Uniform size graded fruits are peeled, cored and sliced on a Ginaca machine in foreign countries. In India, the fruits are sliced, and then core and peel is removed by hand with the help of coring and punching knife. Slices are graded usually for size. Since the fruit contains highly active proteolytic enzymes, injurious to skin, the workers should wear rubber gloves. The slices are filled into cans, covered with syrup, exhausted, seamed, processed and cooled as usual.

xvi) Plum

The Red Victoria and the Yellow Pershore plums are important canning varieties. The Alubukhara plum generally grown in North India, also gives a fairly good canned product.

Generally whole plum with stone is canned. Since plum contains water-soluble red colour, which is due to the presence of anthocyanins, is canned in lacquered cans. Washed fruits are filled into can, either as discrete number or by weight, covered with syrup and processed as usual.

xvii) Other Fruits

There are some minor and lesser-known fruits such as. Date, Pomegranate, Mulberry, Musk melon, Water Melon, Aonla, Carambola, Tamarind, Avocado, Custard Apple, Karonda, etc. which may also be canned as usual. These fruits may be canned as slices, cubes or juice and pulp or beverages.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Why citric acid is added to covering syrup?

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2. State reason for placing the prepared fruits in common salt solution.

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3. Why fruits are processed in open cooker?

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3.4 CANNING OF VEGETABLES

The vegetables are exhausted at 90-100°C for 7-10 minutes or until the centre of the can reaches at least 77°C temperature. The types of can, strength of covering brine and time-temperature for No.2½ and No.10 cans are summarised in Table 3.3.

Table 3.3: Canning time table for non-acid vegetables

Sl. No.	Vegetables	Type of can	Strength of Brine (common salt)	Processing time min. at 0.7 kg per cm^2 steam pressure	
				No. 2½ Can	No. 10 Can
1.	Asparagus	Plain	2.25%	24	40
2.	Bean	Plain	2.25%	40	75
3.	Beet-root	Sulphur resistant	Water or 1.5% Brine	30	40
4.	Cabbage	Plain	2%	40	60
5.	Carrot	Plain	2%	25	50
6.	Cauliflower	Plain	2%	20	–
7.	Curried vegetables	Plain	–	60 to 70	
8.	Mushroom	Plain	2% “	25	40
9.	Okra	Plain	2% “	35	–

10.	Pea, garden	Sulphur resistant	2% Brine & 2.5% sugar solution	45	60
11.	Potato	Plain	2%	45	–
12.	Turnip	Plain	2%	35	50

i) Asparagus

he asparagus shoots are green and white. The tender shoots are used for canning. Just after harvesting the shoots are washed and graded for size and cut according to the height of the can. Shoots are blanched in boiling water for 2-3 minutes then placed in cold water. The blanched shoots are filled into sulphur-resistant cans, covered with 2.0 per cent common salt solution, exhausted, seamed and processed as usual.

ii) Beans

French beans, which are tendered and stringless are used for canning. The beans are washed thoroughly with water and cut into slices about 2.5 cm in length. The slices are blanched in boiling water, drained and filled into plain cans. The beans in the cans are covered with 2 per cent brine, exhausted, closed and processed under pressure in retorts. Sometimes diced beans with diced carrots and garden peas are also canned as mixed vegetables.

iii) Beetroot

Beetroot is washed with water thoroughly. The top and roots are removed with a stainless steel knife. The vegetable is cut in the form of discs or cubes and placed in 1 to 2 per cent common salt solution to preserve the colour. The prepared pieces are filled into vegetable lacquered cans, covered with 2 per cent brine, exhausted, seamed and processed as usual.

iv) Cabbage

Cabbage head with tender yellow leaves is used for canning. After washing, the head is cut into 4 to 8 pieces or shredded into 2.5 cm thick pieces. The pieces are generally blanched in boiling water for 5 to 7 minutes. The blanching water may preferably contain 1 per cent citric acid. After blanching it is cooled in 2 per cent brine to prevent discolouration. The prepared vegetable is filled into plain cans, covered with 2 per cent brine and processed as usual.

v) Carrot

Generally yellow varieties of carrot are used for canning. Tender and small carrots are selected for canning. The carrots are washed well and skin is scrapped with a knife. For large-scale work, mechanical peeler is employed. The peeled carrot is graded for size and used as such or cut into discs or cubes for canning. The carrot is blanched in boiling water for 8 to 12 minutes and packed into plain cans. Brine is used for canning.

vi) Cauliflower

In case of cauliflower, compact flower head is selected and cut into pieces of suitable size. The pieces are canned similar to that of cabbage.

vii) Mushroom

Edible mushrooms, which are not poisonous, are selected for canning. Button mushroom is generally canned whole. Sometimes, mushroom is bleached to a pale colour in a solution of sodium sulphite and citric acid. They are washed with water and blanched in boiling water for 4 to 5 minutes and subsequently dipped in cold water to prevent discolouration. Blanched mushrooms are filled into plain cans, covered with 2 per cent hot brine, exhausted, seamed, processed as usual.

viii) Okra

Okra is also known as Lady's finger. Tender green okras of uniform size are selected. Okra is canned as a whole or as slices. These are washed and blanched in boiling water for 1 to 2 minute and then cooled in brine containing 1.5 per cent common salt. This helps in removal of mucilage. The blanched okras are filled into plain cans and covered with 2 per cent brine, exhausted, seamed and processed as usual. Sometimes, the okras are also canned with thick tomato sauce in order to overcome the mucilaginous property.

ix) Peas

Bonneville is the most popular pea variety for canning in India. We should see that the peas for canning are uniformly ripe and should retain the green colour even after processing. They should also possess good texture and flavour. Large size peas are generally preferred for canning.

Peas are shelled by pea-podding machine and graded by size using sieves with mesh ranging from 0.7 to 1.0 cm. The graded peas are blanched in boiling water for 2 to 5 minutes, and rinsed in cold water. They are filled into plain cans by hand or machine and covered with 2 per cent brine. Sometimes, 2 per cent cane sugar is also added in brine to improve the flavour of the peas. An edible and FPO permitted green colour also may be added to the brine. The cans are exhaussted, closed and processed in a retort as usual. Canned fresh peas are generally known as 'green peas' or 'garden peas'. Dried peas are also canned. The dried peas, which are soaked in water, are canned similar to fresh peas. The dried canned peas are known as 'processed' peas.

x) Potato

Potatoes are canned either whole or slices. Good starchy and firm potatoes are selected and washed to remove the adhered soil. Potatoes are peeled with a knife or by potato peeler, a machine having abrasive surface to remove peel. Peeled potatoes are kept in 2 per cent common salt solution to prevent discolouration. Peeled potatoes are blanched in boiling water for 5 to 7 minutes. Blanched pieces are filled into plain cans, covered with 2 per cent brine, exhausted, seamed, processed and cooled as usual. Some varieties of potato turn bitter after canning, which should not be used.

xi) Tomato

Tomatoes for canning should be firm ripe, medium in size, regular in shape, and of uniform red colour. Tomatoes should have plenty of pulp and free from blemishes.

Tomatoes after washing are placed in boiling water or steam for 2 to 3 minutes to crack the skin and then washed in cold water to remove peel easily. Any green patch is trimmed out. The peeled and trimmed tomatoes are filled into plain cans and covered with tomato juice; and after exhausting and seaming processed in open cooker. It's processing is different from other vegetables as it is acid food.

xii) Turnip

Turnips are red, white and yellow in colour but generally white turnips are canned. Select fibre free tender turnips. They are washed thoroughly with water and cut into about 1 cm thick slices. The pieces are blanched in boiling water for 3 to 5 minutes and cooled. The blanched turnips are filled into cans, covered with 2 per cent brine and processed in retort as usual.

xiii) Other Vegetables

There are several other vegetables, which may be canned similar to the methods given above. They are Karela, Tinda and Parwal. Spinach (Palak) is also canned as puree.

Sarson-ka-Saag (Mustard Green)

Sarson-ka-saag is generally prepared from mustard leaves and spinach in the ratio of 4:1. It has good demand as canned product in India and abroad. The tender shoots of green mustard and spinach are washed, chopped and cooked with salt for 40-45 min. Then mashing is done along with the addition of corn flour or Bengal gram flour (besan). The mass, then fried along with other ingredients and filled into cans, exhausted for 10 minutes and sealed. The cans are processed for 50 minutes in a retort at 0.7 kg/cm^2 and cooled to room temperature. A general recipe for canning of sarson-ka-saag is given below:

Mustard green chopped	800g
Spinach chopped	200g
Tomato	100g
Onion	100g
Garlic	20g
Ginger	80g
Ghee/Oil	100g
Salt (to taste)	15g
Chilli	10g
Corn flour or besan	50g

xiv) Curried Vegetables

Canning of vegetables in brine is a western way of preserving and consuming. There are certain vegetables that are canned as we cook them along with spices and condiments. Certain vegetables like potato, cauliflower, peas, tomatoes are cooked in combination or alone and canned as curried vegetables. Curried vegetables are those vegetables, which are canned along with spices and condiments such as mustard, coriander, red chilli, turmeric, common salt and vegetable oil in form of gravy. The curried vegetables are readily consumed after heating in the cans. In order to prepare the curried vegetables, the oil is heated in a pan, the mustard seed is fried in it, then other ingredients in powder form are added to taste (as done at home while cooking vegetables) and heatings continued. Then required amount of water is added and brought to boil. The curried vegetables are filled into can along with gravy, closed and processed for 60 to 70 minutes at 0.7 kg/cm^2 in a retort.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Why non-acidic vegetables are processed at high temperature in a retort?

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2. Why certain vegetables are not packed in plain cans. Give names and reasons?

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3.5 ASEPTIC CANNING OF FRUIT AND VEGETABLE PRODUCTS

Fruit and vegetable products are packed by using the latest developed technique known as aseptic canning. As you know that this system is basically a high temperature short time (HTST) sterilizing process. This method combines flash sterilization and cooling with aseptic methods of packaging for fluid and semi-fluid products, thus eliminating retorting and cooling. It is being used commercially particularly for bulk packing of products. This system has advantage that quality of the product is maintained better. The nutrient losses are minimum due to HTST processing and shelf life of the product is more.

3.6 LET US SUM UP

Canning is a method of preservation of fruits and vegetables by heat application. The main principle of canning is the destruction of spoilage microorganisms. The canning process includes several unit operations, viz. selection, sorting, grading, washing, peeling, cutting, blanching, filling, syruping or brining, lidding or clinching, exhausting, seaming, processing, cooling and storage. Fruits and vegetables differ in the canning process due to their acid value.

Tin cans of different sizes are used for packing of fruits and vegetables. For some fruits and vegetables lacquer cans are used. If cans are not processed adequately they develop some defects. The defects may be caused by physical and chemical changes, and by microorganisms. Canned products can be stored for 1 to 2 years depending on the quality of raw materials.

3.7 KEY WORDS

Blanching : Blanching is done by immersing fruits and vegetables in hot water or by exposing to steam followed by cooling.

Syruping or brining : After placing prepared fruits or vegetables in can, syrup or brine is added, respectively is called syruping or brining.

Exhausting : The vacuum in the can obtained by heat treatment or by mechanical means is known as exhausting.

Seaming : It is sealing or closing of lids on cans by double seamer. Interlocking of curl of the lid and flange of the can creates double seam.

Processing : The application of heat to fruits and vegetables after hermetic (air tight) sealing in containers is called processing.

Commercial sterilization : It is the term used for those thermally processed products in which microorganisms and their spores do not grow under normal conditions of storage.

Principle purpose of canning : Destruction of spoilage or pathogenic microorganisms and retention the original characteristics of food.

Unit operation : It is one of the steps in a complete process or a physical change in form or place, for example, peeling, cutting, grading, etc.

3.8 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answer should include the following points:

1. • Destruction of microorganisms, which may cause spoilage of foods.
   • Improve the flavour, texture and appearance of food by cooking.
   • Prevent recontamination.

2. Selection of fruits and vegetables → Sorting and Grading → Washing → Peeling → Cutting → Blanching→ Filling → Syruping → Lidding/Brining or Clinching → Exhausting → Seaming → Processing → Cooling → Testing for defects → Storage

3. • Fruits are covered with sugar syrup while vegetables are covered with brine
   • Fruits are processed at 100°C while vegetables are processed at 115° to 121°C.
   • Fruits are processed in open cookers while vegetables are processed in retort under pressure(0.7kg/cm^2)

4. i) Spoilage due to physical and chemical changes:

   - Swell – Hydrogen swell; Flipper, Springer, etc.
   - Overfilling, faulty retort operation, under exhausting, panelling, rust, leakage, bursting, discolouration and stack burning

   ii) Spoilage by microorganisms

   - Flat sour.
   - Thermophilic acid sour
   - Sulphur spoilage, etc.

Check Your Progress Exercise 2

1. Your answer should include the following points:
   - To lower the pH of canned fruit
   - To improve the palatability of canned product

2. Your answer should include the following points:
   - To prevent enzymatic browning
   - To prevent darkening
   - To prevent discolouration

3. Your answer should include the following points:

- In open cooker, normal atmosphere is maintained
- In open cooker temperature of boiling water remain & below 100°C and never increases.
- The fruits and tomato (acidic vegetables) are cooked generally in the open cooker.

Check Your Progress Exercise 3

1. Your answer should include the following points:

   - Vegetables are generally non acidic in nature
   - The pH of non acidic vegetables are above 4.5
   - Non-acidic vegetables are processed at high temperature
   - High temperature can only be attained when processed under pressure in a retort.

2. Your answer should include the following points:

   - Certain vegetables contain water soluble colour
   - Presence of anthocyanins
   - Presence of sulphur compound
   - Asparagus, Beetroot, Peas are packed in lacquered cans

3.9 SOME USEFUL BOOKS

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UNIT 4 FORMS OF WATER IN FOODS, SORPTION AND DESORPTION OF WATER IN FOODS AND WATER ACTIVITY

Structure

4.0 OBJECTIVES

After reading this unit, you should be able to:

- state the meaning of water activity and water sorption isotherms;
- explain the properties of water in solutions;
- describe the effect of water activity on various biochemical reactions, microbial growth, food preservation, etc.; and
- discuss the water activity in packaged and stored food.

4.1 INTRODUCTION

All foods provided by nature, contain water. High water content in foods is most likely to show rapid deterioration due to biological and chemical changes. Our ancestors found that spoilage could be delayed or prevented by drying perishable foods. The water in foods serves as a solvent for many constituents. The removal of water will concentrate these constituents. The increasing concentration, rather than decreasing water content, preserves the food. Water can be removed by heat, sun's radiation, salt or sugar. Thus, any method increasing the concentration of a food's aqueous phase enhances its stability.

Therefore, study of water in foods is also a study of aqueous solution in which the solutes, by their nature and concentration, alter the physical properties of the solvent. It is the state of water in food which influences the microbial growth, enzymatic and non-enzymatic reactions. By controlling the water content, or concentrating the food solution, we may stabilize the food for a longer period. The water content influences the biological or chemical changes, and these changes affect the taste, texture and appearance of the food.

Thus, there is a water related criteria, viz. water content, solute concentration, osmotic pressure, equilibrium relative humidity (E.R.H.), and water activity (a_w). It is the water activity, which is the most useful expression of water requirements for microbial growth and enzyme activity. It becomes more important in defining the quality of food material. Thus, by controlling the water activity of fruits and vegetables, we may predict the freshness, or storability of their processed products.

4.2 PROPERTIES OF WATER IN SOLUTIONS

Water has its own property. When solutes are dissolved in water, the water molecules become oriented with respect to solute molecules. In simple word water molecules and solute molecules are engaged with each other. The water molecules become less free to escape from the liquid into the vapour phase, and the vapour pressure is lowered. There is a relationship between solutes concentration and vapour pressure of liquid or solution. It indicates that with increase in solute concentration, vapour pressure decreases, and it lowers the freezing point but it raises the boiling point of the solution.

The water activity is described as the ratio of water vapour pressure of food (solution) to the water vapour pressure of pure water (solvent) at the same temperature and expressed by

$$a_w = P/P_o$$

P = Vapour pressure of food
P_o = Vapour pressures of pure water

It is expressed as a fraction but under equilibrium condition, equilibrium relative humidity (E.R.H.) is equal to $a_w \times 100$, provided that its vapour pressure is not reduced. The pure water has the water activity of 1.00, which is equivalent to an E.R.H. of 100 per cent. Thus, a food with a water activity of 0.8 would produce an E.R.H. of 80 per cent.

Any addition of solutes in water influences the water activity. For example, an ideal solute of 1 molal concentration has a_w 0.9823, but glycerol has 0.9816, sucrose has 0.9806, while has sodium chloride 0.967. The difference in water activity may be small for non-electrolytes but for electrolytes the difference in water activity is always great. It increases with the increase in the number of ions generated per molecule.

4.3 WATER SORPTION ISOTHERMS

A percentage of total water in a food is strongly bound to specific sites, e.g. hydroxyl groups of polysaccharides. When all sites are (statistically) occupied by adsorbed water the moisture content is termed monolayer value. This monolayer value represents the moisture content at which the food is most stable.

It influences certain chemical reactions. For example, lipid oxidation rates increase at water contents below the monolayer, while rates of non-enzymatic browning increase above it. The capillary forces in foods also influence the water activity, generally it depresses water activity.

To understand the water relations of a food, the water activity levels corresponding to a range of water content must be determined. The data are plotted to provide a water sorption isotherm (Figure 4.1).

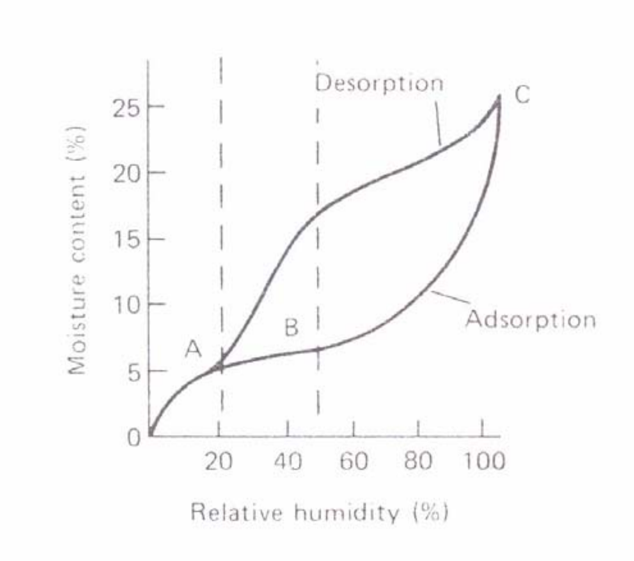

Figure 4.1: Water sorption isotherms

The graphical relationships between water content and water activity (a_w) are termed "isotherms" and the loop is fermed as hystoresis loop. Any changes in temperature affect this relation. Thus, water taken by a dry food is termed adsorption and water removed from a moist material is termed desorption. The difference is greatest at lower temperature (5°C) and not detectable at higher temperature (60°C).

There are different stages of water sorption. In theory, the course of water sorption by a dry material is first by the formation of a monolayer, followed by multiplayer adsorption, the uptake into pores and capillary spaces, dissolution of solutes, and entrapment of water at higher levels of water activity. These phases or stages vary in the food product depending upon chemical composition and structure. Thus, we find that water activity plays a great role in the study of freezing and dehydration of fruits and vegetables. By controlling water activity of the food, oxidative changes and microbial growth can be checked. The water activity can be a basis for the standard specification of food material. And it also becomes the basis of guidelines, for pickled, fermented and acidified foods.

4.4 WATER ACTIVITY AND METHODS

The water in food, which is not bound to its molecules, can support the growth of microorganisms. This unbound or free water is also termed as water activity (a_w).

The water activity and moisture content of a food are not the same. The various foods may have exactly the same moisture content but have different water activities. For example, jams, jellies and plum puddings have 0.8 a_w, while dried fruits have 0.6 a_w.

The water activity can determine the shelf life of a food. There are several factors, including the temperature and pH, that influence the growth of the organisms in food, but water activity may be the most important factor in controlling spoilage. The water activity can predict which microorganisms will and will not be potential cause of spoilage. Hence, the water activity plays a role in determining the activity of bacteria or enzyme, which can have a major impact on the colour, taste and aroma of the product. There are several food preservation methods which to eliminate spoilage by reducing the availability of free water to microorganisms. The processes such as concentration, dehydration, freeze-drying and freezing can reduce the amount of free water in a product.

Water activity or equilibrium relative humidity of a food effects its quality during processing storage, transportation, marketing etc. Any change in the water activity of specific food may lead to the changes in its quality.

Moisture measurement techniques have been classified into three groups based on function: (i) water activity, (ii) atmospheric relative humidity, and (iii) total moisture. The first group deals with direct water activity / E.R.H. measurements as related to foods. The second group deals with relative humidity measurements, which covers food related activities, for example, ambient relative humidity in food storage areas. The third group deals with measurement of total moisture content, regardless of the condition or degree of water binding. These measurement methods are listed below.

Graphic Interpolation, Bithermal Equilibrium, Manometer, Hair Hygrometry, Isopiestic Equilibration, Electric Hygrometry, Chemical Methods, Freezing Point Depression, Dew Point Methods, Relative Humidity Methods, Thermometric Methods, Total Moisture Methods, Gravimetric, Gas Chromatography, Karl Fischer Titration, Nuclear Magnetic Resonance, Thermal Analysis, Moisture Evolution Analysis, Infrared, Vacuum Oven Drying, Solvent Extraction.

The control of water activity in processed products of fruits and vegetables is essential for maintenance of their wholesomeness, safety, texture, and for suppression of undesirable enzymatic and chemical changes. These objectives can be achieved by utilizing water activity adjustment as a legitimate means of food preservation. The water activity adjustment in a food is also affected by a large number of substances added to the food.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Describe water activity.

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2. What do you understand by water sorption isotherms?

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3. List some methods which can measures the water activity.

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4. Why measurement of water activity is essential?

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4.5 EFFECT OF WATER ACTIVITY ON ENZYME REACTIONS

Enzymes are proteinaceous substances that catalyze organic reactions. The enzymatic reactions may be beneficial or detrimental changes occurring in foods. For example, the addition of a proteolytic enzyme, which acts as chill proofing agent, to beer to prevent precipitation of proteins when it is refrigerated. These enzymes develop in foods through the growth of specific types of microorganisms. For example, proteases and lipases synthesize by the mould, *Penicillium roqueforti* that produces desirable flavours during ripening of blue cheese.

Certain enzymes catalyze detrimental changes in food, such as non-microbial decomposition of fruits and vegetables during handling and storage. The enzymes, viz. peroxidase may cause browning; ascorbic acid oxidase may cause oxidation of ascorbic acid. It is therefore, important to thwart the activities of these naturally occurring enzymes in foods. Blanching of fruits and vegetables by hot water or steam is one method to inactivate enzymes and prevent the deleterious changes.

The enzymes also produce free radical by hydrolytic reactions. The water participates actively in these reactions. These reactions are not limited with low moisture foods, since many enzymatic reactions cease at higher concentration than that required for hydrolysis. At low water activity levels free mobile water monolayer is not available to carry out reactions. Under such conditions the enzymatic reactions are suppressed. But, when the water activity of food increased, the enzymatic reaction rates increase. Thus, by controlling water activity, we can check the enzymatic reaction rates. In other words, we may increase the rates of beneficial reactions and reduce the rates of deleterious reactions, and maintain the desired quality of foods.

There are certain enzyme preparations, which can be used to affect desirable changes in foods, These enzyme preparations can be stabilized by use of certain substances such as sodium chloride, glycerol, or propylene glycol. There are other factors, which also affect the stability of enzymes in foods, such as temperature, pH, ionic strength, moisture level, nature of food, time of storage, presence of activators and inhibitors, etc.

The enzymatic activity virtually ceases at water activity values below monolayer value. This is due to the low substrate mobility and its inability to diffuse to the reactive site on the anzymes.

Fungal proteolytic enzymes are strongly inhibited by 2-3% sodium chloride (NaCl), as the activity is in the range of 0.6-0.8. The optimal water activity levels for invertase activity is greater than 0.997. In a glycerol / water mixture, lipoxidase and peroxidase exhibit optimal activity in the range of 0.94-0.97 water activity.

4.6 EFFECT OF WATER ACTIVITY ON NON-ENZYMATIC BROWNING REACTIONS

The water activity plays a great role in influencing the non-enzymatic browning (NEB) reactions in the processed fruit and vegetable products. The substrates for NEB are the reducing sugars such as glucose and fructose and amino groups of amino acids or proteins. Sucrose may be a substrate but does not cause browning. Hydrolysis of sucrose into glucose and fructose during processing may cause browning. A number of factors such as temperature, pH, and water activity also affect the NEB reactions. They are called the formation of browning or Maillard reaction products. These browning reactions deteriorate the quality of the processed products.

The water activity that causes the maximum rate of browning varies with different foods. At low water activity browning is reduced due to lower mobility of reactants, whereas at higher a_w browning is maximum. During browning, condensation reaction produce water and at higher moisture levels, browning is inhibited by end product inhibition. At higher moisture contents, water dilutes the reactants and the rate of browning falls.

Browning that occurs during processing or storage may either increase or decrease the acceptability of a food. For example, in a dehydrated pea soup stored at 54°C, a steady increase in browning rate occurs as the relative humidity of the system is increased. The maximal rate occurs in the 65-70%

relative humidity range. Thus, the temperature and moisture content during storage influence the browning rate in dehydrated products. NEB is a serious problem in the production of intermediate moisture food (IMF), since they are poised at 0.6-0.8 water activity, which places them well within water activity ranges for optimal browning. If the water activity is reduced to the range of 0.40 to 0.50 from 0.65 to 0.75 the browning of IMF can be reduced.

It is clear from the above discussion that maximal browning reaction rates in fruit and vegetable products occur in the 0.65-0.75 water activity range. By checking the water activity we can reduce the non-enzymatic browning.

4.7 EFFECT OF WATER ACTIVITY ON MICROBIAL GROWTH AND SURVIVAL

4.7.1 Microbial Growth

Food is spoiled by microorganisms, i.e. bacteria, yeast and moulds. There are four main phases of the growth cycle of these microorganisms, viz. the lag phase, the logarithmic phase, the stationary phase, and the death phase. Bacteria, yeasts and fungi reproduce by different methods such as binary fission, budding or by hyphal extension, respectively. But the phases through which these organisms pass are broadly similar.

The first phase, i.e., the lag phase, is the period of adjustment or adaptation. Physiologically the microorganisms are very active during this phase. The organisms are metabolizing, but there is a lag in cell division. At the end of the lag phase, each organism divides. However, since all the organisms do not complete the lag period simultaneously, there is a gradual increase in the population until the end of this period, when all cells are capable of dividing at regular intervals. The lag phase is followed by rapid growth, i.e., the exponential or logarithmic phase. During this period, the population is nearly most uniform in terms of chemical composition of cells, metabolic activity, and other physiological characteristics.

The logarithmic phase of growth is followed by a levelling off, the stationary phase. During this phase, the population remains constant for a time, perhaps because the reproduction rate is balanced by an equivalent death rate. Following the stationary phase, the organisms may die faster than new ones are produced, if indeed some organisms are still reproducing. During the death phase, the number of viable organisms decreases exponentially, essentially the inverse of growth during the lag phase.

We should understand that the important criterion in the water relations of a particular microorganism is the minimal water activity permitting growth. From the point of view of food technology and preservation of fruit and vegetable products, less extreme effects may also be detrimental. For example, at certain water activity levels, the population of a microorganism may be insufficient to produce a toxic product or an infectious dose. The reduced water activity along with another chemical or physical agent such as pH or common salt may have synergistic inhibitory effect on the growth of any microorganism. Thus, it is important to consider the effects of water activity on microbial growth and survival.

In general, the microorganisms associated with foods, moulds are more tolerant of a decreased a_w than yeasts, and yeasts are more tolerant than bacteria. In high moisture foods ($a_w > 0.90$) bacteria are mainly responsible for spoilage, food poisoning or fermentation. In intermediate moisture foods (a_w 0.90-0.60) yeasts and moulds are of significance in spoilage. However, most microorganisms re inhibited in low moisture foods ($a_w < 0.60$).

The a_w of most fresh foods is above 0.99. Most spoilage bacteria do not grow below a_w of 0.91 while spoilage moulds can grow as low as 0.80. With respect to food poisoning bacteria, *staphylococcus aureus* has been found to grow at as low as 0.86, while *clostridium botulinum* does not grow below 0.95 a_w. Just as yeasts and moulds grow over a wider pH range than bacteria, the same is true for a_w. The lowest reported values for bacteria of any type is 0.75 for halophilic bacteria, while xerophilic moulds and osmophilic yeasts have been reported to grow at a_w values of 0.65 and 0.60, respectively.

Inhibition of microorganisms in a food is frequently not caused solely by a decrease in a_w, but may also be influenced by pH, temperature, nutrition, preservatives or a competitive microflora. At any temperature, the ability of microorganisms to grow is reduced as the a_w is lowered. The range of a_w over which growth occurs is greatest at the optimum temperature for growth. The presence of nutrients increases the range of a_w over which the organisms can survive.

Factors affecting the germination of spores *clostridium batulinum* have indicated interaction or combined effects of a_w, temperature, pH, oxidation – reduction (O-R) potential, and sodium chloride and sodium nitrate concentrations. Addition of solutes such as glycerol and common salt also influences the water activity of a solution. This shows the availability of solvent or water in a solution, since it reduces with the addition of solutes. Such conditions also influence the growth of microorganisms. For example, non-osmophilic yeast, *saccharomyces*, grows at water activity levels down to 0.93-0.92 in sodium chloride and to 0.91-0.90 in sucrose media. But the osmophihlic yeast will grow in more concentrated environment, i.e., sugar rich and salt-rich foods.

Thus, depending upon the type of microorganism, water activity along with solutes and other factors can be selected to enhance or restrict their growth.

4.7.2 Microbial Survival

The survival of microflora is of concern during two stages of fruits and vegetables. Firstly for short period during processing and secondly for long periods during storage. We should adopt measures to prevent the growth of these microflora. We are concerned especially with the survival of microorganisms in commercially processed fruit and vegetable products. These may be frozen, dried or canned products.

Similar to the rate of multiplication, the rate of inactivation of microorganisms tends to be exponential. It shows that the same proportion of the viable population will be inactivated in each succeeding unit of time. If we plot, the number of viable cells against time, a linear curve would be obtained, and from it rate of death can be determined. This is generally expressed as the decimal reduction time or D-value. It is the time required to destroy 90 percent of the organisms. Mathematically, it is equal to the reciprocal of the slope of the survivor curve and is a measure of the death rate of an organism.

Storage stability of frozen and dried foods

A large number of microorganisms have been reported to grow at and below 0°C. Their growth at and below freezing temperatures depends on several factors of foods, namely, nutrient content, pH, and the availability of liquid water. The a_w of foods may be expected to decrease as temperatures fall below the freezing point. In fruit juice concentrates which contain comparatively high levels of sugars, these compounds tend to maintain a_w at levels higher than would be expected in pure water, thereby making microbial growth possible ever at subfreezing temperatures. Bacteria differ in their capacity to survive during freezing, with the cocci being generally more resistant than gram negative rods. Of the food poisoning bacteria, salmonellae are less resistant than *staphylococcus aureus* or vegetative cells of *clostridia*, while endospores and food poisoning toxins are apparently unaffected by low temperatures.

The heat resistance of microbial cells increases with decreasing humidity or moisture. The preservation of foods by drying is based on the fact that microorganisms and enzymes need water in order to be active. Although some microorganisms are destroyed in the process of drying, this process is not lethal to microorganisms, and indeed many types may be recovered from dried foods. Osmophilic yeasts such as *Saccharomyces rouxii* strains have been reported to grow at an a_w of 0.65 under certain conditions. The most troublesome group of microorganisms in dried foods are the moulds, with the *Aspergillus glaucus* group being the most notorious at low a_w values. In the absence of fungal growth, dessicated foods are subjected to certain chemical changes which may result in the food becoming undesirable upon holding.

Drying usually is accomplished by the removal of water, but any method that reduces the amount of available moisture, i.e., lowers the a_w, in a food is a form of drying. Thus, for example, dried fish may be heavily salted so that moisture is drawn from the flesh and bound by the solute and hence is unavailable to microorganisms. Sugar may be added, as in sweetened condensed milk, to reduce the amount of available moisture.

The potentials of reduced water activity in food preservation with the following considerations are:

i) an a_w of 0.85 inhibits the most common food pathogens,

ii) bacterial spore germination is inhibited at relatively high a_w values,

iii) non-sporeformers, which can grow at an aw below 0.95, are susceptible to pasteurizing temperatures,

iv) sub-optimal conditions of growth impose inhibition at higher levels of water activity,

v) organisms that will grow at low water activities multiply very slowly, and

vi) yeasts and moulds can be suppressed by antimycotics.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. How does water activity affect enzymatic reactions?

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2. Explain "controlling water activity can reduce non-enzymatic browning."

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3. Describe the effects of water activity on the microbial growth.

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4.8 EFFECT OF WATER ACTIVITY ON PACKAGING AND STORAGE

The conditions during storage and transport should be maintained in such a way so that any deterioration is kept to a minimum. These problems are influenced by the temperature and relative humidity during storage and by the type of package in which foods are stored. Therefore, we should consider the water activity requirement in the packaging, storage and transportation of food products.

i) Transportation of processed products

During transportation of processed products the moisture migration may cause condensation. This has proved to be a problem in successful transportation of some commodities due to differences in climatic zones. For example, if cooling is followed by an increase in atmospheric temperature then humidity causes condensation on the inner surface of any container. This causes an increase in the relative humidity of the air above 90 per cent, but aeration can reduce it to a safe level.

Similarly, condensation of moisture on the surface of containers such as canned foods may spoil the label, corrode the can and mould attack. This type of problem can be prevented by drying the container before loading and lacquering the can from outside.

In the atmosphere of equilibrium relative humidity (ERH) a commodity at low water activity, even small decrease in air temperature may cause moisture condensation. For example, the air at 70 per cent ERH and 30^{o}C becomes saturated and hence prone to moisture condensation if its temperature falls by only 6^{o}C, such conditions may also permit the mould growth.

ii) Packaged products

Packaging generally reduces the atmosphere of a commodity to a minimum, hence protects it from outside sources, particularly the migration of moisture and variation in temperature. The quality of a food depends upon its properties, packaging material and the storage environment. We are concerned with the changes influenced by water activity, particularly appearance, taste, odour and texture, resulting from microbiological and biochemical changes. Packages are expected to provide adequate degree of protection to the product. With advances in packaging technology, packages are often expected to provide nutritional and constitutional information to sell the product. The packaging material has to provide desired water activity, which is the main concern. But, there are special requirements that include protection from light and oxygen, retention of preservatives, fragility of the product and the ease with which the package can be filled, handled and stored. Properly sealed cans and glass bottles give complete protection to the packed food against the intake of gases, moisture and microorganisms. The more attention should be given to the flexible films or packaging materials, which exhibit a very wide range of moisture (vapour) and gas permeability.

iii) Packaging materials

The basic flexible materials of importance are aluminium, plastic, regenerated cellulose and paper. The overall permeability of aluminium foil and laminate is near zero. The permeability of plastic film is governed by its thickness. Thicker films generally have lower permeability, greater strength and higher cost. In food packaging application, the materials are combined by lamination, coating or co-extrusion, and they may have properties different from the basic or individual film. Type of food product, its hygroscopicity, environment inside and outside of package, handling during storage, marketing, transportation, etc., usually govern this type of combination of packaging materials. Sometimes, microbiological problems may arise. When moist product is packed in impermeable or low permeable materials, such as glass, metal or films coated with polyvinylidene chloride or polyvinyl chloride, the food will equilibrate with the internal atmosphere of the package, and cooling may cause condensation of moisture, resulting in high water activity in which microbial growth may occur. Hence, we should see that product of relatively low water activity be packed in moisture impermeable packages and some measure of microbial control should also be used. Although, when high water activity products are packed in permeable material, then care must be taken to prevent excessive moisture loss from the product. This can be achieved by careful selection of wrapping material or by control of humidity in the surrounding atmosphere of the package.

iv) Unrefrigerated packaged products

Dehydrated vegetables, which have water activity of 0.30 or below, require protection against moisture and oxygen. Laminates of polyethylene, aluminium foil and paper have been successfully employed for packaging dehydrated vegetables. Dehydrated soups are also packaged similar to dried vegetables, which provide full protection to the product. The dried fruits have much higher water activity levels, may be stored safely in relatively permeable film, where ambient humidity is very low. The potato chips and roasted nuts which depend on their appeal and crispness are not susceptible to unsuitable storage conditions. These products have substantial amount of lipids, hence need additional protection, and therefore hence packaged with nitrogen gas. But for long storage costly items like nuts vacuum packaging in cans or glass jars require. However, for retail marketing, these products are successfully packaged in a wide variety of materials with low water vapour transmission rate, and oxygen permeability. For example, cellulose-plastic combination, poly vinylidene chloride coated-cellulose or polypropylene are used.

v) Refrigerated packaged products

Generally, fresh fruits and vegetables are kept in cool store at suitable temperatures and relative humidity (RH). For example, cured onions and garlic can be stored at 0°C with RH 65-70 per cent, whereas vegetables like cabbage, carrots, cauliflower, leafy greens, green peas, turnip require 95 per cent of RH. Apples are stored at 0-3°C with 85-90 per cent RH depending upon non-chilling and chilling sensitive varieties.

A compromise is required between packaging material of fresh fruits and vegetables that retain water and maintain crispness, but cause condensation and fogging of the films and those which permit loss in weight and crispness, but do not fog. Sometimes, adequate perforations are made in the package for minimum respiration without physiological disorders in the living tissues. Frozen vegetables are commonly packed in polyethylene or paperboard, waxed or plastic coated moisture proof film, to minimize oxygen uptake and loss of moisture. The frozen fruit juice concentrates are packaged in hermetically sealed tin cans or aluminium laminated composite containers.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.

b) Compare your answers with those given at the end of the unit.

1. Describe the role of water activity in packaged products during storage?

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4.9 LET US SUM UP

The fruits and vegetables by nature contain high water; consequently they are highly perishable products. Most likely they show rapid deterioration due to biological and chemical changes. Water acts as a solvent in the food products. The solutes present in aqueous phase, by their nature and concentration, alter the properties of solvent. It is the state of water in food products, which influences the microbial, enzymatic and non-enzymatic reactions. Thus, controlling the water content or concentrating the food solution, the food may be stabilized for a longer period. The solution of food (fruits and vegetables) has its properties, and may be expressed as water activity. The water activity is certainly related with properties of food and has great importance to study its influence on microbial growth/ survival, moisture content of food, packaged food during storage, transport and preservation.

Many enzymatic reactions cease at higher water content than that is required for hydrolysis. At low water activity levels, the free moisture is not available, hence enzymatic reactions are suppressed. The maximum non-enzymatic reactions occur in food equilibrated to 0.65-0.70 water activity, but reduce at higher and lower water activity levels.

The lower level of water activity suppresses microbial growth in food products. Removal of water from foods, reduces its water activity, hence preservation is affected.

Properly prepared fruit and vegetable products, packed in appropriate packaging material and stored under controlled conditions have longer shelf life.

4.10 KEY WORDS

Water activity : Water activity (a_w) is the ratio of vapour pressure of food (p) and pure water (p_o), and expressed by $a_w = p/ p_o$

Sorption isotherm : Water sorption isotherm is a graphical presentation of data which shows the water relationship of a food.

Concentration	:	It is the removal of water from foods mostly by heat application and concentration of soluble solids or solutes.
Enzyme	:	Enzyme may be defined as proteinaceous compounds that catalyse organic reactions.
Preservation	:	Methods to hold food for a longer period than generally kept at ambient conditions. Food is safe, nutritious and free from any microbial infection.
Halophilic bacteria	:	They are salt tolerant bacteria. The extremely halophilic bacteria have evolved to grow only at low levels of water activity and only when these levels are produced by high sodium chloride concentrations.
Osmophilic yeast	:	Sugar tolerant yeast.
Adsorption	:	The taking up of one substance at the surface of another.
Desorption	:	Removal of adsorbed water from a solid. Reverse process of adsorption.
Adsorption isotherm	:	The relation between the amount of a substance adsorbed and its pressure or concentration at constant temperature.
Xerophilic	:	Microorganisms able to inhabit places where the water supply is scanty, or where conditions, e.g., excess of salt, make it difficult to take in water.

4.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercises 1

Your answers should include the following points:

1. The water activity is described as the ratio of vapour pressure of solution (food) and vapour pressure of solvent (water) and expressed by

   $$a_w = p/ p_o$$

   a_w = Water Activity

   p = Vapour pressure of solution (food)
   p_o = Vapour pressure of solvent (water)

   Under equilibrium condition, E.R.H. is equal to $a_w \times 100$. Provided that its vapour pressure is not reduced. The pure water has an a_w of 1.00, which is equivalent to an E.R.H. of 100 per cent.

2. To understand the water relations of a food, the water activity levels corresponding to a range of water contents must be determined. The data are plotted to provide a water sorption isotherm. The water sorption isotherm is a graphical presentation of data, which shows the water relationships of a food. It is useful in showing at what water contents certain desirable or undesirable levels of water activity are achieved.

3. The following methods can be used to measure the water activity:

   Graphical Inter Polation, Bithermal Equilibration Mamometry, Hair Hygrometry, Isopiestic Equilibration, Electric Hygrometry, Chemical methods, Freezing Point Depression and Dew Point Method.

4. The measurement of water activity in a food is essential for maintenance of their wholesomeness, safety, texture, and for suppression of undesirable enzymatic, and chemical changes.

Check Your Progress Exercises 2

Your answers should include the following points:

1. Enzymes are proteinaceous substances that catalyze organic reactions, which may be beneficial or detrimental, occurring in foods. The water participates actively in these reactions. Many enzymatic reactions cease at higher water content than that required for hydrolysis. At low water activity levels, the free mobile water is not available to carry out reactions. Under such conditions the enzymatic reactions are suppressed, but when water activity of food is increased, the enzymatic reactions rate gets increased. Thus, by controlling water activity we can check the enzymatic reactions.

2. The non-enzymatic browning is caused by reactions between glucose or fructose and amino group of food and influenced by water activity level. The maximum level of such reaction occurs in samples equilibrated to 0.65 to 0.70 $a_{w.}$ But reduced at higher and lower levels of water activity. Thus, by controlling water activity, we can reduce the non-enzymatic browning.

3. For microbial growth optimum moisture content in food is essential beyond this limit the growth is suppressed. The lower level of water activity does not provide free moisture whereas concentration of solutes suppresses microbial growth. At very high water content dilution of nutrients prevent their growth.

Check Your Progress Exercises 3

1. Properly dried fruits and vegetables should be packed in such packaging materials, which do not permeate moisture vapour, light and gases. These food packages should be stored at desirable relative humidity and temperature. If there are differences in temperature and relative humidity in the packaged food and its surrounding atmosphere, then the moisture migration may cause condensation, which may create problems in the successful transportation. This can be reduced by aeration. Proper packaging also protects food by maintaining desirable water activity.

4.12 SOME USEFUL BOOKS

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3. Troller, J.A. and Christian, J.H.B. (1978) Water Activity and Food. Academic Press, New York.

4. Verma, L.R. and Joshi, V.K. (2000) Post Harvest Technology of Fruits and Vegetables. Vol. 1 General Concept and Principles. Indus Publishing Company, New Delhi.

UNIT 5 DRYING, DEHYDRATION AND EVAPORATION

Structure

5.0 OBJECTIVES

After reading this unit, you should be able to:

- describe the mechanisms of drying and dehydration of fruits and vegetables;
- reduce the weight and bulk, and water activity of fruits and vegetables;
- explain various methods and types of evaporation and evaporators used;
- define the microorganisms involved in spoilage of dried products;
- determine the drying and rehydration ratio; and
- evaluate the factors affecting the drying rate of fruits and vegetables.

5.1 INTRODUCTION

Drying or dehydration is accomplished by the removal of water from the fruits and vegetables below a certain level at which enzyme activity and growth of microorganisms are affected adversely. Evaporation is an important unit operation commonly employed to remove water from dilute liquid foods to obtain concentrated products. The dried or concentrated fruit or vegetable product is called as high sugar high acid food or high value low volume food. The dried or concentrated products save energy, money and space in packaging storage and transportation. Dehydration or drying process usually involves heating, in which water is removed from solid or near solid substances. Both drying and dehydration mean the removal of water. The term drying is generally used for drying in the sun, while dehydration is generally used for drying the commodities under the controlled conditions. Evaporation process also involves heating where water is removed from the liquid substance. Evaporation, sometimes also termed as concentration, is different from drying and dehydration, since the final product of evaporation process remains in liquid state. Removal of water from food provides microbiological stability and assists in reducing transportation and storage costs. Fruit juice is concentrated by evaporating water. For aromatic juice, it is desirable to heat the juice for short time and cooling rapidly. This minimizes the effect on flavour, aroma, and sugar compounds.

5.2 DRYING PHENOMENA

You are aware that the fruits and vegetables contain sufficient water which allows their spoilage by microorganism and physiological changes. So, the reduction of free water or removal of moisture becomes necessary to provide stability to a product. The drying or dehydration reduces the amount of available moisture, i.e., water activity. The relationship between moisture and solid in fruits sand vegetables is a complex phenomenon. The physiological structure of most fruits and vegetables restricts the rate of migration of water from within to the exposed outer surfaces from where it can evaporate.

Therefore, the changes during dehydration can be explained in terms of heat and mass transfer phenomena. During dehydration a food loses moisture from its surface and gradually develops a dry layer with remaining moisture confined to its centre. A stabilised moisture gradient is formed from the centre to the surface. As a result, the outside dry layer forms an insulation barrier against rapid heat transfer into the food pieces, especially since the evaporating water leaves air voids behind it. In addition to less driving force from decreased heat transfer, the centrally remaining water also has to travel further to get out of the food piece than did surface moisture at the start of drying. And, as the food dries it approaches its normal equilibrium relative humidity, as it does it begins to pick up molecules of water vapour from the atmosphere as fast as it loses them. When these rates are equal drying ceases. The cracking, shrivelling and shrinking may occur during dehydration due to the removal of moisture through diffusion from centre to outer surface. Excessively fast removal of moisture from outer layers may result in case hardening thereby sealing the surface and causing inadequate drying in the centre.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Differentiate between drying and dehydration.

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2. Define evaporation.

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3. What are the main objectives of drying?

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4. How the out side of the product forms a dried layer during drying?

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5.3 FACTORS AFFECTING DRYING

Food dehydration involves two steps (i) to get heat into the product and (ii) to get moisture out of the product. The above two steps are not always favoured by same operating conditions. For example, food may be pressed between two heated plates. This will provide close contact and improve heat transfer into the food through top and bottom, but the close contact of the plates will interfere with the escape of free moisture. Therefore, it may be better to use one bottom hot plate to get heat in and a free surface on top of the food to let moisture out. The following factors influence the drying rate.

i) Temperature

The rate of heat transfer into the food, which provides the driving force for moisture removal, is affected by the temperature difference between heating medium and the food. Greater the temperature difference, more will be the transfer of heat and moisture removal. When the heating medium is air, temperature also plays a role in carrying away the water driven from the food in the form of water vapour. However, moisture creates a saturated atmosphere at the food's surface which slows down the rate of subsequent water removal.

ii) Surface area

The heat and mass transfer is affected by surface area. Higher surface area results into increased rate of drying. Therefore, the food to be dehydrated is sub divided into small pieces or thin layers which speeds up drying for two reasons. First, larger surface area provides more surface in contact with the heating medium and thus, more surface area from which moisture can escape. Second, smaller particles or thin layers reduce the distance through which heat travels to the centre of the food and moisture in the centre of the food travels to reach the surface and escape.

iii) Air velocity

High velocity air, in addition to taking up moisture, sweeps it away from the drying food surface. It also prevents the moisture from making a saturated atmosphere around food and hence helps in subsequent moisture removal.

iv) Dryness of the air

When the food is dried in air, food drys rapidly due to higher absorption and more holding capacity of moisture by dry air than the moist air. Moist air is closer to saturation so can absorb and hold less additional moisture,

The extent of dryness of the air also determines how a low moisture content food can be dried further. Dehydrated food is hygroscopic and each food has its own equilibrium relative humidity. Equilibrium relative humidity (ERH) is the humidity at a given temperature where the food neither loses moisture nor picks up moisture from the atmosphere.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Explain why it is necessary to use bottom plate as hot and free surface on top during drying of a food.

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2. Describe the role of temperature in drying.

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3. How the higher surface area affects the drying rate?

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4. How the product size affects the drying rate?

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5. What is the role of air in drying?

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6. Define ERH.

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5.4 DRYING AND RECONSTITUTION RATIO

5.4.1 Drying Ratio

Drying ratio varies with the type of variety, growing conditions, time of harvest, grade of raw material and loss in preparation. It should not be expressed on the basis of moisture per cent in the material, rather it should be expressed on a dry weight basis, i.e., as the ratio of water content to dry matter. The weight of dry matter going into the dryer remains the same as that is taken out, i.e., only the amount of water changes, while the dry matter does not. Drying ratio is also known as dehydration ratio.

Knowing the water content of a fresh material entering the dryer and of the product leaving the dryer, the drying ratio, or its reciprocal drying yield, can be calculated as follows:

$$\text{Drying ratio} = \frac{\text{Weight entering dryer}}{\text{Weight leaving dryer}} = \frac{100 - M1}{100 - M0} = \frac{T0 + 1}{T1 + 1}$$

Where M0 = per cent moisture of the material entering the dryer
M1 = per cent moisture of the product leaving the dryer
T0 = lb of water per lb of bone (dry material entering the dryer)
T1 = lb of water per lb bone (dry material leaving the dryer)

For example, potatoes, prepared and ready for the dryer, have about 78 per cent moisture, when properly dried they have about 7 per cent moisture. Then

M0 = 78, M1 = 7, T0= 78/22 = 3.55, T1 = 7/93 =0.075

$$\text{Drying ratio} = \frac{100 - 7}{100 - 78} = \frac{3.55 + 1}{0.075 + 1} = 4.23 = 4.23:1$$

$$\text{Drying yield} = \frac{100 - 78}{100 - 7} = \frac{0.075 + 1}{3.55 + 1} = 40.236 \text{ or } 23.6 \text{ percent}$$

It should be noted that over all ratio between weight of raw material entering the dryer and weight of finished product leaving it must take into consideration the losses incurred during preparation and final inspection.

5.4.2 Reconstitution Ratio

Reconstitution (rehydration) means the replinishment of quantity of water replaced by dehydrated foods.

Calculation can be made to express the results in terms of “rehydration ratio”, “coefficient of rehydration” and “per cent of water in the rehydrated material”,

Examples of such calculations are as follows:

i) Rehydration ratio

Suppose the weight of the dehydrated sample used for the test is 10 g (W_D) and the drained weight of rehydrated sample is 60 g (WR). Then

$$\text{Rehydration} = \frac{W_R}{W_D} = \frac{60}{10} = \frac{6}{1},$$ The rehydration ratio is 6 to 1, i.e. 6:1

Coefficient of rehydration

The drained weight of the rehydrated sample is 60 g (W_R), the weight of the dehydrated sample is 10 g (W_D) which contains 5 per cent moisture, and the original material before dehydration contained 87 per cent moisture (A). Then, coefficient of rehydration is

$$\frac{W_R \times (100 - A)}{(W_D - W_M)100} = \frac{60 \times (100 - 87)}{\{10 - (10 \times 0.05)\}} = \frac{780}{9.5} = 0.82$$

Where W_M = Weight of dehydrated sample x moisture per cent
or amount of moisture present in dried sample taken

Per cent of water in rehydrated material

Knowing the drained weight of the rehydrated sample, the per cent of water in the rehydrated material can be calculated by

$$\frac{\text{Drained wt. of (WR) rehydrated sample} - \text{Dry matter content in sample taken for rehydration}}{\text{Drained wt. of rehydrated material}} \times 100$$

$$\frac{60 - 9.5}{60} \times 100 = \frac{5050}{60} = 84.1\%$$

Note: It is suggested that the following conditions be met for better rehydration.

1. Determine the time of soaking and boiling that is compatible with optimum quality of the product.
2. Start the test with at least enough water to submerge the pieces, but do not use so much water that excess amount are present at the end of the test.
3. Shake or stir if necessary to insure wetting of all pieces during the test.
4. Control the rate of heating so as to prevent rapid and variable losses of water while boiling.

5.4.3 Rehydration of Dried Fruits and Vegetables

Factors that affect rehydration process of the dehydrated/ dried products are time, temperature, air displacement, pH and juice strength. Rehydration rates can be accelerated by ultrasonic treatment of the product to be rehydrated in water. Gamma radiation increases the rehydration rates of freeze dehydrated apples. In addition, it can control microbial growth subsequently to dehydration and during storage. At 26°C, freeze dried mushrooms rapidly reach the maximum rehydrability. While at 98°C, the rate of rehydration is slower and the degree of rehydration is also lower.

5.5 SPOILAGE OF DRIED FRUITS AND VEGETABLES

A food is said to be spoiled if it has been damaged or injured so as to make it undesirable for human use. “A product is unfit as a food if discriminating consumer, knowing the story of its production and seeing the material itself, will refuse it as a food”. Obviously the fitness of the food may be subjective but in dried fruits (apple, apricot, dates, figs, peaches, prunes, resins, etc.) a number of microorganisms can be present. In whole dried fruits, these may vary from a few hundred per gram of fruit to thousands. Due to decreased water activity (<0.65 in case of sun dried product), heat treatment during dehydration and fumigation, the microorganisms may be killed or are unable to cause spoilage. But spores of bacteria and moulds are likely to be numerous. Dried fruits may be spoiled due to the development of rancidity as concentrated flavonoids may undergo oxidation.

Dried or partially dried fruits such as dates, figs and prunes, are susceptible to spoilage by yeast, i.e., *Zygosaccharomyces*. In dates, spoilage may occur if moisture level exceeds 23-25%. In prunes (18-20% moisture), *Monascus bisporus* has been found to be the most frequent spoilage microorganism. Attempts to provide very tender and more palatable products have resulted in 26-28% moisture in prunes, which are highly susceptible to spoilage and require chemical preservative. The shelf –life of high moisture prunes may be extended by dipping them in 2% potassium sorbate or 0.1% sodium benzoate solution.

In dried vegetables, microbial counts are usually higher than fruits and can be a few millions per gram. During drying, if trays are not loaded properly, higher microbial contamination can occur. During blanching also, if the water is not properly chlorinated, infection can occur. The main genera responsible for spoilage are *Escherichia, Bacillus, Clostridium, Micrococcus, Pseudomonas, Streptococcus, Lactobacillus, Leuconostoc* etc.

Another reason for the spoilage of low moisture food (dried/ powdered fruits or vegetables, chips, etc.) is the presence of oxygen, light, relative humidity and higher temperature. At very low water activity ($a_w < 0.1$), no microbial or non-enzymatic spoilage can occur except lipid oxidation. At a_w between 0.2-0.6, only non enzymatic browning can occur. Enzymatic deterioration starts if water activity exceeds 0.3. Mould and yeast activities usually start at $a_w > 0.7$ but bacterial growth is apparent at $a_w \leq 0.8$. The rate of reaction also depends upon temperature (in general, for every 10^0C increase in temperature, the rate of reaction is doubled). Dried apricots treated with SO_2 and stored at different temperatures showed that the samples stored at 46.1°C darkened in 3 weeks but those stored at room temperature (21.1°C) did not darken for 3 months, while those stored at 0°C showed no darkening even after 6 months.

Dried fruits and vegetables are also prone to insect attack if not dried and stored properly. Insects not only consume food stuff but also leave much debris which spoils the appearance of the product. These insect can be killed either by heating or by fumigation. In heat treatment, dried fruits are dipped in boiling water or in dilute solution of salt (NaCl, $NaHCO_3$) and then, redried at 54-65°C. Dried vegetables may be heated directly without preliminary dipping. Fumigation with ethylene oxide inside the storage chamber also reduces attack by insects.

Preventive measures for spoilage

It is desirable to keep the initial microbial contamination as low as possible. To check the growth of microorganisms or prevent the dried fruit and vegetable products from spoilage, the following points should be considered.

- All efforts should be made to apply the appropriate preservative technique, keeping in view the various steps i.e., recommended quantity of preservative, suitable pre-treatments and drying temperature for specific time.
- Mechanical disruption of tissues in the processed product should not occur.
- Equipment used for handling should be clean and free from contamination. As far as possible, contamination from the soil micro flora be avoided. Dipping of fruits and vegetables in solution of chlorine (50-125 ppm) removes the adhered micro flora.
- Inhibition of microbial growth can be achieved by storing the food at low temperature or in an inert atmosphere packaging.
- Any canned product showing bulging or popping should be rejected.
- Any juice or squash or such product showing any cottony type material on the surface of juice should be discarded.

- If a product in a can after opening gives off-flavour, like rotten eggs, alcoholic smell or gas formation, contents of the can should not be consumed.
- Low temperature storage helps in restricting physiological activities.
- It is absolutely essential that the environment of packing of a processed product should be microbe-free or least contaminated.
- The quality of water (both chemical and microbial) is the single –most factor which controls the quality of the finished product. It should conform to the prescribed standards of microbiological (indicator microorganisms) and chemical quality.
- The spoilage of canned product can be minimized especially leakage by regularly checking the equipment used in canning (reformers, flinger, double seamer, retort).
- The quality of raw material used has profound influence on the spoilage behaviour of processed product, e.g. sulphur sugar which blackens the canned fruits and vegetables should be avoided.
- Use of lacquered can prevents sulphur staining or hydrogen swell encountered in canned pertinacious or high acid products, respectively.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Differentiate between drying and reconstitution ratios.

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2. What are the factors which affect the reconstitution ratio?

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3. What do you mean by spoilage of food?

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5.6 DRYING METHODS AND EQUIPMENT

There are numerous methods of drying and accordingly large number of driers are available commercially. The method of drying and equipment depend on the food material to be dried, i.e., solid, mixture or liquid. Sometimes, drying methods is unique to a product. The factors considered for a drier include method of heat transfer, source of energy radiation and method of heat application. Most of the commercial driers are insulated to reduce heat losses, and hot air in them is recirculated to save energy. The driers and available having energy saving devices which recover heat from the exhaust air or automatically control the air humidity. Some of the driers and drying methods are described below.

5.6.1 Hot Air Driers

i) Sun and solar drying

Sun drying is the most widely practised fruit and vegetable processing operation, particularly in tropical and subtropical regions, where plenty of sunshine is available. The food material is simply laid out on flat surfaces and turned regularly until dry. In solar drying system, solar energy is collected in a chamber to heat the air, which in turn dries the material. The solar driers may be direct, indirect or mixed of energy collectors.

Both these drying methods are simple and inexpensive. However, the disadvantages of drying food material by these methods are poor control over dying conditions and lower drying rates. This results in lower quality and variability in the dried product.

ii) Kiln driers

These driers are two storey constructions. A furnace on the lower floor generates heat and the warm air rises to upper storey which has a slotted floor. The food such as apple slices or rings are spread over the slotted floor for drying. In this method drying time is relatively longer and there is no control over drying conditions. Therefore, it has limited use. However, the driers have a large capacity and are easy to maintain.

iii) Cabinet driers (tray driers)

These driers consists an insulated cabinet fitted with stainless steel trays. These trays may be of shallow mesh or perforated. A cabinet drier may contain 6 to 96 trays or more depending on use. The heat in these driers may be generated by electricity or through a furnace fired with diesel, petrol or kerosene oil. The food is spread in thin layers (2-6 cm deep) on the trays. Hot air is circulated over and / or through each tray by a system of ducts and baffles for uniform air distribution. Tray driers are used for small scale production (1-20 t/day) or for pilot scale work. They have low capital and maintenance cost.

iv) Conveyor or belt driers

In these driers fruits and vegetables are dried on a mesh belt. Initially the air flow is directed upwards through the bed of food and later on downwards. In two or three stage driers, the food material may be dried into deeper beds (15-25 cm to 250-900 cm thickness). The product is dried uniformly to 10-15 per cent moisture level. In these driers drying conditions can be controlled easily and production rates are usually higher.

v) Tunnel driers

These driers are used for large scale (up to 5000 kg) drying of food material. Thin layers of food are spread on trays and stacked on carts/trucks which move through an insulated hot tunnel. When a dry cart leaves the discharging and of the tunnel it makes room to load another wet cart into the receiving end of the tunnel. The food dehydration in these driers is a semi-continuous process. The drying of food is finished in bin driers as these driers lower the moisture content of semi dried food to 3-6 per cent level.

vi) Belt though driers

These are air convection belt driers used for small and uniform pieces of fruits and vegetables. The food is dried in a mesh conveyor belt which hangs freely between rollers, to form a shape of a trough. The heated air is blown through the bed of food. The belt moves keeping the food pieces in the trough in constant motion to expose new surfaces continuously to hot air. The mixing action moves food away from the drying air thus, allowing time for moisture to move from the interior of the pieces to the dry surface. The moisture removes rapidly. The drier operates in two stages, first to 50-60 per cent moisture and then to 15-20 per cent moisture level. Foods are finished in bin driers. These driers are not suitable for sticky foods.

vii) Bin driers

These are cylindrical or rectangular containers fitted with a mesh base. Hot air passes up through a bed of food at relatively low speeds. They are usually used for finishing (3-6% moisture level) after initial drying in other types of driers. These driers have a high capacity and low capital and running cost.

viii) Fludised bed driers

In these driers hot air is blown through a food bed contained in metal trays with mesh or perforated bases. The greater air velocities make the bed expand, and the food particles become suspended in air and vigorously agitated. The bed is said to be fludised. The air thus acts as with the drying and the fludising medium. Fludising is a very effective way of maximising the surface area of food for drying in a relatively small space. Driers may be batch or continuous in operation. These driers are compact and have good control over drying conditions, high thermal efficiencies and high drying rates. Fludised bed driers are limited to small particulate foods that are capable of being fludised without excessive mechanical damage (e.g., peas, diced or sliced vegetables, powders).

ix) Spray driers

These are air convection driers used for dehydrating liquid food products. In these driers, a fine dispersion of pre concentrated liquid food is first atomized to form droplets (10-200 μm diameter) and sprayed into a current of heated air at 150-300^{0}C in a large drying chamber. The dry particles, suspended in air stream, flow into separation equipment where they are removed from air, collected, and packaged or subjected to further treatment such as instantising. For successful drying uniform atomising is necessary which may be achieved by centrifugal or pressure nozzle or two-fluid nozzle atomizers.

5.6.2 Heated Surface Driers

In these driers heat is supplied to the food material by conduction. These driers have two advantages over hot air driers.

i) large volume of air is not required to be heated before drying commences,
ii) drying may be carried out in the absence of oxygen.

i) Drum or roller driers

The driers may have a single or double or twin hollow drums. The single drum is widely used. In these driers slowly rotating hollow steel drums are heated internally by pressurized steam (120-170°C). A thin layer of food (paste, puree or sludge) is spread uniformly over the outer surface by dipping, by spraying, by spreading or by auxiliary feed rollers. Before the drum has completed one revolution (within 3 minutes), the dried food in the form of thin layer is scraped off by a 'doctor' blade which contacts the drum surface uniformly along its length. The driers have been used successfully to dry apple sauce, purees of apple, banana, mango, papaya, etc.

ii) Vacuum band and vacuum shelf driers

These driers are used to produce puff dried foods. In vacuum band drier a food slurry is spread or sprayed onto a steel belt (or band) which passes over two hollow drums within a vacuum chamber. The food is first dried by steam heated drum and then by steam heated coils located over the band. The dried food is cooled by a second water-cooled drum and removed by a doctor blade. Vacuum shelf drier consists of hollow shelves in a vacuum chamber. Food is placed in thin layers on flat metal trays and vacuum is created in the chamber. Hot air or steam is passed to dry the food.

5.6.3 Freeze Drying

Dehydration by freezing (lyophilization) requires a product to be first frozen in a conventional freezer and then evaporating (sublimating) the water, which is in ice form, directly into the vapour phase at a very low temperature (up to –80°C) and pressure. Freeze driers consist of a vacuum chamber which contains trays to hold the food material during drying, and heaters.

Refrigeration coils are used to condense the vapours. Automatic defrosting devices are fitted alongside to keep the coils free of ice for vapour condensation. Vacuum pumps remove non condensable vapours. The types of driers depend on supply of heat to food. Commercially, conduction and radiation types are used. Different type of freeze driers are contact freeze driers, accelerated freeze driers, radiation freeze driers, microwave and dielectric freeze driers, liquid nitrogen and cryogenic freezing.

5.6.4 Osmotic Drying

The process of osmotic drying is the removal of a percentage of water from a piece of fruit or vegetable by placing it in contact with granular sugar / salt or a concentrated sugar / salt solution. About 40 per cent of the water can be removed by this process. After osmotic dehydration, the product may either be frozen, or dried in air or vacuum drier. The time and temperature of osmotic dehydration depend on the size, shape and the food material. Sometimes, sulphur dioxide treatment is required to preserve the colour. This process is comparatively costlier than conventional drying.

5.6.5 Microwave Drying

Microwave is a form of electromagnetic energy. They are transmitted as waves, which penetrate food material, and are then converted to heat. Microwaves are produced at specific frequency bands. When microwaves are passed into a food material they induce friction in water molecules and produce heat. The extent of heating depends on the water content of the food material. Domestic and commercial microwave ovens are available which may be used to dry fruit juices, pulps, fruit pieces, etc.

5.6.6 Foam Mat Drying

The process is used to dry liquid foods. They are formed into a stable foam by the addition of a stabilizer or a foaming agent and aeration with nitrogen or air. The foam is spread on a perforated belt/tray to a depth of 2-3 mm and dried rapidly in a drier. Foam drying is approximately three times faster than drying a similar thickness of liquid. The thin porous mat of dried liquid is ground to a free flowing powder. The rapid drying and low product temperatures result in a high quality product.

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the important methods of drying?

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2. Explain what you understand by freeze drying?

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3. What is microwave drying?

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5.7 EVAPORATION/CONCENTRATION METHOD AND EQUIPMENT

Liquid foods are usually concentrated by partial removal of water through evaporation. Function of evaporation is to pre-concentrate the food prior to drying, freezing or sterilization. It increases the solids content and reduces the weight and volume of a food. During evaporations, latent heat is transferred from the heating medium (steam) to the food, to raise the temperature of its boiling point. The vapour pressure rises and bubbles of vapour in the liquid are formed due to latent heat of vaporization supplied by the steam. The vapour is then removed from the surface of the boiling liquid. The more common concentrated foods include fruit and vegetable juices and concentrates jams and jellies, tomato paste, fruit purees, etc. Some of the methods and equipment for evaporation or concentration of foods are described below.

5.7.1 Methods of Evaporation

i) Solar evaporation

Solar evaporation is the simplest method of evaporating water with solar energy. This was done to derivate salt from sea water from earliest times and is still practiced. However, solar evaporation is very slow and is suitable only for concentrating salt solutions.

ii) Open kettles

Some foods can be satisfactory concentrated in open kettle that is heated by steam. This is the case for some jellies and jams and for certain types of soups. However, high temperatures and long concentration times damage most foods. In addition, thickening and burn-on of product to the kettle wall gradually lower the efficiency of heat transfer and slow the concentration process. Kettles and pans are still widely used in the manufacture of maple syrup, but here high heat is desirable to produce colour from caramelized sugar and to develop typical flavour.

iii) Flash evaporators

Flash evaporators are used for subdividing the food material and bringing it into direct contact with the heating medium. Clean steam superheated at about 150°C is injected into food which is pumped into an evaporation tube where boiling occurs. The boiling mixture then enters a separator vessel in which the concentrated food is drawn off at the bottom and the steam plus water vapour from the food is evacuated through a separate outlet. Because temperatures are high, foods that lose volatile flavour constituents will yield these to the exiting steam and water vapour. These can be separated from the vapour by essence-recovery equipment on the basis of different boiling points between the essence and water.

iv) Thin-film evaporators

In thin-film evaporators, food is pumped into a vertical cylinder which has a rotating element that spreads the food into a thin layer on the cylinder wall. The cylinder wall of double jacket construction usually is heated by steam. Water is quickly flashed from the thin food layer and the concentrated food is simultaneously wiped from the cylinder wall. The concentrated food and water vapour are continuously discharged to an external separator; from which product is removed at the bottom and water vapour passes to a condenser. In some systems the water vapour temperature is raised by mechanical vapour recompression to yield steam for reuse to save energy. Product temperature may reach 85°C or higher, but since residence time of the concentrating food in the heated cylinder may be less than a minute, heat damage is minimal.

v) Vacuum evaporators

Heat-sensitive foods are most commonly concentrated in low temperature vacuum evaporators. Thin-film evaporators frequently are operated under vacuum by connecting a vacuum pump or steam ejector to the condenser.

It is common to construct several vacuum vessels in series so that the food product moves from one vacuum chamber to the next and thereby becomes progressively more concentrated in stages. The successive stages are maintained at progressively higher degrees of vacuum, and the hot water vapour arising from the first stage is used to heat the second stage. The vapour from the second stage heats the third stage, and so on. In this way, maximum use of heat energy is obtained. Such a system is called a multiple effect vacuum evaporator. System employed in grape juice industry continuously concentrate juice from an initial solids content of 15% to a final solid concentration of 72% at rate of 4500 gal of single strength juice per hour. Similar systems concentrate tomato juice from 6% solids to 30% solids at rate of 15,000 gal or more of single strength juice per hour. Use of energy-saving mechanical vapour recompression is common.

vi) Freeze concentration

When a solid or liquid is frozen, all of its components do not freeze at once, some of the water forms ice crystals in the mixture. The remaining unfrozen food solution is now higher in solid concentration. It is possible, before the entire mixture freezes, to separate the initially formed ice crystals. One way of doing this is to centrifuge the partially frozen slush through a fine mesh screen. The concentrated unfrozen food solution passes through the screen while the frozen water crystals are retained and can be discarded. Repeating this process several times on the concentrated unfrozen food solution can increase its final concentration several- fold. Freeze concentration has been applied commercially to orange juice.

vii) Ultra filtration and reverse osmosis/hyper filtration

Low-temperature separation and concentration processes employing perm selective membranes are increasingly being used in the food industry. These applications are largely dependent on membrane properties such as water permeability rate, solute and macromolecule rejection rate, and length of useful membrane life. Different membranes are required for different liquid foods.

There are two types of pressure-driven membrane separation processes, a) reverse osmosis / hyper filtration, and b) ultra filtration. In the former, macromolecular solutes are selectively removed, whereas the latter separates out relatively larger solute molecules or colloids. Ultra filtration membranes are generally " less tight" than reverse osmosis membranes, that is, they restrict macromolecules such as proteins but with moderate pressure allow smaller molecules such as sugar and salt to pass through. Reverse osmosis membranes are "tighter" and with greater pressure will permit the passage of water but hold back various sugars, salt, and larger molecules. In nature, osmosis involves the movement of water through a perm-selective membrane from a region of higher concentration to a region of lower concentration; the region of lower concentration generally contains solutes in solution and has associated with it an osmotic pressure. It is possible to reverse the normal flow of water through the membrane by applying pressure on the solute side flow of water through the membrane by applying pressure on the solute side of the membrane in excess of the osmotic pressure. This is a reverse osmosis.

viii) Plate evaporator

Plate evaporator is similar to plate heat exchanger. The fluid which is to be evaporated is passed on one side of the plate and steam flows on the other side. The fluid is superheated and passes into a flash chamber. The evaporator flashes-off and the product and vapours are separated. High viscosity fluids can be efficiently circulated in the evaporators with concentration above 60°Brix.

ix) Membrane concentration

A high quality product can be produced by membrane concentration process. The principle involved is the interposition of a membrane between the food stream and a waste or transfer stream, and the establishment conditions providing a driving force for transport of water across the membrane from the feed to the transfer stream. The possibility of obtaining high quality product depends on the use of semi-permeable membranes which means membranes with much less resistance to water transport than to transport of components that are to be retained.

Ostomek is a new process and is a cold direct osmotic concentration process, utilising a thin membrane (25-10 µm) with a molecular weight cut-off of about 100 daltons. High fructose corn syrup is used as an agent to facilitate osmotic concentration as it flows, counter-current to the juice. Heat labile juice such as strawberry would benefit from this cold process, since flavour and colour degrade with exposure to heat. Concentration of clear juice streams are also possible using a continuation of reverse osmosis and evaporation. Cross flow membrane systems are ideally suited for this application because of self cleaning turbulence effect. The reverse osmosis technology is effective in concentrating a low solids juice (7-8°B) two or three folds.

x) Centrifugal evaporators

In these evaporators, a thin film is produced by centrifugal force in single or nested cones. The cones have steam on the alternative side to provide a heat transfer surface. The system operates under vacuum. This allows the total time on the juice transfer surface to be as little as 0.5 second, with only a small increase in product temperature. They are good for extremely heat sensitive and or high viscosity products. Their major draw back is low capacity and high capital cost. These evaporators concentrate as well as distil de-gas and de-odourize the liquids that have high sensitivity to heat.

5.7.2 Types of Evaporators

Several types of evaporators are used in the food industry.

i) Batch-type pan evaporator

One of the simplest and perhaps oldest types of evaporators used in the food industry is the batch-type pan evaporator. The product is heated in a steam jacketed spherical vessel. The heating vessel may be open to the atmosphere or connected to a condenser and vacuum. Vacuum permits boiling of the product at temperatures lower than the boiling point at atmospheric pressure, thus reducing the thermal damage to heat-sensitive products.

The heat-transfer area per unit volume in a pan evaporator is small. Thus, the residence time of the product is usually very long, up to several hours. Heating of the product occur mainly due to natural convection, reducing in smaller convective heat transfer coefficients. The poor heat transfer characteristics substantially reduce the processing capacities of the batch type pan evaporator.

ii) Natural circulation evaporators

In natural circulation evaporators, short vertical tubes, typically 1-2m long and 50-100 mm in diameter, are arranged inside the steam chest. The whole calamari (tubes and steam chest) is located in the bottom of the vessel. The product when heated rises through these tubes by natural circulation while steam condenses outside the tubes. Evaporation takes place inside the tubes and the product is concentrated. The concentrated liquid falls back to the base of the vessel through a central annular section.

iii) Rising-film evaporator

In a rising-film evaporator a low viscosity liquid food is allowed to boil inside 10-15 m long vertical tubes. The tubes are heated from the outside with steam. The liquid rises inside these tubes by vapours formed near the bottom of the heating tubes. The upward movement of vapours cause a thin liquid film to move rapidly upwards. A temperature difference of at least 14°C between the product and the heating medium is necessary to obtain a well developed film. High convective heat –transfer coefficient is achieved in these evaporators. Although the operation is mostly once through, liquid can be recirculated if necessary to obtain the required solid concentration.

iv) Falling-film evaporator

In contrast to the rising- film evaporator, the falling film evaporator is used for high viscous liquids. Film moves downwards under gravity on the inside of the vertical tubes. The design of such evaporator is complicated by the fact that distribution of liquid in a uniform film flowing downwards in a tube is more difficult to obtain than an upward-flow system such as in a rising film evaporator. This is accomplished by the use of special designed distributors or spray nozzles. The falling-film evaporator allows a greater number of effects than the rising film evaporator. For example, if steam is available at 110°C and boiling temperature in the last effect is 50°C, then the total available temperature differential is 60°C. Since rising film evaporator requires 14°C temperature differential across the heating surface, only four effects are feasible. However, as many as 10 or more effects may be possible using a falling-film evaporator. The falling-film evaporator can handle more viscous liquid than the rising film type. This type of evaporator is best suited for high heat-sensitive products such as orange juice. Typical residence time in a falling film evaporator is 20-30 seconds compared with a residence time of 3-4 minutes in a rising film evaporator.

v) Rising/falling-film evaporator

In the rising /falling film evaporator, the product is concentrated by circulation through a rising-film section followed by a falling-film section of the evaporator. The product is first concentrated as it ascends through a rising tube section, followed by the pre concentrated product descending through a falling-film section, there it attains its final concentration.

vi) Forced-circulation evaporator

The forced circulation evaporator involves a non contact heat exchanger where liquid food is circulated at high rates. A hydrostatic head, above the top of the tubes, eliminates any boiling of the liquid. Inside the separator, absolute pressure is kept slightly lower than that in the tube bundle. Thus, the liquid entering the separator flashes to form a vapour. The temperature difference across the heating surface in the heat exchanger is usually 3-5°C. Axial flow pumps are generally used to maintain high circulation rates with linear velocities of 2-6 m/s, compared with a linear velocity of 0.3-1 m/s in natural-circulation evaporators. Both capital and operating costs of these evaporators are very low in comparison to other types of evaporators.

vii) Agitated thin-film evaporator

It is used for very viscous fluid foods. The feed is spread on the inside of the cylindrical heating surface by wiper blades. Due to high agitation, considerably higher rates of heat-transfer are obtained. The cylindrical configuration results in low heat transfer area per unit volume of the product. High pressure steam is used as the heating medium to obtain high wall temperatures for reasonable evaporation rates. The major disadvantages are the high capital and maintaining costs and low processing capacity.

Check Your Progress Exercise 5

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Explain evaporation and concentration of fruit juices.

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2. How the solar evaporation is different from kettle evaporation.

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3. How the osmosis process is different from reverse osmosis.

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4. What are drawbacks of centrifugal evaporator?

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5. What are types of evaporator?

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6. How falling film evaporator is different from rising film evaporator.

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7. What are major disadvantages of agitated thin film evaporator?

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5.8 LET US SUM UP

Removal of water from food is primarily done to lower the water activity (a_w) so that microbial growth is inhibited. It also saves energy, moisture and space in shipping, packaging, storage and transportation of dried fruit and vegetable products, which are known as high value low volume food or high acid high sugar foods. Dehydration industry is a processing industry of the future. There exists quite a good scope for the export of dehydrated fruits and vegetables as the demand for these products is on the rise in the world, particularly in European countries. It is, therefore, necessary to co- ordinate effectively and achieve all that is possible in the field of export, internal demand, right quality and variety of raw material, product promotion, new technologies, etc., with the objective of helping the grower to get remunerative returns for his produce. Evaporation is an important unit operation commonly employed to remove water from dilute liquid foods to obtain concentrated liquid products which provides microbiological stability and assists in reducing transportation and storage costs.

Due to decreased water activity (<0.65 in case of sun dried product), microorganisms may be killed or are unable to cause spoilage in dehydrated products. But spores of bacteria and moulds are likely to be the most numerous. Dried fruits may be spoiled due to the development of rancidity as concentrated flavonoids may undergo oxidation. It is desirable to keep the initial microbial contamination as low as possible and the commodities should be handled and stored in such a way that there are minimum chances of further contamination.

5.9 KEY WORDS

Water activity : Water activity (a_w) is the ratio of vapour pressure of food (p) and pure water (p_o) and expressed by aw = p/p_o.

Sorption isotherms : Water sorption isotherm is a graphical presentation of data which shows the water relationship of food.

Concentration : Removal of water from foods mostly by heat application and concentration of soluble solids or solutes.

Preservation : Methods to hold food for a longer period than generally kept at ambient conditions. Food is safe, nutritious and free from microbial infection.

ERH : Equilibrium relative humidity.

Osmosis : Osmosis means movement of water through a membrane from higher concentration to lower concentration.

Unit operation : It is a step in the complete process or a physical change in form or place, for example, peeling, cutting, grading, etc.

Drying ratio : Drying ratio is the reciprocal of fresh material to dried material.

Spoilage : The food which has been damaged or injured make the food undesirable for human use.

Rehydration ratio : Reconstitution ratio is the quantity of water absorbed by dehydrated foods.

Reverse osmosis : Reverse osmosis means movement of water through the membrane by applying pressure on the solute side of the membrane in excesses of the osmotic pressure.

Evaporation : Evaporation is a heating process in which water is removed from the liquid substance.

5.10 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Your answer should include the following points:

   - Drying of a commodity in the sun with non conventional sources of energy like sun and wind.
   - Drying a commodity under controlled conditions like temperature, relative humidity and air flow.

2. Your answer should include the following points:

   - An unit operation commonly employed to remove water from liquid foods.
   - To obtain concentrated liquid products.

3. Your answer should include the following points:

   - To reduce the weight and bulk of a food.
   - To reduce the water activity.

4. Your answer should include the following points:

   - Due to loss of moisture from the surface.
   - Stabilizing the moisture gradient between surface and centre of the product.

Check Your Progress Exercise 2

1. Your answer should include the following points:

   - To get heat in.
   - To let moisture out.

2. Your answer should include the following points:

   - It provides the driving force for moisture removal.
   - It carries away water in the form of water vapour.

3. Your answer should include the following points:

   - It provides more surface in contact with heating medium.
   - Provides more surface for moisture removal.

4. Your answer should include the following points:

   - Smaller product size reduces the distance through which moisture is to travel from centre of the surface.
   - Smaller product size reduces the distance through which heat is to be transferred from the surface to the centre.

5. Your answer should include the following points:

   - It absorbs more moisture.
   - It sweeps away moisture very fast.

6. Your answer should include the following points:

   - The relative humidity at which product neither gains nor loses its moisture.

Check Your Progress Exercise 3

1. Your answer should include the following points:

   - Drying ratio is the reciprocal of fresh material to dried material.
   - Reconstitution ratio is the quantity of water replaced by dehydrated foods.

2. Your answer should include the following points:

   - Time of soaking
   - Temperature of the water
   - Air displacement
   - pH of the product
   - Juice or sugar content availability in the product.

3. Your answer should include the following points:

   - The food which has been damaged or injured.
   - The food which is not fit for consumption.
   - The food which is attacked by microorganisms.

Check Your Progress Exercise 4

1. Your answer should include the following points:

   - Drying the food material by using hot air.
   - Drying the food material by using heated surface.
   - Drying the food material by freezing.
   - Drying the food material by microwaves.
   - Drying the food material by using sugar or salt and their solutions.

2. Your answer should include the following points:

   - Dehydration by freezing means drying a food material at low temperature (up to –80°C) and low pressure.
   - At low temperature and pressure, the water in ice form in food material is evaporated directly into vapour (sublimation).

3. Your answer should include the following points:

   - Microwaves are a form of electromagnetic energy.
   - Microwaves are when passed into a food material they induce friction in water molecules and produce heat, thus drying the material.

Check Your Progress Exercise 5

1. Your answer should include the following points:
   - Removal of water from the liquid substances.
   - Removal of water to concentrate soluble solids.

2. Your answer should include the following points:
   - Solar evaporation is used for salt concentration.
   - Kettle evaporation is used for maple syrup.

3. Your answer should include the following points:
   - Osmosis means movement of water through a membrane from higher concentration to lower concentration.
   - Reverse osmosis means movement of water through the membrane by applying pressure on the solute side of the membrane in excesses of the osmotic pressure.

4. Your answer should include the following points:
   - Low capacity
   - High capital cost

5. Your answer should include the following points:
   - Batch type evaporator
   - Natural circulation evaporator
   - Rising film evaporator
   - Falling/film evaporator
   - Rising/falling film evaporator
   - Forced circular evaporator

6. Your answer should include the following points:
   - Falling film evaporator is used for high viscous liquids, while rising film evaporator is used for low viscous liquids.
   - High heat sensitive products are more suited to falling film evaporator while low heat sensitive products used in rising film evaporation.

7. Your answer should include the following points:
   - High capital and maintenance cost.
   - Low processing capacity.

5.11 SOME USEFUL BOOKS

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UNIT 6 CHILLING

Structure

6.0 OBJECTIVES

After reading this unit, you should be able to:

- describe chilling and refrigeration cycle;
- explain chilling injury and refrigerated requirements of fruits and vegetables; and
- define evaporative cooling.

6.1 INTRODUCTION

You know that fruits and vegetables are highly perishable and more liable to spoilage than food grains. This is basically because they contain high moisture content. The spoilage of such perishable crops can be delayed by controlling the post harvest environmental conditions of temperature, humidity and atmospheric concentration of gases. Chilling is one such method of regulating temperature. More precisely, chilling mean the use of low temperature without inducing ice formation in foods. The chilling process may be considered complete when the mean temperature of the product has approximately reached the intended value for storage or processing.

The chilling operation is divided into 3 basic types based on its main purpose.

i) Chilling for preservation.

ii) Chilling for development of desired biological and biochemical processes.

iii) Chilling to facilitate some processing treatments, by temporarily changing certain physico-chemical properties.

Chilling for preservation is aimed to extend the shelf-life or keeping quality of a living produce, e.g., fruits and vegetables. This is mainly due to reduction of metabolic activity at low temperature. Chilling may also be used to extend the storage life of products such as pasteurized and sterilized canned foods.

Chilling for development of desired biological and biochemical processes includes fermentation of beer and wine, meat ageing, and processing of many dairy products such as cheeses, etc.

Temporarily changing certain physico-chemical properties to facilitate some processing treatments is used in the processing of bakery products, chocolate, butter, margarine etc. However, this is beyond the scope of the present unit and we would restrict ourselves to chilling for preservation only. In the present unit, we will focus only on the first purpose, i.e., chilling for preservation.

Refrigeration is the most common method of chilling or low temperature storage of fruits and vegetables. Refrigerated storage helps to retard the spoilage in perishable crops in the following manner:

- aging due to ripening, softening, textural and colour changes;
- undesirable metabolic changes and respiratory heat production;
- moisture loss and the wilting;
- spoilage due to invasion by bacteria, fungi, and yeasts; and
- undesirable growth, such as sprouting of potatoes.

One of the most important functions of refrigeration is to control the respiration of crops. Respiration generates heat as sugars, fats, and proteins in the cells of the crop are oxidized. The loss of these stored food reserves through respiration means decreased food value, loss of flavour, loss of saleable weight, and more rapid deterioration. The respiration rate of a product strongly determines its transit and post-harvest life. The higher the storage temperature, the higher will be the respiration rate. Apart from temperature, humidity and concentration of gases are also important. Before observing their effect let us first understand how refrigerator works.

6.2 REFRIGERATION

The refrigerator cycle is based on the principle of making cold which is done by removing heat from the system. If you are science student then you must have surely studied carnot’s engine. Refrigeration is in fact the reverse of carnot’s engine. The refrigeration cycle uses a fluid, called a refrigerant, to move heat from one place to another. The key to understanding how it works is recognizing that at the same pressure, the refrigerant boils at a much lower temperature than water. For example, the refrigerant commonly used in home refrigerators boils between 40 and 50°F (4.4 – 10°C) as compared to water’s boiling point of 212°F (100°C). In the original home refrigerators ammonia was the common refrigerant used. Pure ammonia gas is highly toxic to people and would pose a threat if the refrigerator were to leak, so all home refrigerators don't use pure ammonia. You might have heard of refrigerants known as **CFCs** (chlorofluorocarbons). These were originally developed by Du Pont in the 1930s as a non-toxic replacement for ammonia. CFC-12 (dichlorodifluoromethane) has about the same boiling point as ammonia. However, CFC-12 is not toxic to humans, so it is safe to use in your kitchen. However, many large industrial refrigerators still use ammonia. In the 1970s, it was discovered that the CFCs then in use are harmful to the ozone layer, so as of the 1990s, all new refrigerators and air conditioners use refrigerants that are less harmful to the ozone layer. Freon is the common refrigerant used today. Now we need to study the refrigeration cycle.

Every refrigerator is made up of at least four key parts:

i) Compressor
ii) Heat-exchanging pipes (also known as a condenser)

iii) Expansion valve
iv) Refrigerant

Let's look at the process to see how boiling and condensing a refrigerant can move heat. The process is the same whether it is operating a refrigerator, an air conditioner or a heat pump. This example illustrates a closed-loop system (Figure 6.1).

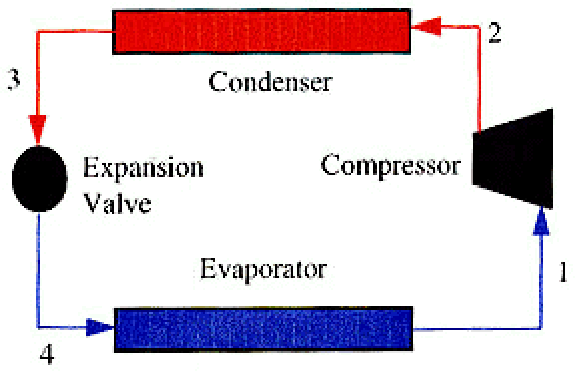


Figure 6.1: Vapour compression refrigeration cycle

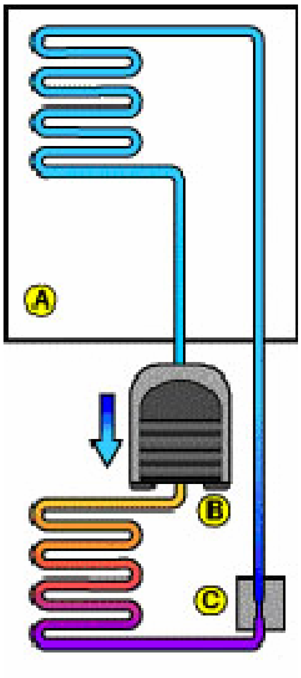
The above diagram shows the simplified, stepwise process of the refrigeration cycle, where the associated parts of the refrigerator fit into it. These four parts will now be explained in detail. Lets begin with evaporator first. As the name implies, refrigerant in the evaporator "evaporates". Upon entering the evaporator, the liquid refrigerant's temperature is between 40 and 50°F and without changing its temperature, it absorbs heat as it changes state from a liquid to a vapour. The heat comes from the warm moist room air blown across the evaporator coil. As it passes over the cool coil, it gives up some of its heat and moisture may condense from it. The cooler drier room air is re-circulated by a blower into the space to be cooled.

The vapour refrigerant now moves into the compressor, which is basically a pump that raises the pressure so it will move through the system. Once it passes through the compressor, the refrigerant is said to be on the "high" side of the system. Like anything that is put under pressure, the increased pressure from the compressor causes the temperature of the refrigerant to rise. As it leaves the compressor, the refrigerant is a hot vapour, roughly 120 to 140°F.

It now flows into the refrigerant-to-water heat exchanger, operating as the condenser during cooling. Again, as the name suggests, the refrigerant condenses here into liquid form. As it condenses, it gives up heat to the loop, which is circulated by a pump. The loop water is able to pick up heat from the coils because it is still cooler than the 120 degree coils.

As the refrigerant leaves the condenser, it is cooler, but still under pressure provided by the compressor. It then reaches the expansion valve. The expansion valve allows the high pressure refrigerant to "flash" through becoming a lower pressure cooled liquid. This pressure drop causes expansion followed by evaporation. Evaporation further causes heat absorption making refrigerant cool. The cycle is complete as the cool liquid refrigerant re-enters the evaporator to pick up room heat. In winter, the reversing valve switches the indoor coil to operate as the condenser and the heat exchanger as the evaporator.

In summary, the indoor coil and refrigerant-to-water heat exchanger where the refrigerant changes phase by absorbing or releasing heat through boiling and condensing. The compressor and expansion valve facilitate the pressure changes, increased by the compressor and reduced by the expansion valve. See a detailed Figure 6.2.



A -- Inside of refrigeration
B -- Compressor
C -- Expansion valve

Figure 6.2: Back panel of a refrigerator

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is chilling?

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2. Where does actual phase change take place in the refrigerator?

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3. What are the common refrigerants used in the refrigerator?

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6.3 DETERMINATION OF REFRIGERATION LOAD

If we want to cool the product then heat must be removed and brought to a specific low temperature. The heat removed is described in terms of refrigeration load. In other words, refrigeration load can be defined as that quantity of heat which must be removed in order to reduce the temperature of the products from its initial temperature to the temperature consistent with good frozen food storage. It is calculated in terms of heat unit as British Thermal Units (Btu), calories (cal) or joules (J). This has, of course, been replaced by International System of Units (SI) which employs joules and gram as units of heat and weight (One Btu = 252 calories = 1055 joules = 1.055 KJ).

One Btu or British Thermal Unit is defined as the quantity of heat which will raise or lower the temperature of one pound of water by 1°F through the range of 32°F to 212°F at normal atmospheric pressure.

A calorie is the amount of heat which will raise or lower the temperature of one gram of water by 1°C from 14.5 to 15.5°C at normal atmospheric pressure.

The specific heat of any substance is the ratio of its heat capacity to that of water. In either case, the specific heat of water is taken as one. Thus, in British system, specific heat is

$$= -\frac{\text{Heat required to raise/lower the temperature of unit mass of water by } 1\,^{\circ}\text{C}}{\text{Heat required to raise/lower the temperature of unit mass of water by } 1\,^{\circ}\text{C}}$$

(Since heat capacity of water = 1).

Or, Specific heat at any temperature = Heat required to raise or lower the temperature of unit mass of water by 1°C or in other words, amount of heat in calories required to raise or lower the temperature of one gram of the substance by 1°C.

Generally heat is of two types – Sensible heat and latent heat.

Sensible heat may be defined as the heat we readily perceive by the sense of touch and which produces a temperature rise or fall as heat is added or removed from a substance. Always remember that specific heat is different in the liquid state and in the frozen state. So, it may be different before and after freezing.

Latent heat is the quantity of heat required to change the state or condition under which a substance exists, without changing its temperature, e.g., a definite quantity of heat must be removed from water at 0°C (32°F) to change it to ice at 0°C. This is known as latent heat of fusion or crystallization.

Similarly, in going from water to steam at 100°C, it is the latent heat of evaporation. In freezing, we are interested in the latent heat of fusion, and this in the case of water is 144 Btu/1b. It is quantitatively different from 144 Btu/lb for substances other than water.

Calculation Refrigeration Load

After you have known the terms, let us see how to calculate refrigeration load. To calculate this we need to understand that to freeze a food it is necessary to bring down its temperature to freezing point. This involves the following:

i) The number of Btu required to cool the product from its initial temperature to its freezing point, or say H_1.

ii) The number of Btu required to change the food from the liquid state to the frozen state at its freezing point, or say H_2.

iii) The number of Btu required to lower the frozen food from its freezing point to the desired storage temperature, or say H_3.

Using this concept, we can calculate refrigeration load using the following equations:

$$H_1 = (S_L) \times (W) \times (T_i - T_f) \qquad (1)$$

$$H_2 = (H_f f) \times W \qquad (2)$$

$$H_3 = (S_S) \times W \times (T_f - T_s) \qquad (3)$$

$$H_{fs} = H_1 + H_2 + H_3$$

Where,

S_L = Specific heat of food above its freezing point

H_f = Latent heat of fusion

S_S = Specific heat of food below its freezing point

H_{fs} = Total heat (Btu) requirement

W = Weight in pounds

T_i-T_f = Difference between the initial temperature and the freezing point (°F).

T_f-T_S = Difference between the freezing point and the desired storage temperature (°F).

Let's take one example:

What is Btu requirement to lower the temperature of 1000 lbs of peas from 70°F to 30°F, and finally to storage given at temperature at 0°F. Given S_L =0.8, H_f = 108, S_S = 0.43.

Here we first have to calculate H_1.

From equation (1)

$$H_1 = (S_L) \times (W) \times (T_i - T_f)$$

$$= 0.8 \times 1000 \times (70 - 30)$$

$$= 0.8 \times 1000 \times 40$$

$$= 32000 \text{ Btu.}$$

Now, calculate H_2.

From equation (2)

$$H_2 = H_f \times W$$

$$= 108 \times 1000$$

$$= 108000$$

Finally, calculate H_3.

From equation (3)

$$H_3 = (H_f) \times (W) \times (T_f - T_s)$$

$$= 0.43 \times 1000 \times (30\text{-}0)$$

$$= 12900$$

$$H_{fs} = H_1 + H_2 + H_3$$

$$= 32000 + 10800 + 12900$$

$$= 152900 \text{ Btu.}$$

Refrigeration load is usually reported in terms of refrigeration. So values should be changed to tonnes by dividing Btu by 288000:

$$\frac{152000}{288000} = 0.527 \text{ tonnes}$$

One ton (2000 1b) of refrigeration is the number of Btu required to convert 1 ton of water at 32°F to 1 ton of ice at 32°F in 24 hrs. Since latent heat of fusion for water = 144 btu/lb, a ton of refrigeration = 144 × 2000 = 288,000 Btu/24 hrs.

6.4 REFRIGERATED STORAGE OF FRUITS AND VEGETABLES

The principal refrigeration requirements of fruits and vegetables are controlled low temperature, air circulation and humidity.

Relative humidity (RH): Most food stores are best at refrigeration temperatures when the relative humidity of air is between 80 and 95 per cent. This is generally related to moisture content of foods. Celery, spinach and several other crisp leafy vegetables require 90-95% RH.

Controlled low temperature: Fruits and vegetables are highly perishable because they respire and produce heat at varying rates. They, therefore, need to be stored at low temperatures. Refrigeration is the gentlest method of extending the shelf life of fruits and vegetables. By and large, it has relatively few adverse effects upon taste, texture, nutritive value and overall changes in food, provided simple rules are followed. Domestic refrigerators usually run at 4.4°–7.2°C (40-45°F). Properly designed refrigerators, refrigerated storage rooms and warehouses provide sufficient refrigeration capacity and insulation to maintain the room within about 1°C. Proper insulation is must to maintain the optimum storage temperature. Refrigeration system must be of appropriate size to handle maximum expected heat load as an undersized system will allow temperature to rise during peak heat load conditions. Different fruits and vegetables evolve different heat during respiration. (Table 6.1) As you can see from the table green beans, broccoli, sweet corn, green peas, spinach and strawberry evolve high heat during respiration. These products are difficult to store.

Table 6.1: Heat evolved from respiration of fruits and vegetables

Commodity	Btu per tonne per 24 hrs	
	32°F (0°C)	40°F (4.4°C)
Apples	300-800	590-840
Beans, green	5,500-6,160	9,160-11,390
Broccoli	7,450	11,000-17,600
Carrots	2,130	3,470
Corn (sweet)	6,500	9,390
Onions	600-1,100	1,260-1,980
Oranges	420-1,030	1,300-1,500
Peach	850-1,370	1,440-2,030
Peas	669-880	-
Peas (green)	8,160	13,220
Potatoes	440-880	1,100-1,760
Spinach	4,240-4,860	7,850-11,210
Strawberry	2,730-3,800	3,660-6,750
Tomatoes (ripe)	1,020	1,250

Based on their respiration rate, the storage requirement and shelf-life of fruits and vegetables is also different, e.g., broccoli, a highly respiring vegetable at a storage temperature of 32^oF has a shelf-life of 7-10 days in comparison to 6-8 months for onions at same temperature. While temperature is the primary concern in the storage of fruits and vegetables, relative humidity is also important. The relative humidity of the storage unit directly influences water loss in produce. Water loss can severely degrade quality-for instance, wilted greens may require excessive trimming, and grapes may shatter loose from clusters if their stems dry out. Water loss means saleable weight loss and reduced profit.

Most fruit and vegetable crops retain better quality at high relative humidity (80 to 95%), but at this humidity, disease growth is encouraged. The cool temperatures in storage rooms help to reduce disease growth, but sanitation and other preventative methods are also required. Maintaining high relative humidity in storage is complicated by the fact that refrigeration removes moisture. Humidification devices such as spinning disc aspirators may be used.

Air circulation: Air must be well circulated in the cold storage rooms. This will help more heat away from food surface to cooling coil. Air, that is, circulated within a cold storage must not be too moist or too dry. If it is high in humidity, moisture will condense on surface of cold foods and moulds will grow on these surfaces. On the other hand, if air is too dry, it will cause excessive drying out. Most food stores are best at refrigeration temperatures when the relative humidity of air is between 80-95% for prolonging the storage period. Foods can be protected from losing excessive moisture by using several packaging methods. This forms a barrier for migration of moisture from food to storage temperature.

6.5 CHILLING INJURY OF FRUITS AND VEGETABLES

Low temperature storage may have some deleterious effects also. One such effect is called as chilling injury. Chilling injury has variable symptoms as ripening failure in climacteric fruits, different forms of external or internal discolouration, pre-disposition to microorganism infection, etc. The exact mechanism by which chilling injury affects the crop has still not been determined. It has been shown to be concerned with loss of membrane integrity and ion leakage and changes in enzyme activity.

General symptoms of chilling injury

i) Surface and internal discolouration, e.g., internal browning in apples and brown vascular streaks in banana.

ii) Surface pitting, e.g., in tomato, papaya, mango, limes and lemons.

iii) Development of off-flavour.

iv) Failure to ripen in some climacteric fruits.

v) Incidence of surface mould growth or decay.

The chilling injury depends on storage temperature and varies with crop, e.g., chilling injury symptoms develop in banana around 12.6°C. However, some varieties may be resistant to chilling injury at this temperature. In mango, generally chilling injury occurs at 10-15°C depending upon variety.

Based on sensitivity to chilling injury, the crops are classified as

- Chilling sensitive, and
- Non-chilling sensitive.

Chilling sensitive

Fruits: banana, mango, avocado, papaya, pineapple, citrus, plantains, pomegranate, sapota, guava, olive, etc.

Vegetables: snap beans, cucumber, muskmelon, watermelon, okra, potato, tomato, spinach, sweet potato, summer squash, etc.

Non-chilling sensitive

Fruits: apple, apricot, cherry, fig, peach, pea, plum, strawberry, etc.

Vegetables: asparagus, lima beans, beet root, cabbage, broccoli and carrots.

Mechanism of chilling injury

The general mechanism of chilling injury involves following changes:

i) *Abnormal respiratory response:* This generally involves a sudden upsurge in respiratory rate and respiratory quotient leading to uneven ripening.

ii) *Changes in lipids:* Chilling injury involves irreversible disorganization of cellular membranes like mitochondrial and vacuolar membranes. A phase transition occurs in the cytoplasm and it changes from soil to gel stage. When gel formation occurs, the cytoplasm becomes viscous and its movement is restricted.

iii) *Increased membrane permeability:* This is evident by high percentage of electrolytes leached out of the cell. This further leads to increased rigidity of protoplasm and resistance to flow.

Approaches to control chilling injury in fruits and vegetables

If the tolerance to chilling in the chilling resistant tissues can be increased or if the development of chilling injury symptoms can be delayed, the storage life can be increased. The following approaches are generally recommended to control chilling injury in fruits and vegetables:

i) Temperature conditioning
ii) Intermittent warming
iii) Controlled atmosphere storage
iv) Application of growth regulators
v) Packaging, waxing and other coatings

i) *Temperature conditioning:* A cool temperature conditioning just prior to critical chilling range increases the tolerance of commodities to chilling during subsequent low temperature storage and delays the development of injury symptoms. A cool conditioning at 10°C for 10 days before storing at 4°C in peppers reduces chilling injury symptoms. Sometimes a double step-wise temperature conditioning may be more effective than single step conditions. A hot conditioning may be useful in some cases, e.g., pre-storage heating at 30°C for 17-22 hrs decrease injury.

ii) *Intermittent warming:* Interrupting low temperature storage with one or more short periods of warm temperature increases storage life of some chilling sensitive crops. Intermittent warming treatment must be given before chilling injury becomes irreversible. If applied too late, results are not seen. Intermittent warming is hypothesized to remove toxic or inhibiting substances that accumulate during chilling.

iii) *Controlled atmosphere storage:* Most products respond favourably to decrease in oxygen level and increase in carbon dioxide concentration. Pre-storage treatment of grapefruit with high carbon dioxide is effective during inhibiting pitting during cold storage.

iv) *Application of plant growth regulators:* Application of some plant growth regulators such as ABA, Triazoles and ethylene decreases chilling injury symptoms.

v) *Packaging, waxing and other coatings:* Packaging in plastic films and coatings help to maintain relative humidity and modify gas concentration and prevent chilling injury symptoms.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Define chilling injury.

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2. Why should you not store banana in refrigerator?

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3. What are the common symptoms of chilling injury?

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4. List some measures to control chilling injury.

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6.6 EVAPORATIVE COOL STORAGE SYSTEM

On-farm cooling facilities are a valuable asset for any produce operation. A grower who has on farm cooling facility for storing produce has greater market flexibility because the need to market immediately after harvest is eliminated. The challenge, especially for small-scale producers, is the set-up cost. Refrigerated storage systems are although best but expensive in terms of capital investment. Innovative farmers and researchers have thus created a number of low-cost structures. One such low cost structure is evaporative cool storage which was developed by scientists at Indian Agricultural Research Institute.

Principle

Evaporative cool storage is also called as zero energy cool chamber. It is based on the simple principle of evaporative cooling. Evaporative cooling occurs when air, that is not already saturated with water vapour, is blown across any wet surface. An evaporative cooler consists of a wet porous bed through which air is drawn, cooled and humidified by evaporation of water. The faster the evaporation, the greater is the cooling. Can you now think and tell why it is called a zero energy cool chamber? It is so called because it does not require any electricity or power to operate and all the materials required to make the cool chamber are available easily and cheaply. It can be installed at any site by even unskilled person as it does not require any specialized skill or raw material. This simple storage structure has many advantages. Let's see what are they?

- No mechanical or electrical energy is needed.
- Allows small farmers to store produce for a few days; so growers are not forced to sell at low prices, and incur losses.
- Ideal for use in packing stations and markets.
- Reduces losses and pays for itself in a short time.
- Can also be used for mushroom cultivation, sericulture and storage of bio-fertilizers.
- Raw materials required are re-usable.
- The fruits and vegetables stored do not suffer chilling injury.

Let us find out how to construct a zero-energy cool chamber at farm level. We need simple raw materials like

i) Bricks, riverbed sand, bamboo, khaskhas (or any plant material of similar nature), gunny bags/cloth, etc.

ii) A source of water like a tap, a tubewell, a well, a pond, or a canal. The water can be drawn from the source to the cool chamber with the help of a flexible tube/pipe or any suitable container.

iii) Design and construction*:* The floor of the storage space is made with a single layer of bricks. The side walls are made with a double layer of bricks leaving approximately 3" space between the bricks. The cavity between the bricks is filled with riverbed sand. About 400 bricks are required to make a chamber of the dimensions as given in Fig. 6.3. The top of the storage space is covered with khaskhas /gunny cloth in a bamboo frame structure.

The cool chamber should be constructed under a shed with a lot of aeration. The cool chamber site should be close to the source of water.

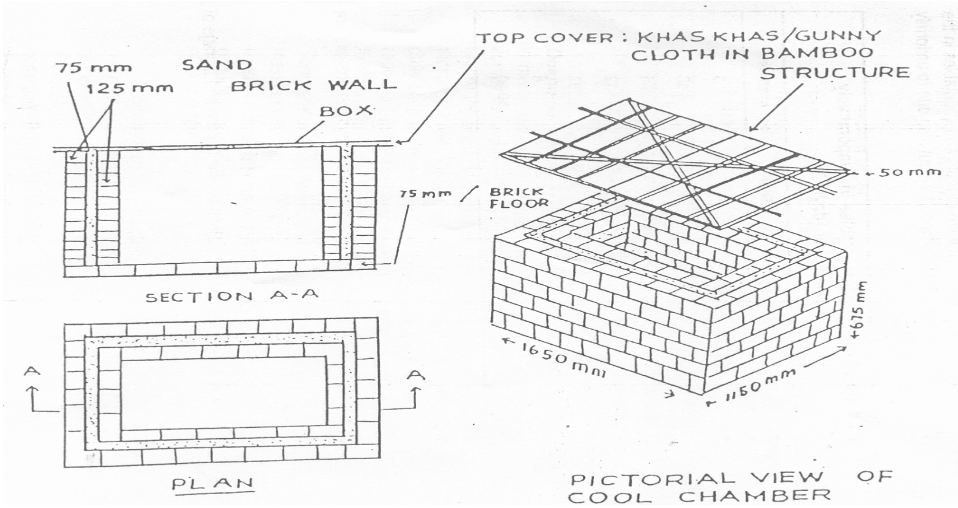

Figure 6.3: Pictorial view of cool chamber

iv) Operation: After construction, bricks of the walls and floor, the sand used in cavity and the top cover made of khaskhas /gunny cloth and bamboo are made completely wet by sprinkling water till they are saturated. It should be ensured before the actual storage of fruits and vegetables that the cool chambers are thoroughly wet. Once the cool chamber is completely wet, sprinkling of water is done once in the morning and once in the evening daily which is enough to maintain the required temperature and humidity. Alternatively, watering can be done by fixing a drip system with a source of water supply. The following precautions are to be observed for smooth functioning of cool chamber:

- Use clean unbroken bricks with good porosity.
- Sand should be clean and free of organic matter and clay.
- Keep the bricks and sand saturated with water.
- Prevent direct exposure to sun.
- Build in an elevated place to avoid water-logging.
- Try to site a place where breezes blow.

Temperature and relative humidity: It has been observed that the average maximum temperature of the cool chamber is considerably low compared to outside temperature throughout the year. During summer, when the maximum outside temperature is 44°C, the maximum cool chamber temperature is never recorded more than 28°C. Similarly, relative humidity of the cool chamber is maintained above 90 per cent practically throughout the year. The minimum relative humidity recorded in the cool chamber is 84 per cent even when the outside humidity is as low as 13 per cent. In general, it is noticed that there is a direct correlation between the outside relative humidity and the temperature difference between the cool chamber and outside. The maximum difference in temperature between cool chamber and outside is noted in the months of April, May and June. This could be attributed to low outside relative humidity during this period. The difference in temperature between the cool chamber and outside could be as high as 18-20°C when the outside humidity is extremely low.

The storage life of fresh fruits and vegetables is considerably increased by keeping them in cool chamber immediately after harvest. Its main advantage is that fruits and vegetables stored in cool chamber do not suffer chilling injury. Increased shelf life of fruits and vegetables in the cool chamber is not only because of low temperature but also due to uniformly high humidity (Table 6.2).

Table 6.2: Shelf life of fruits and vegetables in evaporative cool chamber

Produce	Shelf life (days)		Cool chamber
	Time of storage	Outside	
Leafy vegetables	Summer	< 1	3
Leafy vegetables	Winter	3	8-10
Other vegetables	Summer	1-2	5-6
Other vegetables	Winter	4-5	10-12
Potato	Spring/Summer	40	97
Mango	Summer	4	8
Orange	Winter	8-10	50-60

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is the principle of evaporative cooling?

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2. Why is it difficult to store vegetables like peas and broccoli?

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3. What is the optimum humidity requirement for storage of fruits and vegetables?

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6.7 LET US SUM UP

Fresh fruits and vegetables are perishable. They contain high moisture content and liberate heat during respiration. Storage at low temperature removes respiratory heat and extends the shelf life of fruits and vegetables. Refrigeration is best method for low temperature storage but is expensive and energy intensive. Zero-energy cool chamber is a viable option for low temperature storage of farm produce. It is relatively cheaper and can be constructed using locally available materials. During summer when the maximum outside temperature is 44°C, the maximum cool chamber temperature is never recorded more than 28°C. Similarly, relative humidity of the cool chamber is observed above 90 per cent throughout the year. Low temperature storage also has some drawbacks. Some crops are susceptible to chilling injury, a low temperature storage disorder, which manifests in number of ways like abnormal ripening, browning and pitting.

Temperature conditioning, intermittent warming and controlled atmosphere storage are some of the strategies to control chilling injury disorder.

6.8 KEY WORDS

Chilling injury : Chilling injury is a low-temperature physiological disorder or abnormality of crops where freezing is not a factor.

Specific heat : Specific heat of any substance is the heat required to raise or lower the temperature of unit mass of water by 1°C.

Latent heat : Latent heat is the quantity of heat required to change the state or condition under which a substance exists, without changing its temperature, e.g., a definite quantity of heat must be removed from water at 0°C (32°F) to change it to ice at 0°C.

Refrigeration load : It is defined as that quantity of heat which must be removed in order to reduce the temperature of the products from its initial temperature to the temperature consistent with good frozen food storage.

6.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answers should include the following points:

1. Chilling is the low temperature treatment used to extend shelf life of fruits andvegetables. It does not involve ice formation.

2. Phase change in the refrigerator takes place at two places first at the evaporator and second at the condenser.

3. Common refrigerants used in the refrigerator are ammonia, CFC (Chloro fluoro carbon) and freon.

Check Your Progress Exercise 2

Your answers should include the following points:

1. Chilling injury is a low-temperature physiological disorder observed in some crops. The crops develop some abnormalities during freezing.

2. Banana is never stored in refrigerator because it suffers chilling injury at that storage temperature.

3. Surface and internal discoloration, e.g., internal browning in apples and brown vascular streaks in banana. Surface pitting, e.g., in tomato, papaya, mango limes and lemons. Development of off-flavour and failure to ripen in some climacteric fruits.

4.
   - Temperature conditioning
   - Intermittent warming
   - Controlled atmosphere storage
   - Application of growth regulators
   - Packaging , waxing and other coatings

Check Your Progress Exercise 3

Your answer should include the following points

1. When evaporation of water occurs cooling takes place producing cooling effect. The greater the evaporation the greater is the cooling effect.

2. It is difficult to store peas and broccoli because they are high respiring crops and produce large quantities of heat during respiration.

3. Optimum humidity requirement of most fruits and vegetables is 85-95%.

6.10 SOME USEFUL BOOKS

1. Thompson, A.K. (1996) Post harvest technology of fruits and vegetables. Blackwell Science Ltd., London.

2. Verma, L.R. and Joshi, V.K. (2002) Post harvest technology of fruits and vegetables, Vol. 2, Indus Publishing Co., New Delhi.

3. Potter, N. (2002) Food science, CBS Publishers and Distributor, New Delhi.

UNIT 7 CONTROLLED AND MODIFIED ATMOSPHERE STORAGE

Structure

7.0 OBJECTIVES

This unit shall analyze the basic and applied aspects of controlled/ modified atmosphere storage of fruits and vegetables. Here the issues of physiological basis and problems and prospects of CA / MA storage of fruits and vegetables will be discussed. After studying this unit, you will be able to:

- describe the basic requirement of CA/ MA storage;
- explain physiological effects of CA/MA storage on fruits and vegetables;
- enumerate the methods of atmospheric modification; and
- evaluate the economic benefits of CA/ MA technology.

7.1 INTRODUCTION

The effect of gases on harvested fruits is known since ancient times. In earlier days fruits were used to be taken to temples for improved ripening. This was due to the volatiles released on burning of incense containing hydrocarbon gases that helped ripening of the fruits. In 1819 J.E. Bernard in France noticed that harvested fruits absorb O_2 and liberate CO_2.Atmosphere devoid of O_2 caused no ripening in peach, prunes and apricot for several days but ripening continued when they were placed back in air. A commercial cold storage was built in 1856 by B. Nice for apples and ice was used to maintain a temperature of 1°C. After a decade he started experimenting with modifying the cold store gases inside. In 1907 J. Foulton observed the increase in fruit damage by large accumulation of CO_2 in the storage atmosphere. In 1915 R.W. Thatcher after experiments with apples in sealed boxes containing various levels of gases concluded that CO_2 greatly inhibited ripening. The first scientific evidence on the effect of CO_2 on respiratory rates was established by Kidd and West in

1917 in seeds. In the early 1940 the term of 'gas storage' was replaced by Controlled Atmosphere (CA) storage. Now let us discuss the modern understanding of CA/ MA storage.

Atmosphere at ambient conditions comprises of 78.08% N_2, 20.98% O_2 and 0.03% CO_2. Any deviation from this normal atmosphere composition, e.g., elevated level of CO_2 and reduced levels of O_2 and N_2 or any other combination is known as '**Modified Atmosphere**'. When this deviated normal atmosphere is precisely kept under control then it is termed as "**Controlled Atmosphere**". This control can be done in package (Controlled Atmosphere Packaging) or in the storage chamber (CA-storage). Generally, O_2 below 8 per cent and CO_2 above 1 per cent are used in CA-storage. Atmospheric modification is a supplementary practice to temperature management in preserving quality and safety of fresh fruits, vegetables, ornamentals and their products throughout post-harvest handling and storage.

Essentiality of CA/MA technology should be justified only if (a) the commodities are having high market value, (b) it need longer storage life, (c) require significantly better quality, and (d) fetch better price compared to conventional cool stored produce. Retardation of ripening, reduction in decay, prevention of specific disorders and maintenance of product texture are some of the potential advantages of CA/MA storage. However, initiation or aggravation of certain physiological disorders, viz. black heart in potato, brown stain in lettuce, brown heart in apples and pears, etc., take place in CA-storage if appropriate gaseous regimes are not maintained. A concentration of less than 2 per cent O_2 or more than 5 per cent CO_2 in the storage/ package atmosphere results in irregular ripening of banana, tomato and pear. Too low O_2 or too high CO_2 can increase the susceptibility to decay causing organisms. Off-flavour development in fruits and stimulation of sprouting and retardation of periderm formation in potatoes are some of the ill effects of improper CA-condition. On the other hand, a very high concentration of CO_2 (up to 30%) is extremely beneficial in checking the *Botrytis* rot in strawberry fruits.

The quality retention in fresh horticultural produce in CA storage is mainly due to reduction in the respiratory and metabolic activities and check in ethylene liberation.

Check Your Progress Exercise 1 ✍

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the basic differences between a controlled atmosphere and modified atmosphere storage?

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2. First scientific evidence on the effect of CO_2 on respiratory rate of fruits was established by ______________.

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3. In general the O_2 concentration below ______ % and CO_2 concentration above ________% are used in CA storage.

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4. What are the essentiality factors to be considered while judging the feasibility of a commodity for CA storage?

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7.2 PHYSIOLOGICAL BASIS OF CONTROLLED ATMOSPHERE (CA) STORAGE

Exposure of fresh horticultural crops to low O_2 and/or elevated CO_2 atmosphere within the range tolerated by each commodity reduce their respiration and ethylene production rates. However, outside this range respiration and ethylene production rates can be stimulated indicating a stress response. This stress can contribute to incidence of physiological disorders and increased susceptibility to decay. Elevated CO_2-induced stresses are additive to and sometimes synergistic with, stresses caused by low O_2; physical or chemical injuries; and exposure to temperatures, RH, and/or ethylene concentrations outside the optimum range for the commodity.

The shift from aerobic to anaerobic respiration depends on fruit maturity and ripeness stage (gas diffusion characteristics), temperature, and duration of exposure to stress-inducing concentrations of O_2 and/or CO_2. Up to a point, fruits and vegetables are able to recover from the detrimental effects of low O_2 and/or high CO_2 stresses (fermentative metabolism) and resume normal respiratory metabolism upon transfer to air. Plant tissues have the capacity for recovery from the stresses caused by brief exposure to fungistatic atmospheres (> 10% CO_2) or insecticidal atmospheres (< 1% O_2 and/or 40 to 80% CO_2). **Climacteric fruits are less tolerant and have lower capacity for recovery following exposure to reduced O_2 and/or elevated CO_2 levels than non-climacteric fruits**. The speed and extent of recovery depend upon duration and levels of stresses, stage of maturity and metabolically driven cellular repair mechanism.

Elevated-CO_2 atmospheres inhibit activity of ACC synthase (key regulatory enzyme of ethylene biosynthesis), while ACC oxidase activity is stimulated at low CO_2 and inhibited at high CO_2 concentrations and/or low O_2 levels. Thus, elevated CO_2 atmospheres inhibit ethylene action. Optimum modified atmospheric compositions retard chlorophyll loss (green colour), biosynthesis of carotenoids (yellow and orange colours) and anthocyanins (red and blue colours), and biosynthesis and oxidation of phenolic compounds (brown colour). Controlled atmospheres slow down the activity of cell wall degrading enzymes involved in softening and enzymes involved in lignification leading to toughening of vegetables. Low O_2 and/or high CO_2 atmospheres influence flavour by reducing loss of acidity, starch to sugar conversion, sugar inter-conversions, and biosynthesis of flavour volatiles. When produce is kept in an optimum atmosphere, retention of ascorbic acid and other vitamins result in retention of better nutritional quality.

Specific responses to CA depend upon cultivar, maturity and ripeness stage, storage temperature and duration, and in some cases, ethylene concentrations. Nitrogen is an inert component of CA. Replacing N_2 with argon or helium may increase diffusivity of O_2, CO_2 and C_2H_4, but they have no direct effect on plant tissues and are more expensive than N_2 as a CA component. Super-atmospheric levels of O_2 up to about 80 per cent may accelerate ethylene-induced degreening of non-climacteric commodities and ripening of climacteric fruits, respiration and ethylene production rates, and incidence of some physiological disorders (such as scald on apples and russet spotting on lettuce). At levels above 80 per cent of O_2 some commodities and post-harvest pathogens suffer from O_2 toxicity. Use of super-atmospheric O_2 levels in CA will likely be limited to situations in which they reduce the negative effects of fungistatic or elevated CO_2 atmospheres on commodities that are sensitive to CO_2-injury.

7.3 EFFECTS OF CA STORAGE

The following are some of the beneficial effects of CA storage.

- Retardation of senescence (including ripening) and associated biochemical and physiological changes, i.e., slowing down rates of respiration, ethylene production, softening, and compositional changes.
- Reduction of sensitivity to ethylene action at O_2 levels < 8% and/or CO_2 levels > 1%.
- Alleviation of certain physiological disorders, such as chilling injury of avocado and some storage disorders, including scald of apples.

- Effects directly or indirectly on post-harvest pathogens (bacteria and fungi) and consequently decay incidence and severity. For example, CO_2 at 10 to 15% significantly inhibit development of *Botrytis* rot on strawberries, cherries, and other perishables.
- Low O_2 (< 1%) and/or elevated CO_2 (40 to 60%) can be a useful tool for insect control during storage of dried products from fruits, vegetables, flowers, nuts and grains.

The harmful effects of CA storage of fruits and vegetables are mentioned below:

- Initiation and/or aggravation of certain physiological disorders, such as internal browning in apples and pears, brown stain of lettuce, and chilling injury of some commodities.
- Irregular ripening of fruits, such as banana, mango, pear, and tomato can result from exposure at O_2 levels below 2% and/or CO_2 levels above 5%.
- Development of off-flavours and off-odours at very low O_2 concentrations and very high CO_2 (as a result of anaerobic respiration and fermentative metabolism)
- Increased susceptibility to decay when the fruit is physiologically injured by too-low O_2 or too-high CO_2 concentrations.

7.4 METHODS OF CREATING MODIFIED ATMOSPHERE CONDITIONS

MAP may be defined as the enclosure of food products in gas-barrier materials in which gaseous environment has been changed in order to inhibit spoilage agents, either by maintaining a higher quality within a perishable food during its natural life or actually extending the shelf life.

Modified atmosphere can be created ***passively*** by the respiration of commodity, also called ***commodity generated*** modified atmosphere, and ***active*** modified atmosphere generation.

7.4.1 Passive Modified Atmosphere

If commodity characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration. This atmosphere must be established rapidly and without danger of the creation of anoxic conditions on injuriously high level of CO_2.

7.4.2 Active Modified Atmosphere

Because of the limited ability to regulate a passively established atmosphere, an active modified atmosphere can be created by vacuum packaging or replacing the package atmosphere with the desired gas mixture.

- **Vacuum packaging:** It involves placing a product in a film of low O_2 permeability, the removal of air from the package and application of a hermetic seal. During packaging product compression takes place which makes it unsuitable for many products.

- **Gas packaging:** Gas packaging overcomes the limitations of vacuum packaging. Oxygen, nitrogen and carbon dioxide are gases generally used which have specific role, viz. O_2 is essential for respiration of fresh fruits and vegetables, CO_2 is a bacterial and fungal growth inhibitor and nitrogen is inert, tasteless and less prone to pass either into the product or out through the packaging material.

7.4.3 Available Films for MAP

i) Plastic films: The permeability of plastic films is an important attribute which determines their suitability for packaging of fresh fruits and vegetables. An ideal film allows more CO_2 to exit than O_2 to enter. The CO_2 permeability must be somewhere in the range of 3-5 times greater than the oxygen permeability, depending upon the desired atmosphere. Permeability characters of films commonly used for packaging are presented in Table 7.1.

Table 7.1: Gas and water vapour permeabilities of some selected films available for modified atmosphere packaging of fresh produce

Film	Permeability, cc/m^2 day. atm for 25 meq film at 25°C		Water vapour transmission g/m^2 day atm 38°C and 90% RH
	Oxygen	Carbon dioxide	
LDPE	7800	42000	18
HDPE	2600	7600	7-10
Polypropylene cast	3700	1000	10-12
Polypropylene, oriented, OPP	6000-22000	6000-22000	NA
Rigid PVC	150-350	450-1000	30-40
Plasticized PVC	500-30000	1500-46000	15-40
Ethylene vinyl acetate (EVA)	12500	50000	40-60
Microporous, OPP	50000	50000	Variable
	72000	72000	Variable
	120000	120000	Variable
	200000	200000	Variable

NA: Not available

Low density polyethylene (LDPE) and polyvinyl chloride (PVC) are the main films used in packaging of fruits and vegetables. Gas diffusion across a film is determined by: film structure, film permeability to specific gases, thickness, area, concentration gradient across the film, temperature and differences in preserve across the film.

A list of desirable characteristics of plastic films for MAP of fresh produce is as follows:

- Required permeability for the different gases
- Good transparency and gloss

- Light weight
- Heat tear strength and elongation
- Low temperature heat-sealability
- Non toxic
- Non reactant with produce
- Good thermal and ozone resistance
- Good weatherability
- Commercial suitability
- Ease of handling
- Ease of printing for labeling purposes.

ii) Surface coatings: These are synthetic and natural chemicals which are composed of lipids, resin, polysaccharides, proteins and composite or bilayer substances. These surface coatings help to maintain quality of fresh produce and to reduce the volume of disposable non-biodegradable packaging materials. They also act by altering the gaseous atmosphere within and surrounding the fruit.

Surface coatings have been developed to overcome the limitations of MAP and CA. The risk of condensation on the inner surface and the associated incidence of rots in plastic films is eliminated. Surface coatings are used to modify internal atmosphere composition thereby delay ripening, reduce water loss and improve the finish of skin.

Requirements for edible films and coatings

- Good sensory qualities
- High carrier and mechanical efficiencies
- Enough biochemical, physiochemical and microbial stability
- Free of toxins and safe for health
- Simple technology
- Non polluting
- Low cost of raw materials and process.

Commonly used coatings

Lipids and Resins – Natural waxes-carnuba wax, candelilla wax, rice bran wax, bees wax, Petroleum based - paraffin, polyethylene wax, mineral oil, vegetable oils (corn, soybean), acetoglycerides, oleic acid, resins (shellac, wood resin, coumarone)

Polysaccharide based – They are very effective barriers to O_2 and CO_2 but not water. Cellulose derivatives: methylecellulose (MC), hydroxy propylcellulose (HPC), and hydroxy propylmethyl celluose (HPMC). These are commercially sold under the name of Nature seal, Tal prolong, Semperfresh. Chitosan based is Nutrisave.

Proteins – Their use in restricted due to high permeability to water.

Composite and bilayer coatings: They are mostly used when both the O_2 and moisture barrier properties need to be incorporated in the surface coating materials. That means the coating should have both hydrophobic and hydrophilic substances. For example, coating materials made up of sodium caseinate.

iii) Relative tolerance of fruits and vegetables to O_2 and CO_2 concentrations

The extent of benefits from CA and MA use depend upon the commodity, cultivar, physiological age (maturity stage), initial quality, concentration of O_2 and CO_2, temperature, and duration of exposure to such conditions. Subjecting a cultivar of a given commodity to O_2 levels below and/or CO_2 levels above its tolerance limits at a specific temperature time combination will result in stress to the living plant tissue, which is manifested as various symptoms. Tables 7.2 and 7.3 include classifications of fruits and vegetables according to their relative tolerance to low O_2 or elevated CO_2 concentrations when kept at or near their optimum storage temperature and relative humidity.

Table 7.2: Classification of fruits and vegetables according to their tolerance to low O_2 concentrations

O_2 concentration (%)	Commodities
1.0	Some cultivars of apples and pears, broccoli, mushroom, garlic, onion
2.0	Most cultivars of apples and pears, kiwifruits, apricot, cherry, nectarine, peach, plum, strawberry, papaya, pineapple, olive, cantaloupe, green bean, celery, lettuce, cabbage, cauliflower, brussels sprouts
3.0	Avocado, persimmon, tomato, pepper, cucumber, artichoke
5.0	Citrus fruits, green pea, asparagus, potato, sweet potato

Table 7.3: Classification of fruits and vegetables according to their tolerance to elevated CO_2 concentrations

CO_2 concentration (%)	Commodities
2	Apples (Golden Delicious), Asian and European pear, apricot, grape, olive, tomato, sweet pepper, lettuce, Chinese cabbage, artichoke, sweet potato
5	Most cultivars of apples and peach, nectarine, plum, orange, avocado, banana, mango, papaya, kiwifruit, pea, chilli, egg plant, cauliflower, cabbage, brussels sprouts, radish, carrot

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Which of the following statements are right or wrong? Mark (√) or (X).

   i) The role of CO_2 in CA storage is primarily limited to maintaining the freshness of the produce.

   ii) CO_2 at certain concentration acts as a fungistatic.

   iii) CO_2 at certain concentration acts as a fungicide.

   iv) Excess of CO_2 can cause injury to the produce that is similar to that of mechanical injury.

   v) Reduced level of O_2 results in checking the respiratory rates in CA storage.

2. What are the detrimental effects of CA storage?

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3. Write two different methods of atmospheric modification.

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4. Can we create MA condition by use of surface coating on fruits and vegetables? Mention the different type of surface coatings used in commercial practice abroad.

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7.5 COMMERCIAL APPLICATION OF CA STORAGE

Controlled atmosphere storage systems are used commercially for long-term storage of fresh horticultural crops. Commercial use of CA storage is maximum in apples and pears. Recent researches have shown potential advantages of this method in short-term (a few days) and medium-term (a few weeks) storage of certain types of produce. Optimizing storage conditions requires facilities that allow the temperature and the composition of gases in storage rooms to be controlled precisely. Each product reacts in different way to different concentration of gases.

There are various types of CA systems used in commercial storage. These include generating nitrogen by separation from compressed air using molecular sieve beds or membrane systems. Others are ultra low O_2 (1.0 to 1.5%) storage (ULO), low ethylene (< 1 $\mu L\ L^{-1}$) CA storage; rapid CA storage (rapid establishment of optimal levels of O_2 and CO_2), programmed or sequential CA storage (e.g., storage in 1% O_2 for 2 to 6 weeks followed by storage in 2 to 3% O_2 for the remainder of the storage period), etc. Recent reports of short-term control atmosphere exposure (CAE) techniques indicate a great promise of simulated effect of continuous CA–storage system with particular reference to delay in disease development, delaying the senescence and quality assurance of CA-insensitive climacteric fruits. Other developments include use of atmospheric modification during transport and distribution, improved technologies of establishing, monitoring, and maintaining CA, using edible coatings or polymeric films with appropriate gas permeability to create a desired atmospheric composition around the commodity.

In commercial CA storage the crop is loaded into an insulated store room whose walls have been made gas tight. The temperature is controlled by mechanical refrigeration and the composition of the atmosphere is constantly analysed for carbon dioxide and oxygen levels. Usually the tolerance limits are set at, say plus or minus 0.1%. In active scrubbing, after a predetermined level of CO_2 is reached of the store the atmosphere, is passed through a chemical (CO_2 scrubber) which removes CO_2, and then it is flushed back into the store. In passive scrubbing, the CO_2 scrubber is placed inside the store.

The following factors are to be taken into account with controlled atmosphere storage:

- It is expensive, therefore, only the best fruit should be stored.
- If there is a choice, small fruit should be stored.
- Fruit should be placed in storage as soon as possible after harvest, and in any case within a day.
- The store should be closed and cooled each evening during loading.
- Only one type of crop should be stored in one room and preferably the same cultivar.

The characteristics for a fruit to be compatible with the use of CA are: a long post harvest life, resistance to chilling injury, a large range of non-injurious atmospheres, resistance to fungal and bacterial attack, adaptation to a humid atmosphere, a climacteric fruit that can be ripened during or after storage, and absence of negative CA residual effect.

7.6 ENVIRONMENTAL FACTORS INFLUENCING MA AND CA STORAGES

7.6.1 Temperature and Relative Humidity

The temperature at which a commodity is stored influences the storage life of product, more importantly in film packed commodities. The commodity will cool and warm more slowly than it would if it is exposed directly to ambient temperatures. Temperature also affects the permeability of film. In general, film permeability increases as temperature increases, with CO_2 permeability responding more than O_2 permeability. A film that is appropriate for MAP at one temperature may not be appropriate at other temperature. Relative humidity appears to have little effect on permeability of most films unless actual condensation occurs on the film.

7.6.2 Light

For many commodities, light is not an important factor which influences their post harvest handling. However, green vegetables in the presence of sufficient light, could consume substantial amounts of CO_2 and produce O_2 through photosynthesis. Greening of potatoes can be avoided by using opaque packages.

7.6.3 Sanitation Factors

Packaging of fresh fruits and vegetables in plastic films can create a high-humidity low-oxygen environment that is favourable to pathogenic microorganisms. Care must be taken to avoid conditions favourable to the growth and reproduction of such microorganisms.

7.7 CA SYSTEMS FOR TRANSPORTATION

Many CA systems have been developed for use during transportation. They should be used when transport periods are long and /or fruit is very perishable. Some of the systems in use are:

Oxytral system	Occidental Petroleum Corporation, California, USA	Highway and sea shipment of lettuce, celery, papaya, pineapple
Tectrol system	Transfresh Corporation, California, USA	Lettuce, strawberry, mango, avocado.
CONAIR-Plus System	G+H Montage GmbH, Hamburg, Germany	Apple, avocado, melon, mango.
PRISM CA	Per Mea Inc., St. Louis, Missouri, USA	Apple, pears.
Fresh tainer	Maidstone, England	Apple
NITEC	Spokane, Washington, USA	Apple.

A comprehensive list of most suitable storage atmospheres for CA or MA storage of vegetables is provided in Table 7.4.

Table 7.4: Recommended controlled atmosphere conditions during transport/storage of vegetables

Commodity	Storage temp (°C)	Optimum oxygen (%)	Optimum carbon dioxide (%)	Approximate storage life
Artichoke	0-5	2-3	2-3	29 d
Asparagus	1-5	21	5-10	21 d
Beans. Snap	5-10	8-10	5-10	7-10 d
Beets	8-12	None	None	8 m
Brinjal	0-5	-	-	1-2 wk
Broccoli	0-5	1-2	5-10	2-3 m
Brussels sprouts	0-5	1-2	5-7	2-3 m
Cabbage	0-5	3-5	5-7	6-12 m
Carrot	0-5	None	None	4-5 m
Cauliflower	0-5	2-3	3-4	2-3 m
Celery	0-5	1-4	3-5	1-2 m
Chicory	0-5	3-4	-	2 m
Cucumber	8-12	3-5	0	14-21 d
Leeks	0-5	1-2	3-5	2-3 m
Lettuce	0-5	2-5	0	3-4 wk
Mushrooms	05	air	10-15	3-4 d
Okra	8-12	3-5	0	7-10 d
Onions				
Bulb →	0-5	1-2	0	8 m
Bunching →	0-5	1-2	10-20	2 m
Pea (green)	0-1	5-10	5	5-10 d
Pepper, bell	8-12	3-5	0	2-3 wk
Pepper, chilli	8-12	3-5	0-5%	-
Potatoes	4-12	None	None	-
Pumpkin	7-10	-	-	2-4 m
Radish	0-5	None	None	3-4 wk
Spinach	0-5	air	10-20	2-3 wk
Squashes	7-10	-	-	1-3 m
Tomatoes	5-13	3-5	2-3	2 wks

d=days; wks=weeks; m=months

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Which of the following statements are right or wrong? Mark (√) or (X).

   i) Commercially CA storage is meant for long term storage.

   ii) In ultra low oxygen CA storage the O_2 concentration ranges from 1-1.5%.

   iii) The establishment of CA condition is very slow in ULO system of CA storage.

   iv) Mango fruits respond very well to CA storage than apples.

2. Mention three different environmental factors crucial to maintain the efficacy of CA storage.

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3. Mention any three commercial system of MA/CA storage used during transportation.

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7.8 LET US SUM UP

Atmosphere at ambient conditions comprises of 78.08% N_2, 20.98% O_2 and 0.03% CO_2 under normal conditions. Any deviation from this normal atmosphere composition, e.g. elevated level of CO_2, reduced level of O_2, and N_2 or any other combination is known as '**Modified Atmosphere**'. When this deviated normal atmosphere is precisely kept under control then it is termed as "**Controlled Atmosphere**". This control can be done in package (Controlled Atmosphere Packaging) or in the storage chamber (CA-storage). Generally, O_2 below 8% and CO_2 above 1% are used in CA-storage. Atmospheric modification is a supplementary practice to temperature management in preserving quality and safety of fresh fruits, vegetables, ornamentals and their products throughout post-harvest handling. Essentiality of CA/MA technology should be justified only if (a) the commodities are having high market value,

(b) it significantly enhances storage life, (c) it retains significantly better quality, and (d) it fetches better price compared to conventional cool stored produce. Elevated CO_2-induced stresses are additive to and sometimes synergistic with, stresses caused by low O_2; physical or chemical injuries; and exposure to temperatures, RH, and/or ethylene concentrations outside the optimum range for the commodity.

The beneficial effects of controlled atmosphere storage are retardation of senescence, reduction of sensitivity to ethylene action, alleviation of certain physiological disorders and direct or indirect effect on post-harvest pathogens. It can be a useful tool for insect control. The harmful effects of CA storage of fruits and vegetables are initiation and/or aggravation of certain physiological disorders, irregular ripening of fruits, development of off-flavours and off-odours and increased susceptibility to decay.

If commodity characteristics are properly matched to film permeability characteristics, an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration. It is also called passive MA. Because of the limited ability to regulate a passively established atmosphere, an active modified atmosphere can be created by vacuum packaging or replacing the package atmosphere with the desired gas mixture. The permeability of plastic films is an important attribute which determines their suitability for packaging of fresh fruits and vegetables. Surface coatings help to maintain quality of fresh produce and to reduce the volume of disposable non-biodegradable packaging materials. They also act by altering the gaseous atmosphere within and surrounding the fruit and create a MA condition.

There are various types of CA systems used in commercial storage. These include generating nitrogen by separation from compressed air using molecular sieve beds or membrane systems. Others are ultra low O_2 (1.0 to 1.5%) storage (ULO), low ethylene ($< 1\ \mu L\ L^{-1}$) CA storage; rapid CA storage (rapid establishment of optimal levels of O_2 and CO_2), and programmed or sequential CA storage (e.g., storage in 1% O_2 for 2 to 6 weeks followed by storage in 2 to 3% O_2 for the remainder of the storage period), etc. Many CA systems have been developed for use during transportation. They should be used when transport periods are long and /or fruit is very perishable.

7.9 KEY WORDS

Modified atmosphere : Atmosphere at ambient conditions comprises of 78.08% N_2, 20.98% O_2 and 0.03% CO_2 under normal conditions. Any deviation from this normal atmosphere composition, e.g. elevated level of CO_2, reduced level of O_2, and N_2 or any other combination is known as **Modified Atmosphere.**

Controlled atmosphere : When this deviated normal atmosphere is precisely kept under control then it is termed as **Controlled Atmosphere**.

Passive modified atmosphere : If commodity characteristics are properly matched to film permeability characteristics an appropriate atmosphere can passively evolve within a sealed package as a result of the consumption of O_2 and the production of CO_2 through respiration

Active modified atmosphere : An active modified atmosphere can be created by vacuum packaging or replacing the package atmosphere with the desired gas mixture.

Vacuum packaging : It involves placing a product in a film of low O_2 permeability, the removal of air from the package and the application of a hermetic seal.

Gas packaging : Gas packaging overcomes the limitations of vacuum packaging. Mixed gases or inert gas is used in the package for specific purposes.

Surface coatings : The synthetic and natural chemicals which are composed of lipids, resin, polysaccharides, proteins and composite or bilayer substances are used as surface coating materials for various purposes. These surface coatings help to maintain quality of fresh produce and to reduce the volume of disposable non-biodegradable packaging materials. Edible films and coatings are also available.

Composite and bilayer coatings : It is mostly used when both the O_2 and moisture barrier properties need to be incorporated in the surface coating materials. This means the coating should have both hydrophobic and hydrophilic substances.

7.10 ANSWERS TO CHECK YOUR PROGRESS EXCERCISES

Check Your Progress Exercise 1

Your answer should include the following points:

1. Composition of normal atmosphere is 78.08% N_2, 20.98% O_2 and 0.03% CO_2. Any deviation from this normal atmosphere composition i.e., elevated level of CO_2, or reduced levels of O_2, and N_2 or any other combination is known as **Modified Atmosphere**. When this deviated normal atmosphere is precisely kept under control then it is termed as **Controlled Atmosphere**.
2. Kidd and West (1917).
3. O_2 below 8% and CO_2 above 1%.

4. Essentiality of CA/MA technology should be justified only if (a) the commodities are having high market value, (b) need longer storage life, (c) require significantly better quality, and (d) fetch better price compared to conventional cool stored produce.

Check Your Progress Exercise 2

Your answer should include the following points:

1. i) X ii) √ iii) X iv) √ v) √

2. Initiation and/or aggravation of certain physiological disorders, irregular ripening, development of off-flavours and off-odours, and increased susceptibility to decay.

3. Active and passive modification.

Check Your Progress Exercise 3

Your answer should include the following points:

1. i) √ ii) √ iii) X iv) X

2. Temperature and relative humidity, light and sanitation factors.

3. Any three of the following: Oxytral system, Tectrol system, CONAIR-Plus System, PRISM CA, Fresh tainer or NITEC.

4. Yes, Different types of surface coatings materials are:

   i) Lipid and resin based, e.g., carnuba wax
   ii) Polysaccharide based, e.g., Tal prolong
   iii) Protein based, and
   iv) Composite and bilayer coatings

7.11 SOME USEFUL BOOKS

1. Ludford, P.M. and Isenberg, F.M.R. (1987) Brassica crops. In: Weichman, J. (Ed.) Post-harvest physiology of vegetables, Marcel Dekker Inc., New York.

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3. Pantastico, Er. B. (1975) Post-harvest physiology, handling and utilization of tropical and subtropical fruits and vegetables. A VI Publ. Co; Westport, CT.

4. Wills, R.H.H., Lee, T.H., Graham, De., McGlasson, W.B. and Hall, E.G. (1981) Post-harvest: An introduction to the physiology and handling of fruit and vegetables. A VI Publ. Co., Westport, CT.

5. Burton, W.G. (1982) Post-harvest physiology of food crops. Longman, New York.

UNIT 8 FOOD IRRADIATION

Structure

8.0 OBJECTIVES

After studying this unit, you should be able to:

- describe different kinds of ionizing radiations;
- define mechanism of irradiation;
- explain applications of gamma irradiation;
- illustrate the effect of radiation on nutrients;
- describe the effect of radiation on micro organisms; and
- assess the beneficial aspects of food irradiation.

8.1 INTRODUCTION

Food irradiation is a physical process like drying, freezing, canning and pasteurization. Food can be irradiated wet, dry, thawed or frozen. It is a cold process and does not cause change in texture and freshness of food unlike heat. In fact you will not be able to differentiate between irradiated and non-irradiated food on the basis of colour, flavour, taste, aroma or appearance.

This radiation technique is very effective and due to its highly penetrating nature, it can be used on packed food commodities. It means a food commodity, which is packed, can be radiated for sterilization, disinfestation or disinfection purposes and shipped directly.

As you may be aware that many chemical fumigants / preservatives are used to preserve food commodities. Which sometimes leave toxic residues in foods that may be carcinogenic in nature. Contrary to these chemical fumigants, irradiation does not leave any toxic residue in treated foods. So, it is considered very safe. Besides, radiation-processing facilities are environment friendly and safe to workers and public around.

In spite of all its benefits, the radiation processing technique is not a magic wand. It cannot be used to make spoiled or bad food look good. It cannot eliminate already present toxins and pesticides in food. It is a need based technique and can't be applied to all foods. Amenability of a particular food commodity to irradiation needs to be scientifically established and the food commodities that are duly permitted under PFA Act should only be radiation processed.

8.2 IONIZING RADIATIONS

8.2.1 Kinds of Ionizing Radiations

Gamma rays, X-rays and electron beam are the part of invisible light waves of electromagnetic spectrum (U.V. rays are also part of this invisible range but wavelength is not as short as that of X-rays or gamma rays). These high-energy radiations can change atoms into electrically charged ions by knocking out an electron from the outer orbit and thus, are called ionizing radiations. But, at dose levels approved for food irradiation, these radiations cannot penetrate nuclei and thus, food can never become radioactive.

Other types of radiation energy with longer wavelengths are infrared and microwaves. Infrared radiation is used in conventional cooking. Microwaves, due to their relatively longer wavelength, have lower energy levels but are strong enough to move molecules and generate heat through friction.

Three types of ionizing radiations are approved to be used for food irradiation.

i) Electron beams generated from machine sources operate at a maximum energy of 10 MeV.

ii) X-rays generated from machine sources operate at a maximum energy of 5 MeV.

iii) Gamma rays are emitted from Co-60 or Ce-137 with respective energies of 1.33 and 0.67 million electron volts (MeV).

i) Electron beams

Electron beams are streams of very fast moving electrons produced in electron accelerators. For your better understanding, an electron beam generator is comparable to the device at the back of TV tube that propels electrons into the TV screen at the front of the tube. For irradiation using electron beams, only approved electron accelerators can be used. Electron beams have a selective application in food irradiation due to their poor penetration. They can penetrate only one and one half inches deep into the food commodity. As a result, shipping cartons (pre-packed bulk food commodities) are generally too thick to be processed with electron beams. Since electron beams are generated through machine sources, so they can be switched on or off at will and require shielding.

ii) X-rays

X-rays are also generated through machine sources. X-rays are photons and have much better penetration and are able to penetrate through whole cartons of food products. To produce useful quantities of X-rays, a tungsten or tantalum metal plate is attached to the end of accelerator scan horn. The electrons strike the plate and X-rays are generated which pass through the metal plate and penetrate the food product conveyed underneath. But, remember that this X-ray machine is a much powerful version to the machine used in many hospitals and dental clinics. Since X-rays are generated through machine sources, so they can be switched on or off at will and require shielding.

iii) Gamma rays

The third type of ionizing radiations approved for food processing are gamma rays that are produced from radioisotopes either Co-60 or Ce-137. Contrary to electron beams and X-rays, radioisotopes cannot be switched off or on at will and they keep on emitting gamma rays. Radioisotopes require shielding. Co-60 source is kept immersed under water when it is not in use and Ce-137 is shielded in lead. Due to their continuous operation, radioisotopes need to be replenished from time to time. Gamma rays are photons and have deep penetration ability.

8.2.2 Mechanism of Irradiation

The preservative action of ionizing radiations is due to both primary and secondary effects resulting from interaction of radiations with molecules and microorganisms present in food.

i) Primary effect

The incident radiation interacts with the atoms and molecules present in food and cause ejection of electrons. This leads to ionization and dissociation. The ejected electrons cause further excitation of molecules present in food. These are represented in the equation below:

$$RH \text{ ------------------}\rightarrow RH^{+} + e^{-} \quad \text{Ionization}$$

$$RH \text{ ------------------}\rightarrow R + H \quad \text{Dissociation}$$

$$RH \text{ ------------------}\rightarrow RH^{+} \quad \text{Excitation}$$

ii) Secondary effect (Radiolysis of water)

Since water is present in almost all the foods, either in free or bound form, an understanding of chemical changes which water undergoes is important. Gamma rays excite and ionize water and other molecules along their track, giving rise to excitation, ionization and free radicals. These events contribute a great deal to the secondary effects of gamma radiation.

The summary of happenings can be represented by the equation

$$H_2O \text{ ----}\rightarrow \underset{\text{Free radicals}}{OH^{+}} + \underset{\text{Hydrated electron}}{e^{-}\text{ aq.}} + \underset{\text{free radicals (FR)}}{H^{+}_{FR} + H_2} + H_2O_2 + \underset{\text{Hydronium ion}}{H_3O^{+}}$$

8.2.3 Process of Gamma Irradiation

In a typical gamma irradiation facility, irradiation is carried out inside an irradiation chamber. The later is shielded by 1.5-1.8 meter thick wall. Radiation source Co-60 is contained in slender pencil like stainless steel casings, which in turn are contained in lead shield. Food products, pre-packed or in bulk are placed in suitable containers and carried into the irradiation chamber with the help of automatic conveyor. The conveyor goes through a concrete wall labyrinth. This concrete wall serves as a shield and prevents radiation from reaching the surrounding area.

For irradiation of food products, the radiation source is raised above the water shield, after activating all safety devices. The food containers or boxes move around the source in the cell and get exposed for a specific length of time that allows them to absorb a defined radiation dose.

Gamma irradiation can be compared to switching on a light, illuminating a room and turning it off. Gamma rays pass into the food, affect the food or target organisms present in food and leave the food. Outcome of irradiation depends on type of food products, radiation dose and organisms present in food.

After radiation, proper handling and processing of food should be ensured, because irradiation cannot prevent further contamination from improper handling or processing. Irradiation cannot be used to make spoiled food good or to clean up ‘dirty’ food. If food already looks, tastes or smells bad, it cannot be saved by any treatment including irradiation. The bad appearance, taste or smell will remain.

Food processes such as heating, freezing, chemical treatment and irradiation are not intended to serve as substitutes to good hygienic practices. Both at national and international levels, good manufacturing practices govern the handling of specific foods and their products. They must be followed in the preparation of food, whether the food is intended for further processing by irradiation or any other means.

Irradiators are designed with several layers of overlapping protection systems / safety devices to detect any malfunctioning of the equipments and to protect working personnel from accidental exposure to the radiations. Potentially hazardous areas are regularly and meticulously monitored. A system of inter locks / checks prevents unauthorized entry into the radiation chamber when the source is out of shield.

All irradiation facilities are under strict control of regulatory agencies. In India, irradiation facilities operate under direct control of AERB (Atomic Energy Regulatory Board), Bhabha Atomic Research Centre, Mumbai. These facilities are thoroughly evaluated for their efficacy and safety before a license is issued. Further monitoring is through periodic checks and regular inspections of the facility and in case of any non-compliance, severe penalties and delicensing of facility results.

8.2.4 Units of Irradiation

The units used to measure the effects of radiation are gray and sievert in accordance with recommendations of International Organisation for Standardisation (ISO). Formerly, units used for measuring radiation were the rad and the rem.

The gray (Gy) is the unit used to measure absorbed dose of radiation and is equal to one joule of energy absorbed per kg of matter being irradiated. 1 Gy corresponds to 100 rad.

The unit used to measure the dose equivalent to one given exposure, taking into account the different biological effectiveness of different type of radiation, is the sievert (Sv). 1 Sv corresponds to 100 rem.

The unit used to measure the activity of a given source of radiation is Becquerel (Bq). The former unit was Curie (Ci). 1 Bq is equivalent to 2.7 x 10^{-11} Ci.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Mark which of the following statements are right (√) or wrong (X).

   a) 1 Sv is equal to 100 rem ( )

   b) Irradiation can be applied to all types of foods ( )

   c) Irradiation is a cold process ( )

   d) Irradiation can be used to make bad food look good ( )

   e) No radioactivity is induced in the irradiated foods ( )

2. Describe three kinds of ionizing radiations approved for food irradiation.

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3. Explain briefly the primary and secondary effects of irradiation.

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8.3 EFFECT OF IONIZING RADIATION ON NUTRIENTS

All processes cause changes in nutritional value of foods, even storage causes fresh foods to loose nutrients. It is well demonstrated that irradiation up to 10 kGy does not cause any significant change in the nutritional value of macronutrients, i.e., lipids, proteins and carbohydrates.

Vitamins are the most essential micronutrients present in foods. Certain vitamins like A, E, C, K and B_1 are radiation sensitive. They can be reduced by irradiation but they are similarly reduced when treated by other food processing methods. Irradiation may convert Vitamin C (ascorbic acid) to dehydro ascorbic acid, which is another equally usable form of Vitamin C. Fat soluble vitamins like Vitamin D are radiation resistant and survive irradiation of food products.

Minerals are virtually unchanged. Iron is oxidized but the nutrient value of oxidized iron is same as that of unoxidized iron. Other processes like freezing, thawing, storage have similar effects on iron.

So, the bottom line is that irradiation does not have any adverse impact on the nutritional content of a person's diet.

The FAO / IAEA / WHO Joint Expert Committee has concluded that any food commodity irradiated up to an overall dose of 10 kGy is safe and wholesome for human consumption.

8.4 RADIATION SENSITIVITY OF MICROORGANISMS

In case of living organisms, exposure to radiation causes structural and functional changes in macromolecules thereby leading to cell death / injury. DNA or RNA is the most important target for radiation inactivation of living cells. Please note that a low dose that may cause little chemical changes in food can cause sufficient changes in DNA to cause cell death. As you must be aware that DNA carries genetic information and its intactness is important for it's functioning. So, any damage to DNA will result into severe cell injury / death.

Now, radiation acts on DNA in two ways, i.e., i) direct and ii) indirect. In direct action, DNA absorbs radiation and is damaged. The damage to DNA is of various types – single strand breaks, double strand breaks (dsb), alteration of purine or pyrimidine bases or interchain bond formation. In the indirect action, other molecules like water and the free radicals thus produced react with DNA absorb radiation. This primary and secondary effect (direct & indirect effect) we have studied earlier under section 8.2.2.

Both prokaryotic as well as eukaryotic cells possess various DNA repair mechanism, such as direct rejoining of broken ends, excision repair, past replication repair, etc. The double strand breaks are important because most of the microorganisms cannot repair these damages and cells cannot replicate.

When a population of microorganisms is irradiated with a low dose, only a few of the cells are damaged or killed. With increasing dose, the number of survivors decreases exponentially. Different species and different strains of same species require different doses to reach the same degree of inactivation. In order to characterize organisms by their radiation sensitivity, the decimal reduction dose (D_{10}) is used. D_{10} is the dose required to kill 90 per cent of a population.

i) Bacteria

Bacteria are prokaryotic organisms. The cytoplasm is highly hydrated (70-80% water) and is surrounded by cytoplasmic membrane and a cell wall. Chromosomal DNA is not surrounded by a nuclear membrane. Because of high water content and large amount of DNA, bacteria are very sensitive to radiation.

In general, gram –ve bacteria are more sensitive while some gram +ve cocci are extremely resistant due to their highly efficient DNA repair system. Spores are 10-20 times more resistant than vegetative cells because they have little or no free water and are surrounded by thick impermeable wall. Each bacterium is characterized by a particular D_{10} value reflecting its inherent sensitivity to radiation. Certain extrinsic factors like temperature, O_2 content, water activity, nature of medium and presence or absence of sensitizers or protectors also determine the D_{10} value of a particular microorganism.

ii) Virus

Viruses are simplest biological entities. They are metabolically dormant and do not contain cytoplasm or metabolic enzymes needed for growth. They are the obligate intracellular parasites. The simplest virus particle consists, basically, of a nucleic acid genome (DNA or RNA) and a protein coat. The genome size is 100 to 1000 times smaller than that of bacteria. Therefore, viruses are considerably more resistant to radiation than bacteria or fungi. Further, estimation of dose requirements, to ensure safety from viral infections solely through irradiation, ranged from 20 to 100 kGy, which makes irradiation an unlikely choice for virus treatment in foods.

iii) Yeasts and Moulds

Yeats and moulds are eukaryotic cells, i.e., they have a true nucleus. Generally, they are as sensitive to radiation as vegetative cells of bacteria. However, filamentous fungi contain more than one nucleus (may be 100 nucleus per cell) and are highly resistant to radiation.

iv) Prion

The prion particles associated with BSE (Bovine spongiform encephalopathy), commonly known as mad cow disease, do not have nuclei at all. They are not inactivated by irradiation except at extremely high doses. This means irradiation will work very well to eliminate parasites and bacteria from food but will not work to eliminate viruses and prions.

8.5 EFFECT OF IRRADIATION ON INSECTS (QUARANTINE TREATMENT)

Of all the contaminating organisms to which food irradiation is directed, insects are the most complex. The number of insect species probably exceeds a million and around 500 are considered pests of major importance. Pests and their life stages vary in their sensitivity to radiation. The insects that are not immediately killed by radiation are rendered sterile and unable to reproduce. So, irradiation is most accurately called a Pest Control measure. Lethality is not always quarantine application; requirement can be met by using doses that effectively stop reproduction in insects.

Irradiation has marked advantages over chemical fumigants as:

- Irradiation does not leave harmful toxic residues unlike chemical fumigants/pesticides.
- Even at very low dose levels, radiation affects pests at all life stages. Even eggs can be eliminated by radiation unlike chemical fumigants.
- To control pests in stored grains, insecticides / pesticides may need to be applied repeatedly and thus, leading to higher levels of toxic residues. On the contrary, irradiation is one-time effective process.
- As quarantine treatment, irradiation brings two kinds of useful effects:
- Prevention of transfer of insects from one locality to another, as might occur in the shipment of infested foods. Such a transfer could lead to the establishment of the insects in a new area.
- Prevention of insect damage to foods.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Why viruses and prions are more radiation resistant than bacteria?

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2. What happens when living organisms are exposed to radiation?

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3. i) Name two vitamins which are radiation sensitive.

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ii) Name two vitamins which are radiation resistant.

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iii) What is D_{10}?

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4. Write True (T) or False (F) for the following statements:

   i) Gram +ve cocci are more radiation resistant in comparison to gram –ve bacteria.

   ii) Single strand breaks of DNA are more important in radiation exposure.

   iii) Protein get adversely affected when foods are irradiated at a dose of 10 kGy.

   iv) Irradiation can even eliminate eggs of pests present in food.

   v) Viruses and prions are easily killed by irradiation.

8.6 PRACTICAL APPLICATIONS OF FOOD IRRADIATION

The recommended doses of ionizing radiation for different purposes in food preservation are different as explained below

a) Low dose, up to 1 kGy

- Sprout inhibition in bulbs and tubers (0.03 – 0.15 kGy).
- Delay in fruit ripening (0.25 – 0.75 kGy).
- Insect dis-infestation and elimination of food-borne parasites (0.25 – 1 kGy).

b) Medium dose, 1 – 10 kGy

- Reduction of spoilage microbes to improve shelf-life of meat, poultry and sea foods under refrigeration (1.5 – 3 kGy).
- Elimination of pathogenic microbes in fresh and frozen meat, poultry & sea foods (3 – 7 kGy).
- Reduction of microbes in spices to improve hygiene (10 kGy).

c) High dose, 25 – 70 kGy

- Elimination of viruses.
- Sterilization of packaged meat, poultry and their products which are shelf stable without refrigeration (25 – 70 kGy).
- Sterilization of hospital diets for immuno compromised patients.
- Food for astronauts in space.

8.7 BENEFICIAL ASPECTS OF FOOD IRRADIATION

8.7.1 Decontamination of Spices

Spices, herbs and vegetable seasonings are valued for their distinctive flavours, colours and aromas. Unfortunately, they are often contaminated with high levels of bacteria, moulds and yeasts. If untreated, the spices will result in rapid spoilage of foods they are supposed to enhance. Since spices are often contaminated with pathogenic bacteria, they can result in serious food-borne illnesses.

Spices are generally decontaminated by irradiation or fumigation with ethylene oxide gas (ETO). To understand the advantages of irradiation over ETO, the various points are given below:

i) Effectiveness

Irradiation is considered the most effective way to sanitize spices and the most countries have allowed it worldwide. Irradiation at a dose between 7.5 – 15 kGy (average dose 10 kGy) has been established to effectively control the microbiological contamination. Storage further enhances the sanitation effect because injured cells are unable to repair and die out over the time.

In comparison, ETO is far less effective. Although, it is a known fact that ETO is highly toxic to microbial contaminants but, it cannot be used alone. To stabilize ETO, it is mixed with 80% CO_2 and steam is used to deliver the gases, which in turn, reduces its microbiological efficacy. Infact, steam increases the moisture level of treated spices and may result in increased mould growth. Moreover, ETO has low penetration than radiation and hence, bulk ground spices cannot be treated effectively using ETO.

Further, to meet the requirements of international standards, spices are generally treated twice or more with ETO and thus, can easily result into unacceptable high levels of toxic chemical residues in treated spices. On the contrary, irradiation is an effective one time process.

ii) Toxic residues

ETO reacts with organic spice components to leave harmful residues, like ethylene chlorohydrin and ethylene bromohydrin, in spices. Ethylene chlorohydrin is a known carcinogen that persists in the spices for many months, even after food processing. For this reason, ETO is banned in many countries. On the contrary, irradiation does not leave any harmful toxic residue and is completely safe.

iii) Loss of sensory attributes

The use of steam with ETO is a strong argument against its use as a spice treatment. Steam results in the loss of volatile oils and hence, loss of aroma and flavour. Treatment with ETO can also result in unacceptable colour change. It results into darkening of onion and garlic powder. Chilies, paprika and turmeric may loose their bright colour. It may cause development of off-flavours in mustard and mustard flour.

On the other hand, radiation treatment preserves all sensory attributes in spices. Chili, paprika and turmeric colours are stable to radiation treatment.

iv) Environment safety issues

Since ETO is a known carcinogen, worker safety issues are the biggest concern in ETO operations. Irradiation has been established as an environment friendly food processing technique.

v) Packaging problems

Most spice packaging materials are compatible with irradiation. Spices packed in bulk packages, retail packages, heat-sealed bags, and gas impervious packs, can be easily and effectively irradiated. Irradiation allows the spice package to remain closed and sealed at all times. On the other hand, in ETO treatment gas impervious packs cannot be used. Further, after treating with ETO, spice packages need to be stored open (for a week or so) gas escape. This causes increased warehousing cost as well as recontamination of spices. In irradiation, there is no waiting period after processing and the material can be shipped directly and thus, no additional storage costs are incurred.

So on the basis of above-mentioned facts, it is concluded that irradiation is the most effective method to sanitize spices, particularly because

- it results in cleaner, better quality spices,
- it does not significantly change the sensory or functional properties of spices,
- it results in much lower levels of microbial contamination and thus, it is an effective treatment to meet international standards of food safety.

A prototype commercial demonstration irradiator with a throughput of 20 tonnes per day for treatment of spices is operational in Vashi, Navi Mumbai. This is under the management of Board of Radiation and Isotope Technology (BRIT), a constituent unit of Deptt. of Atomic Energy (DAE), BARC, Mumbai. A commercial irradiator, Shriram Applied Radiation Centre (SARC), a constituent unit of Shriram Institute for Industrial Research, Delhi is also licensed by AERB to irradiate spices for sanitization.

8.7.2 Delayed Ripening in Fruits

Irradiation at low dose levels (0.25 to 0.75 kGy) can delay ripening and over-ripening in mature but unripe tropical fruits like banana, mango and papaya. Climacteric fruits exhibit delay in ripening only if irradiated in the preclimacteric stage. Once the ripening has been initiated, irradiation does not change or alter the course of ripening.

The self-life of irradiated fruits can further be extended by combing other post harvest procedures like waxing, packaging in perforated bags, refrigeration and modified atmosphere.

8.7.3 Sprout Inhibition in Tubers and Bulbs

Traditionally, onions are bulk stored under ambient conditions in chawls, medas or sheds, the size and design of which varies from region to region. During prolonged storage, losses occur due to sprouting, desiccation and microbial rottage. The estimated losses are 30–50 per cent. Low ambient temperature and high humidity during rainy season promote sprouting. The losses through microbial spoilage can be reduced but sprouting can’t be checked by improving ventilation. Sprouting alone causes 25–30 per cent of total losses. Sprouted onions shrivel faster due to increased water loss by transpiration. The reserve food substances present in the fleshy scales are also used up for the sprout growth, which ultimately renders the onion bulb unfit for consumption.

Some chemical sprout inhibitors such as maleic hydrazide and isopropyl carbamate are used in temperate countries but these are not very effective in sub-tropical and tropical climates. Cold storage at 0-1°C with low relative humidity (65-70%) is also practiced in many temperate countries but strict temperature and humidity control is must. Moreover, cold storage is energy intensive and expensive technique.

On the other hand, irradiation at very low dose levels (0.06-0.09kGy) inhibits sprouting when properly cured bulbs are irradiated within 2-3 weeks of harvesting.

Potatoes cannot be stored more than 4-6 weeks at ambient temperature. They are stored in cold storage at 2-4°C having relative humidity 85-95 per cent. Since the refrigeration facilities in India are not meeting the requirements of increased crop production, so it is feared that 25-30 per cent of the commodity is lost within 2-3 months of harvesting due to dehydration and microbial spoilage.

Irradiation of potatoes combined with refrigeration at 15°C can extend the storage period up to six months with minimum losses. Irradiation has extra benefit over prevailing refrigeration technique.

In general, irradiation at the dose levels required for sprout inhibition of bulbs and tubers does not change their texture, and external appearance, sensory qualities and processing potential.

The first prototype commercial demonstration irradiator for potatoes and onions (POTON) with a throughput of 10 tonnes/hour is being set up in Lasalgaon, Nashik, Maharashtra. This unit is under the management of Board of Radiation & Isotope Technology (BRIT), a constituent unit of Department of Atomic Energy (DAE), BARC, Mumbai. Besides, two pilot plant irradiation facilities, namely the Food Package Irradiator in Food Technology Division, BARC, Mumbai and another at the Defense Laboratory, Jodhpur have been licensed for irradiating food items that have been cleared for domestic trade and consumption.

Check Your Progress Exercise 3 ✍

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Describe two important beneficial applications of food irradiation.

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2. Write True (T) or False (F) for the following statements:

   i) To inhibit sprouting in tubers, a medium dose application is desired.

   ii) Medium dose irradiation can eliminate bacterial pathogens present in food products.

   iii) There is no commercial irradiator in India to process onions and potatoes.

3. Write two advantages of irradiation over ETO in decontamination of spices.

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8.8 LET US SUM UP

- Three types of ionizing radiations are approved for food irradiation.
- Any food commodity irradiated up to 10 kGy is wholesome and safe for human consumption.
- Bacteria, viruses and fungi differ in their sensitivities towards radiation.
- Foods are irradiated at different dose (low, medium and high) levels for different applications.
- Irradiation has benefits over chemical fumigants and other food preservation techniques.
- Irradiation is one time, safe, environment friendly and efficient technique.
- Irradiation can effectively address many issues like food safety, food losses and quarantine treatments. This is a very promising technique in the field of food preservation.
- All irradiated products are labelled with an international logo called ‘Radura’. It is also marked with statement “Processed by ionizing radiation” and purpose of Irradiation.

8.9 KEY WORDS

Irradiation : It is the process of preserving the food by ionizing gamma-rays, X-rays and electrons. It destroys the microorganisms and inhibits the biochemical changes.

Gamma-rays : Radioisotopes Co-60 or Ce-137 produce gamma (γ) rays. These rays are photons and have a deep penetration ability.

X-rays : These rays are photons, generated by X-rays machines, operate at an energy level of 5 MeV. They have less penetrative effect them r-rays.

Electron beams : They are fast moving electrons, produced in electron accelerators, operate at a maximum energy level of 10 MeV. They have selective application due to their poor penetration ability.

Mechanism of irradiation : The ionizing radiation preserve the food material by acting in two ways. The primary effect is through ejection of electrically charged or neutral radicals which destroy microorganisms. The secondary effect is ionization of water present in food by radiation. It helps in destruction of microorganism and inhibition of biochemical changes.

8.10 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answer should include the following points:

1. a) √ b) X c) √ d) X e) √

2. The three kinds of ionizing radiations are:

   Gamma rays, X-rays, and Electron beams.

   i) *Gamma rays* – These rays are produced from radio isotopes Co.60 or Ce-137. The gamma rays are photons and have a deep penetration ability. The energies emitted by Co-60 and Ce-137 are 1.33 and 0.67 million electron volts (MeV), respectively.

   ii) *X-rays* – These rays are generated from machine source and operate at an energy level of 5 MeV. These rays are photons and can penetrate through even whole cartons of food.

   iii) *Electron beams* – These are streams of very fast moving electrons produced in electron accelerators and operate at a maximum energy level of 10 MeV. Electron beams have a selective application in food irradiation due to their poor penetration, i.e., only one to one and a half inch deep into the food.

3. The preservative effect of ionizing radiation is due to primary and secondary effects resulting from interaction of radiations with molecules and microorganisms present in food.

The primary effect is due to the ejection of electrons with atoms and molecules present in food. The ejected electrons cause excitation of molecules present in food. The secondary effect of ionization radiation is to excite and ionize water and other molecules, present in food, which in term give rise to excitation, ionization and free radicals.

Check Your Progress Exercise 2

Your answer should include the following points:

1. Since viruses and prions do not contain cytoplasm and metabolic enzymes needed for growth, they are more resistant to irradiation in comparison to bacteria.

2. When living organisms are exposed to radiation structural and functional changes in macromolecules take place which result in cell injury or even death.

3. i) Vitamins A and E.
   ii) Vitamins C and D.
   iii) D_{10} is the irradiation dose required to kill the 90 per cent population of microorganisms present in food.

4. i) T ii) F iii) F iv) T v) F

Check Your Progress Exercise 3

Your answer should include the following points:

1. The two important beneficial applications of irradiation are:

   i) it delays ripening in fruits
   ii) it inhibits sprouting in tubers and bulbs

2. i) F ii) T iii) F

3. The advantages of irradiation are:
   i) It is more effective.
   ii) It does not leave any toxic residues.
   iii) Sensory quality is not affected.
   iv) It is more safe as compared to ETO.
   v) Irradiated food is easy to pack.

8.11 SOME USEFUL BOOKS

1. Food and Drug Administration (HHS) (1997) Irradiation in the Production, Processing and Handling of Food. Final Rule Federal Register, 62, p.64107, & Federal Register 55, p. 18538.

2. Joint FAO/IAEA/WHO study group in High Dose Irradiation (1999) High Dose Irradiation: Wholesomeness of food irradiated with doses above 10 kGy. WHO technical report series 890. World Health Organization, Geneva.

3. Marsden, J.L. (1994) Issue: Irradiation and food safety. American Meat Institute Issues Briefings.

UNIT 10 UTILIZATION OF FRUITS AND VEGETABLES PROCESSING WASTES FOR FOOD, FEED, FUEL AND INDUSTRIAL PRODUCTS

Structure

10.0 OBJECTIVES

After reading this unit, you should be able to:

- list various types of fruit and vegetable by-products and processing wastes;
- evaluate quantity of important wastes and their qualitative composition;
- describe the major value added products obtainable from processing wastes;
- transform the fruit and vegetable wastes into value added products for food, feed , fuel and industry;
- develop value added products from fruit and vegetable wastes by fermentation process; and
- define the fruit and vegetable waste water processing techniques and the products developed from waste water.

10.1 INTRODUCTION

You already know that India is one of the largest producer of fruits and vegetables. Fruits are consumed mostly raw and fresh, while the vegetables are usually consumed after cooking. We also know that fruits and vegetables are more prone to spoilage. This spoilage occurs at the time of harvesting, handling, transportation, storage, marketing and processing.

Fruits and vegetables are rich source of vitamins, carbohydrates and minerals and even the inedible portion is rich in nutrients. In most of the countries up to 80 per cent of the total production of fruits and vegetables are processed. However, in India, only around 2 per cent of the total production is processed and that too mostly at cottage and small scale. At present there are more than 4000 processing units with a turn over of more than 8.0 lakh tones of fruit and vegetable products. The processing waste generated by these factories is either gifted away or it is allowed to add to the environmental pollution.

The processing waste can be categorized into solid or liquid wastes. Solid wastes comprise of peels, skins, fragments, pits, spillage, trimmings, cores, fibre and seeds. Liquid wastes include mainly the wash water coming out of factory after processing operations like raw material washing, container washing, blanching, sterilization, cooling and plant and machinery clean up.

We do not have organized method of waste collection and its handling and utilization. Most of the solid waste is dumped or used as landfills. A part of the solid waste is also utilized for cattle feed and manure. Some of the processing units discharge the liquid waste in municipal sewage system. If we do not attend to these wastes, they become a source of pollution and contamination. If we attend to these wastes in scientific manner these can become a rich source of vital constituents like carbohydrates, proteins, fats, minerals, natural colours, pectin, oils, biogas fuel, etc. Efficient disposal and recycling of these by products and wastes will also provide pollution free environment and vital constituents to our foods, feeds and industries. Besides, utilization of waste for by products development will economise the cost of processed products.

In this unit you will learn about various types of fruit and vegetable wastes, their sources of availability and their utilization for food, feed, fuel and industrial raw material.

10.2 FRUITS AND VEGETABLES WASTES

When we process the fruits and vegetables for juices, squashes, jams, jellies, canning and other products, we get large quantities of left over materials. These are called solid wastes. During processing fruits and vegetables produce different kinds of waste material which are described below:

i) Fruit wastes

a) peel, rag, pulp and seeds in citrus
b) peel, stones, and pulper waste in mango
c) rind and seeds in jack fruit
d) peel, core, seeds in guava
e) seeds, and skins in grape
f) pomace of apple
g) apricot kernel, shell and skin
h) peel, core, trimmings, shreds and leaves of pineapple
i) peel, pseudo stem, leaves of banana
j) over ripe and blemished fruits
k) cull fruits and unmarketable surplus

ii) Vegetable wastes

a) tomato seeds, skins and trimmings
b) asparagus wastes from canning
c) vines and pods from pea canning
d) wastes from dryers
e) peel and cores solids of potato

10.3 BY-PRODUCTS FROM FRUIT AND VEGETABLE WASTES

The solid waste obtained from processing of fruits and vegetables is not really a waste but sometimes is an asset. A number of by-products may be obtained from the waste. Some by-products are extracted chemically while others are prepared by using the waste as such (Table 10.1). Here, we will discuss some of the important products prepared / obtained from solid waste.

i) Fat

Mango processing ends up in considerable proportion of peel and stones. On an average stone content in mango is about 15 per cent. India produces around 21 lakh tonnes mango stones or 16 lakh tonnes kernels. The kernel is obtained by decorticating the seed. The estimated fat content in mango kernel is more than 10 per cent. If we can collect and process half of the stones, India can produce about 80,000 tonnes mango fat.

ii) Magaz

Magaz is a seed kernel. You can obtain magaz by decorticating the seeds of cucumber, pumpkin, water melon, musk melon, etc. These have a big market in confectionary, bakery, ice creams and beverages. Apricot kernel is sweet in taste. It looks like almond. It is used in confectionery along with almond. It is also used to improve the appearance of apricot jam. Magaz production can be a good house hold industry.

iii) Starch

Mango kernel obtained after decorticating the seed and banana pseudo stem are good sources of starch. Banana plants provide about 5 per cent edible starch. You will be happy to know that presently more than 1,40,000 tonnes of starch is available from mango seed kernel and 4-5 tonnes starch per thousand banana plants is available.

iv) Tutti-Frutti

The papain extracted papaya and water melon rind after removal of green portion are most suited for the production of tutti-frutti. For this the raw material is needed to cut into small cubes and dipped in sugar syrup. You can give any colour to the syrup of your choice. The tutti-frutti is used in cakes, ice cream, bakery products, etc.

v) Amchur / pickle

Large quantities of dropped green mangoes are available in orchards after dust and thunder-storms. These dropped mangoes may be used for the preparation of pickles, amchur and raw mango slices.

vi) Food grade flavours

Citrus is a good source of flavour. It is a by-product from shaved citrus peel. You can obtain the shaved peel by shaving the spongy albedo layer of the peel and then the flavour is extracted. The flavour life is enhanced by encapsulation so it is adopted to keep the citrus oil-based flavours safe.

vii) Chutney

You can utilize fresh apple pomace, grape pomace, mango and tomato wastes to prepare chutney of various tastes and colours.

viii) Edible oil

You can obtain edible oil from apricot kernel, grape seed and citrus seed. Apricot oil and kernel paste are used like almond oil and paste in cosmetics and pharmaceutical preparations. Grape oil is used to produce grape resins of lustrous appearance. Tomato seed oil is golden in colour. It is used as salad oil.

ix) Cheese and halwa

Guava core, seeds and peel are utilized for the preparation of cheese and halwa. There are certain varieties of banana which have thick peel. The pulpy portion from the thick peel is scraped and used to make cheese.

x) Flour and fortified atta

You can prepare flour of jack fruit seeds, mango kernel and residues left after extracting juice or the unmarketable surplus of fruits like anola and jamun, and vegetables like carrot, radish, spinach, tomato, bitter gourd, etc., by drying and powdering. The flour may be blended with cereal flour. This powder can be mixed with the wheat flour in 1.5 to 3.0 proportions. This flour contains 5.56-11.5 per cent protein, 16.1 per cent fat, 0.35 per cent minerals and 69.2 per cent carbohydrate. You can market it as a health protective flour.

xi) Jam and jelly

You can use apple pomace to make jelly. The thick rind and inner perigones of jack fruit is also used for preparation of high class jelly. White apricot kernel is added to apricot jam to make it more attractive.

xii) Marmalade

You know that marmalade is prepared from citrus peel. The process involves washing of fruit peel, slicing or comminuting the peel, boiling to tenderize and remove bitterness, cooking with sugar or fruit syrup, and adding pectin.

xiii) Candied peel

You can prepare candied peel from orange or grape fruit peel. The primary use is in baking, where candied peel is a condiment used for flavour, appearance, and texture in products like fruitcakes. The peels are cooked to tenderize, remove bitterness and undesirable flavours, drain and dice. The diced peel is equilibrated and cooked in sugar syrup and food dyes are added. The final product is drained, air dried and packaged in polyethylene containers after coating with fine dust of corn starch.

xiv) Citrus purées and bases

You can utilize citrus pulp and unconsumed fruits to manufacture purees and bases. Preparation generally involves grinding, pasteurizing, addition of pectinase to reduce viscosity, comminuting to make a paste of smooth puree, followed by sieving to remove broken seed hulls and non-disintegrated particles. Different preparations are used for different product base purees.

Table 10.1: Possible by-products from solid wastes in fruit processing units

Fruit / vegetable	Waste (%)	Nature of waste	By-products
Apple	20-30	*Pomace*	Juice, wine, vinegar, pectin cattle feed
Citrus Orange	50	Peel, seeds, pulp	Essential oil, pectin, cattle feed, peel candy, pulp wash etc
Lime	60	Peel, seeds, pulp	Essential oil, pectin, cattle feed, peel candy, etc
Mango	40-60	Peel, Stones, Pulper waste	Pectin, cattle feed, alcohol, fat, starch, tannins, vinegar
Mango peels	12-15	Peel and pulp	Pectin, alcohol, cattle feed
Mango pulper waste	5-10	Fibre	Wine, vinegar, juice
Mango Kernels	15-20	Hull & Kernel	fat, tannins, starch
Pine-apple	30-60	Peel, leaves, core, trimmings, shreads	Brome line, cattle feed, biogas, fiber
Tomato	20-30	Core, peels and seeds	Cattle feed, seed oil and meal
Potato	10-11	Peel and coarse solid	Cattle feed, single cell protein
Banana	20-30	Peel	Poultry and cattle feed
Banana	20-25	Pseudo stem	5% starch
Banana dry leave	20-25 /plant	Dry leave	Cups and Trays
Banana	20-25/plant	Green leave	To serve meals

10.4 INDUSTRIAL PRODUCTS FROM FRUIT AND VEGETABLE WASTES

Apart from utilizing the solid waste for preparation of some products as discussed above, it could also be used for the preparation of some industrial products. Some of these products are described below:

i) Industrial oil

Cashew shell contains about 20 per cent oil and resin. You can use this oil for insulation of electric wiring, break lining and preparing foundry moulds and cores. In many countries cashew shell is finding better place than the cashew nuts. Other sources of sweet and bitter oil are the waste of wild apricots (*chulli*), peach kernels, citrus seed and tomato seed. These oils are used in cosmetics and pharmaceutical, and after refining in food items.

ii) Pectin

Pectin is a by-product of mango and citrus peel, apple pomace, raw papaya, cashew apple, etc. Pectin is used for making jam, pharmaceutical preparations and industrial uses.

iii) Essential oil

Do you know that citrus wastes are a rich source of essential oil? You can extract peel oil in small- scale unit. For such unit you can get fresh peel from fresh-juice vending stands. There are two systems of oil extraction. One, cold pressing and second steam distillation. You can choose any one of these. The current production potential of essential oil is more than 15,000 tonnes per annum.

iv) Natural colour

You know that coaltar dyes have carcinogenic effects. Therefore, it is better to replace them as rapidly as possible the herbal or natural colours. Industries are now extracting colours from blue grape skins, kokum (*Garcinia indica*), phalsa (*Grewia subinaequalis*), jamun, safflower, etc. Methods are also available to produce colour concentrates and powders.

v) Cups and plates

A banana plant contains 20-25 green leaves. Farmers harvest banana along with the plant. The green and dried leaves are used to prepare disposable cups and plates to serve meals.

vi) Other industrial uses

Beside the products described above, there are numerous other items which can be prepared from the fruit and vegetable wastes. The few important ones are:

- Citric acid from lemon peel
- Varnish and resin from tomato peel
- Surfactantants, wetting agents and detergents from tomato seed meal
- Citrus seed and mango kernel oils for soaps and detergents
- Glucosides and bioflavins anti-oxidants from citrus peel
- Papaya latex for proteolytic enzyme papain
- Paper pulp from banana stem
- Fibre from pineapple leaves, mango peel and apple pomace

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the principal fruit and vegetable wastes?

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2. Name the important value added food products, which you can produce from the wastes of fruits and vegetables.

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3. What are the industrial products manufactured from fruit and vegetable wastes?

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4. Give one major source for the following products:

   Fat --- ; Starch ---; Magaz --- ; Natural colour ---; Essential oil ---; Amchur ---; Cheese ---; Health Flour ---%.

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10.5 ANIMAL FEED FROM WASTES

We know that wastes and by-products obtainable from fruits and vegetables are a good source of cattle and poultry feed. Let us know how to utilize the major wastes for feed.

i) Citrus wet peel

Citrus peel contains 6% protein, 5% fat, 12% crude fibre, 7% ash and about 60% nitrogen-free extract. Wet peel contains 70-90% moisture. Wet peel or fresh peel is consumed by the animals directly. This practice is feasible only in the close vicinity of peel availability. Life of wet peel is very short due to rapid decay and sap leakage through transport trailer. It is transportable to only short distances. You can overcome this problem by pressing the wet peel where about 10% moisture is removed. This is called press liquor. Before pressing, you must treat the peel by lime. Storability and transportability of lime treated pressed peel is more as compared to wet peel.

ii) Citrus dried peel

Dried citrus peel is the most common form of animal feed. Before drying, peel is shreded and treated with 0.2 per cent lime. The lime aids in breaking down the pectin and in turn releasing the pectin-bond moisture. The peel is then pressed to remove the moisture. The peel is dried mechanically or in the sun. Process the dry peel into pellets or powder bran. You can use citric molasses as a binding agent. Pellets are easy to feed, easy to store and easy to handle and transport.

iii) Skin, core, trimmings, shreds and leaves

Skin, core, trimmings, seeds, shreds, leaves and pomace make a good cattle feed. One can feed them directly to the animals or dry for future use in various forms. You can also ensile them with rice/wheat straw or with stovers of millets and maize in 1:10 proportion with 1 per cent molasses and 0.2 per cent urea.

iv) Wet pineapple bran

The pineapple skin and ends are the major source of pineapple bran. The process involves maceration of the material and pressing. The pressed material is called wet pineapple bran. In this state it is easier to handle and store for short duration.

v) Dry pineapple bran

It is dried form of wet bran. The dried stuff is easy to handle, store and transport. The citrus peel, pomace of different fruits, residues of vegetables and pineapple bran can be dried in sun, polyhouse or rotary drier. The pineapple press liquor has about the same composition as pineapple juice. It can be concentrated and mixed with bran. You can sell such bran in market as concentrate feed for animal.

vi) Poultry feed

You can prepare quality poultry feed from banana peel, mango seed kernel, dried mango peel and citrus and tomato seeds. The dried peel is milled and used as poultry feed. Citrus seed meal contains 32.5 per cent protein, 7.5 per cent fat and 8.0% crude fibre. Tomato seed meal contains 37 per cent protein. It is energy food for poultry feed. Similarly, apricot kernel oil cake is also rich in protein.

vii) Tomato waste

Tomato waste is available in the form of peel, seed and pomace. After extracting varnish from peel and oil from seed, you get marc or solids. This amounts to 12.4% of fresh tomatoes. The marc contains 8-10 per cent protein and 10-12 per cent fat. Therefore, it is a good source of cattle feed.

viii) Molasses

The extract of mango and citrus waste such as peel, peel juice, pomace and trimmings is raw material to produce feed grade molasses. You can either feed it to the animals in liquid form or convert it into molasses. The waste is collected and lime is added to raise the pH. A reaction time of about 18 minutes is given in the mixing tank. The mixture is pressed and the press liquor is collected in a tank. The residue left after extraction of press liquor is dried. The press liquor is concentrated into molasses by evaporating the liquor to a brix value of 72.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. List the important fruit and vegetable wastes used for manufacture of cattle feed.

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2. List the fruit and vegetable wastes used for poultry feed.

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3. What is pineapple bran? Describe the technique of preparing wet and dry pineapple bran.

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4. What is molasses? What are the raw materials for molasses?

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10.6 PULP WASH, RECOVERY AND UTILIZATION

i) Pulp washing process

During the process of juice extraction you get pulp and pulpy juice as by-products. Scientifically they are called Water Extracted Soluble Fruit Solids (WESFS) or Washed Pulp Solids. For efficient extraction, you can use four-staged countercurrent pulp washing system. Each stage has screw type mixing device. The pulp put into the process at stage-1 exits at stage –4 as spent pulp. Pure water enters at stage-4 and exits at stage-1 as the pulp wash or strong liquor. The average Brix value of orange pulp wash are in the range of 4-7°Brix. The spent pulp goes for feed. The pulp wash is either concentrated or combined with juice which goes for concentration.

Towards the end of fruit season, soluble pectin in the pulp wash increases. This happens especially in grape fruits. The soluble pectin increases viscosity of the strong liquor which retards the concentration process of strong liquor. You can use pectinolytic enzymes to overcome this problem. This enzyme facilitates in viscosity reduction. Manufacturers of juice, beverages and drink products use pulp wash concentrate. This adds fruit solids and natural cloudiness to juice and beverages. This is also cheaper than juice concentrate.

ii) Juice pulp recovery

During juice recovery, the juice contains part of ruptured juice vesicles or floating pulp. This pulp is recovered as a by-product. The juice first goes to a paddle finisher to remove seeds and rag. Then the pulpy juice passes to a conical cyclone separator, called hydrocylone, to remove the embryonic seeds and other defects. The pulpy juice comes out at the top of the hydrocyclone and goes to pasteurizer and again to finisher (screen) for separation of pulp and juice.

This pulp is used for blending in juice concentrates. It adds texture, body and pulpy character to the reconstituted juices or drinks.

iii) Whole juice sacks or edible tissue

The dried juice sack is a by-product of juice from grape fruits and lemons. It has application in number of food products. It is a functional food ingredient. It imparts textural properties. It increases the water binding and retention property of products. The dried juice sacs hydrate readily. It can mute flavour in some food products. The potential uses are: to provide pulp for dry beverages mixes, to provide thickening or gelling in jams, sauces, fibre breads, cake, cookies and cereals.

To separate out the sacks, you need to peel and sectionize the fruit. Now carry out vigorous agitating and rinsing. The sacks start floating in the mixture which recovered by passing the mixture over a vibrating screen. Now dry the sacks carefully in the poly house or mechanical drier.

iv) Peel fiber

Considerable interest has been generated recently in using the fibre in human diet. It is a by-product left after pectin recovery from peel of many fruits like citrus, apple, mango, etc. The pectin free dried peel contains about 60 per cent dietary fibre. This fibre ranks with cereal bran in importance. The manufacturing process involves chopping the residue into small pieces, reacting with calcium hydroxide, pressing to remove soluble sugars and water, blending with sesame flour, dehydration to 8 per cent moisture, and milling to an acceptable small particle size.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are pulp wash and pulp wash solids?

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2. What is juice pulp and how is it used?

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3. What are juice sacks? How can you utilize these sacks?

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10.7 FERMENTATIVE UTILIZATION OF FRUIT AND VEGETABLE WASTE

It is already clear to us that wastes from fruits and vegetables processing industries are valuable natural resources for many products. They have enormous economic potential. We can make a number of value-added products from these wastes. Principally the waste include water and organic substances. The organic substances are simple and complex polysaccharides (sugars, starch, pectin, etc.), vitamins and minerals. Utilization of the wastewater has been discussed under Unit 10.8. Here we will deal with the conversion of organic substances into value-added products through microbial fermentation technology.

The value added products obtainable from fruit and vegetable wastes are:

i) Fermented edible products
ii) Single cell protein
iii) Animal feed
iv) Ethanol
v) Enzyme
vi) Food additives
vii) Organic compounds
viii) Biogas

i) Fermentable edible products

You can prepare a number of beverages such as cider, beer, wine and brandy, and vinegar by fermentation of fruit wastes.

Cider: Dried, culled, undersized, substandard and unmarketable surplus of apples, grapes, oranges, pineapple and their by-products such as pomace are suitable for cider making. Cider is obtained by combining the distillates from fermented pomace with fermented juice. It contains 1 to 8 per cent alcohol, 4 per cent acetic acid, 5 ppm Cu, 10 ppm Fe, and 1 ppm Pb.

Vinegar: You can use mango peel and stones to prepare mango vinegar. We know that fermentable sugars adhere to the fruit processing waste. It is an ideal substrate for fermentation. The alcoholic level in this fermentation remains between 2.5 to 3.5 per cent. This quantity is not sufficient for alcoholic fermentation. Therefore, you need to raise this level by conducting secondary fermentation or by adding cane sugar. The batch type process takes 3-12 days for completion. You can produce mango vinegar by recycling of *Saccharomyces cerevisiae* and immobilized *Acetobacter aceti.* The good quality vinegar will have 5.3 per cent acetic acid, light yellow colour and pleasant flavour. Similarly, we can prepare vinegar from the substandard and unmarketable fruits of plum, pineapple, banana, etc.

ii) Single cell proteins (SCP)

SCP is a non-conventional source of protein. Microbial growth and microbial biomass are the basis for SCP. A number of organisms like yeast, fungi, algae and bacteria are employed for the production of SCP on different kind of substrates (Table 10.2). You can use SCP as protein supplement for food and feed.

Table 10.2: Different substrates and microorganisms to produce SCP

Name of substrate	Microorganism used	Effect on protein content or BOD
Pectin extracted apple pomace	*Trichoderma viride,* *Aspergillus niger* *Candida utilis*	35% content protein
Grape waste and pressed apple pulp	*Aspergillus niger*	35% content protein
Pineapple waste and citrus peel	*Fusarium*	35% content protein
Cassava waste	*Aspergillus niger* *Endomycopsis fibuliger* *Candida utilis* *Aspergillus tomari*	20-22.5% content protein
Molasses	*Saccharomyces cerevisiae* *Torulopsis utilis*	40-47% content protein
Potato peels and wastes from grape and orange	*Pliorotus astreatus* *S. fibuliger* *C. utilis*	31.6% content protein
Sweet potato waste	*fungi imperfecti*	31.6% content protein

The different wastes support the growth of different microorganisms. The microorganisms use these substances as starting materials for fermentation and SCP production by assimilation.

iii) Animal feed

The wastes obtained from processing of fruits and vegetables are rich in fibre but poor in protein content. Owing to their low protein content and low digestibility, these are poor sources of animal feed. You can increase the feed value of these waste materials through substrate fermentation technique. The various substrates and microorganisms employed for preparation of animal feed are given in the Table 10.2.

iv) Ethanol

You can produce ethanol from wastes of fruit and vegetable processing industries. These wastes are rich in cellulose, hemi cellulose and lignins. Solid-state fermentation (SSF) technique is useful to produce ethanol. The ethanol has several uses such as liquid fuel or liquid fuel supplement or solvent for many industries. Apple pomace, cherry wastes, citrus wastes, etc., can produce ethanol by employing *Saccharomyces cerevisiae, Candia utilis* and *Torula* for apple pomace, *S. cerevisiae* for citrus waste, and *E. coli* and *Klebsiella oxyloca* for lignocellulosic wastes.

v) Enzyme

Submerged fermentation (SF) and solid-state fermentation (SSF) techniques are useful for enzyme production. Food production industries have wider application of various enzymes. Different enzymes can be produced by fermenting different wastes of fruits and vegetables. For this you need different types of microorganisms. To produce cellulase and xylanase enzymes from apple pomace you need *T. viridae and Aspergillus spp* as microorganisms. Similarly to produce cellulase, xylanase and ligninase from grape wine waste you need *Cerrena unicolor.*

vi) Food additives

Brewery wastes, apple pomace, pineapple residues, molasses, sweet potato residue, mandarine orange wastes, grape pomace, etc., are potential sources for citric acid production. Industries utilize solid-state fermentation (SSF) technique to produce citric acid on commercial scale. They use microorganisms *Aspergillus niger* for SSF.

You can also produce pectin by growing microorganisms on wastes. *Trichosporon penicilliatum* is the most common microorganism grown over citrus peel for production of pectin. This pectin has high level of neutral sugar and molecular weight.

The use of colours to the food is an ancient practice. Earlier people used natural colours. But now, people turned to the coal tar dyes. These synthetic colours adversely effect our health. On the other hand, the microbial colours have anti- neoplastic activity. Therefore, encouragement is being given to produce microbial colours from the wastes of fruits and vegetables. Microorganisms like *Rhodotorula, Cruptococcus, Phoffia rhodozyma, Monoascus purpureus* and *Bacillus spp* are known to produce pigments through fermentation techniques.

Wastes available from fruits and vegetables are the cheapest renewable sources to produce flavours and gums. Microorganisms can produce specific flavours and aromas like fruity, spicy, *pyrazines*, *terpenes*, *lactones* and esters. Microbial enzymes like *lipase* are used to generate flavours. Similarly, microorganisms can also produce microbial gums like xanthan. *Xanthamonas compestris* are employed to produce xanthan from cabbage and citrus wastes.

vii) Organic compounds

The organic compounds like butamol, acetone, citric acid, lactic acid and acetic acid are produced through microbial fermentation of wastes molasses. 2, 3-butylenes glycol can be produced by fermenting citrus peel juice and citrus waste after adding molasses.

viii) Biogas

Biogas is an important by-product prepared from numerous agricultural wastes. Fruit and vegetable processing waste is rich in biodegradable substances and can be used for the production of biogas. It is produced by anaerobic digestion of the waste. Methanotropic bacteria like *Methanobacterium* and *Methanococus* spp have the ability to utilize CO_2 from these wastes to produce methane – a biogas. Sometimes, pretreatment of the wastes is useful for higher methane production.

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the important value added products you can obtain through microbial fermentation of fruit and vegetable wastes?

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2. Describe briefly the process to produce vinegar.

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3. What is single cell protein (SCP)? To what extent SCP can increase the protein content? List 7 microorganisms used to produce SCP.

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4. What is microbial pigment?

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10.8 FRUIT AND VEGETABLES PROCESSING WASTEWATER TREATMENT AND UTILIZATION

You know that the fruit and vegetable processing industries generate a lot of waste water containing organic material. This waste has high Biological

Oxygen Demand (BOD). BOD is the measured amount of oxygen required by acclimated micro-organism to biologically degrade the organic matter in the waste water to CO_2 and H_2O in a closed system. Oxygen consumed or BOD is proportional to the organic matter converted. If you discharge this waste in the natural water stream without treatment, it will deplete the dissolved oxygen. As a result of this the fish and other biological life in water will parish. The stream water will also become unfit for any domestic use.

The major characteristics of wastewater are pH, total suspended solids (TSS), BOD, oil and grease and nutrients (nitrogen and phosphorous) available for bacterial growth. The quantitative characteristics of some selected fruit and vegetable processing industries are given in the Tables 10.3 and 10.4 below.

Table 10.3: Wastewater characteristics from some selected fruit and vegetable processing industries

Fruit/Vegetable processed	Wastewater (kg / tonne of raw product)	BOD (kg / tonne of raw product)	TSS (kg / tonne of raw product)
Apple	10	09.0	02.2
Apricots	23	20.0	04.9
Dry beans	37	30.0	21.0
Beets	11	26.5	11.0
Carrot	14	15.0	03.5
Cauliflower	71	8.0	03.0
Mushrooms	33	7.0	03.6
Olives	34	13.5	13.0
Peaches	13	17.5	04.3
Pears	15	25.0	-
Plums	10	05.0	01.0
Pickles	15	21.0	04.1
Potatoes/Sweet potato	09	46.5	28.1
Pumpkin	01.2	16.0	38.1

Table 10.4: Wastewater characteristics of some fruit juices

Type of juice production	pH range	BOD range (g/L)	COD range (g/L)
Apple	3.2-3.4	61.5-94.5	85.0-155.0
Orange	3.6-3.8	60.9-5.0	83.4-134.6
Pear	3.2-3.6	88.0-109.2	72.8-175.3
Apricot	3.5	105	194.0
Peach	3.2	100	174.2
Mixed	3.2	65	95.5
Banana	4.1	110	184.1
Grape, white	3.2	80.0-89.0	116.8
Grape, red	2.9	78.0-99.0	115.6

Vegetable	3.8	20.0	050.0

The wastewater from fruit and vegetable industry is not really a waste. It is a useful by-product or a resource material. You can recover the following useful materials from the wastewater as by-product.

- pectin from apple waste
- essences from citrus peels
- alcohol by solid state fermentation
- feed from pomace
- soup and chutney from mushroom wastes
- single cell protein from potato wastes

I. By-product recovery and treatments

The waste water contains oil and grease, suspended solids and organic load. The following steps are involved in recovery of the by-products from waste water.

a) *Screening or removal of solids*

You can remove the floating and suspended matter by passing the wastewater through 20-40 mesh stationery screen or vibrating gyro screens.

b) *Oil and grease removal*

Remove the oil and grease present in wastewater using the principle of density variation in water and oil. You can construct skimming tanks with baffle walls of 24 to 30 min retention capacity for this purpose.

c) *Primary clarification*

Primary clarification is also termed as primary settling. It separates the solids from liquid. The solid particles settle on bottom of tank under gravity. The clarifier is also equipped with oil and grease removal mechanism. It has peripheral drive mechanism for scrapping of sludge. About 50-60 per cent all the settleable solids can be removed by primary clarification. BOD is also reduced to the extent of 25 - 30 per cent.

d) *Aerobic biological treatment*

In this system dissolved starches, sugars and other carbohydrates are utilized by the micro organisms as food. In the process, more bacteria get generated and later get converted to waste bacterial solids. Proper conditions are maintained for bacterial growth through the supply of oxygen and nutrients.

e) *Activated sludge process*

The wastewater is first collected in primary settling tank where 50-60 percent of all settleable solids are separated. The clarified wastewater then flows into the aeration tank where more and more bacteria get generated. Thereafter, the wastewater flows into the secondary settling tank. A part of the activated sludge is returned to the outlet of primary settling tank. This hastens the multiplication of bacteria in the secondary tank. It is aerated in the aeration tank to keep on the bacteria multiplying. BOD removal efficiency of this process ranges between 80 to 85 percent.

f) *Trickling filter*

Trickling filter is a circular tank of about 1.8 m depth. Its width is designed on the basis of the quantity of wastewater. The tank is filled with 100-125 mm aggregates of stones or plastic balls. Wastewater is sprayed on the aggregates with a rotating arm. Microorganisms develop around the aggregates. A microbial film is formed on the surface of the aggregates. This film oxidizes the organic matter present in the wastewater. In this process you can get BOD reduction of 70 - 85 per cent.

g) *Aerated lagoons*

Aerated lagoons are simple wastewater holding basins of 2-4 m depth. The organic wastewater is degraded by aerobic microorganisms. Floating mechanical aerators are fitted for the supply of oxygen. A BOD reduction of 80-95 per cent can be achieved in this method in a retention period of 4-5 days.

h) *Waste stabilization ponds*

This is a natural process of wastewater treatment. The ponds are usually used where land is cheap and temperature is moderate. The pond depth is 0.9 to 1.5 m and area depends on the volume of the wastewater. The wastewater is treated and stabilized by a combination of aerobic, anaerobic and facultative bacteria. In a retention period of 10-40 days it can remove BOD from 80-95 per cent.

i) *Oxidation ditch*

It is an oval shaped closed channel of 1-1.5 m depth. Cage rotors are used for intensive aeration of the waste water. In retention period of 10- 40 days it can remove BOD from 80-95 per cent.

j) *Rotating biological contactors*

The system consists of concrete or steel tank through which the wastewater passes. The rotating biological contactors consist of polymeric material discs. These discs are closely spaced and mounted on a shaft. A drive motor rotates the shaft at a very slow speed of 2 - 3 rpm. The discs are submerged in wastewater tank. When the discs rotate, the wastewater passes through them continuously. The discs expose to wastewater and atmospheric oxygen alternatively. Like this a bio film develops on the disc's surface. In this process BOD reduction is achievable to the extent of 90 per cent.

k) *Activated biofilter process*

The activated bio filter is a biologically active column. It is made biologically active by the return sludge. High level concentrated suspended growth of microorganisms can be obtained in the filter. Achievable BOD removal is quite high in this filter.

l) Combined activated bio filter and activated sludge process

It is a combination of activated bio filter and aeration tank You can achieve best performance and economics by combining aerobic treatment process with activated bio filter. It is becoming popular due to higher organic loading rate, better BOD reduction and lower cost of construction.

II. Bio-energy production

You can utilize the wastewater obtainable from fruit and vegetable processing industries to produce bio-energy through anaerobic biological treatment.

Anaerobic biological treatment process proceeds in two steps. The first step is, degradation of organic matter or waste into volatile acids. In the second step, the volatile acids convert into methane gas. It is an improvement over the conventional anaerobic biological system which takes 30-60 days to complete the treatment process. The two-stage anaerobic reactor enhances energy production and reduces hydraulic retention time to 1-4 days. Layout of the system is shown in Figure 10.1.

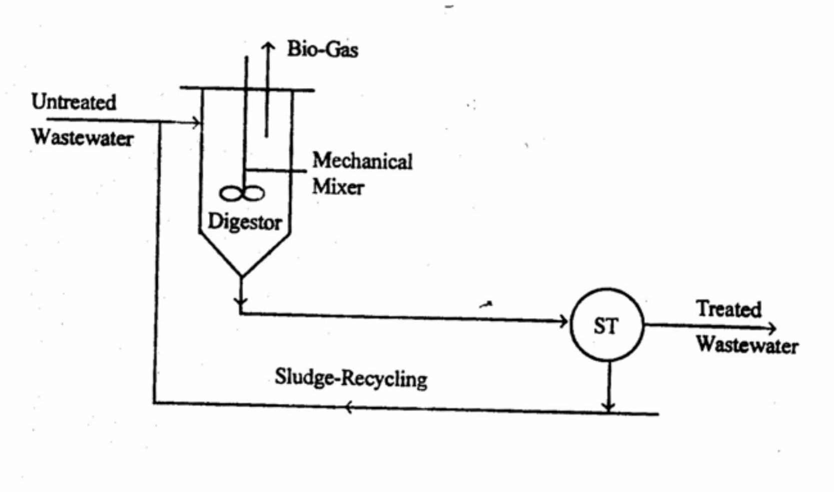

Figure 10.1: Anaerobic biological treatment

III. Utilization of organic solids for soil improvement

a) Solid waste from wastewater treatment plant

The secondary sludge obtained in these systems need drying. You can use sludge drying beds or the ground drying method. This can be used as a good quality compost for agricultural crops. You can palletize this organic waste for direct drilling along with the seeds for better production. Pelletization also helps in storage and economic transportation to distant places.

b) Land application

The wastewater after primary and secondary treatment becomes suitable for land application. You can use this water for irrigation.

c) Wet land application by macrophyte treatment

To utilize the treated wastewater artificial wet lands such as marshes and swamps are created. Floating plants, like water hyacinth, serve as mechanical filters. The wet land becomes useful to grow crops and aquatic species. Fish ponds can also be constructed for economic recovery.

Check Your Progress Exercise 5

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What is fruit and vegetable processing organic liquid waste? Why should it be treated before recycling / use?

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2. What are different methods of by-product recovery from waste water?

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3. Illustrate the method of bio-energy production from waste water.

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4. How can you utilize the solid wastes separated from wastewater? What is the advantage of pelletization.

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10.9 LET US SUM UP

The left over materials after processing of fruit and vegetables into various products are termed as waste. The waste is of two types, viz. solid and liquid. Solid wastes are peel, stone, seeds, trimmings, core, etc. Liquid waste is the wastewater coming out of the processing plant after washing, peeling, sterilizing, etc., of the food stuffs and the machinery.

The solid wastes could either be utilized as such, e.g., animal feed, or a number of by-products could be prepared. Through chemical extractions dietary fibre, pectin, pigments, etc. could be obtained. The microbial fermentation of waste could produce biogas, citric acid, vinegar, ethanol, enzymes, etc.

The wastewater from fruits and vegetable processing industries is a resource for many useful materials such as pectin, essences, alcohol, soup, feed, fuel, manure, etc. Treatment and utilization of wastewater is important both for environmental protection and economic returns. This wastewater has higher and immediate BOD because of the availability of soluble sugars which have a rapid rate of oxidation. The wastewater treatment strategy includes by-product recovery, screening for separation of solids, neutralization, oil and grease removal, equalization, and aerobic, anaerobic and combination of aerobic and anaerobic processes. The solid wastes can be palletized and used as manure.

10.10 KEY WORDS

Aerobic : Reaction or biological degradation in presence of air/oxygen.

Anaerobic : Reaction or biological degradation in absence of air/oxygen.

Activated sludge : Sludge with microbial activity.

Biogas	**:**	Microbial production of methane by *methanotropic* bacteria.
Biodegradable substances	**:**	The biomass convertible by microorganisms.
By-products	**:**	The products manufactured from the leftover materials obtained during processing of fruits and vegetables.
BOD	**:**	Biological oxygen demand measures amount of O_2 required by acclimated microorganism to degrade organic matter biologically.
Cloud	**:**	Unprecipitable suspension of the insoluble essential oils, pectins, lipids and proteins in juice.
Cider	**:**	A product obtained after fermentation of pomace.
COD	**:**	Chamical oxygen demand.
Dietary fibre	**:**	Insoluble hemi cellulose and cellulose, obtained from wastes.
Molasses	**:**	Concentrated form of pre treated juice.
Microbial pigment	**:**	The colour obtained by microbial fermentation of fruit and vegetable wastes is termed as microbial pigment.
Pulp wash	:	Residue obtained by washing the pulp.
Peel seasoning	**:**	Carefully cleaning and drying of peel at low temperature for maintaining the volatile oils.
Pulp wash concentrate	**:**	Evaporated juice or strong liquor up to 50-65°Brix.
Residue	**:**	Leftover materials during consumption and processing.
Single cell protein	**:**	It is microbial biomass used as food supplement.
Strong liquor	:	Liqour obtained during multi-stage extraction of pulp wash having TSS between 4-7°Brix.
Spent pulp	**:**	Residue of pulp wash after extracting strong liquor.
Wastes	**:**	The culled, undersized, disfigured, substandard, spoiled, injured, unmarketable surplus of fruits and vegetables and the leftover materials during by-products utilization including washing are termed as waste.
Whole juice cells	**:**	Juice containing vesicles or sacs.

10.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answer should include the following points:

1. - Wastes are of two types – solids and liquid.
   - Solid wastes are peel, pomace, seed trimmings, core, etc.
   - Liquid waste is the wastewater coming out of the factory after washing fruits, vegetables, machinery, etc.

2. Important food products are fat, starch, magaz, tutti-frutti, jam, jelly, marmalade, chutney, pickle, amchur, flavour, cheese, halwa, health flour, etc.

3. Important industrial products are oils, essential oils, pectin, colours, varnish, surfactants, fibre, glucosides, citric acid, paper pulp, etc.

4. Fat ---*Mango kernel* ; Starch---*Mango kernel;* .Magaz---*Musk melon;* Natural colour---*Blue grape skin;* Essential oil---*Citrus waste;* Amchur---Dropped m*ango;* Cheese---Guava waste; Health Flour---Jack fruit seeds.

Check Your Progress Exercise 2

Your answer should include the following points:

1. Important wastes are peel, pomace, seed, leaves, trimmings, core, etc.

2. Wastes such as banana peel, mango peel, mango seed kernel, citrus and tomato seeds are used as poultry feed.

3. Skin and ends of the pineapple constitute the bran. There are two types of pineapple bran, i.e., wet and dry.

   - The wet bran is prepared by macerating ends and skins and then pressing.
   - Mechanical and natural drying of bran constituents resulted in dry bran.

4. - Molasses is the concentrated form of pressed liquor obtained by treating waste with lime.
   - Raw materials used are peel, pomace, trimmings etc., obtained after processing of mango and citrus fruits.

Check Your Progress Exercise 3

Your answer should include the following points:

1. - The water washings of the pulp remained after juice extraction is known as pulp wash.
   - The solids extracted in the water wash are termed as pulp wash solids.

2. • Juice pulp is the ruptured juice vesicles or floating pulp obtained during juice recovery.
   • It is used for blending in juice concentrates.

3. • The juice sacks are the by-product obtained from the juice of grape fruit and lemon.
   • The juice sacks are dried and used in dry beverages mixes, jams, sauces, cookies, etc.

Check Your Progress Exercise 4

Your answer should include the following points:

1. The important products obtainable from organic waste substances from fruits and vegetable processing industries are single cell protein, animal feed, ethanol, enzyme, pigment, pectin, flavour, etc.

2. The vinegar can be produced from mango peel and stones by double fermentation. The TSS of these wastes is increased by adding came sugar and fermentation is done with *Saccharomyces cerevibial* and immobilized *Acetobacter acet*.

3. The protein supplement obtained from microbial growth and microbial biomass are called SCP. The protein content can be enhance and upto 35 per cent. The microorganisms used for SCP production are *Trichodemia uiride, A.niger, Candia utilis, Fusarium* sp, *A. tomari, S. cerevisiae, S. fibuliqer.*

4. The pigments that are produced through microbial fermentation on fruit and vegetable wastes are called microbial pigments. The microorganism like *Rhodotorula, Cruptococcus,* etc. are known to produce pigments.

Check Your Progress Exercise 5

Your answer should include the following points:

1. • The wastewater discharged from processing industries contain organic matter which have high BOD values.
   • If the waste is discharged without treatment it will deplete the dissolved oxygen.

2. • Screening or Removal of Solids
   • Oil and Grease Removal
   • *Primary Clarification*

3. • The process of bio-gas generation
   • Labelled sketch of the system and its working (10.1)

4. • The separated solid waste could be used as compost.
   • Palletization helps in storage and transportation.

10.12 SOME USEFUL BOOKS

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2. Kaushik, Vijay (2000) Food Science and Nutrition. Mangal Deep Publications, Jaipur.
3. Verma, L.R. and Joshi V.K. (2000) Post Harvest Technology of Fruits and Vegetables. Volume I and II Indus Publishing Company, New Delhi.
4. Wills, Ron, McGlasson, Barry, Graham, Dong and Joyce, Daryl (1998) UNSW Press, Australia.

UNIT 11 FOOD FORTIFICATION

Structure

11.0 OBJECTIVES

After reading this unit, you should be able to:

- list the advantages, limitations and risks in fortifying foods;
- describe the methods of food fortification;
- define the importance of fruits and vegetables in human diet;
- decide the points to be considered for fortification of fruit and vegetable products; and
- prepare fortified fruit and vegetable products.

11.1 INTRODUCTION

All living beings require nutrients to perform various functions of life. While plants can prepare them from simple chemicals present in the soil and the environment, higher organisms can not perform this synthesis and have to depend on plants and other animals for their nutritional requirements. Body performs several functions related to growth and development and it has to cope up with the normal wear and tear process. Several nutrients are required for promoting these activities which should be available in sufficient quantity. But no single food contains all the nutrients; their nature and quantity vary with the source. Improper diet may result in deficiency of one or more of these nutrients. Nutritional deficiencies reduce mental and physical efficiency of people and increase their susceptibility to diseases. It is for this reason the Indian Constitution enshrines in its Article 47 that “the state shall regard the raising of the level of nutrition --- as among its primary duties”. In this chapter we will see how fortification of fruits and vegetables could improve the nutritional status of people.

11.2 NECESSITY OF FOOD FORTIFICATION

11.2.1 Nutritional Requirements of Man

Human body requires at least 45 nutrients; 5 macronutrients (protein, fat, carbohydrate, water and oxygen) and 40 micronutrients, which include 13 vitamins (A, C, D, E, K and eight members of vitamin B group) and 17 minerals (Ca, Cl, Fe, K, Mg, Na, P, and S whose requirements are 1 µg to 1 g per day, and Cr, Co, Cu, F, I, Mn, Mo, Se, and Zn which are required in traces). Water and oxygen are not regarded as nutrients because they are present in foods and readily available for body use.

Nutrient requirements vary from person to person and are influenced by factors like age, sex, height, physiological state, physical activity and environmental conditions. No single food contains all 45 nutrients. Food items included in daily diet should be carefully selected so that the nutritional requirements are fulfilled.

11.2.2 Pattern of Food Consumption in India

In order to survive, man's main effort in ancient times was to collect enough food for his requirements and store them for difficult periods. But he soon realized that foods from different sources differ in nutritive value. Through experience over ages, he selected his foods carefully to meet his nutritional requirements and to ensure a good health. It led to the development of dietary habits. Food habits were also influenced by the foods available in the locality and practices prevalent among them.

Indian Council of Medical Research has divided the foods consumed in India into five groups: (1) cereals, grains and their products, (2) pulses and legumes, (3) fruits and vegetables, (4) milk, meat, egg and their products, and (5) fats and sugars. Cereals constitute major part of the Indian diet. Being rich in carbohydrates, they contribute up to 80 per cent of daily energy intake and about 50 per cent of daily protein intake of an average Indian. They are also dietary source of minerals like calcium, iron and vitamin B.

Pulses and legumes are the major source of proteins in the Indian diet. They are also rich in vitamin B.

Fats and oils and sugar/jaggery serve essentially as source of energy. They improve palatability of foods. Further, fats and oils provide essential fatty acids and act as carrier of fat soluble vitamins. For a good health, maximum of 20 per cent calorie requirements should be derived from fats and oils.

Milk holds a high place in the Indian diet. Milk proteins are of very good quality. It is rich in calcium and riboflavin and is a good source of many other nutrients. But it is deficient in iron and vitamin C.

Fruits and vegetables are rich in vitamin C, beta-carotene, crude fibre and minerals. In general, they are not regarded as a good source of calories and proteins; dried fruits, tree nuts, olives, avocado, beans and peas are some of the exceptions to this. Roots and tubers like potato, tapioca, yams, sweet potato, etc., contain substantial amount of starch and thus contribute substantially to the dietary calories.

Eggs and meat are good source of proteins and vitamins of group B. Their proteins are of very good quality. They are rich in calcium and riboflavin and are good source of many other nutrients.

11.2.3 Strategies to fulfil Nutritional Requirements

Inadequate and insufficient diet may result in deficiency of one or more of these nutrients. Often deficiency of one nutrient results in incomplete utilization of other nutrient(s) present in food. Nutritional deficiencies observed in India are: (i) protein-calorie malnutrition, (ii) vitamin A deficiency, (iii) iron deficiency, (iv) iodine deficiency, and (v) deficiency of vitamins of group B.

The challenge of nutritional deficiency can be overcome by increasing availability of nutrients through higher and diversified production of food and careful planning of diet. Diet planning becomes complicated because (i) foods differ in their nutrient composition, (ii) method of processing/preparation may cause losses, (iii) foods may suffer from certain deficiencies specific to a region such as iodine deficiency in Sub-Himalayan region, (iv) certain group of people may have special requirements of some of the nutrients, and (v) economic status of a group of people or population may limit the choice of food items. Further, all the nutrients present in a food may not be biologically available due to (i) the presence of anti-nutritional factors like trypsin inhibitor, (ii) their poor solubility, (iii) destruction of nutrients in the gastrointestinal tract, (iv) poor digestibility of a food source, or (v) varying degree of losses during preparation/processing.

Other methods of controlling malnutrition are (i) nutrition education, (ii) dietary diversification, (iii) dietary supplementation, and (iv) food fortification. Nutrition education and dietary diversification take long time to show results. Dietary supplementation is a very effective method but it is used in the cases of acute deficiencies in high-risk groups and is expensive. Food fortification is a simple and inexpensive method of fighting the problem of a nutritional deficiency prevalent in a known region or segment of population.

11.3 FOOD FORTIFICATION

The term food fortification is defined as a process of adding one or more dietary essentials to a food. Various terms are used to describe the process of addition of nutrients to foods which are discussed below.

i) **Enrichment:** This term is used for a process in which the level of one or more nutrients, already present in a food, is moderately increased by addition to make its level higher so that it becomes a richer source of that nutrient.

ii) **Fortification:** According to WHO fortification is the addition of nutrient(s) to a food or an article of diet to improve the quality of the diet of a group, community or a population. Level of nutrients added may be more than those found in original or comparable food. Objective of fortification is to help correct nutritional deficiencies in a specific population. Fortification may also include addition of small quantities of nutrient to improve intake of that nutrient by a population.

iii) Nutrification: It is a general term used to indicate the practice of adding vitamins and minerals to compounded and processed foods used as entire meals or meal-replacers, viz., infant formulas, instant breakfast foods etc.

iv) Restoration: Loss of some of the nutrients takes place during handling, transport, processing and storage of foods which can not be prevented. Restoration refers to the replacement of the nutrients lost during the above processes.

v) Standardization: There may be natural or seasonal variations in the nutrient composition of foods. The term standardization refers to the process of adding nutrients to compensate for the above variations and bring them to a predetermined level. It is helpful in meeting the requirements of nutritional labelling.

vi) Supplementation: This term refers to the process in which nutrients not present normally or contained only in very small quantities in a food, are added to it.

The above terms are often used interchangeably. Fortification is now a general term used to indicate addition of nutrients to improve nutritional quality of foods.

11.3.1 History of Food Fortification

Probably the earliest recorded attempt of fortification is of 4000 B.C. when the Persian physician Melamus prescribed a diet including sweet wine laced with iron filings for the sailors. In 1833 a French chemist Boussingault advocated addition of iodine to table salt to prevent goiter in South America and thus may have introduced the concept of "food fortification". Another important observation was made in 1897 when Dutch army doctor Eijkman while working in Indonesia, noted that beriberi was more common in people whose staple diet was polished rice. Vedder and Williams used a crude extract from rice bran, to cure advanced cases of beriberi despite the fact that they were unaware of its active constituent. In 1911, Funk established that the anti-beriberi compound of unpolished rice was an amine. He named this compound as vitamine, i.e., vital amine. Williams continued his work in Philippines and synthesized it. Since this amine contained sulphur, he named it as thiamine, i.e., sulphur amine. A Swiss company, Hoffman-Roche developed a process for adding thiamine, niacin and iron to rice.

Introduction of margarine, a butter substitute, in Denmark led to vitamin A deficiency. Therefore, fortification of margarine with vitamin A was started in 1918. Fortification of flour with thiamine, riboflavin, and niacin and sometimes iron and calcium was started in the United Stated of America during World War II. Addition of vitamin D to infant formulations and milk and dairy products to prevent rickets among children are other examples of early efforts of food fortification.

In India, fortification of salt with lysine, iron and vitamin A was tried in 1970. At present, several food products available in Indian market are fortified, viz., common salt is being fortified with iodine salts, vanaspati with vitamins A and D and bread with lysine. For fortification of salt with iodine, potassium and sodium salts of iodide and iodates are used. They are added at the rate of 30-200 mg per kilogram of salt, depending on the amount of salt consumed per day by a population. In India, salt consumption is 15 gm per day per person. Therefore, potassium iodate is added at the rate of 15 mg per kilogram of salt.

11.3.2 Advantages of Fortification

Food fortification does not require people to change their dietary habits and it does not alter organoleptic qualities of foods. Therefore, it is socially acceptable. The other benefits of fortification are (i) minimum risk of excess intake of the nutrient, ii) safe, quick and cheap method of ensuring availability of a nutrient, (iii) introduction through existing marketing and distribution system without any extra effort, (iv) every segment of affected population gets necessary amount of the nutrient, and (v) synthetic nutrients used in food fortification become available just after their absorption in the intestinal tract.

11.3.3 Limitations of Food Fortification

Food fortification requires knowledge of dietary habits and nutrient intakes in the target group(s). Consumers have to be educated about fortification, particularly if it is causing any change in the sensory qualities of the food or it necessitates any modification in the method of preparation of food at home. Food fortification is a temporary method of improving nutritional status of the people and should ultimately be substituted by balanced diet based on better food supply and food usage.

11.3.4 Safety of Food Fortification

Excessive intake of nutrients may sometimes lead to undesirable interactions with other nutrients. For example, excessive intake of an inorganic element can depress the absorption or utilization of another. Similarly, excessive intake of a strongly reducing nutrient, like vitamin C, can reduce absorption of selenium or carbon and strongly enhance bio-availability of iron. Higher intake of fat-soluble vitamins A and D exert toxic effect, while other vitamins are non-toxic even if ingested at high levels (up to 100 times of recommended level). The safety range is smaller for vitamin A (10 times of RDA) and iron (5 times of RDA). Level of food fortification generally ranges between 15 to 25% per serving, which is much below the critical levels.

In fortified food products, the level of fortification must be documented. Level of nutrients which amount to excessive intake should be established scientifically and the consumers should be made aware of such levels and their adverse effects. Response of consumers on quality of fortified foods, nutritional benefits or other relevant information must be collected and used to improve the product.

11.3.5 Methods of Fortification

Methods used for food fortification with nutrients are as follows:

i) *Dry mixing:* It is used for foods like salt, beverage powders, cereal products, milk powder, etc.

ii) *Dissolution in water:* The nutrients are dissolved in water or the product and mixed, e.g., fruit juices, beverages, drinks, etc.

iii) *Spraying:* Processed foods that require cooking or extrusion like potato chips, fruit bars, etc.

iv) *Dissolution in oil:* Oily products such as vanaspati are enriched by nutrients dissolved in oil.

v) *Adhesion:* It is used for sugar fortification. Vitamin A in powder form is adhered onto the surface of the sugar crystals when used with a vegetable oil.

vi) *Coating:* The vitamins sprayed over the grain must be coated to avoid losses when they are washed before cooking. It is generally used in case of rice.

vii) *Pelleting:* It is also used for rice. The vitamins are incorporated into pellets reconstituted from broken kernels.

11.4 FORTIFICATION OF FRUIT AND VEGETABLE PRODUCTS

Fruits and vegetables posses rich colour and have varied aroma. They add variety to the food, and improve aesthetic appeal of the diet. Fruits and vegetables are generally consumed for their aesthetic appeal but their nutritional significance is not fully realized by the consumers. They are rich sources of vitamins, minerals and dietary fibre. Dietary fibre (hemicelluloses, celluloses, lignins, oligosaccharides, pectin, gums and waxes) though resistant to digestion play an important role in human health. They do not provide nutrients directly, but low dietary fibre have been associated with diseases like cardiovascular diseases, obesity, diabetes, constipation, bowel cancer, etc. Daily intake of 30 g dietary fibre by a normal healthy adult has been suggested. Fruits and vegetables, in general, contain 1.0 to 2.2 % fibre and contribute up to 50% of dietary fibre. Fruits and vegetables, contribute about 90% of total dietary ascorbic acid, 50% of vitamin A, 35% of riboflavin, 25% of magnesium, 20% each of thiamine and niacin, 20% of fat, 7% protein and 10% of food energy.

Nutritional composition of fruits and vegetables depends on species, variety, location, season and agro-climatic conditions. Moreover, nutrient loss also occurs during storage, preparation and processing. Consumer may not be aware of these changes. Fortification helps in standardizing fruit and vegetable products to a pre-decided level of nutrients. It also enables processors to fortify the products to meet the nutrient requirements of specific group of people such as sport persons and athletes.

11.4.1 Principles of Fortification of Fruit and Vegetable Products

Following points are to be considered before fortifying a product:

1. *Principle of need:* There should be a deficiency/ malnutrition in a population which makes food fortification necessary.

2. *Principle of food distribution:* A proper carrier should be identified for fortification programme. Any such carrier that is consumed by a large population should be centrally processed and centrally distributed. Fortified food should be made available to the people who need them at their place.

3. *The principle of stability:* Nutrients should be stable during processing, storage and distribution. To compensate for these losses an overdose of nutrient is added. But for determining overdose, the maximum amount of

particular food likely to be consumed by an individual per day should be known, and it must be ensured that there is no excessive consumption of nutrient.

4. *Principle of compatibility:* Nutrient being used for fortification should be physiologically and chemically compatible to natural or other food ingredients. It is very important that the added nutrient does not react and remains biologically available.

5. *The principle of camouflage:* Fortification should not cause noticeable changes in sensory characteristics of food products. This is an important point to be considered during fortification.

6. *Principle of economy:* Cost of a fortified product is influenced by the cost of nutrient added, form of the nutrient, shelf life of the product and overages needed to achieve a specified shelf-life. Fortification should not make much difference in the cost of the food product.

7. *Principle of accessibility:* Standards and specifications for fortified food and methods of enforcing them should exist.

8. *Principle of disclosure:* The form and amount of nutrient used for fortification should be declared on the label so that the consumers could know it.

9. *Availability of technology and equipment:* Fortification on commercial scale requires special equipment, proven technology and skilled manpower. They should be available.

11.4.2 Fortified Fruit and Vegetable Products

Fruit and vegetable products generally selected for fortification are those which are consumed more regularly and therefore, can serve as a better carrier of nutrients. Beverages, juice concentrates, juice powders, fruit bars, jellies and jams are a few examples of such products. Fortification should ensure that the normal amount of that food product consumed in a day supplies the whole requirement of the consumer for that nutrient.

Retention of nutrients in fruit and vegetable products are affected by the conditions prevailing during processing and storage. Therefore, sufficient overdose should be added to these products.

Information about the nutrient content is given on the label of container on the basis of a serving. The term ‘serving’ denotes that quantity of a food in a meal which is suitable for consumption by an adult male doing light physical activity. Unit of ‘serving’ should be understandable to common consumer, such as cupfuls, teaspoonfuls, etc.

11.4.3 Fortification of Beverages

The term beverage includes fruit juices, squashes, nectars, ready-to-serve beverages, carbonated beverages or aerated waters, synthetic juices, fruit juice concentrates and dry instant drinks. Beverages are the most commonly fortified fruit and vegetable products. They are fortified with vitamin C and to some extent with vitamins A and B. For vitamin A, the substance used is beta carotene, which is a precursor of this vitamin and also gives colour to the juice.

Synthetic sources of vitamins are used, though blending with aonla juice as a source of vitamin C and carrot juice as a source of beta carotene can also be carried out. Losses of vitamins may take place during processing. Therefore, contact of fruit juice with iron and copper should be minimized by using stainless steel or glass lined equipments and vessels and juice should be de-aerated before pasteurization.

Vitamins, particularly thiamin, folic acid and vitamin C, are sensitive to heat. Beverages fortified with these vitamins must not be over heated; their temperature should be kept at 90^0C or less for a maximum period of 15 seconds. Fortification of beverages with vitamin A, folic acid and calcium pentothenate present problems because these nutrients are very unstable at pH around 3.0, which is normal pH of most fruit juices. Further, solubility of folic acid in water is very low.

Vitamin premix is dispersed in juice/ beverage, before homogenization step. Subsequent step of homogenization insures thorough mixing of vitamins in beverage.

Amount of vitamin C added should be such that each serving of 110-170 ml provides about 40 mg, which is the minimum daily requirement of an adult. Since some of the vitamin C may be lost during processing and storage, its 35-70% extra amount is added. In other words, total amount of vitamin C should be 54 to 68 mg per serving.

i) Fortified apple juice

Apple juice contains only 0.2-0.6 mg vitamin C per 100 ml as compared to 9.7-70.0 mg per 100 ml in orange juice. Further, colour of apple juice is light after extraction. But colour of juice becomes dark within 1 hour due to action of enzyme polyphenol oxidase on tannins of juice in the presence of air. Apple juice is fortified with vitamin C to raise its vitamin C content and to utilize oxygen present in the head space. Removal of oxygen from headspace checks oxidation of tannins and thus prevents discoloration of juice. But fortified apple juice, when exposed to oxygen, starts loosing vitamin C at the rate of 1 to 4 mg per 100 ml per day and its colour may again become dark. Therefore, it should be protected from air.

Vitamin C is added at the rate of about 70 mg per 100 ml at the time of extraction when apple juice comes out of press. Excess amount of added vitamin C may get degraded during processing and storage but it ensures that 40 mg of this vitamin per 100 ml remains in the juice.

ii) Fortified orange juice

Vitamin C content of orange juice varies from 27 to 67 mg/ 100 ml depending upon location of orchard, variety, etc. Therefore, orange juice is fortified so that it provides the minimum recommended amount of 40 mg vitamin C per serving.

iii) Fortified fruit juice concentrates and powders

Fruit juice concentrates and powders serve as base for various fruit beverages. They are easy to store and transport and reduce packaging requirements as compared to juices and other beverages. But during preparation, fruit juices are heated for long period which results in greater loss of vitamins. Therefore, they are fortified. High TSS of concentrates protect vitamins and reduce loses during storage. Synthetic orange juice concentrates are prepared using orange pulp and rind. Other ingredients added are gum *arabic*, cellulose gum, natural and synthetic flovours, artificial colour, potassium citrate and calcium phosphate. It is fortified with vitamin A, B and C.

Fortified fruit juice powders are prepared from fruits like apple, peaches, cherry, etc., by foam-mat drying process. In this process solubilized soy protein and methyl cellulose is added to fruit pulp.

Instant dry mixes of beverages and juice powder are fortified with vitamins by dry mixing. Water dispersible forms of vitamins are used. Mixing must be complete but over mixing should not be done because it results is segregation.

iv) Fortified carbonated beverages

Many carbonated beverages are fortified with vitamin C. During carbonation process, CO_2 expels the air. Removal of air and oxygen increases stability of this vitamin. Fortification of carbonated beverages with vitamin C improves nutritional value of the beverage, and some of it react with and remove residual oxygen from the head space of bottle which extends shelf-life of the beverage. Theoretically, 3.3 ml of vitamin C reacts with 1 ml of air. An overdose of vitamin C should be added to carbonated beverages to compensate for the losses.

v) Fortified banana powder

Banana powder fortified with soy protein can be used as a weaning ford for babies. To prepare it, whole soybeans are blanched in boiling water for 30 min, ground into fine paste with 10 times its weight of water and mixed with ripe banana pulp. Ratio of banana solids and soy solids in paste is kept equal. To the blend 100 ppm sodium meta bi-sulphite is added which prevents darkening. The paste is dried to 3% moisture level over a drum drier.

vi) Fortified jellies

To fortify jellies, a concentrated vitamin premix is prepared and some sucrose is added. Fat soluble vitamins are used in water dispensable forms. Vitamin premix is added to the jelly near the end point but before addition of citric acid. Vitamin C reduces the pH of jelly which may prevent their setting. Therefore, pectin jellies are not fortified with vitamin C.

vii) Fortified fruit cloth and fruit bar

Fruit cloth and fruit bars are products prepared from fruit pulp and concentrates by sun drying or drum drying. Fruit clothes from apples, apricots, dates, mango, papaya, etc., are prepared. 'Amavat' or 'Ampapar' is traditionally prepared in India by sun drying ripe mango pulp in the sheets, the thickness of sheet is gradually increased. The fruit bars can be moulded into different forms. They may be pre-treated with SO_2, viz., 0.5% sodium bisulphite. Sulphur dioxide improves colour and protects vitamin C and beta-carotene. Level of total soluble solids in pulp is raised to about 30% by adding sugar, also reduces drying time. Depending upon requirement, citric acid is added to improve the taste and acceptability of fruit bars. It can be fortified with protein powders (skim milk powder, whey protein isolate, ground nut or soy protein isolate, yeast protein), vitamins and other nutrients. Fortification is done by adding nutrients to the pulp concentrate and then drying it or spread the nutrient premix over the surface of dried fruit material.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. How has ICMR classified foods consumed in India?

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2. Define term ‘food fortification’.

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3. What points should be considered before taking up food fortification work?

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4. What is significance of fruits and vegetables in human nutrition?

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5. What are the advantages of fortifying carbonated beverages with vitamin C?

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6. At what stage vitamin C and vitamin pre-mix should be added to apple juice, instant juice powder and fruit jelly?

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7. Discuss the factors which influence stability of vitamin C and beta-carotene in fruit and vegetable products.

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11.5 LET US SUM UP

Nutritional requirements of men are varied and no single food can provide all the dietary essentials. It has resulted in various types of nutritional deficiencies. In such cases fortification offers an inexpensive and quick method for combating problem of nutritional deficiencies. People should be educated about needs and benefits of food fortification. Commonly fortified fruit and vegetable products are beverages, fruit bars and jellies which are consumed by a large section of people. Essentially fortification should be done only when it is necessary as proved by scientific studies, should be safe and effective. It should not be used as a marketing strategy.

11.6 KEY WORDS

Beverages	:	This term includes fruit juices, squashes, nectars, ready-to-serve beverages, carbonated beverages, synthetic juices, fruit juice concentrates and dry instant drinks.
Dietary fibre	:	It is that part of plant food which is resistant to digestion in the human beings.
Fortification	:	It is defined as a process of adding one or more dietary essentials to food.
Fruit bars/clothes	:	They are products prepared by drying fruit pulp and concentrates in the form of sheets.
Overage	:	Extra amount of nutrients added during fortification process to compensate for the losses during processing, storage and distribution.

11.7 ANSWERS TO CHECK YOUR PROGRESS EXCERCISES

Check Your Progress Exercise 1

Your answer should include following points:

1. • Five food groups have been identified by ICMR.
   • i) cereal, grains and their products, ii) pulses and legumes, iii) fruits and vegetables, iv) milk, meat egg and their products and v) fats and sugars.
2. • It is a process of adding dietary essentials.
   • Type of nutrient(s) added, their quantity and objective of adding them.
3. • Necessity of fortification
   • Basic principles of fortification
4. • Enhancement of aesthetic appeal of the diet.
   • High amounts of vitamins, minerals and fibre.
5. • Capability of vitamin C in removing oxygen
   • Nutritional improvement
6. • Vitamin C is added at the time of juice extraction to check.
   • Oxidative discolouration in apple juice.
   • Dry mixing of vitamins to reduce adverse effects of heat on vitamins in pre-mix in instant juice powders.
   • Vitamin premix is added in jelly near the end point but before addition of citric acid.

7. • Effect of heat, pH and oxygen on vitamin C.
   • Effect of pH and oxygen on beta-carotene.

11.8 SOME USEFUL BOOKS

1. Verma, L.R. and Joshi, V.K. (2000) Post-harvest technology of fruits and vegetables, Vol. II, Indus Publishing Co., New Delhi.

UNIT 9 TYPES OF BY-PRODUCTS

Structure

9.0 OBJECTIVES

After reading this unit, you should be able to:

- list fruit and vegetable handling and marketing wastes;
- characterise the wastes;
- describe by-products from fruit processing waste;
- explain the types of by-products from vegetable processing waste; and
- define the uses of these by-products.

9.1 INTRODUCTION

Fruits and vegetables are integral part of a balance diet as they contain vital nutrients like vitamins, fibre and minerals. Due to the diverse agro-climatic conditions of the country, all kinds of fruits and vegetables are grown. The production of fruits (46 MT) and vegetables (96 MT) has increased at a faster rate in the last decade making the country second largest producer of fruits and vegetables in the world after Brazil and China, respectively. Despite the fact that production of fresh fruits and vegetables is very high, the level of their processing remains at a low ebb, i.e., 2 per cent. In the developed and developing nations like USA, Brazil, Malaysia, Philippines and Israel the level of processing of fruits and vegetables is more than 50 per cent of the total product. So, there is a vast scope of increasing the level of processing in the country. At present there are more than 6000 processing units in the country where installed capacity is around 23 lakh tones. The main fruit and vegetable processed products are juice, concentrate, sauce, slices, jam dehydrated, canned etc. During processing, a huge amount of solid waste is generated, which is some times more than 50 per cent of the produce processed. Apart, waste is also generated at the place of production, handling and marketing and places of consumptions like hotels, restaurants, colleges, essential homes, etc. The effective disposal of waste is waste / by product generated vary from place to place depending upon fruits and vegetables and the way they are utilized. The waste products are in various forms. For instance we have the peel, rag and seeds in case of citrus fruits, peel and stones in mangoes; rings and seeds in jack fruit, core and peel in guavas; seeds, skin and trimmings in tomatoes, etc. Many fruit and vegetable processing plants produce a large amount of by-products. Peel, core, pits, veins, stem, leaves, etc., are the materials discarded by fruit and vegetable processing industries. Their appropriate utilization would not only yield other valuables end-products and lower the cost of production but also minimize pollution problem caused by unhygienic disposal methods.

9.2 HANDLING AND MARKETING WASTES OF FRUITS AND VEGETABLES

The harvested fruits and vegetables are cleaned/ washed/ graded according to size and appearance. These are then packed / bagged or loaded in containers for transportation to markets or retail outlets or to the processing unit. A large number and huge quantity of wastes and by products are generated during handling and marketing of fruits and vegetables. The type and quantity of waste depends upon the crop, the packaging material and the duration / time period of handling the produce. Fruits and vegetables are highly perishable in nature and their quality starts deteriorating the moment they are detached from the plant. Environmental conditions such as ambient temperature, relative humidity, produce storage conditions and, above all, infestation of microbes in the produce, are the main factors responsible for quality degradation during handling and marketing. After identifying the type of available waste it is very important to have a knowledge of general characteristics, such as physical, chemical and microbiological, for deciding their appropriate disposal/ utilization.

Various types of by-products available during fruit and vegetable handling and marketing are:

9.2.1 Fruit Wastes

a) Peel, core, and trimmings
b) Seed/ kernel, stem and pomace
c) Cull fruit
d) Over-ripe and blemished
e) Bruised and diseased

9.2.2 Vegetable Wastes

a) Seed, skin and trimmings
b) Vine and pods
c) Peel and pomace
d) Husk and cobs
e) Over mature and cull
f) Bruised and diseased

9.2.3 Packaging Wastes

Various types and sizes of packaging materials are used for different fruits and vegetables. Waste generated during handling and marketing due to various packagings are as follows:

a) Gunny bags
b) Bamboo crates/"tokras"
c) Wooden boxes

d) Plastic sacks or bags
e) Paddy straw/pine waste/leaves or any other coushing material
f) Foam or thermocole
g) Paper bags or corrugated fibre board boxes

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. How many fruit and vegetable processing are industries in the country and what is their installed capacity?

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2. What are the wastes and by products of fruits and vegetables generated during handling and marketing?

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9.3 BY-PRODUCTS FROM FRUIT PROCESSING

The fruit and vegetable processing industry in India is highly decentralized. A large number of units are in the cottage/home scale and small scale sector, having small capacities up to 250 tonnes/annum. But big Indian and multinational companies in the sector have large capacities in the range of 3.0 tonnes per hour or so. In the food processing industries, up to 30 per cent of incoming raw material becomes waste rather than a value-added product. Generally fruit processing wastes are either used as animal feed or as compost.

Specific wastes and by-products from different fruit and vegetable processing industries and their appropriate use are discussed below:

Apple

Apple (*Malus pumila Mill.*) is the most important deciduous fruit. These are mainly grown in the North-Western Indian States of Jammu and Kashmir (J&K), Himachal Pradesh (H.P.) and Uttaranchal hills. The North-Eastern Hills region, comprising of the States of Arunachal Pradesh, Nagaland, Meghalaya, Manipur and Sikkim, also grows some of the deciduous fruits on a limited scale. Major wastes and by-products of apple processing are:

- pomace - obtained after juice extraction
- peel - obtained during canning and murabba preparation
- core and cull fruits

Apple wastes contain pectin varying from 2.5 to 3.4 per cent on fresh weight basis. These wastes can be used for preparation of pectin, cider, vinegar, chutney, etc. Pomace can be dried and utilized for preparation of pectin. Apple pomace being rich source of pectin and a fairly good source of sugars, can be utilized on a small scale for blending with fruits poor in pectin for the preparation of jam, jellies, etc., which require addition of pectin. Apple chutney can be prepared from pomace.

Amla

(Indian goose berry): The amla/aonla (*Emblica officinalis* syn. *Phyllanthus emblica*) is an important minor fruit. Although, it is found growing in different states throughout tropical India, it is more popular in Uttar Pradesh. It is highly nutritive and is one of the richest source of vitamin C. The fruits are made into preserves (*murabba*)**,** pickles, dried chips, candy, toffees, powder, juice, sauce etc. Amla seed is obtained from amla processing industry. The seed can be dried and used in ayurvedic preparations.

Apricot

Apricot (*Prunus armeniaca L.*) is grown in the drier pockets of north-western Himalayas and Leh-Ladakh areas of J&K State. Apricot is a small, soft fruit with white/orange skin. Its kernels are sweet and can be added to jam after removing the seed coat. Generally there are two types of apricot, namely, sweet kernel type and bitter kernel type. Oil can be extracted from kernels and after refining it is just like almond oil and can be used in pharmaceutical and cosmetic preparations. The oil cake is rich in protein and can be used as cattle feed. The kernels are sometimes used for making macaroon paste which is usually made from almonds.

Banana

Banana (*Musa paradisiaca*) is the cheapest, plentiful and most nourshing of all fruits. It is basically a plant of humid tropics and is grown in south, west and east India. All parts of this plant are useful. Various products like banana chip, banana fig, soft drink, flour and powder, jam, etc., can be made. Banana peel and pseudostem are the main waste products from banana processing. The pulpy portion scraped from thick peel of banana can be used for preparation of banana cheese. Pseudostem of banana can be utilized to prepare paper pulp as well as a starch resource for food and feed purposes.

Cashew

Cashew (*Anacardium occidentale*) is an important tropical tree crop. It is mostly grown in malabar coast of India, particularly concentrated in Kerala, Karnataka, Maharashtra, Tamil Nadu and Andhra Pradesh. Every part of cashew is useful to man. The kernels are of high nutritive value, rich in protein, carbohydrate, unsaturated fats, minerals and vitamins. The main by-products are: cashew apple, cashew testa and cashewnut shell liquid. Because of its astringent taste and fibrous texture, only a small quantity of the annual production of cashew apple is consumed locally and a major portion is wasted. About 65 per cent of the juice can be obtained from the apple by extraction. The juice, after removal of astringent and acrid principles, has been found to be suitable for a variety of beverages like clarified juice, cloudy juice and juice blended with other fruit juices. Cashew apples can also be used for the preparation of cashew apple candy, syrup, canned cashew apple, fruit chutney, curried vegetable, pickle, etc. The brown thin skin covering the cashew kernel is called the cashew testa. It is a by-product of the cashew processing industry. Cashew testa is a good source of tannin. At present, this is mostly wasted or occasionally used as a manure in small quantities. However, the disposal of this product is a big problem. Quite often, storage of this husk is found as a ready place for *dryboleum* and so is hazardous in the cashew factories.

The reddish brown viscous liquid inside the two layers of the cashew shell is a versatile industrial raw material known as cashew shell liquid. Its major application is in the manufacture of cashew liquor, cashew cement, laminating resins, rubber compound resins, brake linings, intermediate for chemical industry, epoxy resins, foundry chemicals, composite wood, insulating varnishes, electrical windings, electrical conductors, coating compositions, water and weather proofings, bituminous solutions, specialised protection coatings and compositions based on cardanol.

Citrus

The most important commercial citrus in India is mandarin orange followed by the sweet orange and acid limes. Besides being used as fresh fruits, the citrus fruits are processed into marmalade, juice, concentrate, powder and canned product. The flowers, leaf and rind of citrus contain oils of good fragrance and have good commercial value. Other commercial products are citric acid and pectin, made primarily from cull and unmarketable fruits**.** In case of citrus fruits major waste materials are peel, rags, seeds, and sludge from lime and oranges. The peel can be utilized for getting peel oil, which has a number of uses. The rags can be used for preparation of citrus patty, marmalade and orange toffee. The dried rag can also be used as cattle fed. Orange residues can be fermented into fruit vinegar. Lime juice sludge is used to extract lime oil. Seeds from oranges and lime can be used for extraction of seed oil, which has enormous industrial applications. Juice residues of orange and gulgal can be used to get pectin. Waste from cull, lime, gulgal and khatta can be used to prepare citric acid.

Coconut

Coconut (*Cocos nucifera*) is most beautiful and useful tree of tropics. This crop is of considerable economic importance in the state of Kerala, Tamilnadu, Karnataka and Andhra Pradesh. These have more than 90 per cent of the total production of the crop in the country. There are number of industries which are directly or indirectly dependent on coconut farm. The major wastes and by-products of coconut are stem, leaves, buttons, coconut husk, pit, shell and water. The quire industry utilizes coconut husk and is earning considerable foreign exchange for the country. Quire husk is a waste left over after extraction of fibre from the coconut husk. This light fluffy refuge is a mixture of corcipith, fibre short and apricot. High moisture and saline content are the main problems restricting its utilization. It has been limited agricultural use. It can be used as an accident soil mulchi material. It has certain industrial uses. It can be used for preparation of boards from quire wastes, preparation of installation slabs, air conditioner and refrigeration, manufacturing of moulded articles, expansion joint filler, furfural production, electric plate edited in battery industry and as a tacifying agent in rubber industry. Coconut shell is the endocarp of the coconut fruit. It is available in large quantities near copra making centre or desiccated copra making centre. It can be used as a fuel and manufacturing of fancy articles. Since coconut shells are available in different sizes and shapes, it can be polished and carboned and decorated with lacquer in load with ivory, silver or other metals. A number of fancy articles prepared from coconut shells are lamps, flower, bulb covers, ash tray, paper, tea sets, musical instruments, bangles, etc. Coconut shell flour can be used as a compound film for synthetic season blues, as a fuel for pneumatic moved powder, etc. Furfural can also be extracted from ground coconut shell. Large volumes of coconut water from ripe nuts are run off as waste product by copra manufacturer. The biochemical analysis of coconut water shows negligible amount of sugar. It can be used as a growth media, a rubber coagulant and soft drink. In view of the relatively high potassium content coconut water can be mixed with compost or can be applied directly to coconut palms after mixing with slag lime. Coconut pith can be used for preparing the insulation and as a structural material.

Grape

Major grape (*Vitis vinifera L.*) growing states in India are Maharashtra, Karnatka, Andhra Pradesh and Tamil Nadu. The cultivation of grapes has also started under North Indian conditions. The grapes are used into five different ways, such as, table purpose, canned, juice, wine and raisins. Stem, pomace and seed are main by-products of grape industry. Stem, separated from grapes, normally constitute about 5 per cent of original weight of grapes. The stems can yield cream of tartar (potassium tartrate). The pomace consists of pressed skin and seeds. From the pomace, seeds can be separated and pressed to extract oil, which is edible in refined state. Oil cake can be used to extract tartaric acid. Hulls of decorticated grape seeds can be used to obtain toxin extracts. The pomace can be used for preparation of grape jelly and chutney. It can also be used for preparation of animal feed. Pomace must be dried to less than 10 per cent moisture in order to prevent spoilage by moulding and spontaneous heating. Grape marc can be used for preparation of pectin. Argols (potassium hydrogen tartrate) can be obtained from grape juice settlings.

Guava

Guava (*Psidium guajava L.*) is grown all over the country in tropics and sub tropics. It is a rich source of vitamin C and pectin. It is used for table purpose and for processing to prepare jelly, nectar, juice, cheese, powder and canned guava. Guava peel, seeds, pulp and core are main by-products of guava fruit. These can be utilized to prepare cheese, separately as well as collectively or animal feed. Cheese prepared from peelings only is brown in colour and has satisfactory flavour and good set, whereas cheese from seed is dark brown in colour, sticky and has soft texture and good flavour.

Jack fruit

The Jack fruit (*Artocarpus heterophyllus*) is very popular in eastern and southern parts of the country. The fruit has high nutritive value and is rich source of pectin. It is preserved into pickles, dehydrated, leather, thin *papad* and canned product. Nectar can also be prepared from pulp. The skin and leaves are excellent cattle feed. Seed, thick rind and broken bulbs are the main by-products of jack fruit. Broken bulbs are used to prepare 'leather'. Thick rind with inner perigones can be used for preparation of jelly and pectin. Seeds can be roasted to be used as snack food. Seeds can also be grinded into flour which can be blended with other cereal flours for preparation of products.

Mango

The mango (*Mangifera indica L.*), because of its luscious taste, captivating flavour and great utility, is called the "King of fruits" or "Shahi fruit". It is a major fruit crop grown throughout India. Unripe fruits, because of their acidic taste, are utilized for culinary purpose as well as for preparing pickles, chutney, panna and amchoor. Ripe fruits are utilized in preparing pulp, squash, juice nectar, jam, cereal flakes, dehydrated slices, powder, mango leather (am papar) and toffee. Some mangoes are also sliced and canned for catering to the needs of consumers during off season. The wastes constitute about 50 per cent of the weight of fresh mangoes. Peel and kernel are the wastes from green mangoes as well as ripe mangoes. Pulping machine generates processing wastes. Mango kernel contains about 8.5 per cent crude fibre and 75 per cent N-free extract. Starch obtained from seed kernel can be used to partly replace wheat atta for making chapatees. Oil which forms about 12 per cent of the weight of the kernel is another by-product. Pectin and fibre can be extracted from peel and processing wastes vinegar, citric acid, etc., can be obtained by fermentation of processing waste. The mango waste can also be utilized as animal feed or compost.

Papaya

Papaya (*Carica papaya*) is an important fruit of tropics and subtropics. In India, though it is successfully grown all over the country, the important papaya growing states are Kerala, Tamil Nadu, Assam, Gujarat and Maharashtra. Papaya is a wholesome fruit and ranks second only to mango as a source of precursor of vitamin A. Unripe fruits are commonly used as vegetable for cooking much tenderizer and preparation of tutti-frutti. The ripe fruits are used for table purpose and processed for preparation of jam, soft drink, ice-cream flavouring, crystallized fruits and syrup. Papaya waste a usually peel and trimmings can be used to get proteolytic enzyme papain which has a number of applications in textile, cosmetic and pharmaceutical industries. Pectin can also be recovered from papaya waste.

Passion fruit

Passion fruit (*Passiflora edulis*) is adapted to tropics and subtropic areas with high rainfall. It is a fruit with unique flavour and aroma. Fruit is cut in halves and the pulp scooped out and eaten fresh or added to fruit salad, ice creams or fruit juices. It is processed into fruit nectar, juice, jam, jelly, squash and concentrate. The main wastes of passion fruit are hard rind and seeds. Thick hard rind of this fruit can be used for recovery of pectin, whereas seeds are utilized for extracting oil and pectin.

Peach

Peach (*Prunus persica L. Bats. Ch*) are now being grown commercially in certain areas of the north Indian plains and North-Western States of Jammu and Kashmir, Himachal Pradesh and Uttranchal**.** Peach kernel is the main waste material, which can be used for extraction of kernel oil for industrial uses.

Pear

Pear (*Pyrus communis Berm.f.*) is mainly grown in the North-Western Indian States of Jammu and Kashmir, Himachal Pradesh, Uttranchal and certain areas of the north Indian plains. Peel and core are the main waste by-product obtained from pear and both are used to prepare alcoholic beverage as well as fruit vinegar.

Pineapple

Pineapple (*Ananas comosus)* is most wanted tropical fruit. In India, it is grown mostly in West Bengal, Manipur, Meghalaya, Assam and Tamil Nadu. Pineapple is a good source of vitamins A, B and C and calcium and phosphorus. The processed products from pineapple are slices in cans tit bits, juice, squash, jam and candy. Pineapple wastes constitute 40 to 50 per cent of the fruit weight. Shells, trimmings, peel and pomace are the main waste and by-product of this fruit. Shells and trimmings are utilized to recover pineapple juice mixed with cane sugar syrup for further use in canning of pineapple slices. This juice has also been found useful for preparation of alcohol. The core of pineapple can be used to prepare candies as well as extraction of juice. The press cake from the juice can be used as animal feed. The pomace obtained after extraction of juice from peeled fruit, trimmings and cores can also be used as animal feed. Other products which can be prepared from this waste are alcohol, citric acid, mannosidase, oxalic acid, pineapple gum, flavour and vinegar. Leaves are used for making fine fabric called pina cloth.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the wastes and by products of fruit processing industries?

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2. List by products of coconut processing.

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3. List by products of cashewnut processing.

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4. List by products of mango processing.

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9.4 WASTES AND BY-PRODUCTS FROM VEGETABLES

Tomato

Tomato (*Lycopersicon esculantum*) is an important vegetable crop available round the year. It outranks all other vegetables, except potato crop in popularity and value. It is grown universally in farmer's fields, home gardens and green houses. Peel, seeds and pomace are the wastes obtained during processing of tomato into juice, concentrate, ketchup and sauce. When tomato is canned in lime and sugar solution, some peel and seeds are obtained as wastes. The pomace is either thrown away or used in preparation of compost. Seeds are washed, dried and used for propagation. Edible grade seed oil can also be extracted from seeds. Tomato peel can be utilized for preparation of varnishing and arranging seed oil which compare well with Vit. E and can be used as salad oil and in the manufacture of margarine. The seed meal can be used in fields as fertilizers and also for the preparation of surfactants such as veterinary agents and detergents, etc. The marc constitutes about 12-13 per cent of tomato.

Onion

Onion (*Allium cepa L.*) is one of the most important commercial vegetable crops grown in north as well as in south India. The most important onion growing states are Maharashtra, Tamil Nadu, Andhra Pradesh, Bihar and Punjab. Onions are used as salad and cooked in various ways in all curries, fried, boiled, baked, soup, pickles, etc. The roots are trimmed and the outside skin peeled off leaving the stem clean for further storage/ marketing. Trimmings are obtained as onion wastes. These trimmings are either thrown away or used as compost. The flour component can be extracted from this waste. During handling and grading operations and dehydration loose outer scales are rubbed off. These can also be used as compost.

Potato

Potato (*Solanum tuberosum* L.) is the maximum produced vegetable crop in India. About 80 per cent of the dry matter of potato is starch, which occurs in the form of granules of larger size than those of cereals. Raw potato is generally boiled, cooked, baked or processed into various products such as chips, fingers, cubes, extruded and flour. Potato peel and starch are the waste and by-products obtained during potato processing. Potato peel can be used for preparation of alcoholic beverages as well as compost. Starch is utilized as flour or in cosmetic industry.

Cauliflower

Cauliflower (*Brassica oleracea* L. var. *botrytis*) is an important cole crop. India's production of cauliflower in the world is highest. It is an important winter-session vegetable. It is grown for its white tender head or curd. It is used as vegetable in curries, soups, stuffing in parathas and for pickles. It contains good amount of vitamins and fair amount of protein. Plants are cut below the head and leaves trimmed off. Stalks and trimmings are the main wastes obtained from cauliflower, both in the field as well as in processing industries. These stalks and trimmings can be used as cattle field.

Okra/ Ladyfinger

Ladyfinger (*Abelmoschus esculentus* L.) is a warm season vegetable crop. It is cultivated throughout India for its immature fruits which are generally cooked as vegetable**.** Okra soup and stew are popular dishes**.** Black or brown seeds of ripened okra are roasted and used as a substitute for coffee. The wastes available in the field such as stem of the plant is used for extraction of fibre in paper industry. Stalks are the main by-product in leading processing industry, which can be used as animal feed.

Peas

Pea (*Pisum sativum* L.) is a vegetable crop important from agricultural economy as well as nutrition point of view. Peas are highly nutritive and contain a high percentage of digestible protein along with carbohydrates and vitamins. It is an excellent food taken either as a vegetable or in soup, canned, frozen or dehydrated form. The winnings and rolls are the main waste material from green peas. These wastes can be directly fed to animals or can be dried to make ingredient in animal feed. These wastes are also used as compost.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the wastes and by-products of vegetable processing industries?

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2. List by-products of tomato processing.

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9.5 LET US SUM UP

Fruits and vegetables are valuable parts of a balance diet. The diverse agro-climatic zones of the country make it possible to grow almost all types of fruits and vegetables. Major Indian fruits consist of mango, banana, citrus group, apple, guava, papaya, pineapple and grapes. In case of vegetables, potato, tomato, onion, cabbage and cauliflower account for around 60 per cent of the total vegetable production in the country. Wastes/by-products generated vary from place to place depending upon fruit and vegetable production, marketing sites, processing industries, and major consuming places such as hotels, restaurant, hospitals, schools, colleges and community langars. The fruits and vegetables are processed into various products such as juice, concentrate, canned, dehydrated, jams, jellies, etc. Many fruit and vegetable processing plants produce a large amount of by-products. Peels, cores, pits, veins, stem, leaves, etc., are the materials discarded in processing industries. The waste products are in various forms. For instance peel, rag and seeds in citrus fruits, peel and stones in mangoes; rings and seeds in jack fruit, core and peel in guavas; seeds, skin and trimmings in tomatoes, etc., are obtained. Their appropriate utilization would not only yield other valuables end-products and lower the cost of production but also minimize the pollution problem caused by unhygienic disposal methods. Wastes and by products from important fruits and vegetables such as mango, banana, citrus fruits, apple, guava, papaya, pineapple, grapes, potato, tomato, onion, pea, okra and cauliflower have been discussed. The nutritional quality/characteristic of these by-products varies. Previously, these residues were considered as wastes material to be transported to landfills, burnt, added to soil or fed to cattles. However, these residues are viewed as input materials that can become value-added products with further processing. These wastes are economically utilized for the production of pectin, oil, alcohol, flavours, etc.

9.6 KEY WORDS

By products	:	Any material or product contingent upon or incidental to a manufacturing process.
Processing waste	:	Any material generated as waste, in a food processing operation.
Packaging waste	:	Any material generated as waste from a fruit/ vegetable packaging.
Peel	:	Outer covering of any fruit or vegetable.

Skin	:	Outer layer or covering of a fruit or vegetable.
Core	:	The innermost or centremost part of fruit containing the seeds.
Seed	:	It is a part of plant capable of developing into another such plant.
Pomace	:	Waste material obtained during processing of fruits like apple, citrus, etc.
Stem	:	Stalk of fruit/vegetable or plant.

9.7 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answers should include the following points:

1. There are more than 6000 fruits and vegetables processing industries where installed capacity is around 23 lakh tonnes.

2. Various types of by-products generated during fruits and vegetables handling & marketing are:

   a) *Fruit wastes:* Peel, core, trimmings, seed/ kernel, stem and pomace, cull fruit, over-ripe and blemished fruits and bruised and diseased

   b) *Vegetable wastes:* Seeds, skin, trimmings, vines, pods, peels, pomace, husk, cobs over mature and cull and bruised and diseased

   c) *Packaging wastes:* Different types and sizes of packaging materials are used for different fruits and vegetables in different areas. Major wastes generated during fruit and vegetable handling and marketing due to various packagings are as follows: Gunny bags, bamboo crates/ "tokras", wooden boxes, plastic sacks or bags, paddy straw/pine waste leaves or any other coushing material, foam, or thermocole and corrugated packing or paper bags.

Check Your Progress Exercise 2

Your answers should include the following points:

1. Peel, core, rags, sludge, pits, pomace, veins, seeds, kernel, shell, rind, stem, leaves, etc., are the materials discarded in fruit processing industries. The waste products are in various forms depending upon the type of fruit being processed. For instance we have the peel, rag and seeds in case of citrus fruits.

2. The major wastes and by-products of coconut are stem, leaves, buttons, coconut husk, pit, shell and water.

3. The main by-products of cashew processing industry are cashew apple, cashew testa and cashewnut shell liquid.

4. The wastes and by-products from mangoes constitute about 50 per cent of the weight of fresh fruits. Peel and kernels are the wastes from green mangoes as well as ripe mangoes. Pulping machine generates mixture of peel and pulp.

Check Your Progress Exercise 3

Your answers should include the following points:

1. Trimmings, peel, core, rags, sludge, veins, seeds, stem, leaves, etc., are the materials discarded in vegetable processing industries.

2. Peel, seeds and pomace are the wastes obtained during processing of tomato.

9.8 SOME USEFUL BOOKS

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UNIT 12 PACKAGING – NEED AND IMPORTANCE

Structure

12.0 OBJECTIVES

After reading this unit, you should be able to:

- state the definition of food packaging;
- define the functions of packaging and its importance;
- explain the types of packaging;
- classify various packaging materials;
- describe the properties of packaging technology and its applications in processed food products; and
- design and develop the packages.

12.1 INTRODUCTION

The term food is defined as any substance containing nutrients such as carbohydrates, proteins, and fats that can be ingested by a living organism and metabolised into energy. Food is necessary for survival, growth of physical and mental ability and good health. The need and importance of food was known even to primitive men.

The nutritional status of a nation is complicated in nature as it depends on many inter-related set of factors such as food adequacy and its distribution, levels of poverty, level of literacy, status of women, rate of population growth and the extent of economic growth. In our country, the trend of nutritional level improvement for the last fifteen years has been gradual and modest despite steep rise in population.

The Indian economy is predominant agrarian. Agriculture constitutes 33% of our GDP, supports 64% of work force and earn 19% of our exports. The country produces 46 million tonnes of fruits and 96 million tonnes of vegetables and is the second largest producer next to Brazil and China, respectively. In spite of having such a good production, it incurs a loss of 25-30% every year. The spoilage of food products are due to improper infrastructure facilities for storage, handling, transportation and unscientific and inadequate packaging. India wastes more fruits and vegetables than are consumed in a country like U.K. This indicates that there is an urgent need to give more emphasis on packaging of food.

The level of food processing in our country is very low which has to be considerably increased if losses are to be minimised and also to ensure marketing of good product in packaged form. The selling of loose and exposed product is unhygienic and affects the health of the common masses. There could be considerable amount of savings in this context if all surplus quantity of produce are processed and sold in the market in a packaged form. But, consumer awareness and education are extremely important if this has to be achieved.

Indian consumer prefers to buy fresh produce and cook at home. Generally, processed and packaged forms are less preferred and purchased by Indian consumer as compared to the market trend elsewhere in the world. The primary reason is a myth and an inertia. There is still a perception that processing reduces the nutritive value and add to the cost. This myth needs to be broken on an urgent basis. The fact is that packaging reduces waste, adds value and assures a product to the consumer.

In our country, any fresh produce fruits, vegetables or processed products have never been associated with packaging. It is only in the recent times that the importance of packaging has been accepted. This is mainly due to growing consumer awareness and their willingness to pay for quality and hygienic products. In addition, increase in growth of exports has also made it obligatory to pack the product in attractive and consumer friendly packages. Considerable amount of improvement and development in packaging has taken place, especially for food products, in the last one decade. However, these efforts need to be augmented and implemented effectively to minimise the problems and make the food available more easily and economically. It may be pointed out that there is a tremendous scope for further improvement and development of packaging. In fact, the per capita consumption of packaging materials in India is much lower as compared to other developed and developing countries. Many more food products are still available in Indian market in unpacked condition, particularly the fresh produce like fruits, vegetables, meat, fish, poultry, etc. In order to maintain the hygienic condition of these food products and also to ensure their assured quality, it would be desirable to sell these products in packaged conditions. This will also increase the consumption of packaging materials enormously.

The subject "Food Packaging" has been introduced to modern technology recently. But this technology was existent on earth without having any proper attention. Most of the fruits like coconut, orange, banana, etc., having a skin or peel are available to us in packaged form in hygienic conditions this type of packaging is considered to be natural packaging. Further, the use of dry leaves for wrapping meat, animal skin based bags for storage, etc., wherein vogue since long. But recently, the importance of packaging has been understood in the food supply chain.

Food packaging is defined as a mean or system by which a fresh produce or processed product will reach from the production centre to the ultimate consumer in safe and sound condition at an affordable price. In other words, packaging is a combination of science, art and technology. Packaging is an integral part of production, storage, handling, distribution, retailing and end-use. Packaging is also considered as the last output of production but the first input of marketing. In other words, packaging acts as a tool or instrument for marketing.

The functions of packaging is performed by 3 P's, i.e., Preservation, Protection and Presentation. The above three P's are applicable to consumer products. However, this has minor role to play in industrial products.

Packaging serves two basic objectives, i.e., marketing and logistics. In its marketing function

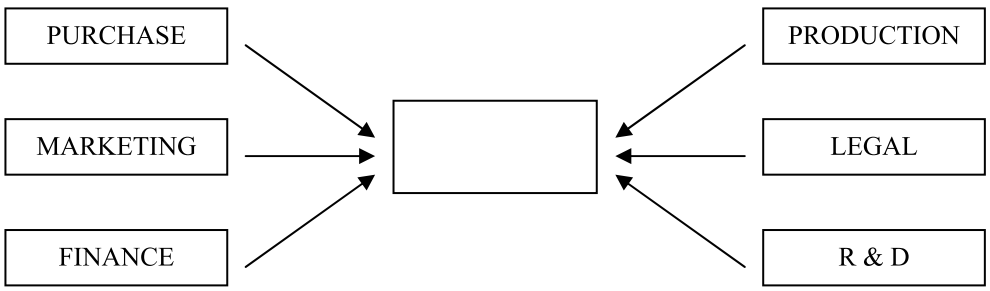
- it provides information about the product to customers,
- it promotes the product with attractive graphics and printing,
- it acts a medium of communication,
- it acts as a silent salesman and it is the final interface between the company and the consumers.

From the logistic perspective, the role of packaging is to ensure the safe delivery of a product to the ultimate customer at minimum cost.

In the logistic perspective, it performs six functions:

- Containment
- Protection
- Apportionment
- Unitisation
- Convenience
- Communication

The packaging function is closely associated with many other functions in an organisation. Effective communication is, therefore, important. In an organisational set up the packaging function is interrelated and this is illustrated below:



Due to this fact, packaging department is considered to be the nucleus in any FMCG (Fast moving consumer goods) company. The launch of any consumer product in a new package needs constant interaction among the inter departments of the company.

The package should be designed to provide efficient storage. However, its design is influenced by:

- Standardization
- Price or cost.
- Package or product adaptability.
- Protective level.
- Handling ability.
- Product packability
- Reusability or recyclability

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. How do you define "Food Packaging"?

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2. What are the important functions of packaging?

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3. What are the factors involved to make a good package design?

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12.2 TYPES OF PACKAGINGS

The container or the package serves mainly as a protectional device to avoid deterioration in the quality of contents against external agencies. However, in many instances, the packages are also designed taking into account the marketing considerations such as sales appeal, easy acceptability, handling convenience and distribution factors. Hence, it is desirable that you should know about the components of packaging or types of packaging available in the market.

12.2.1 Package Components

A broad classification of package components is given below:

i) Unit pack
ii) Intermediate pack
iii) Outer or shipping container
iv) Inner packaging components
v) External reinforcements

i) Unit pack

It is considered to be a package containing single unit, e.g. a toffee or chocolate is wrapped, 200 ml beer is packed in metal container. Unit package should be able to protect the product against the deterioration of quality. Naturally, the material selected for unit pack should have adequate functional properties to serve such function. This package serves as a retail pack and thus the package should have good eye appeal, easy openability and easy to carry or handle. In short, the package should be customer friendly.

ii) Intermediate pack

The unit packs further unitised to satisfy the marketing requirement, are called intermediate packs. For example, 10 unit pack of 100 g of butter packed in paper board carton are unitised to facilitate handling and enhance display value.

iii) Outer or shipping container

The intermediate packs are further packed into corrugated fibre board boxes or wooden boxes or Jute bags or HDPE woven sacks to transport the products. These packages are also termed as transport packages. These packages provide protection to the contents from journey hazards such as shock, vibration, drops and climatic hazards like rain, dust, sea water, etc., during handling, storage and transportation from one place to another.

iv) Inner packaging components

These components are normally given to the transport package by way of providing the resistance of movement of contents during journey due to vibration. The materials like separators are used in package where glass bottles are packed. Cushioning materials like thermocole, expanded polystyrene (EPS), expanded polyethylene (EPE), paper cuttings, wood wool are used either to protect the product against the shock hazards or space fillers to prevent the movement of contents during journey.

v) External reinforcement

The shipping containers are further reinforced by means of either plastic straps or metal straps applied along the girth as well as the length in order to strengthen the shipping container. Reinforcement also helps to improve the stacking strength, avoid bursting in case of failure and increase weight carrying capacity.

12.2.2 Packaging Materials

Packaging materials are broadly classified into two major types.

i) Primary packaging materials
ii) Ancillary packaging materials

I) Primary packaging materials

a) Flexible packaging materials

i) Cellulose based materials
ii) Regenerated cellulose or cellophane

iii) Jute or hession materials
iv) Aluminium foil
v) Plastic films and laminates
vi) Plastic woven sack

(i) Cellulose based materials

These materials are available in two forms, i.e., Paper and paper board. More than 180 gsm paper is generally termed as paper board.

- Paper: Different types of paper used in packaging are:

  - Tissue paper
  - Coated (varnish or wax coated)
  - Butter paper
  - Glassine paper
  - Art paper
  - Kraft paper
  - VPI paper
  - High gloss paper
  - Vegetable parchment paper

- Paper Board : Different types of paper boards used are:

  - Coated board
  - Duplex board
  - Triplex board
  - Asphalted board
  - Grey board
  - Mill board
  - Clay coated board
  - Kraft board
  - Chip board
  - Straw board

(ii) Regenerated cellulose or cellophane

The most common types of cellophane used for packaging are:

- Moisture proof sealable transparent cellophane(MST)
- Moisture proof sealable transparent coloured cellophane (MSCT).
- Moisture proof sealable transparent anchored cellophane (MSAT)
- Moisture proof saran coated cellophane (MXXT)

(iii) Aluminium foil

Different thicknesses of aluminium foils are available for the packaging application.

(iv) Jute or hession materials

Jute fabrics of different types, like single warp and double, are used for making the jute bags. Sometimes, the jute fabrics are also made water proof either by lamination or coating with bitumen or plastic for packaging.

(v) Plastic films and laminates

There are various types of polymeric materials which are converted into plastic films and have got wide application in packaging.

Some of the important polymeric materials are as follows:

- *Polyethylene*
  - Low density polyethylene (LDPE)
  - High density polyethylene (HDPE)
  - High molecular high density polyethylene (HMHDPE)
  - Linear low density polyethylene (LLDPE)
  - Very linear low density polyethylene (VLLDPE)
  - Copolymers like surlyn or primacor (EAA)
- *Polypropylene*
  - Bioxially oriented poly propylene (BOPP)
  - Cast poly propylene (CPP)
  - Tubular quenched poly propylene (TQPP)
- *Polyvinyl chloride (PVC)*
- *Polyethylene terephthalate (PET)*
- *Polystyrene (PS)*
- *Poly carbonate (PC)*
- *Poly amide or nylon (PA)*

Depending on the requirement, the plastic films are converted into composite structure either in co-extruded form or in laminated form. The packaging materials are available either as 3 layered or 5 layered coextruded film.

- LDPE/ HDPE/ LLDPE. (3 layered co-extruded)
- LDPE/ TIE/ NYLON/ TIE/ LDPE.(5 layers co-extruded)

These types of films have got extensive application for the packaging of fresh milk and edible oil.

But for the consumer products like bakery items, snack foods, pan masala, confectionary, etc., the plastic based laminate in three or four layer are commonly used in order to meet the requirement of barrier properties against moisture, oxygen and light.

Some of the important structure of plastic laminates are given below:

Spices	:	BOPP film/ Adhesive/ LDPE. Metallised PET/ Adhesive/ LDPE. BOPP/ Adhesive/ PAPER/ LDPE.
Snack foods	:	Oriented PET/ Adhesive/ Met PET/ Adhesive/ LDPE. Oriented PET/ Adhesive/ Met PET/ Adhesive Aluminum foil/ LDPE.
Mouth refresher	:	Oriented PET/ adhesive/ Opaque BOPP/ adhesive/ Met. PET/ adhesive/ LDPE.

(vi) Plastic woven sack

Available in laminated or non-laminated forms.

b) Rigid packaging materials

The packaging materials are available in following types:

(i) Metal container – Drum, barrels, tin containers aluminium containers TFS Containers (Tin free steel)

(ii) Glass container – Glass bottle, glass jar carboys, ampules

(iii) Plastic containers – Plastic bottles, drum, barrels, jerican

(iv) Plastic crate

(v) Wooden containers – Box, crate

(vi) Corrugated fibre board boxes

(vii) Fibre drum

(viii) Ply wood container

c) Semi rigid packaging materials

The important types of packaging materials are as follows:

i) Aluminium collapsible tube
ii) Plastic collapsible tube
iii) Composite container
iv) Paper based carton

II) Ancillary packaging materials

The important types of materials which have got application in packaging are as follows:

(i) Printing ink – Flexo ink, gravure ink, offset ink
(ii) Adhesives – Lamination adhesive, pasting adhesive, corrugation adhesive
(iii) Labels – Self adhesive pressure sensitive

(iv) Cushioning materials – Resilience, non-resilience and space fillers
(v) Strapes – Plastic metal,
(vi) Tapes – Paper tapes, plastic tapes
(vii) Nails, hooks, clips, etc.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. How do you classify the package components?

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2. What are the three important types of packaging?

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3. Fill up the following blanks:

a) Full form of PET is ________________________________
b) CPP means ________________________________
c) MAP means ________________________________
d) ‘3P’ stands for ________________________________
e) Cushioning materials are ________________________________

4. Tick (✓) the correct answer:

a) Cellophane is

i) Paper ii) Plastics
iii) Regenerated cellulose

b) Corrugated fibre board boxes are considered to be

i) Primary packaging materials
ii) Ancillary packaging materials

12.3 PROPERTIES OF PACKAGING

Packaging is an integral part of product processing and preservation. It has a direct influence on the system in respect to physical and chemical changes. The barrier properties and packaging materials play a significant role in preservation and thus, extension of shelf life of processed food product.

With the advancement of preservation technologies for food products coupled with the introduction of newer packaging materials and systems, it has been possible to introduce new generation products into the market.

Almost all types of packaging materials are used by food industry. Metal cans made of tin plate have been used by the canneries over the years. However, the thin wall tin containers, welded or cemented joint cans with lead free solders and 2 piece tin plate cans are recently introduced in the market for the packaging of fresh produce. The food products are processed at high temperature and pressure to make containers hermetically sealed. These type of containers provide about one year shelf life to the processed food.

Despite of having the difficulties of breakage and more tare weight, the glass bottles are used extensively for packaging of the processed food products. This material is non-toxic, non-reactive and high temperature resistant. The processed food like tomato ketchup is normally hot filled in glass bottles.

The use of paper board cartons as bag in box for packaging of liquid products like edible oil is widely accepted. Paper board carton with appropriate liner is used for packaging tea.

Plastic containers, because of light weight, easy availability, economical, diversified sizes and shapes and recyclablility property are widely used for food packaging.

Dual ovenable containers made of C-PET (Crystalline PET) have a high heat resistance up to 230°C. These trays can be frozen and then directly heated in the oven and, therefore, are used for packaging of ready to eat products.

High gas barrier plastic bottles are produced by co-extrusion blow moulding process or co-injection blow moulding process have got wide application in food packaging. The polyolefin materials like PE/PP bottles are commonly used.

However, the new development of co-extruded bottle made of PE or PP/ tie/ EvoH/ tie/ PE or PP are used for the packaging of edible oil, tomato ketchup, mayonnaise and salad dressings. PVDC coated PET bottles with improved gas barrier properties are used for beer and wine.

The flexible packaging materials having number of advantages are suitable for the packaging of processed food items. A wide variety of combination of packaging materials are developed to improve the barrier properties of moisture, oxygen, CO_2, and light and thus help to enhance the shelf life of food product. Recently, the application of flexible packaging materials have gone up tremendously due to their light weight, high barrier properties and cost effectiveness. These materials are used as monolayers like PE, BOPP, CPP or as composite structure like 3 layered/4 layered laminated form or 3 layered/5 layered coextruded film for the application of packaging of liquid milk, edible oil, spices, snack food, tea, coffee, etc.

In addition, there are certain innovative technologies like retort packaging, aseptic packaging which play a great role in enhancement of shelf life of processed food product. A retort pouch, made of polyester film/ aluminium foil/ cast polypropylene combination has got the property of with standing high temperature and pressure, while sterilized in the retort. This technology is very common in developed countries but in India this has recently been introduction for ready to eat products.

The introduction of aseptic technology to the Indian market has revolutionised the packaging of liquid food products like milk, fruit juices, etc.

Moreover, vacuum packaging and gas flushing techniques are very common in food packaging. Food products rich in fat tend to get rancid due to oxidation and get spoiled. However, evacuation of air from the package and introduction of inert gas like nitrogen inside the package not only retains the shape of the content but also protects from oxidation. This type of packaging is mostly used for snack food items like chips, namkeen, bhujia, etc. However, the products like tea, coffee, spices, etc., could be packed by using only vacuum packaging as the products are powder in nature to extend the shelf life at ambient conditions.

This clearly stated that different types of packaging materials and systems have got unique properties and these are to be chosen depending upon the requirement and application in packaging of various types of processed food products.

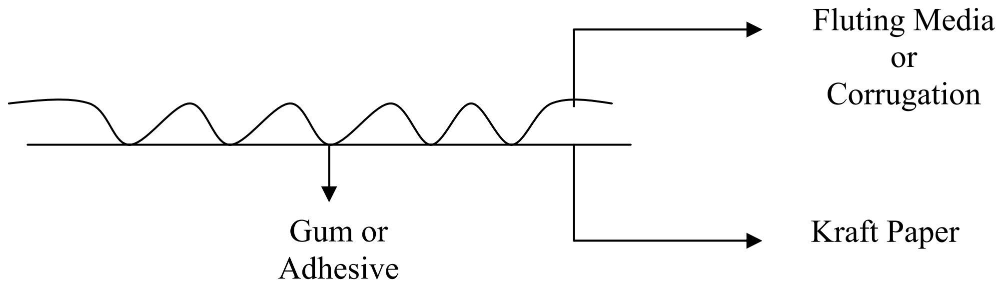
12.4 IMPORTANCE OF SUCCESSFUL PACKAGE

It is strongly desirable to keep the food products as fresh as possible for a longer duration so that these products can be distributed to a longer distance. At the same time, it is also necessary that the package has adequate strength so that the products can be transported without any breakage.

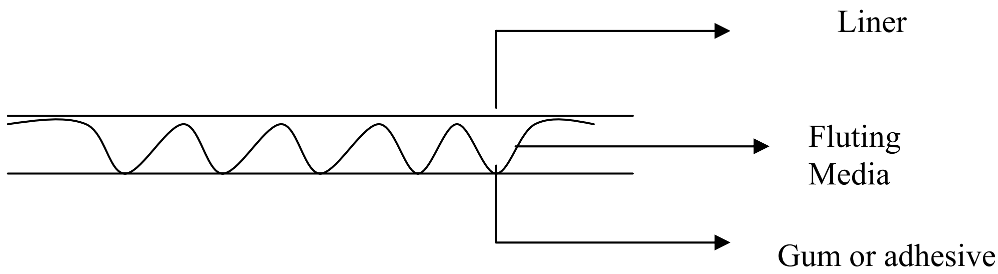
Fresh fruits and vegetables remain biologically alive even after harvest. The physiological function like respiration continues even after the supply of nutrition is cut off. The stored nutrition then begins to be consumed and gets depleted. The metabolic activity of ripening and aging also continues. Due to these facts, it is necessary to make proper ventilation in the package so that the respiration process continues, otherwise the produce will rot or spoil within a short period of time. The use of traditional packages like jute bag and bamboo basket for packaging of fresh fruits and vegetables is now being discontinued as these packages are unable to provide adequate protection to the produce during handling, storage and transportation.

The traditional packages are being slowly replaced by the use of corrugated fibre board boxes. These boxes are made from die-cut corrugated fibre board where the craft papers are passed through corrugating machine to get the fluting media or corrugation and finally stuck into a plain layer of craft paper by means of adhesives or gum to form 2 layer or 2 ply corrugation roll.

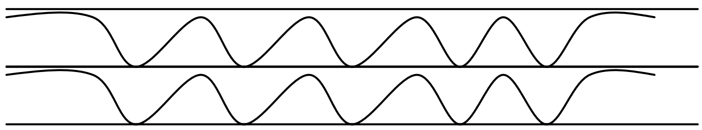
In the same manner, 3 or 5 ply corrugated fibre board boxes can be made by pasting the adequate number of craft liner or facing material. This could be illustrated by the following diagram (Figure 12.1).



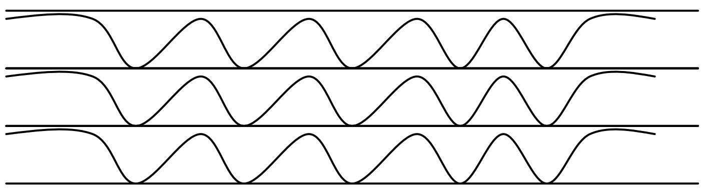
2 ply corrugating roll



3 ply or single wall corrugated fibre board



5 ply or double wall corrugated fibre board



7 ply or triple wall corrugated fibre board

Figure 12.1: Diagram illustrating different plys in a corrugated fibre board

The use of jute or gunny bag for packaging of apples is completely replaced by corrugated fibre board boxes. Similarly, the use of the bamboo busket for packaging of grapes has been discontinued and the fresh grapes are packed only in corrugated fibre board boxes. The new developed boxes are made from die-cut corrugated board with proper ventilation. The boxes are not only having adequate compression strength to prevent the crushing of fruits in stacked condition during storage and transportation but also enhance eye appeal to the consumer through attractive graphics and printing on the outer surface of the packages. The changing trend has substantially reduced the loss of fruits due to damage in transit. These examples clearly indicate that there is an urgent need to have proper package for all types of fresh produce to distribute at distant places by retaining the freshness of the produce. These are easily available, accepted internationally and can be recycled and thus considered to be environment friendly. Sometimes, the outer surface of the boxes are given adequate coating to provide moisture proofness so that packages will not be damaged even after exposing to the high humid condition.

The use of modified atmosphere technology has led to the introduction of newer plastic films, such as OPP (Oriented polypropylene) film, coated by interfacial active agent (such as charcoal) for absorbing water vapour. The other films are:

- PE (Polyethylene) film blended with microporous materials absorbing ethylene gas.
- LLDPE (Linear low density polyethylene) film blended with anti-microbial materials, preventing the growth of bacteria and mould.
- PVC (Polyvinyl chloride) film blended with silver ions for anti-microbial properties.
- Antigas barrier film having micropores which allows oxygen to enter inside the package for respiration and for prolonged shelf life.

There is a wide variety of fresh commodities and each has a different respiration rate and requirements for storage. A judicious selection of the packaging medium is thus very significant to make a successful package for fresh produce.

Similarly, there is a wide variety of processed food products which are produced by using number of ingredients and different processing technologies. This has resulted into wider variation in requirement of packaging for longer shelf life.

You know that shelf life is the time between the production and packaging of a product and the point at which it becomes unacceptable under defined environmental conditions. It is a function of the product, package and the environment through which the product is transported, stored and sold.

The bakery products like bread and biscuit, both made from maida, require different packagings to satisfy the consumer.

Bread has got moisture content of 38 to 40% due to which the crumb of bread is soft in nature and preferred by the consumer. Whenever bread is kept outside, it starts losing moisture and becomes dry and unacceptable to consumers. Hence, bread is to be packed where the packaging materials should have low water vapour permeation or high barriers to moisture content. On the other hand, biscuits are crispy in nature due to low moisture content of about 2 per cent. When the biscuits are kept outside, the product intends to pick up moisture from the environment and becomes soggy and should unacceptable to the consumers. So, the packages for biscuits also have high moisture barriers property where moisture should not move from outside to inside. The properties of foods like ghee, butter or snacks are likely to get changed during storage. The products are fried in oil and when exposed to environment, react with atmospheric oxygen and undergo oxidation. The product becomes rancid resulting into the changes in taste. Moreover, UV light also plays a role to accelerate the oxidative reaction. Hence, the packaging requirement for these items are high barriers to light and oxygen.

Aroma loss in freshly ground spice or stimulating product like tea, coffee is very common. The packaging materials for these items should have high aroma resistance property.

The requirement of packaging for different processed food is required to be understood by you prior to decide the selection of packaging materials. This is possible only by understanding the critical characteristics of the products that means how the product gets spoiled or changes its characteristics or original properties during storage.

Hence, the selection of proper packaging materials with required quality depends upon the requirement of individual variety of processed food product. Considering this, the materials are to be selected so that products can be packed to maintain the quality of food during storage. A successful package can only meet the requirement of desired shelf life of a product.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the important packaging materials used for processed food products?

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2. What are the different types of innovative packaging systems for extending shelf life of food products?

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3. What kind of packaging materials used for fresh produce in place of traditional packaging materials?

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4. Why the processed food products have got different packaging requirements?

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12.5 LET US SUM UP

Food is considered to be one of the basic need of human being for survival, growth of physical and mental ability and good health. This has always played an important role in the rise or fall of economy of the nation because of its effect on the health of population.

It has been reported that there has been an average loss of 25 to 30 per cent of fresh produce in our country which is mainly due to improper handling and inadequate packaging. This has forced us to understand about the importance of packaging and its needs to prevent the material loss.

Food packaging is a system by which the fresh produce or processed one will reach from the production centre to the ultimate consumer in safe and sound condition at an affordable cost. It serves two basic objectives, i.e., marketing and logistics.

The different types of packaging materials have been discussed in detail in this chapter. For processed food, the important packaging materials like metal cans, paper board carton, plastic container and plastic bottle, and flexible packaging materials with different combinations are used. Similarly, the traditional packaging materials like gunny bags or bamboo baskets are being replaced by the introduction of corrugated fibre board boxes with proper ventilation and strength for packaging, handling and transportation of the fresh produce.

In addition, the innovative packaging technologies like aseptic packaging, retort packaging, gas flushing and vacuum packaging for processed food and modified atmosphere packaging for fresh produce have also been discussed. Shelf life is the time between the production and packaging of a product and the point at which the produce first become unacceptable under defined environmental conditions.

The requirement of packaging for different processed food products varies depending on the critical factors of different products. The product requires packaging materials of having moisture barriers, gas barriers, aroma barriers or digest barrier which ultimately play a key role in determining its the shelf life.

12.6 KEY WORDS

LLDPE	:	Linear low density polythylene – a polymeric material.

MAP	:	Modified atmosphere packaging – a packaging system for extending shelf life of fresh produce.
C-PET	:	Crystalline polyster – a polymeric material.
PVDC	:	Poly vinylidine chloride – a coating is given to a polymeric materials to improve the barrier properties.
TFS	:	Tin Free Steel – the base plate is coated with chromium than tin.
Resilience	:	A cushioning material like sponge; it means after pressing it will come back to its original position.
Non-resilience	:	A cushioning material like expanded polystyrene or thermocole, which does not come back after releasing the pressure.
Space filler	:	Cushioning materials like paper cutting, shreded wood wool, used to fill up the space in the package.
Duplex board	:	Two layer of pulp is used to make the paper board
Triplex board	:	Three layers of pulp is used to make the paper board.
Composite container	:	A container where the body is made from paper and the ends are made from either metal or plastics.
Chip board	:	A board made on continuous machine mainly from low grade waste papers. It has got extensive use for making sweet box.
Grey board	:	A board made from mixed waste pulp with or without screenings and having the thickness less than 1 mm, used for packaging of shoes.
Clay coated board	:	High grade bending board, the top of which has been coated with fine clay to produce a surface for printing, mainly used for gift items.
Mill board	:	A homogeneous board made usually of mixed waste papers with or without screenings and mechanical pulp on an intermittent board machine and having thickness not less than 0.5mm.
Straw board	:	A board made from partially cooked straw, bagasse or grass or a mixture of these.
Glassine paper	:	Grease proof and translucent paper.
Waxed paper	:	Dry or wet waxing is done on paper to obtain the resistance to moisture and oil.

VPI paper : This is called vapour phase inhibitor paper. The base paper is kraft paper coated on one side with corrosion inhibiting chemical and is used for protection from rusting.

High gloss paper : High gloss papers are sometimes coated with metallic powder to obtain a decorative finish.

Vegetable parchment : Low grammage chemically bleached paper.

Butter paper : Grease proof paper used for packaging of butter, etc.

Retort pouch : A plastic based laminated pouch which can withstand high pressure and temperature.

12.7 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answer should include the following points:

1.
   - System to deliver the food products from production centre to the consumer in safe and sound condition at an affordable cost.
   - A coordinated system which include production, storage, transportation, retailing and end use.

2.
   - Marketing and logistics functions.
   - To provide the information about the product to the customer and to promote the product to the customer and to promote the product with attractive graphics and printing.
   - To act as a medium of communication and a silent salesman.
   - Logistics functions like containment, protection, apportionment, unitisation, convenience, and communication.

3. 1) Standardisation 2) Price or Cost
   3) Package or Product adoptability 4) Protective level
   5) Handling ability 6) Product packability
   7) Reusability or recyclability

Check Your Progress Exercise 2

Your answers should include the following points:

1.
   - Unit pack, Intermediate packs, Outer or Shipping containers
   - Inner packaging components
   - External reinforcement

2. - Flexible packaging materials
   - Rigid packaging materials
   - Semi rigid packaging materials

3. a) Polyethylene terephthalate
   b) Cost poly propylene
   c) Modified atmosphere packaging
   d) Protection, preservation and presentation
   e) Resilience, non-resilience and space fillers

4. a) Regenerated cellulose
   b) Primary packaging materials

Check Your Progress Exercise 3

Your answer should include the following points:

1. - Metal cans made of tin plate mainly either 3 piece or 2 piece can.
   - Glass bottles as they are non-toxic, non-reactive, and high temperature resistant.
   - Paper board carton like bag in box and lined cartons.
   - Plastic containers as they are light in weight, easily available, economical, and recyclable.
   - Flexible packaging materials like laminated film or coextruded film.

2. - Retort packaging for ready to eat products.
   - Aseptic packaging of liquid food products which have got about one year shelf life.
   - Vacuum and gas packaging for fatty foods in order to prevent oxidation process and thus extends shelf life.
   - Modified atmosphere packaging for extending shelf life of fresh fruits and vegetables.

3. - Dic-cut corrugated fibre board boxes made of either 3ply, 5 ply or 7ply.
   - Boxes should have proper ventilation to facilitate respiration process of fresh produce.
   - Adequate compression strength to resist crushing during handling, storage and transportation.

4. - Processed food products are made of different ingredients.
   - Products have got different initial moisture content (IMC) and critical moisture content (CMC).
   - Critical characters of the products are different like moisture sensitive resulting into the spoilage of products during storage.
   - The packaging materials are chosen depending on the requirement of products to prevent the spoilage and thus to enhance the shelf life.

12.8 SOME USEFUL BOOKS

1. Brody Aaron L. and Marsh Kenneth S. (1986) The Wiley Encyclopedia of Packaging Technology. John Wiley & Sons. Inc., New York.

2. Modern Food Packaging, Indian Institute of Packaging, E-2, MIDC Area, Chakala, Andheri (East), Mumbai, 1998.

3. Packaging of Food Products, Indian Institute of Packaging, E-2, MIDC Area, Chakala, Andheri (East), Mumbair, 1986.

4. Packaging Technology Educational Volumes (Part–2), Indian Institute of Packaging, E-2, MIDC Area, Chakala, Andheri (East), Mumbai, 2001.

5. Sacharow Stanley and Griffin, Jr. Roger C. (1970) Principles of Food Packaging. AVI Publishing Company, Westport, Connecticut.

UNIT 13 PACKAGING MATERIALS

Structure

13.0 OBJECTIVES

After reading this unit, you should be able to:

- describe the manufacturing processes of different packaging materials used for processed food products;
- explain the properties of packaging materials;
- discuss the advantages and disadvantages of packaging materials;
- state the application of packaging materials for different processed food products; and
- define the quality control measures of packaging materials.

13.1 INTRODUCTION

In our country, the packaging technology was not given due importance for long time but recently, the approach has been slightly changed. However, the concept of value addition to the product by means of new types of packaging materials and forms are yet to be recognised by the major quarters of population. Even today, many quarters of community consider that packaging materials always add cost to the product and thus these has been given a low priority. But with the increase standard in living and per capita income, the Indian consumers have moved to new sophistication era resulting in their demand of packaged commodities. The demand of packaging materials also have, therefore, shown a steep rise, particularly in the last three decades.

In fact, the packaging in the country appeared in the 1950's, became noticeable in the 1960's, grew in dimensions in the 1970's and with the advent of the 1980's the industry showed a tremendous progress which is continuing and likely to grow many fold in future. The poor rate of growth in the past had been attributed to lack of awareness, lack of education and skill as well as inadequate support. The other reasons could be the lack of serious attempts on standardisation of packaging materials and systems.

In the wake of industrial growth a number of industries manufacturing and marketing different range of product groups have been setup. Different kind of packages introduced over a period of time have replaced the conventional packs successfully. At the same time, industry strived its best to keep packs with the growing demand and also to cater the export requirement. Moreover, in the WTO era, it has become imperative for the Indian industry to upgrade these technologies to innovate alternate packaging materials at affordable cost to become globally competitive.

Wood, probably the oldest form of packaging medium, still dominates its use in the specific area of packaging like heavy engineering and electronics products and defence articles. But the introduction of fibre board materials like corrugated fibre board box and solid board box have completely replaced wood for the packaging of most of light engineering, automobile, textiles, etc. Today, these materials are considered to be most economical and eco-friendly.

Jute is another type of natural packaging material available in the country and has got extensive application in food grain packaging. This old age system continuing to expand with the new technologies in the combined form and has got newer applications.

Glass is a traditional packaging material. Despite its inherent characteristics like fragility, it is still in use in packaging of processed products due to its reusability.

The indigenous production of tin plates have reduced the import of these materials substantially. But the growth of these materials have been slow due to their expensiveness as compared to other packaging materials like plastics.

Plastics have entered in the packaging scene only from the mid fifty's and early 1960's. These particularly referred to low-density polyethylene and PVC. Subsequently, high-density polyethylene, polypropylene and polyester were introduced. Although, the thermosets were used earlier for caps and closures, but these are being replaced by thermoplastics. In our country, a great revolution has occurred due to the introduction of plastic carry bags in the late 70's and early 80's. Further to this, plastics by virtue of versatility have captured the market in a big way. Meanwhile, the concept of consumerisation has also played a great role in the usage of more plastics for packaging of rice, atta, maida, salt, etc. In addition, plastics packaging materials have entered in the applications of newer systems like blister and skin packaging for processed food, pharmaceuticals, shrink packaging for unitisation, strip packaging for medicine and thermoformed containers for ready to serve food products. With the same pace of development, plastics multilayered collapsible tube has also been introduced in the Indian market for the packaging of toiletries, cosmetics and processed food also.

Aluminium is used as sheets, slugs for collapsible and rigid tubes for packaging pharmaceutical ointments and for foil for making flexible laminates to pack processed food products.

The constant increase in consumer demand has forced to introduce newer packaging system for extending shelf life of food products like fruit juices. One of the most important system, like aseptic packaging system, had been introduced in our country during the early 1970's. Though, there had been certain initial inertia of consumer to purchase these packages due to prohibitive cost but slowly, its advantages were realized. Now, this system has been well accepted and more and more liquid and paste food products are being packed.

In short, packaging is a need based technology. The need of consumer forced to develop newer packaging materials as an alternate media and thus, a wide variety of packaging materials have been invented. But there is always a thrust to develop newer packaging materials at lower price so that more variety of products could be made available in packaged form. The consumption of packaging materials will increase substantially in the years to come.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Write down in chronological order of appearance of packaging materials in the country.

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2. Please tick mark (✓) the correct answer.

a) Which of the packaging material is considered to be the oldest one?

i) Plastics
ii) Wooden container
ii) Paper

b) Which of the packaging material have really gone ahead as compared to others?

i) Aluminium container
ii) Plastics
iii) Glass

c) The most important natural packaging material available in the country is

i) Tin container
ii) Glass
iii) Jute

13.2 GLASS CONTAINERS

Glass, the oldest packaging material, is used as container for over 3000 years. The first glass container was made in Egypt in 1500 B.C. During the first golden age, the Romans produced some exquisite glass ware including containers. This very ancient packaging material has withstood the challenges and competition with many types of packaging materials and the same is being continued till date. With the fast development of science and technology all over the world, newer types of packaging materials like metal, plastic, etc., have been developed resulting into stiff competition with the application of glass containers in packaging. Hence, the use of glass containers have been reduced to a great extent. Despite of having certain inherent characteristics like fragility, tare weight, the glass containers have made an established application in packaging to certain specific areas like carbonated and alcoholic beverages, perfumes, etc. This is mainly due to its certain unique properties which have made it to take a lead over other packaging materials.

I. Properties

a) Chemically inert

It has no inherent property of action which enables the packaging of products without any danger of reaction or spoilage.

b) Non-permeable

Glass does not allow gases, odours, vapours and liquids to pass through its walls.

c) Transparent

You can see the packaged product.

d) Mouldable

Glass containers can be moulded easily in any shape or size ranging from a tiny vial to a 18 gallon carbouy.

e) Strength

The ultimate strength of glass is equal to that of the strongest sheet.

g) Light weight

Glass is as light as aluminium roughly 1/3rd the weight of steel or of a density 2 1/2 times that of water. Progressively, the weight of a given capacity glass container is being reduced by suitable change in design and uniform distribution of glass for increasing the strength of the container.

h) Unlimited supply

Glass container can enter to an unlimited market because of its basic raw materials – sand, lime stone and soda ash which are available in plenty. Arsenic, selenium and cobaloxides are used to make clear glass. Carbon and sulphides are added to make brown (amber) coloured glass. Boron addition provides strength to glass.

II. Advantages

a) This packaging material is used for all types of products like liquid, powder, paste, granules, etc.

b) Glass has got high and low temperature resistance. The processed food products like tomato ketchup is filled hot and can be refrigerated too.

c) Glass containers do not contaminate the contents with crystals or fibres as found in packages made of metals or alloys.

d) Climatic variations do not affect the glass container or the product packed in it.

e) Due to see through property of glass containers, the colour, appearance and consistency of the product can be easily detected.

f) Containers can be made in any size, shape and capacity depending on the requirement.

g) The glass container does not taint, pollute or affect the quality of product packed in it.

h) The closures made of metal, plastic, cork or rubber, depending up on the requirement, can be chosen.

i) Glass containers are impermeable to moisture and gases.

j) Glass containers may be coloured (like brown, green, blue) to protect the product from sum light.

III. Applications

Glass containers have wide applications in the packaging of pharmaceuticals, dairy, liquor, breweries, food, soft drinks, cosmetics, chemicals, inks and other industries. More specially, glass containers are used to pack jams, jellies, squashes, pickles and other preserves. In addition, containers are also used for processed meat and fish products, tea, coffee, spices, baby food, cheese, ghee and vegetable products.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the constituents of glass?

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2. How do you explain the important properties of glass containers?

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3. Mention the important advantages of glass packaging.

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13.3 METAL CANS

Metal cans could be made either from aluminium, tin plate or tin free steel. But the tin plate containers and aluminium containers have got extensive application in packaging. The most popular form of metal containers is tin plate container which has been used in food packaging for the last five decades. Most probably, this packaging material could be considered to be oldest one, next to glass containers, for food packaging industries.

There are two types of tin plate containers namely:

a) Open top container
b) General line container

a) Open top container

This range of containers is a standard variety from which a customer selects the size suitable for its requirement. These are also called as open top sanitary (OTS) cans and are essentially round in shape. A standard open top can is supplied by can making company with bottom seamed to the body and the top ends are supplied as loose. The processed food manufacturer fill the content into the tin can and then seam with the top lid by using a machine called seamer and then the filled tin cans are subjected to heat process. This can is also called as 3-piece can. Open top sanitary cans are widely used for processed food and beverages. One of the recent developments in open top market is the advent of easy open end. This is specially designed and accurately made to components of the can, which is made either of tin plate or aluminium. It is fitted with a "ring pull tab" whenever the customers pull the ring, it gets tear and open the top lid without much efforts. This development has definitely helped the consumer to get away from the traditional method of opening the can with the help of a 'can opener', which requires more time in opening the periphery of the top. Recently DWI can or "Drawn and Wall Iron" can has been developed. These cans are called two piece cans as the cylindrical body and bottom become single piece and lids are separate. These cans score more over conventional 3-piece cans in terms of savings of considerable amount of materials without sacrificing the speed of the machine. But these cans are confined to the applications of pressurised beer and beverages.

b) General line container

General line containers range from tiny containers like pharmaceutical ointment to 15lts capacity containers for vanaspati or biscuits and 20 litre drum for paints and varnishes. A large number of tailor made sizes of containers are added into this category. These containers are round as well as un-round (known as irregular) and are filled with various kinds of fitments made from tinplate, aluminium and plastics. These containers do not have much application for processed foods, rather bakery products, hydrogenated oils and confectionery items are packed in them.

Application

Tin plate containers have got extensive application in packaging of different products like:

i) Beer and beverages
ii) Processed food
iii) Lubricants
iv) Tooth powder/ Talcom powder/ Creams
v) Confectionery
vi) Edible oils
vii) Coffee, baby food and chocolate
viii) Aerosols
ix) Paints
x) Insecticides and pesticides
xi) Thermos flask
xii) Battery cells

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the different types of metal cans?

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2. How do you differentiate between OTS and DWI cans?

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3. What are the main applications of OTS cans?

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4. Give three examples of application for general line can.

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5. Mention five important advantages of metal cans for processed food products.

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13.4 ALUMINIUM FOIL

Over the years, aluminium foil has been established as the best flexible packaging material in terms of barrier properties against moisture, gases, light, aroma, etc., as compared to any other material. No other flexible material can match the characteristics of aluminium because foil retains all metallic properties of aluminium.

Aluminium foil is a continuous web/sheet of aluminium metal rolled to thickness/gauges ranging from 0.005 to 0.2 mm. It is produced from commercial purity aluminium having aluminium content of not less than 98 per cent. Foil in hard or soft temper (i.e., annealed), is available with bright or with one side dull/ matt surface. It is available in plain, coloured, coated, lubricated and embossed forms.

I. Properties

The important properties are as follows:

i) Impermeability: Foil of 0.025 mm thickness is impermeable to moisture vapour and gas transmission.

ii) Non toxic: Due to inertness in nature, the foils are completely non-toxic.

iii) Stable: It does not get brittle at low temperature.

iv) Light and heat barriers: It acts as a barrier against light and heat.

v) ***Tasteless and odourless:*** It neither absorbs any odour from food nor releases any off odour to the food.

vi) *Tagger:* It is pilfer proof diaphragm for tin containers.

vii) *Retort pouch:* Foil is used as middle layer in the three layered flexible laminate helps to withstand temperature and pressure in the retort for extending shelf life of ready to eat products.

Advantages

i) Tearing properties facilitates to use the Web as sealing surface in the blister pack.

ii) Impermeable in nature – extensively used for lamination.

II. Applications

i) *Decorative label:* Foil of 0.009 mm thickness can be laminated to paper for flexible label.

ii) *Confectionery:* 0.009 mm thick foil wax backed by paper like glassine, greaseproof or poster is used to pack chocolates, toffee, etc.

iii) *Biscuit wrappers:* Base laminate of 0.009 mm thick foil and 30 gsm poster paper printed in multicolour and wax coated are used as biscuit wrappers.

iv) *Milk products:* Cheese wrappers are composed of 0.012 mm foil coated by heat sealable, anti corrosive coatings.

v) *Multilayer laminates:* Packaging of instant coffee, Pan masala, snack foods, and also for aseptic pouch.

vi) *Stand up pouches:* These are used for packing ready to serve (RTS) beverages.

vii) *Tea chest lining:* Bulk packaging of tea is done.

viii) *Milk strip:* It is used for capping milk bottles.

13.5 PLASTIC MATERIALS

A plastic material is one which is a solid at ordinary temperatures and allows appreciable and permanent change of form without losing its coherence on the application of pressure and heat.

This quality in synthetic or natural materials containing an organic or inorganic compound of high molecular weight is an essential ingredient. The materials are usually solid in finished form but at some stage during manufacture or processing finished articles can be moulded or shaped by flow. The substances of high molecular weight are synthesized from simple chemical components either by condensation or polymerization reactions, yielding products called synthetic resins. The term ‘plastic’ covers a broader group of materials than the term ‘resin’. Usually, heat and pressure together are used to mould or shape the plastic.

Plastic materials are perhaps the most versatile group of materials used in packaging. The use of plastic is fast growing in India due to easy availability of resins. Plastics are light in weight, very strong, hygienic and non-conductive. They do not rust, rot or react with most chemicals.

The development of plastics has resulted into its application in many ways despite its appearance in the market much later as compared to other packaging materials.

The plastic resins are generally categorised as thermoset or thermoplastic resin. Thermoset resins are those materials which can be heated and set to a definite shape but unable to change into another shape by application of heat. The products like electrical switch and other liner materials made of bekelites are covered under this category. Whereas the thermoplastic materials are flexible in nature. These materials can be changed into different types of plastic films with the help of heat application and further, these could be melted and convert into resin form. For example, different types of plastic films used in packaging may be converted into recycled plastic resin materials with the application of heat.

In the current scenario, about one third of all thermoplastic materials manufactured are used in packaging. The plastic materials used for packaging include the polyolefins, principally polyethylene, and polypropylene, poly vinyl chloride (PVC), polystyrene(PS) and polyethylene terephthalate (PET). Out of these about two thirds are used for packaging of food and beverages. Plastics offer distinct advantage over other packaging materials due to its important characteristics like light weight, good mechanical strength, flexibility and recyclability. These materials have excellent barrier properties towards moisture and gases and thus have got wide application in the packaging of food products.

Some of the important thermoplastic materials which have got extensive application in packaging are normally classified into different group based on the polymerisation process and molecular structure like

a)	Polyolefins	–	Polyethylene and Polypropylene (PP)
b)	Polyvinyl group	–	Polyvinyl Chloride (PVC)
c)	Condensation polymer	–	Polyester (PET), Nylon-6 or Polyamide (PA)
d)	Styrene polymers	–	Polystyrene (PS) and Expanded polystyrene (EPS)
e)	Carbonate group	–	Polycarbonate (PC)

a) Polyolefins groups

Depending upon the molecular weight and density, the polyolefins group materials are available in different forms. The important properties of these materials are given below:

i) Low density polyethylene (LDPE) film

- Density ranges from 0.910 – 0.925 gms/cc
- Average molecular weight is 3×10^5
- Resistance to heat (82 – 100°C)
- Translucent type of clarity
- Water absorption is 0.015%
- Permeability to gas is 1.0 cc/m^2/ 24hrs at 27°C and 1 atmospheric pressure
- Good tensile strength properties and high percentage of elongation.
- Good dart impact resistance

- Resistant to weak acids and alkalies
- Good barrier to moisture vapour

*ii) **Linear low density polyethylene (LLDPE)***

- High film tensile strength properties as compared to LDPE
- High percentage of elongation as compared LDPE
- High tear strength properties
- Better stress crack resistance and low temperature brittleness
- Improved stiffness properties
- Excellent puncture resistance
- Excellent heat seal properties

iii) Medium density polyetheylene (MDPE) film

- Density varies from 0.926 – 0.940 gm/cc
- Average molecular weight is 2×10^5
- Resistance to heat (105 – 121°C)
- Translucent type of clarity
- Percentage of water absorption is 0.01
- Permeability to gas is 1.33 cc/m^2/24 hrs at 27^0 and 1 atmospherics pressure
- Very resistant to weak acids, alkalies, etc.
- Effect of sunlight is yellow.

iv) High density polyethylene (HDPE) film

- Density varies from 0.941 – 0.965 gm/cc
- Average molecular weight is 1.25 x 10^5
- Resistance to heat is 121^0C
- Opaque in nature
- High barrier to moisture vapour
- Permeability to gas is less as compared to other polyethylene films
- Effect of sunlight is yellow

v) High molecular high density polyethylene film (HMHDPE)

- High mechanical strength is both directions
- Pleasant white translucence in clarity
- High tear resistance properties.
- Does not impart any taste or odour
- Suitable for food contact application.
- Less elongation as compared to other polyethylene film.
- Excellent moisture barrier properties

vi) Polypropylene (PP) film

- High tensile strength
- High chemical resistance and high temperature performance than HDPE
- Very low permeability to moisture vapour and gas compared to polyethylene
- High transparency
- Chemical inertness
- High softing point

b) Polyvinyl chloride (PVC)

- It is hard, brittle and transparent material

- Low GTR
- Moderate WVTR and good resistance to fat and oil
- Glass like clarity
- Good mechanical strength
- Retention of flavour
- Excellent printability
- Lower weight/ volume ratio
- Resistant to chemicals

c) Condensation polymer

i) Polyester film (PET) film

- It has got excellent gloss
- Very low moisture and gas permeability.
- High mechanical strength
- Resistant to tear, puncture, burst and flex crack
- Dimensionally stable over a wide range of temp. from
- 70C° to + 130°C
- Excellent machinability
- Excellent printability
- Light in weight
- Free from all kinds of additives
- Good surface properties for metallization

ii) Polyamide or Nylon-6 film

- High mechanical strength
- High elongation capability
- Excellent resistance to cutting, perforation, abrasion and bursting
- High chemical resistance to oils and fats
- Outstanding impermeability to gases and vapours
- Easy printability
- Easy metallising
- Economical
- Could be biaxially oriented

d) Styrene polymers

i) Polystyrene (PS)

Polystyrene is not flexible in nature unlike LDPE and PP and is mostly used as rigid containers in the field of packaging. The important features or properties of this polymer are as follows:

- Crystal clarity of containers
- Availability in attractive light or dark colours
- Lustrous finish
- Rigidity and dimensional stability
- Resistant to chemicals
- Easy processing
- Good barrier to moisture.
- Ability to take post moulding decorations like hot stamp foiling, screen printing, inlay foil moulding, etc.

ii) Expanded polystyrene (EPS)

Expanded polystyrene (EPS) is neither flexible nor rigid in nature rather the material is cushing in nature. Normally, the material is called 'thermocole' which has extensive application in the packaging of electronic and light engineering products. In addition, it is also used for the packaging of sea foods. These materials are manufactured in the following forms, i.e., rigid sheets, flexible sheets, granules, cushion moulded and general purpose moulding.

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.

b) Compare your answers with those given at the end of the unit.

1. What is aluminium foil?

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2. Write the five important properties of aluminium foil.

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3. Indicate four important application of aluminium foil in food packaging.

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4. How do you define plastic material?

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5. What are important groups of polymeric materials used in packaging?

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6. Indicate True or False for the following:

   i) Polypropylene films are more transparent than polyethylene films.

   ii) Polyester films have got more gloss as compared to other plastic films.

   iii) The moisture barrier properties of polyethylene is better than nylon film.

   iv) Polyester film has got better oxygen barrier properties than polyethylene.

   v) Expanded polystyrene has got good cushioning property as compared to polystyrene.

13.6 PLASTIC CONTAINERS

Plastic containers are manufactured with the help of different processes and are available in different forms like bottle, drums, carboys, jars, etc. These have wide application in packaging of processed food products.

The plastic containers are manufactured by means of different processes like:

a) Blow moulding process
b) Extrusion blow moulding process
c) Stretch blow moulding process
d) Injection blow moulding process
e) Coextrusion blow moulding process

13.7 COLLAPSIBLE CONTAINERS

The collapsible containers are mainly available in the form of tube for packaging application. The collapsible tubes are either made from multilayer plastics or aluminium. The aluminium collapsible tubes have been used for long time for the packaging of pharmaceutical products. Now a days, number of products like tooth paste, ayurvedic medicines, cosmetics, stationery, gum, etc., are being packed in collapsible plastic tubes. Due to this innovation, consumers have got alternative packaging materials for the packaging of same products. But it would be necessary for you to understand in detail about both the packaging materials and also applications.

I. Alluminium collapsible tube

The collapsible tube is manufactured by means of extrusion process. However, after extrusion of aluminium slug stampings, tubes remain hard and do not collapse. Tubes are then subjected to annealing process after trimming and threading operation. The annealing is done to impart softness and turning away of greases and other minor extraneous impurities at high temperature. The dimensional accuracy beginning with the slugs punched out from extruded/rolled strips right through the manufacturing process should have a high accuracy with near 'nil' tolerance. Extrusion at a very high pressure, 40 tonnes horizontal or vertical, 'blows' the slug into tube.

After the annealing is over, the tubes are given an enamel coating which is dried for about six minutes in a zig zag conveyor type oven. Then the tubes are printed. Once the tube is ready, it is subjected to capping operation.

Advantages

i) Temper proof: Cannot be refilled or reused.

ii) Protective: Contents remain well protected and free from contamination.

iii) Elegant: Attractive, posses a bright surface and lend themselves to trouble free printing.

iv) Non-toxic and hygienic: Non toxic, non-absorbant and hygienic. Impart no taste, flavour, odour or colour to contents.

v) Light weight: Reduces transport and handling cost.

vi) Complete collapsibility: Highly ductile and ensures complete collapsibility.

vii) Easy availability: Increased production of aluminium has resulted in easy availability of raw material.

viii)Economical: Unbreakable and easy to use and carry.

Applications

a) *Industrial products:* Adhesives, artist's colour, paints, duplicating inks, lubricants and rubber solutions are packed.

b) *Cosmetics and toiletries:* Cosmetic creams, shampoos, deodorant depilatories, hair cream, hair dyes, shaving cream and tooth paste, are packed.

c) *Food products:* Chutney, condensed milk, honey, mustard cream, tomato ketchup, etc., are packed.

d) *House hold items:* Cream detergents, insecticides and rodenticides, shoe polish, mosquito repellent creams, etc., are packed.

e) *Pharmaceuticals:* Antiseptic cream, pharmaceutical creams, ointments, vaginal jellies, veterinary creams, etc., are packed.

II. Multilayer collapsible plastic tube (Lamitube)

The multilayer collapsible plastic tube, commonly known as 'Lamitube', has been introduced in the Indian market recently and now it has taken a lead in many areas by overtaking the aluminium collapsible tube.

The tubes are produced by extruding a continuous tube by a single or more extruders and then cutting into its required length. The tube shoulder is compression moulded and then welded to the tube in line operation. The tubes are then printed separately in multicoulor graphic. As the tube is seamless and printed individually, the printing is continuous all around the tube. A lacquer coat is given further to protect the surface and provide necessary surface finish.

Applications

- Mainly used for different types of cosmetic products like lotions, cream, spray or liquids.
- In toiletry products like tooth paste, shaving cream, etc.
- Available for industrial products like greases, varnishes and creams used for automobile industry.

13.8 COMPOSITE CONTAINERS

A composite container is a canister or a container made from more than constituent material, generally consisting of paper, boards and kraft papers with metal or plastic ends. It is also called as Combican. A laminated composite container is a container made from kraft papers and boards, laminated with polyethylene or aluminium and heat sealed with the membrane to make it completely leakproof. Because of this unique heat sealing property, the aroma retention capacity of the container increases and permeability of moisture vapour decreases

Applications

i) Food products like custard powder, masala powder, etc.
ii) Detergents and detergent powders.
iii) Pharmaceutical products like tablets.
iv) Pesticides.

I. New Developments

Leak proof composite containers are the new addition where the inner layers are made in such a manner that double seaming of the cans become possible to pack liquid product.

The new developed composite can becomes suitable for the packaging of fruit juice, fruit pulp, preservatives, lube oil, motor oil, tooth powder, talcom powder, etc.

Advantages

i) Acts as an alternate packaging material to tin plate container.

ii) This is disposable packaging and can be used for filling of goods with shelf life of 1-2 years.

iii) Composite container is environment friendly.

iv) The stability of the can for a volume upto one litre is as good as tin or glass containers.

v) Seaming or sealing can be effected on the same line as tin plate containers.

Check Your Progress Exercise 5

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the important processes involved for the manufacturing of plastic containers?

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2. Write five important properties of plastic containers.

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3. What are the important types of collapsible containers?

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4. Mention five important advantages of aluminium collapsible tube.

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5. Explain the important applications of 'Lamitube'.

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6. What do you mean by Composite can?

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7. How many methods are available to manufacture composite cans?

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8. What is the new development in Composite containers?

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9. Write three important applications of Composite can.

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13.9 LET US SUM UP

Packaging is considered to be a need based technology. Depending on the requirement of consumer, the development of packaging is also being occurred. On the one hand, continuous development of food technologies resulted into production of new types of products requiring innovate variety of packaging materials and packages to provide effective barrier properties and adequate strength for longer shelf life. On the other hand, the consumers are demanding for lighter, cheaper, durable and attractive packaging materials or packages. This has compelled to develop variety of packaging materials which could be either rigid, semi rigid or flexible in nature. The packaging materials converted directly into package form to pack the processed food products are termed as primary packaging materials. In addition, certain packaging materials like adhesive, printing ink, etc., are called as ancillary packaging materials.

The packaging materials like glass containers, metal containers, plastic containers, composite containers and collapsible containers used prominently for the packaging of processed food products have been discussed in this chapter. The manufacturing process, types of containers, their properties, application in packaging and important quality measures with respect to each materials have also been described in detail.

There has been tremendous use of flexible plastic packaging materials for the packaging of processed food products in the form of consumer packages. These materials are being preferred by the consumer mainly due to thinner, cheaper and lighter in weight.

Though, there has been lot of criticism by the environmental scientist about the application of flexible plastic materials, but there is a constant growth of consumption of these materials. Due to this fact, the properties of these materials have been covered in this chapter.

You have also learnt about another important packaging material the aluminium foil. Its being flexible in nature and has high barrier properties against moisture, gases, light, aroma, etc., this particular material is extensively used as substrate in the flexible laminate to meet the customers requirement. In short, all the important packaging materials, manufacturing processes, properties and applications have been discussed in this chapter.

13.10 KEY WORDS

WTO : World Trade Organisation

Annealing : Regulated way of cooling of an article to eliminate internal stress and thus breakage.

Throat	**:**	The channel of the furnace through which the molten glasses are passed away.
Ring pull top	**:**	A newly designed lid of the can where the lid gets opened up through tearing by puling the ring.
Dead fold characteristic	**:**	It is the characteristic of soft annealed aluminium foil. While the foil is folded, it remains in folded condition and does not come back.
Grease proof	**:**	It is the resistance of aluminium foil by which there will not be any seepage of oil or grease on the other side.
GTR	**:**	Gas Transmission Rate. It is an important property of plastic film.
WVTR	**:**	Water Vapour Transmission Rate. It is another important property of plastic film.
EVAL	**:**	Ethylene Vinyl Alcohol. It is another polymer.
LCC	**:**	Leak proof Composite Container. Enables to make double seaming so that liquid products can be packed.
UV curing	**:**	The drying of printed surface under ultra violet light which improves scuffproofness property.
Tensile strength	**:**	The strength or force by which the polymeric material breaks while under tension.
Parasite	**:**	The thermoplastic material when extruded in the form of pipe under blow moulding process is called as parasites.
Billets	**:**	Billets are the rectangular blocks of caste metal, used for the manufacturing of aluminium foil.

13.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answers should include the following points:

1. i) Wood is the oldest packaging material appeared in the beginning of 1950 for the packaging of heavy engineering and electronic products.

   ii) Jute fibre is considered to be the second appearance as natural packaging material. The material has got tremendous application in packaging of food grains.

iii) Glass containers have appeared in the market as packaging material especially for the packaging of pharmaceuticals, alcoholic beverages, etc.

- Plastics materials have entered in bigway during the period of mid fifties and early 1960's. Initially, polyethylene and PVC have shown the application in packaging.
- In the late 1970's and early 1980's, plastic carry bags have been introduced in the Indian market. Subsequently, these materials have taken a lead over other materials for the packaging application.

2. a) Wooden containers
   b) Plastics
   c) Jute

Check Your Progress Exercise 2

Your answers should include the following points:

1. • The main constituents are sand, lime stone and soda ash.
   • Other ingredients like arsenic, sclenium and cobaloxides are added to make clear glasses.
   • Boron is added to make it stronger.
   • Carbon and sulphides are added to make amber (brown) coloured glass.

2. • Inertness, non permeable, transparent, mouldable
   • Impact strength, light weight and unlimited supply

3. • Used for all types of product packaging
   • High temperature resistance
   • Can be made in any size, shape and capacity
   • Impermeable to moisture and gases
   • Can be made in different colour depending upon the requirement

Check Your Progress Exercise 3

Your answers should include the following points:

1. • General line can
   • OTS can

2. • Open top sanitary (OTS) cans are three piece cans where as Drawn and Wall Iron (DWI) cans are tow piece cans.
   • Open top sanitary cans are mainly used for processed food but the other one is confined to the application of pressurised beer and beverages.

3. • Processed food
   • Edible oil
   • Coffee, baby food and chocolate
   • Paints, insecticides and pesticides

4. • Hydrogenated fat or vanaspati
   • Bakery products
   • Confectionery items

5. • Can be fabricated readily
   • Imperable to light, gases and moisture
   • Non-toxic
   • Amenable to heat sterlization
   • Amenable to printing

Check Your Progress Exercise 4

Your answers should include the following points:

1. A continuous sheet of aluminium metal rolled to thickness ranging from 0.005 to 0.2 mm.

2. Impermable, non toxic, light and heat barriers, tearability, moisture and gas barrier.

3. • Lidding foil, biscuit wrapper.
   • Decorative label, tagger and an important substrate of flexible laminate

4. • A plastic material is a solid at ordinary temperature and allows appreciable and permanent change of form without losing its coleurence on the application of pressure and heat.

5. • Polyolefin group
   • Polyvinyl group
   • Condusation polymer
   • Styrene polymers
   • Carbonate group

6. i) True ii) True iii) True
   iv)True v) True

Check Your Progress Exercise 5

Your answers should include the following points:

1. • Injection blow moulding
   • Co-extrusion blow moulding
   • Extrusion blow moulding
   • Stretch blow moulding

2. • Can be made in any size, shape and capacity
   • Good impact resistance
   • Low permeability to gases and moisture vapour
   • Customer friendly due to innovative opening device
   • Smooth finish surface enhance eye appeal

3. • Aluminium collapsible tube
   • Lami tube

4. • Tamperproof

- Non-toxic and hygienic
- Elegant
- Economical
- Light weight

5. - Cosmetic products
   - Toiletries products
   - Industrial products like greases

6. A can made of dissimilar material where the body is made from paper and the ends are made either from plastic or metal.

7. - Convolute
   - Spiral winding
   - Lap seal method

8. Leak proof composite can which could be used for packaging of liquid products like fruit juice, tube oil etc.

9. - Detergent powder
   - Pesticides
   - Pharmaceuticals products

13.12 SOME USEFUL BOOKS

1. Packaging Technology Education Volumes (Part 1) (2001) Indian Institute of Packaging, E-2, M.I.D.C. Area, Chakala, Andheri (East), Mumbai.
2. Brody Aaron, L. and Marsh Kenneth, S. (1986) The Wiley Encyclopaedia of Packaging Technology.
3. Plastics in Packaging (1986) Indian Institute of Packaging, E-2, M.I.D.C. Area, Chakala, Andheri (East), Mumbai.
4. Bikales Borbert, M. (1971) Moulding of Plastics – Wiley Interscience, a division of John Wiley & Sons Inc, New York.

UNIT 14 PACKAGING PROCESS AND MACHINERY

Structure

14.0 OBJECTIVES

After reading this unit, you should be able to:

- describe about the packaging systems for the transportation of fresh or chilled fruits and vegetables;
- explain the mechanism of various packaging systems for processed food products;
- discuss about the manufacturing processes of different packaging materials; and
- define the machinery, techniques and processes used for packaging processed food products.

14.1 INTRODUCTION

In India, the processed food industry requires primarily the technology in three areas. These are food preparation, packaging and techniques that allow the extension of shelf life of food products. Moreover, the constant research work in the field of food technology has made it possible to develop newer products which require different packagings. At the same time, there has been continuous effort by the industries as well as Government to promote the exports of processed food products. Exportable products require different packagings in terms of durability, higher strength properties, attractiveness and also shelf life.

In order to meet the requirement of export market, there has been enormous development of packaging technology in terms of newer materials, systems and machinery. These developments have not only made it possible to compete with the International brand but also made a position on the shelf of super markets.

Moreover, the newer system of packagings have made the products available throughout the year by enhancing the shelf life. At the same time, there has been enormous development in the packaging machinery also. The newer types of packaging machinery accelerated the productivity with high accuracy and low wastage.

On the other hand, the conversion technology of packaging materials resulted in the availability of various options for processing technology. This technology enabled to manufacture newer types of packaging materials having high barrier properties in order to improve the shelf life of processed foods and higher impact strength to withstand shock and vibrations during handling, storage and transportation. This conversion processes also enhance the productivity with low energy inputs and reduce the cost of packaging materials.

However, there is a constant need to upgrade the existing processing machinery by way of incorporating newer techniques and systems so that the Indian food products and packages could become globally competitive.

14.2 PACKAGING OF FRESH/CHILLED FRUITS AND VEGETABLES

Fresh or chilled (at 4^0C temperature) fruits and vegetables are basically living tissues, high in water content and diverse in terms of morphology, composition and physiology. The package design depends on the requirement of the produce within the frame work of handling and marketing system. The main causes of deterioration in fresh produce are metabolic changes, mechanical injury and attack by pests and diseases. Though, there are variety of packages but there is no rigid rule that a particular material or style is to be followed for a particular type of fruits and vegetables.

I. Product characteristics of fresh produce

i) Highly perishable in nature and are very easily affected by the climatic conditions, distribution hazards and microbial decay.

ii) Respiration process of fresh produce releases oxygen and carbon dioxide. Rapid respiration results in fast ripening or aging of the produce.

iii) Loss in moisture of fresh fruits and vegetables during storage and transportation resulting into drying causing wilting, shrivelling and loss of rigidity. In addition, there will also be loss in weight.

iv) Appearance of microorganisms like bacteria and mould.

v) Very low temperature causes chilling injury which damages the delicate tissues of fresh produce and thus restrict the shelf life.

vi) Changes in colour, texture, odour and flavours.

II. Requirement of package design

a) Pre-cooling

Pre-cooling of fresh fruits and vegetables after harvesting is required to slow down the enzymatic and respiratory activity, minimize susceptibility to micro organisms and to reduce water loss and ethylene production. Pre-cooling helps in removing the field heat prior to storage. The different methods of pre cooling are forced air cooling, vacuum cooling and hydro cooling.

b) Ventilation

The package should be provided with proper ventilation holes during transportation. Cold air is constantly circulated through the container to remove the heat transmitted during the cooling process.

c) Mechanical damage

The package should have adequate impact strength to withstand the shock and vibration which occur during handling, storage and transportation resulting into mechanical injury of fruits and vegetables. In addition, the fresh or chilled produce will have bruising affect during transit due to vibration.

III. Packaging materials

The packages for fresh fruits and vegetables can be classified as:

A) Consumer/ Retail packs

B) Transport/ Bulk packs

A) Consumer or retail package

Consumer packages are small in size designed to hold half dozen or one dozen fruit or ½ kg to 1 kg vegetables. There are many types of consumer packs used for the packaging of fresh fruits and vegetables. The selection for the type of consumer pack depends on marketing characteristics of the product. The most commonly used packages are listed below:

i) *Flexible plastic film:* Plastic pouches made of LDPE, PVC or PP are used for the packaging of horticultural produce.

ii) *Trays with overwrap:* The trays used are usually made of moulded pulp tray or thermoformed plastic materials like EPS, PVC and PP. The produce is placed in individual cavities so that abrasion and brushing is avoided. Transparent LLDPE based cling films are used to wrap the trays. The films are semi permeable and allow exchange of gases for respiration of the product.

iii) *Plastic punnets:* Punnets made from either PET or PVC are food grade, odourless and light in weight. These are also amenable to stacking during storage.

iv) *Plastic net bag:* The plastic net bags have feature to stretch and accommodate all sizes and shapes of produces. These nets are generally made of HDPE or PA (Polyamide).

v) *Foam sleeve:* This is a tubular film made of polyethylene foam available in different colours, diameters and lengths. It is hygienic, non-toxic and odourless. This could be easily slipped over the individual fruit in a snug fit form.

vi) *Shrink wrap:* This is one of the latest trend to shrink wrap the individual produce. This pack restricts the moisture loss. In addition, it provides see through property. The films most commonly used are LDPE or LLDPE.

B) Transport packs

The normal size of transport package is between 15 to 20 kg which is suitable to carry by hand. Transport packages can be broadly classified as follows:

(a) Rigid containers:

i) *Bamboo basket:* Bamboo baskets are widely used even today as transport pack for domestic market. These are available in various shapes, sizes and designs but they do not have the rigidity and stackability during long distance transport.

ii) *Wooden box or container:* The conventional baskets are replaced by wooden box. However, the use of wooden boxes are discouraged now a days as they directly promote deforestation.

iii) *Plastic crates:* Crates made of HDPE or PP have got high impact strength. In addition, these are reusable, amendable to withstand journey by different mode of transportation and also provide good stackability during storage and transportation.

iv) *Solid fibre board:* These materials have got very limited application.

v) *Corrugated fibre board boxes:* The boxes are widely used as shipping containers for fresh produce because of numerous advantages over wooden boxes.

vi) *Plastic corrugated box:* These are usually made of HDPE or PP. HDPF have got light impact strength and low degradation by Ultra Violet radiation while polypropylene has a better scratch resistance.

(b) Flexible containers:

Sacks made of either plastic, jute or paper could be used for the packaging of horticultural produce. This facilitates breathing of fresh produce and have also got high stackability during storage and transportation.

IV. New trend

Modified atmosphere packaging (MAP) is a system involving the removal of air from the packages and replacing with a single or mixture of gases. The gas mixture used depends on the type of the produce.

The MAP system is a dynamic one where respiration and permeation occur simultaneously. Factors affecting both of these must be considered when designing a package. The selection of a film or combination of more than one film (laminates) depends on the expected transpiration and respiration rate of the produce.

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the important characteristics of fresh fruits and vegetables?

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2. What are the different packaging options for fresh fruits and vegetables?

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3. Explain the new trend of packaging for the enhancement of shelf life for fresh fruits and vegetables.

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14.3 PACKAGING OF FROZEN FOODS

Freezing is considered to be one of the most important technique for the preservation of food products. This technique is mostly employed for the preservation of fresh fruits and vegetables. At low temperature, both microbial growth rate and metabolic activity of foods are reduced by a factor of 1/2 to 1/3 for each 10°C drop in temperature.

Frozen fruits and vegetables should be stored nearly at –16°C to maintain the superior quality. Storing frozen foods at temperatures higher than –16°C increases the rate of deterioration and reduces their shelf life. Fruits and vegetables of high quality and good nutritional value can be achieved under frozen conditions. However, these are primarily based on the following aspects.

a) Physical and chemical changes which take place during freezing process

b) The effect of freezing on fruit and vegetable tissues

c) Food spoilage microbiology

I. Critical factors of frozen food

During freezing operation fruits and vegetables undergo certain physical and chemical changes which affect their quality. Under physical changes, the following critical aspects are to be considered.

i) Moisture is lost as ice crystals evaporate from the surface of the product, producing freeze burn – a grainy, brownish spot where the tissues become dry and tough.

ii) This freeze-dried surface area is prone to development of off flavour.

iii) Freezing of fruits and vegetables consequences into freezing of water resulting into rupturing of cell walls. The texture of the produce, when thawed, becomes much softer as compared to raw produce. This kind of physical change is generally found in vegetables like tomato, which become mushy and watery. However, this type of change is less noticeable in high starch vegetables such as peas, corn and beans.

Similarly, some chemical changes also occur in fresh fruits and vegetables during freezing. The important critical factors to be considered are:

i) Development of brown colour and loss of vitamin C due to enzymatic reactions. In order to prevent this reaction, there is a need to inactivate the enzymes by blanching. This process also helps in destroying the microorganisms present on the surface of fruits and vegetables.

ii) The development of rancid oxidative flavours is another chemical change that takes place through contact of the frozen product with air.

Most of frozen fruits maintain high quality for 8 to 12 months. Unsweetened fruits lose quality faster than those packed in sugar syrup as sugar itself acts as a preservative. Similarly, most of frozen vegetables maintain a high quality for 12 to 18 months at –16°C or lower. Longer storage of frozen fruits and vegetables may not be unfit for consumption but the quality of produce is reduced drastically.

II. Requirement of packaging

Considering the critical factors responsible for the physical and chemical changes of produce that occur due to freezing, the packaging materials should have the following properties to meet the requirement.

i) The packaging materials should have high moisture barrier property so that the material could be used as wrapper to prevent “freeze burn”.

ii) Frozen foods also require the packaging material with high oxygen barrier property so that the products could be wrapped to prevent the development of oxidative rancid flavour.

iii) The packaging materials should have light barrier property so that the effect of UV light in the oxidative reaction could be minimised.

iv) The material should have good printability and heat seal property.

v) The packaging materials should also have low temperature resistance so that wrapped product could be freezed at low temperature without having any crackness on the materials.

III. Types of packaging materials and packages

Frozen fruits and vegetables are normally subjected to blanching or sealing process to destroy the enzymes. Subsequently, they are packed prior to freezing operation. In general, there are two types of packages namely dry pack and tray pack.

a) Dry pack

This is the method used to pack the blanched and drained vegetables into containers or freezer bags. The vegetables like broccoli, pack tightly in the freezer bag by arranging the heads and stems in alternate manner so that there should not be any air inside the bag. This kind of bag is normally made from either low density polyethylene (LDPE) or PVDC coated plastic film, 3 layered laminate structures with PET/Al-foil/Polyethylene or five layered coextruded multilayered plastic film (PE/Tie/ Nylon/ Tie/ PE). These type of packaging materials have high impact strength, low temperature resistance and moisture barrier. These packages can be subjected to freezing at a temperature of –16°C or below.

b) Tray pack

This type of packages, where the trays are made of collapsible corrugated fibre board, are made from either 3 ply or 5 ply. However, top layer of the board is coated with plastic film to provide water proof property. This kind of board is converted into tuck-n-type tray by means of die-cut machine. However, one single layer LDPE film is spread on the tray so that the produce may not have direct contact on the inner surface of the board. The blanched and drained vegetables are then placed on the tray. As an alternative, the plastic bag filled with blanched and drained vegetables can further be packed into collapsible tray.

IV. Properties of packs

i) Tray pack can be more attractive by way printing on the surface as compared to dry pack.

ii) While freezing, tray pack may not be deformed as the package will have adequate strength. But there is a possibility of deformation or appearance of wrinkles on the products during freezing.

iii) Dry packs are cheep as they are made from either single or multilayered flexible packaging materials.

iv) Dry pack made of plastic bag should have good heat seal property whereas the tray pack should have high compression strength.

v) In both the cases, the selection of flexible packaging material is very important as the materials should have low temperature resistance.

V. New developments

i) Aluminium tray

Tray can be made from aluminium sheet instead of paper board. This type of package can be stored at even –40°C without any damage to the tray. Moreover, the oxygen barrier property is excellent and prevention of freezer burn is good.

ii) Plastic tray

Plastic tray made of HDPE is extremely used as transport package for the storage of fruits during freezing. However, the individual fruit is washed properly, packed in plastic bag with sugar syrup, heat sealed and then stored in plastic tray for freezing.

VI. Application

The following fruits and vegetables are normally available in frozen form.

A) Fruits **:** Apples, apricots, peaches, straw berries, pine apples, citrus fruits, etc.

B) Vegetables **:** Beans, carrots, cauliflower, peas, potatoes, pumpkin, spinach and other green vegetables.

Check Your Progress Exercise 2

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What changes could occur during freezing of fruits and vegetables?

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2. Write down the important critical factors to be considered for frozen foods.

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3. Discuss the important requirements of packaging of frozen foods.

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4. Mention two most important types of packages used for frozen foods.

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14.4 PACKAGING OF DEHYDRATED FRUITS AND VEGETABLES

Dehydration of fruits and vegetables or removal of water from fruits and vegetables is the simplest techniques of food preservation. There are number of products which are available in the dehydrated form, for example raisin, mushrooms, apples etc.

The drying process has to be controlled so as to avoid common problems such as tissue shrinkage, browing and heat damage, case harding, loss of rehydrability or solubility and loss of flavour volatiles. Many a times, the dehydrated product is subjected to agglomeration or instantanization for better solubility and quality.

I. Product characteristics

i) Highly moisture sensitive and tends to absorb moisture resulting into stickiness.

ii) Changes in colour, texture and odour during storage.

iii) Susceptible to microbial spoilage due to the appearance of fungal growth on the surface.

iv) Certain products are oxygen sensitive resulting into rancidity which affects the taste of products.

II. Packaging requirement

i) Air tight package

The package could be made of high moisture barrier plastic films like coextruded plastic film, polyester/ polyethylene laminate, etc. The package should be air tight in the form of either pillow pouch, made in FFS machine, or 3 sides sealed pouch.

ii) Plastic containers

The plastic containers made of either PET blow moulded HDPE could be used.

iii) Vacuum package

The dehydrated fruits and vegetables could be packed in plastic pillow pouch and then subjected to vacuumisation. The vacuum pack will help to avoid oxidation rancidity and also protect the product from moisture absorption. Thus, the shelf life of product will be enhanced. The plastic pouch could be made either from laminate made of aluminium foil/polyethylene or polyester/ polyethylene.

iv) Gas package

To enhance the shelf life a product can be packed by creating a vacuum and flushing with inert gas in a container. As an alternative, laminated plastic pouch could be vaccumised, gas flushed and sealed in automatic FFS machine.

v) Pouch in box

The vacuum pouch of dehydrated products could further be packed into composite can and sealed at top to make it air tight. In some cases, the vacuum pouch could to be packed in either carton made from duplex board or 3 ply microflutted (E flute) corrugated fibre board box.

14.5 MANUFACTURING OF PACKAGING MATERIALS

14.5.1 Glass Containers

I. Composition

The main constituent of glass are sand, lime stone and soda ash. The sand used is known as silica or glass sand. Silica sand is melted at the first stage of making glass where soda ash helps it to melt with greater ease. Glass made with the glass sand and soda only is partly soluble in water. When crushed lime stone is added, the resistance of glass to water increases greatly. There are few other chemicals that are added to these three main ingredients to make the glass container stronger and cleaner or coloured as may be required.

In some cases, arsenic, selenium and cobalt oxides in proper proportion are added to make clear glass. The green or brownish shade in glass comes from the impurities in natural sand, mainly iron.

Boron from borax is added to glass to make the container stronger and to increase its resistance to acids. This chemical also reduces the thermal expansion of the glass.

Colours are added to glass by adding small quantities of chromium, cobalt, iron and other colourants depending on the colour required.

For amber (brown) glass, carbon and sulphide are added. Depending upon the qualities and the colour, raw materials are mixed in requisite proportions.

II. Manufacturing process

Depending upon the requirement of type and colour of glass containers to be manufactured, the raw materials are weighed, mixed thoroughly and fed into a glass melting furnace by maintaining a temperature of about 2700°F (1560°C). The melted glass is then passed into the refining chamber of the furnace. Impurities are retained in the melting chamber and the purified glasses are passed through a channel in the furnace called “Throat”. The molten glass passing through the ‘throat’, enters into the refining zone of the furnace where some bubbles, normally escaped through the throat, are allowed to be fined or eliminated and then it enters to the gob feeder. At the precise position, just above the forming machine, the glass is allowed to leave the furnace through a cylindrical hole in the bottom of the feeder and the stream of glass is cut off to a predetermined diameter and length of shears to form a gob. The gob falls into a blank mould, usually made of cast iron, to be shaped into a parison or semifinished container. It is then transferred into a second mould, called finished mould, whose internal cavity is accurately machined to correspond to the desired external shape of the container. The glass container as it emerges from the finished mould has a temperature about 800°C but it cools and hardens quickly. It is then immediately transferred to a tunnel like annealing with planned heating zones to cool slowly. This gradual and regulated cooling of the container eliminates the internal stresses and as it emerges from the other end of the lehr. Then the glass containers are inspected for any faults or defects before packed into corrugated fibre board boxes for the despatch to the user industries.

14.5.2 Metal Cans/Open Top Cans

The tin plate is purchased in the form of sheets either locally or imported. Depending up on the requirement the thickness of tinplate used varies from 0.006” to 0.012”. The following steps are used for the decoration and the manufacturing of tin plate (Figure 14.1).

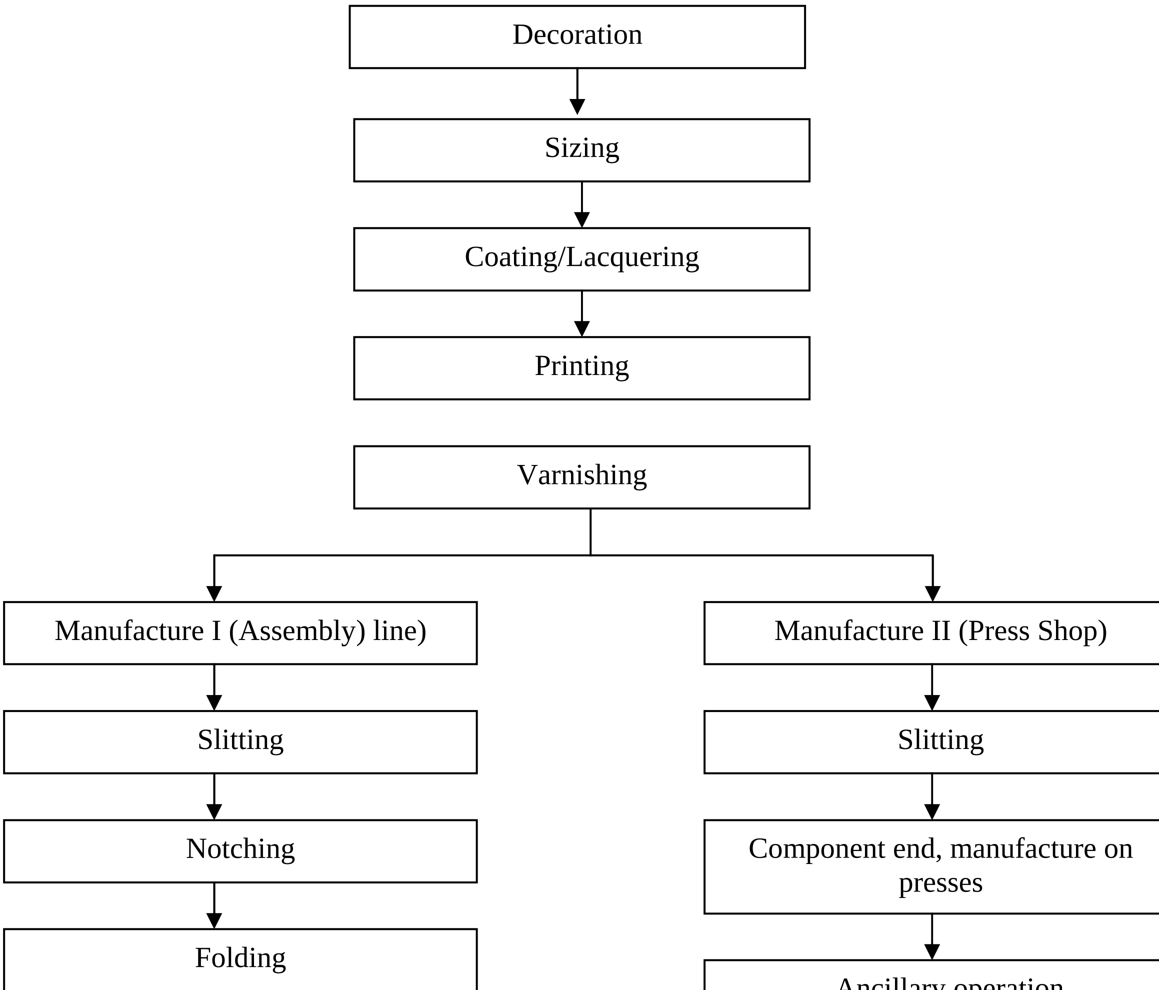

Figure 14.1: Flow diagram of decorated tin plate manufacturing

Though, the plastic containers are constantly replacing tin plate containers in many areas, even though, tin plate containers are continued to be an ideal packaging material for processed food due to the following advantages:

i) They are strong enough to protect the contents during handling and transportation.

ii) The materials are light enough for commercial handling.

iii) They can be readily fabricated into desired sizes.

iv) They are impervious to air and water.

v) They are capable of being heated for sterilization. These containers can with stand the internal pressures during processing of the food.

vi) The materials are not harmful or toxic to their contents.

vii) They can be easily printed for good market appeal.

viii) They can be manufactured at very high speed.

ix) The processed food has got maximum shelf life of 12 months in tin plate containers as compared to any other packaging material.

14.5.3 Plastic Materials

A) Plastic rigid container

Different manufacturing processes are involved in the production of plastic containers by using thermoplastic materials.

a) Blow moulding process

In this process, the thermoplastic materials are extruded in the form of pipe (it is called as parasite) through an annular die (directed downwards) and then blowing it inside the cavity of a closed mould with the help of compressed air to assume the shape of the cavity. Depending on the die, the plastic containers of different capacities, sizes and shapes are manufactured. This method has got most of the major advantages over extrusion and injection techniques and is used to produce thermoplastic hollow ware like bottles.

b) Extrusion blow moulding

Basic parts of this machine are the extruder, die head, mould, clamping unit, blow pin and new blowing unit and control system.

At the first stage, extrusion of the parison is accomplished with a heated, hollow barrel in which a rotating screw conveys solid feed material, compresses and melts it and finally pumps the melt through a tubing die to form the parison. The actual shape and design of the screw is dependent on the theological properties of the plastic materials. Hence, for different types of polymers, different screws are used.

After the plastic has been melted at a low temperature to maintain high melt strength the vertically extruded tube supports itself and then the plastic melt is fed into an extrusion head. For polyethylene, die head with programmable mandrels can be used.

c) Stretch blow moulding process

This method differs from the conventional blow moulding. In that the parison is "Biaxially Oriented" to impart much superior mechanical properties to the blow moulding containers. This process has the following sequence:

- Formation of a parison by injection moulding or by extrusion
- Longitudinal stretching of the parison
- Radial orientation while blowing the parison into the mould
- Ejection

This process can be continuous or in two stages. In the 2-stage process, perform is moulded first and then subsequently reheated, stretched and blown in a secondary operation. Mineral water bottles made of PET are manufactured by using this technique.

d) Injection blow moulding

It is almost same as stretch blow moulding. A parison is injection moulded over a core pin and the threaded neck is formed. The core pin can be shaped so that the plastic can be thin and thick at different points to produce an acceptable bottle. The injection-moulded perform is then transferred to a blow station where the core pin opens and allows air to blow a bottle into the shape of the blow mould. This method is quite popular in advanced countries for moulding small bottles up to 250 ml capacity. In India, injection blow moulding method is yet to be used.

e) Co-extrusion blow moulding

This method can only be accomplished through the multilayer combination of resins to produce co-extruded bottles. This system includes additional extruders and head system where the plastic is brought in at different points and layered to form a parison and follow the same process of blow moulding technique.

The polymeric materials like polystyrene (PS), high density polyethylene (HDPE), polypropylene (PP), polycarbonate (PC), etc., are normally used to manufacture the rigid containers by using the injection blow moulding process.

f) Compression moulding

The science of compression moulding, particularly thermosetting plastics and rubber, is well established. The use of this technique is very rare for processing thermoplastics because of longer moulding cycles involved. In principle, this technique involves the following steps

i) Filling the heated female mould cavity with the moulding powder.
ii) Pressing the powder with the male mould into shape after a breathing stroke.

iii) Maintaining the desired temperature and pressure over a length of time.
iv) Cooling the mould to a minimum possible temperature.
v) Ejection of the article.

B) Plastic films

The thermoplastic polymeric materials are also used to make the flexible plastic films having thickness from 8 to 250 microns. Plastic films are manufactured mainly by two methods, i.e. blown film co extrusion process and cast film co extrusion process.

In case of blown film coextrusion process, the extrusion machine used with either 3 or 5 extruders. However, single extruder machine can also be used to make plastic film by using blown techniques. In this process, polymeric material of single or multiple type is blended and fed into separate hopper, subjected to melt with separate melt channels and then passed through one die that is bonded to form single web of multilayer co extruded plastic film. Now a days, blown film coextrusion process has become very popular as this technique provides plastic films higher impact strength, barrier properties and high seal strength.

In cast film co-extrusion process, the individual layers are combined in multilayer adapters and distributed across the width of a cast film die. Now a days, multilayer co-extruded plastic sheets are being produced by using this technique. This kind of cast plastic sheet has got wide application in manufacturing of thermoformed containers, used extensively for the packaging of processed food products.

Check Your Progress Exercise 3

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What are the constituents of glass?

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2. Indicate the steps followed for the manufacturing of glass.

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3. What are the important steps followed for the manufacturing of metal containers?

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4. What is called parasite in blow moulding process of plastics? What are the sequences in the stretch blow moulding process?

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14.6 ASEPTIC PACKAGING

Aseptic packaging can be defined as a procedure consisting of sterilization of the packaging materials or container, filling of a commercially sterile product in a sterile environment and producing containers which are hermetically sealed so that recontamination or reinfection is prevented. This results in a product which is shelf stable under ambient conditions. The term ‘aseptic’ is derived from the Greek word ‘Septices’ and implies the absence or exclusion of any unwanted organisms from the product, package or other specific areas. The term ‘hermetic’ is used to indicate suitable mechanical properties to prevent the passage of microorganisms and gas or vapour into or from the container.

I. Steps followed in aseptic system

Aseptic processing comprises the following:

a) Sterilization of the product before filling

b) Sterilization of the packaging material or container before filling operation

c) Filling the product into the sterile package by maintaining the aseptic condition

a) Sterilization of product

The product sterilization is carried out by in-process or on-line sterilization which is popularly known as the ultra high temperature (UHT) or high temperature short time (HTST) depending upon the product treatment. The essential difference between the sterilization through autoclave, i.e., conventional canning method, and on-line UHT treatment is that in canning, the sterilization is done after the product is packed, whereas in UHT method, the sterilization is done prior to packaging. Normally, the sterilization temperature is maintained at 133–135°C for 3 to 5 seconds under HTST/UHT method to make the product sterile. However, there may be slight variation in temperature and duration depending on the type of product.

b) Sterilzation of packaging materials and equipment

Different kind of sterilizing agents like heat, chemicals and radiation are used alone or in combination for sterilization of aseptic equipment and packaging materials.

i) Heat

Initially, product supply lines and fillers are commonly sterilized by moist heat in the form of hot water or saturated stream under pressure. 'Dry heat' in the form of superheated steam or hot air may also be used to sterilize equipment. However, due to the relatively high dry heat resistance of bacterial endospores, the time-temperature requirements for dry heat sterilization is high. Systems enjoying moist heat are frequently sterilized at temperatures ranging from 121–129°C, while 176–232°C is used for sterilization by dry heat.

ii) Hydrogen peroxide

Hydrogen peroxide (H_2O_2) is not an efficient sporicide when used at room temperature. Therefore, most aseptic packaging systems use H_2O_2 (at concentrations of 30 to 50%) as a sterilant for packaging materials followed by hot air (60–125°C) to dissipate residual hydrogen peroxide.

Other chemicals which have been used as sterilents for acid foods include various acids, ethanol, ethylene oxide and peracetic acid.

iii) Radiation

A dose of approximately 1.5 megaradians (MGRAD) Gamma radiation is commonly used to decontaminate containers for acid and acidified foods. Doses required to sterilize containers for use with low acid foods are considerably higher than those required for acid and acidified foods.

Ultraviolet (UV-C) light has been used to decontaminate food contact surfaces. The low penetration and problems associated with shadowing limit the use of UV-C for aseptic systems packaging of low acid foods.

c) Filling of the product under aseptic condition

Once the product has been brought to the sterilization temperature, it flows into holding tube. The tube provides the required residence time at the sterilization temperature. No external heating of holding tube should take place.

A deaerator is used to remove air from the product processed and packed aseptically. The deaerator generally consists of a vessel in which the product is exposed to a vacuum on a continuous flow.

The sterilized product is accumulated in an aseptic surge tank prior to packaging. The product is pumped into the surge tank and is removed by maintaining a positive pressure in the tank with sterile air or other sterile gas.

Aseptic packaging system has been introduced in India by Tetrapack Company and marketing the different process food in tetra packs. The most commonly system is followed by Tetra pack, called as Tetra classic aseptic (TCA) system. The packages produced have a tetra hedronal shape. The ratio of packaging material to packaged product is a very favourable one, i.e., the amount of packaging material needed to package the volume of food is small.

Similarly, the TBA/3 (Tetrabrik Aseptic) system was introduced into the Indian market in the beginning of 1970. The containers produced are 'brick shaped' and easier and more efficient to handle during storage and distribution.

The tetrabrik packages are brik like shape and made of six layers of packaging materials. Composition of Tetrapack Aseptic carton is given below (Figure 14.2). The 6 layers in the brick provide total protection to the packaged product.

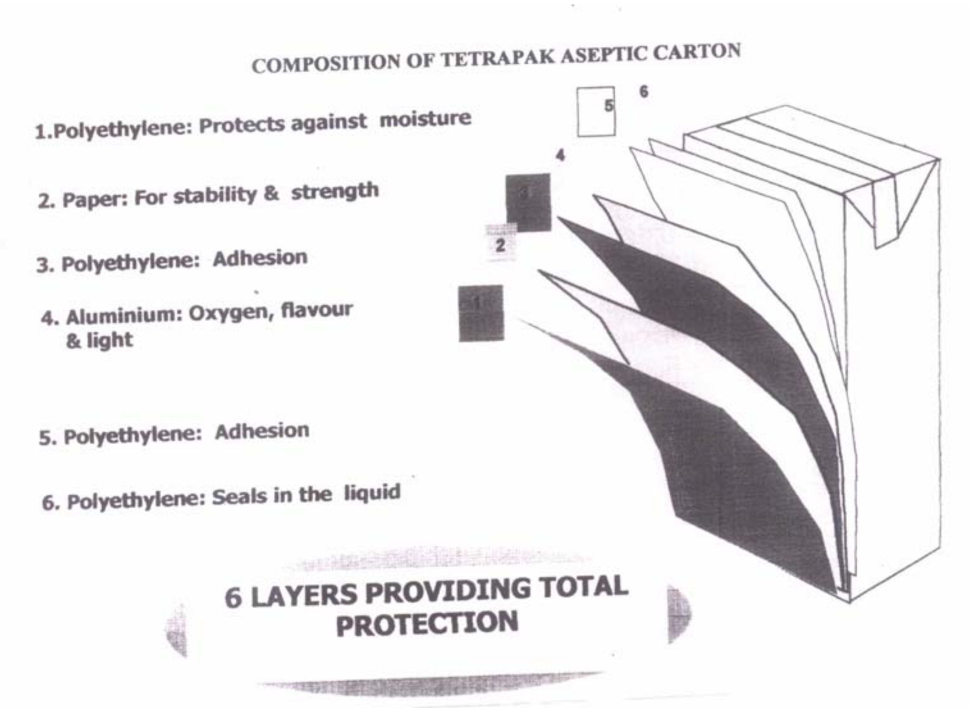

Figure 14.2: Composition of tetrapack aseptic carton

A number of processed food products which are liquid or semi solid in nature, are available in the aseptic packages. The common products aspeticall packed are fresh milk and flavoured milk, fruit juices, yougurt, vegetable oil, chocolate milk, Milk curd, cream.

II. Types of aseptic packages

A variety of consumer packages may be filled aseptically as listed below:

i) Carton box

ii) Bags and pouches

iii) Cups and Trays – Polypropylene based multilayered materials with EVOH barrier materials are used.

iv) Glass bottles and Jars

Check Your Progress Exercise 4

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. Define aseptic packaging system?

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2. What are the steps followed in this technique?

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3. How do you sterilize the product under this process?

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4. Describe the different sterilizing agents for packaging materials.

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5. Give examples of types of aseptic packaging.

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6. What are the applications of this technique?

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14.7 VACUUM AND INERT GAS PACKAGING

Vacuum packaging is the simplest and common method of modifying the internal gaseous atmosphere in a pack. The food product is placed in a pack made of a plastic film or laminate of low oxygen permeability. Air is then evacuated and the package is sealed. An evacuated package collapse around the product so that pressure inside is much less than atmosphere.

Similarly, the gas and vacuum package is dealt with the removal of air from the pack and the vacuum space is replaced by a single gas or mixture of gases. The gas mixture used is dependent on the type of product.

I. Vacuum packaging

In this process a vacuum is applied to remove the air from a preformed flexible pouche, containing the processed food product and then sealing it. The plastic film used should have low oxygen permeability under good vacuum condition, the oxygen level is reduced to less than 1%.

The main significance behind this technique is to extend the shelf life of processed food product. The processed foods having high content of fat like deep fried potato or banana chips, namkeen, bhujia, roasted peanut, roasted ground nut, etc., become rancid due to reaction with oxygen present in container. Due to this fatty foods become bitter in taste and unacceptable to the consumers.

In order to preserve these products, there is a need to evacuate the air from inside the package. However, this technique is most suitable for the products which are powder in from like tea, skimmed milk powder, etc. But this technique is not suitable for granular or flaked or bakery products as the products get crushed due to evacuation of air from the package.

II. Gas packaging

Gas packaging can be achieved by two fundamental methods. One is the replacement of air with a gas or a mixture of gases mechanically. The other is by generating the atmosphere within the package either passively, as in the case of fruits and vegetables, or actively by using suitable atmosphere modifiers such as oxygen absorbents, carbondioxide absorbents or emitters. In general, gas flushing process is usually performed on a form-fill-seal machine. Gas is injected into the package to replace the air. This dilutes the air in the head space surrounding the food product. When most of the air has been replaced, the package is sealed. There is a limit to the efficiency of the system since replacement of air in the package is accomplished by dilution. Typical residual oxygen levels in gas flushed packs are 2-5% oxygen. Inert gas like nitrogen is also used to flush the packages.

In case of fresh fruits and vegetables, the atmosphere inside the package is modified passively. Fruits and vegetables continue to respire even after harvest. That means, the produce consumes oxygen and produce carbon dioxide and water vapour. If the respiration characteristics of the commodity can be accurately matched to the permeability of the film used for packaging, then a favourable modified atmosphere can be created passively within the package and an equilibrium concentration of oxygen and carbondioxide is established. Equilibrium modified atmosphere (EMA) containing 2.5 per cent oxygen and 3.8 per cent carbon dioxide could delay the maturation process and softening of the vegetables, reduces chlorophyll degradation, microbial spoilage and enzymatic browning.

Under active packaging, the package containing food products where certain additives are incorporated either in the packaging film or within packaging container to modify the head space atmosphere. Different additives are added to the package to act as oxygen absorbant, carbon dioxide absorbant or scavenger, ethylene absorbant and ethanol vapour generator, etc. This is relatively a new technology and presently quite expensive.

14.8 FORM-FILL AND SEAL EQUIPMENT

Over the years, the form-fill-seal machine has gained popularity and acceptance for packaging of commodities. This particular equipment is suitable for flexible packaging materials and as well as semi rigid packaging materials. The machine operates with either one or two ebs of films which are transported vertically and horizontally. This machine helps to form a package from packaging material and allows to fill the package with the product. Then there is a provision to seal the package and make it ready for transport. Due to this fact, this particular packaging machine is also considered as system packaging.

There are two types of form-fill-seal machines which have got extensive application for the packaging of processed food products.

i) Vertical form-fill-seal machine.
ii) Horizontal form-fill-seal machine.

i) Vertical form-fill-seal machines

This particular machine performs different operations like film formation, back seal production and making top and bottom cross seal simultaneously. The film is fed from a roll and the operations are as follows:

a) Form-fill-tube

Film formation starts at the forming shoulder. In this process, the flat film passes over the shoulder to form a round tube shape with sides overlapping each other. In some cases, machine uses a metal tube to maintain the shape. The back seal could be formed either as LAP, FOLD OVER or FIN to make the basic shape of the pouch or package.

b) Heat seal along back

Once the tubular shape has been formed, the overlapping edges of the flexible packaging materials are sealed. This is normally done with the help of a pair of heated jaws which come together and press the overlap edges of film to make the back or centre seal. In most of the cases, the impulse seal is used for certain film types while other methods such as hot air or high frequency are also used. This machine creates the longitudinal seal that is generally centered on the back of the bag formed at the front of the forming tube.

c) Cross seal formation

Once the tube has been formed with back or centre seal, cross sealing and filling takes place. The bottom of the pouch is then sealed with the help of heating elements in the horizontal jaws and then the seal is cut at the middle and allow to drop the filled package freely. In this case, the horizontal seal where one part act as top seal of the bottom pouch and the other part will be the bottom seal of the subsequent pouch and the operation thus continuous.

Vertical form-fill-seal machines are particularly suited for material that drop freely on its own weight. These are fed by fillers that are normally positioned at the top of the machine. Fillers are (i) gravimetric where a cup is filled, levelled and discharged to the pouch or (ii) auger filler where product volume is measured by the number of revolution of a screw within the tube or (iii) weight fillers based on a scale system where precise quantities by weight are accumulated and released to the bag machine. Edible oil, milk, sugar, cereals, pan masala, spices, tea powder, etc., are packed by this machine.

ii) Horizontal form-fill-seal machine

This type of machine is extensively used for the packaging of processed food products. In this machine, the flexible film is moved horizontally through the machine which form or folds it into a simple 'V' shape. Once 'V' shape is formed, proportional heat control dies make the side seals and the pouches or bags are separated. Horizontal film advancement is intermittent or continuous. This machine has a control device based on electromechanical, electronic or micro processor. Products like chocolates and other confectionery items, sauces, salt, sugar, tomato ketchup, pickles, etc., could be packed by using the machine.

Types of pouches / package formed

By using the form-fill-seal (FFS) machine either vertical or horizontal, the flexible pouches could be made in the form of pillow pouch, 3-side seal pouch or 4 side seal pouch. A single web is used to form pillow pouch or 3 sides seal pouch either by vertical or horizontal FFS machine. In case of pillow pouch, there will be one centre seal at back and two seals, i.e., one at top and the other at bottom. But two numbers of independent web can also be used to make 4 sides seal pouch in this machine. Figure 14.3 illustrates a form-fill-seal machine.

Figure 14.3: A form-fill-seal machine

Check Your Progress Exercise 1

Note: a) Use the space below for your answer.
b) Compare your answers with those given at the end of the unit.

1. What do you mean by vacuum packaging?

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2. What are the steps followed for gas packaging?

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3. How many types of FFS machines are available in India?

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4. What are the applications of FFS machine for processed food packaging?

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5. Fill up the following gaps:

   i) In Vertical FFS machine, the fillers are _____________ , _____________ and _____________.

   ii) In vacuum packaging, the oxygen level is reduced to____________.

   iii) EMA contains _____________ oxygen and _____________ carbon dioxide.

   iv) In active packaging, normally _____________ and _____________ are used to absorb oxygen and ethylene.

   v) In gas flushing technique, inert gas _____________ and _____________ are normally used.

14.9 LET US SUM UP

Food products either in fresh or processed form available in the market are consumed by the human beings. There has been constant growth in production of fresh fruits and vegetables but unfortunately, it is not distributed in proper manner across the country. This is mainly due to improper handling and storage mechanisms and also inadequate packaging. In addition, there could also be other reasons like improper infrastructure facilities and transportation. As the fresh produce is highly perishable in nature and continue to respire there is special requirement of its packaging. Similarly, chilled and frozen foods have different packaging requirements.

Aseptic packaging has got extensive application in the packaging of fruit juices for longer shelf life. The foods which have got high fat content, require modern packaging systems like vacuum and gas packaging to enhance the shelf life of these products in consumer pack. Dehydrated fruits and vegetables have got special requirement of packaging which has also been covered in this unit.

For any packaging system, packaging machinery plays an important role. In fact, good and effective machinery has made possible to pack processed food products without much loss in their quality. Form-fill-seal machine is considered to be one of the important machine for system packaging of variety of food products like powders, granules and pastes.

You have also understood the manufacturing processes for the production of important packaging materials like glass bottles, tin plate containers, plastic films and plastic containers which are normally considered as primary packaging materials. These materials have got wide application in the packaging of processed food products.

In short, you have learnt the important packaging materials, their manufacturing process, packaging systems and machinery in this unit.

14.10 KEY WORDS

Annealing : Regulated way of cooling an article to eliminate internal stress and thus breakage.

Throat : The channel of the furnace through which the molten glass is passed away.

Parasite : The thermoplastic material when extruded in the form of pipe under blow moulding process, is called parasite.

HTST : High temperature short time. This is the latest technique of sterilization of food products where the microbes are completely killed within short period of time.

Freeze burn : During freezing moisture is lost from the surface of the product, the product tissue becomes dry and tough brownish and a grainy spot occurs on the surface.

Parison : A semi finished container or a blank mould made of cast iron, used normally prior to sent the gob into finished mould.

Gob : A stream of glass cut off to a predetermined diameter and length of sheats to form a gob.

TBA : Tetrabrick aseptic system which was introduced in Indian market by Tetrapak Company in the year of 1970.

TCA : Tetra classic aseptic system. This system produces the package of hedronal shape.

EMA : Equilibrium modified atmosphere containing 2.5% oxygen and 3.8% carbon dioxide, it can delay the maturation process and the softening of vegetables, microbial spoilage and enzymatic browning.

14.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

Your answers should include the following points:

1. • Highly perishable in nature.
   • Changes in colour, texture, odour and flavours.
   • Apearance of micro-organisms like moulds.
   • Damages of delicate tissues due to chilling injury.
   • Loss in moisture causing loss in weight.
2 • Consumer package:

   Flexible plastic film, plastic punnets, plastic net bag, foam sleeve, plastic crate, shrink wrap, etc.

   • Transport Package:

   ➢ Bamboo basket, wooden box, corrugated fibre board box.
   ➢ Plastic crate, solid fibre board, plastic corrugated box.
   ➢ Jute sacks, plastic woven sacks, multi wall paper sacks.

3. Modified atmosphere packaging where the atmospheric gas mixture is modified inside the package by considering the requirement of fresh fruits and vegetables. The shelf life of fresh fruits and vegetables increases to a great extent in this packaging.

Check Your Progress Exercise 2

Your answers should include the following points:

1. • Physical and chemical changes.
   • The effect on tissue of fruits and vegetables.
   • Food spoilage microbiology.

2. i) Physical changes that occur are

   • Freezer burn – a grainy, brownish spot on the surface, tissue becomes dry and tough.
   • Development of off flavour.
   • Changes in texture as the cell wall ruptures due to the formation of ice crystal during freezing.

   ii) Chemical changes that occur are

   • Development of brown colour due to enzymatic browning.
   • Loss of vitamin C.
   • Development of oxidative rancid flavour on the frozen foods.

3. • High moisture barrier property
   • Barrier property to avoid oxidative rancidity.

- Light barrier property to control the oxidative rancidity.
- Low temperature resistance.

4. • Dry packs – LDPE, PVDC coated plastic film, Five layered coextruded plastic film (PE/Tie/Nylon/Tie/PE)
   • Tray packs – made of aluminium sheets, plastic corrugated board, 3 ply or 5 ply corrugated fibre board sheet.

Check Your Progress Exercise 3

Your answers should include the following points:

1. • The main constituents are sand, lime stone and soda ash.
   • Other ingredients like arsenic, selenium and cobalt oxides are added to make clear glass.
   • Boron is added to make the glass strong.
   • Carbon and sulphides are added to make amber (brown) coloured glass.

2. • Raw materials are mixed and fed into melting furnace at (1482°C).
   • Melted glass is passed into refining chamber of furnace and then to form a gob.
   • Gob passes through a parison and then to a finished mould at a temperature of 800^0C to form the glass container.
   • Finally, the glass container cools and hardens quickly.

3. • **Decoration Sizing** – Coating/ Lacquering → printing → varnishing.
   • **Assembly Section** – Slitting → Notching → Folding → Soldering/ Cementing.
   • **Press Shop** – Slitting → Component end → Ancillary operation.

4. • Thermoplastic material extruded in the form of pipe is called parasite.
   • Formation of a parison by injection moulding or extrusion process and then stretching the parison.
   • Radial orientation while blowing the parison into mould.
   • Ejection.

Check Your Progress Exercise 4

Your answers should include the following points:

1. Aseptic packaging is a system by which the commercially sterile products are packed in sterilized containers and the filling operations are also held in sterilized environment.

2. • Sterilization of the product before filling.
   • Sterilization of packaging materials or containers before filling operation.
   • Filling of the product into the sterile package by maintaining the aseptic condition.

3. Products are sterilized by means of UHT method where a temperature of −135°C for 3 to 5 seconds are maintained. However, there may be slight variation in temperature and duration depending upon the type of product.

4. • Moist heat at 121–129°C and dry heat at 176–232°C.
   • Hydrogen peroxide at 30 to 50% concentration.
   • Radiation

5. • Carton box
   • Bags and pouches
   • Cups and trays.
   • Bottles and jars.
6. • Fresh milk and flavoured milk
   • Fruit juices
   • Vegetables oil
   • Cream
   • Chocholate milk

Check Your Progress Exercise 5

Your answers should include the following points:

1. Vacuum packaging is a technique by which all the air inside the package is evacuated resulting into collapsing of package around the product so that pressure inside the package is much less than the atmosphere.

2. Replacement of air from inside the package → inert gas or mixture of gases are injected mechanically → package is sealed.

3. • Vertical Form – Fill-Seal machine
   • Horizontal Form – Fill- Seal machine

4. • Vertical FFS Machine.
   • Edible oil, sugar, spices, ghee, pan masala, milk, fruit juices, hydrogenated fat etc.
   • Horizontal FFS Machine.
   • Confectionery, Sauces, Pickles, Tomato ketchup etc.

5. • Gravimetric, augar and weight fillers
   • 1%
   • 2.5% and 3.8%
   • oxygen seavanger and ethylene absorbant
   • Nitrogen and carbondioxide

14.12 SOME USEFUL BOOKS

1. Bikales Norbert M, Moulding of Plastics (1971) WILEY-Interscience, a division of John Wiley & Sons, Inc, New York.

2. Modern Food Packaging (1998) Indian Institute of Packaging, E-2, MIDC Area, Chakala, Andheri (East), Mumbai.

3. Packaging Technology educational volumes, (Set-A) (2001) Indian Institute of Packaging, E-2, MIDC Area, Chakala, Andheri (East), Mumbai.

EXPERIMENT 1 ADEQUACY OF BLANCHING OF FRUITS/ VEGETABLES

Structure

1.1 INTRODUCTION

Inadequate blanching has a negative effect on quality of finished product. As various types of fruits and vegetables differ in size, shape, heat conductivity, and natural levels of their enzymes, blanching treatments have to be established on experimental basis.

The larger the food item, the longer it takes for heat to reach the center. Thus, small fruit or vegetable may be adequately blanched in boiling water in a minute or two; larger ones may require several minutes.

Objectives

After going through this experiment, you should be able to:

- blanch any given fruit or vegetable; and
- determine the blanching time of any given fruit/vegetable.

1.2 EXPERIMENT

1.2.1 Principle

Adequacy of blanching is determined in terms of inactivation of two most important and heat resistant enzymes catalase and peroxidase in vegetables and some fruits. If these are destroyed, then the other significant enzymes would also be inactivated.

1.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/Material)

- Heating vessels (SS Patiala)
- Stainless steel sieve
- Weighing balance
- Measuring cylinders-Plastic
- Heating equipment a) cooking gas cylinder; b) gas burner
- Carrots, Beans, Cabbage, Potatoes
- Potable water
- Labels

- 1% Guaicol in alcohol solution –1 g guaicol is dissolved in about 50 ml of 50% ethyl alcohol and then the volume is made up to 100 ml with the same solvent.
- Peroxide solution 0.3%-5ml perhydrol is brought to 150 ml with distilled water.

1.2.3 Procedure

i) Peel and cut the vegetables into small pieces. Weigh 100g of the prepared vegetable.

ii) Take 400ml water in a beaker and boil. The ratio of water:vegetables is 4:1.

iii) Dip the prepared 100g vegetables in to boiling water and start the timer.

iv) After every 30seconds remove 1g(approx) of vegetables from the beaker and immediately put in cold water.

v) Take this 1g of sample, homogenized in a motar-pestle.

vi) Filter through a muslin cloth and do the tests for the presence of catalase and peroxidase enzyme.

Catalase presence test

Take 1ml of extract and add 1ml of H_2O_2 solution. In the presence of Catalase, a strong oxygen generation (effervescence) is observed for 2-3 minutes.

$$2H_2O_2 \longrightarrow 2\,H_2O + O_2\uparrow$$

Peroxidase presence test

i) To the same tube to which H_2O_2 is added, add 0.5ml guaicol solution. Keep the tube aside for sometime for colour development.

ii) Appearance of red colour confirms the presence of Peroxidase.

iii) Continue step (4) to (6) till red colour with guaicol ceases to appear.

iv) The time taken from zero minute to the time when red colour is no more observed is called Blanching time for the vegetable under study.

1.2.4 Observation

i) Catalase inactivation time and temperature.

ii) Peroxidase inactivation time and temperature.

Note: For cabbage, Catalase inactivation by blanching is sufficient; blanching further to Peroxidase inactivation would have negative effects on product quality and even complete browning.

For all other vegetables and for potatoes, both tests MUST be negative, for Catalase and for Peroxidase.

Observation Table

Vegetable/Fruit	Time(seconds)	Catalase	Peroxidase

1.2.5 Results

Based on the results of the above exercise, the given vegetable is adequately blanched as no colour development took place.

Absence of colour development indicates adequate blanching.

1.3 PRECAUTIONS

- Select only microbiologically safe vegetables.
- Remove all spoiled, rotten vegetables/fruits.
- Maintain clean, hygienic working atmosphere.

EXPERIMENT 2 CANNING OF FRUITS AND VEGETABLES

Structure

2.1 INTRODUCTION

Canning is a preservation technique used to preserve fruits and vegetables in order to increase their shelf life. It also enables the processor, to store excess amount of fruits and vegetables available in season to be used in off-season.

Objectives

After going through this experiment, you should be able to:

- utilize fruits/vegetables for canning;
- increase the shelf life of the fruit/vegetable; and
- process seasonal fruits/vegetables to be used in off-season.

2.2 EXPERIMENT

2.2.1 Principle

The principle of canning is to sterilize the food inside by a heat process, after sealing the can, to increase its shelf life.

2.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/Material)

- Heating vessels (SS Patiala)
- Stainless steel sieve
- Weighing balance
- Measuring cylinders-Plastic
- Heating equipment a) cooking gas cylinder; b) gas burner
- Double seamers.

2.2.3 Procedure

Testing of cans

The empty cans are tested for leaks with a vacuum or air pressure tester. Can is subjected to the gradual air pressure inside it. It is kept in water and the leakage is determined by bubbling. Thus, the maximum pressure the can is able to withstand is determined.

Specifications for a can is that it should be able to withstand pressure not less than 15 pounds.

Canning of fruits and vegetables

Canning of fruits/vegetables involves the following steps:

A) Preparation of fruit and vegetable for canning

i) Sorting and grading

ii) Washing

iii) Peeling, coring and pitting

The washed fruits and vegetables are prepared for canning by peeling, coring, etc.

a) Peeling

- By hand or with knife
- By machine
- By heat treatment
- By lye solution

b) Cores and pits: In fruits they are removed by hand or by machine. e.g., Pineapple. Coring removes fibres and proteolytic enzymes.

iv) Blanching

B) Filling in the cans

C) Syruping or Brining

D) Liding

E) Exhausting

F) Sealing

Flow Diagram of Canning Operation

Receiving raw material & selection

↓

Weighing

↓

Washing

↓

Cutting into slices

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Pitting/Coring

↓

Sorting

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Washing

↓

Filling in the pre-sterilized cans

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Syruping/Brining

↓

Exhausting

↓

Closing & Sealing

↓

Processing

↓

Cooling

↓

Storage

↓

Marketing

2.2.4 Observations

- Size of the can used
- Amount of fruit or vegetable/Number of cans used
- Time of exhausting
- If there is any leakage
- If there is any swelling of can
- If can remains flat (seems to be normal and properly processed without any defect)
- Tapping sound a) metallic; b) dull.

2.2.5 Results

The given fruit/vegetable is adequately canned. The procedure followed for canning of fruits and vegetables is correct. The can remains flat and without any defect.

2.3 PRECAUTIONS

- The cans used should be checked for corrosion.
- Fruits and vegetables should be absolutely fresh. It should be free from all-unsightly blemishes, insects damage and malformation
- Ripe, firm and evenly matured fruits should be selected. Over ripe fruit is generally infected with microorganisms and would yield a pack of poor quality. Under-ripe fruit will generally shrivel and toughen on canning.
- Worker should wear apron and cover the head with a cap.

EXPERIMENT 3 CUT-OUT ANALYSIS OF CANNED PRODUCT

Structure

3.1 INTRODUCTION

Cut-out analysis refers to the analysis of packed / finished product for various quality parameters. It is done to check the overall acceptability of the canned product.

Objectives

After going through this experiment, you should be able to:

- if the given canned product is as per specifications;
- the adequacy of heat treatment (over-processing or under-processing)
- the condition of the can and the canned product;
- the adequacy of blanching that has been given before processing;
- corrosion of interior of can; and
- other types of microbial spoilage like hard swell or soft swell of can.

3.2 EXPERIMENT

For measuring Salt and acidity you should consult practical of Course-III (BPVI-003) and Course-VII (BPVI-007)

3.2.1 Principle

The testing of overall acceptability of the canned product is done by observing the physical condition of the can and chemical, microbial and organoleptic quality of the products.

3.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/Material)

- Canned products
- Can opener
- Weighing balance
- Refractometer
- Vacuum and pressure gauges
- Seam testing or headspace gauge
- Hot plate
- Burette-50ml capacity

- Pipette-5ml capacity
- Silver nitrate(0.1N)
- Fehling's Solution A and B
- Methylene blue
- Potassium chromate
- Distilled water

3.2.3 Procedure

i) Note the external conditions of can such as body dents or scratches, leakage around seams, condition of ends, etc. In describing the conditions of the can, categorize as per the following:

- Flat cans
- Flipper
- Springer
- Swell

ii) Gross weight: Weigh the can as such and note the gross weight.

iii) Vacuum or Pressure-Use a gauge, which indicates both, vacuum and pressure. Open the can with a good can opener.

iv) Inspection of content: As soon as the can is opened, note the appearance on the surface. Underfilling and overfilling can be seen. Cloudiness in the syrup or brine, or unsatisfactory appearance of the fruit or vegetable must be noted.

v) Gross headspace: This is the distance from the top of the double seam to the surface of the contents of the can. Measure it with a seam-testing gauge or headspace gauge.

vi) Drained weight: Weigh the empty dried sieve. Then, empty the contents of the can in such a manner so as to distribute the product evenly upon a circular sieve which should be so inclined as to facilitate drainage of syrup or brine. Allow the product to drain for 5 minutes.

vii) The drained weight = (weight of the sieve along with the contents- weight of the dry sieve).

viii) Net weight: The net weight is the weight of the contents along with the syrup. Wash the empty can with water and record the empty weight of the can. Subtract the empty weight from gross weight to get the net weight of the contents.

ix) Internal condition of the can: When cans have been emptied and washed, examine the internal surface for evidence of corrosion, blistering or defects in lacquer, pitting, scratching, discolouration, leaks, evidence of scortching along seams, etc. State whether internal surface is lacquered or not.

x) Syrup or brine: Note the colour, clarity and the flavour of syrup or brine. Determine the soluble solids in canned fruits using a refractrometer.

xi) Salt content in brine/total sugars in syrup: For the can containing fruits, determine the total reducing sugars by Lane-Eynon method, whereas for a vegetable, determine the salt content by Mohr's titration.

xii) Inspection of can contents

- *Colour*: It is an essential feature to be considered. Pale or dull appearance makes the product unattractive and unappetizing. Blemished and diseased fruit must be noted very carefully. Discoloration, if any, should be noted.
- *Firmness*: Soft, pulpy or disintegrated fruit pieces must be noted.
- *Flavour:* The flavour is an important factor. Subject the product to a panel of judges and report the flavour in terms of good, acceptable, normal, slight off –flavour or unpalatable.

xiii) Bacteriological examination: The principle of canning is to sterilize the food inside by a heat process after sealing the can. In the canned fruit products, the low pH generally inhibits the growth of bacteria, and only yeasts, moulds and enzymes have to be destroyed. They are comparatively less heat-resistant and are killed by heating for a short period in boiling water. Vegetables of a pH higher than 4.5 are capable of supporting the growth of heat resistant spore forming organisms and hence their processing is based on destruction of spores of toxin producing *Clostridium botulinum.* Sometimes leaker spoilage may occur, which is a post-processing spoilage caused by the percolation of the cooling water through the unsettled seam immediately after processing.

To detect the presence of living bacteria in the canned product, incubate the cans at 37°C and 55°C for 7 days. The organisms growing at 37°C usually cause spoilage accompanied by the production of gas (CO_2) which causes the cans to become springers and then a hard swell. If left too long in the incubator, the cans may blow up. A can, which swells at 37°C indicates the presence of living mesophilic organism, usually caused by leakage.

Subject the swollen cans for bacteriological examinations-TPC, yeast and moulds etc.

3.2.4 Observations

Record the observations in a cut out proforma as mentioned below:

Cut-out Performa

A) Product Details

i) Name of the product
ii) Date of manufacture
iii) Date of inspection
iv) Description of the product

B) Inspection of the can conditions

i) Size of the can
ii) External appearance
iii) Condition of ends of can
iv) Vacuum
v) Gross weight
vi) Headspace
vii) Drain weight
viii) Weight of empty can

ix) Net weight
x) Weight of syrup
xi) No. of pieces
xii) Internal can corrosion

C) Inspection of cans content-organoleptic evaluation

i) Slices	Appearance Colour Texture Taste Foreign matter
ii) Syrup	Appearance Color °Brix

D) Microbiological examination

3.2.5 Results

FPO specifies standards for canned products. Compare the results obtained with the following FPO standards for canned products, tabulate as per the table given below and conclude whether the given canned product complies the FPO standards.

S. No.	Parameter	FPO standard	Results for given canned product	Comments
	CANNED FRUITS			
1.	**Drained weight**	Not less than 50%, Exception Berry fruits-40%		
2.	**Drained solids**			
2a)	Appearance	Free from blemished,stalks,leaves etc		
2b)	Texture	Free from disintegration, damage from bruises and uniformly prepared		
2c)	Organoleptic quality	Characteristic taste		
3.	**On whole product**			
3a)	Preservatives	Not permitted		
3b)	Added colour	Permitted only in cherry & strawberry		
	CANNED VEGETABLES			
1.	**Drained weight**	Not less than 55%, Exception canned tomatoes-50%		

2.	**On Solids**			
2a)	Appearance	Free from pods, stalks, detached skins, woody fibres, roots and blemishes.		
2b)	Texture	Free from disintegration, damage from bruises		
3.	**On Brine**			
3a)	Added colour	Not permitted except for processed peas		
3b)	Preservatives	Not permitted		

3.3 PRECAUTIONS

- Maintain clean and hygienic working atmosphere.
- Titration should be done as rapidly as possible.
- Normality of silver nitrate should be checked.

EXPERIMENT 4 TESTING OF FLEXIBLE PACKAGING MATERIAL

Structure

4.1 INTRODUCTION

All foods undergo varying degrees of physical, chemical and biological deterioration during storage. This may lead to losses in organoleptic quality, nutritional value, safety and aesthetic appeal of the food product.

The highly sensitive organic and inorganic compounds which make up food that contribute to texture and consistency of unprocessed and manufactured products are affected by nearly every variable in the environment. Heat, cold, light and other radiation, oxygen, moisture, dryness, natural food enzymes, microorganisms, industrial contaminants, time, etc., can adversely affect foods.

Therefore, packaging food in suitable materials is of paramount importance in increasing the shelf life of the products. Packaging is the physical entity that functions as the wall between the contents and the exterior.

Seal strength/Tensile strength is a fundamental property indicative of the serviceability of the packaging material. In the packaging of food products, tensile strength of a flexible packaging **material determines the resistance to rupture when subjected to a pulling force**. Packaging materials of high tensile strength are required when packages are made in semi-automatic pouch forming and filling machines, and to hold heavy packaged items. It is measured using a Instron tensile strength measuring machine

Another property, Elongation at break is also an important parameter of a flexible packaging material, especially for food products which are likely to experience drops during distribution. Such materials need to have a higher elongation property. It is measured on the same machine as that of tensile strength, and **is a measure of the extent to which materials will stretch before breaking.**

Objectives

After going through this experiment, you should be able to:

- test the quality standard of packaging materials;
- predict the quality and shelf-life of the processed product;
- determine the tensile strength/seal strength of the pack; and
- elongation at break.

4.2 EXPERIMENT

Testing methods can be divided into:

i) Chemical parameters: Identification of the plastics, resistance to grease, etc.

ii) Mechanical parameters: Barrier properties, strength, heat-seal ability and clarity

In our practical course, we would be doing the following three main tests

i) Water Vapour Transmission rate (WVTR)
ii) Leak test
iii) Seal strength

The procedure and details for each of the above mentioned methods are described below in Experiment Nos. 4a, 4b and 4c, respectively.

EXPERIMENT 4A TO DETERMINE THE WATER VAPOUR TRANSMISSION RATE (WVTR) FOR THE GIVEN PACKAGING MATERIAL/ PRODUCT PACK

Structure

4A.2 EXPERIMENT

4A.2.1 Principle

The water vapour permeability of the package is defined as the rate at which water is transmitted into the package from the test atmosphere (Normally 90± 2% RH at 37.8° C ± 1°C) surrounding it while a desiccant is sealed within.

4A.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/ Material)

- Anhydrous calcium chloride
- Humidity Cabinet – It should have a provision for circulation of air
- Analytical balance-Readability of 0.0001g
- Oven

4A.2.3 Procedure

i) Dry anhydrous calcium chloride in an oven at 200°C for 1 hour.

ii) Place known weight of the desiccant within the pack to be tested. The weight should be more than the half capacity of the pack. Prepare three such experimental samples.

iii) Label each pack as 1, 2, and 3. Seal the packs and record the weight for each pack.

iv) Pre-warm the sealed packets at 37.8°C. Place the warm samples in the test chamber/humidity cabinet maintained at 90±2% R H and 37.8±1°C.

v) Remove one pack from the chamber after 24 hours, weigh and immediately place it back. Repeat the same for all packs.

vi) Repeat the above, till no change in the weight gain is observed.

4A.2.4 Observations

i) Plot the weight gained against time.

ii) The end point is indicated by at least three successive points on a straight line.

iii) The slope of this portion of the curve is measure water vapour permeability.

4A.2.5 Results

- Calculate the average Water Vapour Transmission Rate for the sample by taking the average of the slopes obtained for the three packs.
- Report the water vapour permeability as grams of water per 15 days (till whatever time the weight gain becomes constant) for the package as a unit.

4A.3 PRECAUTIONS

- For accurate weighing, check the bubble of the analytical balance and adjust it to the centre.
- While weighing the packs, care must be taken to take out only one pack at a time and immediately place it back after recording the weight.
- Carry out the experiment in triplicates in order to get most representative results.

EXPERIMENT 4B TO PERFORM THE LEAK TEST ON THE GIVEN FOOD PRODUCT PACK

Structure

4B.2 EXPERIMENT

4B.2.1 Principle

Leak test is done to check: 1) if the seal integrity of the pouch/pack is proper or not 2) if the seal integrity is good enough to undergo handling during transportation.

It is usually used as an online check to see if all the settings of temperature and pressure of the sealing machine are correct.

4B.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/ Material)

- Water bath.

4B.2.3 Procedure

i) Fill the water bath with water up to the indicated level.

ii) Hold the pack to be tested from the upper most corners and immerse the same in water while holding it tightly with both the hands.

iii) Observe for the bubbles rising from the seal areas of the pack.

4B.2.4 Observations

- Report if there is any air bubble.

4B.2.5 Results

Air bubbles rising in the water bath indicate a leak in the pack. Hence, the product will not be stable till the indicated period as mentioned on the pack.

If no bubbles are observed, it may be concluded that the product seal is intact and pack is free from any leak.

EXPERIMENT 4C TO DETERMINE THE SEAL STRENGTH OF THE GIVEN PACK

Structure

4C.2 EXPERIMENT

4C.2.1 Principle

The strength of the seal in a flexible packaging is determined by the temperature, pressure and time of sealing. The tensile strength and elongation of the flexible material are important parameter to check the seal strength.

4C.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/ Material)

- Instron Tensile Strength Testing Machine

4C.2.3 Procedure

i) Select the packs to be tested for the seal strength.

ii) Cut the back seal of the pack (or top seal/bottom seal whichever is to be tested) yielding a strip about 15mm wide and maximum 50mm in length. Care should be taken not to cut off any of the back heat seal region (or top seal/bottom seal whichever is to be tested).

iii) Place the seal specimen in the Intron tensile test clamps.

iv) Set the machine at a pull rate of 15mm/min using a 5 Kg load cell is used.

v) Begin the test pull. Record the peak value (g/15mm) obtained.

4C.2.4 Observations

i) Calculate the maximum force(peak value) from the chart recorder and record as g/inch.

ii) Following parameters may also be calculated or noted directly from the machine:

a) **Breaking Factor**, Kg/cm=Maximum Load/original thickness of specimen.

b) **Tensile strength at break**, Kg/cm2= Maximum load at break/Original minimum cross-sectional area of specimen.

c) **Elongation at break** %= Elongation at the moment of rupture of specimen/Initial length of specimen*100.

4C.2.5 Results

- The results are expressed as maximum force required in grams/inch.

  A larger value for elongation is an index of toughness, since it indicates that the material will absorb large amounts of energy before breaking.

4C.3 PRECAUTIONS

- Care should be taken while cutting the test specimen. A precision cutter with sharp edges should be used so that there is no damage to the seal area to be tested.
- The material placed between the jaws should not be touched while the test is running.
- Calibrate the equipment, as mentioned in the manual provided along with the instrument, before conducting the test.

EXPERIMENT 5 PREPARATION OF FRUIT-BASED CARBONATED DRINKS

Structure

5.1 INTRODUCTION

People of all age groups consume beverages to quench their thirst. These beverages are non-alcoholic and include fruit based drinks, synthetic drinks, sweetened aerated water or carbonated drinks. The cold drinks are in demand for greater part of the year in the country. India produces more than four thousand million bottles of aerated water annually. This aerated water contains synthetic colouring and flavouring additives, which may potentially be allergenic. It is a huge business in comparison to fruit juices and beverages. These aerated waters if fortified / substituted with fruit juices will provide more nutrition than aerated water and would prove a boon to the consumer as well as grower.

Thus, the fruit based carbonated beverages can provide a new product having natural colour and flavour along with nutrition.

Objectives

After going through this experiment, you should be able to:

- utilize fruit juices for new type of beverages;
- produce fruit based carbonated drinks;
- avoid use of synthetic colouring and flavouring agents; and
- utilize indigenous fruits.

5.2 EXPERIMENT

5.2.1 Principle

The fruit based carbonated drinks can be produced and preserved by hurdle technology, i.e., chemical preservative, carbon dioxide and heat treatment without addition of synthetic colouring and flavouring additives.

5.2.2 Requirements (Equipment/Machinery/ Instrument and Chemicals/ Material)

a) Preparation and preservation of fruit juice

- Fruit mill
- Hydraulic press
- Stainless steel (S.S.) Tanks
- Heating vessels (S.S. Patiala)
- Stainless steel sieve
- Glass bottles
- Crown corking machine
- Crown corks
- Heating equipment a) Cooking gas cylinder; b) Gas burner
- Thermometer
- Weighing balance

b) Preparation of carbonated fruit drinks

- Carbonating machine including CO_2 gas cylinder
- Water chiller
- Water filtering unit

c) Chemicals / materials

- Fruit juice, (Fruits-Jamun, Amla, Lime and coloured grapes)
- Sugar
- Citric acid
- Sodium benzoate
- Labels
- Carbon dioxide gas
- Potable water
- Filtration cloth

5.2.3 Procedure

a) Preparation and preservation of fruit juices

Fully ripe fruits are selected; injured and spoiled fruits are sorted out. Cull fruits can also be used. Fruits are cleaned and washed thoroughly with clean water. Fruits are crushed in a fruit mill and the crushed mass is pressed into a hydraulic press to get juice. The juice is filtered and preserved either by chemical preservative or by heat application (i.e., pasteurization or sterilization). The processed fruit juice could be stored at refrigerated temperature for better quality during storage.

b) Preparation of carbonated fruit drinks

Preparation of fruit syrup: Carbonated drinks are made by post-mixed method. Fresh or preserved fruit juice is used to prepare syrup base. Syrup base is prepared by mixing fruit juice, sugar, citric acid and water and preserved by sodium benzoate. These ingredients are mixed in such a way so that the syrup base has 50% (or °Brix) total soluble solids and 1.0% acidity.

The general formulations based upon our past experience of commercial productions are given in the box below:

Recipes	Aonla	Grape	Jamun	Lime
Juice (kg)	1.0	1.0	1.0	1.0
Sugar (kg)	1.17	1.066	1.16	3.254
Citric acid (g)	11.43	12.00	11.11	-
Water (kg)	0.322	0.443	0.341	2.254
Sodium benzoate (g)	1.25	1.25	1.25	3.25
Total (Kg)	2.50	2.50	2.50	6.50

The amount of above ingredients may be altered as per requirement.

The sugar and citric acid are dissolved in water by heating to a boil, filter through a four-fold muslin cloth and then cooled. After cooling it is mixed with the juice thoroughly. The sodium benzoate is mixed with a small quantity of clean water and then mixed thoroughly with the syrup base and filled into the clean and presterilized glass bottles leaving a head space of 4 cm and sealed by crown corking, labelled and stored at low temperature (5-6°C).

Carbonation: The properly filtered clean water is chilled to a temperature of 4°C. The chilled water is taken into the carbonator and the desired pressure of carbon dioxide gas is maintained, so desired gas volume is achieved in the finished drink when measured.

The desired amount (50g) of a fruit juice syrup is dosed into the previously sterilized and clean glass bottles (200 ml capacity) and then filled with the carbonated chilled water and sealed by crown corking.

The fruit based carbonated drinks can be stored for a week if prepared without preservative. But if preserved with sodium benzoate and heat processing then it can be stored for a period of 3 months at ambient temperature (30°C) under dark conditions and 6 months if stored at low temperature (6-7°C).

Heat processing: Bottles are placed in the water heated to a temperature of 70°C in a stainless steel or aluminium vessel so as to maintain a temperature of 66°C for 30 minutes in the contents of the bottle. After heat processing, the bottles are removed and cooled under fan. After cooling, bottles are washed, shaken a little bit and stored, labelled and marketed as and when required.

5.2.4 Observations

In fruit juice and syrup base

i) Total soluble solids (TSS)
ii) Acidity
iii) pH

In final carbonated fruit drinks

i) TSS
ii) Acidity

iii) PH
iv) CO_2 gas volume
v) Sensory quality on the basis of colour, flavour and taste (0-9 score of Hedonic scale)

For measuring TSS, acidity and pH you should consult the practical manual III Food Chemistry and Physiology and VII Food quality Testing and Evaluation.

Calculations

CO_2 gas volume: For measuring gas volume in a carbonated beverage, a gas volume tester is required. It is screwed on the top of the neck of the bottle. By pressing the handle crown cork is punctured and gas pressure is observed in the pressure gauge which is released by unscrewing the side valve until the first bubble rise in the liquid. Then shut the valve and shake the bottle until gauge reaches maximum pressure. Note the pressure on the gauge. Remove the crown cork and note the temperature of the drink. With these values, gas volume is seen through a Table 5.1. Gas volume denotes how many gas volumes are dissolved in one volume of liquid.

5.2.5 Results

Analysis of finished beverage

- Gas volume (gas volume about 2.5 to 3.5 are acceptable for fruit based drinks)
- TSS
- pH
- Acidity
- Sensory quality

The product which has received a score of 5.5 and above is acceptable.

Any abnormal change in TSS, acidity or pH will indicate that the product is not fit for consumption.

5.3 PRECAUTIONS

- Select only microbiologically safe fruits.
- Remove all spoiled, rotten fruits.
- Thick glass bottles should be used, which can sustain CO_2 gas pressure.
- Maintain clean, hygienic working atmosphere.
- Workers should wear apron and head gear.
- Proper CO_2 gas pressure should be maintained in the cylinder containing chilled water.

Table 5.1: Gas volume test chart (Volumes of carbon dioxide dissolved by 1 volume of water)

Temp., (ºF) in bottle — **Gauge pressure of bottle (lbs. per sq. in)**

	16[a]	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64
	2.7	2.9	3.1	3.3	3.4	3.6	3.8	4.0	4.1	4.3	4.5	4.7	4.8	5.0	5.2	5.4	5.6	5.7	5.9	6.1	6.2	6.4	6.6	6.8	6.9
46	2.7	2.8	3.1	3.2	3.4	3.5	3.7	3.9	4.0	4.2	4.4	4.6	4.7	4.9	5.1	5.3	5.4	5.6	5.8	6.0	6.1	6.3	6.4	6.6	6.8
47	2.6	2.8	3.0	3.1	3.3	3.5	3.6	3.8	4.0	4.1	4.3	4.5	4.6	4.8	5.0	5.2	5.3	5.5	5.7	5.9	6.0	6.2	6.3	6.5	6.7
48	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.7	3.9	4.1	4.2	4.4	4.6	4.7	4.9	5.1	5.2	5.4	5.6	5.7	5.9	6.1	6.2	6.4	6.6
49	2.5	2.7	2.9	3.0	3.2	3.3	3.5	3.7	3.8	4.0	4.1	4.3	4.5	4.6	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.1	6.3	6.4
50	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.7	3.9	4.0	4.2	4.4	4.5	4.7	4.9	5.0	5.2	5.4	5.5	5.7	5.9	6.0	6.2	6.3
51	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	4.0	4.2	4.3	4.5	4.6	4.8	5.0	5.1	5.3	5.4	5.6	5.7	5.9	6.1	6.2
52	2.4	2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.6	3.8	3.9	4.0	4.2	4.4	4.5	4.7	4.9	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.1
53	2.3	2.5	2.7	2.8	2.9	3.1	3.3	3.4	3.6	3.7	3.8	4.0	4.2	4.3	4.4	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.0
54	2.3	2.4	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4	4.5	4.7	4.8	5.0	5.2	5.3	5.4	5.6	5.7	5.9
55	2.3	2.4	2.6	2.7	2.8	3.0	3.1	3.3	3.4	3.6	3.7	3.9	4.0	4.1	4.3	4.4	4.6	4.7	4.9	5.1	5.2	5.3	5.5	5.6	5.8
56	2.2	2.4	2.6	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	3.9	4.1	4.2	4.4	4.5	4.7	4.8	5.0	5.1	5.2	5.4	5.5	5.7
57	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.7	3.9	4.0	4.1	4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.4	5.6
58	2.1	2.3	2.5	2.6	2.7	2.8	3.0	3.1	3.3	3.4	3.5	3.7	3.8	3.9	4.1	4.2	4.4	4.5	4.6	4.7	4.9	5.1	5.2	5.3	5.5
59	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4.0	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.1	5.3	5.4
60	2.1	2.2	2.4	2.5	2.6	2.7	2.9	3.0	3.1	3.3	3.4	3.5	3.7	3.8	3.9	4.1	4.2	4.3	4.5	4.6	4.7	4.9	5.0	5.2	5.3
61	2.0	2.2	2.3	2.4	2.6	2.7	2.8	3.0	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4.0	4.1	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2
62	2.0	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.2	3.3	3.4	3.6	3.7	3.8	4.0	4.1	4.2	4.3	4.4	4.6	4.7	4.8	5.0	5.1
63	2.0	2.1	2.3	2.4	2.5	2.6	2.7	2.9	3.0	3.1	3.2	3.4	3.5	3.6	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.6	4.8	4.9	5.0
64	1.9	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.1	4.2	4.3	4.4	4.6	4.7	4.8	4.9
65	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.6	3.8	3.9	4.0	4.1	4.2	4.4	4.5	4.6	4.7	4.8
66	1.9	2.0	2.2	2.2	2.4	2.5	2.6	2.7	2.8	3.0	3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.1	4.2	4.3	4.4	4.5	4.7	4.8
67	1.8	2.0	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	3.2	3.3	3.4	3.5	3.7	3.7	3.8	4.0	4.1	4.2	4.3	4.4	4.6	4.7
68	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.9	3.0	3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.6
69	1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.2	3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5
70	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.5
71	1.7	1.8	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.6	3.7	3.9	4.0	4.1	4.2	4.3	4.4
72	1.7	1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3
73	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	3.2	3.4	3.5	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2
74	1.6	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2
75	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1
76	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.4	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1
77	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
78	1.5	1.6	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.9	3.1	3.1	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
79	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9

A figure in this column represent the volume of carbon dioxide gas (reduced to 0º and 760 mm.) dissolved by I volume of water at the temperatures indicated, if the partial pressure of the carbon dioxide gas is 760 mm. Hg, solubility data correspond to Bohr and Bock published in Landolt-Bornstein, Physikalische-Chemische Tabellen. Figures in body of the table were calculated for various temperatures and pressures based on the Boyle-Mariotte law for isothermal compression.

Source: The Chemistry and Technology of Food and Food Product, by M.B. Jacobs, 1951, 2nd Edn., Vol. III, p. 2374.