UNIT 1 UNIT OPERATIONS

Structure

1.0 OBJECTIVES

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

- comprehend the use and utility of food engineering in the food processing sector;
- know various systems of units and dimensions of quantities used in food engineering; and
- understand the principles of thermal processing and effective utilization of freezing, evaporation and dehydration in food processing and preservation.

1.1 INTRODUCTION

Most food processing operations are designed to extend the shelf-life of the product by reducing or eliminating microbial activity. This general objective implies that the processing operation meets the minimum requirement of ensuring any human health safety concerns associated with microbial activity. It must be acknowledged that most, if not all, food processing operations will influence the physical and sensory characteristics of the product. It is now a common practice within the food industry to utilize processing operations as an approach to enhance the physical and sensory characteristics of food products for better consumer acceptance.

The aims of the food processing are fourfold:

1. To extend the period during which a food remains wholesome (the shelf life) by preservation techniques which inhibit microbiological or biochemical changes and thus allow greater time for distribution and home storage;

2. To increase variety in the diet by providing a range of attractive flavours, colours, aromas and textures in food (collectively known as *eating, sensory* or *organoleptic quality);* a related aim is to change the form of the food to allow further processing (for example the pulping of fruits);

3. To provide the nutrients required for health (termed as *nutritional quality*);

4. To generate income for the entrepreneur or manufacturing company.

All the food processing activities involve a combination of procedures to achieve the intended changes to the raw materials. These procedures are conventionally categorized as *unit operations,* each of which has a specific, identifiable and predictable effect on a food item. A number of unit operations, same or different in nature form a process. The combination and sequence of operations, same or different in nature determines the nature of the final product.

In this unit, we will take up some basic concepts and unit operations that are important in food engineering.

1.2 DIMENSIONS

In food processing, we will talk of several parameters/quantities that make sense of when their dimensions and units are known. A dimension defines a physical entity, which can be observed and / or measured, quantitatively. For example, time, length, area, volume, mass, force, temperature, and energy are all considered dimensions. A unit expresses the quantitative value of a dimension. For example, length may be measured as metres, centimetres, or millimetres. According to the selected unit, the magnitude would be different.

Primary dimensions, such as length, time, temperature, mass, and force, express a physical entity. Secondary dimensions involve a combination of primary dimensions (e.g., volume is length cubed; velocity is distance divided by time).

It is necessary for equations to be dimensionally consistent. Thus, if the dimension of the left-hand side of an equation is “length,” it is necessary that the dimension of the right-hand side is also “length” otherwise the equation is inconsistent. In solving numerical problems, it is always useful to write units for each of the dimensional quantities within the equations. This practice is helpful to avoid mistakes in calculations.

1.3 ENGINEERING UNITS

Physical quantities are measured using a wide variety of unit systems. The most common systems are the Imperial (English) system; the centimeter, gram, second (CGS) system; and the meter, kilogram, second (MKS) system. The use of these systems, along with a myriad of symbols to designate units, has often caused considerable confusion. International organizations have attempted to standardize unit systems, symbols and the quantities to avoid confusion. As a result of international agreements, the "System International" or the SI system has emerged. The SI system consists of seven basic units, two supplementary units, and a series of derived units.

1.3.1 Base Units

The SI system is based on a choice of seven well-defined units, which by convention are regarded as dimensionally independent. The seven base units are as given in Table 1.1

Table 1.1: SI base units

Measurable attribute of phenomenon or matter	Name	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

1.3.2 Derived Units

Derived units are algebraic combinations of base units expressed by means of multiplication and division. Often, for simplicity, derived units carry special names and symbols that may be used to obtain other derived units. Some commonly used derived units are summarized in Table 1.2.

Table 1.2(a): Derived units expressed in terms of base units

Quantity	SI Units	
	Name	Symbol
Derived units expressed in terms of Base Units		
Area	square metre	m^2
Volume	cubic metre	m^3
Acceleration	metre per second squared	m/s^2
Density	kilogram per cubic metre	kg/m^3
Magnetic field strength	Ampere per metre	A/m
Concentration (of amount of substance)	mole per cubic metre	mol/m^3
Specific volume	cubic metre per kilogram	m^3/kg

Table 1.2(b): Derived units with specific names

Quantity	SI Units			
	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
Derived units with specific names				
Frequency	hertz	Hz		cycles.s^{-1}
Force	newton	N		m.kg.s^{-2}
Pressure	pascal	Pa	N/m²	m^{-1}.kg.s^{-2}
Energy	joule	J	N/m	m².kg.s^{-2}
Power	watt	W	J/s	m².kg.s^{-3}
Capacitance	farad	F	C/V	m^{-2}.kg^{-1}.s^{-4}.A²
Conductance	siemens	S	A/V	m^{-2}.kg^{-1}.s^{-3}.A²

Table 1.2(c): Derived units expressed by means of special names

Quantity	SI Units		
	Name	Symbol	Expression in terms of SI base units
Derived units expressed by means of special names			
Dynamic viscosity	pascal second	Pa.s	m^{-1}.kg.s^{-1}
Moment of force	newton metre	N.m	m².kg.s^{-2}
Surface tension	newton per metre	N/m	kg.s^{-2}
Heat capacity, entropy	joule per kelvin	J/K	m².kg.s^{-2}.K^{-1}
Specific heat capacity	joule per kilogram kelvin	J/(kg.K)	m².s^{-2}.K^{-1}
Specific energy	joule per kilogram	J/kg	m².s^{-2}
Thermal conductivity	watt per metre kelvin	W/(m.K)	m.kg.s^{-3}.K^{-1}

1.3.3 Supplementary Units

This class of units contains two purely geometric units, which may be regarded either as base or derived units. Both of them are given in Table 1.3.

Table 1.3: SI supplementary units

Quantity	SI Units	
	Name	Symbol
Plane angle	radian	rad
Solid angle	steridian	sr

1.4 SYSTEM AND PROPERTIES

1.4.1 System

A careful description of the system is vital in engineering analysis. A region prescribed in space or a finite quantity of matter is called a system and that is enclosed by an envelope, which is stated to be the boundary of the system. The boundary of a system can be real, such as walls of a tank, or it can be an imaginary surface that encloses the system. For example, in Figure 1.1, the boundary in system A is along the walls of a storage tank; thus it does not include the pipe and the valve. However, in system B, the boundary envelops the tank, valve and the pipe. The composition of the system is described by the components present inside the system boundary.

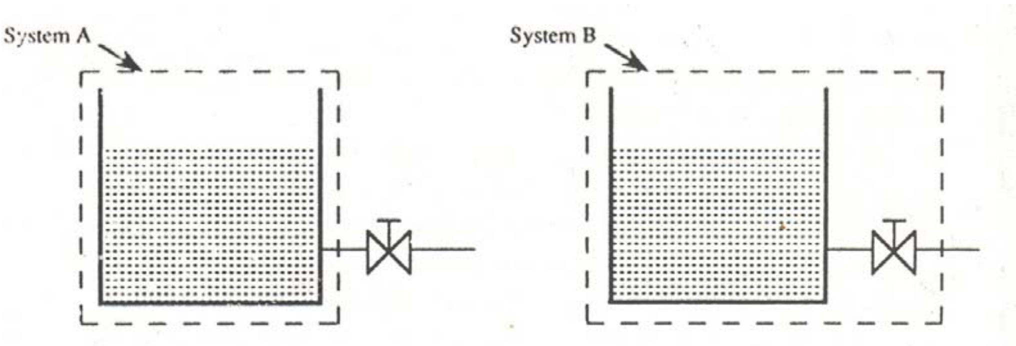

Figure 1.1: Examples of systems and their boundaries

Both closed and open systems are often encountered. In closed systems, the boundary of the system is impervious to any flow of matter. In an open system, heat and/or matter can flow into or out of the system. For example, a system boundary that contains only a small section of the wall is impervious to the flow of matter, and may be considered a close system. On the other hand, system B in Figure 1.1 is an open system since both heat and liquid can flow through the system.

1.4.2 Properties

Properties are those observable characteristics, such as pressure and temperature, which define the equilibrium state of a thermodynamic system. Properties do not depend on how the state of a system is attained: they are only functions of the state of a system. Thus, properties are independent of the process by which a system attained a certain state.

Intensive Properties

Intensive properties do not depend on the size of a system, such as temperature, pressure and density.

Extensive Properties

An extensive property depends on the size of the system: for example, mass, length, volume, energy. This definition implies that an extensive property of a system is a sum of respective partial property values of the components of a system. These properties, one of which may be mass are required to uniquely give an extensive property of a single component system.

The ratio of two extensive properties of a homogenous system is an intensive property. For example the ratio of two extensive properties mass and volume is density, which is an intensive property.

The state of a system is defined by independent properties. Once the properties become fixed, when the state of the system is defined, they are called dependent properties.

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 a dimensionally consistent equation?

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2. Enlist different systems of measurement and state the most acceptable one among them.

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3. Write the SI units of the following:

Quantity	Unit	Quantity	Unit
Length		Frequency	
Thermodynamic temperature		Pressure	
Amount of substance		Power	
Area		Moment of force	
Density		Specific energy	
Concentration		Thermal conductivity	

4. Differentiate between the following

i) Open & closed systems

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ii) Intensive & extensive properties

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1.5 THERMAL PROCESSING

Since many of the processes utilized to preserve food products depend on the addition of thermal energy, it is important to understand the principles associated with food preservation through the addition of thermal energy. The design of a thermal process to achieve food preservation involves two principles: (a) the use of elevated temperatures to increase the rate of reduction in the microbial population present in the raw food material and (b) the transfer of thermal energy into the food product required to achieve the desired elevated temperatures.

The information in this section will address the typical parameters used to quantify the influence of elevated temperatures on reduction of microbial populations. Details will be presented in subsequent sections.

1.5.1 Influence of Elevated Temperatures on Microbial Populations

When microbial population in a food is exposed to an elevated temperature, changes in individual microbial cells within the population and a reduction in the viability of the microorganisms result in a reduction of the population with time of exposure when quantified by standard microbiological procedures. A typical pattern of microbial population change as a function of time when the population is exposed to an elevated temperature is illustrated in Figure 1.2. The reduction in population occurs in a logarithmic manner with increasing time at a given constant elevated temperature.

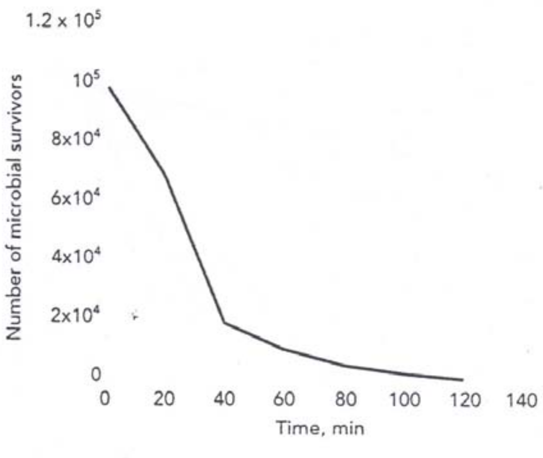

Figure 1.2: Changes in microbial population as a function of time at a constant elevated temperature

Decimal Reduction Time

The decimal reduction time (D Value) is defined as the time necessary for 90% reduction in the microbial population. When the microbial population is plotted against corresponding heating time on semi log coordinates, the D value is the time required for a one log cycle reduction in the number of microorganisms (Figure 1.3). The initial microbial population has no influence on the D value since the magnitude is directly related to the slope of the straight line. Exposure of the microbial population to higher temperatures results in a decrease in the D value. In fact, a plot of decimal reduction time as a function of temperature on semi log coordinates results in a linear relationship (Figure 1.4). This curve is known as thermal resistance curve.

Based on the definition, the following equation can be used:

$$\log N_0 - \log N = t/D \qquad (1.1)$$

or,

$$N/N_0 = 10^{-t/D} \qquad (1.2)$$

where N_0 is the initial number of microorganisms (t=o), N is the number of microorganisms surviving after heating for time 't' at a temperature and D is decimal reduction time for the microorganism under conditions of heating.

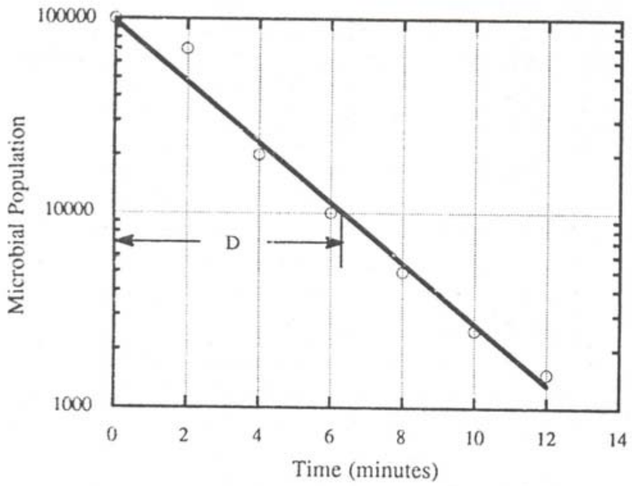

Figure 1.3: Semi-logarithmic plot of microbial population versus heating time at an elevated temperature

Thermal Resistance Constant

The temperature increase required to cause a one log cycle reduction in the decimal reduction time is defined as the thermal resistance constant (z). The thermal resistance constant, or z-value, is a second quantitative parameter normally used to quantify the thermal process required for a given microbial population. A large z-value suggests that a given increase in temperature of exposure for the microbial population results in a small change in decimal reduction time. In most situations, this observation would indicate that the microbial population contains vegetative cells or microbial spores; the spores exhibit greater heat resistance or higher z-value than vegetative populations which are characterized by a lower z-value. It is important to note that the complete characterization of the impact of elevated temperature on microbial population requires reference to both the decimal reduction time (D) and the thermal resistance constant (*z*). The *z*-value as shown in Figure 1.4 can be expressed by the following equation:

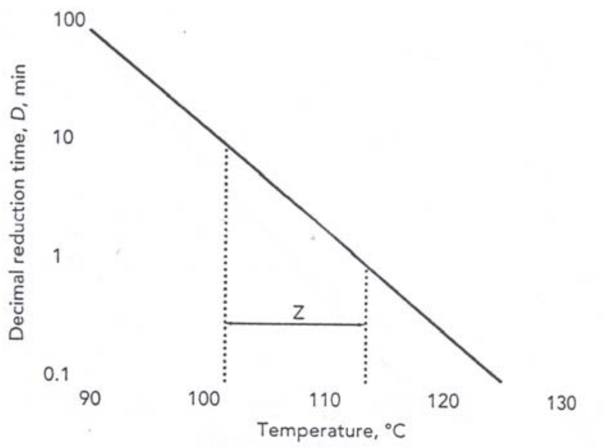

Figure 1.4: Thermal resistance curve of microbial population

$$z = \frac{T_2 - T_1}{\log D_{T_1} - \log D_{T_2}} \qquad (1.3)$$

where D_{T_1} and D_{T_2} are decimal reduction times for micro-organisms at temperatures T_1 and T_2, respectively and 'z' is thermal resistant constant.

Thermal Death Time

The third quantitative parameter found frequently in thermal processing is the thermal death time, or F-value, which finds use in the actual thermal process. Thermal death time is defined as the time required for achieving a *stated reduction* in the microbial population at a given temperature. The key part of the definition is the stated reduction, which may be the reduction in the population of microbial pathogens required to establish product safety. Alternatively, the stated reduction may be the reduction in the population of a vegetative microorganism causing product spoilage, and the stated reduction is that required to achieve the desired product shelf-life.

A thermal death time curve would appear to be very similar to a thermal resistance curve (Figure 1.4), but would cover the entire range of times required to achieve the desired or stated reduction in microbial population. A typical thermal death time curve is presented in Figure 1.5. Note that the curve describes the entire reduction in microbial population from time zero until the population has been reduced to a defined level of microbial survivors. This point has been defined as the thermal death time, or F-value.

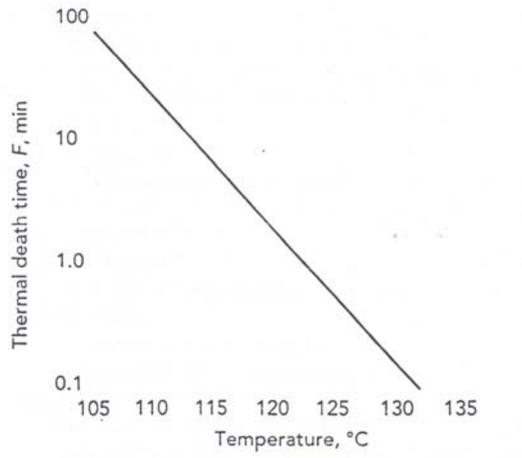

Figure 1.5: Thermal death time curve

The similarity in the thermal resistance and the thermal death time curve is evident from Figures 1.4 and 1.5. Each log cycle reduction in the microbial population on the thermal resistance curve represents a decimal reduction time, or D-value. It follows that F-values may be expressed as multiples of D-values. The most common of these relationships is F = 12D for *Clostridium botulinum* in *com*mercial sterilization of low acid foods. It must be emphasized that any given F-value will apply to a single elevated temperature. In other words, different elevated temperatures result in different F-values or times required achieving the same stated level of reduction in microbial population.

Inter-relationships

The relationships between microbial populations and time, as well as the impact of temperature, are very similar to the relationships used to describe kinetic parameters in first-order chemical reactions. The reaction rate constant *(k)* is used to describe the change in concentration of a reactant as a function of time. In microbial populations, the D-value is utilized to describe the same relationship. It follows that the relationship between the reaction rate constant *(k)* and the decimal reduction time (D) is given by Eq. (1.4):

$$k = \frac{2.303}{D} \quad (1.4)$$

The influence of temperature on reaction rate is described by Q_{10} or the activation energy constant (E). It follows that a relationship between Q_{10} and thermal resistance constant (z) must exist. It is relatively easy to demonstrate that this relationship is as shown in Eq. (1.5):

$$Q_{10} = 10^{\frac{10}{z}} \quad (1.5)$$

The relationship between the activation energy constant (E) and the thermal resistance constant (z) is more complex. It must be noted that the activation energy constant (E) is obtained from an Arrhenius plot: the natural logarithm of the reaction rate constant *(k)* versus the inverse of absolute temperature. Nevertheless, the relationship has been derived and presented in Singh and Heldman (1993) as Eq. (1.6):

$$E = \frac{2.303RT_A^2}{z} = \frac{19.15T_A^2}{z} \quad (1.6)$$

where R is the universal gas constant and $T_{A,}$ represents the mid-point between two absolute temperatures used to define the z-value in the relationship. The relationship between the activation energy constant and the thermal resistance constant applies over limited ranges of temperature where the experimental data utilized to quantify the z-value were measured.

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 thermal death time & decimal reduction time.

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2. Compute the first order rate constant corresponding to the decimal reduction time of 4.1 minutes.

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3. Estimate Q_{10} for a z value of 11°C.

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4. Estimate the activation energy of a microorganism having a thermal resistance constant of 11°C at 100°C?

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1.6 REFRIGERATION

Refrigeration system allows transfer of heat from the cooling chamber to a location where the heat can be discarded. The transfer of heat is accomplished by using a refrigerant, which like water changes state – from liquid to vapour. The primary purpose of refrigerating foods is to extend shelf-life by slowing down degradatory reactions and limiting microbial growth. Through reduction in rates of chemical, biochemical and microbial kinetics (rates of lipid oxidation, non enzymatic browning, sugar conversion, enzymatic browning, and respiration reactions), low temperature storage can extend the shelf-life of fresh and processed foods. Typically, refrigerated storage means holding food in a temperature range of –1 to 8°C.

Other factors besides low temperature may influence shelf-life of refrigerated foods. For fresh foods, these include the type of food and variety, the condition of the food at harvest (mechanical damage, microbial contamination, and degree of maturity), and the relative humidity of storage atmosphere. For processed foods, factors affecting shelf life include type of food, degree of microbial or enzyme destruction during processing, hygienic factors during processing and packaging, and the nature of the package (barrier properties).

1.6.1 Components of a Refrigeration System

The major components of a simple mechanical vapour compression refrigeration system are shown in Figure 1.6. As the refrigerant flows through these components its phase changes from liquid to gas and then back to liquid. At location D, just prior to the entrance of the expansion valve, the refrigerant is in a saturated liquid state. After passing through the expansion valve, the refrigerant experiences a drop in pressure accompanied by a drop in temperature. Due to the drop in pressure, some of the liquid refrigerant changes to gas. The liquid gas leaving the expansion valve is termed 'flash gas'.

The liquid/gas mixture enters the evaporator coils at location E. In the evaporator, the refrigerant completely vaporizes to gas by accepting heat from the media surrounding the evaporator coils. The saturated vapour may also get superheated due to gain of additional heat from the surroundings.

The saturated or superheated vapours enter the compressor, where the refrigerant is compressed to a high pressure. This high pressure must be below the critical pressure of the refrigerant and high enough to allow condensation of the refrigerant at a temperature slightly higher than that of commonly available heat sinks, such as ambient air or water. Inside the compressor, the compression process of the vapours occurs at constant entropy (called an isentropic process). As the pressure of the refrigerant increases, the temperature increases, and the refrigerant become superheated.

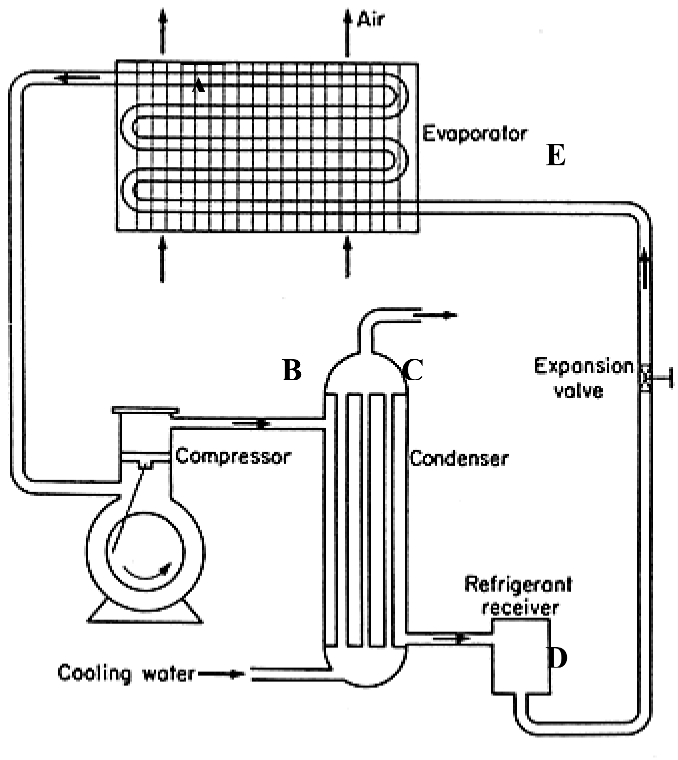

Figure 1.6: Mechanical refrigeration circuit

The superheated vapours are then conveyed to the condenser. Using either an air cooled or water cooled condenser, the refrigerant discharges heat to the surrounding media. The refrigerant condenses back to the liquid state in the condenser (saturated liquid). The temperature of the refrigerant may decrease below that of its condensation temperature (sub cooled) due to additional heat discharged to the surrounding media. The saturated or sub cooled liquid then enters the expansion valve and the cycle continues.

The process can also be followed on the pressure-enthalpy chart shown in Figure 1.7.

1.6.2 Some Useful Mathematical Expressions

Cooling Load

The cooling load is the rate of heat energy removal from a given space (or object) in order to lower the temperature of that space (or object) to a desired level. A typical unit of cooling load used in commercial practice is 'ton of refrigeration'. One ton of refrigeration is equivalent to the amount of heat required to melt one ton of ice in one day at 0^0 C {(1000 kg x 336 kJ/kg)/24 hr} = (336000 kJ / 86400 s) = 3.888 kW. Thus a mechanical refrigeration system that has a capacity to absorb heat from the refrigerated space at the rate of 3.888 kW is rated as one ton of refrigeration.

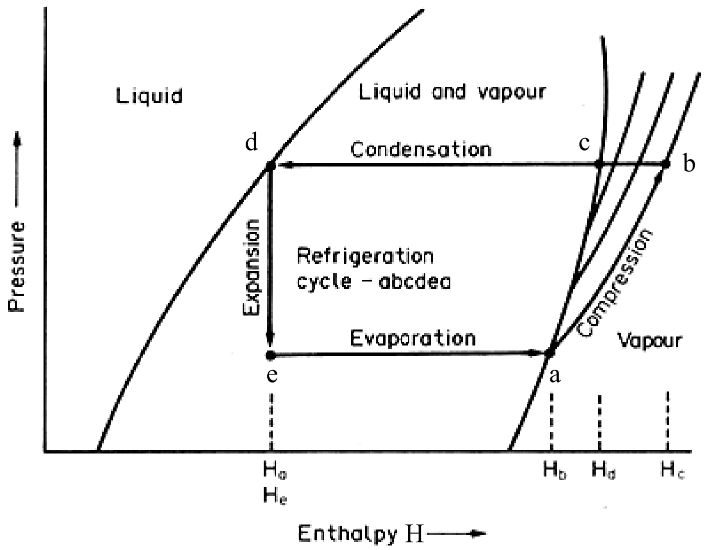

Figure 1.7: Pressure/enthalpy chart

The factors which contribute to the cooling load include the sensible heat, heat of respiration (in case of fresh produce); heat infiltration through walls, floor and ceiling; heat gain through doors; heat given by lights, people and use of fork lifts for material handling; etc.

Coefficient of Performance

The coefficient of performance (C.O.P.) is defined as a ratio between the heat absorbed by the refrigerant as it flows through the evaporator to the heat equivalence of the energy supplied to the compressor. In other words, it is the ratio of the useful refrigeration effect obtained from the system to the work expended on it to produce that effect.

$$C.O.P. = \frac{H_a - H_e}{H_b - H_a} \qquad (1.7)$$

where H_a is heat content of vapour learning evaporator, H_b is heat content of vapour learning compressor, H_d or H_e is heat content of liquid entering evaporator.

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 principle behind shelf-life extension through refrigeration.

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2. Enlist the various components of a vapour compression refrigeration system along with their functions.

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3. Define cooling load and C.O.P.

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1.7 FOOD FREEZING

Food freezing is a preservation process that depends on the reduction of product temperatures to levels well below the temperature at which ice crystals begin to form within the food. By reducing the temperature of the product to –10°C to –20°C, the normal reactions that cause deterioration of foods are reduced to negligible or minimal rates. These temperature levels eliminate microbial growth as a concern in shelf-life of the food product. As would be expected, the shelf-life of a frozen food is a function of temperature, with lower temperatures leading to longer shelf-life.

The limitations of freezing as a food preservation process include both quality concerns and energy requirements. The formation of ice crystals within the structure of most food products creates changes in the structure that are at times irreversible and most often cause negative changes in the quality characteristics of the product. The refrigeration requirements associated with the food-freezing process, as well as maintaining the low temperatures associated with frozen food storage and distribution are factors that must be considered while evaluating the costs of this preservation process. The value of the shelf-life extension achieved by food freezing must be balanced against the added costs associated with energy requirements for the production and storage of the frozen foods.

1.7.1 Theory

In theory, the freezing process is the removal of the thermal energy from the food product to the extent required to reduce the temperature below the freezing temperature of water. The thermal energy removed, as a part of freezing is primarily latent heat of fusion required to convert water to ice within the product.

If the temperature is monitored at the thermal center of food (the point that cools most slowly) as heat is removed, a characteristic curve is obtained (Figure 1.8).

The six portion of the curve are as follows:

AS The food is cooled to below its freezing point θ_f which, with the exception of pure water, is always below 0°C. At point S the water remains liquid although the temperature is below the freezing point. This phenomenon is known as sub-cooling and may be as much as 10°C below the freezing point

SB The temperature rises rapidly to the freezing point as ice crystals begin to form and latent heat of crystallization is released.

BC Heat is removed from the food at the same rate as before. Latent heat is removed and ice forms, but the temperature remains almost constant. The freezing point is depressed by the increase in solute concentration in the unfrozen liquor, and the temperature therefore falls slightly. It is during this stage that the major part of the ice is formed.

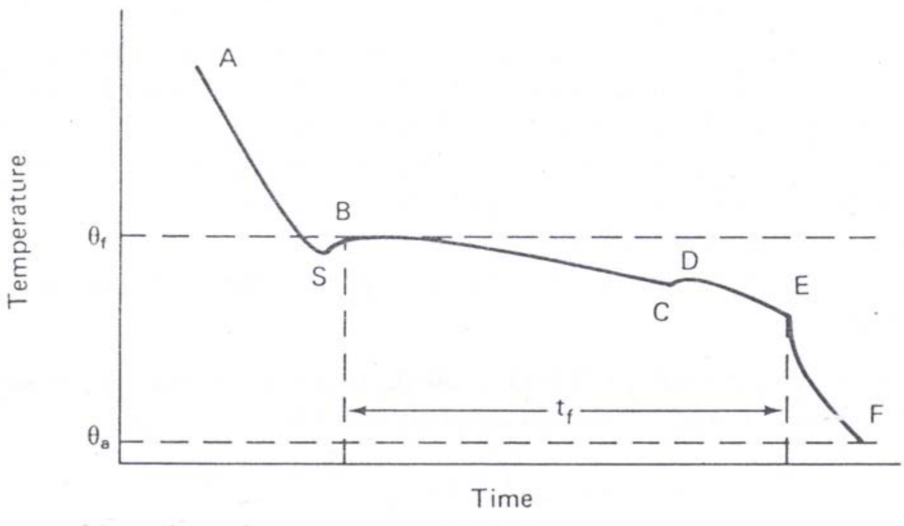

Figure 1.8: Time temperature relationships during freezing

CD One of the solutes becomes supersaturated and crystallizes out. The latent heat of crystallization is released and the temperature rises to the eutectic temperature for that solute

DE Crystallization of water and solutes continues. The total time t_f taken (the freezing plateau) is determined by the rate at which heat is removed.

EF The temperature of the ice-water mixture falls to the temperature of the freezer. A proportion of the water remains unfrozen at the temperature used in commercial freezing; the amount depends on the type and composition of the food and the temperature of freezing.

Ice Crystal Formation

The freezing point of a food is the temperature at which a minute crystal of ice exists in equilibrium with the surrounding water. However, before an ice crystal can form, a nucleus of water molecules must be present. Nucleation therefore precedes ice crystal formation. The rate of ice crystal growth during freezing is controlled by the rate of heat transfer for the majority of the freezing plateau. The rate of mass transfer does not control the rate of crystal growth except towards the end of the freezing period when solutes become more concentrated. The time taken for the temperature of the food to pass through the critical zone (Figure 1.9) therefore, determines the number and the size of the ice crystals.

Solute Concentration

The increase in solute concentration during freezing causes changes in pH, viscosity and redox potential of the unfrozen liquor. As the temperature falls individual solutes reach saturation point and crystallizes out. The temperature at which a crystal of an individual solute exists in equilibrium with the unfrozen liquor and ice is its eutectic temperature. However, it is difficult to identify individual eutectic temperatures in the complex mixture of solutes in foods, and the term final eutectic temperature is used. This is the lowest temperature of the solutes in the food. Maximum ice crystal formation is not possible until this temperature is reached. Commercial foods are not frozen to such low temperatures and unfrozen water is therefore always present.

Volume Changes

The volume of ice at 0^0 C is 9% greater than that of pure water, and an expansion of foods after freezing would therefore be expected. However, the degree of expansion varies considerably owing to the moisture content (higher moisture content produce greater changes in volume), cell arrangement, the concentration of solutes (high concentrations reduce the freezing point) and the freezer temperature (this determines the amount of unfrozen water and hence the degree of expansion). Temperatures below 0^0 C cause shrinkage in the volume of ice formed during freezing process.

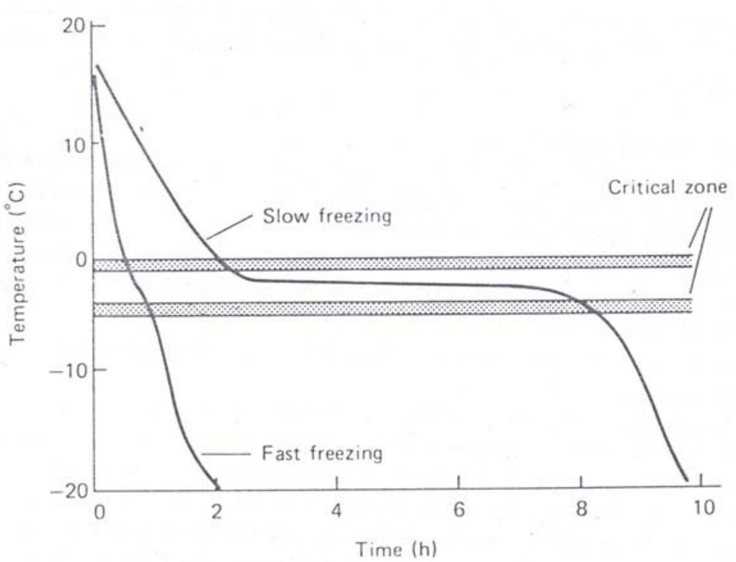

Figure 1.9: Temperature changes of food through the critical zone during freezing

1.7.2 Freezing Systems

The freezing process can be accomplished using either indirect or direct contact systems. Most often, the type of system used will depend on the product characteristics, before and after freezing is completed.

Indirect Contact Systems

In numerous food products freezing systems the product and the refrigerant are separated by a barrier throughout the freezing process. This is called an indirect contact system (Figure 1.10). Although many systems use a non-permeable barrier between product and refrigerant, indirect freezing systems include any system without direct contact, including those where the package material becomes the barrier. These include plate freezer, air blast freezer and freezer for liquid foods.

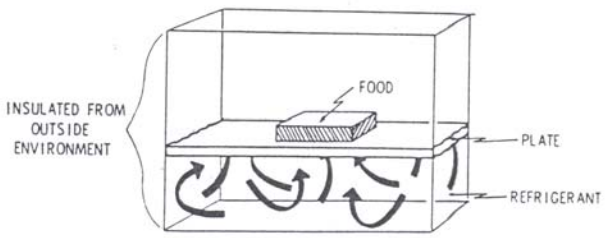

Figure 1.10: Schematic diagram of indirect contact freezing

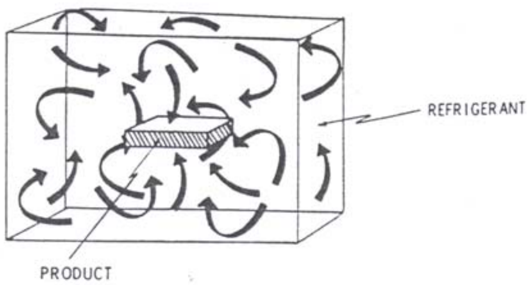

Figure 1.11: Schematic diagram of direct contact freezing

Direct Contact Systems

Direct contact freezing systems operate with direct contact between the refrigerant and the product (Figure 1.11). In most situations these systems operate more efficiently since there is no barrier to heat transfer between the refrigerant and the product. All direct contact freezing systems are designed to achieve rapid freezing, and the term individual quick freezing (IQF) applies. This includes fluidized bed freezing immersion freezing and cryogenic freezing.

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 food freezing.

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2. Define eutectic point.

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3. Enlist the factors affecting volume changes during freezing.

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4. Differentiate between indirect and direct contact freezing systems.

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1.8 EVAPORATION

Evaporation is an important unit operation commonly employed to remove water from dilute liquid foods to obtain concentrated liquid products (for e.g. manufacture of tomato puree from juice). Removal of water from foods provides microbiological stability and assists in reducing packaging, transportation and storage costs. Evaporation is also a necessary step before drying and crystallization process. Evaporation differs from dehydration, since the final product of evaporation process remains in liquid state.

The evaporator in which the vapour produced are discarded without further utilizing its inherent heat is called a single effect evaporator, whereas the evaporator in which the inherent heat of the vapour is reused again as heating medium is called a multiple effect evaporator.

The evaporation process is largely dependent on the principle of heat transfer and the factors, which hamper heat transfer, are the major impediments for the process. Some of these factors are: (1) Boiling point rise, (2) Heat sensitivity of the liquid, (3) Fouling & foaming properties of the food, etc.

1.8.1 Boiling Point Elevation

Boiling point elevation of a solution (liquid food) is defined as the increase in boiling point over that of pure water, at a given pressure. A simple method to estimate boiling point elevation is the use of Duhring's rule. The Duhring's rule states that a linear relationship exists between the boiling point temperature of a solution and the boiling point temperature of water at the same pressure. Duhring lines for sodium chloride – water system are shown in Figure 1.12.

1.8.2 Types of Evaporators

Several types of evaporators are used in the food industry. In the following paragraphs we would discuss some of the most commonly used evaporators.

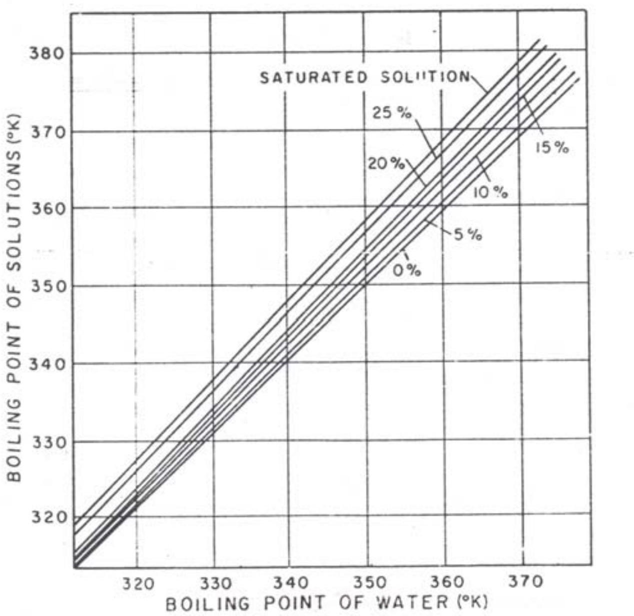

Figure 1.12: Duhring lines for sodium chloride – water system

Batch Type Pan Evaporator

One of the simplest and perhaps oldest types of evaporators used in food industry is the batch-type pan evaporator (Figure 1.13). The product is heated in a steam jacketed spherical vessel. The heating vessel is either open to atmosphere or connected to a condenser and vacuum system.

Heating of the product occurs mainly due to natural convection, resulting in smaller convective heat transfer coefficients. The poor heat transfer coefficients substantially increase the residence time of the product and reduce the processing capacities of these evaporators.

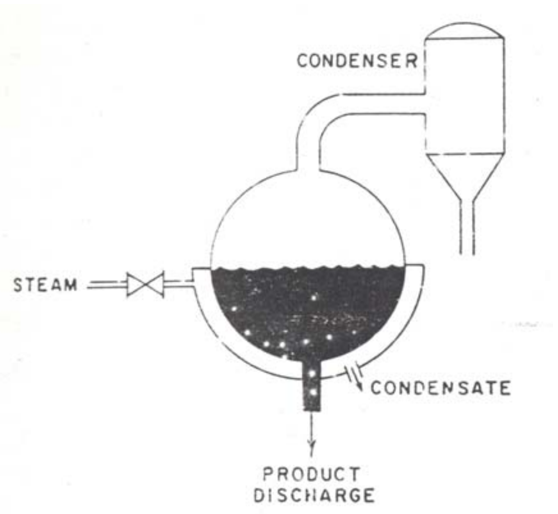

Figure 1.13: Batch type pan evaporator

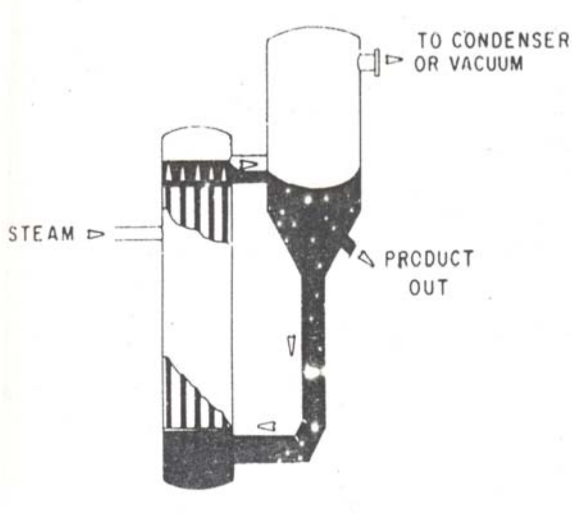

Figure 1.14: Natural circulation evaporator

Natural Circulation Evaporators

In natural circulation evaporators (Figure 1.14), short vertical tubes are arranged inside a steam chest. The whole calendria (tubes and steam chest) is located at 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.

Rising Film Evaporator

In a rising film evaporator (Figure 1.15), a low viscosity liquid food is allowed to boil inside 10-15 m long vertical tubes. The tubes are heated from outside with steam. The liquid rises inside these tubes by vapours formed near the bottom of the heating tubes. The upward movement of vapour causes a thin liquid film to move rapidly upward. A temperature differential of at least 14°C between the product and the heating medium is necessary to obtain a well-developed film. High convective heat-transfer coefficients achieved in these evaporators mostly makes the operation once through. However, liquid can be recirculated to obtain the required solid concentration.

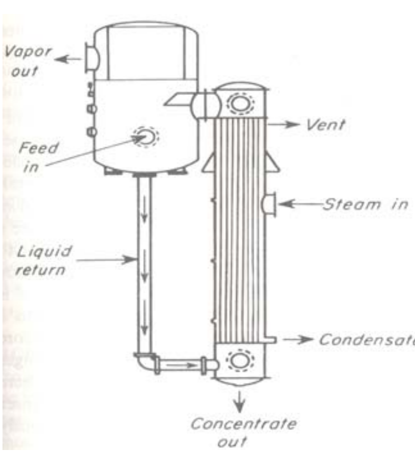

Figure 1.15: Rising film evaporator

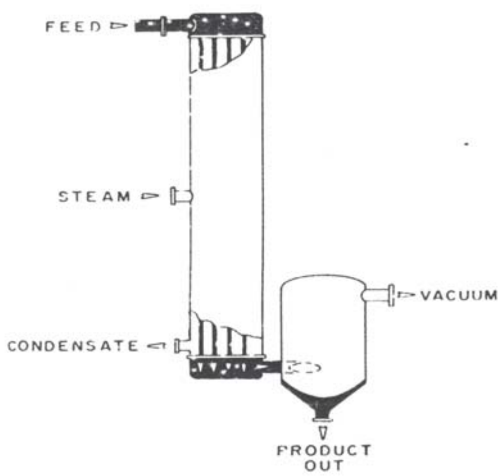

Fig 1.16: Falling film evaporator

Falling Film Evaporator

In contrast to the rising film evaporator, the falling film evaporator has a thin liquid film moving downward under gravity on the inside of the vertical tubes (Figure 1.16). The distribution of liquid in a uniform film flowing downward is accomplished by the use of specially designed distributors or spray nozzles. The falling film evaporator can handle more viscous liquids than the rising film type. These evaporators are best suited for highly heat sensitive products. Typical residence time in a falling film evaporator is 20-30 seconds, compared with residence time of 3-4 minutes in a rising film evaporator.

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. As shown in Figure 1.17, the product is first partially 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.

Forced Circulation Evaporators

The forced circulation evaporator involves a non contact heat exchanger where liquid food is circulated at high rates (Figure 1.18). 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 convection evaporators. Both capital and operating costs of these evaporators are very low in comparison to other types of evaporators.

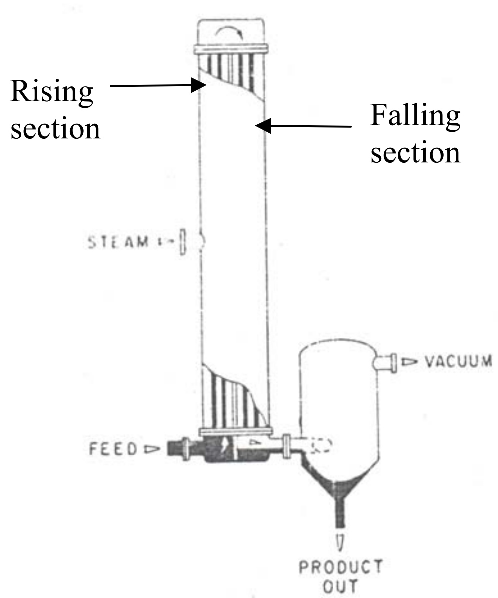

Figure 1.17: Rising / Falling film evaporator

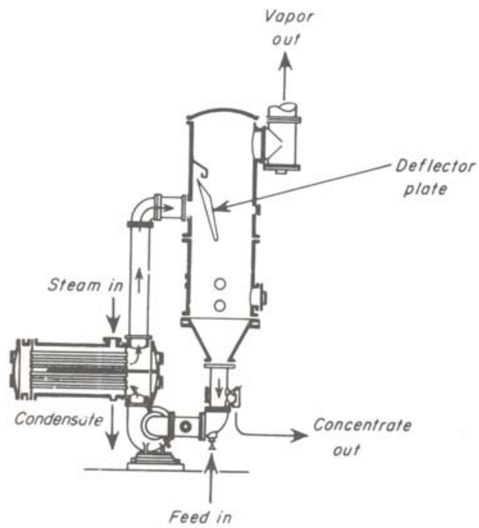

Figure 1.18: Forced circulation evaporator

Agitated Thin Film Evaporator

For very viscous fluid foods, feed is spread on the inside of the cylindrical heating surface by wiper blades, as shown in Figure 1.19. Due to high agitation, considerably higher heat transfer rates are obtained. The cylindrical configuration results in low heat transfer area per unit volume of the product. High pressure steam may be used as the heating medium to obtain high wall temperatures for reasonable evaporation rates. The major disadvantages are the high capital and maintenance costs and low processing capacity.

In addition to the tubular shape, plate evaporators are also used in the industry. Plate evaporators use the principles of rising / falling film, falling film, wiped film and forced circulation evaporators.

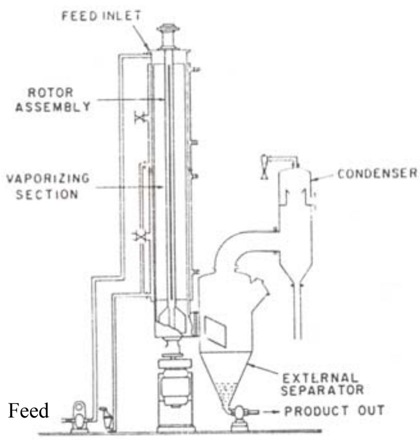

Figure 1.19: Agitated thin film evaporator

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. Differentiate between evaporation and dehydration.

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2. Define boiling point elevation.

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3. Write short notes on the following.

   a) Batch type pan evaporator
   b) Rising film evaporator
   c) Forced circulation evaporator
   d) Agitated thin film evaporator

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1.9 DEHYDRATION

Drying is one of the oldest methods of preserving food. Primitive societies practiced the drying of meat and fish in the sun long before recorded history. Today the drying of foods is still important as a method of preservation. Dried foods can be stored for long periods without any deterioration in quality. The principal reasons for this are that the microorganisms, which cause food spoilage and decay, are unable to grow and multiply in the absence of sufficient water and many of the enzymes which promote undesired changes in the food cannot function without water.

Preservation is the principal reason for drying, but drying can also occur in conjunction with other processing. For example, in the baking of bread, application of heat expands gases, changes the structure of the protein and starch molecules and dries the loaf.

Drying of foods implies the removal of water from the foodstuff. In most cases, drying is accomplished by vaporizing the water that is contained in the food, and to do this the latent heat of vaporization must be supplied. There are, thus, two important process-controlling factors that enter into the unit operation of drying:

a) Transfer of heat to provide the necessary latent heat of vaporization,

b) Movement of water or water vapour through the food material and then away from it to effect separation of water from foodstuff.

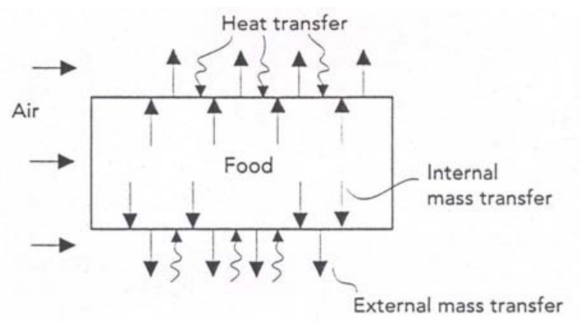

Figure 1.20: Principle of drying of food

1.9.1 Basic Drying Theory

Pure water can exist in three states, solid, liquid and vapour. The state in which it is at any time depends on the temperature and pressure conditions and it is possible to illustrate this on a phase diagram**,** as in Figure 1.21.

If we choose any condition of temperature and pressure and find the corresponding point on the diagram, this point will lie, in general, in one of the three-labelled regions, solid, liquid, or gas. This will give the state of the water under the chosen conditions.

Under certain conditions, two states may exist side by side, and such conditions are found only along the lines of the diagram. Under one condition, all three states may exist together; this condition arises at what is called the triple point, indicated by point O on the diagram. For water it occurs at 0.0098°C and 0.64 kPa (4.8 mm of mercury) pressure.

If heat is applied to water in any state at constant pressure, the temperature rises and the condition moves horizontally across the diagram, and as it crosses the boundaries a change of state will occur. For example, starting from condition A on the diagram adding heat warms the ice, then melts it, then warms the water and finally evaporates the water to condition A'. Starting from condition B, situated below the triple point, when heat is added, the ice warms and then sublimes without passing through any liquid state.

Liquid and vapour coexist in equilibrium only under the conditions along the line OP. This line is called the vapour-pressure line. The vapour pressure is the measure of the tendency of molecules to escape as a gas from the liquid.

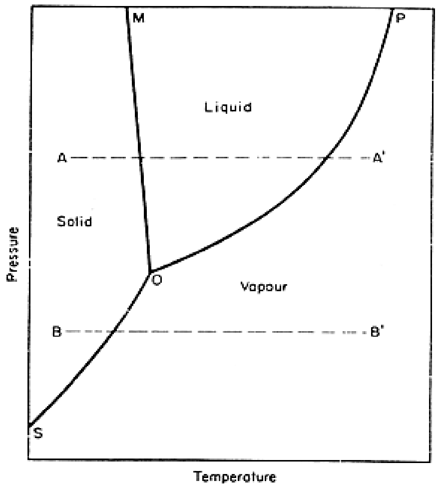

Figure 1.21: Phase diagram for water

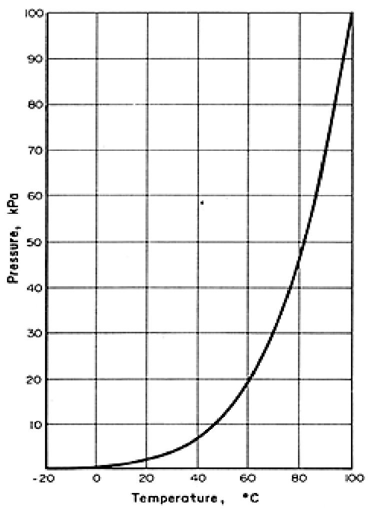

Fig 1.22: Vapour pressure/temperature curve for water

Boiling occurs when the vapour pressure of the water is equal to the total pressure on the water surface. The boiling point at atmospheric pressure is of course 100°C. At pressures above or below atmospheric, water boils at the corresponding temperatures above or below 100°C as shown in Figure 1.22 for temperatures below 100°C.

Recently, state diagrams have been employed to depict conditions of water in foods and its use has improved our knowledge of drying technology. The state diagram shown in figure 1.23 for simple system of solute and solvent, is a phase diagram based on components of the food product supplemented by the glass transition curve. The glass transition curve represents a meta stable transition where viscosity is effectively so high that the product does not ‘flow’ over time scale of importance to food stability. Below this curve on the state diagram, the food is stable to diffusion related processes (such as moisture migration) for extremely longer times.

Heat Transfer in Drying

The rates of drying are generally determined by the rates at which heat energy can be transferred to the water or to the ice in order to provide the latent heats, though under some circumstances the rate of mass transfer (removal of the water) can be limiting. All three of the mechanisms by which heat is transferred - conduction, radiation and convection - may enter into drying. The relative importance of the mechanisms varies from one drying process to another and very often one mode of heat transfer predominates to such an extent that it governs the overall process.

As an example, in air drying the rate of heat transfer is given by:

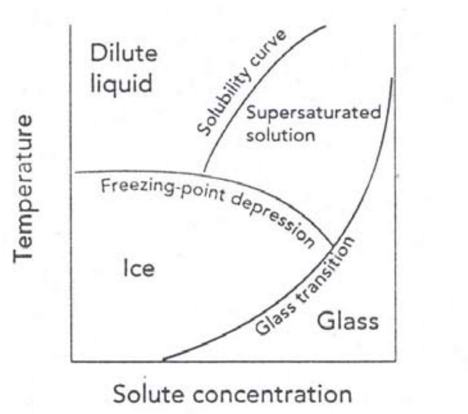

Figure 1.23: State diagram for a simple binary mixture

$$q = UA\,(T_a - T_s) \qquad (1.8)$$

where q is the heat transfer rate in J s^{-1}, U is the overall heat-transfer coefficient in J s^{-1} m^{-2} k^{-1}, A is the area through which heat flow is taking place, T_a is the air temperature and T_s is the temperature of the surface which is getting dried.

In cases where substantial quantities of heat are transferred by radiation, it should be remembered that the surface temperature of the food might be higher than the air temperature. Estimates of surface temperature can be made using the relationships developed for radiant heat transfer although the actual effect of combined radiation and evaporative cooling is complex. Convection coefficients also can be estimated using the standard equations.

As drying proceeds, the character of the heat transfer situation changes. Dry material begins to occupy the surface layers and conduction must take place through these dry surface layers that are poor heat conductors. Therefore, the heat is transferred to the drying region progressively more slowly.

Mass Transfer in Drying

In heat transfer, heat energy is transferred under the driving force provided by a temperature difference, and the rate of heat transfer is proportional to the potential (temperature) difference and to the properties of the transfer system characterized by the heat-transfer coefficient. In the same way, mass is transferred under the potential gradient force provided by a partial pressure or concentration difference. The rate of mass transfer is proportional to the potential (pressure or concentration) gradient and to the properties of the transfer system characterized by a mass-transfer coefficient.

Writing the relationship symbolically, analogous to heat transfer (Eq. 1.8), we have

$$w = k_G A(H_a - H_s) \quad (1.9)$$

where w is the mass being transferred kg s^{-1}, A is the area through which the transfer is taking place, k_G is the mass-transfer coefficient in this case in units kg m^{-2} s^{-1} , and the quantity within brackets i.e., $(H_a - H_s)$ is the humidity difference in kg kg^{-1}(kg of moisture per kg of air).

Unfortunately the application of mass-transfer equation is not as straightforward as heat transfer, one reason being because the movement pattern of moisture changes as drying proceeds. Initially, the mass (moisture) is transferred from the surface of the material and later, to an increasing extent, from deeper within the food to the surface and thence to the air. So the first stage is to determine the relationships between the moist surface and the ambient air and then to consider the diffusion through the food. In studying the surface/air relationships, it is necessary to consider mass and heat transfer simultaneously. Air for drying is usually heated and it is also a major heat-transfer medium. Therefore, it is necessary to look carefully into the relationships between air and the moisture it contains.

Factors Influencing Drying

There are many factors that influence the rate of drying. These are related to either: (1) the process conditions present during drying, as determined by dryer type and operating conditions, or (2) the nature of the food product placed inside the dryer. The process conditions include dry look temperature, air velocity, wet bulb depression, pressure etc. whereas those of food product include surface area, constituent orientation, cellular structure, type and concentration of solutes.

Drying Methods

The methods involved in industrial drying of foods include: (1) Cabinet drying, (2) Tunnel drying, (3) Spray drying, (4) Vacuum drying, (5) Foam mat drying, (6) Freeze drying, (7) Fluidized bed drying, (8) Microwave drying, (9) Drum drying etc. The principles of different drying methods and the equipments used will be dealt in detail in subsequent blocks.

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. Enumerate the principle of drying and its controlling factors?

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2. Define triple point of water.

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3. Triple point of pure water occurs at _______°C temperature and _________ kPa pressure.

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4. Define vapour-pressure line.

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5. Define glass transition curve.

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6. What is the driving force for heat and mass transfer during drying of foods?

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7. Enlist the factors that influence drying.

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1.10 LET US SUM UP

We have learnt that there are magnitudes of various quantities and properties, which do not make sense unless, qualified with appropriate units. Although there are different systems of units such as MKS, CGS, FPS and SI, it is the SI system of units that is internationally accepted. A system for the purpose of analysis may be either a closed or an open system. Thermal processing of food is required to ensure that the population of harmful micro-organisms is reduced to acceptable level and then not allowed to grow for an intended period of time. The concepts of Decimal reduction time, thermal resistance constant and thermal death time have been presented. Then, the processes of evaporation, refrigeration and dehydration as they relate to food processing have been introduced. Simple relationships for estimating the extents of these unit operations have been presented.

1.11 KEY WORDS

Dimensions :	A dimension defines a physical entity, which can be observed and / or measured, quantitatively.
Units :	A unit expresses the quantitative value of a dimension.
Open system :	The composition of the system is described by the components present inside and outside the system boundary.
Close system :	The composition of the system is described by the components present inside the system boundary.
Intensive Properties :	Properties that does not depend on the size of a system.
Extensive Property :	Depends on the size of the system: for example, mass, length, volume, energy. This definition implies that an extensive property of a system is a sum of respective partial property values of the components of a system.
Decimal reduction time :	The decimal reduction time (D) is defined as the time necessary for 90% reduction in the microbial populationly heating at a constant temperature.
Thermal resistance constant :	It is defined as the temperature increase required to cause a one log cycle reduction in the decimal reduction time.
Thermal death time :	Thermal death time is defined as the time required for achieving a *stated reduction* in the microbial population at a given temperature.
Evaporator :	Completely vaporizes the refrigerant by heating it.

Compressor : Compresses the refrigerant at constant entropy.

Condenser : Condenses the refrigerant after going the heat to the surrounding medium

Expansion valve: It is the point of differentiation between the high pressure and low pressure sides of the refrigeration cycle.

Cooling load : The cooling load is the rate of heat energy removal from a given space (or object) in order to lower the temperature of that space (or object) to a desired level.

Coefficient of performance : The coefficient of performance (C.O.P.) is defined as a ratio between the heat absorbed by the refrigerant as it flows through the evaporator to the heat equivalence of the energy supplied to the compressor.

Eutectic temperature : The temperature at which a crystal of an individual solute exists in equilibrium with the unfrozen liquor and ice is its eutectic temperature.

Boiling point elevation : Boiling point elevation of a solution (liquid food) is defined as the increase in boiling point over that of pure water, at a given pressure.

Triple point : Triple point of water is defined as a condition in which pure water can exist in all the three states i.e., solid, liquid and vapour.

1.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. A dimensionally consistent equation is the one, which is balanced on both of its sides in terms of the dimensions, i.e. the LHS & RHS are dimensionally equal.
2. The different measuring systems are FPS, CGS, MKS and SI. The most acceptable and standard among them is the SI system.
3.

Quantity	Unit	Quantity	Unit
Length	m	Frequency	s^{-1}
Thermodynamic temperature	K	Pressure	$m^{-1}.kg.s^{-2}$
Amount of substance	Mol	Power	$m^2.kg.s^{-3}$
Area	m^2	Moment of Force	$m^2.kg.s^{-2}$
Density	Kg m^{-3}	Specific Energy	$m^2.s^{-2}$
Concentration	Mol m^{-3}	Thermal conductivity	$m.kg.s^{-3}.K^{-1}$

4. i) Open system is one which allows flow of heat and/or matter into or out of the system along its boundary whereas closed system is one in which the boundary is impervious to any flow of matter.

   ii) Intensive properties are those, which do not depend on the size of the system whereas extensive properties are those, which are dependent on the size of the system.

Check Your Progress Exercise 2

1. Thermal death time is defined as the time required to achieve a *stated reduction* in the microbial population at a given temperature, whereas, the decimal reduction time D is defined as the time necessary for 90% reduction in the microbial population.

2. $$k = \frac{2.303}{D} = \frac{2.303}{4.1} = 0.56 / \min ..$$

3. $$Q_{10} = 10^{10/z} = 10^{10/11} = 8.1$$

4. $$E_A = \frac{19.15}{z} T_A^2 = \frac{19.15}{11} (383)^2 = 2.55 X 10^5 \, kJ / kg$$

Check Your Progress Exercise 3

1. Refrigeration involves the principle of transfer of heat from the cooling chamber or object to a location where the heat can be discarded with the use of a refrigerant, which like water changes state – from liquid to vapour.

2. a) Evaporator: It completely vaporizes the refrigerant by accepting heat from the media surrounding the coils.

   b) Compressor: It compresses the refrigerant to a high pressure so as to condense it at a temperature slightly higher than the heat sink.

   c) Condenser: Condenses the refrigerant to saturated / sub-cooled liquid by discharging heat to the surrounding media.

   d) Expansion valve: It is essentially a metering device that controls the flow of refrigerant into the evaporator. It separates the high pressure region from the low pressure region.

3. Cooling load is defined as the rate of heat energy removal from a given space (or object) in order to lower the temperature of that space (or object) to a desired level whereas C.O.P. is defined as the heat absorbed by the refrigerant as it flows through the evaporator to the heat equivalence of the energy supplied to the compressor.

Check Your Progress Exercise 4

1. Food freezing is defined as a preservation process that depends on the reduction of product temperatures to levels well below the temperature at which ice crystals begin to form within the food.

2. Eutectic temperature is defined as the temperature at which a crystal of an individual solute exists in equilibrium with the unfrozen liquor and ice.

3. The factors affecting volume changes during freezing are: (1) moisture content, (2) cell arrangement, (3) concentration of solutes and (4) freezer temperature.

4. In indirect contact freezing systems the product and the refrigerant are separated by a barrier throughout the freezing process whereas in direct contact freezing systems there is no such barrier between the refrigerant and the product.

Check Your Progress Exercise 5

1. Evaporation is a unit operation commonly used to remove water from dilute liquid foods to obtain concentrated liquid products whereas dehydration is used to remove water and obtain dry solid product i.e evaporation involves partial removal of water from the food products whereas drying involves complete removal of moisture from the foods.

2. Boiling point elevation of a solution (liquid food) is defined as the increase in boiling point over that of pure water, at a given pressure.

Check Your Progress Exercise 6

1. Drying of foods implies the removal of water from the foodstuff, which is accomplished by supplying the latent heat of vaporization.

   The two important process-controlling factors that enter into the unit operation of drying are:

   a) Transfer of heat to provide the necessary latent heat of vaporization,

   b) Movement of water/water vapour through the food material and then away from it to effect separation of water from foodstuff.

2. Triple point of water is defined as a condition in which pure water can exist in all the three states i.e., solid, liquid and vapour.

3. 0.0098°C and 0.64 kPa.

4. Vapour-pressure line is defined as a line along which liquid and vapour coexist in equilibrium.

5. The glass transition curve represents a metastable transition where viscosity is effectively so high that the product does not ‘flow’ over time scale of importance to food stability.

6. The driving force for heat transfer is temperature gradient whereas that of mass transfer is pressure or concentration.

7. The factors that influence the rate of drying are (1) the process conditions present during drying, as determined by dryer type and operating conditions (temperature, air velocity, relative humidity, pressure etc.), or (2) the nature of the food product placed inside the dryer (surface area, constituent orientation, cellular structure, type and concentration of solutes).

1.12 SOME USEFUL BOOKS

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

2. Charms, S.E. (1978) The Fundamentals of Food Engineering. AVI Publishing Co. West Port, Connecticut.

3. Earle, R.L. (1983) Unit Operations in Food Processing. Pergamon Press, Oxford.

4. Watson, F.L. and Harper, J.C. (1988) Elements of Food Engineering. Van Nostrand Reinhold, New York.

5. Heldman, D.R. and Lund, D.B. (1992) Handbook of Food Engineering. Marcel Dekker, New York.

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

UNIT 2 MOISTURE CONTENT AND EQUILIBRIUM MOISTURE CONTENT

Structure

2.0 OBJECTIVES

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

- understand the importance of water in food preservation and its related issues;
- understand the importance of moisture content in food materials & methods of their determination and control; and
- understand equilibrium moisture content (EMC), its importance in food processing operations and methods of determination of EMC.

2.1 INTRODUCTION

Water is abundant in all living things and, consequently, in almost all foods, unless steps have been taken to remove it. It is essential for life, even though it contributes no calories to the diet. Water also greatly affects the texture of foods, as can be seen when comparing grapes and raisins (dried grapes), or fresh and wilted green leafy vegetables.

Almost all food processing techniques involve the use of water or modification of water in some form. Further, because micro-organisms cannot grow without water, the water content has a significant effect on the keeping quality of a food. This explains why freezing, dehydration, or concentration of foods increases shelf life and inhibits microbial growth.

Water is important as a solvent or dispersing medium, dissolving small molecules to form true solutions and dispersing larger molecules to form colloidal solutions. Acids and bases ionize in water, and water is also necessary for many enzymes to catalyze and chemical reactions to occur, including hydrolysis of compounds such as sugars. It is also important as a heating and cooling medium and as a cleansing agent.

2.2 CHEMISTRY OF WATER

The chemical formula of water is H_2O. Water contains strong covalent bonds, which hold the two hydrogen and one oxygen atoms together. The oxygen can be regarded as being at the center of a tetrahedron, with a bond angle of 105° between the two hydrogen atoms in liquid water and a larger angle of 109° 6' between the hydrogen atoms in ice.

The bonds between oxygen and each hydrogen atom are polar, having a 40% partial ionic character. This means that the outer shell electrons are unequally shared between the oxygen and hydrogen atoms, the oxygen atom attracting them more strongly than each hydrogen atom. As a result, each hydrogen atom is slightly positively charged and each oxygen atom is slightly negatively charged. They are therefore, able to form hydrogen bonds.

2.3 PROPERTIES OF WATER

2.3.1 Specific Heat

Specific heat is the energy required to raise the temperature of unit quantity of water by unit temperature and is the same whether heating water or ice. It is relatively high as compared to other substances, due to the hydrogen bonds. The unit of specific heat in SI system is $J\ Kg^{-1}\ K^{-1}$.

2.3.2 Latent Heat

Latent heat is the amount of heat uptake by unit quantity of water to change its state (liquid to solid & vice versa or liquid to vapour & vice versa) without any change in its temperature.

Latent heat of Fusion

It is the energy required to convert unit quantity of ice to water at freezing point and the unit is J/g of ice at the freezing point.

Latent Heat of Vaporization

It is the energy required to convert unit quantity of water to vapour at boiling point and is expressed in J for 1 g of water at the boiling point.

The specific and latent heats of water are all fairly high as compared to most other substances, and this is an important consideration when water is used as a medium of heat transfer. It takes considerable energy to heat water, and that energy is then available to be transferred to the food. Foods heated in water are slow to heat. Water also must take up considerable heat to evaporate. It takes heat from its surroundings; thus it is a good cooling agent.

2.3.3 Vapour Pressure

If a puddle of water is left on the ground for a day or two, it will dry up because the liquid evaporates. The water does not boil, but individual water molecules gain enough energy to escape from the liquid as vapour. Over time, an open, small pool of water will dry up in this way. If the liquid is in a closed container, at equilibrium, some molecules are always evaporating and vapour molecules are condensing, so there is no overall change in the system. The vapour (gaseous) molecules that have escaped from the liquid state exert a pressure on the surface of the liquid known as the vapour pressure.

When the vapour pressure difference is high, the liquid evaporates (is vaporized) easily and many molecules exist in the vapour state; the boiling point is low. Conversely, a low vapour pressure difference indicates that the liquid does not vaporize easily and that there are few molecules existing in the vapour state. There is a higher boiling point for these liquids. When the vapour pressure reaches the external pressure, the liquid boils.

The vapour pressure difference increases with increasing temperature. At high temperatures, the molecules have more energy and it is easier for them to overcome the forces holding them within the liquid and to vaporize, so there are more molecules in the vapour state.

The vapour pressure decreases with addition of solutes, such as salts or sugars. In effect, the solutes dilute the water; therefore, there are less water molecules (in the same volume) available to vaporize and, thus, there will be fewer in the vapour state, and the vapour pressure will be lower. There is also attraction to the solutes, which limits evaporation.

2.3.4 Boiling Point

Anything that lowers the vapour pressure increases the boiling point. This is due to the fact that the vapour pressure is lowered at a particular temperature, more energy must be put in; in other words, the temperature must be raised to increase the vapour pressure again. The external pressure does not change if salts or sugars are added, but it is harder for the molecules to vaporize so the temperature at which the vapour pressure is the same as the external pressure (boiling point) will be higher. One mole of sucrose elevates the boiling point by 0.52°C, and one mole of salt elevates the boiling point by 1.04°C. Salt has double the effect of sucrose because it is ionized, and for every mole of salt, there is one mole of sodium ions and one mole of chloride ions. Salts and sugars decrease the freezing point of water in a similar fashion.

If the external pressure is increased by heating in a pressure cooker or retort (commercial pressure cooker), the boiling point increases, and a shorter time period than normal is required to process the product (the basis of preserving food by canning). For example, food may be heated in cans in retorts, and the steam pressure is increased to give a boiling point in the range of 115-121°C. Conversely, if the external pressure is decreased, for example, at high altitude, water boils at a lower temperature, and requires a longer amount of time to process canned product.

2.3.5 Water as a Dispensing Medium

Substances can be dissolved, dispersed or suspended in water, depending on their particle size and solubility. Water dissolves small molecules such as salts or sugars or water-soluble vitamins to form a true solution, which may be either ionic or molecular.

Solution

An ionic solution is formed by dissolving substances, which ionize in water, such as salts, acids, or bases forming ionic solution. Taking sodium chloride as an example, the solid contains sodium (Na^+) and chloride (Cl^-) ions held together by ionic bonds. When placed in water, the water molecules reduce the attractive forces between the oppositely charged ions, the ionic bonds are broken, and the individual ions become surrounded by water molecules, or hydrated.

Polar molecules such as sugars, which are associated by hydrogen bonding, dissolve to form molecular solutions. When a sugar crystal is dissolved, hydrogen bond interchange takes place and the hydrogen bonds between the polar hydroxyl groups of the sugar molecules are broken and replaced by hydrogen bonds between water and sugar molecules. Thus, the sugar crystal is gradually hydrated, each sugar molecule being surrounded by water molecules.

Colloidal Dispersion

Molecules that are too big to form true solutions can be dispersed in water, depending on their size. Those with a particle size range of 1 nm to 100 nm are dispersed to form a colloidal dispersion or a sol. Examples of such molecules include cellulose, cooked starch, pectic substances and some food proteins. Colloidal dispersions are often unstable; thus proper care must be taken to stabilize them where necessary if they occur in food products. They are particularly unstable to such factors as heating, freezing, or pH change. Changing the conditions in a stable dispersion can cause precipitation or gelation; this is desirable in some cases, for example when making pectin jellies.

Sol is a colloid that pours – a two phase system with a solid dispersed phase in a liquid continuous phase, for example a hot sauce. A gel is also a two phase system, but it is an elastic solid with a liquid dispersed phase in a solid continuous phase.

Suspension

Particles that are larger than 100 nm are too large to form a colloidal dispersion. They form a suspension when mixed with water. The particles in a suspension separate out over time, whereas no such separation is observed with colloidal dispersions. An example of a suspension would be uncooked starch grains in water. They can be suspended throughout the liquid by stirring, but if left undisturbed, they will settle down, and sediment will be observed at the bottom of the container.

2.4 TYPES OF WATER AND WATER ACTIVITY

2.4.1 Types of Water

Water is abundant in all living things and, consequently, in almost all foods, unless steps have been taken to remove it. Most natural fresh foods contain 70% of their weight, or greater of water, and fruits and vegetables contain upto 95% or greater water. Water that can be extracted easily from foods by squeezing, or cutting or pressing is known as free water, whereas water that cannot be extracted easily is termed bound water.

Bound water is usually defined in terms of the way it is measured; different methods of measurement give different values for bound water in a particular food. Many food constituents can bind or hold on to water molecules, so that they cannot be easily removed and they do not behave like liquid water. Some characteristics of bound water include the following:

- It is not free to act as a solvent for salts and sugars.
- It can be frozen only at very low temperatures (below the freezing point of water).
- It exhibits essentially no vapour pressure.
- Its density is greater than that of free water.
- It has more structural bonding than liquid water, thus it is unable to act as a solvent.

Water may also be entrapped in foods such as pectin gels, fruits, vegetables and so on. Entrapped water is immobilized in capillaries or cells, but if released by cutting or damage, it is free to flow. Entrapped water has the properties of free water and has no properties of bound water.

2.4.2 Water Activity (A_w)

Water activity or A_w, is a ratio of the vapour pressure of water in a solution (P_s) as compared to the vapour pressure of pure water (P_w) at a given temperature.

$$A_w = \frac{P_s}{P_w} \tag{2.1}$$

Living tissues require sufficient levels of water to maintain turgor, and the A_w must be high. However, micro-organisms such as bacteria, mould and yeast multiply at high A_w. Because their growth must be controlled, prevention techniques against the spoilage these micro-organisms cause take into account the water activity of the food.

Jam, jellies and preserves and pickles are prepared using a high concentration of sugar, and salt. Sugar and salt are both effective preservatives due to the fact that they lower A_w. Salt lowers the A_w more effectively than sugar due to its chemical structure that ionizes and attracts water.

Properties of Food that Control the Water Activity

Certain properties of the food and the way water interacts with the components of a food result in different degree of binding or tying up of the water. The more tightly water is bound; the lower is its water activity (A_w). The three major physical effects that lower water activity are:

1. **Colligative effect**: When a solid solute dissolves in water, it interacts with water in three dimensions through dipole – dipole, ionic and hydrogen bonds. These interactions affect the properties of water based on the amount of the added molecules relative to the amount of water molecules present. This interaction is called a colligative effect.

2. **Capillary effect**: A second effect that depresses water activity is the capillary effect. The vapour pressure of water above a curved liquid meniscus is less than that of pure water because of changes in the hydrogen bonding between water molecules as a result of the surface curvature. Since foods have a myriad of capillaries, some lowering of the water activity should result. The Kelvin equation predicts this lowering by:

$$A_w = \exp - \frac{2\gamma_s \cos\theta \overline{V_L}}{rRT} \quad (2.2)$$

where,

γ_s = surface tension of liquid in a pore,

θ = wetting angle,

$\overline{V_L}$ = molar volume of liquid in cm^3/mole,

r = capillary radius,

R = gas constant (8.314×10^7 ergs/°K mole) and,

T = °K.

Most pores in foods are in the 10 – 300 µm range. Assuming complete wetting (cos θ) and pure water (γ_s=72.3 dyne/cm) in the pores, the Kelvin equation predicts an A_w in the range of 0.989 – 0.999. Thus the A_w is lowered very little by capillarity. However, 5 – 7% of the pore volume in foods is of pores of 0.01 – 0.001 µm, which lowers the A_w above the vapour space to values of 0.899 – 0.34. Thus, smaller capillaries have a greater effect on lowering of A_w.

3. **Surface interaction**: Finally, water directly interacts with other chemical groups on molecules through dipole – dipole force, ionic bonds (H_3O^+ or OH^-), van der Walls forces (hydrophobic bond), and the hydrogen bond. These water molecules, so bound, require extra energy to be transferred from the liquid to the vapour state and thus are less free to the vapour, resulting in reduced A_w. This effect is more pronounced at low A_w. The point of critical importance is the monolayer. This is the moisture content at each polar and ionic group has a water molecule bound to it, to form the start of a liquid like phase. Reactions which depend on water as a reaction phase medium do not occur below this moisture content at appreciable rates.

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 the importance of water in food systems.

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2. Write short notes on the following:

a) Vapour pressure

b) Boiling point

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3. Differentiate between the following

a) Ionic and molecular solution

b) Colloid and suspension

c) Free and bound moisture

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4. Define water activity (A_w).

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5. Enlist the properties of food that control water activity. Explain any one.

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2.5 ROLE OF WATER IN FOOD PRESERVATION AND SHELF LIFE OF FOODS

Control of the water level in foods is an important aspect of food quality. Foods may be more desirable either crispy or dry. Freezing and drying are common food preservation processes that are used to extend the shelf life of foods because they render water unavailable for pathogenic or spoilage bacteria.

2.6 WATER HARDNESS AND TREATMENTS

The hardness of water is measured in parts per million of calcium carbonate. Soft water contains 0-60 ppm and has no mineral salts. It contains some organic matter. Hard water contains more than 60 ppm dissolved salts. Water may exhibit temporary hardness due to iron, or calcium and magnesium bicarbonate ions [$Ca(HCO_3)_2$ and $Mg(HCO_3)_2$]. The water may be softened as it is boiled (soluble bicarbonates precipitate in boiling and leave deposits or scales) and insoluble carbonates may be removed from the water.

Permanent hardness of water cannot be removed by boiling as it contains either calcium or magnesium sulphates ($CaSO_4$ or $MgSO_4$) as well as other salts that are not precipitated by boiling. Permanent hardness is removed by the use of chemical softeners. Hard water exhibits less cleaning effectiveness than soft water due to the formation of insoluble calcium and magnesium salts with soap. The use of detergents rather than soap prevents this formation.

Water has a pH of 7 when it is neither acidic nor alkaline. Water is acidic if the pH is less than 7 and alkaline if the pH is more than 7. Tap water displays a variance on either side of neutral. It may be slightly alkaline or slightly acidic depending on the source. Hard water has a pH of upto 8.5. Chlorinated water is that which has had chlorine added to kill or inhibit the growth of microorganisms. Manufacturing or processing plants may require potable soft water of good quality to prevent turbidity, off-colour and off-flavour in food products. The use of tap water, which is not sufficiently soft, is not advisable for use in food products.

2.7 MOISTURE MEASUREMENT TECHNIQUES

There are several methods for determination of moisture content of food materials. The choice of method depends on many factors, such as (1) the form in which water is present in the product, (2) the relative amount of water present, (3) the rapidity of determination, (4) accuracy of method, (5) product's nature whether easily oxidized or decomposed, and (6) cost of equipment used.

Moisture content is determined mainly by two methods, (1) direct, also called primary and (2) indirect, also called as secondary methods. The accuracy of moisture content determination by direct methods is high, but time consuming. Indirect methods are faster and mostly employ the electrical properties of the grain.

2.7.1 Direct Methods

Air Oven Method

2-3 / 25-30 grams of ground / unground representative sample is placed in an air oven at a temperature of 130°C / 100°C for 2-3/72-96 hours. The moisture content of the samples is measured by the difference in initial and final weights of the sample. The selection of sample size, temperature and duration may be different for different materials.

Vacuum Oven Method

2-3 grams of representative sample of ground material is placed in a vacuum oven (25 mm vacuum) and dried at 100°C for 72-96 hours. Here also the moisture content is measured by the difference in initial and final weights of the sample.

Brown-Duvel Fractional Distillation Method

100 grams of the sample is mixed along with 150 ml of mineral oil and boiled. Moisture from the sample is evaporated, collected, condensed and measured in a graduated cylinder. The time required for moisture determination is about 30 minutes.

Infra-red Method

Moisture content is directly measured by evaporation of water from the sample with an infra red heating lamp. The infra red lamp evaporates the moisture of the product and the difference in initial and final weights gives a measure of the amount of moisture in the food.

2.7.2 Indirect Methods

Electrical Resistance Method

The electrical conductivity or resistance of a product depends upon its moisture content. This principle is employed in resistance measuring devices. The food sample is kept in a container at a particular compaction and temperature. The electrical resistance is then measured across it and the resistance is calibrated to give the moisture content.

Dielectric Method

Similar to the electrical resistance method, but here the capacitance of the sample is measured when a high frequency current is passed through the sample placed between the two plates of the condenser.

Chemical Method

The removal of water by strong desiccants ($CaCl_2$) is caused by the vapour pressure gradients. The moisture moves from the samples to the drying agent, due to vapour pressure gradient between the sample and the desiccant. The hydration of salt is accompanied by evolution of heat. The heat of evolution helps in driving the water out of the samples. Calcium chloride, when heated to redness reacts with superheated steam to form HCl and Calcium hydroxide.

$$CaCl_2 + H_2O \rightarrow Ca(OH)_2 + 2HCl \quad (2.3)$$

2.8 EMC AND ITS RELEVANCE TO FOOD PRESERVATION

Most of the food products absorb or loose moisture from environment. When the ambient temperature rises and humidity of air decreases, the water present in foods vaporizes. Consequently the food loses moisture which results in desiccation / drying. In other words, if the vapour pressure of water present in the foods is more than the vapour pressure of moisture in air, the water present in food vaporizes and diffuses into the atmosphere. Alternatively, if the vapour pressure of water in the foods is less than the atmospheric vapour pressure, foods will absorb moisture from the atmosphere. This property of gaining or loosing of moisture as per the atmospheric conditions is known as hygroscopicity.

The moisture content attained by foods with respect to the set of atmospheric temperature and relative humidity is called the equilibrium moisture content (EMC) of the food. In such condition, the food moisture is in equilibrium with the surrounding air.

2.8.1 Importance of EMC

EMC is of particular importance for drying and storage of food materials. The usefulness of EMC are:

i) EMC gives an idea whether the food material will gain or lose moisture under a particular atmospheric condition.

ii) It gives an idea about rate of moisture removal.

iii) EMC helps to determine drying characteristics.

iv) With the knowledge of EMC, it can be predicted as to what final moisture level a product can be dried with the heated air.

2.8.2 Hysteresis Effect

When food products in the process of loosing moisture attains equilibrium moisture content with the surroundings, the EMC is known as desorption EMC. But when a dry product gains moisture from the surroundings and attains EMC, that value of EMC is said to be adsorption EMC. At some relative humidity and temperature level there is a meaningful difference between the desorption and adsorption EMC values. The desorption EMC values are higher than the adsorption EMC values. The differences between desorption and an adsorption curve is known as hysteresis effect (Figure 2.1). As seen from the figure, the differences between the adsorption and desorption values are more significant for the intermediate range of moisture contents.

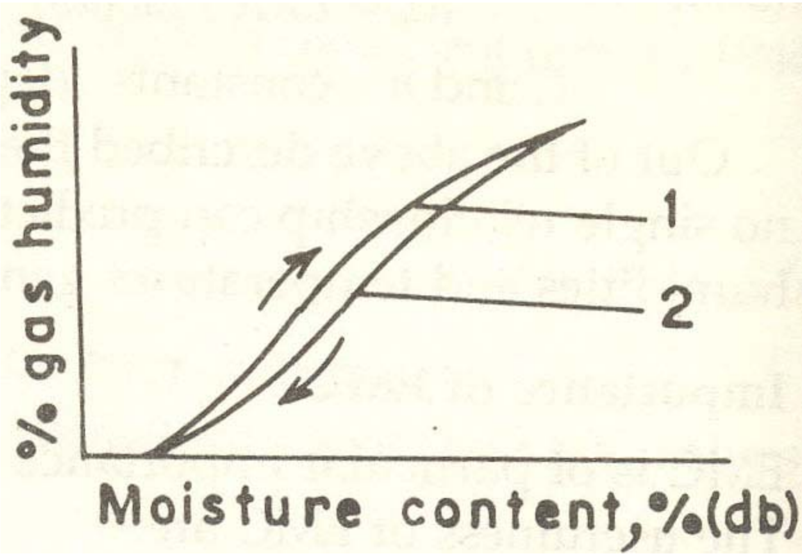

Figure 2.1: Hysteresis effect: 1) Adsorption EMC curve, 2) Desorption EMC curve

2.9 EMC DETERMINATION METHODS

The methods of determination of EMC of food materials can be categorized into two: (1) static method and (2) dynamic method. In the static method, food is left in the air with known temperature and humidity until it attains equilibrium, while in the dynamic method the conditioned air is agitated or moved by mechanical means and the food attains equilibrium condition further.

2.9.1 Static Method

In static methods, to bring the atmospheric air to desired relative humidity levels different concentrations of acids or salt solutions are used. Static methods are generally time consuming, and to bring the food to equilibrium condition, 3 – 4 weeks are required. Thus in case of high humidity and high temperature conditions, chances of attack of moulds are high. Decomposition and change in food structure is also possible. It is essential to maintain the required humidity and temperature conditions of air throughout the test period. Temperature is normally maintained using an incubator or oven whereas relative humidity is maintained using acid/salt solutions in desiccators.

2.9.2 Dynamic Method

Desorption Method

The property of dry air to absorb moisture from moist foods is employed. Most foods are put in an airtight container. When the air comes in equilibrium to food its relative humidity is measured by a hygrometer. Since the container has small quantity of air, it reaches equilibrium with the food within a short period.

Isotenoscopic Method

This method also employs absorption of moisture by dry air to determine EMC of the food material. But in this method arrangement is available to measure directly the vapour pressure exerted by the moist foods (Figure 2.2). The food sample is kept in a conical flask.

Isotenoscope is a U tube filled with the liquid of negligible vapour pressure. The arms of the tube has an enlarged section above the level of liquid to prevent drawing of liquid out of the tube while evacuating or readmitting air to the flask. The isotenoscope is connected to a vacuum pump through a vacuum storage jar. Atmospheric pressure can be brought back into this jar by means of a valve'V_1'. The 'V_2' is a shut off valve connecting closed while all air is evacuated from the flask, the vacuum storage jar, and from the system. Under this condition, vapour pressure builds up in the flask, which forces the liquid in the two arms of the isotenoscope to dissimilar level. Bleeding a small amout of air into the vacuum storage jar then equalizes the level of the liquid. This equalization pressure is continued until vapour pressure buildup in the flask has reached the maximum for the temperature of water bath. Valve 'V_2' is then closed and the absolute pressure indicated in the manometer is read. The isotenoscope is removed from the flask and a properly weighed stopper closes the flask. The weight of flask with sample is recorded to determine sample moisture content.

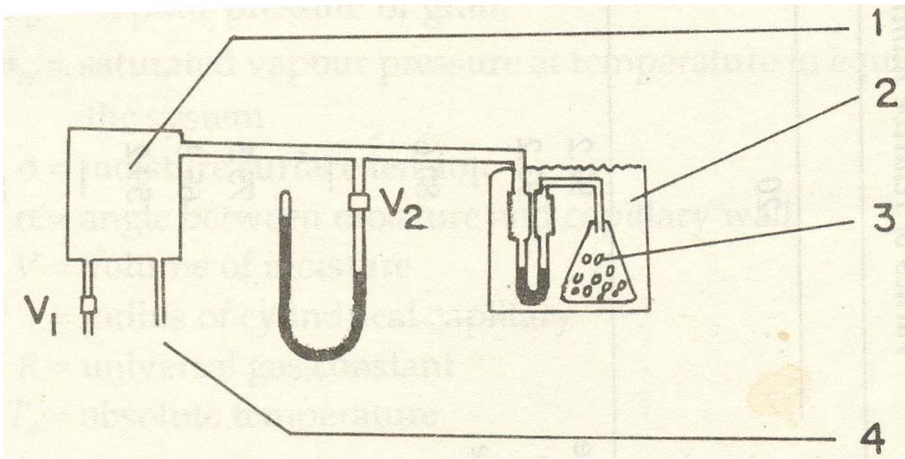

Figure 2.2: Schematic diagram of an isotenoscope: 1) Vacuum storage jar, 2) Constant temperature water bath, 3) Sample flask and 4) Vacuum pump

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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 is hardness of water and how can it be removed?

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2. Define EMC and hysteresis.

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3. Enlist the different moisture measurement techniques and explain any one method.

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4. Enlist the different EMC measurement techniques and explain any one method.

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2.10 LET US SUM UP

Let us now recapitulate the information presented in this unit. Water is an important material in the food processing activities. It is necessary to take into account the behaviour and properties of water while planning for any food processing activity. Water in food products may be present in bound, entrapped and free forms. Water contained in a food material is expressed in terms of moisture content on either dry or wet weight basis. Another way to express the moisture content in a food material is to determine its water activity. Higher the free water content, higher is the water activity at a given temperature. Water activity and spoilage of a food material are positively correlated. Methods of moisture content determination could be direct as well as indirect. Oven method is one of the direct methods, which is accurate but time consuming. Measurement of electrical conductivity or dielectric constant of a food material is quick but indirect method of moisture content determination. A food material, when placed in the air of specific temperature and humidity, attains moisture content, which is called its equilibrium moisture content (EMC). Depending on whether the food material gained the moisture or lost it to attain the EMC, the two values may be different and this behaviour of food material is known as Hysteresis. EMC determined can be through either static or dynamic methods. Isotenoscope is an apparatus to determine EMC of food materials dynamically.

2.11 KEY WORDS

Moisture content : It indicates the amount of free moisture in any material.

Water activity : Water activity or A_w, is a ratio of the vapour pressure of water in a solution (P_s) as compared to the vapour pressure of pure water (P_w) at a given temperature.

Hygroscopicity : It is the property of gaining or loosing of moisture (due to vapour pressure difference) as per the atmospheric conditions.

Specific heat : Specific heat is the energy required to raise the temperature of unit quantity of water by unit temperature and is the same whether heating water or ice.

Latent heat of fusion : It is the energy required to convert unit quantity of ice to water at freezing point and the unit is J/g of ice at the freezing point.

Colloidal dispersion : Molecules that are too big to form true solutions can be dispersed in water, depending on their size and the mixture is called as colloidal dispersion.

Suspension : Particles that are larger than 100 nm are too large to form a colloidal dispersion. Those form a suspension when mixed with water. The suspended particles settles down if the suspension is left undisturbed.

Free water : Water that can be extracted easily from foods by squeezing, or cutting or pressing.

Bound water : Water that cannot be extracted easily is termed bound water.

Entrapped water : Water bound by food constituents so that they cannot be easily removed and they do not behave like liquid water.

EMC : The moisture content attained by foods with respect to the set of atmospheric temperature and relative humidity

Hysteresis : The difference between the adsorption and desorption EMC at any given temperature and relative humidity.

Isotenoscope : Equipment used for measuring dynamic EMC

2.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Foods are living systems where water is the basis of several biochemical processes including the growth of micro-organisms. Foods with high water content have, therefore, limited usable life. Water content in foods needs to be regulated to a manageable level for achieving the intended shelf-life.

2. a) Vapour pressure: Water in air normally exists in vapour form. As you know, air is composed of mainly oxygen, nitrogen, carbon di oxide, water vapour and other gases in small amounts. Each of these constituents of air contributes to the atmospheric pressure depending upon their relative magnitudes. Water vapour also contributes a small fraction to the pressure.

   b) Boiling point: Boiling point is the temperature at which water starts boiling. At mean sea level, the boiling point for pure water is 100°C or 373°K.

3. a) Ionic solutions have charged particles like anions and cations. Molecular solutions have the solutes in molecular form, which are not electrically charged.

   b) Colloid is a mixture of liquid and solid particles, which are so fine that they exhibit Brownian movement. The colloids remain in perpetual suspension. A true suspension retains its apparent homogeneity for a short time after stirring. The suspended particles then settle down.

   c) Free water is the water in a food material that can be extracted easily by squeezing, or cutting or pressing, whereas the water that cannot be extracted easily is termed bound water.

4. Water activity or A_w, is a ratio of the vapour pressure of water in a solution (P_s) as compared to the vapour pressure of pure water (P_w) at a given temperature.

$$A_w = \frac{P_s}{P_w}$$

5. The properties of food that control water activity are:

   a) Colligative effect
   b) Capillary effect
   c) Surface interaction

   Colligative effect: When a solid solute dissolves in water, it interacts with water in three dimensions through dipole – dipole, ionic and hydrogen bonds. These interactions affect the properties of water based on the amount of the added molecules relative to the amount of water molecules present. This interaction is called a colligative effect.

Check Your Progress Exercise 2

1. The hardness of water is measured in parts per million of calcium carbonate. The water may be softened as it is boiled (soluble bicarbonates

precipitate in boiling and leave deposits or scales) and insoluble carbonates may be removed from the water.

2. EMC: The moisture content attained by foods with respect to the set of atmospheric temperature and relative humidity is called the equilibrium moisture content (EMC) of the food.

   Hysteresis: At a relative humidity and temperature level there is a meaningful difference between the desorption and adsorption EMC values. The desorption EMC values are higher than the adsorption EMC values. The differences between desorption and an adsorption curve is known as hysteresis effect.

3. Different moisture measurement techniques are:

   Direct methods:

   a) Air oven method
   b) Vacuum oven method
   c) Brown-Duvel fractional distillation method
   d) Infra-red method

   Indirect methods:

   a) Electrical resistance method
   b) Dielectric method
   c) Chemical method

   Electrical resistance method: In this method, the food sample is kept in a container at a particular compaction and temperature. The electrical resistance is then measured across it and the resistance is calibrated to give the moisture content.

4. Different EMC measurement techniques are:

   i) Static method
   ii) Dynamic method

      a) Desorption method
      b) Isotenoscopic method

   Desorption method: Most foods are put in an airtight container. When the air comes in equilibrium to food its relative humidity is measured by a hygrometer.

2.13 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.

UNIT 3 CLEANING AND GRADING

Structure

3.0 OBJECTIVES

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

- understand the importance of cleaning and grading in the food processing operations;
- know the cleaning and grading devices and their operating principles; and
- should be able to select a suitable cleaning and grading device for any given operation.

3.1 INTRODUCTION

Cleaning and grading are important post harvest operations undertaken to remove foreign and undesirable materials from the produce and to separate the produce into various fractions. The comparative commercial value of food products is dependent on their grade factors. These grade factors further depend upon (1) physical characteristics like size, shape, moisture content, colour, etc., (2) chemical characteristics like odour, and (3) biological factors like insect damage.

It is difficult to clearly differentiate between the processes of cleaning and grading because these are carried out simultaneously with the common procedures. The operation of cleaning and grading of the products are performed by exploiting the differences in engineering properties of the materials. These products may be used either for food or seed purposes.

3.2 DEFINITIONS AND OBJECTIVES OF CLEANING

Cleaning and grading both are the processes of separation. Cleaning generally means the removal of foreign and undesirable material from desired grains / products. The objective is to reduce the cost of further handling as unnecessary fraction would have been separated. Besides the clean material fetches higher prices. In this sense, cleaning is a value addition operation.

Grading refers to the classification of the cleaned product into various quality functions depending upon the commercial value and usage. For example, separating ripe tomatoes from unripe ones. This also is a value addition operation.

3.3 METHODS OF CLEANING

The undesirable material from the mixture could be removed by wet, dry or a combination of wet and dry methods.

3.3.1 Wet Method

The wet method of cleaning consists of spraying clean water over the mixture in a trough of water to remove the undesirables. Then the desirable washed material is appropriately dried to remove the adhering moisture. It is important in this process that the desirable material should not get affected by the washing treatment and that the water used for washing is clean so as not to leave any residue after washing and drying.

3.3.2 Dry Method

The dry methods of cleaning are based on the specific properties of the constituents of the mixture such as:

1. Size
2. Shape
3. Specific gravity or weight
4. Surface roughness
5. Aerodynamic properties
6. Ferro-magnetic properties
7. Colour
8. Electrical properties

Cleaners based upon size

Screen cleaners/graders: It performs the separation according to size alone. The mixture of grain and foreign matter is dropped on a screening surface, which is vibrated either manually or mechanically. A single screen can make the separation into two fractions. The screening unit may be composed of two or more screens as per the cleaning requirement.

A hand-operated screen cleaner (Figure 3.1) is made of mild steel. The separation takes place due to difference in size of grain and foreign matter. The cleaner is operated by hanging on an elevated point with the help of four ropes. Produce is fed on the screening surface in batches. The screens can be changed as per the grain to be handled. The cleaner is swung to and fro till all the grain is screened. The cleaned grain is retained by the bottom sieve which can be discharged by pulling a spring loaded shutter. Impurities of larger size, stubbles, chaff etc. are retained on the top sieve and can be removed easily. Down stream from the bottom sieve consists of dust, dirt, brokens, shrivelled produce etc. drop down during the operation.

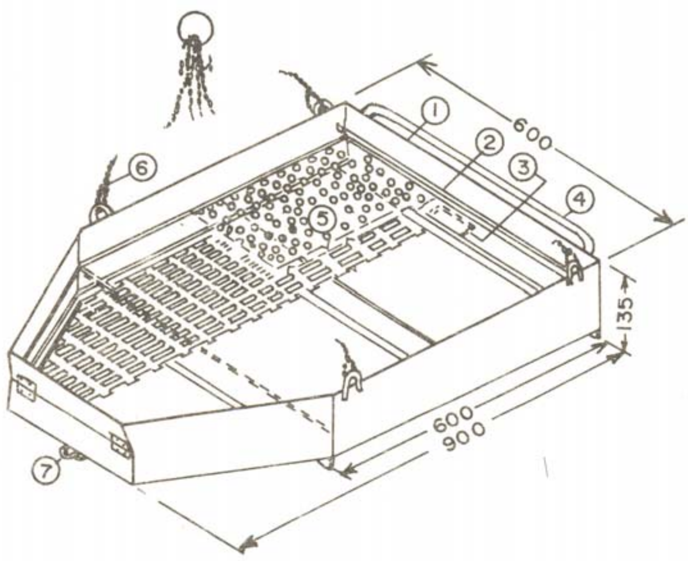

Figure 3.1: Hand operated double screen grain cleaner. 1) frame 2) draper rod 3) screen handle 4) handle 5) scalper and grader screens 6) rope attachment 7) shutter opening attachment

Air screen cleaners: The screens used in combination with air blast performs satisfactory cleaning and separation operations for most of the granular materials. The air-screen cleaner uses three cleaning systems: blowing or aspiration, scalping screens and grading lower screens. The air-screen grain cleaner can be classified in two distinct types: *(i)* vibratory screen, *(ii)* rotary screen, based on movement of the screening surface.

Vibratory air-screen cleaner: The screening unit is composed of double or multiple (up to 8 number) screens. These screens are tightened together and suspended by hangers in such a manner that these have horizontal oscillating motion and slightly vertical motion. These two motions in combination move the grain down the screen and at the same time toss sufficiently above the screen so that the bed of grain is properly stirred. The slope of the screen is adjustable to control the rate of downward travel of the grain. The screens are available in various shapes like; round, triangular or slotted holes as discussed earlier. Sometimes the holes of the screen are clogged when the machine makes fine degree of sorting. To avoid the clogging, the screens are generally fitted with a brush which moves under the screen and pushes the clogged material back through the screen. Other such devices can also be used for this purpose. A simple vibratory type air-screen cleaner is shown in Fig. 3.2.

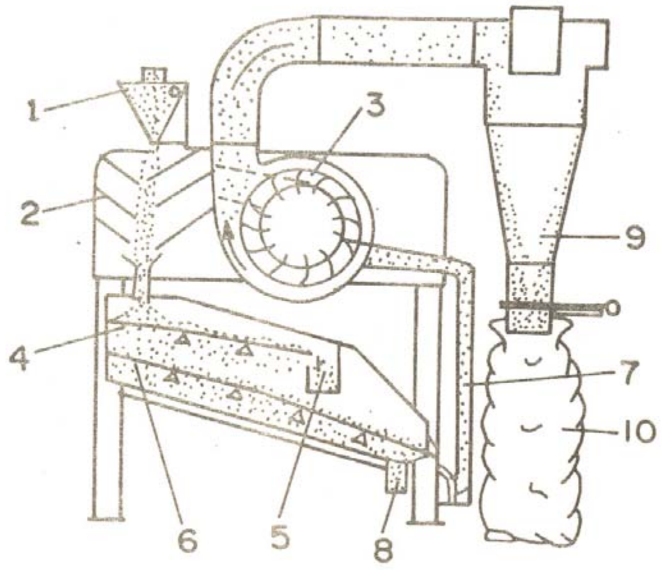

Figure 3.2: Schematic diagram of a vibratory air screen cleaner. 1) Feed Hopper, 2) Baffle plate, 3) Blower, 4) Upper screen, 5) Discharge channel, 6) Sand sifter, 7) Ascending separator, 8) Discharge funnel, 9) Centriclone, 10) Dust Bag

Rotary screen cleaner: The rotary screen cleaner has normally circular decks. Their motion is circular in horizontal plane. These have either single or double drum. A single drum rotary screen cleaner is shown in Figure 3.3. The machine consists of a rotary screen, aspirator and hopper and equipped with an electric motor, which gives drive to the rotary screen and the aspirator. The mixture is fed into the hopper. The sound grains pass through the screen perforation into the centre of the screen drum, whereas oversized material is retained above and pass out though an outlet. The sound grains come out at the centre side of the screen drum rotating at low speed and fall onto the vibratory screen which remove the dirt particles. The light particles like straw and dust are sucked away by the aspirator and discharged through the aspirator outlet. The cleaned grains are delivered through the discharge chute.

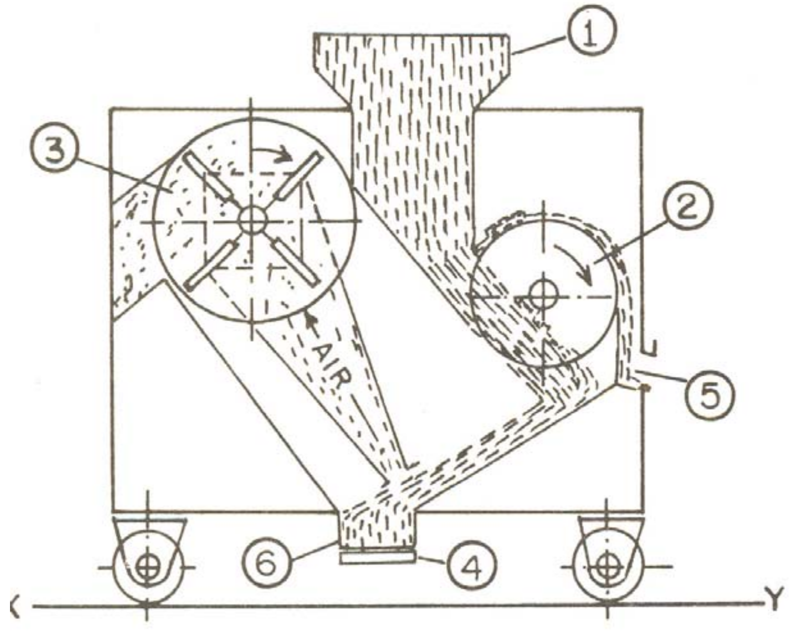

Figure 3.3: Diagram of a single drum rotary screen cleaner. 1) Feed hopper, 2) Rotary screen, 3) Aspirator, 4) Discharge chute, 5) Over size foreign matter outlet, 6) Vibratory screen

Specific gravity cleaners

The specific gravity separator makes the separation according to difference in density or specific gravity of the materials. This separator works on two principles, (1) the characteristics of grains to flow down over an inclined surface, (2) the floatation of the particle due to upward movement of air.

The main part of the device is a triangular-shaped perforated deck. The deck is properly baffled underneath to ensure uniform distribution of air over it. The pressure or terminal velocity of the air rising through the deck can be controlled very closely within a wide range (Figure 3.4).

The mixture of produce is fed into the feed box. The air is blown up through the porous deck surface and bed of the grain by a fan at such a rate that the material is partially lifted from contact with the deck surface. The lightest materials are lifted to the top of the stratified mass. The air does not lift the heavier particles. The stratified mass moves along the direction of conveyance due to oscillating motion of the deck and is discharged at the right edge of the deck.

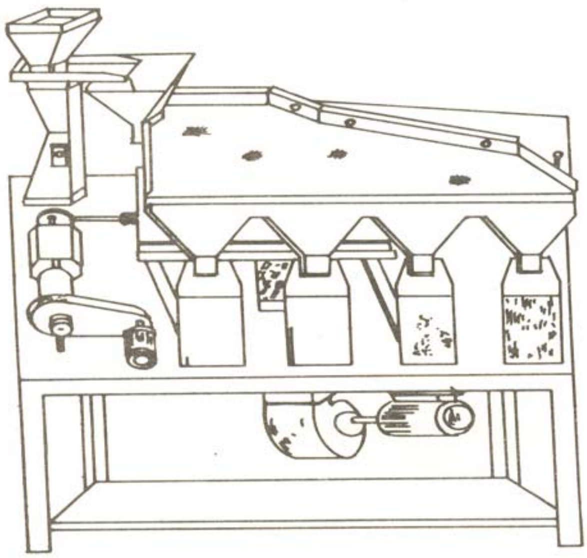

Figure 3.4: Specific gravity separator

Aerodynamic cleaners

The pneumatic separation is based on the difference in aerodynamic properties of various constituents of the mixture. The aerodynamic properties of a particle depend upon its shape, size, density, surface and orientation with respect to air current. Both the aspirator and the pneumatic separator use terminal velocity of the grain to separate different fractions. This refers to the velocity of air required to suspend particles in a rising air current.

In a pneumatic separator, the fan is placed at the intake end of the machine, which creates higher pressure than the atmospheric pressure. The high pressure air blast separates the materials. The mixture of products is introduced into a confined rising air stream; the air current lifts the particles with low terminal velocities whereas the particles with higher terminal velocities than air velocity fall down. The air velocity can be adjusted by altering the speed of fan or by changing the opening of air inlet (Figure 3.5).

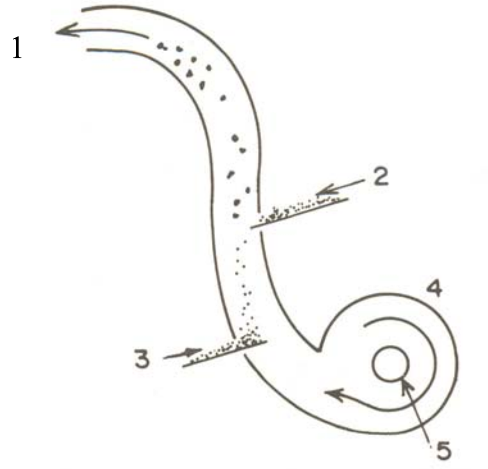

Figure 3.5: Diagram of a pneumatic separator. 1) Undersirable material removal, 2) Uniform feeder, 3) Clean grain outlet, 4) Centrifugal blower, 5) Control for air intake

3.4 METHODS OF SEPARATION

We often encounter mixtures of food materials, which need to be separated into different fractions for either subsequent marketing or processing. Fruits harvested from an orchard are normally of different sizes, which would fetch lower prices as compared to the graded fruits packed nicely. There are several similar situations where it is necessary to separate different fractions from a mixture. This separation could be achieved by utilizing one or more of the properties of the constituents of the mixture. The most common property is the size. The other properties normally utilized for separation are weight, specific gravity, surface roughness, optical properties and magnetic properties. The basic principles of the operation of different separators are being presented in the following sections.

3.4.1 Size Based Separators

The bulk food material such as a basket of fruits or vegetables is fed to a container from which the individual food items are segregated on the basis of their diameter or length or any other significant dimensions. In case of handy materials such as dry fruits and nuts, even oscillating sieves could be used for the separation. However, fresh fruits and vegetables get easily damaged, therefore, they need to be carefully handled. The relative motion between the food items and the separator is minimized. A grader for separating mangoes on size basis is shown in Figure 3.6. As you may note the fruits roll on the continuously diverging channel and, thus, the separation takes place.

Figure 3.6: Size based mango grader

3.4.2 Specific Gravity Separators

Some materials, when separated on size basis do not give the correct classification, for example, some groundnut pods may attain a particular size, the kernels in them remain immature. Obviously, such pods are not desirable and need to be separated from the pods that have bold kernels. This separation could be achieved by letting the mixture float in a fluid. Based on the specific gravity, the fractions will settle down differently. A cream separator in dairy processing is also categorized under specific gravity separators.

3.4.3 Colour Separators

The colour separator separates the fruits, vegetables or grains due to difference in colour or brightness. The colour separators are generally used for larger crop seeds like peas and beans. These seeds differ in colour because of varietal differences and also due to immaturity or disease. The mud balls and discoloured or defective seeds can be removed with the help of electronic separator. The material mixture is fed uniformly into the optical chamber of the separator.

Two photocells are fixed at a particular angle, which direct both beams to one point of the parabolic trajectory of the grains. A needle is placed on the other side, which is connected to a high voltage source (Figure 3.7). When a beam falls on a dark object through photoelectric cells, current is generated on the needle. The needle end receives a charge and imparts it to the dark seeds. The grains are then passed between two electrodes with a high potential difference between them. The seed is compared with a selected background or colour range, and is separated into two fractions according to difference in colour. Since this machine views each produce individually, the capacity is low.

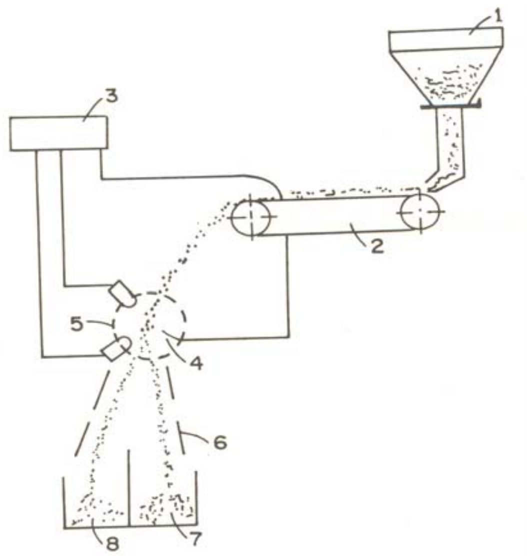

Figure 3.7: Schematic of a colour separator 1) hopper, 2) belt conveyor, 3) amplifier, 4) charging needle, 5) optical chamber, 6) deflecting electrodes, 7) foreign material, 8) desired material

3.4.4 Weight Based Separators

Certain food items are of regular shape or size. They are separated on weight basis. The food items are conveyed over a set of pan balances arranged in such a way that the lowest weight objects travels farthest. Heavier object tips the balances earlier and get collected in a trough. The lighter object passes on these balances and moves farther till the appropriate balance tips down and the object is picked up for separation into the correct class.

3.4.5 Magnetic Separators

The magnetic separator performs separation on the basis of surface texture and stickiness properties of the grain. Since the grains do not contain any free iron, therefore, are not attracted by the magnet. A selective pre-treatment of mixing finely ground iron powder to feed mass is given. The grain mixture is fed to a screw conveyor or other mixing device that tumbles and mixes the grain with a proportioned amount of water. Due to moisture, iron powder adheres to rough, cracked, broken and sticky seed coats. Moisture does not remain on smooth grains so no iron powder adheres to smooth surfaced grains.

The grain mixture is fed onto the top of a horizontal revolving magnetic drum, the smooth grains that are relatively free of powder fall along the drum simply by gravity. The materials with iron powder are attracted by the magnetic drum and stick to it and are removed by rotary brush or break in the magnetic field as shown in Figure 3.8.

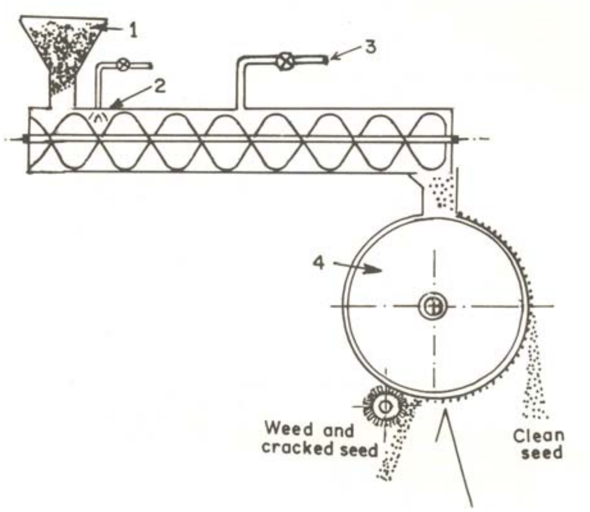

Figure 3.8: Magnetic Separator. 1) Feed hopper, 2) Water spray, 3) Iron powder mixing, 4) Magnetic drum.

3.4.6 Surface Texture/Roughness Separator

The mixture to be separated is fed over the centre of an inclined draper belt moving in upward direction. The round and smooth grains roll or slide down the draper at faster rate than the upward motion of the belt, and these are discharged in a hopper. The flat shape or rough surfaced particles are carried to the top of the inclined draper and dropped off into another hopper. (Figure 3.9). The belts of different degrees of roughness may be used as a draper for separate materials. If rolling tendencies of the grain are predominant, the rough canvas belt may be used. The smooth, plastic belt may be used in case sliding action is desired for the lower fraction. Feed rate, speed of draper and angle of inclination are other important variables for effective separation of dissimilar materials.

The feed rate is kept low enough to give opportunity to each grain for separation. The speed of the draper may be varied to simulate with the length of incline. The angle of inclination is adjusted to assure rolling or sliding of the desired lower fraction. To increase the capacity of the separator, number of belts may be used one above another in a single machine.

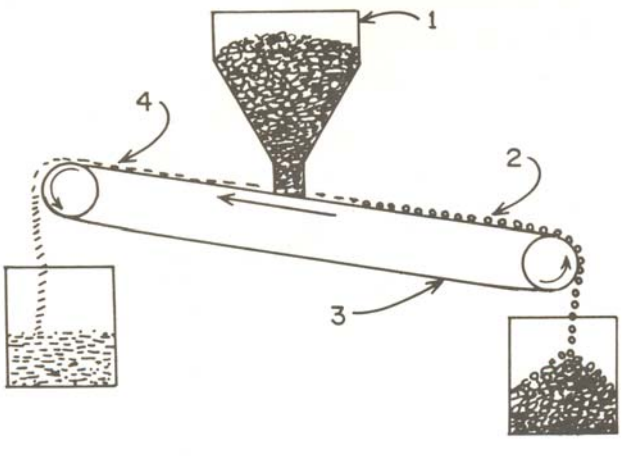

Figure 3.9: Inclined draper. 1) Feed hopper, 2) Round seed, 3) Canvas draper, 4) Flat seed/impurities.

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 cleaning and grading.

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2. Enlist five different characteristics of foods that are used for its separation from unwanted materials.

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3. Describe the working principle of the following:

i) Air screen separator
ii) Inclined draper
iii) Pneumatic separator
iv) Colour sortor

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3.5 SCREENS

The basic purpose of any screen is to separate a mixture of particles / items of different sizes into two distinct fractions. These fractions are, (1) the - underflow, the particles that pass through the screen, and (2) the overflow or oversize, the materials that are retained over the screen. A screen can be termed as **ideal** screen that separates the mixture in such a way that the largest particle of underflow is just smaller than screen opening, while the smallest particle of overflow is just larger than the screen opening. But in practice a given screen does not gives perfect separation as stated above, and is called **actual** screen. The underflow may contain material coarser than screen size, whereas the overflow may contain particles smaller than screen size as shown in Figure 3.10.

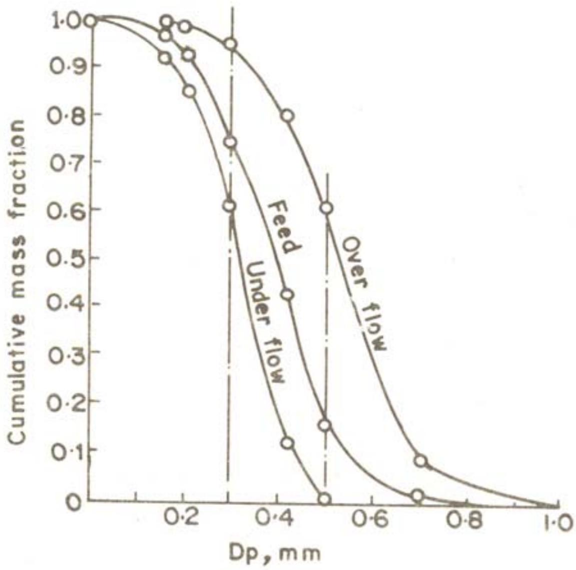

Figure 3.10: Graphical representation of various flows of a screen

In most screens the grain/ seed drops through the screen opening by gravity. Coarse grains drop quickly and easily through large opening in a stationary surface. With finer particles, the screening surface must be agitated in some way. The common ways are, (1) revolving a cylindrical screen about a horizontal axis and (2) shaking, gyrating or vibrating the flat screens.

3.5.1 Grizzly

The grizzly is a simple device consisting of a grid made up of metal bars, usually built on a slope, across which the material is passed. The path of material flow is parallel to the length of bars. The bars are usually so shaped that the top is wider than the bottom. The grizzly is often constructed in the form of a short endless belt so that the oversize is dumped over the end while the sized material passes through. In this case bar length is transverse to the path of materials. The grizzly is used for coarsest and rough separations.

3.5.2 Revolving Screen/Cylinder Sorter

Trommel or revolving screen is a cylinder that rotates about its longitudinal axis. The wall of the cylinder is made of perforated steel plate or sometime the cloth wire on a frame, through which the material falls as the screen rotates. The axis of cylinder is inclined along with the feed end to the discharge end. Sizing is achieved by having smallest opening screen at the feed end with progressively larger opening screens towards the discharge end. This type of sorter is simple and compact with no vibration problem. But the capacity of cylinder sorter is lesser than the vibrating screen of same size. Although it is an accurate sizer, it does not perform well with friable material or in cases where particle degradation is undesirable because tumbling produces some autogeneous grinding. The speed of rotation of the trommel is kept within the limit at which the material is carried from bottom to a distance equal to the radius of cylinder before it starts tumbling. The inclination of cylinder sorter for dry granular materials is kept up to 125 mm/m. Changing the speed of operation and the inclination of cylinder can change the capacity, bed depth and efficiency of these screens. Effective screening area (not the total surface of cylinder) is calculated by multiplying the length of cylinder by $\frac{1}{3}$ of the diameter.

3.5.3 Shaking Screen

Like the vibrating screen, shaker is a rectangular surface over which material moves down on an inclined plane. Motion of the screen is back and forth in a straight line. Although in some cases vibration is also given to the screen. Unlike the vibrating screen, the shaker does not tumble or turn material enroute except that some shaking screens have a step-off between surfaces having different size openings, so that there may be two or three tumbles over the full length of the screen. The shaker is widely used as combined screen and conveyor for many types of bulk material.

3.5.4 Rotary Screen

Rotary and gyratory screens are either circular or rectangular decked. Their motion is almost circular and affects sifting action. These are capable of accurate and complete separation of very fine sizes but their capacity is limited. These screens are further classified into two categories.

Gyratory Screens

This is generally a single decked machine. It has horizontal plane motion, which is circular at feed end and reciprocating at the discharge end. The drive mechanism is at the feed end and is either a V-belt or direct coupling. The shaft that imparts motion to the screen is a counter balanced eccentric. The shaft moves about a vertical axis. At the discharge end most rotary screens have linkage to the base frame, usually a self-aligning bearing. Gyratory screens operate with screening surface nearly horizontal.

Circular Screens

These are also rotary screens but their motion in horizontal plane is circular over the entire surface. Similar to the gyratory screens, the screening surface of circular screens is also little bit tilted for allowing the material to move over them.

3.5.5 Vibratory Screen

The vibratory screens are agitated by an eccentric unit. When materials to be separated are put on a vibratory screen, because of its vibration, materials are also agitated and separated during their transit over the screen. The eccentricity is usually of two types, (1) a shaft to which off centre weights are attached, and (2) a shaft that itself is eccentric or off centred. In the later case the eccentricity is balanced by a fly wheel for providing uniform vibration. Most vibrating screens are inclined downward from the feed end. Vibration is provided to the screen assembly only, and the body and other surrounding structure are isolated from vibration. Generally, upto three decks are used in vibrating screens. The capacity of vibrating screen is higher than any other similar sized screen and is very popular for cleaning and grading of granular agricultural products.

3.5.6 Horizontal Screen

Horizontal screens are special case of vibrating screen. These are designed for operation with low head room. They operate absolutely flat without the aid of gravity. All sorting, stratification and material transportation' take place on the strength of a sharp forward thrust which imparts motion to particles with a missile like trajectory, while the return stroke pulls the deck out from underneath the bed. Effectiveness of these screens is higher because material is kept on the screen for a longer period in comparison to inclined screens.

3.5.7 Other Screens

Various other types of screens used for cleaning and separation are listed below:

1. Rotex screens
2. Hummer screens
3. Circular vibrators
4. Symon's rod deck screens
5. Resonant vibrant screens
6. Centrifugal screens

3.5.8 Particle Motions in Separation Equipment

There are four different regime motions that can take place for the rigid particles placed on a moving trough depending upon the frequency of oscillation. The regimes are given below:

1. Particles stationary with respect to trough.
2. Particles slip during part of cycle and remain adherent to the trough during the rest of cycle.
3. As regime (2) with slip and gliding motion.
4. Particles purely in stick and slip motion.

Reciprocatory Motion

This can be either purely in horizontal plane or in an inclined plane. Depending upon the plane, the motion of particles is different as given below:

a) **Horizontal reciprocating motion:** This motion is obtained with an eccentric and a connecting rod and is usually in a path parallel to the horizontal projection of the path of material as it moves from inlet to outlet as shown in Figure 3.11. If the pitch (amplitude) is steep enough the motion has a substantial vertical component to the screen surface, which initiates sliding motion, and a large quantity of material can be moved.

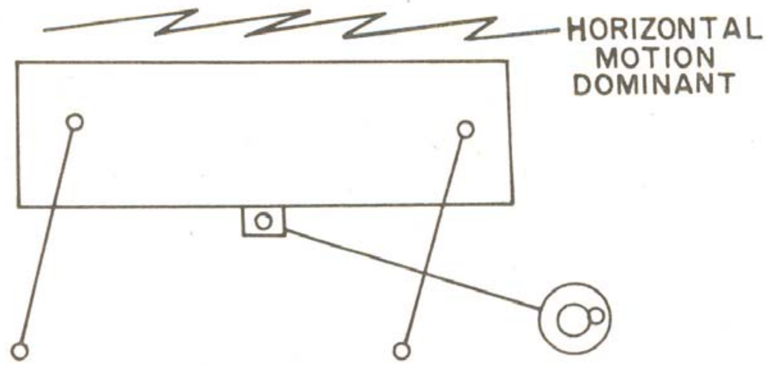

Figure 3.11: Horizontal reciprocating motion

b) **Inclined reciprocating motion:** The screen can be moved in an inclined plane reciprocatingly by eccentric and connecting rod unit (Figure 3.12). Such motion would have a vertical and horizontal components parallel to the horizontal projection of path of moving material. Combined horizontal and vertical motion can also be achieved by a rotary drive attached directly to the screen and operating in a vertical plane parallel to the path of the material flow. The horizontal motion is shown in Fig 3.13b and the vertical motion is shown in Fig 3.13a. The vertical component lifts the material from the screen surface for a fraction of time. The vertical motion can loosen the mass of material thus dislodging finer particles to settle at the bottom. The combined vertical and horizontal motion is also effective in moving large volume of material rapidly over the surface. This technique is useful in coarse sifting or where the screen openings are substantially larger than the particle size.

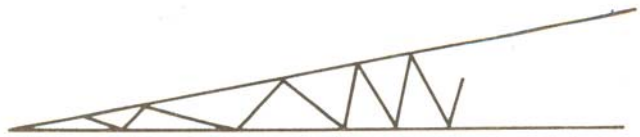

Figure 3.12: Inclined reciprocatory motion

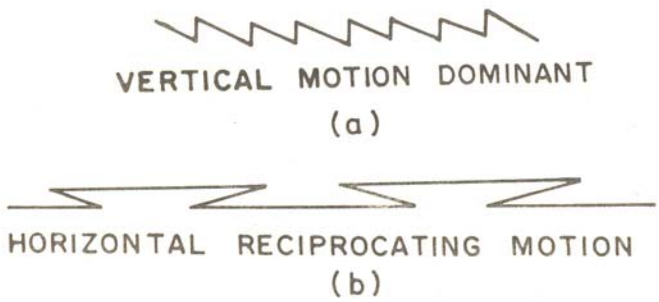

Figure 3.13: a) and b) Vertical and horizontal reciprocating motion

Combined Horizontal and Reciprocating Motion

In this, an eccentric drive is used to change the horizontal reciprocating motion into a rotary motion in a horizontal plane at inlet end, whereas the other end has reciprocating motion. In such arrangement there is a component of reciprocating motion both in parallel and perpendicular to the direction of material flow at inlet and this gradually changes into an elliptical motion at the central section of the screen and finally becomes a true reciprocating motion at the discharge end as shown in Figure 3.14. This section is effective in spreading the material to the sides of screen at the inlet end. The looping path of the material also presents more screen openings since particle moves not only back and forth but also from side to side across the screen surface.

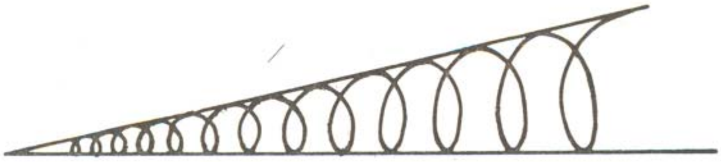

Figure 3.14: Combined horizontal and reciprocating motion

Horizontal Rotary Motion

If the screen surface is rotated in a horizontal plane the material will travel in the overlapping loop path during the passage from inlet to discharge end as shown in Figure 3.15. The multidirectional motion overcomes inter particle friction and maximum number of openings are available, thus screening can be accomplished on a relatively shorter distance. Rotary motion is provided by an off-centred weight attached to the screen through the frame and it is rotated at proper speed in horizontal plane. This imparts desired frequency and motion. The amplitude of movement is controlled by the magnitude and eccentricity of weight as well as the position, which affects its leverage on the screen. Sifters may also be driven by means of one or more directly connected eccentrics. The speed of eccentric and the amount of eccentricity control the frequency and amplitude of motion.

Figure 3.15: Horizontal rotary motion

3.5.9 Perforated Metal Screens

i) **Round openings:** The round openings in a perforated sheet metal screen are measured by the diameter (mm or in.) of the openings. For example, $\frac{1}{18}$ screen has round perforation of $\frac{1}{18}$ in. in diameter or 2 mm.

ii) **Oblong openings:** The oblong or slotted openings in a perforated sheet metal screen are designated by two dimensions; the width and length of the opening. While mentioning oblong openings the dimension of width is listed first then the length as 1.8 x 20 mm. Generally, the direction of the oblong opening is kept in the direction of the grain flow over the screen.

iii) **Triangular openings:** There are two different systems used to measure triangular perforations. The most commonly used system is to mention the length of each side of the triangle in mm, it means, 9 mm triangle has 3 equal sides each 9 mm long. The second system is to mention openings according to the diameter in mm that can be inscribed inside the triangle. This system is identified by the letter Vas 9V, l0V etc.

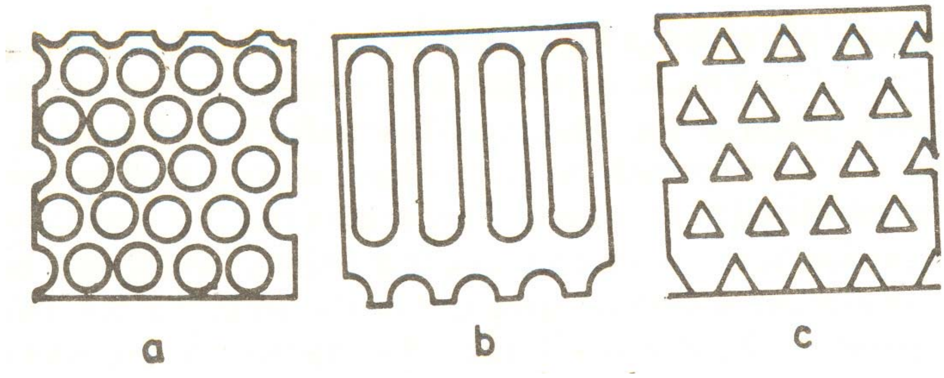

Figure 3.16: Perforated metal screens. a) Round holes, b) Oblong holes, c) Triangular holes

3.5.10 Wiremesh Screens

i) **Square mesh:** The square openings in wire mesh are measured by the number of openings per inch in each direction. A 9×9 screen has 9 openings per inch (Figure 3.17).

ii) **Rectangular mesh:** the rectangular openings in wire mesh screens are measured in the same way as square wire mesh screen. A 3×6 rectangular wire mesh screen will have 3 openings per inch in one direction and 6 openings per inch in the other direction. The rectangles formed by the wire mesh are parallel to the direction of grain flow (Figure 3.18).

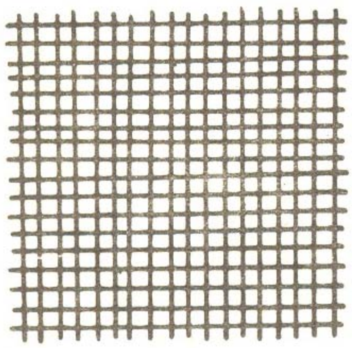

Figure 3.17: Wire mesh screen (square openings)

Figure 3.18: Wire mesh screen (rectangular openings)

3.6 EFFECTIVENESS AND EFFICIENCY OF SCREENS, CLEANERS, GRADERS AND SEPARATORS

The screen effectiveness may be defined as the ability of a screen in closely separating the feed into overflow and underflow according to its size. If the screen functions properly, all material 'O' would be in the overflow, while all the material 'U' would be in the underflow. The material balance in a screening operation can be derived as follows:

F = mass flow rate of feed, kg/hr.
O = mass flow rate of oversize, kg/hr.
U = mass flow rate of undersize, kg/hr.
m_f = mass fraction of material in feed.
m_o = mass fraction of material in overflow.
m_u = mass fraction of material in underflow.

The total quantity of feed is the sum of overflow and underflow

$$F = O + U$$

or,

$$Fm_f = Om_o + Um_u \qquad (3.1)$$

Substituting O = F – U and, U = F – O

$$\frac{O}{F} = \frac{m_f - m_u}{m_o - m_u} \qquad (3.2)$$

and, $$\frac{U}{F} = \frac{m_o - m_f}{m_o - m_u} \qquad (3.3)$$

A common measure of screen effectiveness is the ratio of actual amount of oversize material in the overflow to the amount of oversize material entering with the feed.

Thus,

$$E_o = \frac{Om_o}{Fm_f} \qquad (3.4)$$

and $$E_u = \frac{U(1 - m_u)}{F(1 - m_f)} \qquad (3.5)$$

Overall effectiveness $$E = E_o x E_u = \frac{OUm_o(1 - m_u)}{F^2 m_f (1 - m_f)} \qquad (3.6)$$

Substituting the values of

$$\frac{O}{F} \text{and} \frac{U}{F}, \; E = \frac{(m_f - m_u)(m_o - m_f)m_o(1 - m_u)}{(m_o - m_u)^2(1 - m_f)m_f} \qquad (3.7)$$

The effectiveness of screening or cleaning efficiency for an air screen cleaner as suggested by Bureau of Indian Standards (BIS) is:

$$\text{Cleaning efficiency} = \frac{E(F - G)(E - F)(1 - G)}{F(E - G)^2(1 - F)} \qquad (3.8)$$

where, E = fraction of clean seed at clean seed outlet

F = fraction of clean seed in feed

and G = fraction of clean seed at foreign matter outlet

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. Enlist four types of screen that are available for cleaning and grading of foods. Describe any one of them.

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2. Define screen effectiveness.

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3. During the evaluation of an air screen grain cleaner with two screens the followings were observed.

   i) The impurities present in feed were 6.5%.
   ii) The impurities present in clean grain were 0.5%.
   iii) The outflow of blower contained 0.2% clean seed.
   iv) The overflow of the 1st screen contained 1 % clean seed.
   v) The underflow contained 0.5% clean seed.

   Compute the cleaning efficiency of the cleaner.

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4. During evaluation of an air screen grain cleaner with 2 screens 250*g* samples were collected for analysis of clean seed fraction from different outlets. The data are presented in the following Table. Calculate the cleaning efficiency of the cleaner.

Sample fraction	Feed, g	Clean grain outlet, g	Blower outlet, g	Oversize outlet, g	Undersize outlet, g
Cleaned seed, g	231.25	246.5	1.25	4.5	2.0
Impurities, g	18.75	3.5	248.75	245.5	248.0

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3.7 LET US SUM UP

In this unit, we have learnt the basics of cleaning and grading operations as specialized forms of the separation process. The methods of cleaning and grading are based upon the properties of the materials. Various machines used for the cleaning and grading operations have been introduced. Screens are used very commonly in the separation processes and, therefore, various types of screens have been presented. The analysis of the screened material ultimately provides the basis of determining the cleaning and separation efficiency.

3.8 KEY WORDS

Cleaning : Generally means the removal of foreign and undesirable material from desired grains / products.

Grading : Refers to the classification of the cleaned product into various quality functions depending upon the commercial value and usage.

Cleaning efficiency : It is the ratio of the actual amount of impurities present in a mixture to the impurities obtained during the cleaning process.

Magnetic separator : Uses the magnetic properties of metallic contaminants to separate them from the produce.

Colour sorting : Uses the colour differences between the produce and the unwanted materials for sorting.

Pneumatic separation : Uses the property of terminal velocity to separate materials.

Screen effectiveness : It may be defined as the ability of a screen in closely separating the feed into overflow and underflow according to its size.

3.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Cleaning is defined as the method of removal of foreign or undesirable material from the foods whereas grading is defined as the classification of the cleaned produce into various fractions based on qualitative or quantitative parameters.

2. The five characteristics of foods that are used for its separation from unwanted materials include:

   i) Size
   ii) Shape
   iii) Specific gravity or weight
   iv) Surface roughness
   v) Aerodynamic properties

3. i) Air screen separator: Air blast in conjunction with screens is used to achieve the separation. Air blast helps to separate dust and lighter material before the remaining material is separated by screens.

   ii) Inclined draper: The mixture to be separated is fed over the centre of an inclined draper belt moving in upward direction. The round and smooth grains roll or slide down the draper at faster rate than the upward motion of the belt, and these are discharged in a hopper. The flat shape or rough surfaced particles are carried to the top of the inclined draper and dropped off into another hopper. The belts of different degrees of roughness may be used as a draper for separate materials.

   iii) Pneumatic separator: A blower is placed at the inlet of the separator. The mixture is suspended in the air and the different fractions get separated due to their differing terminal velocities.

   iv) Colour sortor: Colour or brightness is sensed by photocells. The photocell gives an output based on the colour/brightness variation and the product is separated if the output is below or above the threshold level.

Check Your Progress Exercise 2

1. Four types of screen that are available for cleaning and grading of foods are:

   a) Horizontal screen
   b) Rotary screen
   c) Grizzly screen
   d) Vibratory screen

Grizzly screen: Grizzly is made up of coarse grid of metal bars usually put on a slope. The path of material flow is parallel to the length of bars. The grizzly is used for rough and coarse separation like crushed stones, ores etc.

2. The screen effectiveness may be defined as the ability of a screen in closely separating the feed into overflow and underflow according to its size.

3. i) fraction of clean seed in feed = 100 - 6.5 = 93.5 or 0.935

   ii) fraction of clean seed in clean grain outlet = 100 - 0.5 = 99.5 or 0.995

   iii) fraction of clean seed in foreign matter outlets = $\frac{0.2}{100}+\frac{1}{100}+\frac{0.5}{100}$

   $= 0.002 + 0.01 + 0.005$

   $= 0.017.$

   Then E = 0.0995, F = 0.935 and G = 0.017

   Therefore, Cleaning efficiency = $\dfrac{E(F-G)(E-F)(1-G)}{F(E-G)^2(1-F)}$

   $$= \frac{0.995(0.935-0.017)(0.995-0.935)(1-0.017)}{0.935(0.995-0.017)^2(1-0.935)}$$

   = 91.18%

4. i) Fraction of clean seed at clean seed out let, $E = \dfrac{246.5}{250.0} = 0.986$

   ii) Fraction of clean seed in feed $F = \dfrac{231.25}{250.0} = 0.925$

   iv) Fraction of clean seed in-foreign matter outlets $G = \dfrac{1.25}{250.0}+\dfrac{4.5}{250.0}+\dfrac{2.0}{250.0} = 0.031$

   Therefore, Cleaning efficiency = $\dfrac{E(F-G)(E-F)(1-G)}{F(E-G)^2(1-F)}$

   $$= \frac{0.986(0.925-0.031)(0.986-0.925)(1-0.031)}{0.925(0.986-0.031)^2(1-0.925)}$$

   = 82.34%

3.10 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.

UNIT 4 STORAGE

Structure

4.0 OBJECTIVES

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

- explain the importance of storage;
- understand the type of damages take place during storage;
- identify the traditional and improved storage system being followed; and
- underline the types of losses take place.

4.1 INTRODUCTION

Horticultural crops not only provide us with nutritional and healthy foods, but also generate a cash income to growers. Appropriate production practices, careful harvesting and proper packaging, storage and transport contribute to the good produce quality. Once a crop is harvested it is impossible to improve its quality. The horticultural crops, because of their high moisture content are inherently more liable to deteriorate especially under tropical conditions. Moreover, they are biologically active and carry out transpiration, respiration, ripening and other biochemical activities, which deteriorate the quality of the produce.

Losses during post harvest operations due to improper storage and handling are enormous and can range from 10-40 percent. Post harvest losses can occur in the field, in packing areas, in storage, during transportation and in the wholesale and retail markets. Severe losses occur because of poor facilities, lack of know-how, poor management, market dysfunction or simply the carelessness of farmers. Losses can be reduced if proper storage process is adopted after harvesting.

Storage of fresh fruit and vegetable produce is an important economic aspect as it stabilizes prices, avoids glut in the market, and makes fruits and vegetables available in off season. Storage extends the usefulness and availability of vegetables and fruits since deterioration of the freshness is minimized. Storage also avoids wastage, relieves stress during main season and assures regular supply to the consumers with high quality fruits and vegetables. If not stored, the farmers have to sell the produce soon after harvest at throwaway prices in the market and they suffer great loss. Therefore, creation of storage facilities is essential for proper development of vegetable and fruit industries in the country.

4.2 STORAGE PARAMETERS FOR FRESH PRODUCE

Temperature and humidity management remains the most effective tool for extending the shelf life of fresh horticultural produce. The following table gives approximate storage life and recommended temperature and humidity levels for commercial storage.

Commodity	Temp (^{0}C)	Relative humidity (%)	Approximate storage life	Highest freezing point
Apples	-1 to 4	90-95	1-12 months	-1.5
Apricots	-0.5 to 0	90-95	1-3 weeks	-1.0
Bananas, green	13 to 14	90-95	-	-0.7
Blackberries	-0.5 to 0	90-95	2-3 days	-0.7
Blueberries	-0.5 to 0	90-95	2 weeks	-1.2
Cranberries	2 to 4	90-95	2-4 months	-0.8
Currants	-0.5 to 0	90-95	1-4 weeks	-1.0
Dewberries	-0.5 to 0	90-95	2-3 days	-1.2
Elderberries	-0.5 to 0	90-95	1-2 weeks	-
Loganberries	-0.5 to 0	90-95	2-3 days	-1.2
Raspberries	-0.5 to 0	90-95	2-3 days	-1.0
Strawberries	0	90-95	5-7 days	-0.7
Carambola	9 to 10	85-90	3-4 weeks	-
Cherries, sour	0	90-95	3-7 days	-1.7
Cherries, sweet	-1 to -0.5	90-95	2-3 weeks	-1.8
Coconuts	0to 1.5	80-85	1-2 months	-0.9
Dates	-18 or 0	75	6-12 months	-15.7
Figs, fresh	-0.5 to 0	85-90	7-10 days	-2.4
Grapes	-1 to -0.5	90-95	1-6 months	-2.1
Guavas	5 to 10	90	2-3 weeks	-

Kiwifruit	-0.5 to 0	90-95	3-5 months	-1.6
Lemons	7 to 13	85-90	1-6 months	-1.4
Limes	9 to 10	85-90	6-8 weeks	-1.6
Loquats	0	90	3 weeks	-
Lychees	1.5	90-95	3-5 weeks	-
Mangos	13	85-90	2-3 weeks	-0.9
Nectarines	-0.5 to 0	90-95	2-4 weeks	-0.9
Olives, fresh	5 to 10	85-90	4-6 weeks	-1.4
Papayas	7	85-90	1-3 weeks	-0.9
Passion fruit	7-10	85-90	3-5 weeks	-
Peaches	-0.5-0	90-95	2-4 weeks	-0.9
Pears	-1.5 to -0.5	90-95	2-7 months	-1.5
Persimmons, Japanese	-1	90	3-4 months	-2.1
Pineapples	7 to 13	85-90	2-4 weeks	-1.1
Plums and prunes	-0.5 to 0	90-95	2-5 weeks	-0.8
Pomegranates	5	90-95	2-3 months	-3.0
Quinces	-0.5 to 0	90	2-3 months	-2.0
Artichokes, globe	0	95-100	2-3 weeks	-1.1
Beans, dry	4 to 10	40-50	6-10 months	-
Beans, green or snap	4 to 7	95	7-10 days	-0.7
Beans, lima	3 to 5	95	5-7 days	-0.6
Bean sprouts	0	95-100	7-9 days	-
Beets, bunched	0	98-100	10-14 days	-0.4
Beets, topped	0	98-100	4-6 months	-0.9
Broccoli	0	95-100	10-14 days	-0.6
Brussels sprouts	0	95-100	3-5 weeks	-0.8
Cabbage	0	98-100	3-6 weeks	-0.9
Carrots	0	95-100	2 weeks	-
Carrots, mature	0	98-100	7-9 months	-1.4
Cauliflower	0	95-98	3-4 weeks	-0.8
Celery	0	98-100	2-3 months	-0.5
Corn, sweet	0	95-98	5-8 days	-0.6
Cucumbers	10 to 13	95	10-14 days	-0.5
Eggplants	8 to 12	90-95	1 week	-0.8

Garlic	0	65-70	6-7 months	-0.8
Ginger	13	65	6 months	-
Greens, leafy	0	95-100	10-14 days	-
Horseradish	-1.0 to 0	98-100	10-12 months	-1.8
Lettuce	0	98-100	2-3 weeks	-0.2
Watermelons	10 to 15	90	2-3 weeks	-0.4
Mushrooms	0	95	3-4 days	-0.9
Okra	7 to 10	90-95	7-10 days	-1.8
Onion, green	0	95-100	3-4 weeks	-0.9
Onion, dry	0	65-70	1-8 months	-0.8
Onion sets	0	65-70	6-8 months	-0.8
Parsley	0	95-100	2-2.5 months	-1.1
Parsnips	0	98-100	4-6 months	-0.9
Peppers, chilli (dry)	0 to 10	60-70	6 months	-
Peppers, sweet	7 to 13	90-95	2-3 weeks	-0.7
Potatoes	0	90-95	5-10 months	-0.6
Pumpkins	10 to 13	50-70	2-3 months	-0.8
Radishes	0	95-100	3-4 weeks	-0.7
Spinach	0	95-100	10-14 days	-0.3
Sweet potatoes	13 to 16	85-90	4-7 months	-1.3
Tomatoes, mature-green	13 to 21	90-95	1-3 weeks	-0.6
Tomatoes, firm-ripe	8 to 10	90-95	4-7days	-0.5
Turnips	0	95	4-5 months	-1.0
Turnip greens	0	95-100	10-14 days	-0.2

4.3 DAMAGES DURING STORAGE

Insect/ pests form one of the most important factors responsible for losses in agricultural production at various stages. Living organisms and the environment interact to bring about spoilage of stored products. Living organisms may be plants, insects, pests, man, animal, bacteria, fungi etc. High post-harvest losses are caused by the invasion of fungi, bacteria, insects and other organisms. Micro-organisms attack fresh produce easily and spread quickly, because the produce does not have much of a natural defence mechanism and has plenty of nutrients and moisture to support microbial growth. Control of Post harvest decay is becoming a more difficult task, because the number of pesticides available is falling rapidly as consumer concern for food safety increases.

It is estimated that 5 to 10% of the world food production is damaged by insects during storage. The estimated losses due to insects in India have been estimated to be around 3% of the country's production. Insects feed on the germ and endosperm causing loss in weight as well as nutrients. Besides, they cause contamination with their excreta and dead bodies. The damages can be grouped into, (1) direct damages, and (2) indirect damages.

4.4 DIRECT DAMAGES

i) Few insects consume germ as well as some endosperm and the others eat away both. It causes in loss of weight, loss of nutrients, loss of germination power, loss in gradation and consequently falls in market value.

ii) The contamination may be with the dead bodies, excreta, cast skin, odour.

iii) Structures and containers also get damaged by causing tunneling in wooden parts.

4.5 INDIRECT DAMAGES

i) It occurs when heat is created and migration of moisture takes place.

ii) It creates distribution of parasites to man. Few tape worms select stored grain insects as intermediate hosts.

4.6 SOURCES OF INFESTATION

Infestation sources are mainly five types, the field itself, infested bags, infested transport, infested godown and infested stocks.

Field: Insects may attack the crop in the field itself and same is brought to the storage centers where it continues attack. The infestation may be visible or invisible. Fumigation should be done immediately to check the growth of insects.

Infested bags: When new bags are used for packing the newly harvested produce, the insects hiding in the seams of the bags may attack the freshly harvested produce. The gunnies should be fumigated prior to packing the freshly harvested produced.

Infested transport: *DDVP* or Malathion should be sprayed on transport used for carrying the newly harvested produce. If the bullock cart or tractor trolley has been used as the transport for carrying infested stocks on the previous occasion, the left over insects may attack the fresh produce.

Infested godowns: The Godowns *should* be thoroughly cleaned and fumigated as insects present in the cracks and crevices of the wall or that hibernate in the structures, may emerge out and attack the produce.

Infested stocks: In case sound produce/stocks are brought to a storage unit godown where infested stocks are in storage, cross infestation may takes place.

4.7 STORAGE REQUIREMENTS

For successful storage the conditions needed is a better product, optimum required temperature, atmospheric humidity, right stage of maturity for the product to be stored, and freedom from diseases and other injury. There is rapid deterioration in injured or diseased products during storage, particularly under conditions favourable for the development of storage rots. The main storage principles are:

Relative Humidity

Transpiration rates (water loss from produce) are determine by the moisture content of the air, which is usually expressed as relative humidity. At high relative humidity, produce maintains saleable weight; appearance, nutritional quality and flavour, while wilting, softening and juiciness are reduced. Leafy vegetables with high surface-to-volume ratios; injured produce and immature fruits and vegetables have higher transpiration rates. High temperatures, low relative humidity and high air velocity increase transpiration rates.

Relative humidity needs to be monitored and controlled in storage. Control can be achieved by a variety of methods:

1. Operating a humidifier in the storage area.
2. Regulating air movement and ventilation in relation to storage room load.
3. Maintaining refrigeration coil temperature within the storage room.
4. Using moisture barriers in the insulation of the storage room or transport vehicle.
5. Wetting the storage room floor.
6. Using crushed ice to pack produce for shipment.
7. Sprinkling leafy vegetables, cool-season root vegetables and immature fruits and vegetables with water.

Temperature

Respiration and metabolic rates are directly related to room temperatures within a given range. The higher the rate of respiration, the faster the produce deteriorates. Lower temperatures reduce respiration rates and the ripening and senescence processes, which prolong the storage life of fruits and vegetables. Low temperatures also slow the growth of pathogenic fungi, which cause spoilage of fruits and vegetables in storage.

Producers should give special care and attention to proper storage conditions for produce with high to extremely high respiration rates, as these crops will deteriorate much more quickly.

It is impossible to make a single recommendation for cool storage of all fruits and vegetables. Climate of the area where the crop originated, the plant part, the season of harvest and crop maturity at harvest are important factors in determining the optimum temperature. A general rule for vegetables is that cool-season crops should be stored at cooler temperatures (0 to 1.7°C) and warm-season crops should be stored at warmer temperatures (7 to 13°C).

Freezing injury

Temperatures that are too low can be just as damaging as those too high. Freezing will occur in all commodities below 0^{o}C. Whether injury occurs depends on the commodity. Some can be repeatedly frozen and thawed without damage, while others are ruined by one freezing.

Injury from freezing temperatures can appear in plant tissues as loss of rigidity, softening and water soaking. Injury can be reduced if the produce is allowed to warm up slowly to optimum storage temperatures and if it is not handled during the thawing period. Injured produce should be marketed immediately, as freezing shortens its storage life.

Chilling injury

Fruits and vegetables that require warmer storage temperatures (4.5 to 13°C) can be damaged if they are subjected to near-freezing temperatures (0°C). Cooler temperatures interfere with normal metabolic processes. Injury symptoms are varied and often do not develop until the produce has been returned to warmer temperatures for several days. Besides physical damage, chilled produce is often more susceptible to disease infection.

Quality and condition of material

If the fruits are over ripe, they will rot and get spoilt early and quickly. If they are not ripe, the shrinkage can take place and make the product unfit for consumption. The flavour and aroma also changes leading to an appreciable reduction in sugar content and development of acidic (or off-flavour) flavours under storage or transit due to high content of acids. There is also a considerable change in original colour of skin, flesh, firmness, etc, and the product (fruit, root, etc.) becomes soft. The chemical changes continue to take place in immature product (fruits etc) after harvest. The starch content begins to decline and there is increase in sugar content. Also a slow inversion of sucrose to reducing sugars takes place.

Total nitrogen content almost remains the same, but the form of nitrogen is changed, that is, protein and nitrogen decrease compared to soluble nitrogen, fats, oils and waxes increase in storage but oil content increases faster compared to rest. Regarding enzymes the activity of oxidase remains almost constant while catalase activity becomes faster in storage. The mineral constituents also remain constant in the storage. The respiration rate is faster till the fruits are fully mature and finally over mature

Ethylene, a natural hormone produced by some fruits as they ripen, promotes additional ripening of produce exposed to it. The old age saying that one bad apple spoils the whole bushel is true. The damaged or diseased fruits produce high levels of ethylene and stimulate the other apples to ripen too quickly. As the fruits ripen, they become more susceptible to disease. Ethylene "producers" should not be stored with fruits, vegetables, or flowers that are sensitive to it. The result could be loss of quality, reduced shelf life and specific symptoms of injury. Ethylene producers include apples, apricots, avocados, ripening bananas, honeydew melons, papayas, peaches, pears, plums and tomatoes.

Advantages of storage

1. The wastage is avoided.
2. The stress during main season is relieved. It is easy to carry over the produce from periods of high production to periods of low production.
3. Distress selling during glut is offset which ensures remunerative price to the grower.
4. It assures regular supply to the consumer of high quality fresh fruit and vegetables throughout the year at reasonable prices.
5. It is easy to supply and hold regular trade of vegetables from the place of production to the place of consumption.

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. Why storage of fruit and vegetables are required?

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2. What are the factors responsible for proper storage of fruits and vegetables?

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3. What are the sources of Infestation in storage?

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4. What are various injury occur to fruit and vegetables during storage?

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4.8 STORAGE PROCESS

Most rapidly maturing tropical fruits, soft fruits of all kinds, and leafy vegetables with a large surface area tend to have high respiration rates and normally have short storage lives. In contrast, most temperate fruits, cured potatoes and onions, and vegetable root crops often have lower respiration rates and consequently longer storage lives. Respiration of all produce increases with temperature, which is why all storage techniques aim for a reduction in temperature of the produce.

- Lower storage temperature offers the additional advantage of greatly reduced water loss from the produce with reduced transpiration. High relative humidity slows down water loss and enhances storage life of the produce. Stores should ideally be maintained at the highest relative humidity (RH) that the crop could tolerate.

It is important to retain adequate circulation of the air within a store and around the produce to ensure efficient cooling. However, over-rapid air movement can drastically increase water loss by the produce. Therefore, the choice of the correct storage technique is governed by:

- the type of produce, its temperature from harvest and its respiration rate as well as produce quality;
- the storage temperature and humidity best suited to the produce and intended storage life, with implicating chill damage or unnecessary microbial spoilage;
- appropriateness to the market place and its requirements;
- and above all, the economics of the whole operation.

The different types of storages are (i) ground or pit storage; (ii) natural caves (iii) air-cooled storage; (iv) evaporative cooling (v) ventilated Storages (vi) improved Zero-energy Cool Chamber (vii) refrigerated storages; (viii) controlled atmosphere (CA), modified atmospheres (MA) or Hypo baric storage.

4.9 TRADITIONAL STORAGE STRUCTURES

Ground storage or pit storage

This method of storing vegetables is very commonly followed to the hills, especially in the snow-bound, arid dry template area, deep in the Himalayas. It is always available, simple, cheap, easily made and effective method practiced in some areas. The vegetables like potato, beetroot, carrot, radish, turnip, sweet potato and cabbage are piled in layers in the pit or trenches dug at a higher, well-drained place where water after snow melting does not accumulate. The pits may be pucca or kuchcha and lined with straw or leaves, the produce is then covered with straw followed by a thin layer of soil or prevents severe freezing injury. However, the trenches/ pits are also covered with wooden planks or tree branches and a small hole is kept for proper aeration at each corner.

Cellers and caves

The cellers are sophisticated type of below ground storage. These can be part of above ground buildings or underground rooms, where access is easy. The caves are also the natural shelters available under big rocks, which are used for storing vegetables. Good drainage, protection from rains or snowfall and natural hazards are essential. The performance of cellers is improved by providing controlled ventilation, openings for entrance of cold air and exit for warm air by conventional circulation whenever cooling is required. Though optimum temperatures generally cannot be retained. A good, cellar/cave will provide satisfactory storage for hard vegetables.

4.10 IMPROVED STORAGE STRUCTURES

Air-cooled storage

These are simply insulated structures, above ground and partly underground, which are cooled by circulation of colder monoxide air. When the temperature of the produce is of desired level and the temperature of the outside air is comparatively lower, air is circulated at the stock in the store mechanically through bottom inlet vents and top dampers. Fans if fitted are controlled manually or automatically. Air-cooled stores are cheap, easy to install and to operate, which are still widely used for the storage of potato and sweet potato, because both these products need relatively higher storage temperatures to avoid accumulation of sugar and chilling injury, respectively. Potatoes are commonly stored in bulk, piled in stores with air delivery even under the floor or at floor level and with sufficiently spaced air outlets.

Evaporative cooling

This utilizes the evaporation of water using heat of respiration of the vegetables. Water should be near or around the vegetables. Hot, dry air is thus cooled when it flows through a wet surface. The temperature may be reduced 1°-5°C and relative humidity increases by 20-30 percent depending on the prevailing temperature and relative humidity. The hotter and drier the surrounding microclimate, the greater the decrease in temperature and higher the increase in relative humidity. Evaporative cooling is very useful, especially in vegetables which easily wilt, shrivel, or soften because of low relative humidity. A few applications of evaporative cooling can be; (i) sprinkling fresh vegetables with water; (ii) keeping fresh vegetables in moist containers (earthen pots or jars); (iii) keeping vegetables inside drip coolers. There are locally developed structures with sides which could absorb water to be evaporated like jute sack or charcoal held on two sides by wire netting. Water is allowed to drip on the walls continuously

Ventilated Storages

Before the advent of refrigeration, ventilated storage was the only means available for storage of fresh produce and today is still in wide use all over the world for a variety of crops. Ventilated storage is ambient air storage, which makes use of controlled ventilation for cooling of the produce and maintenance of lower temperatures. It requires much lower capital investment and operating costs than refrigerated storage and is perfectly adequate for some crops and conditions where:

- Production is being stored for local use.
- The crops to be stored have a relatively long natural and storage life.
- Regular inspection is possible to remove spoilage centers.
- There is a significant difference between day and night temperatures, for example at altitudes above 1000 meters and most temperate latitudes.
- The need is for relatively short storage periods.

A ventilated store may be used for onions, garlic, yams and sweet potato. However, ambient or ventilated storage for most other commodities is neither a practical nor an economic proposition because spoilage rates are simply too high. Some ventilated storage at the retail point may be an every day reality for small shopkeepers but larger ships and supermarkets, and most importers and wholesalers use refrigerated stores. Hanging onions and garlic are the simplest form of ventilated storage. In low temperature areas, storage houses for potatoes have air inlets at the sides near the floor level and outlets near the ceiling. These storage houses are found ventilated. The entry and exit of fresh air is mechanically controlled by thermostats, which also measure temperature inside and outside the room. Air is allowed to enter when it is cold and to leave when it is hot.

Improved Zero-energy Cool Chamber

A low cost zero-energy cool chamber, developed at IARI, New Delhi, recently is based on the principle of evaporating cooling. Raw material readily available is used for installing the short-term double-walled storage for fresh vegetables and fruits. The inside temperature of the chamber maintained is between 17-18°C (lower than outside) with relative humidity of about 90 percent during the peak summer months and also throughout the year. Such chambers are quite suitable for storage of fresh vegetables for short duration. Moreover, these are cheap, economical and within the reach of an average vegetable grower.

4.11 MODERN STORAGE STRUCTURES

Refrigerated Storage

Refrigerated storage is a well-established technology widely used for storing horticultural crops all over the world and is undoubtly the most effective method of prolonging the storage shelf life of fresh vegetables and reduces post-harvest losses by arresting metabolic breakdown of fungal deterioration of the commodity. Its application is limited only by cost and benefit considerations. Essentially, all crops can benefit by being stored at a suitable low temperature, which extends the storage life and preserves quality.

Many horticultural crops have storage life spans ranging from less than one month to several months when refrigerated. Therefore, refrigerated storage can be used continuously only if different crops with different harvesting seasons can share the facility. There are other important reasons why this method is not used in many tropical and sub-tropical countries, where refrigeration is needed most. The initial investment cost is too high and its energy consumption too large for many countries

When this method is to be used on a large-scale, the total value of the commodity should be considered. It may keep the commodity fresh for a long period but if it is not profitable to put in refrigerated store or even to rent a refrigerated room, then it is economical to use other methods of storage. Many tropical and subtropical fruit and vegetables are susceptible to low temperature injury. Due to the lack of money to erect and run cold storages by the individual farmer or farming community, the use of cold storages is limited. However, some well-to-do farmers and government agencies have created these facilities and are making use of them for storing high-priced vegetables. As the commodities have their optimum temperature and relative humidity at which they keep fresh for the longest possible time, therefore the cold room should have the desired temperature and relative humidity

The commodities should be cooled as soon as possible. Root and bulb vegetables should be properly cured before storing for better protection from micro-organisms. For better results, avoid mixing different commodities because most of the fruit & vegetables release ethylene on their ripening, thus leafy vegetables root and bulb vegetables and green fruit vegetables should not be mixed. Only good quality produce should be stored in different chambers. Storing of poor quality produce may not be economical in the long run. The faster the temperature of the vegetable is lowered down to the optimum, the longer is the shelf life of the commodity. Cooling vegetables and fruits immediately after harvesting before storage at the optimum temperature is an effective way to remove both field and product heat leading to slow deterioration. The fast cooling is called pre-cooling and is done by cooling in special pre-cooling chambers or equipment with air (room cooling)- with a much higher capacity to cool than a usual cold room. In lead water (hydro cooler), the vegetable is sprayed or immersed in ice water, here the cooling time is determined by the temperature difference between the water and the vegetable, the nature of the vegetable and type of container used.

4.12 CONTROLLED ATMOSPHERE (CA) AND MODIFIED ATMOSPHERE (MA) OR HYPERBOLIC STORAGE

The fresh horticultural produce consumes oxygen for respiration and releases carbon dioxide and ethylene. The ethylene further enhances ripening. Reducing oxygen and increasing carbon dioxide can increase the shelf life. In CA storage the levels of CO2, O2 and N2 in the storage room are monitored. CA storage combined with refrigeration reduces respiration and delays yellowing and quality changes. However the tolerance of individual varieties of horticultural crops needs to be considered.

Commercial application of CA storage is limited to only a few crops, apples and pears being the most popular ones. It is not used for other crops because the benefit is too slight to cover the cost. The technologies involved are complicated and sophisticated. The cost of building, facilities, and management for CA storage is considerably higher than for refrigerated storage. Therefore it should not be recommended for any crop without a thorough cost and benefit analysis.

While in modified atmosphere (MA), the respiration of the commodity is allowed to reach a desirable low level of O2 and high level of CO2 inside a closed chamber, container, plastic bag or plastic tent and the gases are maintained at those levels. Both the systems are best used with refrigerated storage involving manipulation of CO2, O2 and N2. Other gases such as ethylene, acetylene and propylene are also considered. MA differs from CA only in how precisely the addition of pressures is modified. CA storage is more precise than MA storage without basis or reducing the atmospheric gaseous pressure exerted on the stored valuable vegetables. The CA is seldom used commercially for vegetables, whereas the use of plastic bags to line containers or as retain packages is an example of modified atmosphere. For prevention of accumulation of too much CO2 and decrease of too much O2, a few holes can be made.

Danish cabbage has been reported to be kept better during four to five months at 0˚C in gas mixtures with 2.5 to 5% oxygen and carbon dioxide than it has in air. Mature green tomatoes may keep green for five to six weeks at 13˚C in an atmosphere at 3% oxygen with 97% nitrogen. After removal to air at 18˚ C, these tomatoes ripened normally with acceptable flavour. Mushroom in refrigerated storage has been kept better for short periods in atmosphere with 5 to 10% carbon dioxide than air.

All types of controlled atmosphere storage require frequent gas analysis to determine when aeration is required to add oxygen or to remove carbon dioxide

Therefore, the fresh fruit and vegetables storage can help in bringing lucrative returns to the vegetable growers and others dealing with the vegetable, trade, and supplying fresh, full of flavour, aroma and attractive vegetables from the different areas, in original state to the consumers. Thus, there is great potentiality of storing vegetables and fruits for both fresh and in processed form.

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 is various storage structure required in traditional storage system?

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2. What is various storage structure required in improved storage system?

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4.13 LOSSES IN STORAGE

Fruits, vegetables, root crops, ornamentals collectively called horticulture products are inherently perishable. Losses occur in the period between harvesting and consumption. The loss is generally a result of multiple causes and malpractices along the marketing chain.

About 20% of the damage to produce takes place during harvesting and field handling. The grower should ensure that the produce is harvested well, is kept in good condition till it is treated, kept in safe storage, consumed or sold.

If post harvest treatments are being used, they should start immediately after the produce has been harvested, to ensure that the essential freshness and nutritional values are maintained to the maximum.

Losses during post harvest operations due to improper storage and handling are enormous and can range from 10-40 percent. Post harvest losses can occur in the field, in packing areas, in storage, during transportation and in the wholesale and retail market. Severe losses occur because of poor facilities, lack of know-how, poor management, market dysfunction or simply the carelessness of farmers. Proper storage conditions, temperature and humidity are needed to lengthen the storage life and maintain quality once the crop has been cooled to the optimum storage temperature.

4.14 INDIAN STANDARDS

Various Indian standard are notified by Bureau of Indian Standards, New Delhi, these are given below.

Indian Standards on Storage and Marketing Structures for Agricultural Commodities

IS:

600-1955	Code of practice for construction of BUKHARI type rural food grain storage structure.
601-1955	Code of practice for construction of KOTHARI type food grain storage structure.

602-1955	Code of practice for construction for MORAI type rural food grain storage structure.
603-1960	Code of practice for construction of underground rural food grain storage structure.
607-1965	Code of practice for construction of bagged food grain storage structures suitable for trade and government purposes (revised).
609-1955	Code of practice for improvement of existing structures used oriented to be used for food grain storage.
631-1961	Aluminium food grain storage bins.
1497-1959	Layout for regulated market yards for agricultural commodities.
1787-1961	Layout for regulated market yards for fruits and vegetables.
1788-1961	Layout for regulated market yards for cattle.
2059-1962	Layout for regulated market yards for tobacco.
2821-1964	Thermo-sampler.
3453-1966	Code of practice for construction of hexagonal type concrete-cum-masonary bins for bulk storage of food grains.
5503(PartI)-1969	General requirements for silos for grain storage: Part I Constructional requirements.
5503(PartII)-1969	General requirements for silos for grain storage: Part II Grain handling equipment and accessories.
5606-1970	Steel bins for grain storage.
5826-1970	Constructional requirements for flat storage structures for grain (capacity above 200 tonnes).
6151 (Part I)-1971	Storage management code: Part I Terminology.
6151 (Part II)-1971	Storage management code: Part II General care in handling and storage of agricultural produce and inputs (superseding IS: 610-1955 and IS: 611-1955).
6201-1971	Constructional requirements for flat storage structures for grains (100-200 tonnes capacity).
6663-1972	Method for determination of angle of repose of grains.

Indian Standards on Storage Structures and Storage Management

IS:

607-1971	Code of practice for construction of bagged storage structures (second revision).

3453-1966	Code of practice for construction of hexagonal type concrete-cum-masonry bins bulk storage of food grains.
3503(Part I)-1969	General requirements for silos for grain storage: Part I Constructional requirements.
3503 (Part II)-1969	General requirements for silos for grain storage: Part II Grain handling equipment and accessories.
5606-1970	Steel bins for grain storage.
5826-1970	Constructional requirements for flat storage structures for grain (capacity above 200 tonnes).
6151 (Part I)-1971	Storage management code: Part I Terminology.
6151 (Part II)-1971	Storage management code: Part II General care in handling and storage of agricultural produce and inputs.
6151 (Part III)-1976	Storage management code: Part III Specific care in handling and storage of agriculture produce and inputs.
6201-1971	Constructional requirements for flat storage structures for grains (100 to 200 tonnes capacity).
6883-1972	Method for determination of angle of repose of grains.
7147 (Part I)-1973	Steel bins for domestic storage: Part I GHARELU KOTHI.
7247	Code of practice for fumigation of agricultural produce
7247 (Part I)-1973	Methyl bromide.
7247 (Part II)-1973	Ethylene dibromide.
7247 (Part III)-1973	Aluminium phosphate.
7247 (Part IV)-1975	Ethylene dichloride and carbon tetrachloride mixture.
7715-1975	Methods for testing suitability of bins for safe storage of food grains.
7716-1975	Method for testing efficacy of fumigation for disinfestations of grains in domestic bins.
8455-1977	Code of practice for construction of polyethylene embedded bins for bulk storage of food grains.

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 reason for post harvest losses of fruit and vegetables?

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2. What percentage of losses takes places during storage?

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4.15 LET US SUM UP

Storage of fresh fruits and vegetables produced is an important economic aspect as it tends to stabilize prices to make use of higher production period to low production period, to avoid glut in the market, to make fruits and vegetables available in off season to earn better return. Due to improper storage, infestation takes place in the produce. Proper storage conditions should be maintained during storage. Various parameters such as relative humidity, temperature, etc. are important during storage. Storage can be made in various types of storage structures depending upon capacity and resources available. Important storage methods are Ground storage or pit storage, evaporating cooling, Ventilatated storage, Refrigerated storage, controlled and modified storage.

4.16 KEY WORDS

Temperature : It is the temperature of surroundings of fruits and vegetables stored.

Infestation : It refers to attack of insects and pests on stored product.

Refrigerated storage : In this condition storage temperature ranges from –1C to 10 C. Storage below –1 C is termed as freezer storage.

Airtight storage : Airtight storage refers to storage conditions in which air is minimum (.2% by volume) leading to arrest the insect infestation in dry grains.

4.17 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Your answer should include the following points:
   - Need for storage,
   - Storage conditions for optimum condition,
   - Suitable storage condition for various fruit and vegetables.

2. Your answer should include the following points:

   - various factors,
   - relative humidity,
   - temperature,
   - moisture content.

3. Your answer should include the following points:

   Various types of infestation takes places in storage, it include direct damages and indirect damages, all type of sources for infestation should be noted.

4. Your answer should include the following points:

   Various types of injury like freezing and chilling injury should be mentioned

Check Your Progress Exercise 2

1. Your answer should include the following points:

   - Ground storage or pit storage,
   - Cellers and caves.

2. Your answer should include the following points:

   - Air-cooled storage,
   - Evaporating cooling,
   - Ventilated storage,
   - Improved Zero-energy cool chamber.

Check Your Progress Exercise 3

1. Your answer should include the following points:

   Reasons for post harvest losses and factor effecting losses.

2. Your answer should include the following points:

   Percentage of losses taken place during post harvest operations.

4.18 SOME USEFUL BOOKS

1. Srivastava, S.S. (2000) Horticulture Science, Central Book House, Raipur.
2. Sahay, K.M. and Singh, K.K. (1991) Unit Operations of Agricultural Processing, Vikas Publishing House Pvt. Ltd.

3. Arya, Prem Singh (1997) Vegetable Growing In India, MP Publication Pvt. Ltd.

4. Yadav, P.K. and Singh, Jitendra (2000) Fruit Production and Preservation, Agrobios (India) Jodhpur.

5. Michel, A.M. and Ojha, T.P. (1966) Principle of Agricultural Engineering, Jain Publications, New Delhi.

6. Hardenburg, R.E., Watada, A.E. and Wang, C.Y. (1986) ***The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks.*** U.S. Dept. of Agriculture, Agricultural Handbook No. 66. pp. 130.

7. Kader, A.A. (ed.) (1992) ***Postharvest Technology of Horticultural Crops.*** University of California, Division of Agriculture and Natural Resources. Oakland, California, USA, pp. 296.

8. Janet Bachmann and Richard Earles, NCAT Agriculture Specialists August 2000 ***Postharvest Handling of Fruit & Vegetables*** By ATTRA Ozark Mountains at the University of Arkansas in Fayetteville at P.O. Box 3657, Fayetteville, AR 72702.

9. Fu Wen Liu ***Horticultural Crops Abstract*** Department of Horticulture, National Taiwan University.

UNIT 5 SIZE REDUCTION

Structure

5.0 OBJECTIVES

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

- understand the principles and methods of size reduction;
- describe various size reduction equipments and their efficiencies; and
- understand the importance of size reduction and able to decide the suitability of different machinery for various uses.

5.1 INTRODUCTION

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

5.2 PRINCIPLES OF SIZE REDUCTION

Crushers and grinders are the equipment mostly used for size reduction of agri-cultural products. An ideal size reducer should fulfil the following conditions, namely (1) large capacity, (2) should yield a pre-desired sized product or range of size, (3) small power input requirement per unit of product handled and (4) easy and trouble free operation. Usually the performance of any milling equipment is compared with respect to an ideal operation as standard. The characteristics of the actual equipment are compared with those of the ideal unit.

Size reduction results in the production of small particles which may be required either for larger surface area or because of their definite shape, size and number. Amount of power required to create smaller particles is one of the parameters of the efficiency of operation. Second parameter is the desired uniformity of size. The actual unit seldom yields a uniform sized product. Irrespective of uniformity of feed size the ground product consists of a mixture of various particle sizes. In some equipment there is a provision to control the magnitude of the largest particles like the hammer mill, but the fine size is beyond control. In some size reducing machine fines are minimized but they can not be eliminated altogether.

5.3 METHODS OF SIZE REDUCTION

Solids may be broken in many different ways, but only four of them are commonly used in size-reduction machines: (1) compression, (2) impact, (3) attrition or rubbing, and (4) cutting. A nutcracker, a hammer, a file, and a pair of scissors exemplify these four types of action. Sometimes size reduction results from the attrition of a particle by one or more other particles or from intense shear in the supporting fluid. In general, compression is used for coarse reduction of hard solids, to give relatively few fines; impact gives coarse, medium, or fine products; attrition yields very fine products from soft, nonabrasive materials. Cutting gives a definite particle size and sometimes a definite shape, with few or no fines.

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

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

Shearing: It is a process of size reduction which combines cutting and crushing. The shearing units consist of a knife and a bar. If the edge of knife or shearing edge is thin enough and sharp, the size reduction process nears to that of cutting, whereas a thick and dull shearing edge performs like a crusher. In a good shearing unit the knife is usually thick enough to overcome the shock resulting from material hitting. In an ideal shearing unit the clearance between the bar and the knife should be as small as practicable and the knife as sharp and thin as possible.

Cutting: In this method, size reduction is accomplished by forcing a sharp and thin knife through the material. In the process minimum deformation and rupture of the material results and the new surface created is more or less undamaged. An ideal cutting device is a knife of excellent sharpness and it should be as thin as practicable. The size of vegetables and fruits are reduced by cutting.

5.4 SIZE REDUCTION EQUIPMENT

Size-reduction equipment is divided into crushers, grinders, ultrafine grinders, and cutting machines. *Crushers* do the heavy work of breaking large pieces of solid material into small lumps. A primary crusher operates on run-of-mine material, accepting anything that comes from the mine face and breaking it into 150 to 250 mm lumps. A secondary crusher reduces these lumps to particles perhaps 6 mm in size. *Grinders* reduce crushed feed to powder. The product from an intermediate grinder might pass a 4O mesh screen; most of the product from a fine grinder would pass a 200 mesh screen with a *74 µm* opening. An *ultrafine grinder* accepts feed particles no larger than 6 mm; the product size is typically 1 to 50 *µm. Cutters* give particles of definite size and shape, 2 to 10 mm in length.

The principal types of size-reduction machines are as follows:

A. Crushers (coarse and fine)

   1. Jaw crushers
   2. Gyratory crushers
   3. Crushing rolls

B. Grinders (intermediate and fine)

   1. Hammer mills; impactors
   2. Rolling-compression mills

      a) Bowl mills
      b) Roller mills

   3. Attrition mills
   4. Tumbling mills

      a) Rod mills
      b) Ball mills; pebble mills
      c) Tube mills; compartment mills

C. Ultrafine grinders

   1. Hammer mills with internal classification
   2. Fluid-energy mills
   3. Agitated mills
   4. Colloidal mills

D. Cutting machines

   1. Knife cutters; dicers; slitters

These machines do their work in distinctly different ways. Compression is the characteristic action of crushers. Grinders employ impact and attrition, sometimes combined with compression; ultrafine grinders operate principally by attrition. A cutting action is of course characteristic of cutters, dicers, and slitters.

5.4.1 Crushers

Crushers are slow-speed machines for coarse reduction of large quantities of solids. The main types are jaw crushers, gyratory crushers, smooth-roll crushers, and toothed-roll crushers. The first three operate by compression and can break large lumps of very hard materials, as in the primary and secondary reduction. Toothed-roll crushers tear the feed apart as well as crushing it; they handle softer feeds like coal, bone, and soft shale.

Jaw crushers: In a jaw crusher feed is admitted between two jaws, set to form a V open at the top. One jaw, the fixed, or anvil, jaw, is nearly vertical and does not move; the other, the swinging jaw, reciprocates in a horizontal plane. It makes an angle of 20° to 30° with the anvil jaw. An eccentric drives it so that it applies great compressive force to lumps caught between the jaws. The jaw faces are flat or slightly bulged; they may carry shallow horizontal grooves. Large lumps caught between the upper parts of the jaws are broken, drop into the narrower space below, and are recrushed the next time the jaws close. After sufficient reduction they drop out the bottom of the machine. The jaws open and close 250 to 400 times per minute.

The most common type of jaw crusher is illustrated in Figure 5.1. In this machine an eccentric drives a pitman connected to two toggle plates, one of which is pinned to the frame and the other to the swinging jaw. The pivot point is at the top of the movable jaw or above the top of the jaws on the centerline of the jaw opening. The greatest amount of motion is at the bottom of the V, which means that there is little tendency for a crusher of this kind to choke. Some machines with a 1.8 by 2 m feed opening can accept rocks 1.8 m in diameter and crush 1200 ton/h to a maximum product size of 250 mm. Smaller secondary crushers reduce the particle size of precrushed feed to 6 to 50 mm at much lower rates of throughput.

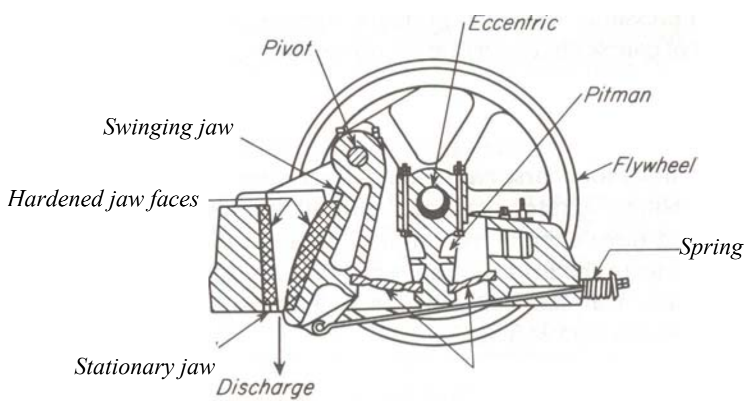

Figure 5.1: Jaw crusher

Gyratory crushers: A gyratory crusher may be looked upon as a jaw crusher with circular jaws, between which material is being crushed at some point at all times. A conical crushing head gyrates inside a funnel-shaped casing, open at the top. As shown in Figure 5.2, the crushing head is carried on a heavy shaft pivoted at the top of the machine. An eccentric drives the bottom end of the shaft. At any point on the periphery of the casing, therefore, the bottom of the crushing head moves toward, and then away from, the stationary wall. Solids caught in the V-shaped space between the head and the casing are broken and rebroken until they pass out the bottom. The crushing head is free to rotate on the shaft and turns slowly because of friction with the material being crushed.

The speed of the crushing head is typically 125 to 425 gyrations per minute. Because some part of the crushing head is working at all times, the discharge from a gyratory is continuous instead of intermittent as in a jaw crusher. The load on the motor is nearly uniform; less maintenance is required than with a jaw crusher; and the power requirement per ton of material crushed is smaller. The biggest gyratories handle up to 4500 ton/h. The capacity of a gyratory crusher varies with the jaw setting, the impact strength of the feed, and the speed of gyration of the machine. The capacity is almost independent of the compressive strength of the material being crushed.

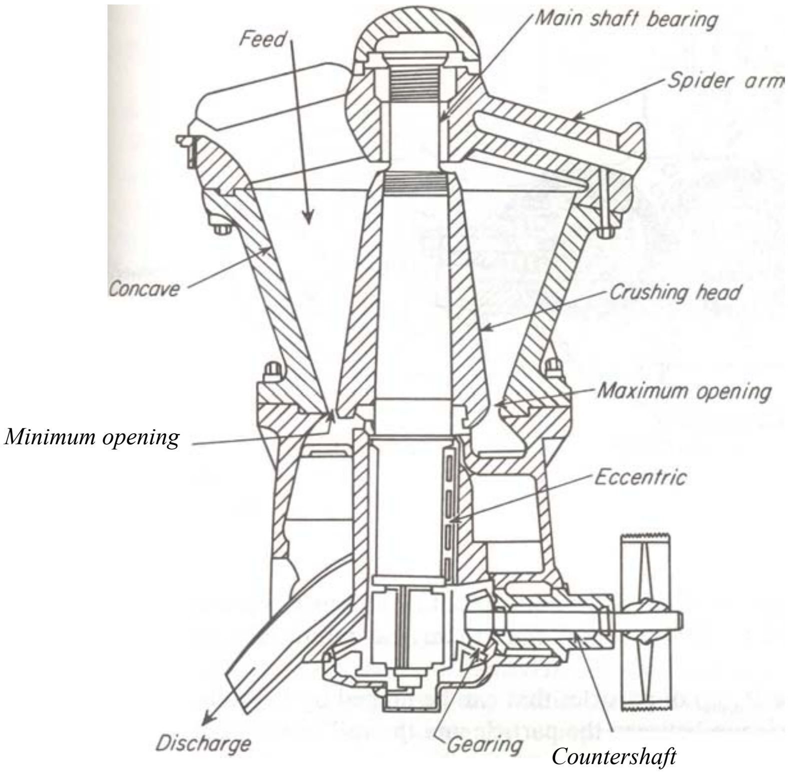

Figure 5.2: Gyratory crusher

Smooth-roll crushers: Two heavy smooth-faced metal rolls turning on parallel horizontal axes are the working elements of the smooth-roll crusher illustrated in Figure 5.3. Particles of feed caught between the rolls are broken in compression and drop out below. The rolls turn toward each other at the same speed. They have relatively narrow faces and are large in diameter so that they can "nip" moderately large lumps. Typical rolls are 600 mm in diameter with a 3OO mm face to 2000 mm in diameter with a 914 mm face. Roll speeds range from 50 to 300 r/min.

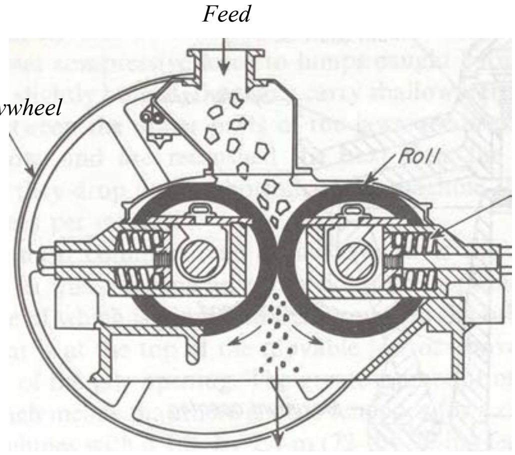

Figure 5.3: Smooth roll crusher

Smooth-roll crushers are secondary crushers, with feeds 12 to 75 mm in size and products 12 mm to about 1 mm. The limiting size $D_{p.max.}$ of particles that can be nipped by the rolls depends on the coefficient of friction between the particle and the roll surface, but in most cases it can be estimated from the simple relation.

$$D_{p.max.} = 0.04R + d5.1 \quad (5.1)$$

where R = roll radius
d = half the width of the gap between the rolls.

The maximum size of the product is approximately equal to *2d.*

The particle size of the product depends on the spacing between the rolls, as does the capacity of a given machine. Smooth-roll crushers give few fines and virtually no oversize. They operate most effectively when set to give a reduction ratio of 3 or 4 to 1; that is, the maximum particle diameter of the product is one-third or one-fourth that of the feed. The forces exerted by the roll are very great, from 8700 to 70,000 N/cm of roll width. To allow unbreakable material to pass through without damaging the machine, at least one roll must be spring mounted.

Toothed-roll crushers: In many roll crushers the roll faces carry corrugations, breaker bars, or teeth. Such crushers may contain two rolls, as in smooth-roll crushers, or only one roll working against a stationary curved breaker plate. A single-roll toothed crusher is shown in Figure 5.4 Machines known as *disintegrators* contain two corrugated rolls turning at different speeds, which tear the feed apart, or a small high-speed roll with transverse breaker bars on its face turning toward a large slow-speed smooth roll. Some crushing rolls for coarse feeds carry heavy pyramidal teeth.

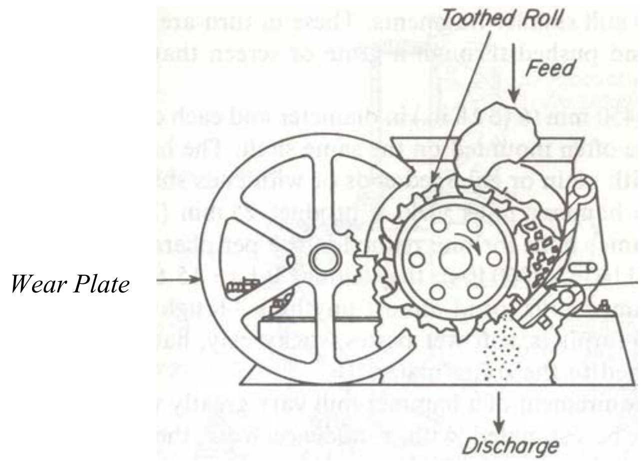

Figure 5.4: Single-roll tooth crusher

Other designs utilize a large number of thin-toothed disks that saw through slabs or sheets of material Toothed-roll crushers are much more versatile than smooth-roll crushers, within the limitation that they cannot handle very hard solids. They operate by compression, impact, and shear, not by compression alone, as do smooth-roll machines. They are not limited by the problem of nip inherent with smooth rolls and can therefore reduce much larger particles. Some heavy-duty toothed double-roll crushers are used for the primary reduction of coal and similar materials. The particle size of the feed to these machines may be as great as 500 mm; their capacity ranges up to 500 tons/h.

5.4.2 Grinders

The term *grinder* describes a variety of size-reduction machines for intermediate duty. The product from a crusher is often fed to a grinder, in which it is reduced to powder. The chief types of commercial grinders described in this section are hammer mills and impactors, rolling-compression machines, attrition mills, and tumbling mills.

Hammer mills and impactors: These mills all contain a high-speed rotor turning inside a cylindrical casing. The shaft is usually horizontal Feed dropped into the top of the casing is broken and falls out through a bottom opening. In a hammer mill the particles are broken by sets of swing hammers pinned to a rotor disk. A particle of feed entering the grinding zone cannot escape being struck by the hammers. It shatters into pieces, which fly against a stationary anvil plate inside the casing and break into still smaller fragments. These in turn are rubbed into powder by the hammers and pushed through a grate or screen that covers the discharge opening.

Several rotor disks, 150 to 450 mm in diameter and each carrying four to eight swing hammers, are often mounted on the same shaft. The hammers may be straight bars of metal with plain or enlarged ends or with ends sharpened to a cutting edge. Intermediate hammer mills yield a product 25 mm to 20-mesh in particle size. In hammer mills for fine reduction the peripheral speed of the hammer tips may reach 110 m/s; they reduce 0.1 to 15 ton/h to sizes finer than 200-mesh. Hammer mills grind almost anything tough fibrous solids like bark or leather, steel turnings, soft wet pastes, sticky clay, hard rock. For fine reduction they are limited to the softer materials.

The capacity and power requirement of a hammer mill vary greatly with the nature of the feed and cannot be estimated with confidence from theoretical considerations. They are best found from published information or better from small-scale or full-scale tests of the mill with a sample of the actual material to be ground. Commercial mills typically reduce 60 to 240 kg of solid per kilowatt hour of energy consumed.

An *impactor,* illustrated in Figure 5.5, resembles a heavy-duty hammer mill except that it contains no grate or screen. Particles are broken by impact alone, without the rubbing action characteristic of a hammer mill. Impactors are often primary-reduction machines, processing up to 600 ton/h. They give particles that are more nearly equidimensional (more "cubical") than the slab-shaped particles from a jaw crusher or gyratory crusher. The rotor in an impactor, as in many hammer mills, may be run in either direction to prolong the life of the hammers.

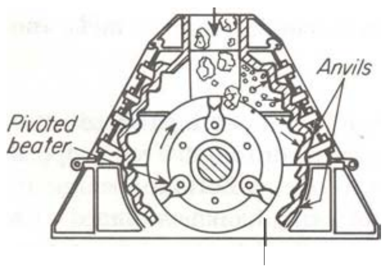

Figure 5.5: Impactor

Rolling-compression machines: In this kind of mill the solid particles are caught and crushed between a rolling member and the face of a ring or casing. The most common types are rolling-ring pulverizers, bowl mills, and roller mills. In the roller mill illustrated in Figure 5.6, vertical cylindrical rollers press outward with great force against a stationary anvil ring or bullring. They are driven at moderate speeds in a circular path. Plows lift the solid lumps from the floor of the mill and direct them between the ring and the rolls, where the reduction takes place. Product is swept out of the mill by a stream of air to a classifier separator, from which oversize particles are returned to the mill for further reduction. In a bowl mill and some roller mills the bowl or ring is driven; the rollers rotate on stationary axes, which may be vertical or horizontal. They pulverize up to 50 ton/h. When classification is used, the product may be as fine as 99 percent through a 200-mesh screen.

Attrition mills: In an attrition mill particles of soft solids are rubbed between the grooved flat faces of rotating circular disks. The axis of the disks is usually horizontal, sometimes vertical. In a single-runner mill one disk is stationary and one rotates; in a double-runner machine both disks are driven at high speed in opposite directions. Feed enters through an opening in the hub of one of the disks; it passes outward through the narrow gap between, the disks and discharges from the periphery into a stationary casing. The width of the gap, within limits, is adjustable. At least one grinding plate is spring mounted so that the disks can separate if unbreakable material gets into the mill. Mills with different patterns of grooves, corrugations, or teeth on the disks perform a variety of operations, including grinding, cracking, granulating, and shredding, and even some operations not related to size reduction at all, such as blending.

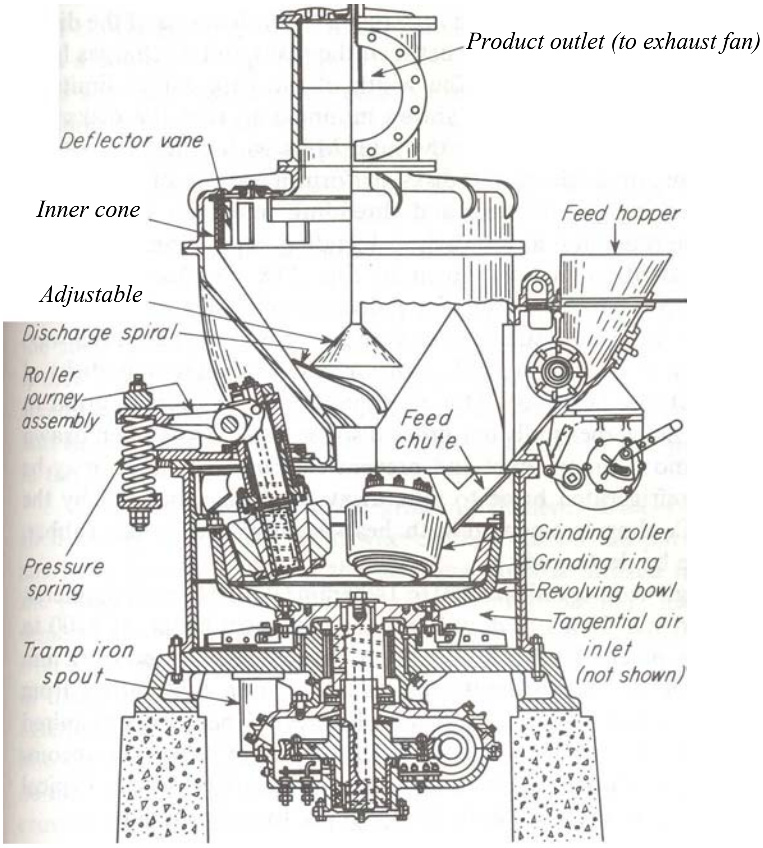

Figure 5.6: Roller mill

A single-runner attrition mill is shown in Figure 5.7. Single-runner mills contain disks of buhrstone or rock emery for reducing solids like spices, starch, insecticide powders, and carnauba wax. Metal disks are usually of white iron, although for corrosive materials disks of stainless steel are sometimes necessary. Double-runner mills, in general, grind to finer products than single-runner mills but process softer feeds. Air is often drawn through the mill to remove the product and prevent choking. The disks may be cooled with water or refrigerated brine to take away the heat generated by the reduction operation. Cooling is essential with heat-sensitive solids like spices, rubber which would otherwise be destroyed.

The disks of a single-runner mill are 250 to 1400 mm in diameter; turning at 350 to 700 r/min. Disks in double-runner mills turn faster, at 1200 to 7000 r/min. The feed is precrushed to a maximum particle size of about 12 mm and must enter at a uniform controlled rate. Attrition mills grind from 1 to 8 ton/h to products that will pass a 200-mesh screen. The energy required depends strongly on the nature of the feed and the degree of reduction accomplished and is much higher than in the mills and crushers described so far. Typical values are between 8 and 80 kWh (10 and 100 hp-h) per ton of product.

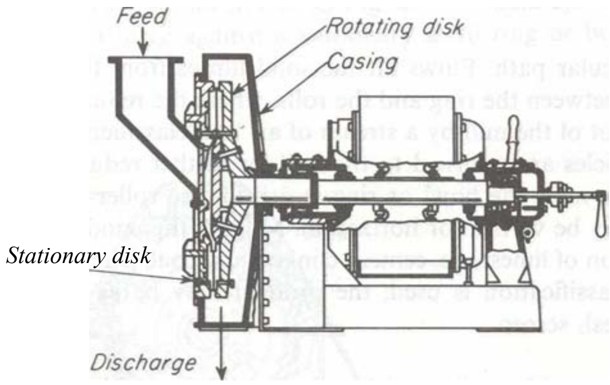

Figure 5.7: Attrition mill

Tumbling mills: A typical tumbling mill is shown in Figure 5.8. A cylindrical shell slowly turning about a horizontal axis and filled to about half its volume with a solid grinding medium forms a tumbling mill. The shell is usually steel, lined with high-carbon steel plate, porcelain, silica rock, or rubber. The grinding medium is metal rods in a rod mill, lengths of chain or balls of metal, rubber, or wood in a ball mill, flint pebbles or porcelain or zircon spheres in a pebble mill. For intermediate and fine reduction of abrasive materials tumbling mills are unequaled.

Unlike the mills previously discussed, all of which require continuous feed, tumbling mills may be continuous or batch. In a batch machine a measured quantity of the solid to be ground is loaded into the mill through an opening in the shell. The opening is then closed and the mill turned on for several hours; it is then stopped and the product is discharged. In a continuous mill the solid flows steadily through the revolving shell, entering at one end through a hollow trunnion and leaving at the other end through the trunnion or through peripheral openings in the shell.

In all tumbling mills, the grinding elements are carried up the side of the shell nearly to the top, from whence they fall on the particles underneath. The energy expended in lifting the grinding units is utilized in reducing the size of the particles. In some tumbling mills, as in a *rod mill,* much of the reduction is done by rolling compression and by attrition as the rods slide downward and roll over one another. The grinding rods are usually steel, 25 to 125 mm in diameter, with several sizes present at all times in any given mill. The rods extend the full length of the mill. They are sometimes kept from twisting out of line by conical ends on the shell. Rod mills are intermediate grinders, reducing a 20 mm feed to perhaps l0 mesh, often preparing the product from a crusher for final reduction in a ball mill. They yield a product with little oversize and a minimum of fines.

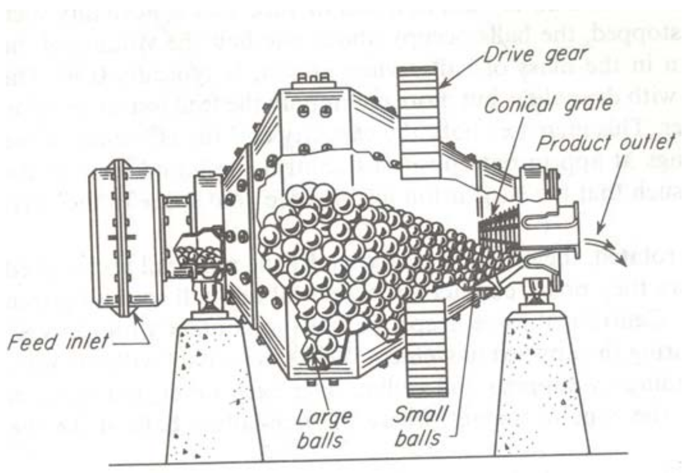

Figure 5.8: Conical ball mill

In a *ball mill* or *pebble mill* most of the reduction is done by impact as the balls or pebbles drop from near the top of the shell. In a large ball mill the shell might be 3 m in diameter and 4.25 m long. The balls are 25 to 125 mm in diameter; the pebbles in a pebble mill are 50 to 175 mm in size. A *tube mill* is a continuous mill with a long cylindrical shell, in which material is ground for 2 to 5 times as long as in the shorter ball mill. Tube mills are excellent for grinding to very fine powders in a single pass where the amount of energy consumed is not of primary importance. Putting slotted transverse partitions in a tube mill converts it into a *compartment mill.* One compartment may contain large balls, another small balls, and a third pebbles. This segregation of the grinding media into elements of different size and weight aids considerably in avoiding wasted work, for the large, heavy balls break only the large particles, without interference by the fines. The small, light balls fall only on small particles, not on large lumps they cannot break.

Segregation of the grinding units in a single chamber is a characteristic of the *conical ball mill* illustrated in Figure 5.8. Feed enters from the left through a 60° cone into the primary grinding zone, where the diameter of the shell is a maximum. Product leaves through the 30° cone to the right. A mill of this kind contains balls of different sizes, all of which wear and become smaller as the mill is operated. New large balls are added periodically. As the shell of such a mill rotates, the large balls move toward the point of maximum diameter, and the small balls migrate toward the discharge. The initial breaking of the feed particles, therefore, is done by the largest balls dropping the greatest distance; small particles are ground by small balls dropping a much smaller distance. The amount of energy expended is suited to the difficulty of the breaking operation, increasing the efficiency of the mill.

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.
c) Use separate sheets where no space is provided.

1. Enlist the different characteristics of an ideal size reducing machine.

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2. Describe various methods of size reduction with suitable examples.

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3. Classify the size reduction machines according to the methods used.

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4. Write short notes on the following:

   i) Jaw crusher
   ii) Toothed roll crusher
   iii) Hammer mill
   iv) Attrition mill
   v) Tumbling mill

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5.4.3 Ultrafine Grinders

Many commercial powders must contain particles averaging 1 to 20 μm in size, with substantially all particles passing a standard 325-mesh screen that has openings 44 μm wide. Mills that reduce solids to such fine particles are called *ultra fine grinders.* Ultrafine grinding of dry powder is done by grinders, such as high-speed hammer mills, provided with internal or external classification, and by fluid-energy or jet mills. Ultrafine wet grinding is done in agitated mills.

Classifying hammer mills: A set of swing hammers is held between two rotor disks, much as in a conventional hammer mill. In addition to the hammers the rotor shaft carries two fans, which draw air through the mill in the direction shown in the figure and discharge into ducts leading to collectors for the product. On the rotor disks are short radial vanes for separating oversize particles from those of acceptable size. In the grinding chamber the particles of solid are given a high rotational velocity. Coarse particles are concentrated along the wall of the chamber because of centrifugal force acting on them. The air stream carries finer particles inward from the grinding zone toward the shaft in the direction *AB.* The separator vanes tend to throw particles outward in the direction *BA*. Whether or not a given particle passes between the separator vanes and out to the discharge depends on which force predominates- the drag exerted by the air or the centrifugal force exerted by the vanes. Acceptably fine particles are carried through; particles that are too large are thrown back for further reduction in the grinding chamber. Changing the rotor speed or the size and number of the separator vanes varies the maximum particle size of the product. Mills of this kind reduce 1 or 2 ton/h to an average particle size of 1 to 20 *μm,* with an energy requirement of about 40 kWh/metric ton.

Fluid energy mills: In these mills the particles are suspended in a high - velocity gas stream. In some designs the gas flows in a circular or elliptical path; in others there are jets that oppose one another or vigorously agitate a fluidized bed. Some reduction occurs when the particles strike or rub against the walls of the confining chamber, but most of the reduction is believed to be caused by interparticle attrition. Internal classification keeps the larger particles in the mill until they are reduced to the desired size.

The suspending gas is usually compressed air or superheated steam, admitted at a pressure of 7 atm through energizing nozzles. The grinding chamber is an oval loop of pipe 25 to 200 mm in diameter and 1.2 to 2.4 m high. Feed enters near the bottom of the loop through a venturi injector. Classification of the ground particles takes place at the upper bend of the loop. As the gas stream flows around this bend at high speed, the coarser particles are thrown outward against the outer wall while the fines congregate at the inner wall. A discharge opening in the inner wall at this point leads to a cyclone separator and a bag collector for the product. The classification is aided by the complex pattern of swirl generated in the gas stream at the bend in the loop of pipe.2 Fluid-energy mills can accept feed particles as large as 12 mm but are more effective when the feed particles are no larger than 100-mesh. They reduce up to 1 ton/h of non sticky solid to particles averaging! to 10 11m in diameter, using 1 to 4 kg of steam or 6 to 9 kg of air per kilogram of product. Loop mills can process up to 6000 kg/h.

Agitated mills: For some ultrafine grinding operations, small batch non rotary mills containing a solid grinding medium are available. The medium consists of hard solid elements such as balls, pellets, or sand grains. These mills are vertical vessels 4 to 1200 L in capacity, filled with liquid in which the grinding medium is suspended. In some designs the charge is agitated with a multiarmed impeller; in others, used especially for grinding hard materials (such as silica or titanium dioxide), a reciprocating central column “vibrates” the vessel contents at about 20 Hz. A concentrated feed slurry is admitted at the top, and product (with some liquid) is withdrawn through a screen at the bottom. Agitated mills are especially useful in producing particles 1 */lm* in size or finer.

Colloid mills: In a colloid mill, intense fluid shear in a high-velocity stream is used to disperse particles or liquid droplets to form a stable suspension or emulsion. The final size of the particles or droplets is usually less than 5 */lm.* Often there is little actual size reduction in the mill; the principal action is the disruption of lightly bonded clusters or agglomerates. Syrups, milk, purees, ointments, paints, and greases are typical products processed in this way. Chemical additives are often useful for stablizing the dispersion.

In most colloid mills the feed liquid is pumped between closely spaced surfaces one of which is moving relative to the other at speeds of 50 m/s or *more.* In the mill shown schematically in Figure 5.9 the liquid passes through the narrow spaces between the disk-shaped rotor and the casing. The clearances are adjustable down to 25 */lm.* Often cooling is required to remove the heat generated. The capacities of colloid mills are relatively low, ranging from 2 or 3 L/min for small mills up to 440 L/min for the largest units.

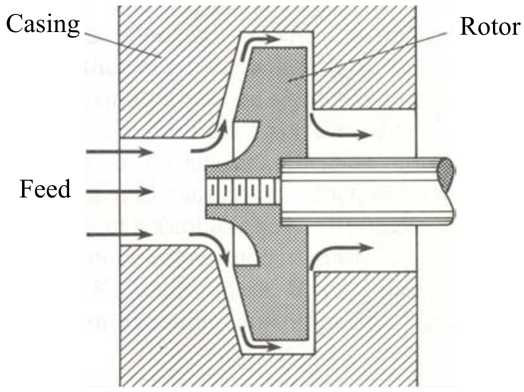

Figure 5.9: Schematic drawing of colloid mill

5.4.4 Cutting Machines

In some size-reduction problems the feed stocks are too tenacious or too resilient to be broken by compression, impact, or attrition. In other problems the feed must be reduced to particles of fixed dimensions. These requirements are met by devices that cut, chop, or tear the feed into a product with the desired characteristics. The sawtoothed crushers mentioned above do much of their work in this way. True cutting machines include rotary knife cutters and granulators. These devices find application in a variety of processes but are especially well adapted to size reduction problems in the manufacture of rubber and plastics.

Knife cutters: A rotary knife cutter, as shown in Figure 5.10, contains a horizontal rotor turning at 200 to 900 r/min in a cylindrical chamber. On the rotor are 2 to 12 flying knives with edges of tempered steel or stellite passing with close clearance over 1 to 7 stationary bed knives. Feed particles entering the chamber from above are cut several hundred times per minute and emerge at the bottom through a screen with 5 to 8 mm openings. Sometimes the flying knives are parallel with the bed knives; sometimes, depending on the properties of the feed, they cut at an angle. Rotary cutters and granulators are similar in design. A granulator yields more or less irregular pieces; a cutter may yield cubes, thin squares, or diamonds.

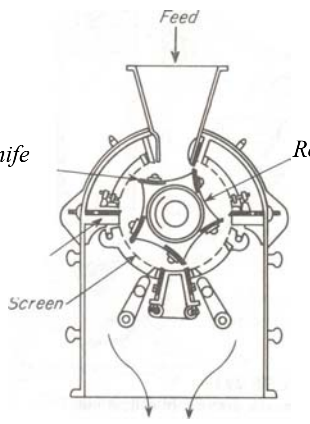

Figure 5.10: Rotary knife cutter

5.5 EFFICIENCY OF SIZE REDUCTION

The ratio of the surface energy created by crushing to the energy absorbed by the solid is the crushing efficiency, η_c. If e_s is the surface energy per unit area, in meter times kg force per square meter, and A_{wb} and A_{wa} are the areas per unit mass of product and feed, respectively, the energy absorbed by a unit mass of the material W_n is

$$W_n = \frac{e_s\left(A_{wb} - A_{wa}\right)}{\eta_c} \tag{5.2}$$

The surface energy created by fracture is small in comparison with the total mechanical energy stored in the material at the time of rupture, and most of the latter is converted into heat. Crushing efficiences are therefore low. Typical crushing efficiencies range between 0.06 and 1 percent.

The energy absorbed by the solid W_n is less than that fed to the machine. Part of the total energy input W is used to overcome friction in the bearings and other moving parts, and the rest is available for crushing. The ratio of the energy absorbed to the energy input is, η_m, the mechanical efficiency. Then, if W is the energy input,

$$W = \frac{W_n}{\eta_m} = \frac{e_s\left(A_{wb} - A_{wa}\right)}{\eta_m \eta_c} \tag{5.3}$$

5.6 ENERGY REQUIREMENT FOR SIZE REDUCTION

The cost of power is a major expense in crushing and grinding, so the factors that control this cost are important. During size reduction, the particles of feed material are first distorted and strained. The work necessary to strain them is stored temporarily in the solid as mechanical energy of stress, just as mechanical energy can be stored in a coiled spring. As additional force is applied to the stressed particles, they are distorted beyond their ultimate strength and suddenly rupture into fragments. New surface is generated. Since a unit area of solid has a definite amount of surface energy, the creation of new surface requires work, which is supplied by the release of energy of stress when the particle breaks. By conservation of energy, all energy of stress in excess of the new surface energy created must appear as heat.

If $\dot{m}$ is the feed rate, the power (P) required by the machine is

$$P = W\dot{m} = \frac{\dot{m}e_s\left(A_{wb} - A_{wa}\right)}{\eta_c \eta_m} \quad (5.4)$$

The average particle size of a mixture of particles is defined in several different ways. Probably the most used is the volume-surface mean diameter, $\overline{D}_s$, which is related to the specific surface area A_w. It is defined by the following equation

$$\overline{D}_s \equiv \frac{6}{\phi_s A_w \rho_p} \quad (5.5)$$

where ϕ_s, spehiricity of particle, and

ρ_p, density of particle, kg/m^3

Substituting A_{wb} and A_{wa} from equation 5.5 in 5.4 we get

$$P = \frac{6\dot{m}e_s}{\eta_c \eta_m \rho_p}\left(\frac{1}{\phi\overline{D}_{sb}} - \frac{1}{\phi\overline{D}_{sa}}\right) \quad (5.6)$$

where $\overline{D}_{sa}$ is mean diameter of feed, and

$\overline{D}_{sb}$ is mean diameter of product

5.6.1 Empirical Relationships

Rittinger's Law: A crushing law proposed by Rittinger in 1867 states that the work required in crushing is proportional to the new surface created. This "law," which is really no more than a hypothesis, is equivalent to the statement that the crushing efficiency, η_c, is constant and, for a given machine and feed material, is independent of the sizes of feed Md product. If the sphericities ϕ_a and ϕ_b are equal and the mechanical efficiency is constant, the various constants in equation (5.6) can be combined into a single constant K_r, known as Rittinger's constant and Rittinger's law written as

$$\frac{P}{\dot{m}} = K_r\left(\frac{1}{\overline{D}_{sb}} - \frac{1}{\overline{D}_{sa}}\right) \quad (5.7)$$

Kick's Law: In 1885 Kick proposed another "law," based on stress analysis of plastic deformation within the elastic limit, which states that the work required for crushing a given mass of material is constant for the same reduction ratio, that is, the ratio of the initial particle size to the final particle size. This leads to the relation

$$\frac{P}{\dot{m}} = K_k \ln\frac{\overline{D}_{sa}}{\overline{D}_{sb}} \quad (5.8)$$

where K_k is a constant.

A generalized relation for both cases is the differential equation

$$d\left(\frac{P}{\dot{m}}\right) = -\frac{K d\overline{D}_s}{\left(\overline{D}_s\right)^n} \tag{5.9}$$

Solution of equation (5.9) for n = 1, 2 leads to Kick's law and Rittinger's law, respectively.

Both Kick's law and Rittinger's law have been shown to apply over limited ranges of particle size, provided K_k and K_r are determined experimentally by tests in a machine of the type to be used and with the material to be crushed. They thus have limited utility and are mainly of historical interest.

Bond Crushing Law and Work Index : A somewhat more realistic method of estimating ,the power required for crushing and grinding was proposed by Bond in 1952. Bond postulated that the work required to form particles of size D_p from very large feed is proportional to the square root of the surface-to-volume ratio of the product s_p/v_p *and* $s_p/v_p = 6/\phi_s D_p$, from which it follows that

$$\frac{P}{\dot{m}} = \frac{K_b}{\sqrt{D_p}} \tag{5.10}$$

where K_b is a constant that depends on the type of machine and on the material being crushed. This is equivalent to a solution of equation (5.9) with n = 1.5 and a feed of infinite size. To use equation (5.10), a work index W_i *;* is defined as the gross energy requirement in kilowatt hours per ton of feed needed to reduce a very large feed to such a size that 80 percent of the product passes a *100 μm* screen. This definition leads to a relation between K_b and W_i . If D_p is in millimeters, P in kilowatts, and $\dot{m}$ in tons per hour,

$$K_b = \sqrt{100x10^{-3}}\, W_i = 0.3162 W_i \tag{5.11}$$

If 80 percent of the feed passes a mesh size of D_{pa} millimeters and 80 percent of the product a mesh of D_{pb} millimeters, it follows from equations (5.10) and (5.11) that

$$\frac{P}{\dot{m}} = 0.3162 W_i \left(\frac{1}{\sqrt{D_{pb}}} - \frac{1}{\sqrt{D_{pa}}}\right) \tag{5.12}$$

The work index includes the friction in the crusher, and the power given by equation (5.12) is gross power. For dry grinding, the power calculated from equation 5.12 is multiplied by 4/3.

5.7 SCREEN ANALYSIS

The most common method of classification of comminuted product is screening of the ground material through set of sieves, which is also called as 'screen analysis.' Bureau of Indian Standards has standardized mesh sizes for screen analysis. The size of openings of standard screens are given in Table 5.1

Table 5.1: Test sieves and their respective sizes

BSS	ASTM	BISS	Width of opening in inches	Width of opening in mm
	4	480	0.1870	4.750
5	6	340	0.1252	3.250
6	7	280	0.1109	2.818
7	8	240	0.0945	2.399
8	10	200	0.0800	2.032
10	12	170	0.0659	1.676
12	14	140	0.0553	1.405
14	16	120	0.0473	1.201
16	18	100	0.0394	1.000
18	20	85	0.0332	0.954
20	-	-	0.0322	0.894
22	25	70	0.0279	0.708
25	30	60	0.0233	0.592
30	35	50	0.0197	0.500
36	40	40	0.0165	0.420
40	-	-	0.0158	0.401
44	45	35	0.0133	0.351
48	-	-	0.0132	0.336
50	-	-	0.0116	0.295
52	50	30	0.0117	0.286
60	60	25	0.0099	0.251
72	70	20	0.0083	0.211
80	-	-	0.0073	0.186
85	80	18	0.0070	0.177
100	100	15	0.0060	0.157
120	120	12	0.0049	0.124
150	140	10	0.0041	0.104
170	170	9	0.0035	0.089
200	200	8	0.0030	0.075
240	220	7	0.0025	0.064
300	270	6	0.0021	0.053
325	-	5	0.0017	0.044
350	325	-	-	0.044
400	-	4	0.0015	0.038

For determination of average particle size in ground food grains, a set of Bureau of Indian Standard Screens is arranged serially in a stack. For food grain flour analysis, a set of BIS sieves No. 100, 70, 50, 40, 30, 20 and 15 with pan and cover are taken. A sample of 250 g of ground product is dried in an oven to constant weight. The dried sample is placed in the topmost sieve and the set is placed on the sieve shaking machine and shaken for 5 minutes.

5.8 FINENESS MODULUS

The fineness modulus indicates the uniformity of grind in resultant product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100. An example of determination of fineness modulus is presented below:

Determination of fineness modulus

BIS sieve No.	Weight of material retained	% material retained	Fineness modulus	Average particle size, mm
100	0.0	7 × 0.00 = 0.00	$\frac{279.72}{100} = 2.7972$	$D = 0.135\,(1.366)^{F.M.}$ $= 0.323$ mm
70	2.8	6 × 1.12 = 6.72		
50	18.4	5 × 7.36 = 36.8		
40	28.7	4 × 1.48 = 45.92		
30	90.8	3 × 6.32 = 108.96		
20	98.5	2 × 39.4 = 78.8		
15	6.3	1 × 2.52 = 2.52		
Pan	4.5	0 × 1.80 = 0.00		
		279.72		

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.
c) Use separate sheets where no space is provided.

1. Write short notes on the following:

   i) Colloid mill,
   ii) Knife cutter.

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2. Define crushing efficiency and mechanical efficiency.

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3. Typical crushing efficiencies vary between ………….. % and ……….. %.

4. Wheat (4.33 mm size) was milled by a burr mill at two different gaps between the burr stones. 250 g of the flour was analyzed by BIS sieves for particle size determination as given below. The power required to mill wheat, at first setting was 8.0 kW.

   Calculate the power requirement of the mill in second setting using (1) Rettinger's law and (2) Kick's law. The capacity of the mill is 0.2 t/hr.

BIS sieve No.	**Mass fraction of flour retained over sieve, g**	
	I setting	**II setting**
100	–	–
70	10.1	1.5
50	16.7	13.3
40	36.0	36.1
30	82.2	74.8
20	96.0	104.6
15	8.0	8.4
Pan	0.0	11.3

5. What is screen analysis?

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6. What is fineness modulus?

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5.9 LET US SUM UP

We will now recollect the major concepts presented in this unit. Size reduction is an important unit operation to facilitate the processing of food. The four methods of size reduction are crushing, impact, shearing and cutting. A large number of size reducing machines have been developed to meet the specific needs of the raw materials and the food processing. There are two basic parameters which are considered in the design or selection of a size reducing equipment. The first is the energy required for the size reduction. Finer the final particle size, larger will be the energy requirement. Rittinger, Kick, and Bond have proposed different empirical equations for estimating the energy requirement in size reduction. Effort should be made to use one or more of these equations to ensure that the size reduction operation is being carried out efficiently. The other basic parameter is the quality of the final product which is expressed in terms of particle size distribution. Fine mass modulus is computed from the particle size distribution obtained from screen analysis of the final product. It indicates the uniformity of the particle sizes in the final product.

5.10 KEY WORDS

Size reduction/ Comminution : The term *size reduction* is applied to all the ways in which particles of solids are cut or broken into smaller pieces.

Crushing : When an external force applied on a material excess of its strength, the material fails because of its rupture in many directions.

Impact : When a material is subjected to sudden blow of force in excess of its strength, it fails, like cracking of nut with the help of a hammer.

Shearing : It is a process of size reduction, which combines cutting and crushing. The shearing units consist of a knife and a bar.

Cutting : It is a method of size reduction accomplished by forcing a sharp and thin knife through the material.

Grinders : The term *grinder* describes a variety of size-reduction machines for intermediate duty. The product from a crusher is often fed to a grinder, in which it is reduced to powder.

Rittinger's law : A crushing law proposed by Rittinger in 1867 states that the work required in crushing is proportional to the new surface created.

Kick's law : It is based on stress analysis of plastic deformation within the elastic limit, which states that the work required for crushing a given mass of material is constant for the same reduction ratio, that is, the ratio of the initial particle size to the final particle size.

Crushing efficiency : It is the ratio of the actual and the theoretical energy requirement for crushing a material into a given size multiplied by 100.

Screen analysis : Is the most common method of classification of comminuted product obtained using screening of the ground material through set of sieves.

Fineness modulus : The fineness modulus indicates the uniformity of grind in resultant product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100.

5.11 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. i) large capacity,
   ii) should yield a predesired sized product or range of size,
   iii) small power input requirement per unit of product handled, and
   iv) easy and trouble free operation.

2. Solids may be broken in many different ways, but only four of them are commonly used in size-reduction machines:

   i) *compression, e.g. a nutcracker:* Application of external force in excess of the material strength. The particles produced after crushing are irregular in shape and size.

   ii) *impact, e.g. a hammer:* Material is subjected to sudden blow of force in excess of its strength, which causes rupture.

   iii) *attrition, or rubbing, e.g. a file:* It combines cutting and crushing. The shearing units consist of a knife and a bar. If the edge of knife or shearing edge is thin enough and sharp, the size reduction process nears to that of cutting, whereas a thick and dull shearing edge performs like a crusher.

   iv) *cutting. e.g. a pair of scissors:* Accomplished by forcing a sharp and thin knife through the material. In the process minimum deformation and rupture of the material results and the new surface created is more or less undamaged.

3. Size-reduction equipment are: crushers, grinders, ultrafine grinders, and cutting machines.

   They work on the methods of compression, impact, attrition, or rubbing, and cutting. Compression is the characteristic action of crushers. Grinders employ impact and attrition, sometimes combined with compression; ultrafine grinders operate principally by attrition. A cutting action is of course characteristic of cutters, dicers, and slitters.

4. i) *Jaw crusher:* In a jaw crusher feed is admitted between two jaws, set to form a V open at the top. The jaws open and close 250 to 400 times per minute.

   ii) *Toothed roll crusher:* The particle size of the feed to these machines may be as great as 500 mm; their capacity ranges up to 500 tons/h.

   iii) *Hammer mill:* These mills all contain a high-speed rotor turning inside a cylindrical casing. The shaft is usually horizontal Feed dropped into the top of the casing is broken and falls out through a bottom opening.

   iv) *Attrition mill:* In an attrition mill particles of soft solids are rubbed between the grooved flat faces of rotating circular disks. The axis of the disks is usually horizontal, sometimes vertical.

   v) *Tumbling mill:* A cylindrical shell slowly turning about a horizontal axis and filled to about half its volume with a solid grinding medium forms a tumbling mill. For intermediate and fine reduction of abrasive materials tumbling mills are unequaled.

Check Your Progress Exercise 2

1. i) *Colloidal mill:* In a colloid mill, intense fluid shear in a high-velocity stream is used to disperse particles or liquid droplets to form a stable suspension or emulsion. The final size of the particles or droplets is usually less than 5 */lm.* The principal action is the disruption of lightly bonded clusters or agglomerates.

   ii) *Knife cutter:* A rotary knife cutter, as shown in Fig. 5.10, contains a horizontal rotor turning at 200 to 900 r/min in a cylindrical chamber. On the rotor are 2 to 12 flying knives with edges of tempered steel or stellite passing with close clearance over 1 to 7 stationary bed knives. Feed particles entering the chamber from above are cut several hundred times per minute and emerge at the bottom through a screen with 5 to 8 mm openings.

2. Crushing efficiency η_c is the ratio of the surface energy created by crushing to the energy absorbed by the solid whereas mechanical efficiency η_m is the ratio of the energy absorbed to the energy input to any size reduction machine.

3. 0.06 % and 1%.

4. Determination of flour sizes of two setting by sieve analysis:

i) Average particle size of product in I setting:

BIS sieve No.	Weight of material retained	% material retained	Fineness modulus	Average particle size, mm
100	0.0	7 × 0.00 = 0.00	$\frac{295.08}{100} = 2.9508$	D = 0.135 (1.366)$^{F.M.}$ = 0.338 mm
70	10.1	6 × 4.04 = 24.24		
50	16.7	5 × 6.68 = 33.40		
40	36.0	4 × 14.40 = 57.60		
30	83.2	3 × 33.28 = 99.84		
20	96.0	2 × 38.40 = 76.80		
15	8.0	1 × 3.20 = 3.20		
Pan	0.0	0 × 0.00 = 0.00		
		295.08		

ii) Average particle size of product in II setting:

BIS sieve No.	Weight of material retained	% material retained	Fineness modulus	Average particle size, mm
100	0.0	7 × 0.00 = 0.00	$\frac{264.76}{100} = 2.6476$	D = 0.135 (1.366)$^{F.M.}$ = 0.308 mm
70	1.5	6 × 0.60 = 3.60		
50	13.3	5 × 5.32 = 26.60		
40	36.1	4 × 14.44 = 57.76		
30	74.8	3 × 29.92 = 89.76		
20	104.6	2 × 41.84 = 83.68		
15	8.4	1 × 3.36 = 3.36		
Pan	11.3	0 × 4.52 = 0.00		
		264.76		

Determination of Power Requirements:

i) According to Rettinger's Law

$$\frac{P}{\dot{m}} = K_r\left(\frac{1}{\overline{D}_{sb}} - \frac{1}{\overline{D}_{sa}}\right)$$

or $$\frac{8.0}{0.2} = K_r\left(\frac{1}{0.338} - \frac{1}{4.33}\right)$$

or $40 = K_r \times 2.7276$

or $K_r = 14.6649$

Putting the value of K_r in II setting,

$$\frac{P}{0.2} = 14.6649\left(\frac{1}{0.308} - \frac{1}{4.33}\right)$$

or P = 0.2 × 14.6649 × 3.0157 = 8.85 kW

ii) According to Kick's Law

$$\frac{P}{\dot{m}} = K_k \ln \frac{\overline{D}_{sa}}{\overline{D}_{sb}}$$

or $$\frac{8.0}{0.2} = K_k \ln \frac{4.33}{0.338}$$

or $K_k = 15.6846$

Putting the value of K_k in II setting,

$$\frac{P}{0.2} = 15.6846 \ln \frac{4.33}{0.308}$$

or P = 8.2916 kW

5. Screen analysis is a method of classification of comminuted product by screening of the ground material through set of standard sieves.

6. The fineness modulus is an indicator of the uniformity of grind in the resultant/final product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100.

5.12 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.

UNIT 6 MILLING

Structure

6.0 OBJECTIVES

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

- understand the principles and methods of milling;
- describe the various milling equipments, their efficiencies and relevant methods used for various products; and
- understand the importance of milling, their impact and utility and be able to decide the suitability of different machinery for various products.

6.1 INTRODUCTION

Milling is a general trade name, which normally means reduction of food material into various end products like meal, pulp, flour, splitted products etc. Milling includes cleaning, grading, separating, mixing, pearling, polishing, dehusking, size reduction etc. The meaning of the term milling varies with the commodity. For example, milling of wheat refers to a grinding operation to produce flour, whereas in rice industry, milling refers to overall operations in a rice mill i.e. cleaning, dehuskng, paddy separation, bran removal and grading of milled rice. Milling also refers to extraction of juice, oil or separation of fibre etc.

Most of the agricultural products are in solid form which is generally difficult to handle, compared to liquid and gases. In processing, solids appear in many forms as large irregular pieces or finely divided powders. These particles may be hard and abrasive, soft, brittle, dusty or sticky and plastic. According to the forms of solids, means are to be found to manipulate them into end products and possibly to improve their handling and processing characteristics.

6.2 METHODS OF MILLING

The methods of milling are similar to those discussed in the previous unit on size reduction. However, in case of fruits and vegetables, milling may refer to the juice extraction, cutting for different purposes, etc. For oilseeds it is the expression of oil by compression, solvent extraction etc. and for grains it will vary from one grain to another, for example rice milling would mean hulling, shelling, polishing etc. whereas for wheat it is simple grinding and separation into different fractions and for pulses the dehulling and splitting of the grains.

6.3 MILLING EQUIPMENT

6.3.1 Milling Equipment for Solid Foods

Size reduction of fibrous foods

Most fruits and vegetables fall into the general category of 'fibrous' foods. Fruits and vegetables have an inherently firmer texture and are cut at ambient or chill temperatures. There are five main types of size reduction equipment, classified in order of decreasing particle size, as follows.

1. Slicing equipment consists of rotating or reciprocating blades which cut the food as it passes beneath. In some designs food (Figure 6.1) is held against the blades by centrifugal force. In other (for slicing meats) the food is held on a carriage as it travels across the blade. Harder fruits such as apples are simultaneously sliced and de-cored as they are forced over stationary knives fitted inside a tube. In a similar design (the hydro cutter) foods are conveyed by water at high speed over fixed blades.

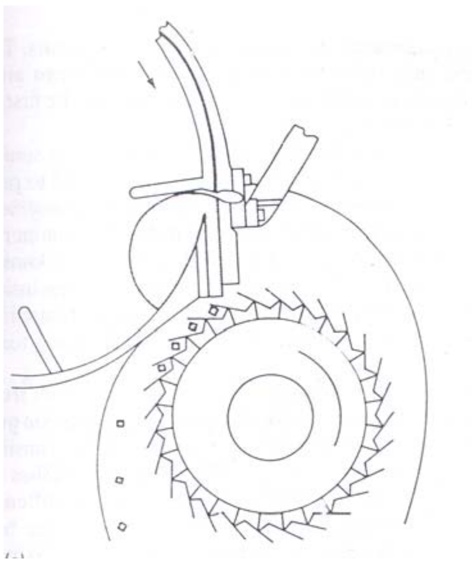

Figure 6.1: Slicing equipment

2. Dicing equipment is for vegetables, fruits and meats. The food is first sliced and then cut into strips by rotating blades. The strips are fed to a second set a rotating knives which operate at right angles to the first set and cut the strips into cubes (Figure 6.2).

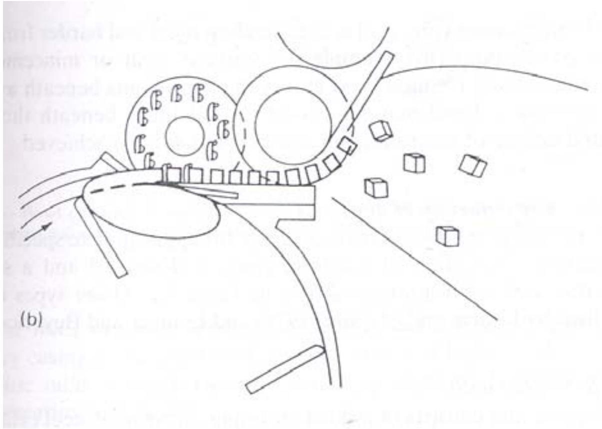

Figure 6.2: Dicing equipment

3. *Flaking equipment* for flaked nuts, fish or meat is similar to slicing equipment. Adjustment of the blade type and spacing is used to produce the flakes.

4. *Shredding equipment.* Typical equipment is a modified hammer mill in which knives are used instead of hammers to produce a flailing or cutting action. A second type of shredder is known as the *squirrel cage disintegrator.* Here two concentric cylindrical cages inside a casing are fitted with knife blades along their length. The two cages rotate in opposite directions and food is subjected to powerful shearing and cutting forces as it passes between them.

5. *Pulping equipment* is used for juice extraction from fruits or vegetables and for pureed and pulped meats. A combination of compression and shearing forces is used in each type of equipment. A rotary grape crusher consists of a cylindrical metal screen fitted internally with high-speed rotating brushes or paddles. Grapes are heated if necessary to soften the tissues, and pulp is forced through the perforations of the screen by the brushes. The size of the perforations determines the fineness of the pulp. Skins, stalks and seeds discarded from the end of the screen. Other types of pulper, including roller presses and screw presses are used for juice expression.

   A *bowl chopper* (Figure 6.3) is used to chop meat and harder fruits and vegetabes into a coarse pulp (for example for sausage meat or mincemeat preserve). A horizontal, slowly rotating bowl moves the ingredients beneath a set of high-speed rotating blades. Food may be passed several times beneath the knives until required degree of size reduction and mixing has been achieved.

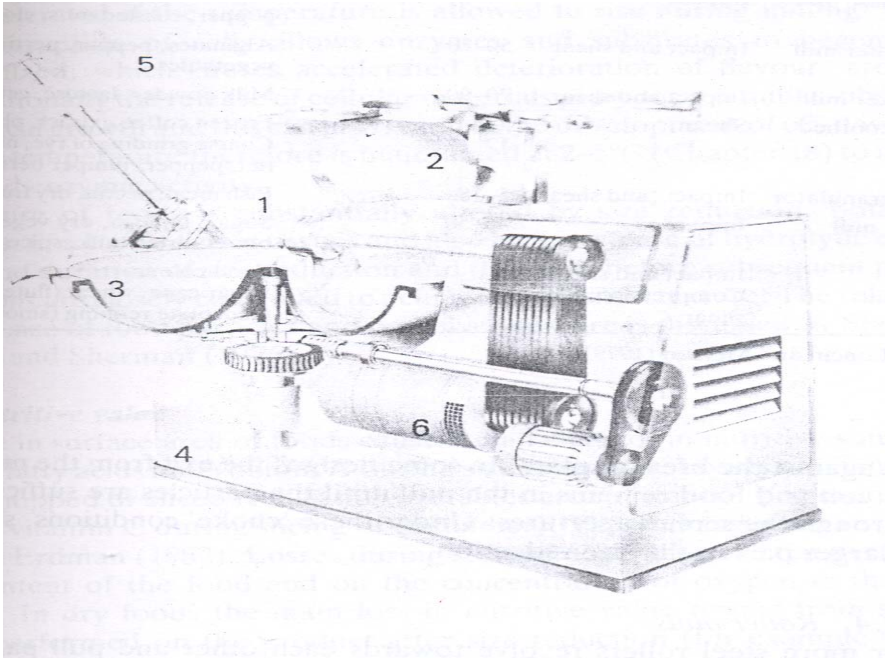

Figure 6.3: Bowl chopper: 1) Cutting blades, 2) Cover, 3) Rotating cutter bowl, 4) Casings; 5) Rotating unloader disc; 6) Main motor drive

Size reduction of dry foods

There are a large number of mills available for application to specific types of food.

Ball mills

This type of mill consists of a slowly rotating, horizontal steel cylinder which is half filled with steel balls 2.5-15cm in diameter. At low speeds or when small balls are used, shearing forces predominate. With larger balls or at higher speeds, impact forces become more important. A modification of the ball mill named the *rod mill* has rod instead of balls to overcome problems associated with the balls sticking in adhesive foods.

Disc mills

There are a large number of designs of disc mill. Each type employs shearing forces for fine grinding or shearing and impact forces for coarser grinding. For example,

1. single-disc mills in which food passes through an adjustable gap between a stationary casing and a grooved disc which rotates at high speed,
2. double-disc mills in which two discs rotate in opposite directions to produce greater shearing forces, and
3. pin-and-disc mills which have intermeshing pins fixed either to the single disc and casing or to double discs. (Figure 6.4)

These improve the effectiveness of milling by creating additional impact and shearing forces.

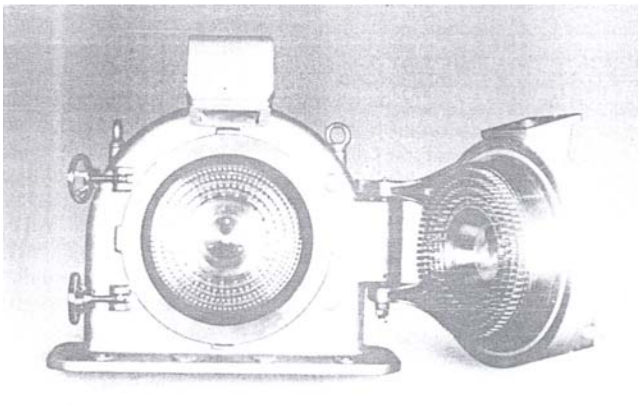

Figure 6.4: Pin and disc mill

Hammer mills

A horizontal cylindrical chamber is lined with a toughened steel breaker plate. A high-speed rotor inside the chamber is fitted with hammers along its length (Figure 6.5). In operation, food is disintegrated mainly by impact as the hammers drive it against the breaker plate. In some designs the exit from the mill is restricted by a screen and food remains in the mill until the particles are sufficiently small do pass through the screen apertures. Under these 'choke' conditions; shearing forces play a larger part in the size reduction.

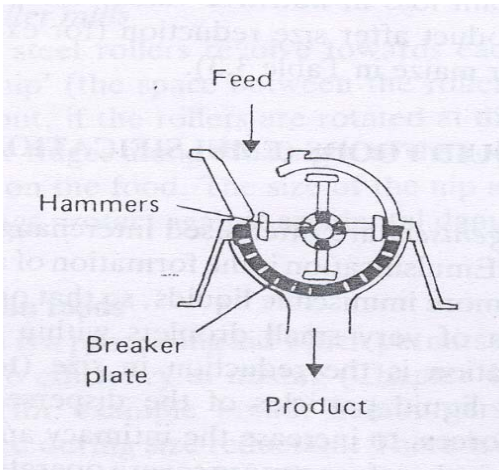

Figure 6.5: Hammer mill

Roller mills

Two or more steel rollers revolve towards each other and pull particles of food through the 'nip' (the space between the rollers) (Figure 6.6). The main force is compression but, if the rollers are rotated at different speeds, or if the rollers are fluted (shallow ridges along the length of the roller), there is an additional shearing force exerted on the food. The size of the nip is adjustable for different foods and overload springs protect against accidental damage from metal or stones.

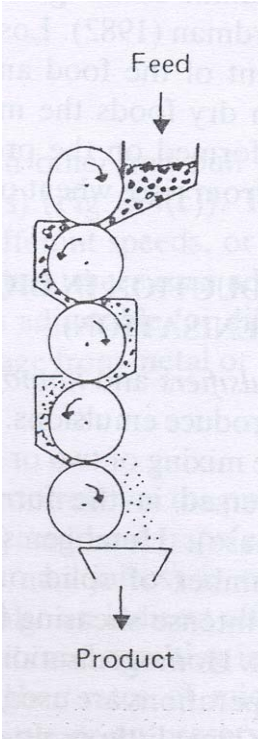

Figure 6.6: Roller mill

6.3.2 Milling Equipment for Liquid Foods (Emulsification and Homogenisation)

The terms emulsifiers and homogenisers are often used interchangeably for equipment used to produce emulsions. Emulsification is the formation of a stable emulsion by the intimate mixing of two or more immiscible liquids, so that one (the dispersed phase) is dispersed in the form of very small droplets within the second (the continuous phase). Homogenisation is the reduction in size (to 0.5-3μm) and increase in number of solid or liquid particles of the dispersed phase, by the application of intense shearing forces, to increase the intimacy and stability of the two substances. Homogenisation is therefore a more severe operation than emulsification. Both operations are used to change the functional properties or eating quality of foods. They have little or no effect on nutritional value or shelf life.

The four main types of homogenizer are as follows:

1. high-speed mixers;
2. pressure homogenisers;
3. colloid mills;
4. ultrasonic homogenisers.

High-speed mixers

Turbine or propeller-type high-speed mixers are used to pre-mix emulsions of low-viscosity liquids. They operate by shearing action on the food at the edges and tips of the blades.

Pressure homogenisers

These consist of a high-pressure pump, operating at 10,000-70,000kPa, which is fitted with a homogenizing valve on the discharge side. An example of one of the many different designs of valve is shown in Figure 6.7. When liquid is pumped through the small, adjustable gap (300μm) between the valve and the valve seat, the high pressure results in a high liquid velocity (8400 ms^{-1}). There is then an almost instantaneous drop in velocity as the liquid emerges from the valve. These extreme conditions of turbulence produce powerful shearing force. The collapse of an air bubbles (termed *cavitation)* and impact forces created in some valves by placing a hard surface (a *breaker ring)* in the path of the liquid further reduce the globule size. In some foods (for example milk products) there may be inadequate distribution of the emulsifying agent over the newly formed surfaces, which causes fat globules to clump together. A second similar valve is then used to break up the clusters of globules. Pressure homogenisers are widely used before pasteurisation and ultrahigh-temperature sterilisation of milk, and in the production of salad creams, ice cream and some sauces.

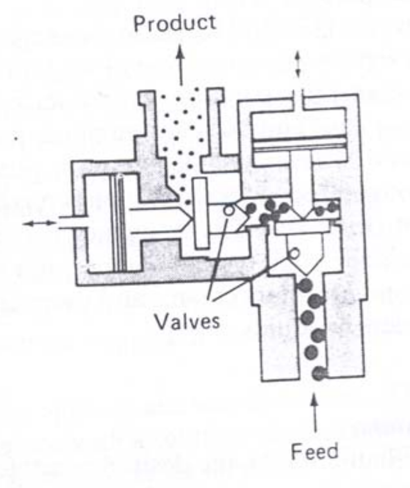

Figure 6.7: Hydraulic two-stage pressure homogenizing valve

Colloidal mills

These homogenisers are essentially disc mills. The small (0.05-1.3 mm) gap between a vertical disc which rotates at 3000-15000 rev min^{-1}, and a similar-sized stationary disc creates high shearing forces. They are more effective than pressure homogenisers for high-viscosity liquids, but with intermediate-viscosity liquids they tend to produce larger droplet sizes than pressure homagenisers do. Numerous designs of disc, including flat, corrugated and conical shapes, are available for different applications. Modifications of this design include the use of two counter-rotating discs or intermeshing pegs on the surface of the discs to increase the shearing action. For highly viscous foods (for example peanut butter, meat or fish pastes) the discs may be mounted horizontally (the *paste mill).* The greater friction created in viscous foods may require these mills to be cooled by recirculating water.

Ultrasonic homogenisers

High-frequency sound waves (18-30 kHz) cause alternate cycles of comprssion and tension in low-viscosity liquids and cavitation of air bubbles, to form an emulsion with droplet sizes of 1-2μm. In. operation, the dispersed phase of an emulsion is added to the continuous phase and both are pumped through the homogenisers at pressures of 340-1400kPa. The ultrasonic energy is produced by a metal blade, which vibrates at its resonant frequency. Vibration is produced either electrically or by the liquid movement (Figure 6.8). The frequency is controlled by adjusting the clamping position of the blade. This type of homogeniser is used for the production of salad creams, ice cream, synthetic creams and essential oil emulsions. It is also used for dispersing powders in liquids.

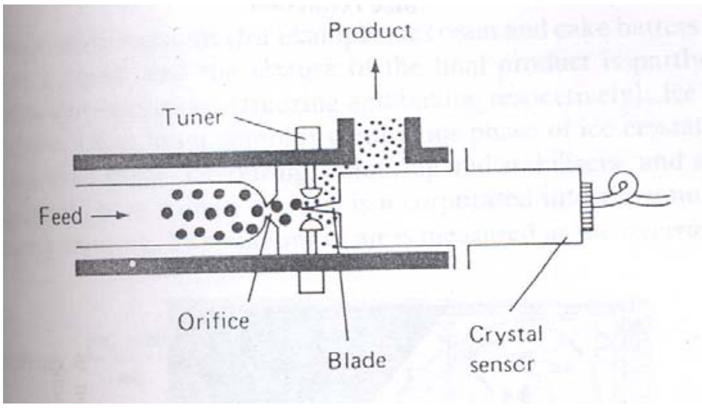

Figure 6.8: Ultrasonic homogenizer

6.4 EFFICIENCY OF MILLING

To achieve good results from any milling machine the followings should be given due care, (1) feed should be *of* proper size and feeding rate should be uniform, (2) hard or unbreakable material is not-allowed to enter the mill, (3) after grinding the product is removed as soon as possible, and (4) there should be some arrangement to remove the heat generated during milling operation.

Determination of power requirement for a particular grinding job is difficult. The exact amount of power requirement depends on type of material, moisture content of feed, material feed rate, type and condition of mill, product particle size requirement, nature of abrasive surface etc.

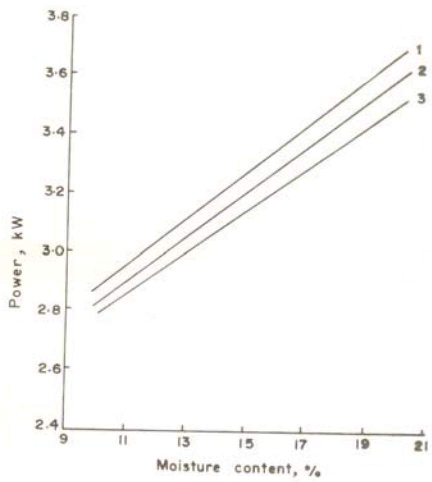

Figure 6.9: Effect of moisture content on power requirement: 1) 2800 rpm, 2) 2680 rpm, 3) 2560 rpm.

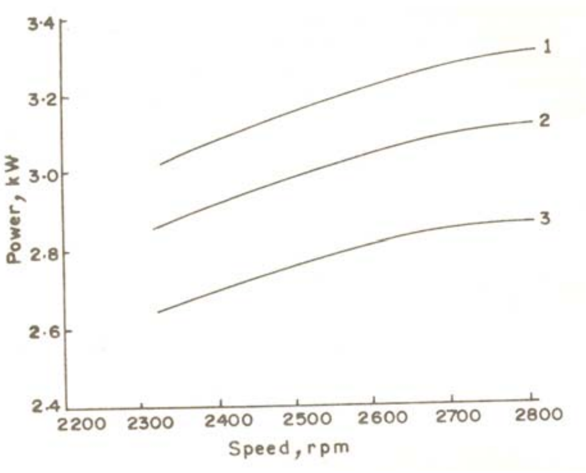

Figure 6.10: Effect of speed of operation on power requirement: 1) 17.9% moisture content, 2) 15% moisture content, 3) 11.8% moisture content.

Grains at higher moisture content are more difficult to grind than dry grains. The effect of moisture upon the power requirement for grinding of wheat with swinging hammer mill is shown in Figure 6.9. It was also found that fibrous materials require more power for grinding than non-fibrous material. At increased rotational speed the power requirement also increases (Figure 6.10).

Energy consumption: In size reduction of solids, bulk of the energy input is dissipated as heat energy. This energy raises the temperature of milled product, the mill and the air. Some of the energy is lost during vaporization of grain moisture. Comparatively small fraction of energy input is utilized for creation of new surfaces. During grinding of grains the temperature rise is observed to be 20°C or more in emery burr mills. This temperature rise may partially decompose some materials. Therefore, there should be some arrangement to remove this heat. In some abrasive mills provision is made to draw ambient air for cooling purposes.

6.5 METHODS OF SEPARATION

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

One of the commonest forms of separating in the food industry is the hand sorting and grading of individual units as in the case of vegetables and fruit. However, because of the high cost of labour, mechanical and electronic sorting devices have been developed. Difference in colour can be detected with a photocell and off-colour products rejected. This can be done at enormous speeds with automatic rejection of discoloured or mouldy nuts or kernels of grain that flow past the photocell. In the case of peanuts to be made into peanut butter, each peanut individually passes through a light beam that activates a jet of air to blow the discoloured peanuts from the main stream when an off-colour changes the amount of reflected light. Light shining through eggs can detect blood spots and automatically reject such eggs. Automatic separation according to size is, easily accomplished by passing fruits or vegetables over different size screens, holes, or slits.

The skins of fruits and vegetables may be separated using a lye peeler (Figure 6.11). Peaches, apricots, and the like are passed through a heated lye solution. The lye or caustic softens the skin to where it can be easily slipped from the fruit by gentle action of mechanical fingers or by jets of water. Differences in the density of the fruit and skin can then be used to float away the removed skin.

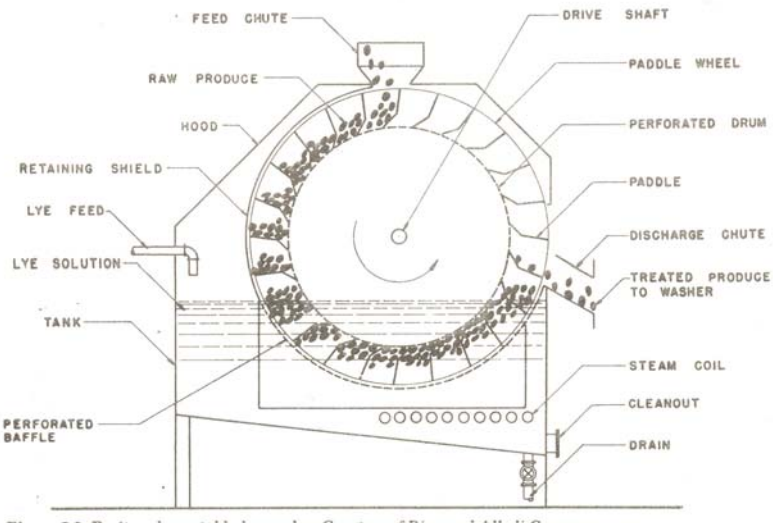

Figure 6.11: Lye peeler

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

Crystallization is used to separate salt from seawater, or sugar from sugar cane juice. Here, evaporation of some of the water causes super saturation, and crystals form. Since crystals are quite pure, this is also considered a purification process. The crystals are then separated from the suspending liquid by centrifugation.

Newer methods of separation include several techniques involving manufactured membranes with porosities or permeabilities capable of separations and fractionations at the colloidal and macromolecular size level. Ultrafiltration uses membranes of such porosity that water and low-molecular-weight salts, acids, and bases pass through the membrane but larger protein and sugar molecules are retained. This selective separation process, carried out at ambient temperatures, avoids the heat damage to sensitive food constituents that is often associated with water evaporation at high temperatures. Further, removal of acids and salts with the water prevents their concentration, which would otherwise be detrimental to sensitive retained solids.

6.6 RELEVANT STANDARDS

There are many relevant standards developed by the Bureau of Indian Standards, Codex Alimentarieus, etc. which needs to be followed for different methods and processes. These can be obtained from respective organizations.

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.
c) Use separate sheets where no space is provided.

1. Write short notes on the following:

   i) Slicer ii) Flaker
   iii) Dicer iv) Pulper

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2. Write short notes on the following:

   i) Bad mill ii) Disc mill
   iii) Roller mill iv) Colloidal mill

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6.7 LET US SUM UP

Milling is one of the important unit operations in fruit and vegetable processing industry. A suitable and adequate milling would prove to be a boon for any food industry because a proper selection would reduce the energy consumption and enhance the quality and profitability of a food processing industry.

6.8 KEY WORDS

Slicing equipment : It consists of rotating or reciprocating blades which cut the food as it passes beneath.

Dicing equipment : Dicing equipment is for vegetables, fruits and meats. The food is first sliced and then cut into strips by rotating blades. The strips are fed to a second set of rotating knives which operate at right angles to the first set and cut the strips into cubes.

Flaking equipment : *Flaking equipment* for flaked fish, nuts or meat is similar to slicing equipment. Adjustment of the blade type and spacing is used to produce the flakes.

Pulping equipment : *Pulping equipment* is used for juice extraction from fruits or vegetables and for pureed and pulped meats. A combination of compression and shearing forces is used in each type of equipment.

6.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. All the short notes should contain the following points:
   - Principle of operation.
   - Suitability of use.
   - Final product and
   - Its relative importance in a food industry.
2. All the short notes should contain the following points:
   - Principle of operation.
   - Suitability of use.
   - Capacity
   - Final product and
   - Its relative importance in a food industry.

6.10 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.

UNIT 7 MATERIAL HANDLING

Structure

7.0 OBJECTIVES

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

- understand the principles and concepts of material handling;
- know various available material handling devices and their drive mechanisms; and
- understand the importance of material handling and decide the suitability of different machinery for various uses.

7.1 INTRODUCTION

Material handling is an activity that uses the right method to provide the right amount of the right material at the right place, at the right time, in the right sequence, in the right position and at the right cost. Material handling includes a number of operations that can be executed either by hand (manual) or by mechanical means or devices to convey material and to reduce the human drudgery. Mechanical handling devices aim to lighten the work of human labour. After harvesting, crops are moved, transported or conveyed from place to place. In earlier periods all these operations were manual. The crops were primary processed and bagged/boxed by human labour. Foods were transported several times through storage and processing plants, and the processed food products were conveyed manually to consumers. Thus, foods were handled too much involving increased costs and human drudgery. But in modem times, some of the mechanical devices have replaced human labour, other supplement it or in some case make possible to handle larger quantities of grains per unit human labour.

7.1.1 Material Handling Principles

Various principles involved in material handling are:

1. Thorough study the problem and identification of problem areas, constraints and goals.
2. Develop plans, which meets our basic requirements, is flexible and includes desirable features.
3. Integrate various activities such as receiving, shipping, production assembly, etc.
4. Make the unit load size as large as possible.
5. Use the cubic space as effectively as possible.
6. Where possible standardize equipment and procedures.
7. Design equipment and methods that allow effective interaction between humans and machines.
8. When evaluating handling equipment, examine energy requirement and costs.
9. To the extent possible, use methods and equipment that minimize adverse effects on the environment.
10. Where possible mechanize methods to achieve efficiency.
11. Use methods and equipments that provides the maximum flexibility.
12. Simplify, combine or if possible eliminate unnecessary moves or equipment.
13. Use gravity as much as possible to transfer material keeping in mind safety and product damage.
14. Use safe handling equipment and methods.
15. To the extent possible computerize, so as to achieve better material and information control.
16. Integrate material and information flows.
17. Evaluate each alternate layout and select the most effective and efficient one.
18. Evaluate each alternate solution and select one based on cost per unit handled.
19. Perform preventive maintenance.
20. Develop equipment replacement plan based on after-tax life cycle costs.

7.1.2 Systems Approach to Materials Handling

When establishing methods of materials handling, a systems approach covering raw materials, materials in process and finished products is needed, in order to optimize flow rates in the correct sequence throughout the production process and to avoid bottlenecks or shortages. Additionally the flow of foods through a factory should be as simple as possible to reduce costs, to avoid confusion, which could lead to the contamination of processed foods by raw foods, to improve working conditions and to attain the benefits.

7.2 MATERIAL HANDLING DEVICES

7.2.1 Conveyors

Conveyors are widely used in all food processing industries for the movement of solid materials, both within unit operations and between operations (Table 7.1). There are a large number of conveyor designs, produced to meet specific applications. Common types include the following.

1. **Belt conveyor:** This is an endless belt, which is held under tension between two rollers, one of which is driven. The belts may be stainless steel mesh or wire, synthetic rubber, or a composite of canvass, steel and polyurethane or polyester. Flat belts are used to carry packed foods, and trough-shaped belts are used for bulk materials. Belts may be inclined up to 45°, if they are fitted with cross slats to prevent the product from slipping. Metal or wooden slatted conveyors are used instead of belts for greater load bearing and a reduced risk of damage to the conveyor.

2. **Roller conveyor** and skate wheel conveyor. Free-running (unpowered) rollers or wheels are either horizontal, to allow packed foods to be pushed along, or slightly inclined for transport under gravity. Rollers are heavier and stronger than wheels and therefore able to carry heavier loads. However, they are more difficult to start and stop, and more difficult to use around corners. Steeper inclines produce greater acceleration of packages, and a fall of approximately 10 cm in 3 m is sufficient for most purposes. Powered conveyors are used horizontally, or at a maximum inclination of 10-12°.

Table 7.1: Applications of materials-handling equipment

	Conveyors	Elevators	Cranes and hoists	Trucks	Pneumatic equipment	Water flumes
Direction						
Vertical up		*	*			
Vertical down		*	*		*	
Incline up	*	*			*	
Incline up	*	*			*	*
Horizontal	*			*	*	
Frequency						
Continuous	*	*			*	*
Intermittent			*	*		
Location served						
Point	*	*			*	*
Path	*				*	*
Limited area			*			
Unlimited area				*		
Height						
Overhead	*	*	*		*	
Working height	*			*	*	*
Floor level	*		*	*		*
Underfloor	*				*	*

Materials						
Packed	*	*	*	*		
Bulk	*	*	*	*	*	
Solid	*	*	*	*	*	*
Liquid				*	*	*
Service						
Permanent	*	*	*		*	*
Temporary			*	*		

3. **Chain conveyor:** This is used to move churns, barrels, crates and similar bulk containers by placing them directly over a driven chain, with protruding lugs, located at floor level. A similar monorail conveyor is used for moving meat carcasses on an overhead track.

4. **Screw conveyor:** This consists of a rotating helical screw inside a metal trough. It is used to move bulk foods (for example flour and sugar) and small-particulate foods (for example peas or grains). The main advantages are the uniform, easily controlled discharge, the compact cross-section (without a return conveyor) and total enclosure to protect the product and to prevent contamination. They may be horizontal or vertically inclined but are generally limited to a maximum length of 6 m as, above this, high friction forces result in excessive power consumption.

5. **Vibratory conveyors:** These impart a vertical movement to food, to raise it a few millimetres off the conveyor, and a forward movement, to move the food along the conveyor. The amplitude of vibration is adjusted to control the speed and direction of movement. This precise control makes vibratory conveyors useful as feed mechanisms for processing equipment. They are also useful, for moving sticky or friable foods (snack foods).

6. **Flight conveyors:** Here, bulk material (for example grain or flour) is dragged through an enclosed channel by an endless chain fitted with hooks or flights. Chain speeds are low (6-10m min^{-1}) and the inclination is limited to 30°, above which the material slips back.

7.2.2 Elevators

Four common types of elevator are as follows:

1. **Bucket elevators:** consist of metal or plastic buckets fixed between two endless chains. They have a high capacity for free-flowing powders and particulate foods. The shape and spacing of the buckets, the method of discharge and the speed of the conveyor (15-100 m min^{-1}) control the flow rate of materials.

2. **Magnetic elevators:** are used for conveying cans within canneries. They have a positive action in being able to hold the cans in place and are thus able to invert empty cans for cleaning and operate at high speeds with minimal noise.

3. **Flight elevators**: are essentially inclined flight conveyors. They have flexibility in use for a wide range of free-flowing bulk foods, high capacity and good space utilization.

4. **Pneumatic elevators:** Powders or small-particulate foods are suspended in air, which is re-circulated at 1000-1700 m min^{-1} inside a system of pipes. The air velocity is critical; if it is too low, the solids settle out whereas, if it

is too high, there is abrasion damage to the pipe surfaces. Similar equipment is used to classify foods and to dry foods. A build-up of static electricity is prevented by control over the moisture content of the food and earthing the equipment. This is necessary when conveying powders to minimize the risk of dust explosions. This type of equipment has a smooth operation and cannot be overloaded. It has few moving parts; low maintenance costs and only requires a supply of compressed air at 700 kPa.

7.3 PRINCIPAL DRIVE MECHANISMS, SUITABILITY OF USE AND ENERGY REQUIREMENT FOR MATERIAL HANDLING

7.3.1 Belt Conveyors

A belt conveyor is an endless belt operating between two pulleys with its load supported on idlers. The belt may be flat for transporting bagged material or V-shaped or some other enclosed shape for moving bulk grains. The belt conveyor consists of a belt, drive mechanism and end pulleys, idlers and loading and discharge devices (Figure 7.1). Belt conveyors have antifriction bearing, therefore, these have a high mechanical efficiency. Material carried by belt conveyor lie still on the surface of belt or there is no relative motion between the product and belt. This results in generally no damage to material. Belt can be run at higher speeds, so, large carrying capacities are possible. Horizontally the material can be transported to longer distance but there is a limit to carry the material on elevation. A properly designed and maintained belt conveyor has long service life and low operating costs. Compared to other types of horizontal conveying system, the initial cost of belt conveyor is high for short distances. But for longer distances, the initial cost of belt conveying system is competitive or low.

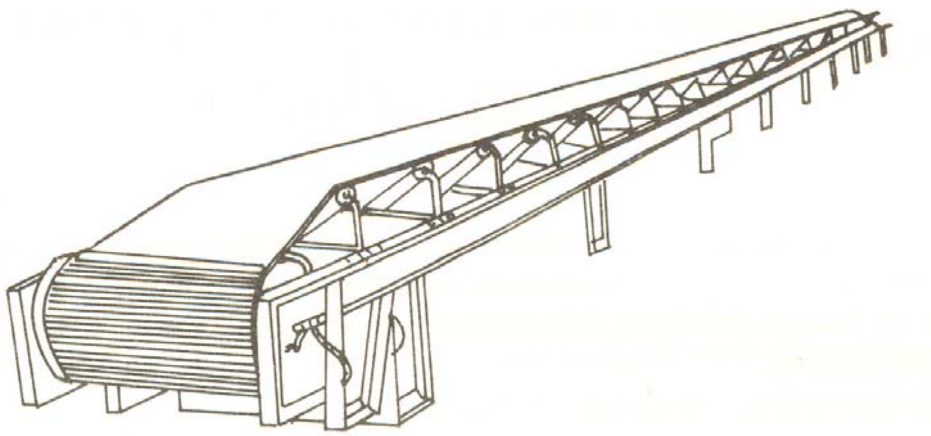

Figure 7.1: Belt conveyor

The design of belt conveyor system is based on available space, horizontal conveying length and conveying lift, characteristics of the material to be conveyed and capacity requirement. On the basis of overall requirement and information, the following will be determined to design a belt conveyor, belt width, belt speed, required horsepower, maximum belt tension and breaking strength of the belt, diameter of the pulleys and idlers and quality of belt (thickness).

The first step in the design of a belt conveyor with a specified conveying capacity is to determine the speed and width of the belt. The belt speed should be selected to minimize product spillage. The selection of belt width will depend upon the capacity requirement, speed of operation, angle of inclination of belt conveyor, trough angle and depth. The capacity of belt conveyor can be given by;

$$\text{Capacity, m}^2\text{/hr} = (\text{area of cross-section, m}^2) \times (\text{belt-speed, m/min}) \times 60 \qquad (7.1)$$

The load cross sections of troughed belt is shown in Figure 7.2.

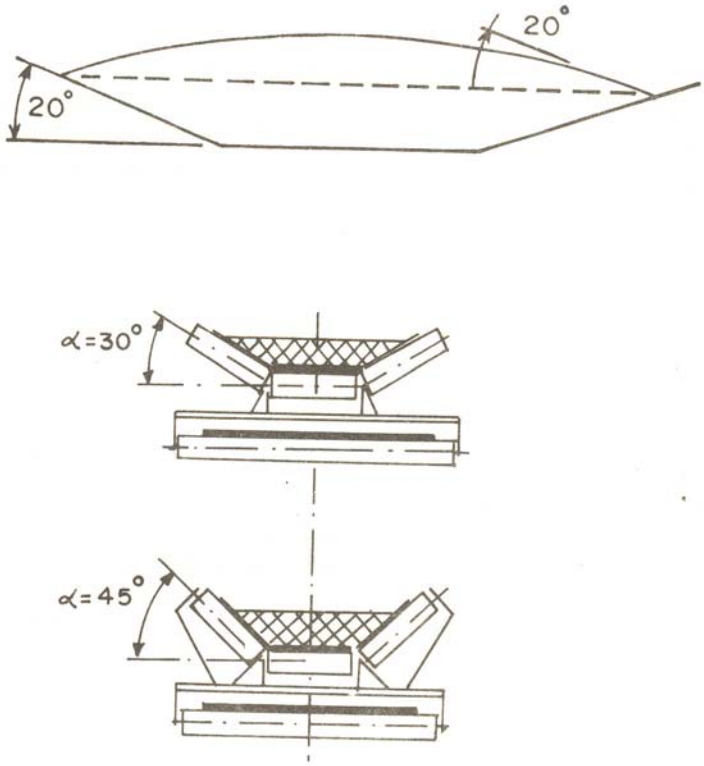

Figure 7.2: Various troughing configurations

The horsepower required for operation of belt conveyor for conveying grains can be calculated by the following equations. These equations are based on lift, friction resistance of the belt and pulleys and trippers. The values of constants are given in Table 7.2.

$$HP_1 = \frac{\text{Beltspeed, m/min.}}{0.3048} \text{x} \frac{(A+B)(3.281L)}{100} \qquad (7.2)$$

$$HP_2 = \text{Capacity, t/hrX} \frac{0.48 + 0.01L}{100} \qquad (7.3)$$

$$HP_3 = \frac{\text{Lift, m}}{0.3048} \text{x} 1.015 \text{x} \frac{\text{Capacity, t/hr}}{1000} \qquad (7.4)$$

where, L = length of belt, m
A & B are constants.

Table 7.2: Values of constants A and B

Belt width, cm	Constants		Additional horsepower for tripper
	A	B	
36	0.20	0.00140	0.70
41	0.25	0.00140	0.85
46	0.30	0.00162	1.00
50	0.30	0.00187	1.40
60	0.36	0.00224	1.70
76	0.48	0.00298	2.50

The majority of belt conveyors for transporting bulk material use some type of rubberised conveyor belt made up of carcass. The pull of load is taken by the longitudinal strength of belt while the transverse strength supports the load. The belt is protected from damage by a rubber cover. The thickness of top rubber cover varies with thickness and wear resistance requirements.

7.3.2 Screw Conveyors

The screw conveyor consists of a tubular or U-shaped trough in which a shaft with spiral screw revolves. The screw shaft is supported by end and hanger bearings. The rotation of screw pushes the grain along the trough. A typical screw conveyor is shown in Figures 7.3a and b. The screw conveyor is used for conveying of products generally for short distances. Screw conveyor requires relatively high power and is more susceptible to wear than other types of conveyors. The pitch of a standard screw, which is the distance from the center of one thread to the center of the next thread, is equal to its diameter.

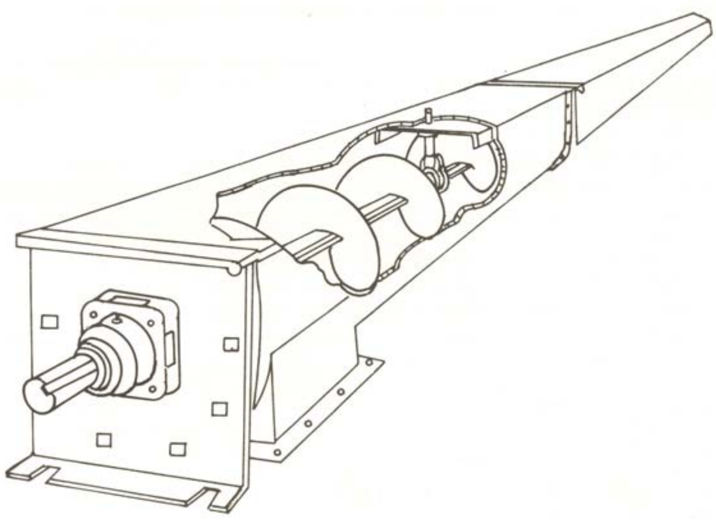

Figure 7.3a: Screw conveyor

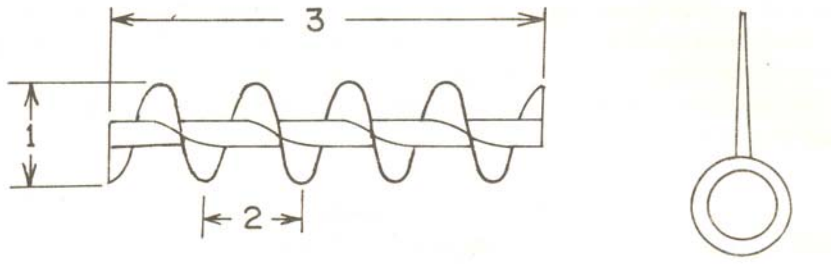

Figure 7.3b: Screw conveyor-details: 1) Screw diameter, 2) Pitch of screw, 3) Screw length

As the screw conveyor's driving mechanism is simpler, and no tensioning device is required, the initial cost of the conveyor is lower than any other conveyor with the same length and capacity. The main parts of a screw conveyor are, screw blade, screw shaft, coupling, trough, cover, inlet and outlet gates, bearings and drive mechanism.

The screw conveyor is generally used to move grains horizontally. However, it can also be used at any angle up to *90°* from the horizontal, but the capacity correspondingly reduced as *per* the inclination of conveyance.

The screw basically consists of a shaft and the screw blade or flight. The flight is a continuous one-piece helix, shaped from a flat strip of steel welded onto the shaft. The screw shaft is usually a joint less tube with thick sides and a high tensile strength to reduce the weight. The thickness of the steel strip helix decreases from the inner edge to the outer edge. Troughs of screw conveyor have different shapes. Most common is U shaped trough. In an enlarged or *flared* trough the sidewalls become wider at the top (Figure 7..4). This type of trough is usually used *for* conveying non-easy flowing materials, which may have lumps. The tubular trough is completely closed with circular cross-section and mostly used *for* conveying materials at inclination or *for* vertical lift.

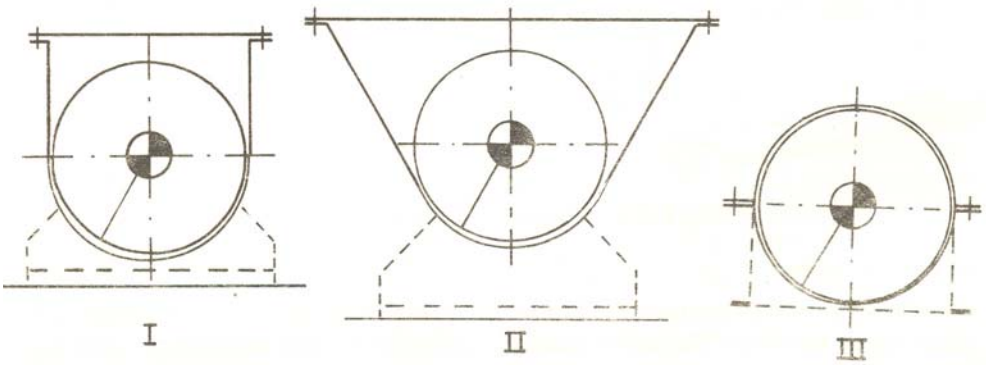

Figure 7.4: Various shapes of screw conveyor trough I) U-trough, II) Flared trough, III) Tubular trough.

For operational reasons, some gap is provided between the edge of the screw blade and the trough walls. Due to this gap it is not possible to completely empty the trough of a horizontal screw conveyor. If the screw conveyor is used to convey different materials, mixing of products is possible. Also when the food particles are pressed between the screw edge and trough walls, they can be damaged. During conveyance the kernels are also subjected to continuous friction with the trough walls. Screw conveyor may be designed for clockwise or counterclockwise rotation. The change in direction of rotation does not affect the capacity.

The capacity of screw conveyor is influenced by the screw diameter, inclination of the screw blade, speed of the blade, shaft diameter and cross-section of loading. The theoretical conveyance capacity of the screw conveyor can be given by the following equation.

$$\text{Capacity Q, m}^3\text{/hr} = 47.2\,(D^2 - d^2) \times p \times n \qquad (7.5)$$

where, D = screw diameter, m
d = shaft diameter, m
p = pitch, m
n = rpm

The theoretical capacity is more than the actual capacity because of screw housing clearance and the loading factor (Figure 7.5).

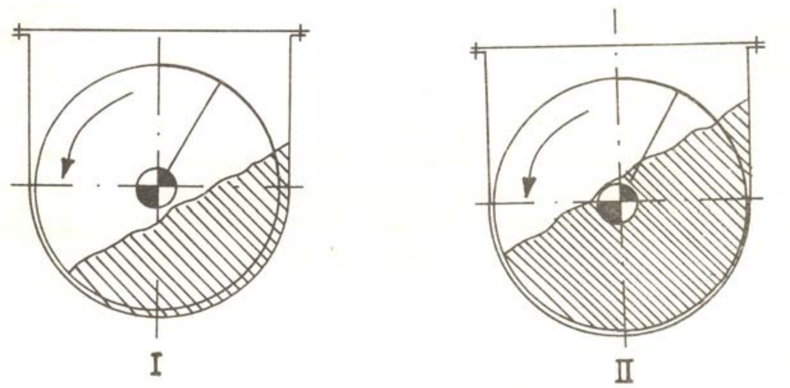

Figure 7.5: Screw conveyor loading factor I) 30% loading, II) 55% loading

The power requirement of screw conveyors for horizontal operation may be determined by the following equation:

$$\text{HorsePower} = \frac{QLWF}{4500} \qquad (7.6)$$

where, Q = conveyor capacity, m^3/min.
L = conveyor length, m
W = bulk material weight, kg/m3
F = material factor (for paddy 0.4)

If the calculated horsepower is less than 1.0, double the value.

Horsepower	=	1 to 2	multiply the value by 1.5
Horsepower	=	2 to 4	multiply the value by 1.25
Horsepower	=	4 to 5	multiply the value by 1.1

For horsepower values of more than 5, no correction is required.

Screw conveyors can be operated in an inclined position. In this case, the material will be conveyed upward. The capacity of inclined screw conveyor decreases than the horizontal operation. A screw conveyor inclined 15 degrees will carry about 75% of the rated horizontal capacity. At an inclination of 25 degrees, it will carry about 50% of the rated horizontal capacity.

7.3.3 Pneumatic Elevator

The pneumatic conveyor moves granular materials in a closed duct by a high velocity air stream. Pneumatic conveying is a continuous and flexible transportation method. The material is carried in pipelines either by suction or blowing pressure of air stream. The granular materials because of high air pressure are conveyed in dispersed condition. For dispersion of bulk material, air velocities in the range of 15-30 m/s is necessary. The pneumatic conveying system needs a source of air blowing or suction, means of feeding the product into the conveyor, and a cyclone or receiving hopper for collection of products. There are three basic systems of pneumatic conveying. These are pressure or blowing system, suction or vacuum system, and combined push-pull or suck-blow system.

In blowing or positive pressure systems, the product is conveyed by using air pressures greater than the atmospheric pressure. This system consists of a fan or blower, an air-lock feeder for introducing the product into the system, ducts and suitable air and product separating device. The product is fed into the pneumatic conveying system from the bottom of a hopper.

The feeder should be able to feed product at a specified rate in a pneumatic conveying system from the supply hopper at one pressure to the conveying pipeline at another pressure. The most common type of feeder is rotary feeder (Figure 7.6). It consists of a bladed rotor with pockets at the inlet port. When the rotor moves, the products are dropped to outlet port and to the conveying pipeline. The advantage of rotary feeder is that it meters the supply of products into the conveying pipeline. It also affects the air lock, which is necessary for the operation of the system.

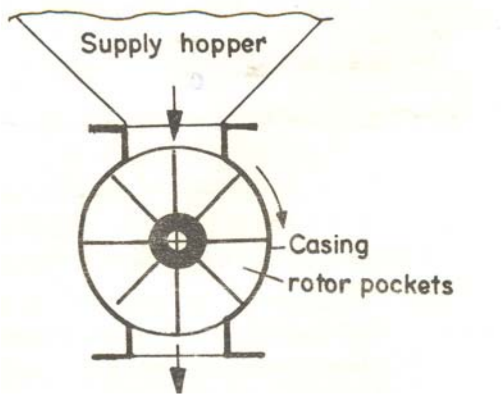

Figure 7.6: Rotary feeder for pneumatic conveyor

The selection of air mover is the most important aspect of the design of a pneumatic conveying system. In design, the two factors, (1) supply air pressure and (2) the volumetric flow rate of air should be considered. .

The supply pressure's value depends upon the working pressure drop required for the length of conveying line and across the filter. The magnitude of air pressure depends on the conveying length and the properties of the product to be conveyed. The volumetric flow rate of air depends on the necessary air velocity and pipe or duct size used in the system. In pneumatic conveying systems, fans and blowers with high volumetric flow rates and low pressures to positive displacement compressors producing high pressures are used. .

For separation of product particles from air, air-product separators are used. Cyclones are mostly used to collect the particles. Cyclone is a device, which removes the bulk of the product particle from the conveying air stream by centrifugal force. In some cyclone, a fabric filter is attached to remove residual dust and fine product particles from the air stream (Fig. 7.7). The conveying air is first passed through the cyclone and then it goes to the fabric filter for secondary separation of finer particles.

Limitations of Pneumatic Conveying

1. Erosion of solid surfaces and equipment surfaces by solid particles with conveying air stream. The rate of erosion of solid surfaces increased remarkably with conveying of abrasive products.
2. In case of bends or misaligned sections, the erosion problem becomes severe. In industrial installations, the erosion of duct system poses major problem in the operation of pneumatic conveying system.
3. In a pneumatic conveying system, chances of repeated impacts between the particles and the solid surfaces are high. Due to such impacts, product degradation results, because of this changes take place in the product size distribution and consequently the market value diminishes.

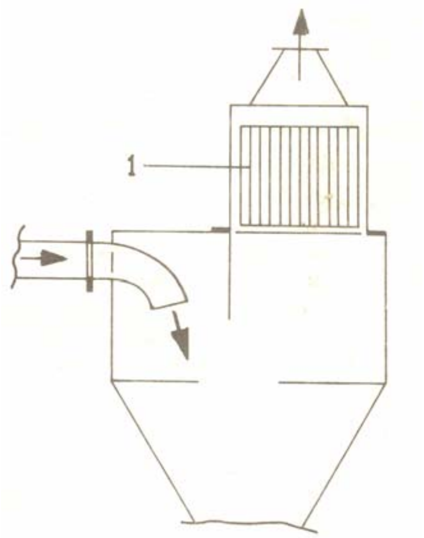

Figure 7.7: Separation of product particles from air by means of fabric filter

7.3.4 Bucket Elevator

A bucket elevator consists of buckets attached to a chain or belt that revolves around two pulleys one at top and the other at bottom. The vertical lift of the elevator may range between few meters to more than 50 m. Capacities of bucket elevators may vary from 2 to 1000 t/hr. Bucket elevators are broadly classified into two general types, 1) spaced bucket elevators and 2) continuous bucket elevators. The above two types are further subdivided into various classes.

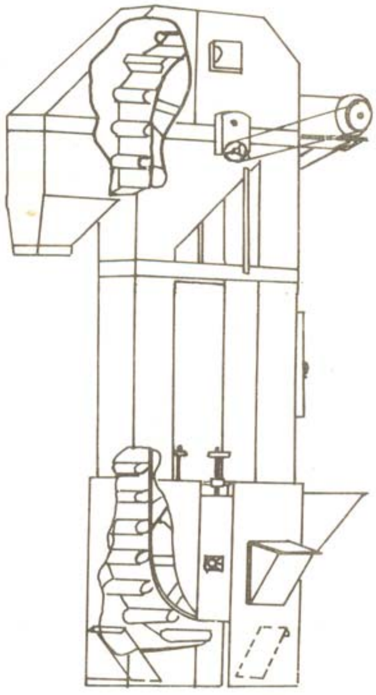

Figure 7.8: Bucket elevator

The spaced bucket elevators are further classified as, 1) centrifugal discharge elevators, 2) positive-discharge elevators, 3) marine leg elevators and 4) high-speed elevators. The continuous bucket elevators are classified as 1) super capacity bucket elevators, and 2) internal-discharge bucket elevators.

The spaced-bucket centrifugal discharge type is most commonly used for elevating the grains. A centrifugal discharge bucket elevator is shown is Figure 7.8. The bucket elevator is a very efficient device for the vertical conveyance of bulk grains. Bucket elevators with belts are employed in food industries for vertical conveyance of grains, derivatives and flours. Bucket elevators are usually mounted at a fixed location, but they can also be mounted in a mobile frame. Bucket elevators have high capacities and it is a fairly cheap means of vertical conveyance.

It requires limited horizontal space and the operation of conveying is enclosed in housing, thus it is dust free and fairly quite. The bucket elevator has limited wear problem since the product is enclosed in buckets. In a bucket elevator, the conveyor belt with buckets runs over pulleys at the upper and lower ends. The top pulley is driven pulley while the lower pulley is return and tension pulley. Buckets are usually made of steel or plastic and are bolted onto the belt. The buckets may be enclosed in a single housing called leg, or two legs may be used. The return leg may be located at some distance from the elevator leg. The houSing or legs are also made of steel, are welded or bolted together, and are dust tight. The curved hood is designed for proper centrifugal discharge of the grains. The boot can be loaded from the front or back or both (Figure 7.9). The various discharge types of bucket elevators are shown in Figure 7.10. The product flow is discharged either by means of gravity or centrifugal force.

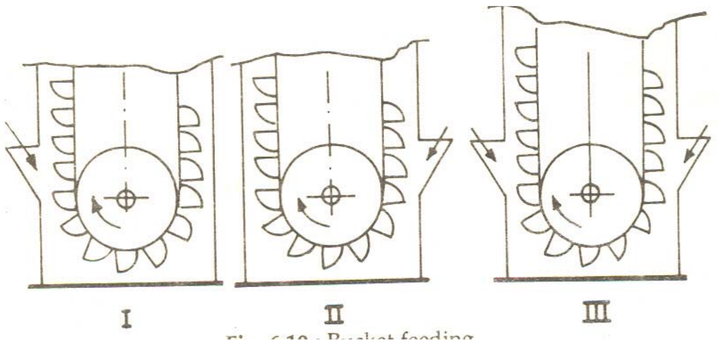

Figure 7.9: Bucket feeding I) Front feed, II) Back feed, III) Combined feed.

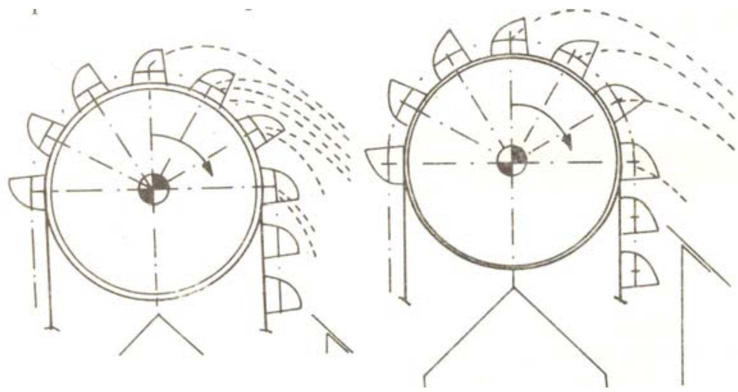

Figure 7.10: Bucket elevator's discharge methods: 1) Low speed gravitational discharge, 2) high speed centrifugal discharge.

The bucket elevator's capacity mainly depends on bucket size, conveying speed, bucket design and spacing, the way of loading and unloading, the bucket and the characteristic of bulk material. Belt speed is the first critical factor to consider. Bucket elevators with a belt carrier can be used at fairly high speeds of 2.5 to 4 m/ s. The speed of the belt depends on the head pulley speed. If the belt speed is too low, the discharge of the grains becomes more difficult, with too high speed the buckets are not fed well. A properly designed bucket elevator driven at the correct speed will make a clean discharge.

The gravitational discharge occurs with non-adhesive bulk material elevated at low speed and by means of buckets mounted closely together. In such discharge, the contents of a bucket flow over the rear side of the previous bucket. With purely centrifugal discharge, complete contents of a bucket are projected towards the discharge chute. Such type of discharge is obtainable with high belt speeds and smaller diameter drive pulleys. In elevating of grains the discharge from bucket elevators is a combination of centrifugal and gravitational discharge. Part of the bucket contents is projected by the centrifugal force, the rest flows out by gravity.

When a product mass turns around a pulley, it is influenced by two forces, (1) gravitational force, which is oriented downwards and (2) centrifugal force. The magnitude of the centrifugal force which is oriented outward can be given by

$$c_f = \frac{WV^2}{gr} \tag{7.7}$$

where, W = weight of grain
V = velocity of product mass
g = acceleration due to gravity .
r = radius of the wheel plus one-half of the projection of the bucket

For optimum centrifugal discharge, and calculation of the speed of head pulley, the resultant force is zero, it means that the centrifugal force is equal to the force of gravity, or, $c_f = W$

Hence, $$W = \frac{WV^2}{gr} \quad \text{or,} \quad V = \sqrt{gr}$$

Since velocity, $$V = \frac{2\pi nr}{60} \quad (n = \text{rpm}) \qquad (7.8)$$

$$\frac{2\pi nr}{60} = \sqrt{gr} \quad \text{or,} \quad n = \frac{60\sqrt{g}\sqrt{r}}{2\pi\sqrt{r}\sqrt{r}} = \frac{29.9}{\sqrt{r}} \qquad (7.9)$$

The bucket elevator's capacity may be calculated by the following equation.

Elevator capacity, m^3/hr = bucket capacity, m^3 x number of bucket per meter of belt x belt speed, m/min. × 60 (7.10)

$$Capacity, t/hr = \frac{Capacity, m^3/hr \times material density, kg/m^3}{1000} \qquad (7.11)$$

Drive mechanism

The drive mechanism of a bucket elevator is located near the elevator head. At the elevator head, the belt is turned around the drive pulley. Drive motor with gearbox and couplings are mounted on a rigid and separate frame. For serving the elevator head section, the drive mechanism, a working platform is provided. Usually a ladder is provided for access to this platform.

The theoretical horsepower requirement for the bucket elevator can be calculated by the following equation.

$$hp = \frac{QHF}{4500} \qquad (7.12)$$

where, Q = capacity of bucket elevator, kg/min
H = lift of elevator, m
F = factor; 1.5 for elevators loaded on the up side and 1.2 for elevators loaded on the bottom side

The theoretical horsepower should be increased 10-15% to provide for friction and power requirements for loading, power transmission and drive losses.

7.4 INTERACTION BETWEEN MATERIAL AND HANDLING DEVICES

Interaction between the material and the handling device is one of the important considerations for the selection of a suitable material handling device. The suitability of the different material handling devices for food products have been already discussed in section 7.2 and 7.3.

7.5 SELECTION OF MATERIAL HANDLING DEVICES

The selection of proper conveying system is important for ease in operation and getting desired capacity for a particular product. Before selecting a conveying system, the following principles should be taken into account.

1. The conveying device has to be selected according to the characteristics of the products being conveyed
2. The stability of the conveyor must be ensured under all normal working and climatic conditions.
3. The capacity of conveying and speed rating should be maintained at specified limits.
4. The dead load of the conveyor should be low in relation to the weight of transported product.
5. In a conveying system possibility of use of gravity should be taken into consideration.
6. The capacity of handling/conveying equipment should match with the capacity of processing unit or units.
7. Spillage of conveyed products should be avoided. Pollution of the environment due to noise or dust by the conveying system should also be avoided.

The four basic issues (Figure 7.11) relating to integration of material handling (MH) equipment into a manufacturing environment are (1) extraction to extract information about individual material handling tasks, (2) filtering and matching of individual tasks with individual resources, without regard to system performance and economy, (3) aggregation of tasks into sets that are then matched with technologies and (4) system selection and specification.

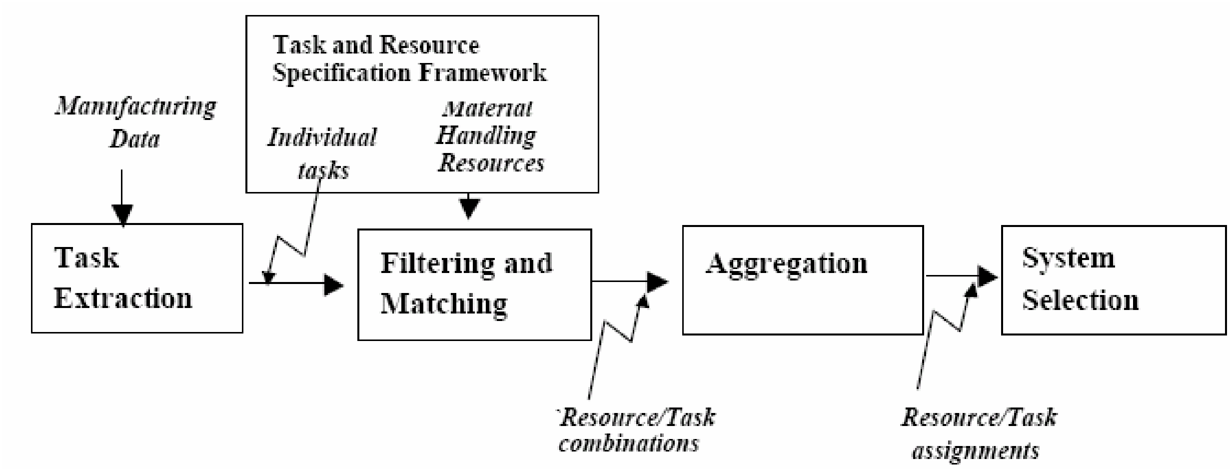

Figure 7.11: Major steps of procedure for selecting and specifying material handling equipment for manufacturing.

7.6 COST OF MATERIAL HANDLING

The cost of material handling will depend on (i) material to be carried, (ii) distance over which the material is to be carried, (iii) height of material elevation, (iv) efficiency of the material handling device, (v) maintenance cost of the material handling device, (vi) cost of the device, (vii) life span of the material handling device, (viii) method of loading and unloading of the material onto and from the device, etc.

There is no thumb rule as to which material handling device would be economical for a particular operation. It has to be therefore, decided keeping in mind the actual activity to be undertaken.

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.
c) Use separate sheets where no space is provided.

1. Write a short note on the importance of material handling in food industry.

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2. Enlist any five principles of material handling.

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3. Write short notes on the following:

i) Belt conveyor
ii) Screw conveyor
iii) Bucket elevator

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4. Differentiate between conveyors and elevators.

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5. A belt conveyor carrying 1 $m^3$of material having a bulk density of 600 kg/m^3 per meter length of belt is moving at 2.5 m/min. The length and width of the belt is 100 m and 60 cm respectively. Calculate the capacity and horsepower requirement of the conveyor.

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6. A screw conveyor having shaft and screw diameters as 15 and 25 cm respectively rotates at 500 rpm. Considering the pitch of the screw to be equal to its shaft diameter, calculate the capacity of the conveyor. If the conveyor length is 10 m, bulk density of the material is 500 kg/m^3, calculate the horsepower requirement of the conveyor assuming the material factor as 0.5.

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7. A bucket elevator having 100 buckets of 0.2 m^3 capacity is running at a speed of 1 m/s. The length of the elevator is 10 m and material bulk density is 700 kg/m^3. Calculate the capacity and horsepower requirement of the bucket elevator.

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7.7 LET US SUM UP

Conveyors and elevators are the two much important classes of material handling equipment. Once we know the characteristics of the material to be handled and other critical requirements, one could select an appropriate conveyor/elevator. These conveyors/elevators could be chain, belt, bucket, screw, pneumatic, magnetic, vibratory types. Proper selection and design of capacity and power units leads to the minimization of the cost of material handling.

7.8 KEY WORDS

Material handling : It is a method of carrying the material from one place to another either horizontally or vertically.

Selection of material handling equipment : It is a method of adoption of the most appropriate handling device to suite ones own requirement.

Elevators : Used for transfer of materials in horizontal direction where the angle of lift is very steep.

Power requirement : It is the amount of energy required per unit time to operate any system.

Capacity : It is the total material that any given system can carry for a given time and energy utilized.

7.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Importance of material handling in food industry:
2. Five principles of material handling are:
   - Thoroughly study the problem and identify problem areas, constraints and goals.
   - Develop plans, which meets our basic requirement, is flexible and includes desirable features.
   - Integrate various activities such as receiving, shipping, production assembly, etc.
   - Make the unit load size as large as possible.
   - Use the cubic space as effectively as possible.
3. i) A belt conveyor is an endless belt operating between two pulleys with its load supported on idlers. The belt may be flat for transporting bagged material or V-shaped or some other enclosed shape for moving bulk grains.

   ii) The screw conveyor consists of a tubular or U-shaped trough in which a shaft with spiral screw revolves. The screw shaft is supported by end and hanger bearings. The rotation of screw pushes the grain along the trough.

iii) A bucket elevator consists of buckets attached to a chain or belt that revolves around two pulleys one at top and the other at bottom. The vertical lift of the elevator may range between few meters to more than 50 m. Capacities of bucket elevators may vary from 2 to 1000 t/hr.

4. Conveyors are mainly used for horizontal or inclined transmission of materials. The inclination is limited to the material transported, whereas, elevators can be used to lift materials vertically irrespective of the material they carry.

5. i) Calculate capacity by using equation 7.1.
   ii) Hp = Hp1 (Equation 7.2) + Hp2 (Equation 7.3) + Hp required for tripper (Table 7.2)

6. i) Calculate capacity by using equation 7.5.
   ii) Calculate horse power by using equation 7.6.

7. i) Calculate capacity by using equation 7.11.
   ii) Calculate horse power by using equation 7.12.

7.10 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.

UNIT 8 TRANSPORTATION AND PACKAGING

Structure

8.0 OBJECTIVES

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

- understand the principles and methods of transportation;
- describe the various types of packaging material and their selection for food packaging; and
- decide the suitability of different types of packaging material.

8.1 INTRODUCTION

The prevention of food losses is of vital concern to growers as well as processors, and various measures can be applied at all stages between the grower and the consumer in order to reduce wastage, improve food security and generate income and profit.

The use of appropriate packaging and transportation is one of these measures and when properly applied can have a dramatic effect, reducing losses and ensuring that products reach the customer in the best possible condition. Appropriate packaging and transportation can range from the proper use of containers in which to transport produce to local markets, through to sophisticated systems that can extend the shelf-life of a processed foodstuff for a year or more.

Essentially, packaging:

- Aims to provide protection from all types of external damaging effects;
- Is an integral part of the food processing chain and helps both producers and consumers to transport, store, sell, purchase and use foods more efficiently;
- Is a means of ensuring that the product is delivered to the user in known quantities and in the expected condition for a specified shelf-life;
- Is a means of making the food more attractive in order to promote its use and increase sales;
- Conveys information to customers about the type of food they are buying, how to prepare it, its shelf-life, and that it conforms to relevant food legislation.

Thus, at its simplest level, packaging contains and protects, while at its most sophisticated it takes on additional roles such as preserving, selling, information and enhancing the convenience element of the product.

The type of packaging required depends mainly on the nature of the product, the length of time and conditions under which it will be transported and stored before use, the final market for which it is intended and local food laws. If the food is to be consumed near to where it is produced and eaten quickly after processing, little or no packaging may be required. However, if the product is aimed, for example, at a distant export market, the packaging requirements can become extremely complicated. At the point of sale, good packaging and presentation helps to attract customers, and may provide extra convenience in use.

8.2 METHODS OF TRANSPORTATION AND THEIR SUITABILITY WITH RESPECT TO PRODUCT

Damage in transit is one of the oldest problems in packaging. The hazard that packages meet cannot be anticipated and are mostly accidents. Protection is required against the average hazard encountered and not against the most severe one. The distribution system of a consumer good in its simplest form is shown below.

PRODUCTION
↓
PACKING
↓
FACTORY GODOWN
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SALES GODOWN
↓
DISTRIBUTION GODOWN
↓
RETAILERS STORAGE
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RETAIL STORE SHELF
↓
CONSUMER SHELF
↓
RECYCLING - OTHER USE
↓
REUSE

Figure 8.1: Distribution system for a consumer good

The distribution hazards encountered in any system which needs to be taken care of to decide the packaging material depends on the mode of transportation, method of handling and storage. The transportation modes and hazards there in are:

8.2.1 Bullock or Horse Drawn Cart

- Used for short distance transport.
- Stacking height upto 5 feet.
- Drop height upto 5 feet.
- Bumping due to rough road surface.
- Directional placements of packages may not be possible.

8.2.2 Road-Trucks

- Used for long and short distances.
- Package dimensions should suit the body dimensions for maximum space utilization.
- Door to door service.
- Delays in journey during rainy season.
- Freight rates generally higher than that of rail.
- Lower standard packages accepted than in rail.

Hazards

- Stacking height upto 7 feet.
- Drop height upto 4 feet.
- Puncturing of fibreboard boxes by protruding bolts etc. of the sides.
- Bumping due to irregular road surfaces.

8.2.3 Rail-Goods Trains

- Tran-shipment necessary.
- Pilferage is a major problem.
- Proper handling instructions essential.
- Packages can be sent on railways risk.
- Packages are to conform to rules and regulations of the railways.
- Door to door delivery possible only by container service.
- No problem for inter-state transport.
- Less interruption of journey even in rainy season.

Hazards

- Stacking height upto 8 feet.
- Vibration due to rail joints and track conditions.
- Shunting shock.
- Very high temperature (upto 70°C) in steel wagons in summer.

8.2.4 Sea-Ship

- Packages are carried in ship holds and decks.
- Normally the journey is preceeded and followed by other modes of transport. Hence packages should conform to the regulation of other modes also.
- Require proper handling instructions in different languages and figures.
- Freight rates by Cubic volume.

Hazards

- Stacking height upto 10-15 feet.
- Manual or machine handling.
- Very high relative humidity in the holds.
- Salt spray water on the decks or on the docks.
- Vibration due to engine propeller
- Swaying due to waves.

8.2.5 Air-Cargo

- High freight charges and hence lighter packages to be used.
- Limitations on size & weight of packages.
- Less journey time.
- Better handling.
- No cooling facility available.

Hazard

- High frequency vibration due to engine.
- Low temperature and pressure when flying at high altitudes.

8.3 SPECIAL REQUIREMENTS FOR TRANSPORATION OF AGRICULTURAL MATERIALS

Agricultural materials are living and continue all the physiological functions even after harvest. Therefore, it requires special care during its handling, packaging and transportation. Fresh as well as processed products meant for human consumption are of utmost importance keeping in view the seriousness of different health hazards associated with the contamination of foods during transportation. Most of the requirements with respect to the advantages, hazards and precautions are discussed in section 8.2 and 8.7.

8.4 TRANSPORATION COSTS

Transportation costs would depend on many factors like methods of transportation, efficiency of transportation, input costs for transportation, allowable time limit for transportation, losses during transportation, cost of the produce that is being transported and other associated costs. All these must be taken into consideration before deciding the method of transportation so as to minimize losses and optimize the profits.

8.5 ROLE OF PACKAGING OF AGRICULTURAL AND FOOD MATERIALS

Packaging is an integral part of food processing. It performs two main functions: to advertise foods at the point of sale, and to protect foods to a pre-determined degree for the expected shelf life. The main factors that cause deterioration of foods during storage are:

- mechanical forces (impact, vibration, compression or abrasion),
- climatic influences that cause physical or chemical changes (UV light, moisture, oxygen, temperature changes),
- contamination (by micro-organisms, insects or soils) and
- pilferage, tampering or adulteration.

In addition the package should not influence the product (for example by migration of toxic compounds, by reactions between the pack and the food or by selection of harmful micro-organisms in the packaged food). Other requirements of packaging are smooth efficient and economical operation on the production line, resistance to breakage (for example fractures, tears or dents caused by filling and closing equipment, loading/unloading or transportation) and minimum total cost.

The main marketing considerations are:

- the brand image and style of presentation required for the food,
- flexibility to change the size and design of the containers, and
- compatibility with the method of handling distribution, and the requirements of retailer.

In summary, the package should be aesthetically pleasing, have a functional size and shape, retain the food in a convenient form, possibly act as a dispenser and be suitable for easy disposal or re-use. The package design should also meet any legislative requirements concerning labelling of foods.

8.5.1 Packaging Functions

The functions of packaging are numerous and include such purposes as protecting *raw* or processed foods against spoilage and contamination by an array of external hazards. Packaging serves as a barrier in controlling oxygen and water levels, facilitates ease of use, offers adequate storage, conveys information and provides evidence of possible product tampering. It achieves these goals by assisting in the following manners:

- Preserving against spoilage of colour, flavour, odour, texture, and other food qualities.
- Preventing contamination by biological, chemical, or physical hazards.
- Controlling absorption and losses of O_2, water vapour and other volatile substances.
- Facilitating ease of using product contents-such as packaging that incorporates the components of a metal together in meal "kits" (e.g. tacos).
- Offering adequate storage before use-such as stockable, resealable, pourable.
- Preventing/indicating tampering with contents by tamper-evident labels.
- Communicating information regarding ingredients, nutrition facts, manufacturer name and address, weight, bar code information, and so forth via package labelling.
- Marketing-standards of packaging, including worldwide acceptability of certain colours and picture symbols vary and should be known by the processor; packages also carry such information as merchandising messages, health messages, recipes, and coupons.

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.
c) Use separate sheets where no space is provided.

1. Describe the importance of packaging and transportation in the production and processing chain of foods.

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2. Enlist the suitability and hazards related to the following modes of transport.

   i) Rail-good train
   ii) Air cargo

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3. Enlist three factors that cause deterioration of foods during storage.

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4. List any five functions of packaging.

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8.6 PACKAGING OF LOW AND HIGH MOISTURE FOODS

Packaging containers of foods both low and high moisture are classified as primary, secondary, and tertiary. A ***primary*** container is the bottle, can, drink box, and so forth that contains food. It is a direct-food-contact surface and is, therefore, subject to approval by competent authority, which tests for the possible migration of packaging materials into food.

Several primary containers are held together in ***secondary*** containers, such as corrugated fiberboard boxes (commonly, but not correctly, referred to as cardboard), and do not have direct food contact. In turn, several secondary containers are bundled into ***tertiary*** containers such as corrugated boxes or overwraps that prepare the food product for distribution or palletizing. They offer additional food protection during storage and distribution where errors, such as dropping and denting or crushing cartons, may occur. They prevent the brunt of the impact from falling on the individual food container.

8.6.1 Packaging Materials

In choosing the appropriate packaging for their product, packers must consider many variables. For example, *canners* must make packaging choices based on cost, product compatibility, shelf life, flexibility of size, handling systems, production line filling and closing speeds, processing reaction, impermeability, dent and tamper resistance, and consumer convenience and preference. Processors who use films for their product must select film material based on its "barrier" properties that prevent oxygen, water vapour, or light from negatively affecting the food.

The most common food packaging materials include metals, glass, paper, and plastic. Some examples of these leading materials appear in the following text.

Metal

Metals such as steel and aluminum are used in cans and trays. A metal can forms a hermetic seal, which is a complete seal against gases and vapor entry or escape, and it offers protection to the contents. The trays may be reusable, or disposable recyclable trays, and either steamtab1e or No. 10 can size. Metal is also used for bottle closures and wraps.

1) **Steel** has a non-corrosive coating of tin inside, thus the name "tin can," where as **tin-free steel** (TFS) relies on the inclusion of chromium or aluminum in place of tin. Steel is manufactured into the traditional three-piece construction can, which includes a base, cylinder, and lid, and also a two-piece can, consisting of a base and cylinder in one piece without a seam, and a lid. The latter are lightweight and stackable. The five primary types of steel vacuum closures include side seal caps, lug caps, press-twist caps, snap-on caps, and composite caps.

2) **Aluminum** is easily formed into cans with hermetic seals. It is also used in trays and for wraps such as aluminum foil, which provide an oxygen and light barrier. It is lighter in weight than steel and resists corrosion.

Glass

It is derived from metal oxides such as silicon dioxide (sand). It is used in forming bottles or jars (which receive hermetic seals) and thus protects against water vapour or oxygen loss. The thickness of glass must be sufficient to prevent breakage from internal pressure, external impact, or thermal stress. Glass coatings, similar to eyeglass coatings of silicones and waxes, may be applied to glass containers in order to minimize damage-causing nicks and scratches.

Paper

It is derived from the pulp of wood and may contain additives such as aluminium particle laminates, plastic coating, resins, or waxes. These additives provide burst strength (strength against bursting), wet strength (leak protection), and grease and tear resistance, as well as barrier properties that assure freshness, protect the packaged food against vapour loss and environmental contaminants, and increase shelf life.

Varying thicknesses of paper may be used to achieve thicker and more rigid packaging.

- Paper is thin (one layer) and flexible, typically used in bags and wrappers. Kraft (or strong" in German) paper is the strongest paper. It may be bleached and used as butcher wrap or may remain unbleached and used in grocery bags.
- Paperboard is thicker (although still one layer) and more rigid. Ovenable paperboard is made for use in either conventional or microwave ovens by coating paperboard with PET polyester.
- Multilayers of paper form *fiberboard,* which is recognized as "cardboard".

Plastic

It has shrink, nonshrink, flexible, semirigid, and rigid applications, and varies in its degree of thickness. Important properties of the many types of plastics that make them good choices for packaging material include the following:

- Flexible and stretchable.
- Lightweight.
- Low-temperature formability.
- Resistant to breakage, with high burst strength.
- Strong heat sealability.
- Versatile in its barrier properties to O_2, moisture, and light.

8.7 PACKAGING FOR PHYSICAL DISTRIBUTION AND TRANSPORATION

Any package is functionally incomplete if the goods received at the distribution is unacceptable. Hence, the secondary and tertiary packaging, which can withstand the physical abuses during handling, transportation and storage, is also very important. The most commonly used conventional transport containers for fresh and processed food includes wooden boxes, corrugated fibreboard boxes, plastic crates, high-density polyethylene drums, steel drums and pails. Sacks are also generally used to bring fresh produce to the processing centres from the fields. The selection of a transport container is based on the characteristics of the product, the kind of handling and transportation hazards likely to be encountered at various stages of the distribution system.

8.7.1 Transportation Containers

The primary function is to contain the article. It may need to be designed to prevent pilferage during the journey between manufacturer and ultimate consumer. A third and the most important property of the shipping container is its compatibility with the product contained within it. The other important aspect of a shipping container is labelling regarding what it contains, how much it contains and when it is packed and possibly sales promotion.

Wooden Containers

Wooden containers are one of the earliest shipping container since wood was then available in plenty. But presently, use of wood is discouraged as our forests are depleting year by year. There is a stiff competition from fibreboard containers both in terms of cost and performance. Still the wood container is widely used for perishables in the domestic market. The requirement for such a purpose include:

- Aeration required for the dissipation of heat and exchange of gases.
- High stacking strength and stability.
- There should be no fungus and mould growth when stored at high relative humidity.
- Dimensional stability.

Corrugated Fibre Board Boxes (CFB)

The corrugated fibreboard is made of paperboard liners and corrugating medium. The structure of corrugated fibreboard consists of a fluting medium running in a sinusoidal wave form between the two liners, thus separate the liners by a distance to obtain good stiffness.

Unbleached virgin coniferous craft is most appropriate for liner materials. It has a high tearing resistance and stiffness and a low rate of moisture absorption from air. Other materials like straw, bagasse, bamboo etc. have lower performance particularly when exposed to higher relative humidities. In case these materials are used, their substance has to be increased at least by 50% to get the satisfactory performance.

In case of packaging for fruits and vegetables, ventilation holes for the dissipation of heat and exchange of gases are very much essential. Careful attention must be given to the number, size. shape and position of these holes without sacrificing the strength of the box.

Inserts and cushioning materials are generally used for packing glass bottles. Pouches and fresh produce. There are various types of inserts and cushioning materials that are being used.

- **'Cell pack'** – Traditional partitioning method contribute to the stacking strength of the box.
- **'Paper honey comb'** – Can be adopted to different produce size and shape.
- **'Moulded pulp trays'** – Generally used for eggs and fruit and vegetables.
- **'Expanded polystyrene inserts'** – Can be produced in short runs at reasonable costs.
- **'Thermoformed PVC trays'** – Generally used for packaging produce in single layers only.
- **'Paper wool or wood wool'** – In combination with paper tissue, gives good protection if tightly packed.
- **'Plastic foam net'** – Generally used for glass bottles and large size fruits.

Barrels and Drums

Metal and wooden barrels are commonly in use. The metal barrels include steel and aluminium. Aluminium barrels are used for storing beer. Wooden barrels are made of staves bound together with hoops and may be 'tight' or 'slack'. The tight ones are used for storing heavy solids. semisolids and liquids. The wooden barrels are also used for storage and ageing of alcoholic liquors.

A drum is a cylindrical shipping container differing from barrels in having straight sides and flat or bumped ends designed for storage and shipments as an unsupported outer package that may be shipped without boxing or crating. Drums can be either metal drums (usually from Aluminium or Steel) fibre drums, ply wood drums and plastic drums. Metal drums are single wall, with either double head, partial opening, with convex or flat head or flat full removable head construction. The capacity usually ranges from 12-110 gallons. The inner surfaces of the metal drums are coated with lacquers. The commercially used lacquers are oleoresinous types. phenolic resins, vinyls, and epoxy resins.

Fibre drums are made by fibreboard of plies not less than 0.3 mm thick. The capacity of these drums varies between 0.5 to 100 gallons. The advantages of fibre drums are they are not returnable and has good stackability, low tare weight and easy opening and closing features. Printing can improve their appearance. Care should be taken not to expose these drums at high relative humidities.

The basic types of fibre drums are;

- Plain drums – No moisture proofness.
- Liquid tight drums – has rubber or plastic gaskets.
- Water vapour proof drums – Inside laminated with asphalt paper or polyethylene.
- Lined and coated drums – Prevents direct contact between content and fibreboard.

Fibre drums are generally used for shipping semisolids having a minimum viscosity of 5000 cps. It is also used for liquid insecticides fruit juices and other food stuffs. Plywood drums are made of 3 ply veneer which laps and joined with staples. The ply wood drums are primarily used to pack dry products and have an excellent weight to strength ratio.

The polyethylene drums are rigid and self supporting. They are available between 5-55 gallons capacity. The advantages of these drums are its flexibility, non toxicity, light weight, durability, high chemical resistance. The polythene drums have good resistance to breakage.

Sacks

Sacks are generally made from flexible low cost materials like jute, textiles, papers and plastics. Paper sacks are made of two or more plies of sack krafts, which is pure sulphate paper having a substance of 70 gsm or more.

Plastic sacks are generally made from polyvinyl chloride, polyethylene and polypropylene. The advantages of plastic sacks are, it weighs only 2/3 of multiwall paper sack and has better weather and impact resistance. These sacks are made by extrusion and blowing. The closures are made by sticking or heat sealing.

Sacks made from a combination of plastic and jute are also commercially available. Fresh fruit and vegetables are generally packed in sacks for transportation from harvesting fields to packing houses and/or retail markets. Sacks do not provide support for the product against superimposed loads and also offers less resistance to impact loads. Possibilities of sifting and spilling are common.

Bag-in-Box

In this system, the bag is supported on the outside by a rigid container made of paper board or corrugated board carton. It is generally used to fill a variety of liquid and dry products like tea, instant coffee, milk foods, baby foods, glucose powder, biscuits, spices, aseptic and non-aseptic fruit juices, edible oil, ghee etc. This system is tamperproof and offers cost effectiveness. Depending on the product, wide range of plastic films, laminates, coextruded barrier films, metallised film and aluminium foil can be used for the inner construction.

There are two methods of producing bag-in-box packages:

- Lined carton system,
- Coated and laminated carton system.

In the case of lined carton system, the inner liner is made from a suitable laminate such as LDPE/Paper/HDPE, paper/foil/LDPE and polyester to give the required shelf-life protection to the product. The outer carton is made of duplex board for protection against damages.

The second method combines the carton forming/gluing operation with a lining feed mechanism. Products considered for bag-in-box packaging should be tested for compatibility with the package and performance under handling shipping conditions.

Palletisation

A pallet is a platform made to hold one or more boxes, bags, cartons etc. in a group. The pallet is one of the simplest single devices for material handling. The other advantages of palletisation are:

- Reduced labeling requirements.
- Better utilization of storage space because of higher stacking strength.
- A reduction in mechanical strains and damages.
- A reduction of the total distribution time.
- A better maintenance of produce quality.

A pallet can be made of wood, corrugated and honey comb paperboard, plastic, reinforced plastic or metal. The choice is based on the service conditions, such as weight of load, climatic environment, durability requirement, local availability and costs.

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.
c) Use separate sheets where no space is provided.

1. Define primary, secondary and tertiary packaging.

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2. Describe the suitability of plastics for packaging of foods.

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2. Describe the suitability of wooden containers and CFB box for packaging and transportation of foods.

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8.8 QUALITY TESTING OF PACKAGES AND PACKAGING MATERIALS

An essential part of any packaging programme is the testing and evaluation of the complete packaged unit, as well as the various components. It is good economics to determine the optimum design in the beginning to maintain uniform performance throughout the life of the package. A good test programme will indicate the results to be expected in the field and it will yield dividends far in excess of its original cost and good management demands an objective evaluation of every step in the packaging operation.

To predict the performance of a package, there is a necessity to use a wide array of test procedures in package performance analysis with the following aspects:

- Identification of various materials used in packaging.
- Suitability of the materials for the intended use.
- Knowledge of materials properties both when used alone and when used in combination with other packaging materials.
- Ability to evaluate the material performance in the final package form in contact with packaged product.
- Determining the durability of materials through normal or even abnormal handling and abuse (including shipping).

8.8.1 What is Testing?

A test can generally be defined as an act of determining a given property or characteristics of a product (packaging material or package) by taking one or more measurements qualitatively or quantitatively according to prescribed procedure.

8.8.2 Why Testing?

Tests on packaging materials and packages are performed mainly for the following purposes:

- Comparison with competitive material to compare the offers.
- Current checks over the uniformity of new supplies of packaging materials, i.e., to check for change in quality if any from batch to batch.
- Quality checks during the production of packaging materials or packaged commodities.
- Evaluation of the suitability of packaging materials for certain factors like protection against mechanical or climatic hazards.

8.8.3 Steps in Test Methods

- Scope: The purpose and limitations of the methods are to be elaborated to avoid ambiguity.
- Significance: Relevance, the test has with respect to actual or intended performance.
- Terminology: The technical terms and abbreviations used should be fully defined or explained when they are not in common use
- Apparatus: All the various equipments necessary should be fully described in all the details, including dimensions range and accuracies etc.
- Materials: All reagents etc. are to be given in detail.
- Sampling: Enough attention has to be paid to proper sampling since a test can be only as informative as the sample permits

- Test specimen: The test sample consists of a minimum number of specimens and these specimens are to be prepared as required for the measurement of property and to suit the requirement. Preparation of the specimens is very important for the reliability of the test results.

- Conditioning: Time, temperature and relative humidity, to which the specimen are to be preconditioned and also conditions during testing.

- Test procedure: Method of actual measurement when there are more than one procedure. The procedure to be followed is described in detail.

- Method of evaluation: This gives the method (calculations) employed to arrive at the test property from the observations (readings) taken.

- Report: This tells how the results are to be reported and includes the method of presentation, its form (tables, graphs, diagrams etc.). Some times the precision of the test is also included in the report.

8.8.4 Package Functions and Characteristics

Mostly the evaluation of packaging materials is based on package functions and the characteristics of package.

Product Protection

1. Storage life of food products: Mainly depends upon the barrier properties of the packaging materials for:

   - Humidity: Water vapour transmission.
   - Gases: Oxygen/Carbon dioxide/Nitrogen/Sulphur dioxide.
   - Aroma: Specific organic vapour and transmission rate.

2. Product damage and integrity:

   In terms of resistance to stresses in distribution.

   - Impact resistance.
   - Dart impact and Spencers impact value for the film.
   - Compression resistance for finished packages.

   In terms of resistance to bursting:

   - Bursting strength.

   In terms of resistance to repeated stresses as in vibrations:

   - Gelboflex crack resistance for films/laminates/coextruded films.

3. Product packaging compatibility:

   Chemical resistance:

   - Grease resistance.
   - Tainting.
   - Migration of constituents from packaging materials into foods.

4. Pilferage and adulteration:

   Good closure and joints required.

   - Heat seal in plastic pouches.

Machinability

1. Easy sliding on machine:
   - Reduced friction.
   - Slip of packaging material surface (kinetic coefficient of friction).
2. Resistance to stresses in packaging operations:
   - Tensile strength and elongation.
   - Resistance to tear propagation.
   - Heat seal range and hot tack

Consumer and Marketing Functions

1. Ease of opening and reclosures:
   - For flexible pouches a 'V' – notch to start tear (good with foil laminates and cellophanes) may not be suitable for polythene and Nylon films.
   - Fold retention for closures of laminate pouches
2. Ease of dispensing:
   - Wide mouth for solids and pasty foods.
   - Clean squeeze out from flexible pouches (Non stickiness to the package wall).
   - Ease of disposal – problems for the future, particularly for non-recyclable multilayer plastic packs.

8.8.5 General Common Tests for Films, Foils, Laminates and Paper and Paper Board

Thickness

Thickness is the perpendicular distance between the two outer surfaces of the material and is normally expressed in units of length. Many physical properties of packaging materials are dependent upon the thickness, e.g. WVTR and GTR of films are inversely proportional to thickness and decreases with increase in thickness. For paper board, thickness is reported in points or in mm. (1 point = 1/1000") for papers, it is in mm or inches. For films, thickness is reported in micron, mils. or in gauges (25 micron (μm) = 1 mil = 1/1000" = 100 gauge = 0.025 mm.

The Basis Weight (for paper and paper boards)

The basis weight is the average weight of an arbitrarily selected area of the paper (weight per unit area i.e. gms/ sq.metre or lbs/1000 sq.ft for paper boards). As the packaging papers are sold and purchased only in terms of weight the basis weight assumes special significance. Most of the physical properties such as burst strength; thickness and bulk are evaluated and specified in accordance with the particular basis weight involved.

Tensile Strength Test

The tensile strength of paper is defined as the force applied parallel to the plane of the specimen of specified width and length under specified condition of loading (K gms/15 mm or lbs/inch width). The test indicates the durability and serviceability of papers in many packaging operations such as wrapping, bagging. printing etc. Usually tensile strength is more in machine direction than in transverse direction and extension is less in machine direction than in transverse direction. Plastic films are normally tested at higher speeds because of higher extensibility. The stress strain curve helps in locating yield point and knowing the yield strength etc.

The Bursting Strength Test

This test measures the ability of a paper or paper board to withstand pneumatic or hydraulic pressure build up. For films, foils, laminates and papers the pneumatic type test is used. Heavy papers and paper boards are tested on hydraulic type of testers (lbs/sq.in or kg/sq. cm). The test gives a sort of combined tear and tensile properties. In many cases it serves as good index of the quality of fabrication of packaging materials. Another Associated property is Burst factor. The burst factor = Bursting strength (in gm/sq.cm)/Basis weight (in gm/sq.mt).

Water Vapour Transmission Rate

The water vapour transmission rate (WVTR) is measured as the quantity of water vapour in gms that will permeate from one side to the other side of the film of an area of one square metre in 24 hours, when the relative humidity difference between the two sides is maintained at 90% gradient at 37.8°C. The property is important to estimate the efficiency of the packaging material or a package for resistance to the flow of water vapour and is helpful in considering the selection of barrier materials for hygroscopic foods.

Gas Transmission Rate

The gas transmission rate (GTR) is normally determined by measuring the change in volume at constant pressure (atmospheric), or the change in pressure at constant volume and the quantity of gas flowing across the film is compiled as volume at NTP.

$$\text{GTR} = \frac{\text{V}.(76)\text{x}24}{\text{At}(\text{P1} - \text{P2})} \text{ cc/ m}^2\text{/ 24 hrs.atm} \qquad (8.1)$$

where ‘V’ is the volume (at NTP) of gas transmission through 'A' sq. metres of the test material in time 'f, when the average pressure difference between the two sides is maintained at (P1-P2) cm of Hg. The temperature of the test can be changed as per the requirement. GTR is an important property to estimate the efficiency of the packaging material or a package for resistance to the flow of gases and helps in selection of barrier materials for oxygen sensitive foods.

Grease Resistance

Grease resistance is measured by exposing one side of the test specimen creased or uncreased to a grease containing red dye. The time required for the red stain to show on the unexposed side is taken as a measure of this property. For plastic films, the test can be performed directly in pouches using groundnut oil coloured with red sudan dye.

Tearing Resistance for Papers

The papers are tested for their tearing resistance properties in two ways:

i) Internal tearing: The energy required to propagate an initial tear is measured (More followed in practice).
ii) Edge tearing: The energy required to initiate a tear is measured. The test is done on both the directions of paper. The work done in tearing is measured by the loss in the potential energy of the pendulum of the instrument. Tear Factor: is a term similar to Burst Factor, one finds in use.

$$\text{Tear factor} = \frac{\text{Tearing resistance in gms.}}{\text{Basis weight in GSM}} \times 100 \qquad (8.2)$$

Impact Tests for Plastics

These tests are designed to measure the ability of the films to withstand fracture by shock. The test is a measure of toughness of the material. It is a combination of deformation and breaking properties.

The Abrasion Resistance

This test is designed to measure the ability to withstand surface wear and rubbing. It is a measure of some mechanical properties like hard resillience. The procedure consists in abrading the sample with a wheel of standard abradent for a definite number of revolutions and finding the weight loss of the sample.

Heat Seal Strength

The test is used for heat sealable plastic packaging materials. The heat seal strength may be expressed as percentage of the tensile strength of the base material (gm/ cm width). The strength of heat seal depends upon temperature, dwell time, pressure and the type of heat sealing surfaces and each material has optimum values under these conditions. .

Environmental Stress Cracking

The purpose of the test is to study the influence of some reagents like soaps, wetting agents, oils or detergents on plastics, determined by exposing the specimens for a specific time to those environments and observing the cracks. The test report consists of the percentage of failures.

Identification of Plastic Films

Different types of plastics used in packaging differ in their properties. It becomes necessary to identify them for their proper selection. Though there is no systematic method for identifying packaging films, based on some characteristics of various films, such as appearance, odour, feel and drape, they can be identified by a few simple tests like specific gravity, solubility, burning and copper wire test etc. For laminates and coextruded films, it is difficult to identify by such simple tests. Nowadays IR spectroscopy and NMR are used to identify qualitatively as well as quantitatively.

Specific Tests

Apart from these common tests, there are some specific tests for different packaging materials which are enlisted in various standards developed by the Bureau of Indian Standards and other organizations.

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.
c) Use separate sheets where no space is provided.

1. Define testing and enlist three reasons for testing of packages.

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2. Describe two tests each for the following packaging materials.

i) Paper and foils.
ii) Plastics.

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8.9 STANDARDS FOR SAFE PACKAGING

The packaging laws and regulations affecting food products are mainly covered under:

- The Standards of Weights and Measures Act, 1976, and the Standards of Weights and Measures (Packaged Commodities) Rules, 1977 (SWMA).
- The Prevention of Food Adulteration Act, 1954, and the Prevention of Food Adulteration Rules, 1955 (PFA).
- The Fruit Products Order, 1955 (FPO)
- The Agmark Rules

8.10 DISPOSAL OF PACKAGING MATERIALS

Indiscriminate use of different packaging materials for packaging of food products has caused a serious problem of pollution and ecological imbalance due to the problem of their disposal. Packaging waste contributes in great proportion to the increase in the volume of waste and to the saturation of landfills. The packaging sector, especially the plastics industry, is currently under some attack from the environmental point of view due to problems in waste disposal, pollution by litter and waste of resources.

At present, the following different principal methods are used to control solid waste disposal.

i) Land in-fill
ii) Incineration
iii) Composting
iv) Direct constructional use (unsorted) (v) Reuse (sorted)
v) Pyrolysis
vi) Chemical treatment

In the case of land in-fill method, the waste is reduced in particle size and then deposited in a special location, which may be excavated and covered with a minimum level. The process is hygienic and can reclaim wasteland. Incineration comprises the burning of waste till all combustible matter is fully oxidized. Composting involves biodegradation leading to a bland product, which is useful in agriculture. In direct constructional use, the waste is treated to compact, compressed with binders like bitumen and the resulting blocks are used for construction of roads, artificial islands, causeways, airfields, etc.

Packaging materials like metal, paper and glass can be segregated and reused or recycled. Pyrolysis is a method of heating material in the absence or presence of a limited amount of oxygen and the components can be separated for reuse. The chemical treatment is oriented towards a specific component of waste like hydrolysis of polyurethanes in scrap automobiles and degradation of paper to sugars or alcohols.

When the product is removed from the packed container, it becomes litter, which is harmful, polluting and expensive and this has to be disposed off quickly.

8.10.1 Recycling of Packaging Materials

Recycling of packaging materials play a very important role in saving the raw material, energy and to minimize the environmental pollution.

Recycling of tin-plate is a cumbersome process, since the lacquers / lithography and tin has to be separated from the base steel. Then the base steel can be sent to the steel-producing plant for remelting to produce fresh steel plate for reuse. The separation of steel from tin in two-piece cans and lids is easier and more economical. Similarly, chromium can be separated from the tin-free steel and the base steel can be reused for production of fresh base plate.

By recycling aluminium, more than 90 per cent of the energy can be saved by melting and reprocessing the metal. It is also claimed that the quality of recycled aluminium is better. About 50-60 per cent of the aluminium cans are recycled.

With respect to plastic packaging materials, PET can be reprocessed and used for stuffings, plates, piping, fibres, etc. Used PET bottles are not suitable for production of fresh PET bottles. Plastic-wastes are also used for recovery of energy by incineration.

8.10.2 Biodegradable Plastics

Plastics used in food packaging at present are non-biodegradable. The overflowing landfills cannot absorb the large quantity of plastic trash created in many countries. To reduce the waste, the best solution is a combination of biodegradable plastics, plastics recycling and composting. Biodegradable plastics are biodisintegratable plastics, which disintegrate into polymer chains and break down into water and carbon dioxide.

The first generation biodegradable plastics are made of polymers containing about 6 per cent starch (normally, corn starch), which biodegrades and a pro-oxidant, which enhances the reaction of the polymer with oxygen in the air. New biodegradable plastics contains up to 97 per cent starch.

Biodegradable plastics have the same strength and flexibility as commonly used petroleum-based plastics and can be melted, moulded and shaped as required. However, they are not suitable for applications requiring high-temperature resistance or impact. The same production techniques like injection moulding, extrusion blow-moulding, melt casting or spinning used for plastic-based plastics can be used without retooling the manufacturing plant. Biodegradable plastics are viable alternatives and are gradually becoming popular commercially.

Other than biodegradable plastics, chemical and photodegradable plastics have also been developed. They are chemical plastic, for which a natural catalyst like metal salt is added and the photodegradable plastic for which a light-sensitive chemical is added to or sprayed on the plastic to make it disintegrate in ultraviolet light.

8.11 SPECIAL PACKAGING

Other than the traditional packaging materials, there are some special ones, which can be selectively used for packaging of foods. Some of them are discussed in the following paragraphs:

8.11.1 Edible Films

Natural edible films extend shelf life, although for shortest time periods than synthetic non-edible packaging materials. Examples of edible films include casings, such as in sausage, and edible waxes, such as those applied to fruits and vegetables, the waxes function to improve or maintain appearance, prevent mold, and contain moisture while still allowing respiration. Food may be coated with a thin layer of polysaccharides such as cellulose, pectin, starch and vegetable gums, or proteins, such as casein and gelatin. Cut dried, fruit pieces are often sprayed with an edible film prior to their inclusion into items such as breakfast cereal.

8.11.2 Foil

These may be used in snack bags (chips, etc.) or as a laminate in aseptic packaging. It is used as a wrapping for dry, refrigerator, or freezer storage. It provides a moisture-proof and vapour-proof barrier,

8.11.3 Laminates

These are multilayers of foil, paper, or plastics which may be utilized selectively according to the specific food packaging need, In combination, the various laminates may provide more strength and barrier protection than the individual laminate material. Laminates provide barriers useful in controlling O_2, water vapor, and light transmission, and they provide good burst strength. The laminates may resist pinholes and flex cracking. Retort pouches are examples or laminates used in packaging and contain polyester film, aluminum foil, and polypropylene.

8.11.4 Vacuum Packaging

Vacuum packaging modifies the atmosphere surrounding the food by removing oxygen, and it extends shelf life. Vacuum-packaging machines are available for small-, medium-, or large-scale production capacity and may be used to successfully package a variety of food sizes and forms such as small cheese blocks, large primal cuts of meat, or liquids. The procedure used for vacuum packaging is to place the food in a flexible-film, barrier pouch, and put it inside a vacuum-packaging chamber, where oxygen is removed. This creates a skintight package wall and protects against the entry of escape of gases such as air and CO_2, or water vapor. It assures inhibition of microbial growth, which would alter microbial and organoleptic properties such as appearance and odor. Water weight loss and freezer burn are also inhibited with this packaging method.

8.11.5 Modified Atmosphere Packaging (Map) Or Gas Flush Packaging

Modified atmosphere packaging modifies the internal package atmosphere of food. It is primarily applied to fresh or minimally processed foods that are still undergoing respiration, and it is used for the packaging of baked goods, coffees and teas, dairy products, dry and dehydrated foods, lunch kits, and processed meats in order to keep the meat pigment looking desirable. It is also used for nuts and snack food applications. MAP is one of the most widely used packaging technologies.

Modified atmosphere packaging contains the food under a gaseous environment that differs from air, in order to control normal product respiration (ethylene, CO_2, water vapor, and O_2*)* and growth of aerobic microorganisms. Nitrogen gas, which is odorless, tasteless, colorless, nontoxic, and nonflammable, is introduced into the food package after all atmosphere has been removed from the pouch and vacuum chamber and just prior to hermetic sealing of the package. This modification offers protection from spoilage, oxidation, dehydration, weight loss and freezer burn, and extends shelf life.

Unlike vacuum packaging, the film used for MAP remains loose-fitting, This avoids the crushing effects of skintight vacuum packaging, When used in combination with aseptic packaging, which reduces the microbial load, MAP becomes a more effective technology, Most new and minimally processed foods use MAP in combination with aseptic technology and reduced temperature.

8.11.6 Controlled Atmosphere Packaging

Both controlled atmosphere (CA) in storage environments and controlled atmosphere packaging (CAP) permit controlled oxygen and carbon dioxide exchange. Today, CAP containers control O_2, CO_2, water vapor, and ethylene concentration and, worldwide distribution of produce depends on CAP for high-quality food.

Clostridium botulinum is an anaerobic bacteria that grows in the absence of available oxygen. Therefore, it may grow in anaerobic packaging environments. To retard its growth in CAP food products, foods must have short storage times and be held at cold temperatures. Control of water activity (Aw) and salt is also necessary to prevent growth as sodium competes with the bacteria for water absorption

8.11.7 Active Packaging Technologies

Typically, packaging serves in a passive role by protecting food products from the external environment. It provides a physical barrier to external spoilage, contamination, and physical abuse in storage and distribution. Today, packaging more actively contributes to the product development, controls maturation and ripening, helps in achieving the proper color development in meats, and extends shelf life. It plays an active role in protecting foods. Examples of active packaging technologies are listed in the following:

Active packaging for fresh and minimally processed foods provide the following:

- Edible moisture or oxygen barrier (to control loss of moisture and enzymatic oxidative browning in fresh cut fruits and vegetables and to provide controlled permeability rates matched to the respiration rate of the fruit).
- Edible antimicrobial (biocidal) polymer films and coatings (which release controlled amounts of chlorine dioxide into the food, depending on temperature and humidity; or destroy E. coli 0157:H7 in meats, and prevent mold growth in fruits).
- Films that are scavengers of off-odours.
- Oxygen scavengers for low oxygen packaging.

Active packaging for processed foods provides the following

- Edible moisture barrier.
- O_2, CO_2, and odour scavenger.

Other active packaging technologies include the following:

- Microwave doneness integrators (indicators).
- Microwave susceptor films to allow browning and crispness (french fries, baked products, popcorn).
- Steam release films.
- Time-temperature indicators (TTI) which are unable to reverse their colour when the product has been subject to time-temperature abuse for frozen products.

8.11.8 Aseptic Packaging

In order to destroy any *Cl. botulinum* spores and extend the shelf life of low-acid foods, *aseptic packaging* may be utilized. Independent sterilization of both the foods and packaging material, with assembly under sterile environmental conditions, is the rule for aseptic packaging.

The container is filled with a sterile (no pathogens or spores) or commercially sterile (no pathogens, but some spores) liquid food product, and sealed in a closed, sterile chamber. Once packed, the product requires no refrigeration. Liquids such as creamers, milk, or juices may be packed in this manner. Triple or multiple packs of flavoured milk and juice, with attached straws, are available on grocery shelves. The market leaders of aseptic packages have introduced easy-open, easy-pour features into their canons. The plastic devices are injection moulded and adhere to the package tops.

8.11.9 Flexible Packaging

It is available for packaging use in the foodservice industry and is finding more applications at the retail level, including packaging for bagged cereals and sliced deli meat. Non-rigid packaging containers such as stand-up pouches or tubes and zippered bags are examples of flexible packaging used for peanuts, peanut butter, or produce such as fresh-cut lettuce and peeled baby carrots. (The packaging must also be resealable to meet consumer demands and may have zipper handles or spouts with screw-off tops.)

Flexible packaging is adequate for the plethora of low-fat/no-fat food products such as salty snack foods that are available in the marketplace. It keeps these products fresh by providing flavour and aroma barriers, which keep outside doors out and flavours in. It is used for fresh fruits and vegetables and matches respiration rate as closely as possible.

Manufacturers are offering more food products in flexible packaging and find that "cost savings and environmental concerns are two of the driving forces behind the switch to flexible packaging". "Faster, better, stronger, cheaper… the packaging industry continually tries to improve the process. Nowhere is this more apparent than in flexible packaging".

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.
c) Use separate sheets where no space is provided.

1. Enlist three standards for safe packaging of foods.

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2. Enlist the principal methods used to control solid waste disposal.

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3. Write short notes on the following:

   i) Edible films
   ii) Vacuum packaging
   ii) Modified atmosphere packaging
   iv) Controlled atmosphere packaging
   v) Active packaging
   vi) Flexible packaging

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8.12 LET US SUM UP

After studying the contents of this unit, you can appreciate that there are several options for transportation and packaging of food materials. Depending upon the location and the commodity, a rigid combinations of mode of transportation and packaging with minimum losses and at least cost.

While manual and animal drawn carts have their relevance for small distances, motorized transport is required to haul the food material over long distances. The tractor, truck, rail, sea and air transport modes have their useful mass based on the perishability, urgency, cost and benefit attributes.

The role of packaging is to facilitate handling and marketing and to ensure the minimum spoilage during storage, handling and transport. The packaging also has a criterion of consumer appeal. Besides food quality, the issue of food and environmental safety have also become important. The disposal of used packaging material so as not to cause pollution needs to be given due considerations.

8.13 KEY WORDS

Transport	:	It refers to the transfer of material from one place to another be it the transport of raw materials to the processing industry or the finished product from the industry to the market place.
Transmission rate of packages	:	It refers to the transfer of a particular component like water vapour, oxygen, etc. across the packaging material per unit area per unit time.
MAP	:	Modified atmosphere packaging contains the food under a gaseous environment that differs from air, in order to control normal product respiration (ethylene, CO_2, water vapour, and O_2) and growth of aerobic microorganisms.
CAP	:	Controlled atmosphere packaging (CAP) permit controlled oxygen and carbon dioxide exchange.
Active packaging	:	Packaging more actively contributes to the product development, controls maturation and ripening, helps in achieving the proper colour development in meats, and extends shelf life. It plays an active role in protecting foods.
Vacuum packaging	:	Vacuum packaging modifies the atmosphere surrounding the food by removing oxygen, and it extends shelf life.
Aseptic packaging	:	It is packaging of the food material in a sterile environment.
Biodegradable Plastics	:	Biodegradable plastics are biodisintegratable plastics, which disintegrate into polymer chains and break down into water and carbon dioxide.
Transportation cost	:	Involves all costs involved and each must be taken care to optimize profits.
CFB	:	The corrugated fibreboard is made of paperboard liners and corrugating medium. The structure of corrugated fibreboard consists of a fluting medium running in a sinusoidal wave form between the two liners, thus separate the liners by a distance to obtain good stiffness.
Bag-in-box	:	In this system, the bag is supported on the outside by a rigid container made of paper board or corrugated board carton.
Palletization	:	A pallet is a platform made to hold one or more boxes, bags, cartons etc. in a group.

8.14 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Appropriate packaging and transportation is one of these measures applied at all stages between the grower and the consumer in order to reduce wastage, improve food security and generate income and profit. When properly applied it can have a dramatic effect, towards reduction of losses and ensuring quality product for the customer. Appropriate packaging and transportation ranges from the proper use of containers in which to transport produce to local markets, through to sophisticated systems that can extend the shelf-life of a processed foodstuff for a year or more.

2. i) Suitability

- Tran-shipment necessary.
- Pilferage is a major problem.
- Proper handling instructions essential.
- Packages can be sent on railways risk.
- Packages are to conform to rules and regulations of the Railways.
- Door to door delivery possible only by container service.
- No problem for inter-state transport.
- Less interruption of journey even in rainy season.

Hazards:

- Stacking height upto 8 feet.
- Vibration due to rail joints and track conditions.
- Shunting shock.
- Very high temperature (upto 70°C) in steel wagons in summer.

ii) Suitability

- High freight charges and hence lighter packages to be used.
- Limitations on size & weight of packages.
- Less journey time.
- Better handling.
- No cooling facility available.

Hazards:

- High frequency vibration due to engine.
- Low temperature and pressure when flying at high altitudes.

3. Three factors that cause deterioration of foods during storage are:

- mechanical forces (impact, vibration, compression or abrasion),
- climatic influences that cause physical or chemical changes (UV light, moisture, oxygen, temperature changes),
- contamination (by micro-organisms, insects or soils).

4. Four packaging functions are as follows:

- Preserving against spoilage of colour, flavour, odour, texture, and other food qualities.
- Controlling absorption and losses of O_2 and water vapour.

- Offering adequate storage before use-such as stockable, resealable, pourable.
- Preventing/indicating tampering with contents by tamper-evident labels.

Check Your Progress Exercise 2

1. A ***primary*** container is the bottle, can, drink box, and so forth that contains food. It is a direct-food-contact surface. Several primary containers are held together in ***secondary*** containers, such as corrugated fiberboard boxes (commonly, but not correctly, referred to as cardboard), and do not have direct food contact. In turn, several secondary containers are bundled into ***tertiary*** containers such as corrugated boxes or overwraps that prepare the food product for distribution or palletizing.

2. a) Different types of plastics available for food packaging.
   b) Their suitability for packaging of food materials.
   c) Their relative advantages and disadvantages.

3. a) Describe wooden containers and CFB box.
   b) The type of foods that can be packed using wooden containers and CFB box.
   c) Their advantages and disadvantages if any, over other packaging materials.

Check Your Progress Exercise 3

1. A test can generally be defined as an act of determining a given property or characteristics of a product (packaging material or package) by taking one or more measurements qualitatively or quantitatively according to prescribed procedure. Three reasons for testing of packages include the following:

   - Comparison with competitive material to compare the offers.
   - Current checks over the uniformity of new supplies of packaging materials, i.e., to check for change in quality if any from batch to batch.
   - Quality checks during the production of packaging materials or packaged commodities.

2. i) Tensile strength and tearing strength tests

   ii) Water vapour transission rate and bursting strength tests

Check Your Progress Exercise 4

1. The three packaging laws and regulations affecting food products are:

   - The Standards of Weights and Measures Act, 1976, and the Standards of Weights and Measures (Packaged Commodities) Rules, 1977 (SWMA).
   - The Prevention of Food Adulteration Act, 1954, and the Prevention of Food Adulteration Rules, 1955 (PFA).
   - The Fruit Products Order, 1955 (FPO)

2. The principal methods used to control solid waste disposal are:

   i) Land in-fill.
   ii) Incineration.
   iii) Composting.
   iv) Direct constructional use (unsorted).
   v) Reuse (sorted).
   vi) Pyrolysis.
   vii) Chemical treatment.

3. In all the short notes the following points needs to be covered:

   i) The definition.
   ii) Use and principle.
   iii) Foods suitable for the method.
   iv) Advantages and disadvantages of the method.

8.15 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. Vaclavik, C.A. and Christian, E.W. (1999) Essentials of Food Science. Aspen Publisher, Inc., Maryland, USA.

UNIT 10 JAMS, JELLIES, MARMALADE AND OTHER SUGAR-BASED PRODUCTS

Structure

10.0 OBJECTIVES

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

- importance of sugar, sweeteners, confections and sugar substitutes;
- types and sources of sugar and its role in food systems;

- methods of preparation of fruit jam, jelly, marmalade and other sugar-based products; and
- special care to be taken during the preparation of these sugar based products.

10.1 INTRODUCTION

Though India ranks first in the total production of fruits and vegetables, an appreciable amount of the produce is culled or of inferior quality. These culled fruits can be effectively utilised for the preparation of value added products like jam, jelly, marmalade, preserves, candies and other sugar based products.

The preparation of such sugar based products is one of the most important aspects of home scale preservation as well as industrial level processing of fruits. This method of preservation with high sugar concentration is principally based on the reduction in moisture content so as to arrest the microbial spoilage.

In this unit, first we'll learn about the various types of sugars, sweeteners, and their sources. The role of sugar in food system is dealt with. The preparation of the sugar based products and the special care taken during processing is described in detail. The quality aspects and packaging are also briefed in this section.

10.2 SUGAR

Sugars are carbohydrates, an important source of energy for the body. When we talk about sugar we usually refer to table sugar or sucrose, from cane or beet. There are many other types of sugars. Some occur naturally in fruits, vegetables and milk.

All sugars provide the same amount of calories (approximately 4 kilo calories or 16 kilo Joules per gram) and impart sweetness. There are two general classes of sweeteners – nutritive and non-nutritive. Nutritive sweeteners contain calories and provide energy, while non-nutritive sweeteners have no calories and provide no energy. Sucrose is the major nutritive sweetener; other sweeteners of this group are starch hydrolysates HFCS, glucose, fructose, lactose, polyols, maple syrup and honey. Examples of non-nutritive sweeteners are saccharin, acesulfame K, aspartame, etc.

10.2.1 Sources of Sugar

Sucrose is available in a variety of plant sources. However, the two most important sources of sugar for commercial production include sugarcane and sugar beet. In India, sugar is manufactured from sugarcane in the form of jaggery, open pan sugar, and vacuum pan sugar.

Sugar from Sugarcane

Jaggery: It is obtained mostly from sugarcane and also from palmyra, date palm and coconut. The harvested sugarcane is crushed to obtain juice. The sugarcane juice so obtained is freed from coarse suspended impurities and boiled in open pans. Jaggery has a light colour, good flavour, hardness and crystalline structure with good keeping quality. It contains about 65-85% sucrose, 10-15% invert sugar and 2.5% ash. Jaggery finds use in the preparation of non -crystalline candies and a variety of sweets.

Khandasari sugar: This is obtained by boiling the clarified sugarcane juice quickly to a required consistency to introduce the crystallization of sugar. The crystals are recovered by centrifugation and dried.

Sugar: It is manufactured from sugarcane juice in three different form, raw sugar, refined sugar and white sugar. The juice obtained by pressing the sugarcane is dark green in colour and turbid. It is mildly acidic with a pH of 5-5.4 and the sucrose content is 10-18%. This juice on filtration, evaporation and centrifugation will give raw sugar, which contain 96-97% sucrose. This raw sugar on refining will give refined and white sugar. The recovery of sugar is about 10-11%weight of sugarcane.

Sugar from Sugar Beet

Beet sugar is obtained from sugar beet. The clear liquid extracted from sugar beet on evaporation with controlled temperature yields a thick syrup. Raw sugar crystals are obtained from this thick syrup. The raw sugar on purification gives white sugar. Powdered sugar for icing of confectionary, cake and bakery products is made by pulverizing granulated sugar with or without edible starch.

10.2.2 Sweeteners

They are manufactured mainly from any starch source such as wheat, maize or corn, and are liquefied in the presence of enzymes. The liquid then undergoes saccharification after it is cooled to about 60^{o}C or so. Various types of sweeteners of this group are discussed below.

Starch hydrolysates: Starch syrup (glucose or maltose syrup), dried starch syrup, glucose and high fructose syrup are some of the sweeteners derived from starch degradation. Starch saccharification is carried out by either acidic or enzymatic hydrolysis under controlled processing conditions to yield starch hydrolysates with different composition to suit the diversified requirements. Their industrial uses include manufacture of soft caramel candies, alcoholic beverages and soft drinks, canning and processing of fruits and vegetables.

High fructose corn syrup: The commercial value of high fructose corn syrup (HFCS) is based on their increased sweetness as compared to the starting material, glucose, obtained from starch. The manufacturing process of HFCS include the use of specific enzymes for the liquefaction of starch, saccharification and isomerisation. The refined dextrose liquor is concentrated or blended to a dry solid level of 40-50%.

Glucose (Dextrose): Starch from corn, potatoes or wheat is saccharified enzymatically by α-amylase and /or microbial amyloglucosidase. After starch hydrolysis the product will contain 95% glucose. The syrup is purified and evaporated to crystallize glucose as α-D-glucose mono hydrate. Drying or crystallization gives the anhydrous form. Glucose is used as invigorating and strengthening agent in many nourishing formulations.

Fructose: Fructose is obtained by acid hydrolysis of inulin, a natural polymer of fructose found in tubers. Fructose is 1.5 times sweeter than sucrose and is used as sugar substitute for diabetics.

Lactose: Lactose is prepared from whey concentrates. The concentrate is heated, filtered, and evaporates to yield a yellow lactose. This raw lactose on filtration and crystallization will give α-D lactose monohydrate. β-lactose which is more soluble and easily digestible compared to α-lactose is also obtained by heating lactose solution.

Sugar alcohols: Polyols are so-called sugar alcohols. They do occur naturally but most are made commercially by the transformation of sugars. Isomalt is the most commonly used polyol and is derived from sucrose. Polyols are sweet and can be used in foods in a similar way to sugars although they can have a laxative effect when eaten in large quantities. Sugar alcohols are slightly lower in calories than sugar and do not cause a sudden increase in blood glucose. They include sorbitol, xylitol, lactitol, mannitol, and maltitol and are used mainly to sweeten sugar-free candies, cookies, and chewing gums.

Maple syrup: Maple syrup with sugar content of about 65% is obtained by evaporating the sap of maple tree. The sap from the tree has no flavour but develops a special flavour during evaporation. Maple syrup is used as a sweetener and as a flavouring agent.

Honey: Honey is produced by honeybees which suck up the nectar and honey due from flowers and other sweet saps of plants and store the nectar in their honey sac or pouch. Based on its end use, honey is classified as honey for domestic use of highest purity and bakery honey of less purity. Honey is marketed as liquid or as semisolid creamed honey and contains about 38% fructose, 31% glucose and 2% sucrose.

10.2.3 Confections

Chocolate confectionery: Chocolate is made from non-alkalized cocoa liquor by mixing with sucrose, cocoa butter and aroma substances including milk solids, nuts, coffee paste etc.. The ingredients are processed through several steps to yield a final product. The various processing steps include mixing, refining, ripening, conching, tempering and molding. The finished chocolate contains at least 40% cocoa liquor or a blend of liquor and cocoa butter and up to 60% sugar. Cocoa and chocolate products require careful storage condition of dry (55-65% humidity), cool (10-12^{o}C), well aerated space protected from light and odourous substances.

Sugar confectionery: Sugar confectionery includes both crystalline and amorphous types made from boiled sugar syrup. The temperature of boiling sugar solution and ingredients used will determine the nature of the end product. Crystalline confectionery or candies have a smooth texture, amenable for cutting with knife and easily chewable. Amorphous candies have a heterogeneous soft structure and break into pieces rather than be cut with knife.

Crystalline confectionery is made by adding ingredients such as invert sugar, glucose or corn syrup, which aid the formation of fine sugar crystals from sugar syrup. Amorphous confectionery is made by preventing crystallization of the sugar either by cooking the sugar solution at high temperature and allowing the product to harden quickly or by adding large amounts of ingredients, which inhibit crystallization.

10.2.4 Role of Sugar in Food Systems

Sugar (glucose) is the primary energy source. Sugar is used to improve the palatability of many foods and can thereby encourage a more varied diet. Using sugars can improve the texture and colour of baked goods. Sugars produce the moistness, attractive colour and crispy texture to food products. The various functional properties of sugar in food system include:

- Source of energy
- Nutritional aspects
- Flavour and colour production
- Sweetening
- Texturing
- Plasticizing action and
- Humectancy

10.2.5 Types of Sugar

Because of its diverse functional characteristics, sugar is used in many types of food preparation. Although this handbook focuses on the functions of "regular" sugar, the most common type used in the home, sugar is available in many other forms.

Granulated Sugar

There are many types of granulated sugar. Most of them are used only by food processors and professional bakers and are not available in the market. The types of granulated sugars differ in crystal size. Each crystal size provides unique functional characteristics that make the sugar appropriate for the food processors' special need.

Regular sugar, extra fine or fine sugar: "Regular" sugar, as you know, is the sugar found in every home's sugar bowl and most commonly used in home food preparation. It is the white sugar called for in most cookbook recipes. The food processing industry describes "regular" sugar as extra fine or fine sugar. It is the sugar most used by food processors because of its fine crystals that are ideal for bulk handling and are not susceptible to caking.

Fruit sugar: Fruit sugar is slightly finer than "regular" sugar and is used in dry mixes such as gelatin desserts, pudding mixes and drink mixes. Fruit sugar has a more uniform crystal size than "regular" sugar. The uniformity of crystal size prevents separation or settling of smaller crystals to the bottom of the box, an important quality in dry mixes and drink mixes.

Bakers special: Bakers Special's crystal size is even finer than that of fruit sugar. As its name suggests, it was developed specially for the baking industry. Bakers Special is used for sugaring doughnuts and cookies as well as in some commercial cakes to produce fine crumb texture.

Superfine, ultra-fine, or bar sugar: This sugar's crystal size is the finest of all the types of granulated sugar. It is ideal for extra fine textured cakes and meringues, as well as for sweetening fruits and iced-drinks since it dissolves easily.

Confectioners/powdered sugar: This sugar is granulated sugar ground to a smooth powder and then sifted. It contains about 3% cornstarch to prevent caking. Confectioners sugar is available in three grades ground to different degrees of fineness. The confectioners sugar available in supermarkets is the finest of the three and is used in icings, confections and whipping cream. Industrial bakers use the other two types of powdered sugar.

Coarse sugar: The crystal size of coarse sugar is larger than that of "regular" sugar. Coarse sugar is normally processed from the purest sugar liquor. This processing method makes coarse sugar highly resistant to colour change or inversion (natural breakdown to fructose and glucose) at high temperatures. These characteristics are important in making fondants, confections and liquors.

Sanding sugar: Another large crystal sugar, sanding sugar, is used mainly in the baking and confectionery industries to sprinkle on top of baked goods. The large crystals reflect light and give the product a sparkling appearance.

Jaggery

Brown sugars come in many different styles but are essentially one of the two types: sticky browns and free-flowing browns. The sticky browns were originally the sort of mixture that comes out of a cane sugar crystallizing pan. The extreme of this, still made in India today, is "jaggery" or "gur" which is essentially such a mixture boiled until dry. Brown sugar consists of sugar crystals coated in a molasses syrup with natural flavour and colour. Dark brown sugar has more colour and a stronger molasses flavour than light brown sugar. Lighter types are generally used in baking and making butterscotch, condiments and glazes. Dark brown sugar has a rich flavour that is good for gingerbread, mincemeat, baked beans, plum pudding and other full flavoured foods.

Free flowing brown sugars: These sugars are fine, powder-like brown sugars that are less moist than "regular" brown sugar. Since it is less moist it does not lump and is free-flowing like granulated white sugar.

Burnt sugar / caramelized sugar: Sugar caramelized by cooking at high temperature. Prepared in specialty items requiring a special flavour and colour. Not available for purchase, but can be made at home.

Liquid Sugars

Liquid sugar syrup: There are several types of liquid sugar. Liquid sucrose (sugar) is essentially liquid granulated sugar and can be used in products wherever dissolved granulated sugar might be used. Amber liquid sucrose is darker in colour and can be used where the cane sugar flavour is desirable and the non-sugars' are not a problem in the product. Granulated white sugar dissolves in water. They are used in beverages, jams, candy, ice cream, syrups, and cooked fondants.

Invert sugar: Inversion or chemical breakdown of sucrose results in invert sugar, an equal mixture of glucose and fructose. Available commercially only in liquid form, invert sugar is sweeter than granulated sugar. One form of liquid invert was specially developed for the carbonated beverage industry and can be used only in liquid products. It is used mainly in food products to retard crystallization of sugar and retain moisture. This can also be used in confectionery, canning and baking

10.2.6 Sugar Substitutes

Artificial sweeteners are non-nutritive (zero calories per serving), high intensity sugar substitutes. These are sweet synthetic substances, often used in place of other sugars in food manufacturing and cooking. One packet of these sweeteners is equivalent to the sweetness of 2 tones of table sugar. No low calorie sweetener is perfect for all uses. They provide products with increased stability, improved taste, lower production costs and more choices for the consumer. They have very long shelf lives and can be stored in original packaging in a dry location at room temperature. Some of the non-nutritive sweeteners used in food are saccharin, acesulfame K, aspartame, sucralose, Alitame, Cyclamate and stevia.

Saccharin is 300 times sweeter than sugar, but has a slightly bitter or metallic aftertaste. Saccharin is available under the trade name "*Sweet'N Low*". It is currently produced from a purified compound found in coal tar. It is not metabolized in the digestive tract and is excreted rapidly in the urine. As a result, saccharin does not contribute calories to the diet. Saccharin continues to be important for a wide range of low-calorie and sugar-free beverage applications. Saccharin also is used in cosmetic products, vitamins and pharmaceuticals.

Acesulfame K: Acesulfame K Acesulfame potassium) is 200 times sweeter than table sugar. Its trade name is *Sunette*. The chemical structure is similar to saccharin. This is used in baked goods, frozen desserts, beverages, and candies. It has excellent shelf life and does not break down when cooked or baked. It does not provide calories since the body does not metabolize it and it is excreted in the urine without being changed. Acesulfame-K is usually used in combination with aspartame or other sweeteners because it enhances and sustains the sweet taste of foods and beverages and helps to extend the shelf life of the food product.

Aspartame: It is produced from two amino acids aspartic acid and *phenylalanine* and is 180 times sweeter than sucrose. The trade name of Aspartame is *"NutraSweet"* and *"Equal*". During digestion, aspartame is broken down into these two individual amino acids. It is also broken down when exposed to heat, resulting in a loss of its sweet taste.

Sucralose: It is known by its trade name, "*Splenda*". It is 600 times sweeter than sugar and is used in baked goods, beverages, gelatin, and frozen dairy desserts. Sucralose is derived from sucrose (table sugar). It closely resembles table sugar in taste, is highly water-soluble, and is exceptionally stable at high temperatures. Sucralose is not absorbed from the digestive tract, so it adds no calories to consumed food. In addition, sucralose does not increase blood sugar levels. Because sucralose is so much sweeter than sugar, it is bulked up with malto-dextrin, a starchy powder, so it will measure more like sugar. It has good shelf life and doesn't degrade when exposed to heat.

Alitame: Like aspartame, alitame is made from amino acids, D-alanine and L-aspartic acid. Alitame is 2,000 times sweeter than sugar. It is currently approved for use in Australia, New Zealand, Mexico, and China.

Cyclamate: It was initially marketed as tablets that were recommended for use as a tabletop sweetener for people with diabetes and others who had to restrict their intake of sugar. Although it is approved for use in many countries, cyclamate is banned in the United States due to concerns over potential carcinogenicity.

Stevia: This is derived from a shrub. The cultivation of this plant in our country has increased in recent years. Though it can impart a sweet taste to foods, it cannot be sold as a sweetener because it is an unapproved food additive. However, stevia can be sold as a "dietary supplement", though it cannot be promoted as a sweetener.

10.2.7 Role of Sugar in Jams, Jellies and Other Sugar-based Fruit Products

Recipes use just about one part fruit to one part sugar in jams, jellies, and preserves. In these foods, sugar helps to retain the original flavour, aroma, colour and other quality attributes of the fruit. Fruit flavours are condensed and strengthened, resulting in the distinctive texture and pleasant appearance of jellies and preserves.

During gel formation, pectin, a natural component of fruits, forms a gel only in the presence of sugar and acid. Sugar prevents spoilage of jams, jellies, and preserves after the container is opened. Once the jam jar is opened, sugar attracts all water and water is transferred from the microorganisms into the concentrated sugar syrup. The micro flora is dehydrated and laid up, and cannot multiply further.

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 the role of sugar in food products?

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2. What do you mean by sugar alcohol? Give any two examples.

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3. What are artificial sweeteners? Give any two examples.

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10.3 FRUIT JAM

Jam is a product with reasonably thick consistency, firm enough to hold the fruit tissues in position and is made by boiling fruit pulp with sufficient sugar. Jams contain 0.5-0.6% acid and invert sugar should not be more than 40%. FPO specifications for jam are given in section no. 2.14.

10.3.1 Preparation of Jam

Jam can be prepared from one kind of fruit or from two or more kinds. It may be made from practically all varieties of fruit. Apple, papaya, carrot, strawberry, mango, grapes, pineapple, etc. are used for the preparation of jams. Various combinations of different varieties of fruit can be often made to advantage, pineapple being one of the best for blending purposes because of its pronounced flavour and acidity.

Preparation of fruit pulp: Sound fruit is sorted, washed in running water or, preferably, brush-washed and prepared. The mode of preparation varies with the nature of the fruit. For example, mangoes are peeled, steamed and pulped; apples are peeled, cored, sliced, heated with water and pulped; plums are scalded and pulped; peaches are peeled and pulped; apricots are halved, steamed and pulped; berries are heated with water and pulped or cooked as such.

Addition of sugar: To make jams and jellies, up to a maximum of 25% of corn syrup for sweetness can be utilized. Generally, cane sugar of good quality is used in the preparation of jams. The proportion of sugar to fruit varies with type and variety of fruit, its stage of ripeness and acidity. A fruit pulp to sugar ratio of 1:1 is generally followed. This ratio is usually suited to fruits viz., berries, currants, plums, apricots, pineapple and other tart fruits.

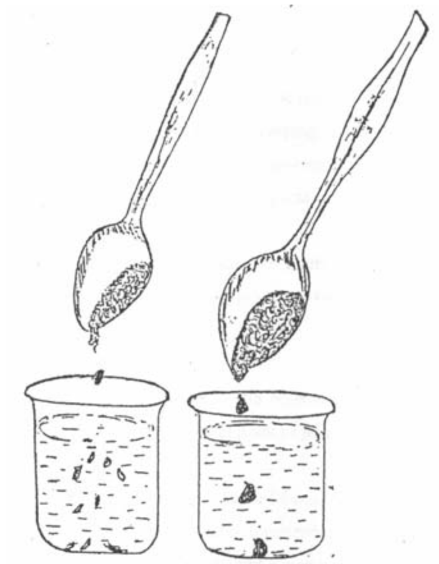
Addition of acid: Citric, malic or tartaric acids are present naturally in different fruits. These acids are also added to supplement the acidity of the fruits deficient in natural acids during jam making. Addition of acid becomes necessary as adequate proportion of sugar- pectin- acid is required to give good set to the jam. The recommended pH for the mixture of fruit juice and pectin is 3.1. The acidity of finished jam varies between 0.5 to 0.7 % depending on the type of the jam. It is often advisable to add acid at the end of cooking which leads to more inversion of sugar. When acid is added in the beginning, it will result in poor set.

Processing/boiling: Fruit pulp is cooked with the requisite quantities of sugar and pectin, and finished to 69% Total Soluble Solids (TSS). Permitted food colours, requisite amount of citric acid and flavourings are added at this stage. The boiling process, in addition to excess water removal, also partially inverts the sugar, develops the flavour and texture. During jam boiling, all micro-organisms are destroyed within the product. When this is filled hot into clean receptacles which are subsequently sealed, and then inverted the hot jam contacts the lid surface, thus prevents the spoilage by micro-organisms during storage.

10.3.2 Judging of End Point

Concentration of jam is finished at an optimum point avoiding over cooking which leads to economic losses due to less yield. But under cooking will result in the spoilage of jam during storage due to fermentation. The finishing or end point of jam can be determined by the following methods.

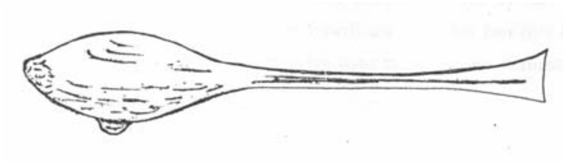
Drop test: This method is the simplest way to determine the finishing point of jam, commonly used by housewives where no other facilities are available. In this method, a little quantity of jam is taken from the boiling pan in a tea spoon and allowed to air cool before putting a drop of it in a glass filled with water. Settling down of the drop without disintegration denotes the end point (Figure 10.1).



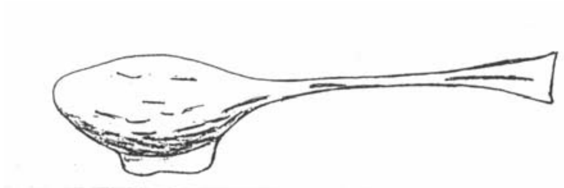
(a) (b)

Figure 10.1: Determination of end point of jam/jelly drop test. a) Unfinished; b) End point

By sheet test: In this test, a small portion of jam is taken with a large spoon or wooden ladle, cooled slightly and then allow to drop off keeping the spoon or ladle in horizontally inclined position. If the jam drops like syrup, further concentration is needed. If it is in the form of flake or forms a sheet, the finishing point is attained (Figure 10.2).



(a)



(b)

Figure 10.2: Determination of end point of jam/jelly sheet test. a) Unfinished; b) End point

Refractometer method*:* This is the most common method used by small and large scale fruit processing industries for jam making (Figure 10.3). The cooking is stopped when the refractometer shows 69 ^{o}Brix.

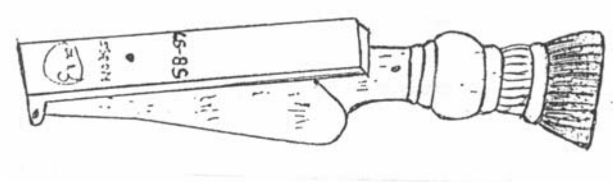


Figure 10.3: Refractometer

Boiling point method*:* Jam containing 69% TSS boils at 106 ^{o}C at sea level. This method is simplest and best to determine the finishing point of jam.

By weighing method: Weighing method is more laborious and time consuming. Here the boiling pan is weighed before and again after transferring the extract and sugar in to it. The end point is attained when the net jam weight is one and a half times of the quantity of sugar added.

10.3.3 Packaging

The product is packed in cans or glass jars, and cooled, followed by labelling and packaging. Containers including can or jar gets sterilized when hot jam (not less than 85^{o}C) is poured in them. Boiling the containers in hot water can also effect sterilization.

10.3.4 Special Care/ Problems in Jam Production

Crystallization: The final product should contain 30–40% invert sugar. If the percentage is less than 30, cane sugar may crystallize out on storage and if it is more than 50 the jam will become a honey-like mass due to high inversion of sugar into glucose. Corn syrup or glucose may be added along with cane sugar to avoid crystallization.

Sticky or gummy jam: Because of high percentage of total soluble solids, jams tend to become gummy or sticky. This problem can be solved by addition of pectin or citric acid, or both.

Premature setting: This is due to low total soluble solids and high pectin content in the jam and can be prevented by adding more sugar. If this cannot be done a small quantity of sodium bicarbonate is added to reduce the acidity and thus prevent pre-coagulation.

Surface graining and shrinkage: This is caused by evaporation of moisture during storage of jam. Storing in a cool place can reduce it.

Microbial spoilage: The mould attack on jam can be eliminated by storing them at less than 90% RH (Preferably at 80% RH). It is also advisable to add 40 ppm sulphur dioxide in the form of KMS. In the case of cans, sulphur dioxide should not be added to the jam as it causes blackening of the internal surface of the can.

10.4 FRUIT JELLY

A jelly is a semisolid product prepared by boiling a clear, strained solution of pectin containing fruit extract, free from pulp, after addition of sugar and acid. A perfect jelly should be transparent, well set, but not too stiff, and should have the original flavour of the fruit. It should be of attractive colour and keep its shape when removed from the mould. It should be firm enough to retain a sharp edge but tender enough to quiver when pressed. It should not be gummy, sticky, or syrupy or have crystallized sugar. The product should be free from dullness with little or no syneresis, and neither tough nor rubbery.

10.4.1 Preparation of Jelly

Jellies are gellified products obtained by boiling fruit juices with sugar, with or without the addition of pectin and food acids. Jellies are usually manufactured from juices obtained from a single fruit species only, obtained by boiling in order to extract as much soluble pectin as possible.

Selection of fruits: Guava, sour apple, plum, papaya, certain varieties of banana and gooseberry are generally used for preparation of jelly. Other fruits can also be used but only after addition of pectin powder, since these fruits are low in pectin content. Fruits can be divided into four groups according to their pectin contents. This classification is highly useful in preparation of jelly, because pectin is the important component, which is responsible for the texture of the jelly. The classification is as follows.

- Rich in pectin and acid: sour apple, grape, lemon, sour oranges, jamun, sour plum.
- Rich in pectin but low in acid: apple, unripe banana, pear, ripe guava, etc.
- Low in pectin but rich in acid: sour apricot, sweet cherry, sour peach, pineapple and strawberry.

- Low in pectin and acid: ripe apricot, peach, pomegranate, strawberry and any other overripe fruit.

Extraction of pectin/boiling: After selection, the fruits are washed thoroughly as with jam preparation discussed earlier. Most of the fruits are boiled for extraction of the juice in order to obtain maximum yield of juice and pectin. Boiling converts protopectin into pectin and softens fruit tissues. Very juicy fruits do not require the addition of water and are crushed and heated to boiling only for 5 min. Firm fruits are cut or crushed and boiled with water for 5 min. The length of boiling will vary according to the type and texture of fruit. The amount of water added to the fruit must be sufficient to give a high yield of pectin e.g. apples require one half to an equal volume of water, where as citrus fruits require 2-3 volumes of water for each volume of sliced fruits.

Straining and clarification: Pectin extract is obtained by straining the boiled fruit mass through bags made of linen, flannel, or cheese cloth folded several times. For large scale production, the fruit extract is made to pass through filter presses for clarity.

Analysis of extract: Clarified extract is analysed for pH, acidity, soluble solids and pectin content by common laboratory methods. For determining pectin content the easiest way adopted is precipitating the pectin with alcohol. A rapid test for evaluation of juice pectin content is by mixing a small sample of juice with an equal volume of 96% alcohol in a tube. The mixture from the tube is then emptied on a plate. The appearance of a compact gelatinous precipitate indicates a sufficient pectin content for jellification (Figure 10.4). Insufficient pectin will remain in numerous small granular lumps.

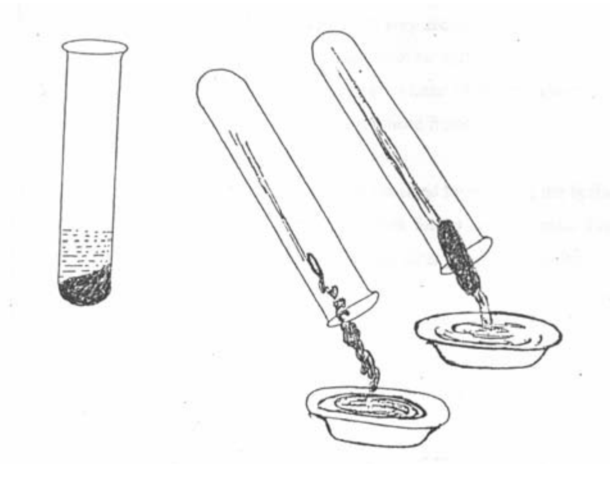


Figure 10.4: Pectin test for jelly extract. a) Low pectin extract; b) High pectin extract

Addition of sugar and pectin: Based on the pectin test of the fruit extract, quantity of sugar to be added is worked out. For the extract rich in pectin, sugar equal to the quantity of the extract is added. To the extract with moderate pectin 650 – 750 g of sugar should be added to each kg of extract. For juices rich in pectin, jellification will occur without pectin addition. If pectin content is less, 1-2% powder pectin will be added to the juice.

Addition of acid: Jelly strength increases with increasing hydrogen ion concentration until an optimum pH is reached which is generally 3.2 at 65%

sugar concentration. Jellying strength depends on the quantity of pectin and the acid present in the original fruit extract.

Processing/boiling: The juice is boiled up to remove about half of the water that has to be evaporated. Then the calculated sugar quantity is added gradually. The remainder of the water is evaporated until a TSS (refractometric extract) of 65% is reached. During boiling it is necessary to remove foam / scum formed. Product acidity must be brought to about 1% (malic acid) corresponding to pH > 3. Any acid addition is performed always at the end of boiling. Boiling of jellies is performed in small batches (25-75 kg) in order to avoid excessively long boiling time which brings about pectin degradation.

10.4.2 Judging of End Point

Boiling of jelly should not be prolonged, because excessive boiling results in greater inversion of sugar and destruction of pectin. The end point can be judged by sheet test, drop test, refractometry, thermometer, and by weighing the boiling mass. Methods like sheet test, drop test, and weighing of the boiling mass can be done in the similar way as in the case of jam preparation.

Refractometer method: This is the most common method used in fruit processing industries for jelly making. The cooking is stopped when the refractometer shows 65^{o} Brix.

Temperature test: A solution containing 65% TSS boils at 105^{o}C. Heating of the jelly to this temperature would automatically bring the concentration of solids to 65%. Endpoint of finishing jelly should be 4.5-5^{o}C higher than that of the boiling point of water at that place.

10.4.3 Packaging

After jelly is ready, it is skimmed to remove foam. It is cooled slightly before pouring into dry and hot glass jars. Cooling is optional and is carried out up to 85^{o}C, in double wall baths with water circulation. Filling is performed at a temperature not below 85^{o}C in receptacles (glass jars, etc.), which must be maintained still for about 24 hours to allow cooling and product jellification.

10.4.4 Important Considerations in Jelly Making

Pectin, acid, sugar (65%), and water are the four essential ingredients in jelly. Pectin test and determination of end point of jelly formation are very important for the quality of jelly.

Pectin: Pectin is the most important constituent of jelly. Stiffness of the gel increases with increasing concentration of pectin up to a certain point beyond which the addition of more pectin has little effect. Too little pectin gives a soft syrup instead of gel. Pectin tends to keep the sugar from crystallizing by acting as a protective colloid, but is not effective when the concentration of sugar is 70% or more. The amount of pectin extracted varies with the method of extraction, the ripeness of the fruit, the quantity of the water added for extracting the juice and the kind of fruit. Usually about 0.5-1.0 % of pectin in the extract is sufficient to produce good jelly. If the pectin content is higher a firm and tough jelly is formed and if it is less the jelly may fail to set.

Acid: The jellying of extract depends on the amount of acid and pectin present in the fruit. Tartaric acid gives a better result compared to citric and malic acid. The final jelly should contain at least 0.5% but not more than 1% total acid. Higher percentage of acid may cause syneresis of jelly.

Sugar: This is an essential constituent of jelly, which imparts to it sweetness as well as body. If the concentration of the sugar is high, the jelly retains less water resulting in a stiff jelly. When sugar is boiled with an acid it is hydrolysed into dextrose and fructose. Because of this partial inversion of the sucrose, a mixture of sucrose, glucose and fructose are found in the jelly. This mixture is more soluble in water than sucrose alone and hence the jelly can hold more sugar in solution without crystallization.

10.4.5 Problems in Jelly Making

The most important difficulties that are experienced are as follows:

- ***Failure to set:*** This may be due to the addition of too much sugar, lack of acid or pectin, cooking below/ beyond the end-point.

- ***Colour changes:*** Darkening at the top of the jars can be caused by storing them in too warm place or by an imperfect jar seal.

- ***Gummy jelly:*** It is the result of prolonged or over cooking in which more than desired inversion of sugar occurs

- ***Stiff jelly:*** Over cooking or using too much pectin makes too tough jelly which fails to spread when applied on bread.

- ***Cloudy or foggy jellies:*** It is due to the use of non-clarified juice or extract, use of immature fruits, over-cooking, over-cooling, non-removal of scum, faulty pouring, and premature gelation.

- ***Formation of crystals:*** It is due to addition of excess sugar and also due to the over-concentration of jelly. This excess sugar comes from over cooking, too little acid or from under cooking.

- ***Syneresis or weeping of jelly:*** The phenomenon of exudation of fluid from a gel is called syneresis or weeping and is caused by several factors. The factors include; excess of acid, too low concentration of sugar, insufficient pectin, premature gelation, and fermentation

- ***Presence of mold:*** Due to imperfect sealing and insufficient sugar.

- ***Colour fading:*** This is due to high temperature and bright light in storage room. Another possible cause could be the insufficient processing to destroy the enzymes affecting colour or the elevated processing temperature, which might cause colour fading. Trapped air bubbles can also contribute to the chemical changes by oxidation.

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 problems in jam preparation?

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2. How will you judge the end point of a jelly?

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10.5 MARMALADE

This is fruit jelly in which slices of the fruit or its peel are suspended. The term is generally used for products made from citrus fruits like oranges and lemons in which shredded peel is used as the suspended material. In the preparation of marmalade, pectin and acid contents are kept on higher side than jelly. Bitterness is regarded as desirable characteristic of product. Marmalades are classified into two: jelly marmalade and jam marmalade.

10.5.1 Jelly Marmalade

Good quality jelly marmalade can be prepared from a combination of Sweet orange/ Mandarin orange and sour orange in a 2:1 proportion. Shreds of sweet orange (Malta) peel are used in the preparation.

10.5.2 Preparation of Jelly Marmalade

Sound, ripened fruit is sorted, washed, and prepared. The mode of preparation varies with the nature of the fruit. The fruits are then cut in to slices and are boiled for the preparation of extract.

Preparation of extract: The extraction of pectin, filtration/ straining of the extract and analysis of the extract is carried out in the same way as that of jelly preparation. This is explained under the headings 2.4.1.

Preparation of peel shreds: The outer layer of yellow portion of citrus fruits is peeled off carefully. The stripped-off peel is cut into slices of about 2-2.5 cm long and 1-1.2 mm thick. Boiling in water with 0.25% sodium bicarbonate or 0.1% ammonia solution can soften the shreds. Before addition to the jelly, the shreds may be kept in heavy syrup for some time to increase their bulk density to avoid floating on the surface when it is mixed with jelly.

Boiling: The fruit extract is boiled before the addition of sugar. During boiling, the impurities in the form of scum, are occasionally removed. When the temperature of the mixture reaches 103^oC, the prepared shreds of peel are mixed in it at the rate of 5-7% of the original extract. Boiling is continued till the end point is reached. The end point is judged in the same way as in the case of jelly. Like jelly, marmalade also contains 65% TSS at 105^oC. Boiling should not prolong for more than 20 min, after the addition of sugar to get bright and sparkling marmalade.

Cooling: The marmalade is cooled to permit the absorption of sugar by the shreds from the surrounding syrup. If the marmalade is filled in hot, the shreds may come to the surface instead of remaining in suspension. During cooling, the product is gently stirred occasionally for uniform distribution of shreds. When marmalade temperature reaches around 85^oC, viscosity of syrup increases and a thin film begins to form on surface, which prevents shreds from coming to surface.

Flavouring: This is done by adding some flavour or orange oil to the product near the end of boiling to supplement the flavour lost during boiling. Generally, a few drops of orange oil are mixed in marmalade before filling into containers.

Packaging and Storage: Like jams and jellies, marmalade is also filled into jars and cans at a temperature around 85^0C. Storage of marmalade must be done in dry rooms (relative humidity at about 75%), well ventilated, medium cool places (temperature 10-20^oC), disinfected and away from direct sunlight and heat. These measures are necessary because marmalade is a hydroscopic product and, by water absorption, favourable conditions for mould development are created.

10.5.3 Jam Marmalade

Jam marmalade is practically made by the method used for preparation of jelly marmalade except that the pectin extract is not clarified. The orange peel after removing albedo portion is sliced into 0.3 cm thick pieces and treated in the same way as recommended for jelly marmalade. The sliced fruit of orange, lemon, or grape fruit after removing peel is mixed with little quantity of water and boiled to soften. The boiled mixture is pressed through coarse pulper to remove seed and to get thick pulp. The pulp is mixed with equal quantity of sugar and cooked to a consistency of 65^o Brix or consistency of jam. The treated shreds are mixed in the jam when it is slightly cool. Some orange oil is also mixed in the marmalade before filling into containers. Filling and packaging is done in the similar way as adopted for packaging of jelly and jelly marmalade.

10.5.4 Problems in Marmalade Making

Browning during storage is very common which can be prevented by the addition of 0.09g of potassium metabisulphite (KMS) per kg of marmalade and not using tin containers. KMS dissolved in a small quantity of water is added to the marmalade while it is cooling. KMS also eliminates the possibility of spoilage due to moulds.

10.6 PRESERVES

A mature fruit/ vegetable or its piece impregnated with heavy sugar syrup till it becomes tender and transparent is known as preserve. When fruits are placed in a concentrated sugar syrup, the water moves out of the fruit and sugar moves into it until equilibrium is reached by osmosis. Apple, Cherry, anola, pineapple, pear, mango, papaya, strawberry, etc., can be used for making preserves. FPO specifications for preserves are given in Quality section (2.14).

10.6.1 Preparation Methods

Preparation involves primary operations like, selection of fruits, peeling, puncturing (to promote sugar penetration) and blanching. Blanching may be done with or without addictives to inactivate natural enzymes and to reduce the oxidative discolourisation. The blanched fruits are then treated for firming the texture of product. Now, sugar is added concentrated, and packed after the addition of preservatives. Different processes employed for the preparation of preserves from fruits and vegetables at commercial level are explained below.

Rapid process: Fruits are cooked in a low sugar syrup. Boiling is continued with gentle heating until the syrup becomes sufficiently thick. Rapid boiling should be avoided as it makes the fruit tough. The final concentration of sugar should not be less than 68 % which corresponds to a boiling point of 106 ^{o}C. This is simple and cheap process but the flavour and colour of the product are lost considerably during boiling.

Slow process: In this method, the fruits are blanched until it becomes tender. Sugar, equal to the weight of fruit, is then added to the fruit in alternate layers and the mixture allowed to stand for 24 hours. Then by boiling on second, third, and 4th day consecutively the strength of syrup is raised to 70 % TSS. A small quantity of citric or tartaric acid is also added to invert a portion of the cane sugar and thus prevent crystallization. The prepared preserve is then packed in containers.

Vacuum process: The fruit is first softened by boiling and then placed in the syrup which should have 30-35% TSS. The fruit syrup blend is then transferred to a vacuum pan and concentrated under reduced pressure to 70 % TSS. Preserves made by this process retain the flavour and colour of fruit better than by the other two methods.

Packaging of preserve: The preserve is cooled quickly, drained free of syrup and then filled in dry containers. Freshly prepared boiling syrup containing 68% TSS is then poured into the jars/containers which are then sealed air tight. In commercial scale production, however, it is better to sterilize the cans to eliminate any possibility of spoilage of product during storage.

10.7 CANDIED FRUIT/ VEGETABLE

A fruit or vegetable impregnated with cane sugar or glucose syrup, and subsequently drained free of syrup and dried, is known as candied fruit/vegetable. The most suitable fruits for candying are pineapple, cherry, anola, karonda, papaya, apple, peach, peels of orange, ginger etc.

Preparation: The process for making candied fruit is practically similar to that for preserves. The only difference is that the fruit is impregnated with syrup having a higher percentage of sugar or glucose. A certain amount (25-30 %) of invert sugar or glucose is substituted for cane sugar. The total sugar content of the impregnated fruit is kept at about 75% to prevent fermentation. It is desirable that cane sugar and invert sugar in the final syrup should be in equal proportion approximately. The syrup left over from the candying process can be used for candying another batch of the same kind of fruit.

Draining and drying: The fruit removed from the syrup is drained for about half an hour and unwanted pieces are removed. The fruit or peel is then wiped with a wet sponge or dipped for a moment in boiling water to remove adhering syrup. Then it is dried in shade or in a dryer at about 66^{o}C for 8 to 10 hours until the fruit is no longer sticky to handle.

10.8 GLAZED FRUIT/ VEGETABLE

Covering of candied fruits /vegetables with a thin transparent coating of sugar, which imparts them a glossy appearance is known as glazing. The FPO specifications for glazed fruits are given in quality section.

Preparation: Glazed fruits are prepared by passing the dried candid fruit through a sugar syrup. The sugar syrup is prepared by boiling a mixture of cane sugar and water (2:1) in a steam pan at 113 to 114 ^{o}C and skimming the impurities as they come up. Heating is then stopped and syrup is cooled to 93^{o}C. Granulation of sugar is achieved by rubbing the syrup with a wooden ladle on the side of the pan. Granulated candies are then placed on trays in warm dry room. To hasten the process, fruits may be dried in a dryer at 49^{o}C for 2 to 3 hours till they become crisp. These are then packed in air tight containers for storage.

10.9 CRYSTALLIZED FRUITS/ VEGETABLES

Candied fruits/ vegetables when covered or coated with crystals of sugar, either by rolling in finely powdered sugar or by allowing sugar crystals to deposit on them from a dense syrup are called crystallized fruits.

Preparation: The candied fruits are placed on a wire mesh tray which is placed in a deep vessel. Cooled syrup (70% TSS) is gently poured over the fruit so as to cover it entirely. The whole mass is left undisturbed for 12 to 18 hours during which time a thin coating of crystallized sugar is formed. The tray is then taken out carefully from the vessel and the surplus syrup drained off. The fruits are then placed in a single layer on a wire mesh trays and dried at room temperature or at about 49 ^{o}C in dryers.

10.10 FRUITS BAR/LEATHER

Fruit bar or leather can be prepared from different fruit pulps like mango, peach, plum, apricot, papaya, etc. The fruit pulp is taken and its TSS is raised to 30 ^{o} Brix by adding sugar. This pulp is then spread on stainless steel trays smeared with glycerol which are dried in a mechanical dehydrator at 60 $\pm$ 5 ^{o}C for 2 hours. Usually five layers are dried one above the other and the final product is packed in polythene bags.

10.11 FRUIT TOFFEES

This is made by mixing fruit pulp with other ingredients like glucose, milk powder and edible fat. The fruit pulp is first concentrated to half its volume. Generally, for one kilo gram of concentrated pulp, 160 g of glucose, 320 g of milk powder and 200 g of edible fat is added. This mixture is further heated to a thick consistency (75- 80 ^{o}Brix) followed by spreading it as a sheet of one cm thickness on a glycerol smeared flat tray and allowed to cool. Then these are cut into pieces (called as toffees) of desired size, wrap and store it in cool dry place.

10.12 PACKAGING OF THE FINISHED PRODUCT

Since candied and crystallized fruits are hygroscopic, they require waterproof packaging. These are packed in paper cellophane cartons. But with the development of packaging technology various types of flexible films are used, which are cheaper and highly effective in controlling moisture absorption and entry of other undesirable material from outside atmosphere into the food.

10.13 PROBLEMS IN PREPARATION OF PRESERVES/ CANDID FRUITS

- **Fermentation**: It is due to the low concentration of sugar used in the initial stages of preparation.
- **Floating of fruits in jar**: It is due to filling of the preserve without cooling.
- **Toughening of fruit skin or peel**: This is due to inadequate blanching or cooking.
- **Fruit shrinkage**: This is due to cooking of fruits in heavy syrup.
- **Stickiness**: It is due to insufficient consistency of the syrup, poor quality packaging and damp storage conditions.

10.14 QUALITY PARAMETERS

Quality is a measure of the degree of excellence or degree of acceptability by the consumer. The quality characteristics of a product may be due to sensory (colour, texture and flavour), hidden (nutritive value, toxicity, etc.), and quantitative characteristics (yield of jam, jelly etc.). Food quality control is generally defined as the regulation by law of food manufacture, distribution and sale, in order to prevent health hazards and fraud to the consumer. FPO act regulates the manufacture, storage and sale of fruit and vegetable products. The details of FPO and other aspects of quality are detailed in Unit 1.

The FPO specifications includes: methods of preservation, permissible colours in the preparations and also the minimum quality requirements of the final products. FPO specifications for jam jelly, marmalade, preserve, candy and other sugar based products are as follows:

Product		**Specifications**	
		Minimum % of TSS in final product	**Minimum % of prepared fruit in final product**
1.	Fruit jam	68	45 (25% in case of strawberry jam)
2.	Fruit jelly	65	45
3.	Marmalade	65	45
4.	Fruit preserve	68	55

	Product	**Specifications**	
		Total Sugar (%)	**Reducing sugar as % of total sugar**
1.	Candied and crystallized or glazed fruit and peel	Not less than 70	Not less than 25

Permissible limits of preservatives in fruit beverages

Sl. No.	**Product**	**Preservative**	**Parts per million (ppm)**
1.	Fruit jam, jelly, marmalade and preserve	Sulfur dioxide	150
2.	Crystallized, glazed fruits (including peel)	Sulfur dioxide	150

Some important quality considerations

- Jelly made from sugar and chemical pectin shall be clearly declared as synthetic jelly.
- When dry fruit is used for making jam it shall be clearly declared on the label.
- When preserves are packed in sanitary top cans, the contents shall not be less than 85% of the total space of the can.

10.15 LET US SUM UP

You must have now well understood that the basic principle behind the preparation of sugar based products is the addition of sugar and concentrating them by evaporation to a point where microbial spoilage is arrested.

We have also seen the importance of sugar and various sweeteners and their role in processed foods like jam, jelly etc. The methods for preparation of jam, jelly, marmalade and other sugar based products are detailed in this unit. The special care taken during their preparation are also traced out. A brief note of quality standards and packaging is also included.

10.16 KEY WORDS

Artificial sweeteners : They are synthetic, calorie free, high intensity sugar substitutes, sometimes used in place of other sugars in food manufacturing and cooking.

Glazing : Coating candied fruit with a thin transparent layer of sugar, which imparts them a glossy appearance, is known as glazing.

Crystallized fruit : These are candied fruits covered or coated with crystals of sugar.

Jam : Jam is a product with reasonably thick consistency, firm enough to hold the fruit tissues in position, and is made by boiling fruit pulp with sufficient sugar.

Jelly : Jelly is a semi solid product prepared by boiling a clear, strained solution of pectin containing fruit extract, free from pulp, after addition of sugar and acid.

Humectancy : Ability to retain water.

Inversion of sugar : Inversion is a chemical process in which sucrose breaks down to its constituent sugars: glucose and fructose.

Marmalade : Marmalade is a fruit jelly in which slices of the fruit or its peel are suspended.

Preserve : A mature fruit or its piece impregnated with heavy sugar syrup till it becomes tender and transparent is known as preserve.

10.17 SELF TEST FOR THE COMPLETE UNIT/ ASSIGNMENT

1. List out the various types of sugars.

2. How is marmalade different from jelly?

3. What is preserve? Why vacuum process is better compared to rapid and slow process?

4. What is a glazing? How it is different from crystallized fruit?

10.18 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. The various functional properties of sugar in food system include: source of energy, nutritional aspects, flavour and colour production, sweetening, texturing, plasticizing action and humectancy. Sugars provide readily accessible fuel for physical performance.

2. Sugar alcohols or polyols are slightly lower in calories than sugar and do not cause a sudden increase in blood glucose. Polyols are sweet and can be used in foods in a similar way to sugars although they can have a laxative effect when eaten in large quantities. Commercially they are made by the transforming sugars and are used mainly to sweeten sugar-free candies, cookies, and chewing gums. Eg: sorbitol, and mannitol.

3. Artificial sweeteners are non-nutritive or calorie free, high intensity sugar substitutes. These are sweet synthetic substances, often used in place of other sugars in food manufacturing and cooking. Eg: aspartame and saccharin.

Check Your Progress Exercise 2

1. The various problems encountered in the production of jam includes: Crystallization: due to the lower percentage of invert sugar(<30 %), Sticky or gummy jam: due to high percentage of TSS, Premature setting: due to low TSS and high pectin content, Surface graining and shrinkage: caused by evaporation of moisture and microbial spoilage during storage.

2. The end point of jelly can be judged by sheet test, drop test, refractometry, thermometer, and by weighing the boiling mass. Refractometer method is the most common method used in fruit processing industries for jelly making. The cooking is stopped when the refractometer shows 65 ^{o}Brix.

Answers to Assignments

1. Various types of sugars are available for different food preparations. They are Granulated Sugar, Brown Sugars and Liquid Sugars. Granulated sugar includes: Regular sugar, Fruit Sugar, Bakers Special, Superfine, Ultra -fine, Bar Sugar, Confectioners Sugar, Coarse Sugar, Sanding Sugar, where as Brown Sugars includes: Free Flowing Brown Sugars and Caramelized Sugar. The Liquid Sugars includes Liquid Sugar syrup and invert Sugar.

2. Marmalade is a fruit jelly in which slices of the fruit or its peel are suspended. The term is generally used for products made from citrus fruits like oranges and lemons in which shredded peel is used as the suspended

material. In the preparation of marmalade, pectin and acid contents are kept on higher side than jelly.

3. A mature fruit/ vegetable or its piece impregnated with heavy sugar syrup till it becomes tender and transparent is known as preserve. Since the concentration process is done under vacuum, i.e., at low temperature, the flavour and colour retention will be more in vacuum process. Where as the same will be lost at higher operating temperature in rapid and slow process.

4. Covering of candied fruits /vegetables with a thin transparent coating of sugar, which imparts them a glossy appearance is known as glazing. Where as crystallized fruits are candied fruits/ vegetables covered or coated with crystals of sugar, either by rolling in finely powdered sugar or by allowing sugar crystals to deposit on them from a dense syrup.

10.19 SOME USEFUL BOOKS

1. Girdhari Lal, Siddappa, G.S. and Tandon, G.L. (1995) Preservation of Fruits and Vegetables, ICAR, New Delhi.

2. Sivasankar, B. (2002) Food Processing and preservation, Prentice–Hall of India Pvt. Ltd., New Delhi- 110 001.

3. Verma, L.R. and Joshi, V.K. (2000) Post harvest Technology of Fruits and Vegetables: Handling, processing, fermentation and Waste management, Volume-1, General Concepts and principles, Indus Publishing company, New Delhi.

UNIT 11 PICKLES, CHUTNEYS, SAUCES AND TOMATO PRODUCTS

Structure

11.0 OBJECTIVES

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

- various methods of pickling and their keeping quality;
- preparation of chutney and sauces;

- preparation of various tomato products viz., Tomato Juice, Tomato Puree, Tomato Paste, Tomato Cocktail, Tomato Ketchup, Tomato Sauce, Tomato Soup; and
- quality standards, packaging and storage aspects of finished products.

11.1 INTRODUCTION

In the previous unit, you have learnt about the sugar based products from fruits and vegetables. Now we will see the preservation technique using salt, vinegar, spices, oil etc. Pickles, chutney and sauces are pleasant preserves of mainly fruits and vegetables and are good accompaniment of Indian as well as continental foods. These products improve the taste of food, stimulate the appetite and enhance digestion. Besides providing the diet with a variety, these products also make a nutritional contribution to the food and save time in a busy household schedule.

In this unit, we will study the pickling by different methods, their shelf life and causes of spoilage. An attempt has also been made to illustrate the different processing methods of chutney and sauces. Detailed processing steps of various tomato products and the quality aspects of the finished products are also included.

11.2 PICKLES

Pickle is an edible product preserved in a solution of common salt and vinegar. It is one of the most ancient method of preserving fruits and vegetables. Pickles are good appetizers and add to the palatability of meal. They stimulate the flow of gastric juice and thus help in digestion. Several kinds of pickles are sold in Indian market. Mango pickle ranks first. Pickles can also be prepared from fruits and vegetables like lemon, amla, onion, cauliflower, cabbage, beans, cucumber, bitter gourd, jackfruit, turnip etc. These are commonly made in homes as well as commercially prepared and exported. Fruits are generally preserved in sweetened and spiced vinegar, while vegetables in salt.

11.2.1 Pickling Process

The preservation of food in common salt or in vinegar is called pickling. Pickling may also be the result of fermentation by lactic acid forming bacteria, which are naturally present in large numbers on the surface of fresh vegetables and fruits. These bacteria can grow in acid medium and in the presence of 8-10% salt solution, whereas the growth of majority of undesirable organisms is inhibited. Lactic acid bacteria are most active at 30^{o}C, so this temperature should be maintained, as far as possible, in the process of pickling. Pickling is done in two stages.

Stage I can be done by any of the three following methods:

i) Fermentation with dry salting,
ii) Fermentation in brine, or
iii) Salting without fermentation.

Stage II is finishing and packing.

11.2.2 Fermentation with Dry Salting

In this method, the vegetable is treated with dry salt. The salt extracts the juice from the vegetables and forms the brine, which is fermented by lactic acid bacteria. The method of dry salting in general is as follows:

The vegetable is washed, drained, weighed for preparing pickles. Several alternate layers of the prepared vegetable and salt (20-30 g of dry salt/ kg vegetables) are kept in a vessel which is covered with a cloth and a wooden board and allowed to stand for 24 hrs. During this period brine is formed by osmosis. As soon as the brine is formed, the fermentation process starts and the CO_2 begins to evolve. When fermentation is over, gas formation stops. Under favourable conditions fermentation is completed in 8-10 days, however in cold weather it may take 2 to 4 weeks. When sufficient lactic acid has been formed, lactic acid bacteria stops to grow and no further change takes place in vegetables. However, precaution should be taken against spoilage by aerobic microbes, because in the presence of air "pickles scum", a kind of wild yeast, is formed which brings about putrefaction and destroys the lactic acid. Therefore the product may be preserved and kept by excluding air.

11.2.3 Fermentation in Brine

Steeping of the vegetables in a salt solution of pre determined concentration for a certain length of time is called brining. When vegetables are placed in brine, it penetrates in the tissues of the vegetables and soluble material present in vegetable diffuses into the brine by osmosis. The soluble material includes fermentable sugars and minerals. The sugars serve as food for lactic acid bacteria, which convert them into lactic and other acids. The acid brine thus formed acts upon vegetable tissues to produce characteristic taste and aroma of pickle.

The amount of brine required is usually half the volume of vegetables. Brining is the most important step in pickling. The growth of the majority of spoilage organisms is inhibited by brine containing 15% salt. Lactic acid bacteria, which are salt-tolerant, can thrive in brine of 8-10% strength though fermentation takes place fairly well even in 5 % brine. In a brine containing 10 % salt, fermentation proceeds somewhat slowly. Fermentation takes place to some extent up to 15 % but stops at 20% brine strength. It is, therefore, advisable to place the vegetables in 10 % salt solution for vigorous lactic acid fermentation. After fermentation process, the salt content is now increased gradually, so that by the time pickle is ready, salt concentration reaches 15%.

11.2.4 Salting Without Fermentation

Vegetables are washed, prepared and is mixed with salt (250 g/kg of prepared material). This high salt concentration will inhibit the fermentation. Vegetables packed with large amount of salt get cured. Then, they are drained and excess of salt is removed by soaking them in cold or warm water. Thereafter, the vegetables are stored in plain vinegar of 10% strength for several weeks. Vegetables can also be stored in sweetened and spiced vinegar. The spices can be added in the ground form or essential oil of spices may be added to impart the spice flavour.

11.3 VARIOUS PICKLES

At present, pickles are prepared with salt, vinegar, oil or with a combination of above ingredients with spices. These methods are discussed below:

11.3.1 Preservation with Salt

Salt improves the taste and flavour and hardens the tissue of vegetables and controls fermentation. Salt content of 15% or above prevents microbial spoilage. This method of preservation is generally used only for vegetables, which contains very little sugar. Since the sugar content is less, sufficient lactic acid cannot be formed by fermentation to act as preservative. However, some fruits viz., mango, lemon, etc. are also preserved with salt. An example for pickle preparation with salt is shown in Figure 11.1.

Mangoes (Matured green)
↓
Washing
↓
Peeling
↓
Slicing
↓
Putting slices in jar
↓
Sprinkling salt
↓
Putting in sun for one week
(shaking jar at least twice a day to mix the salt)
↓
Mixing spices
↓
Storage at ambient temperature
(In cool dry place)

Figure 11.1: Flow chart of mango pickle

11.3.2 Preservation with Vinegar

This technology is based on the addition of food grade vinegar which has a bacteriostatic action in concentrations up to 4% acetic acid and bactericidal action in higher concentrations. Vegetables preserved in vinegar need to reach a final concentration of 2-3% acetic acid in order to assure their preservation. To achieve this final concentration, a 6-9% acetic acid vinegar is used, as related to the specific ratio of vinegar: vegetable. This higher concentration treatment helps to expel the gases present in the intercellular spaces of vegetable tissue.

In vinegar pickles, salt (2-3%) and sometimes sugar (2-5%) are also added. If the vinegar concentration is lower than 2%, vinegar pickles need to be submitted to a pasteurization in order to assure their preservation. Mango, garlic, chilies, etc. are preserved as such in vinegar. Vinegar pickles are the most important pickles consumed in other countries. Figure 11.2 shows the schematic flow chart of onion pickle by using vinegar as preservative.

Onion (small)
↓
Peeling
↓
Blanching for 5 minutes
↓
Filling blanched onions in jar
↓
Addition of salt
↓
Keeping for 1-2 days
↓
Draining off water
↓
Addition of vinegar and Spices
↓
Storage

Figure 11.2: Flow chart of onion pickle

11.3.3 Preservation with Oil

Oil pickles are highly popular in India. They are highly spiced. In India, mustard oil, rapeseed oil, sesame oil are generally used. The fruits or vegetables should be completely immersed in the edible oil. Cauliflower, lime, mango and turnip pickles are the most important oil pickles. The pickle remains in good condition for one to two years if handled properly. A schematic flow chart of lemon pickle by using oil as preservative is shown in Figure 11.3.

Lemon
↓
Washing
↓
Cutting into 4 pieces
↓
Squeezing out juice from $1/4^{th}$ amount of fruit
↓
Mixing spices and salt with juice
↓
Mixing with pieces
↓
Filling in jar
↓
Keeping in sun for 4-6 days
↓
Addition of oil after heating
↓
Cooling it
↓
Storage

Figure 11.3: Flow chart of lemon pickle

11.3.4 Preservation with Salt, Vinegar, Oil and Spices

This method combines the advantages of fermentation action of salt and the preservation action of both vinegar and oil. The flavouring property of spices is also made use of. The spices are usually fried in oil and mixed to the prepared fruit/ vegetable before the addition of vinegar. The spices can be added separately or in the form of spice vinegar. A schematic flow chart of tomato pickle by using salt, vinegar, oil and spices as preservative is shown in Figure 11.4.

Tomatoes
↓
Washing
↓
Blanching for 5 minutes
↓
Cooling immediately in water
↓
Peeling & Cutting into 4-6pieces
↓
Frying all ingredients in a little oil (except vinegar)
↓
Mixing with pieces
↓
Heating for 2 minutes & Cooling
↓
Addition of vinegar & remaining oil
↓
Filling in jars & storage

Figure 11.4: Flow chart of tomato pickle

11.4 CONTAINERS USED FOR PICKLING

Metallic vessels should be non corrodible. Usually, wide mouthed jars are used as they are easy to clean. The container should not impart any colour, taste, and flavour of its own to the pickle. Glass vessels, stainless steel, monel metal and aluminum containers are generally used as cooking utensils. The ladles, spoons and measuring vessels should also be of non corrosive materials.

11.5 KEEPING QUALITY

Properly brined vegetables will keep well in vinegar for a long time. The duration of brining is of utmost importance. If the vegetables are soaked for a short time of about 12 hrs only, the curing of the vegetable tissues will be incomplete with the result that the pickle will not have proper texture and taste. Brining has, therefore, to be controlled properly. On curing, the vegetables becomes semi translucent, and their colour changes from green to dark olive green or yellowish green. This is an indication of correct curing. This usually takes 4-5 weeks. By this method the vegetables can be kept more or less for an indefinite period, provided the right storage conditions are maintained. If the vegetable is kept in brine of 10% or less, all air should be excluded from the containers. During curing, the vegetables lose their 'raw' flavour and become firm and crisp.

Shelf life of fermented products: Some vegetables can be stored for years in high concentration of salt solution without a serious loss in quality though they are not stored for more than a year normally. The brine fermented products can be further processed with or without mild heat processing. During fermentation in bulk containers, microbial action influences the shelf stability. Complete conversion of fermentable carbohydrate to lactic acid and other end products renders the packaged products stable to subsequent fermentation. This is due to the presence of residual sugar, which leads to gas pressure and brine turbidity in the final package as a result of yeast and lactic acid bacterial growth. Preservatives like sodium benzoate, benzoic acid, sorbic acid and potassium bi-sulphate may be added to the product to enhance the keeping quality. Microorganisms (e.g. mould) producing softening enzymes should be excluded as they are active at pH values at which the packaged products are held.

11.6 CAUSES OF SPOILAGE

Different kinds of spoilage occur in pickles. They are as follows:

Bitterness: Use of strong vinegar or excess spice or prolonged cooking of spices imparts a bitter taste to the pickle.

Blackening: This is caused by iron which enters through the brine or from the equipment. Some times specific organisms also cause blackening.

Blemishes in pickled onions: Blemishes may sometime occur in the pickles and especially in onion pickles in vinegar. In the case of onions, white blotch is sometimes seen under the first layer of the skin. This appears to be owing either to some kind of fermentation or non removal of all the brine prior to the final pickling of the cured onion in the vinegar.

Cloudiness: When vegetables are placed in vinegar, it is generally presumed that the products will not spoil. In the case of onion and some other vegetables, however, sometimes the vinegar become cloudy turbid, there by spoiling the appearance of the pack. These raw materials being of a very solid structure, the acetic acid in the vinegar may not penetrate deep enough to prevent the activity of bacteria or other microbes that may be present in them . Hence the fermentation stars from inside rendering the vinegar cloudy. This activity of microbes can only be checked by proper brining. Cloudiness may also be caused by the use of a vinegar of inferior quality or imitation vinegar, or possibly by chemical action between the vinegar and the impurities such as calcium, magnesium and iron compounds that may be present in the salt used. This may also be caused by the reaction between the vinegar and minerals naturally present in the vegetable itself.

Dull and faded product: This is due to use of inferior quality materials or insufficient curing.

Scum formation: When vegetables are placed in the brine for curing a white scum is invariably formed on the surface owing to the growth of wild yeast. This scum may be thin or thick in appearance, varying from an almost imperceptible film to a thick wrinkled layer. It retards the formation of lactic acid. As this action may help in the growth of putrefactive bacteria, which causes the vegetable to become soft and slippery, it is essential to remove the scum as soon as it is formed. Addition of about 1% acetic acid helps to prevent the growth of wild yeast on the brine, without in any way hindering the formation of lactic acid. For this reason some manufacturers add a small amount of vinegar to the brine in the initial stage.

Shrivelling: This occurs when vegetables (e.g. cucumber) are placed directly in a very strong solution of salt or sugar or vinegar, Hence, a dilute solution should be used initially and its strength gradually increased.

Softness and slipperiness: This is the most common form of spoilage and caused by the action of bacteria. It is invariably owing to inadequate covering with brine or owing to the use of a week brine. By using a brine of proper strength and by keeping the pickle well below the surface of the brine, this kind of spoilage can be eliminated.

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 the principle of pickling?

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2. What is the need for a higher initial vinegar concentration in vinegar pickling?

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3. What are the causes of pickle spoilage?

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11.7 CHUTNEYS

A chutney is basically a mixture containing fruit or vegetable, spices, salt and/ or sugar, vinegar, etc. The method of preparation is similar to that adopted in the case of jams except that spices and vinegar are added. Chutney of good quality should be reasonably smooth, palatable, appetizing and have the true single flavour of the fruit or the vegetable used for the preparation.

11.7.1 Preparation of Chutney

Ripe fruit or vegetable is selected, cut into slices or pieces of suitable size and are softened by boiling in water. These are then, slowly cooked at a temperature below boiling point. Onion and garlic are added at the start to mellow their strong flavours. Spices are coarsely powdered before they are added to the product. Whole spices, if used, are bruised and tide loosely in muslin cloth before adding to the mixture and removed before bottling. Vinegar, sugar, and spices are added just a little before the final stage of boiling. This prevents the loss of some essential oils of spices and vinegar due to volatilization.

Long cooking of sugar darkens the colour of the chutney. For the preparation of dark colour chutney brown sugar is usually preferred, where as, white sugar is preferred for white colour chutneys. Spiced vinegar gives high quality product. Chutneys usually get thickened on cooling. The chutneys are bottled, while hot, in clean and warm jars which are then, adequately sealed and sterilized. A schematic flow chart of chutney production is shown in Figure 11.5.

Fruit/Vegetable
↓
Grading for Ripeness & Freshness
↓
Washing
↓
Peeling, Slicing/Crown Removing/Coring
↓
Boiling
↓
Cooking with Onion and Garlic and/or Ginger
↓
Adding Coarsely Powdered Spices/ Spiced Vinegar & vinegar
↓
Coking till required consistency obtained
↓
Boiling hot and Sealing
↓
Sterilizing
↓
Cooling
↓
Labelling & Storage

Figure 11.5: Flow chart of chutney production

11.8 SAUCES

Sauces and chutneys are usually made from the same raw materials, spices and flavours, however, difference is that, all sauces are sieved and as a result, are thinner and of smoother consistency than chutneys. The sieving is done to remove the skin, seeds and stalks of fruits, vegetables, and spices and to give a smooth consistency. Here the cooking process is longer compared to the chutney due the use of fine pulp or juice.

Sauces are generally of two kinds, and they are the thin sauces and the thick sauces. A good sauce whether thin or thick, have a continuous flow with no skin, seeds and stalks of the fruit and/ or vegetables and spices used for its preparation, and possesses pleasant taste and aroma. The details of thin and thick sauces are given below:

11.8.1 Thin Sauces

Thin sauces mainly consist of vinegar extract of various flavouring materials like, spices and herbs. Their quality depends mostly on the piquancy of the material used. Some sauces are matured by storing them in wooden barrel or casks. During storage they develop flavour and aroma. Freshly prepared products have often a raw and strong taste and they should, therefore, be matured by storage.

Preparation: For the preparation of thin sauces of high quality, the spices, herbs, fruits, and vegetables are macerated in cold vinegar. Some times, they are also prepared by boiling them in vinegar. The sauce is filtered through a fine or coarse mesh sieve of non corrodible metal, according to the quality desired. The skin, seeds and stalks of fruits, vegetables and spices used, should not be allowed to pass through the sieve as they spoil the appearance of the sauce. The usual commercial practice is to prepare vinegar extracts of each kind of spice and fruit separately, either by maceration or by boiling in vinegar and then blending these extracts suitably before filling the sauce into barrels for subsequent maturation.

Soya sauce made from soybeans and Worcestershire sauce made from tamarind are examples of thin sauces. The Worcestershire sauce is utilized in the preparation of cocktail also. Figure:6 shows a schematic flow chart of thin sauce production.

Preparation of Thin Sauce

Fruit/Vegetable
↓
Grading for Ripeness & Freshness
↓
Washing
↓
Macerated in cold vinegar with spices & herbs
↓
Extraction of pulp
↓
Cooking with spices/spiced vinegar and Vinegar
↓
Filtering
↓
Bottling
↓
Sealing
↓
Sterilizing
↓
Cooling
↓
Labelling & Storage

Figure 11.6: Flow chart of thin sauce production

11.8.2 Thick Sauces

A sauce which does not flow freely and which is highly viscous is called a thick sauce. On the other hand thin sauces are less viscous in consistency. Thick sauces also contain more of sugar and less of acid. Generally spices and colouring added are practically similar to those in the case of thick ketchups and sauces. It should contain at least 3% acetic acid to ensure its keeping quality. The acidity should not however, exceed 3.4% as otherwise the sauce would taste sharp. The sugar content may usually varied from 15-30% according to the kind of sauce made. Usually malt vinegar is used. In addition to contributing to acidity of the sauce, it also improves its flavour. The sweetness is derived partly from dates, raisin, apple and tomato and partly from the sugar added. The colour of the sauces varies with the raw material use. Some times a little caramel is added.

Preparation: The manufacturing process is the same as for chutneys. Thickening agents are also added to prevent or retard sedimentation of solid particle in suspension in the sauce. In this country apple pulp is often used for this purpose. The starch obtained from maize, potato, arrow root, sago and rye are also used as thickening agents. Indian gum, gelatin, Irish moss, pectin and other similar substances can also be used subject to the food laws of our country. Tomato sauce and apple sauce are some of the examples for thick sauce. Preparation of tomato sauce is explained under the section 3.10.5.

11.9 SOUPS AND OTHER MIXES

Ready to serve soups such as tomato soup, mushroom soup, mixed vegetable soups, especially dried vegetable mixtures for quick preparation of soups at home, are gaining popularity in these days. Liquid soups are generally canned. They are warmed at the time of serving. The preparation and bottling of tomato soup is explained under tomato processing (3.10.8).

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. Differentiate between thin sauce and thick sauce.

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2. How is ketchup different from sauce?

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3. What is the percentage of sugar in sauce & ketchup? What will happen to the product if the whole quantity of sugar is added initially?

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11.10 TOMATO PRODUCTS

Tomato is grown in our country in abundance, in all seasons. The farmer will get a very low profit during the peak-harvesting season and nearly 25% of the produce is spoiled due to improper post harvest practices. Such losses can be avoided by converting tomatoes into delicious products. Tomato can be processed to a variety of products like; canned tomato, paste, puree, juice, ketchup and sauce. In India tomato sauce and ketchup are very popular and are being manufactured on an increasingly large scale.

11.10.1 Tomato Juice

This product is characterised not only by its organoleptical properties (taste, colour, flavour) but also by its vitamin content close to those of fresh tomatoes. Modern technology is oriented to a maximum maintenance of organoleptic properties and of vitamin content.

At same time, it is important to assure juice uniformity by avoiding cellulosic particle sedimentation. A good quality juice should contain about 0.4 % acid (in terms of citric acid), 0.5% salt, and 1 % sugar. Juice stability is assured by a flash pasteurization, which assures the destruction of natural micro-flora, while keeping the initial properties. The modern technological flow sheet covers the following main operations:

Preparation of Tomato Juice

Pre-washing and washing: Pre-washing is carried out by immersion in water, cold or heated up to 50°C (possibly with detergents to eliminate traces of pesticides). Then washing is performed with water sprays.

Sorting: Only sound ripe red coloured tomatoes are used for the juice preparation. This is done on rolling sorting tables. This enables the removal of non-standard tomatoes – with green parts, yellow coloured, etc.

Crushing and pulping: Crushing is carried out in a special equipment. Fluted wooden roller crushers are utilized for this purpose. The crushed tomatoes can be pulped by the hot process or by the cold process. In hot pulping, crushed tomatoes are boiled in their own juice in steam jacketed stainless steel pans or in aluminium pans for 3 to 5 minutes. This process facilitates the extraction, dissolves pectic substances and contributes to the maintaining of vitamins and natural pigments. In some modern installations, this step is carried out under vacuum at 630-680 mm Hg and in very short time. Whereas in cold pulping, the tomatoes are crushed in cold and as such passed through a pulper. Here the extraction of juice is difficult and yield will be less compared to hot process.

Extraction: Extraction of juice and part of pulp (maximum 80%) is performed in special equipment / tomato extractors with the care to avoid excessive air incorporation. In some installations, as an additional special care, a part of pulp is removed with continuous centrifugal separators.

Deaeration and Homogenization: The air from the extracted juice is removed by using a deaerator under high vacuum. Homogenization is done for mincing of pulp particles and is mandatory in order to avoid future potential product "separation" in two layers.

Filling and bottling: After flash pasteurization at 130-150°C for 8-12 second, the juice is cooled at 90°C. This cooled juice is filled in receptacles (cans or bottles) at the same temperature (90^0C). The receptacles are then closed followed by their inversion for about 5 to 7 minutes. Cooling has to be carried out intensely. Full cans do not need further pasteurization because the bacteria that have potentially contaminated the tomato juice during filling are easily destroyed at 90°C due to natural juice acidity.

For bottles, it may be possible to avoid further sterilization if the following conditions can be strictly adhered: washing and sterilizing of receptacles, cap sterilization (with formic acid), filling and capping under aseptic conditions, in a space with UV lamps. Since this is quite difficult to achieve, it may be necessary to subject the bottles for pasteurization in water baths.

11.10.2 Tomato Puree

Tomato pulp without skin or seeds, with or without added salt, and containing not less than 9.0% of salt free tomato solids is known as "Medium tomato puree". It can be concentrated further to 'heavy tomato puree', which contains not less than 12% solids.

Preparation of tomato puree: Manufacturing steps fall into three successive categories: (i) obtaining tomato juice from the raw materials; (ii) juice concentration and (iii) tomato puree pasteurization. Tomato pulp and juice extraction is done from ripe tomatoes in the same manner as tomato juice preparation.

Concentration of the pulp is carried out either in an open cooker or in a vacuum pan. In open cooking, most of the vitamins are destroyed and the product becomes brown. On the other hand, use of vacuum pans, nutritive value is preserved and browning is also reduced. However this method is quite expensive. Ordinarily tomato juice can be concentrated to lower range in an open cooker, but for obtaining higher concentrations a vacuum pan is required. The end point is judged by determining the TSS. This is done by using either a specific gravity hydrometer or by a refractometer.

Tomato puree pasteurization assures the microbiological stability of the product. For this purpose, the puree coming out from concentration equipment is passed continuously and in a "forced" mode through a tubular pasteurizer from which it emerge, at a temperature of 90-92° C. The pasteurized puree is then filled hot in to cans or in glass receptacles.

11.10.3 Tomato Paste

The product with highest production volumes among concentrated products is tomato paste, which is manufactured in a various range of concentrations, with a minimum of 25% and up to 44% refractometric extract. The product is very similar to tomato puree except that the solid concentration is more. Tomato paste is the product obtained by removal of peel and seeds from tomatoes, followed by concentration of juice by evaporation under vacuum. Good quality tomato paste is a homogenous mass, with a high density, without foreign bodies (seeds, peel, etc.), with a red colour, and an agreeable taste and smell, close to those of fresh tomatoes.

Preparation procedure is also similar to that of tomato puree. Here the tomato juice obtained is further concentrated so that it contains not less than 25% tomato solids. This is known as tomato paste. On further concentration to 33% or more of solids, it is called concentrated tomato paste. Paste of good quality must have a volatile acidity of maximum 0.15% as lactic acid. An 8% salt addition is accepted. The end point is judged by using a refractometer. The product with required TSS is then pasteurized and filled into receptacles in the same way as explained under tomato puree.

11.10.4 Canned Tomato

The process of sealing tomatoes hermetically in containers and sterilizing them by heat for long storage is known as canning. The principle of canning is the destruction of spoilage microbes within the sealed container by thermal processing, i.e., by means of heat. Schematic representations of the unit operations are shown in Figure 11.7.

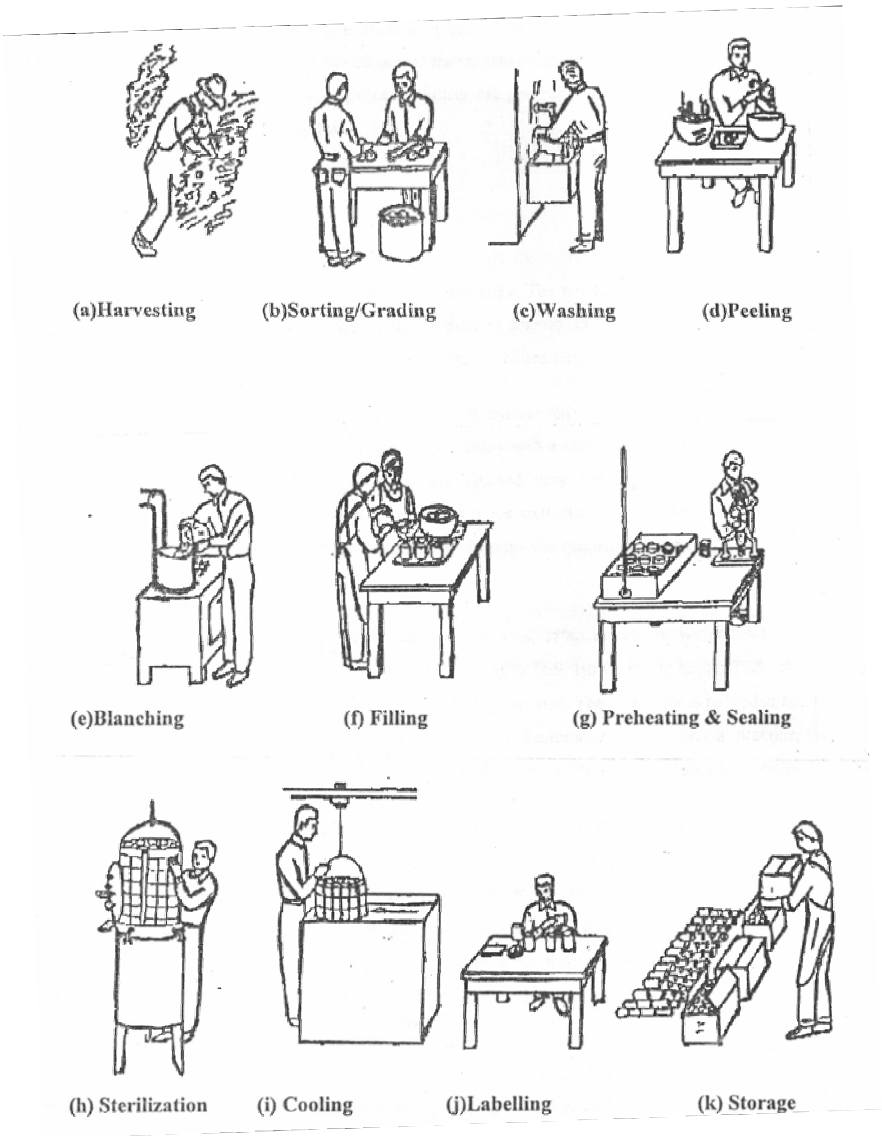

Figure 11.7: Schematic representation of fruit canning unit operations

Canning process: Canning involves the pre-treatments like selection of sound fruits and vegetables, grading, washing, peeling, cutting, blanching and cooling .The blanched tomato pieces are filled in plain cans and tomato juice is used as covering liquid. The filled cans are now subjected to exhausting for the removal of air and are then sealed immediately. The sealed cans are then thermally processed at high temperature (100°C) for about 25-30 minutes. After thermal processing, the cans are cooled rapidly to about 39°C to stop the cooking process and stored after labelling.

11.10.5 Tomato Sauce

Tomato sauce is the concentrated product prepared from the liquid extract from mature, sound, whole tomatoes to which is added salt, spices, sugar, vinegar, with or with out onion, garlic, or other vegetable flavouring ingredients. The final concentrated product contains not less than 12% tomato solids and 25% TSS. FPO specifications are given under quality standards.

Sauces can be obtained from fresh tomatoes or from concentrated products (tomato paste or concentrated tomato juice), those from fresh tomatoes being of superior quality. Technological processing covers the following steps: concentrated juice processing, addition of flavour/taste ingredients (salt, sugar, vinegar, spices, etc.), boiling, fine sieving, filling of receptacles, closing and pasteurization (45 min at 85°C).

Special care: About one third of the sugar required is added at the time of commencement of boiling to intensify and fix the red tomato colour. If the whole quantity of sugar is added initially, the cooking time will be longer and the quality of pulp will be adversely affected. Generally the sugar content in sauces/ ketchups varies from 10- 26 %. On the other hand, salt bleaches the colour of the tomato product. It is therefore desirable to add towards the end of cooking process. Spices are generally added in powdered form to the product by spice bag method.

11.10.6 Tomato Ketchup

Tomato ketchup is a popular condiment all over the world. Tomato ketchup is similar to tomato sauce except that it is thick in consistency. The amount of spices added in case of tomato ketchup is considerably higher than in tomato sauce. Thick sauces made from fruits and vegetables other than tomatoes are not called ketchups.

Preparation: Clean, wholesome tomatoes of intense red colour and of meaty, not watery texture are used for sauce making. High acidity and a rich tomato flavour are additional desirable qualities. Sound tomatoes are washed very thoroughly, cored, sliced, heat crushed and pulped (through a pulper or juice extractor) to remove seeds and skins. Tomato pulp or paste is then cooked with the requisite quantities of spices, onions, garlic, sugar, salt and vinegar.

The whole mass is concentrated to the required TSS (28%). A ketchup with a 28-30% TSS has a better flavour than those with more than 30% TSS. However the higher TSS ketchup generally keep for a long time, once the bottle is opened. The end point is judged either by means of a specific gravity hydrometer or by a refractometer. In commercial practice, the juice is concentrated to one third of its original volume as determined with a gauge stick.

Bottling: The mass is finally passed through the finisher, fitted with a very fine sieve, to remove any tomato fibre, and other impurities. The sieved ketchup is filled into clean, dry bottles. The ketchup should be filled hot (88^{o}C) to prevent browning and loss of vitamins during subsequent storage. Bottles are cleaned, labelled and packaged for marketing. Preservation is assured either by use of preservatives or by pasteurization.

11.10.7 Dried Tomato/Tomato Powder

Dried tomato is used for the production of flakes and tomato powder. For the preparation of dried product, tomatoes should be ripe, of good red colour and should be firm. Tomato pigments are stable because they are rich in carotene; therefore, pre-processing, such as blanching and sulphiting, is not necessary. Alternatively the slices may be dipped for 3 min in a solution containing 0.7% $K_2S_2O_5$ (KMS) plus 10% salt.

Washing and sorting are followed by cutting in halves lengthwise to eliminate the liquid and the seeds. Empty the tomatoes and then cut them lengthwise into slices of 6 to 8 mm thickness and place them in dryers. The tomatoes are dry when the raw material / dry product ratio is about 25:1. On an average, 40 g of dried products are obtained from I Kg of fresh tomatoes. The yield depends on the dry tomato residue and the degree of drying.

The dried slices may be reduced to flakes by rubbing through a sieve of about 10 mm mesh. This gives a better-looking product, which is easy to handle. The product may also be ground into powder but this will tend to cake and the colour is less appealing than the flakes. The product is then cooled (half an hour at room temperature), bagged and labelled for storage. The product must be kept in a dark place to reduce infestation by photophilic insects.

11.10.8 Tomato Soup

Soup is becoming very popular in India. Stored soup is warmed at the time of serving. The main constituents of the soup are tomato juice, butter or cream, spices, flour or starch (for thickening), onion, etc.

Preparation: In its preparation the first step is the preparation of tomato pulp just as in the case of tomato juice. Neutralize about $1/6^{th}$ of the acidity of the juice by adding a thin paste of sodium bicarbonate in water. The juice is then concentrated in a boiling pan. While it is being concentrated, add the spices in a cloth bag as in the case of tomato ketchup. In the meantime, mix the flour/ starch and butter/cream with one portion of juice (usually 10 to 15% of the total juice) to form a smooth paste. When the juice in the pan has been sufficiently concentrated, add this paste to it. Continue boiling to the desired consistency. Stirring is done continuously to prevent clotting of the starch. At the end, add sugar and salt and boil the mixture for about two minutes to dissolve them.

Bottling: The tomato soup is filled into cans and closed them properly for sterilization. Sterilization is carried out at 115^0C for 40- 45 minutes. The sterilized cans are cooled and stored in ambient temperature in a cool and dry place.

11.10.9 Chilly Sauce

It is highly spiced product made from ripe, peeled and crushed tomatoes and salt, sugar, spices, vinegar, with or without onion and garlic. The method of preparation is similar to that for tomato sauce except that the total unstrained pulp is used and the seeds are not removed. Hot product is filled in bottles or cans and processed in water at 85-90^{o}C for 30 minutes.

11.10.10 Tomato Pickle

Tomato pickles can be produced by using a combination of preservatives like salt, oil, spices and vinegar. The detailed method of the pickling process and flow chart for the same is explained under the section 3.3.4.

11.10.11 Tomato Chutney

Tomato chutney is produced from tomato pulp, and other ingredients like sugar, salt, vinegar, spices, onion, ginger, garlic, etc. The preparation of tomato chutney is similar to that of the chutney produced from other fruits and vegetables. The method of preparation is explained under the section 3.7.1.

11.10.12 Tomato Cocktail

Tomato cocktail is gaining popularity in many of the high-class hotels and restaurants. It is prepared just before serving and some times is also served from stock. In the later case, the cocktail is preserved by pasteurization in bottles. Although the recipes vary, the main constituent is tomato juice to which common salt, vinegar, Worcestershire sauce (Sauce from tamarind), lemon juice, etc. are added in different proportions to suit the palate.

The preparation of tomato juice is done in the similar way as explained in earlier products. Fresh or canned juice can be used for the cocktail production. Boil the tomato juice with the spices loosely tied in a cloth bag for about 20 minutes in a covered vessel. Then add the limejuice, vinegar and common salt. Only crystal clear limejuice should be used, because any sediment in it will impart an undesirable flavour.

Bottling: When all the ingredients have been mixed and the cocktail is ready for bottling, heat the cocktail to 82^{o}C to 88^{o}C and fill it into bottles, which have been sterilized and kept hot for filling. Close the bottles and keep them immersed in boiling water (100^{o}C) for 30 minutes and then cool them.

11.11 MICROBIOLOGY OF RAW & FINISHED PRODUCTS

When tomatoes of poor quality are used in the preparation of tomato products, excessive amount of moulds, yeast, bacteria and fragments of insects lower the quality of the product. There are some prescribed limits for the mould, yeast and bacteria count permitted in the tomato products. Of these, mould count is the most important as it is the sure and positive indication of the condition of the tomatoes used. The insect fragment count is also highly indicative of gross contamination of the fruit and unhygienic conditions during handling and preparation of the raw material and finished products.

A minimum of 10 minutes heating of the sauce with 0.5% acetic acid could ensure the destruction of spore formers and addition of 750 ppm of sodium benzoate to the sauce would prevent microbial spoilage during storage.

11.12 PROBLEMS IN TOMATO PROCESSING AND MEANS TO AVOID THEM

11.12.1 Tomato Juice

- "Separation" in layers is due to not enough homogenisation or low / insufficient viscosity. In the first case it is necessary to intensify homogenisation; and in second to increase the pre-heating temperature to 60° C in order to obtain protopectine hydrolysis and pectolytic enzymes inactivation.
- Moulding of the juice is brought about by significant infection of raw materials, inadequate washing and control or by use of contaminated packages. The preventive measures should be decided after cause analysis. Good pasteurization can destroy all moulds but the bad juice taste remains.
- Fermentation of juice is manifested by a significant development of gases. Prevention methods are the same as for moulding.
- Tomato juice turns sour, without the formation of gases; this defect is initiated by thermophyl and thermo-resistant bacteria; the juice acquires a vinegary taste. Prevention: maintenance of flash pasteurization temperature at 130-135°C.
- Excessive vitamin C losses are due to a simultaneous action of heating and oxygen from air. It can be prevented by blocking air going into crusher and extractor, close receptacles in vacuum and assure an intensive de-aeration (vacuum degree 700 mm Hg) at a temperature of at least 35-40°C.
- Weak colour of tomato juice can be avoided by the utilisation of mature tomatoes and with a pulp of as red a colour as possible.

11.12.2 Tomato Paste and Puree

- Presence of sand is caused by inadequate washing or by a significant contamination of raw material; this can be prevented by a more intensive pre-washing and washing of tomatoes.
- There may be mould especially at the surface of tomato paste packed in drums. This can be prevented by accurate pre-washing and washing, following pasteurization instructions, packing in clean drums or receptacles, and closing receptacles immediately after filling.
- Fermentation is manifested by a weak alcohol smell or by a weak vinegar taste; when the fermentation is more advanced there is gas production in the product mass. Prevention: as for moulding prevention.

11.12.3 Tomato Sauces

Surface of the product turns black at the contact zone with air; this is due to the action of iron on the tannins from spices, tomato seeds, etc. Prevention is by avoiding iron equipments, avoiding crushing of tomato seeds and by sealing the receptacles under vacuum.

11.13 QUALITY STANDARDS

The importance of quality and its considerations has been discussed in detailed in Unit 1. Now we will see the FPO specifications for the products discussed in the present unit. FPO specifications for tomato products, pickles, chutneys and sauces are as follows:

Sl. No.	Product	Minimum TSS (%)	Mould count
1.	Tomato juice	5.00	Not in excess of 30% of the field examined.
2.	Tomato soup	7.00	
3.	Tomato puree	9.00	Not in excess of 60% of the field examined
4.	Tomato paste	25.00	
5.	Tomato ketchup/ sauce	25 .00(minimum acidity as acetic acid 1%)	Not in excess of 40% of the field examined
6.	Sauces other than tomato and soybean	15 .00(minimum acidity as acetic acid 1.2%)	Not in excess of 40% of the field examined

Permissible limits of preservatives in fruit beverages

Sl. No.	Food product	Preservative	Parts per million (ppm)
1.	Pickles and chutneys made from fruits and vegetables	Benzoic acid or Sulfur dioxide	250 100
2.	Tomato and other sauces	Benzoic acid	750
3.	Dehydrated vegetables	Sulfur dioxide	2000
4.	Tomato puree and paste	Benzoic acid	250

Some important considerations:

- In case of oil pickles the name of the fruit or vegetable used shall be declared on the label.
- When more than one vegetable is used in vinegar pickle the product shall be labeled as ‘mixed pickles’.
- In case of sauces other than tomato and soybean, the names of fruits, vegetables or dried fruits used shall be declared on the label.
- In case of fruit chutney, the names of fruits may not be declared on the label, However, in case of mango chutney or other chutneys the content shall be declared on the label.

- Permissible limit of Copper (a toxic element) in tomato ketchup is 50 ppm, where as the same can be up to 100 ppm in tomato puree, paste, juice powder and cocktails.

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 various unit operations in tomato juice preparation?

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2. List out the problems in tomato juice processing.

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3. How can we prevent microbial spoilage in tomato product?

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4. What are the three major steps in tomato puree and paste preparation?

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11.14 LET US SUM UP

Chutney, sauce and pickle are various processed products from fruits and vegetables prepared by using preservatives like salt, vinegar, oil, spies etc. In making such products, the major objective is to provide consumer with more variety among the processed foods and to provide convenience to have fast food. Apart from extending the shelf life of fruits and vegetables, these products enhance sensory properties and nutritive value of food

You must now be well versed with the methods of pickling and chutney and sauce preparation. We have also seen how to obtain diversified products from tomato fruit. Finally, the keeping quality, standards, packaging and storage aspects of the finished products are also explained in this section.

11.15 KEY WORDS

Brine	:	Solution of common salt.
Brining	:	Steeping of the vegetables in a salt solution of pre determined concentration for a certain length of time.
Vinegar	:	It is a liquid obtained by alcoholic and acetic fermentation of material containing sugar. It contains about 4% acetic acid.
Chutney	:	It is an unstrained, concentrated product, which contains a mixture of fruit or vegetable, spices, salt and/ or sugar, vinegar.
Sauce	:	It is a strained, concentrated product, which contains a mixture of fruit or vegetable, spices, salt and/ or sugar, vinegar. These are thinner and smoother in consistency than chutneys.
Tomato paste	:	It is a concentrated and strained tomato product and contains not less than 25% tomato solids.
Tomato puree	:	It is a concentrated and strained tomato product but thinner than the paste and containing not less than 9.0 % of salt free tomato solids.
Spice bag	:	Bruised spices tide loosely in muslin cloth
Ketchup	:	Thick sauces made from tomato

11.16 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. The preservation of fruit or vegetable in common salt or in vinegar is called pickling. Pickling is the result of fermentation by lactic acid forming bacteria, which are generally present in large numbers on the surface of fresh vegetables and fruits. These bacteria can grow in acid medium and in

the presence of 8-10% salt solution, whereas the growth of a majority of undesirable organisms is inhibited.

2. Vegetables preserved in vinegar need to reach a final concentration of 2-3% acetic acid in order to assure their preservation. To achieve this final concentration, a 6-9% acetic acid vinegar is used, as related to the specific ratios vinegar: vegetables. This higher concentration treatment also helps to expel the gases present in the intercellular spaces of vegetable tissue.

3. Different kinds of spoilage occur in pickles. They includes: bitterness, blackening, blemishes in case of onion pickles, cloudiness, dull and faded product, scum formation, shrivelling and the most common one is, softness and slipperiness.

Check Your Progress Exercise 2

1. Thin sauces mainly consist of vinegar extract of various flavouring materials like, spices and herbs. Their quality depends mostly on the piquancy of the material used. Where as thick sauce does not flow freely and is highly viscous. Thin sauces are less viscous in consistency. Thick sauces also contain more of sugar and less of acid.

2. Thick sauces made from tomato are known as ketchup. It is similar to sauce except that it is thick in consistency. The amount of spices added in case of ketchup is considerably higher than in sauce. Thick sauces made from fruits and vegetables other than tomatoes are not called ketchups.

3. Generally the sugar content in sauces/ ketchups varies from 10- 26%. If the whole quantity of sugar is added initially, the cooking time will be longer and the quality of pulp will be adversely affected. About one third of the sugar required is added at the time of commencement of boiling to intensify and fix the red tomato colour.

Check Your Progress Exercise 3

1. The various unit operations in tomato juice production include: Pre-washing, washing, sorting, crushing, pulping, extraction of the juice, de-aeration, homogenization, filling and bottling. The filled juice is subjected to flash pasteurization and intensively cooled to ambient temperature for storage.

2. The various problems in the production of tomato juice are as follows: i) Separation in layers due to improper homogenization, ii) Moulding of the juice, iii) Fermentation of juice, iv) Souring of tomato juice, v) Excessive vitamin C losses, and vi) Weak colour of tomato juice.

3. A minimum of 10 minutes heating of the sauce with 0.5% acetic acid could ensure the destruction of spore formers and addition of 750 ppm of sodium benzoate to the sauce would prevent microbial spoilage during storage.

4. The major manufacturing steps of tomato puree and paste fall into three, which includes: i) obtaining tomato juice from the raw materials, ii) juice concentration, and iii) tomato puree preservation by pasteurization.

10.17 SOME USEFUL BOOKS

1. Dauthy, M.E. (1995). Fruit and vegetable processing, FAO Agricultural Service Bulletin 119, Food and Agriculture Organization of the United Nations, Rome.

2. Girdhari Lal, Siddappa, G.S. and Tandon, G.L. (1995). Preservation of Fruits and Vegetables, ICAR, New Delhi.

3. Verma, L.R. and Joshi, V.K. (2000). Post harvest Technology of Fruits and Vegetables: Handling, processing, fermentation and Waste management, Volume-2, Technology, Indus Publishing company, New Delhi.

UNIT 12 DEHYDRATED PRODUCTS FROM FRUITS AND VEGETABLES

Structure

12.0 OBJECTIVES

The various points to be understood from this section are as follows:

- purpose of drying/ dehydration of drying of fruits and vegetables;
- procedure for dehydration of fruits and vegetables;
- methods and principles of different dehydration techniques; and
- packaging, storage and quality aspects of the dried products.

12.1 INTRODUCTION

Drying is the oldest known method of preserving food. Drying or dehydration is the removal of the majority of water contained in the fruit or vegetable. Although preservation is the primary reason for dehydration, it also lowers the cost of packaging, storing and transportation by reducing both the weight and volume of the final product. In addition, dried foods add variety to our diets. In the process of drying sufficient moisture is removed to protect the product from spoilage. The processing should be done in such a way that the food value, natural flavour and characteristic cooking quality of the fresh material are retained after drying

In this unit, we will examine the various steps in the preparation of dehydrated fruits and vegetables. The importance of water activity and the effect of drying on product quality are also discussed in this section. We'll see the working principles of various methods of drying and the comparative merits and demerits of these techniques. You can also learn about the packaging, storage and the special care to be adopted during drying process.

12.2 DEFINITION

Drying or dehydration means the process of removal of moisture by the application of artificial heat under controlled conditions of temperature, humidity and air flow. In this process a single layer of fruits or vegetables, as a whole or as pieces/slices are spread on trays which are placed inside the dehydrator. The initial temperature of the dehydrator is usually high which is gradually reduced.

12.3 USE OF DRIED FRUITS AND VEGETABLES

Of all food preservation methods, drying has received the most widespread and enthusiastic publicity in recent years. The use of dehydrated product has increased due to its advantages over other preservation techniques. The advantages are:

- The weight of a product is reduced to $1/4^{th}$ to $1/9^{th}$ of its original or fresh weight and thus the cost of transport is reduced.
- Due to reduction in bulk of the product, it requires less storage space.
- No preservative is added for its preservation.
- Nutrient concentration is very high per unit weight of dried product.
- Cost of processing is very low, as there is less labour and no sugar requirement.

Dried Fruits tend to be chewy and make delicious snacks. Pieces of dried fruits are good in cookies, muffins, cakes and breads. They can also be reconstituted and used in sauces, pies or added to gelatin salads, cooked cereals and ice cream. In addition to dried fruits, fruit leathers may also be used as snack foods.

Dried Vegetables can be used as chips or reconstituted for a cooked side dish. These are also used in soups, stews, casseroles and stuffings or made into powders. Campers and hikers value dried foods for their light weight, keeping qualities and ease of preparation.

12.4 STATE OF WATER IN FOODS

We know that the micro-organisms can grow very well at high moisture contents (above 80%). They get this water from the food in which they grow. If the water is removed from the food, water will transfer out from the bacterial cell too. This will stop multiplication of bacterial cells. In dehydration, it is important to understand the behaviour of water so that it can be removed most effectively and still leave a high quality product. Partial drying will be less effective than total drying, though for some micro-organisms partial drying may be quite sufficient to arrest bacterial growth and multiplication. Bacteria and yeasts generally require more moisture than moulds. Moulds can grow even on semi-dry foods on which bacteria and yeasts are difficult to survive. Example: moulds growing on partially dried fruits.

Water activity (a_w)

Food technologists often use a measure of "water activity" to describe how water interacts in food products. Water activity determines the lower limit of available water for microbial growth. It is defined as the ratio of the vapour pressure on the aqueous solution to that of pure water at the same temperature. Quantitatively, water activity is a measure of unbound, free water in a system available to support biological and chemical reactions. Water activity, and not absolute water content, is what bacteria, enzymes and chemical reactants encounter and are affected by, at the micro-environmental level in food materials. At the usual temperatures permitting microbial growth, most bacteria require a water activity in the range of about 0.90 to 1.00. Some yeasts and moulds grow slowly at a water activity down to as low as about 0.65.

The a_w has a major role to play on microbial spoilage and chemical changes produced in the food. The water activity of solutions containing solutes such as sugar, salts etc. will be less than 1. For food products, the a_w is generally less than 1. a_w is related to the moisture content of food, the types and concentration of different solutes, and the structure of the food. Two foods with the same water content can have different a_w values depending upon the degree to which water is free or otherwise bound to food constituents.

Free water and Bound water

The state of water in food is denoted by two types viz.; "free water and bound water". The working definition for these terms is "free water is that which gives water activity of one. Bound water gives water activity less than one. In drying process free water is relatively easy to remove from the food products, while bound water takes more energy to release from the food. This is because the bound water is bonded to the cell solutes. Thus the energy required to remove a molecule of water from a food increases as the water activity decreases. This is important to those who design drying operations, since energy is required to provide sufficient driving force for drying.

As a food product dries out and the water molecules becomes less mobile, physical changes also occur in the food. As water is removed, the product becomes more viscous, until a solid state is achieved on complete removal of the water. Thus the state of water present in the food or water activity plays an important role in determining the product quality.

12.5 FACTORS INFLUENCING DEHYDRATION

The drying operation of fruits and vegetables is a complex one since it involves simultaneous exchange of moisture and heat. Drying time in conventional ovens or dehydrators vary considerably depending on the amount of food dried, its moisture content, and temperature and humidity. Some foods require several hours and others may take more than a day. Prolonging drying time (by using lower temperatures) or interrupting drying time may result in spoilage.

Various factors that effect the rate of drying of horticulture produce include the following:

1. Composition of raw material.
2. Size, shape and arrangement of stacking of the produce.
3. Temperature, relative humidity and velocity of air.
4. Pressure.
5. Heat transfer to surface.

It is important to control the air temperature and circulation during the drying process. If the temperature is too low or the humidity too high (resulting in poor circulation of moist air) the food will dry more slowly than it should and microbial growth can occur. Watch temperature closely at the beginning and at the end of the drying period. If the temperature is too high in the initial phase, a hard shell may develop on the surface. This will prevent the removal of moisture from the interior portion and the moisture is trapped inside the food material. This is known as *case hardening*. Temperature, if too high at the end of the drying period may cause food to scorch. Temperature between 49^{o}C to 60^{o}C are recommended for drying fruits and vegetables. Temperature up to 65^{o}C may be used at the beginning, but should be lowered as food begins to dry. However during the last hour of the drying period, the temperature should not exceed 55^{o}C.

12.6 DRYING RATE CURVES

The drying rate curves show the rate of removal of moisture from the fruit or vegetable. There are three different ways to express this physical phenomenon. They are relation ships between drying rate, drying time and moisture content.

Drying time vs. drying rate: While drying, foods do not lose water at a constant rate and the rate of water removal under any set of fixed conditions drops-off as drying progresses (Figure 12.1). In practice, while we may remove 90% of the water in 2 hours, it may require more than 2 hours to remove most of the remaining 10% water. This becomes asymptotic so that zero moisture is never reached under practical operating conditions. This relation is explained in the drying curve "Drying time Vs Drying rate".

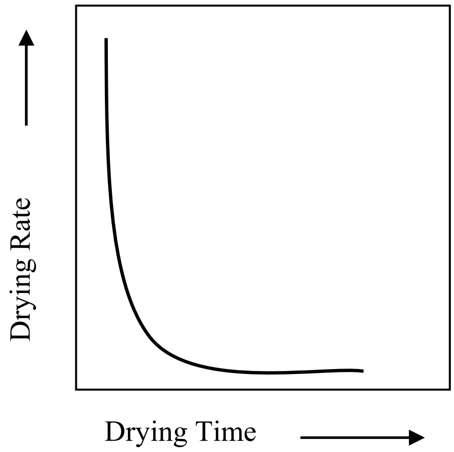
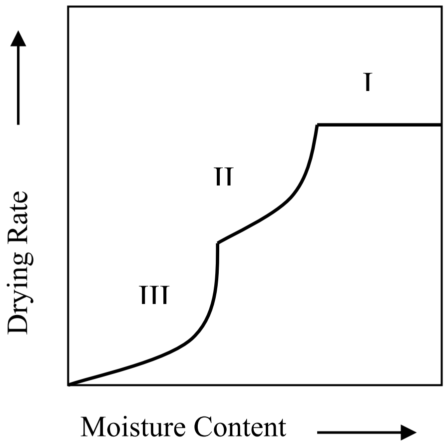


Figure 12.1: Drying time vs. drying rate

Moisture content vs. drying rate: At the beginning of drying, generally, water continues to evaporate from the food pieces at a rather constant rate. This is followed by an inflection in the drying curve, which leads to the falling rate period of drying. The precise shape of the normal drying curve varies with different food materials, different types of dryers and drying conditions. But the drying of most fruits and vegetables generally shows constant and falling rate periods. This relationship is as shown in the Figure 12.2. As the moisture content decreases, the drying rate changes from constant rate of drying to falling rate of drying. During the falling rate period, the rate of water movement from the interior of the food to the surface falls below the rate at which water evaporates to the surrounding air.



I- Constant rate of drying
II- First falling rate of drying
III- Second falling rate of drying

Figure 12.2: Moisture content vs. drying rate

Drying time vs. moisture content: The Figure 12.3 shows a drastic reduction of moisture in the initial phase of drying which reduces to a minimum as drying progresses. During drying process, the moisture content available in the commodity reduces and the removal of water to about 2% without product damage is exceedingly difficult.

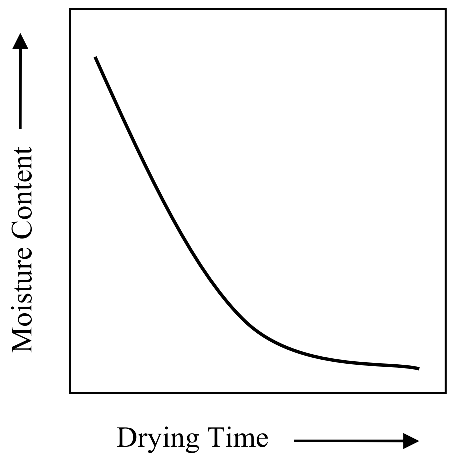


Figure 12.3: Drying time vs. moisture content

12.7 PROCEDURES FOR DRYING

Drying of fruit/ vegetable involves three stages; pre-drying treatments, drying of the commodity and post drying treatments. The flow diagram of drying process is shown in Figure 12.4.

Fruit/vegetables
↓
Washing
↓
Peeling
↓
Preparation
↓
Blanching
↓
Spreading on flat wooden trays
↓
Sulphuring (usually @1.8 to 3.6 kg per tonne of fruit)
↓
Drying/Dehydration
↓
Sweating
↓
Packing
↓
Storage

Figure 12.4: Flow chart of dehydration of fruit/vegetable

12.8 PRE-DRYING TREATMENTS

Pre-drying treatments include raw material preparation and colour preservation.

12.8.1 Raw Material Preparation

This includes selection of fruits, sorting, washing, peeling (for some fruits and vegetables), cutting into the appropriate form, and blanching (for some fruits and most vegetables). Fruits and vegetables are selected and sorted according to size, maturity and soundness. It is then washed to remove dust, dirt, insect matter, mould spores, plant parts and other material that might contaminate or affect the colour, aroma, or flavour of the fruit or vegetable. Peeling or removal of any undesirable parts is followed by washing. The raw product can be peeled by hand, with lye or alkali solution, with dry caustic and mild abrasion, with steam pressure, with high-pressure washers, or with flame peelers.

12.8.2 Blanching

Blanching is used to destroy enzymatic activity in vegetables and some fruits, prior to further processing. To achieve adequate enzyme inactivation, food is heated rapidly to a preset temperature, held for a preset time and then cooled rapidly to near ambient temperatures. The factors that influence blanching time are: the type of fruit or vegetable, the size of the pieces of food, blanching temperature and method of heating. The two most widespread commercial methods of blanching involve passing food through a bath of hot water or an atmosphere of saturated steam. It involved immersion in hot water (95^o to 100^o C) or exposure to steam to inactivate the enzymes present in fruits and vegetables. Both types of equipments are relatively simple and inexpensive.

12.8.3 Sulphuring

The final step in the pre-drying treatment is colour preservation, also known as sulphuring. The majority of fruits are treated with sulphur dioxide (SO_2) for its antioxidant and preservative effects. The presence of SO_2 is very effective in retarding the browning of fruits. In addition, SO_2 treatment reduces the destruction of carotene and ascorbic acid, which are the important nutrients for fruits.

In addition to colour preservation, the presence of a small amount of sulphite in blanched, cut vegetables improve storage stability and makes it possible to increase the drying temperature during dehydration. This will decrease the drying time and increase the dryer capacity without exceeding the tolerance for heat damage.

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 water activity? And why it is important for drying process?

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2. What are the factors influencing dehydration?

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3. What is the purpose of blanching?

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12.9 DRYING METHODS – THEIR PRINCIPLES AND METHODOLOGIES

Dehydrated fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method used. The selection of the optimal method is determined by quality requirements, raw material characteristics, and economic factors. There are three types of drying processes:

- Sun and solar drying,
- Atmospheric dehydration including stationary or batch processes (kiln, Oven, and cabinet/tray dryers) and continuous processes (tunnel,

continuous belt, fluidized-bed, foam mat, spray, drum and microwave-heated dryers), and

- Sub-atmospheric dehydration (vacuum belt, vacuum drum and freeze dryers).

12.9.1 Sun Drying

Sun drying depends on the weather, honors of sunshine, the temperature and the relative humidity outside. If you live in a hot, dry climate, sun drying may be successful. Its advantage is the low cost. The only investments are drying trays, netting to protect against insects and the food itself. Its main disadvantage is time. What would take 6 to 10 hours to dry using other methods may take 3 to 5 days in the sun. To avoid scorching, move the food into the shade to finish when it is about two-thirds dry.

12.9.2 Solar Drying

It is a modification of sun drying in which the sun's rays are collected inside a specially designed unit with adequate ventilation for removal of moist air. The temperature in the unit is usually 20 to 30 degrees higher than in open sunlight, which results in a shorter drying time. While solar drying has many advantages over sun drying, lack of control over the weather is the main problem with both methods. Solar drying utilizes black-painted trays, solar trays, collectors, and mirrors to increase solar energy and accelerate drying. A typical solar dryer is shown in Figure 12.5.

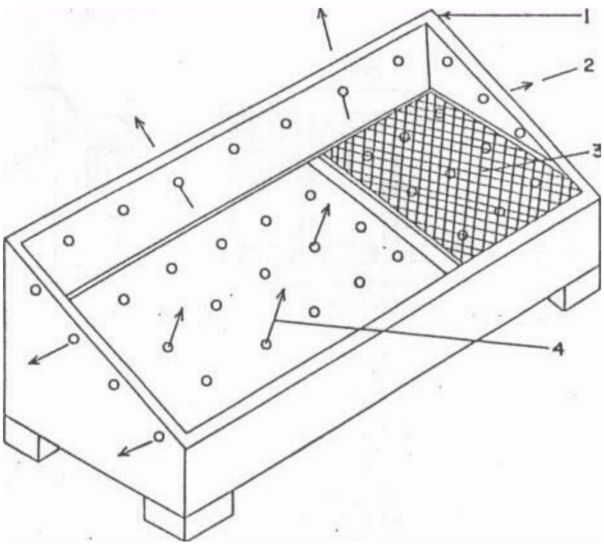

Figure 12.5: Solar cabinet driers: 1) Frame, 2) Exit air, 3) Drying tray, and 4) Air intake

12.9.3 Oven Drying

It is the most practical way to experiment with dehydration. It requires little initial investment, protects foods from insects and dust, and does not depend on the weather. Continual use of an oven for drying is not recommended because ovens are less energy efficient than dehydrators, and energy costs tend to be high. Also, it is difficult to maintain a low drying temperature in the oven, and foods are more susceptible to scorching at the end of the drying period. Oven-dried foods usually are darker, more brittle and of less flavour than foods dried by a dehydrator.

12.9.4 Osmotic Drying

Osmotic drying consists of removing a percentage of moisture from a fruit or vegetable by placing it in a concentrated solution of sugar, salt, or a combination of both. The principle of this drying is osmosis. It is the process of diffusion of water from dilute solution to concentrated solution through a semi permeable membrane. Here fruit cell wall itself will act as a semi permeable membrane. This is shown in Figure 12.6.

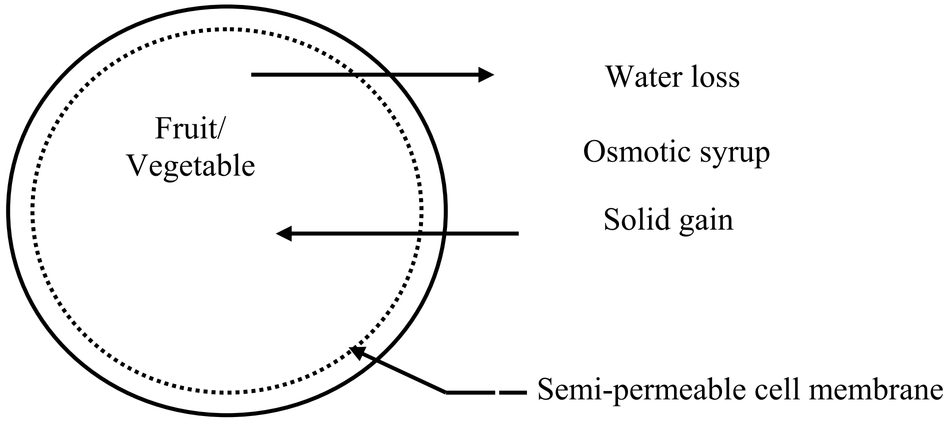

Figure 12.6: Principle of osmosis

The product is reduced to about 50% of its original weight by the osmotic dehydration process. This partial drying process is accompanied by any other drying processes viz. solar drying, vacuum drying, freeze drying, cabinet drying etc. The sugar syrup protects colour and flavour during the drying process. The product has a porous texture and retain a large percentage of the flavour volatiles of the fresh food. The various factors affecting the osmotic dehydration process are type of osmotic agent, concentration, temperature, agitation of syrup, size of the fruit pieces and fruit-to-syrup ratio.

12.9.5 Cabinet Dryers/Tray Dryers

In tray dryers, the food is spread out, generally as thin layer on trays in which the drying takes place. A typical tray dryer is shown in Figure 12.7. Heating may be by an air current sweeping across the trays, by conduction from heated trays or heated shelves on which the trays lie, or by radiation from heated surfaces. Most tray dryers are heated by air, which also removes the moist vapours. Hot air is circulated through the cabinet at 0.5–5.0 m/s per square metre tray area. A system of ducts and baffles is used to direct air over and/or through each tray to promote uniform air distribution. Tray dryers are used for small scale production (1-20 t/day) or for pilot scale work. They have low capital and maintenance costs but have relatively poor control and produce more variable product quality.

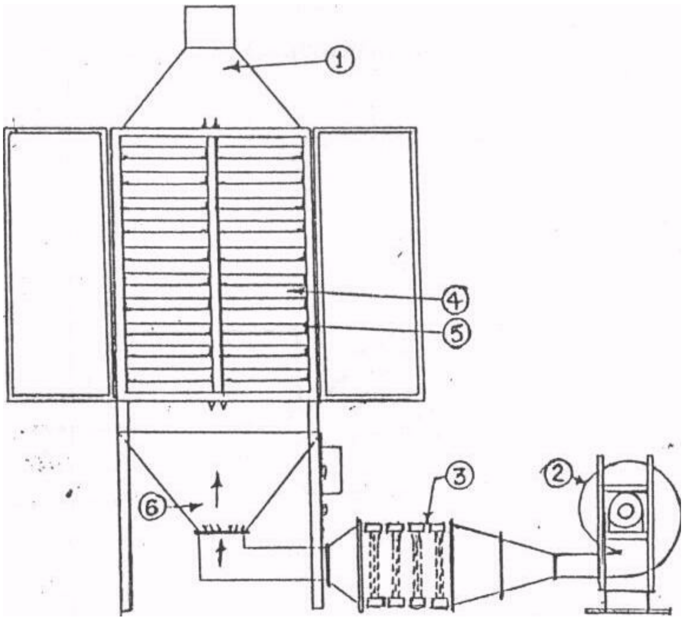

Figure 12.7: Schematic diagram of a typical tray drier: 1) Exit air, 2) Blower, 3) Heater, 4) Inter space between trays, 5) Trays, and 6) Plenum chamber

12.9.6 Tunnel Dryers

Tunnel dryers are the most flexible, efficient, and widely used dehydration system available commercially. These may be regarded as developments of the tray dryer, in which the trays on trolleys move through a tunnel where the heat is applied and the vapour removed. The product trucks are moved through the tunnel at a rate required to maintain the residence time needed for dehydration. The product may be moved in the same direction as the air flow to provide concurrent dehydration (Figure 12.8a), or the tunnel may be operated in a counter-current manner (Figure 12.8b) with product moving in the direction opposite to air flow. Sometimes the dryers are compartmented, and cross-flow may also be used. Typically a 20 m tunnel contains 12-15 trucks with a total capacity of 5000 kg of food. This ability to dry large quantity of food in a relatively short time (5-16 hours) made tunnel drying widely used.

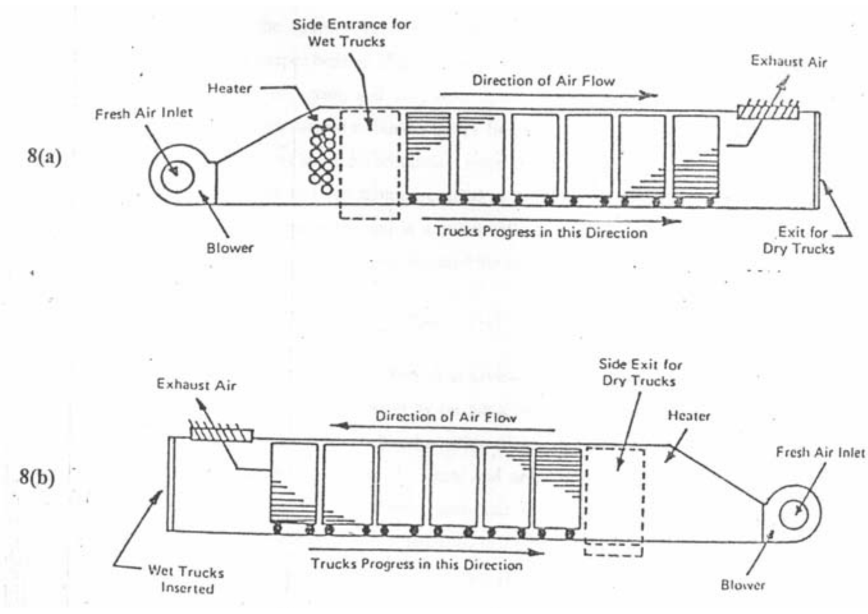

Figure 12.8: Schematic of tunnel driers: a) Concurrent flow drier, b) Counter-current flow drier

12.9.7 Conveyor Dryers or Belt Dryers

Continuous conveyor dryers are up to 20 m long and 3 m wide. Food is dried on a mesh belt in beds 5-15 cm deep. The air flow is initially directed upwards through the bed of food and then downwards in later stages to prevent dried food from blowing out of the bed. This is explained in the Figure 12.9. Two or three stage dryers mix and repile the partly dried shrunken food into deeper beds(to 15-25 cm and 250- 900 cm in three stage dryers). This improves uniformity of drying and save floor space. Foods are dried to 10-15% moisture content and then transferred to bin dryers for finishing. This equipment has good control over drying conditions and high production rates. It is used for large scale drying of foods (for example: fruits and vegetables are dried in 2-3.5 h at up to 5.5 t/h). It has independently controlled drying zones and is automatically loaded and unloaded, which reduces labour cost. As a result, it has largely replaced the tunnel dryer.

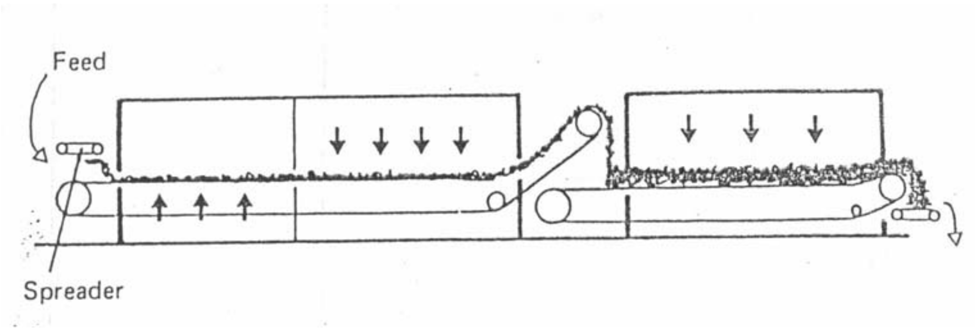

Figure 12.9: A typical two stage conveyor drier/belt drier

12.9.8 Foam Mat Drying

Foam mat drying is another application of conveyor dryers. In this method, liquid foods viz. fruit juices are formed into a stable foam by the addition of a stabilizer (e.g.: Xanthan gum, sorbitol, mannitol, alginic acid, etc.) and aeration with nitrogen or air. The foam is spread on a perforated belt to a depth of 2-3 mm and dried rapidly in two stages by concurrent and then counter current air flows. Foam mat drying is approximately three times faster than drying a similar thickness of liquid by belt drying. The thin porous mat of dried food is ground to a free flowing powder which has good rehydration properties. The rapid drying and low product temperatures result in a high quality product. However a large surface area is required for high production rates, and capital costs are therefore high.

12.9.9 Fluidized Bed Dryers

In a fluidized bed dryer, the food material is maintained suspended against gravity in an upward-flowing air stream. The air thus acts as both the drying and fluidizing medium, and the maximum surface area of food is made available for drying. There may also be a horizontal air flow helping to convey the food through the dryer. Heat is transferred from the air to the food material, mostly by convection. A schematic diagram of fluidized bed dryer is shown in Figure 12.10.

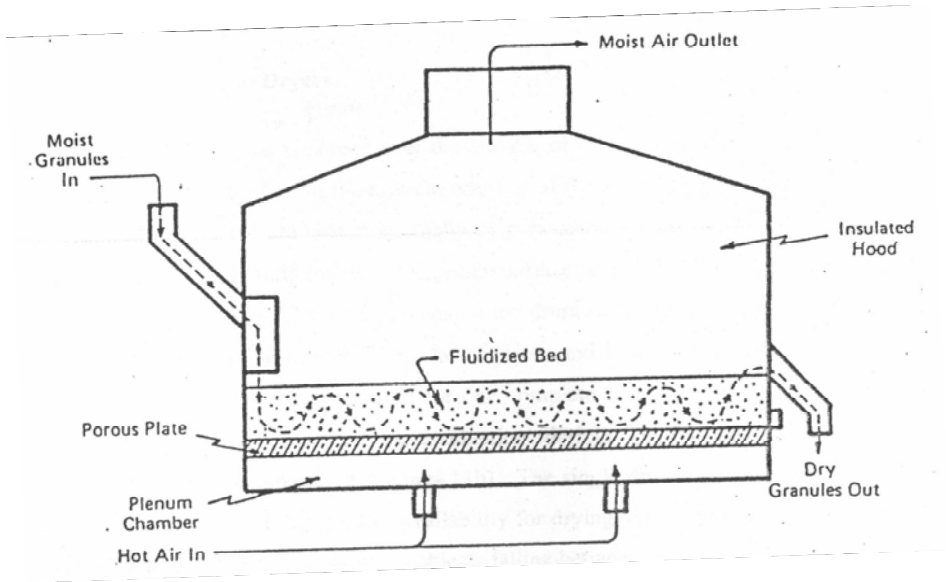

Figure 12.10: Schematic illustration of fluidized bed drier

Fluidized bed dryers are compact and have good control over drying conditions. They have relatively high thermal efficiencies and high drying rates. Fluidized bed dryers are limited to small particulate foods that are capable of being fluidized without excessive mechanical damage (e.g.: peas, diced or sliced vegetables, powders etc.)

12.9.10 Roller or Drum Dryers

In these dryers, the food in liquid or slurry form is spread over the surface of a heated drum. The drum rotates, with the food being applied to the drum at one part of the cycle. These drums are made of hollow steel drums and are heated internally by pressurized steam to 120-170^{o}C. A thin layer of food is spread uniformly over the outer surface by dipping, spraying, spreading or by auxiliary feed rollers. The food remains on the drum surface for the greater part of the rotation, during which time the drying takes place, and is then scraped off by using a 'doctor' blade. Usually the time taken for one complete revolution is 20s to 3 minutes. Drum drying may be regarded as conduction drying. Dryers may have a single drum (Figure 12.11a) or double drum (Figure 12.11b). The single drum is widely used as it has greater flexibility, a larger drum area availability for drying, easier access for maintenance and no risk of damage caused by metal objects falling between the drums.

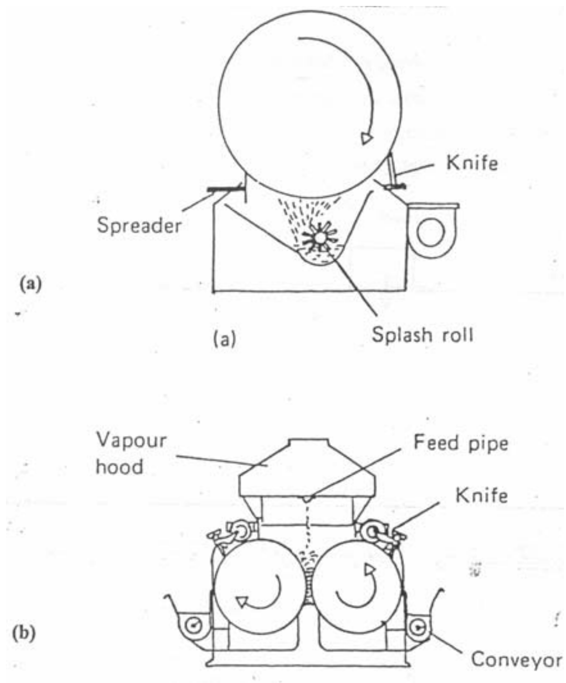

Figure 12.11: Drum driers: a) Single drum, b) Double drum

12.9.11 Spray Dryers

In a spray dryer, liquid or fine solid material in a slurry is sprayed or "atomized" in the form of a fine droplet (10–200 μm)dispersion into a current of heated air (150-300 ^oC). Complete and uniform atomization is necessary for successful drying. Air and solids may move in parallel or counter flow. A schematic of spray dryer is shown in Figure 12.12.

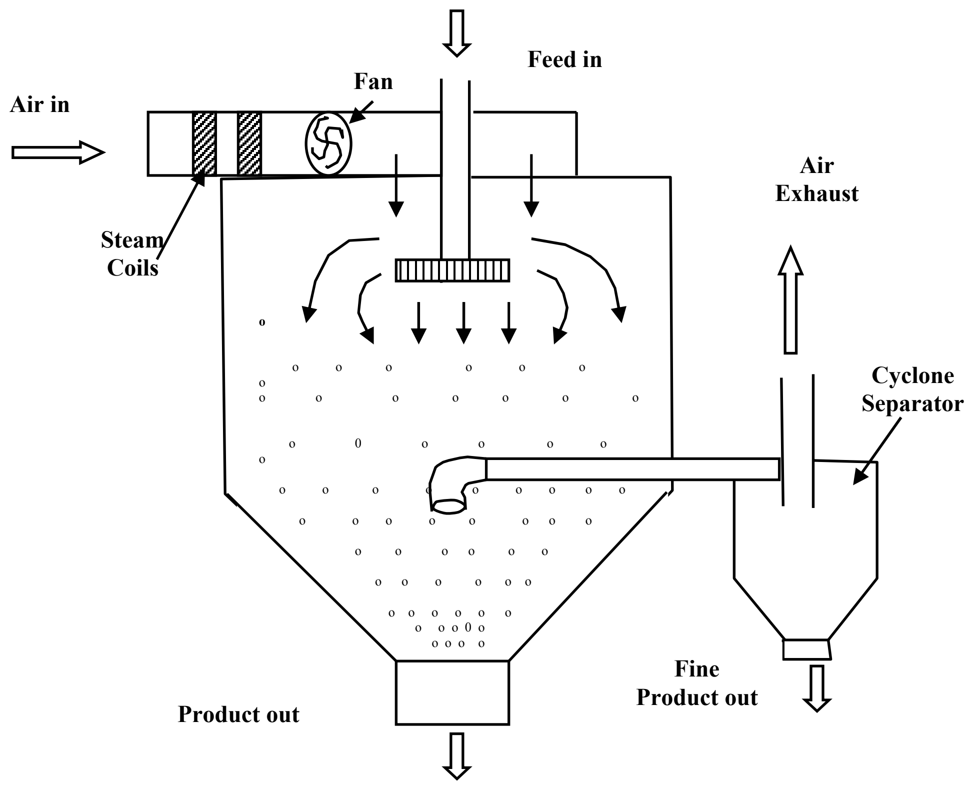

Figure 12.12: Typical schematic arrangement of a spray dryer

Drying occurs very rapidly, so that this process is very useful for materials that are damaged by exposure to heat for any appreciable length of time. The dryer body is large so that the particles can settle, as they dry, without touching the walls on which they might otherwise stick. Commercial dryers can be very large of the order of 10 m diameter and 20 m high. The dry powder is collected at the base of the dryer and removed by a screw conveyor or a pneumatic system with a cyclone separator.

The main advantages are rapid drying, large-scale continuous production, low labour costs and simple operation and maintenance. The major limitations are high capital costs and the requirement for a relatively high-free moisture content to ensure that the food can be pumped to the atomizer.

12.9.12 Microwave Drying

Microwaves are the portion of the electromagnetic spectrum between far infrared and the conventional radio frequency region. As the microwaves passes through the material such as fruits, the molecules within the food attempt to align themselves with the electric field direction. As they oscillate around their axis, heat is produced by the intermolecular friction within the product. This heat is responsible for the moisture removal from the fruits and vegetables. The depth of penetration is an important factor in microwave drying. A typical microwave dryer and its parts are shown in Figure 12.13.

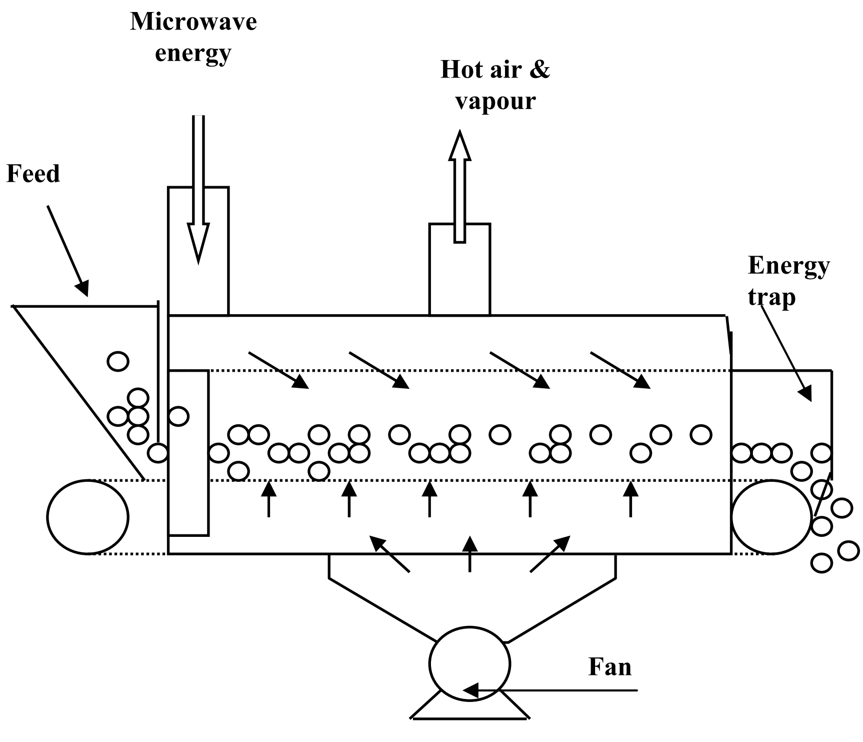

Figure 12.13: Schematic of a continuous microwave drying equipment

This method has been made use in drying of fruit juices, pulps, and fruit segments. Microwaves are endowed with some special characteristics such as (i) A penetrating quality which results in uniform heating of materials, ii) Selective absorption of radiation by liquid water, and iii) Capacity for easy control. These imparts some unique effects to the dehydrating materials such as improved quality and good texture.

12.9.13 Pneumatic Dryers

In a pneumatic dryer, the solid food particles are conveyed rapidly in an air stream, the velocity and turbulence of the stream maintaining the particles in suspension. Heated air accomplishes the drying and often some form of classifying device is included in the equipment. In the classifier, the dried material is separated, the dry material passes out as product and the moist remainder is recirculated for further drying. Pneumatic dryers have relatively low capital costs, high drying rates and thermal efficiencies, and close control over drying conditions. They are often used after spray drying to produce food which have a lower moisture content than normal. In some applications the simultaneous transportation and drying of the food may be useful method of material handling.

12.9.14 Rotary Dryers

The foodstuff is contained in a horizontal inclined cylinder through which it travels, being heated either by air flow through the cylinder, or by conduction of heat from the cylinder walls (Figure 12.14).

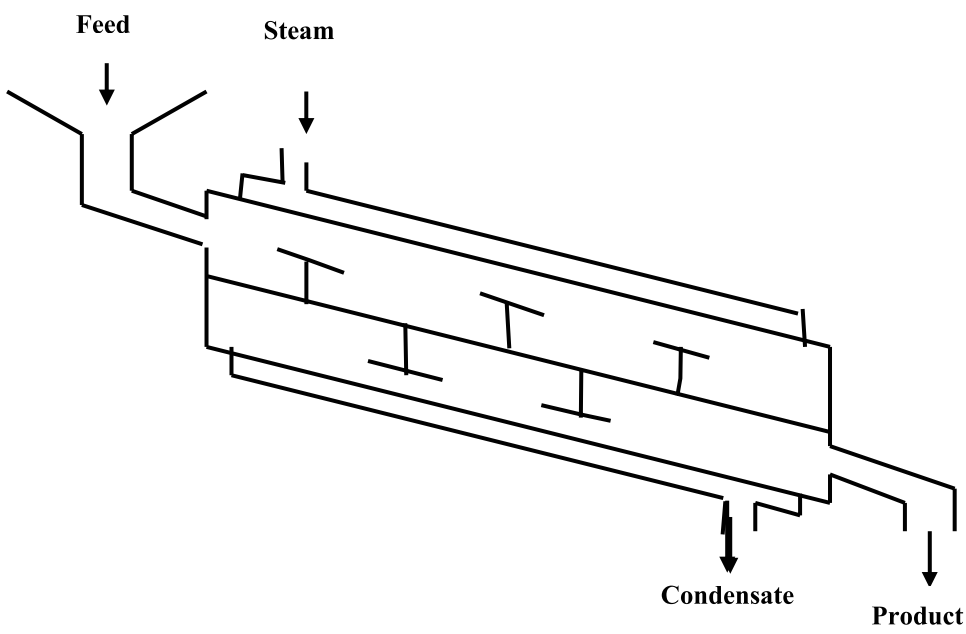

Figure 12.14: Rotary dryer

In some cases, the cylinder rotates and in others the cylinder is stationary and a paddle or screw rotates within the cylinder conveying the material through. The air flow may be parallel or counter current. The agitation of the food and the large area of food exposed to the air produce high drying rates and a uniformly dried product. This method is especially suitable for foods that tend to mat or stick together in belt or tray dryers. However, the damage caused by impact and abrasion in the dryer restrict this method to relatively few foods.

12.9.15 Vacuum Drying

Vacuum dryers are substantially the same as tray dryers, except that they operate under a vacuum, and heat transfer is largely by conduction or by radiation. It occurs at low air pressures and includes vacuum shelf, vacuum drum, and vacuum belt and freeze dryers. The main purpose of vacuum drying is to enable the removal of moisture at less than the boiling point under ambient conditions. Because of the high installation and operating costs of vacuum dryers, this process is used for drying raw material that may deteriorate as a result of oxidation or may be modified chemically as a result of exposure to air at elevated temperatures. In vacuum drying, the moisture in the food is evaporated from the liquid to the vapour stage.

12.9.16 Freeze Dryers

The material is held on shelves or belts in a chamber that is under high vacuum. In most cases, the food is frozen before being loaded into the dryer. Heat is transferred to the food by conduction or radiation and the vapour is removed by vacuum pump and then condensed. Schematic illustration of freeze drying system shown in Figure 12.15a. In one process, given the name accelerated freeze drying, heat transfer is by conduction; sheets of expanded metal are inserted between the foodstuffs and heated plates to improve heat transfer to the uneven surfaces, and moisture removal. The pieces of food are shaped so as to present the largest possible flat surface to the expanded metal and the plates to obtain good heat transfer. A refrigerated condenser may be used to condense the water vapour. A cross sectional view of freeze dryer is shown in Figure 12.15b.

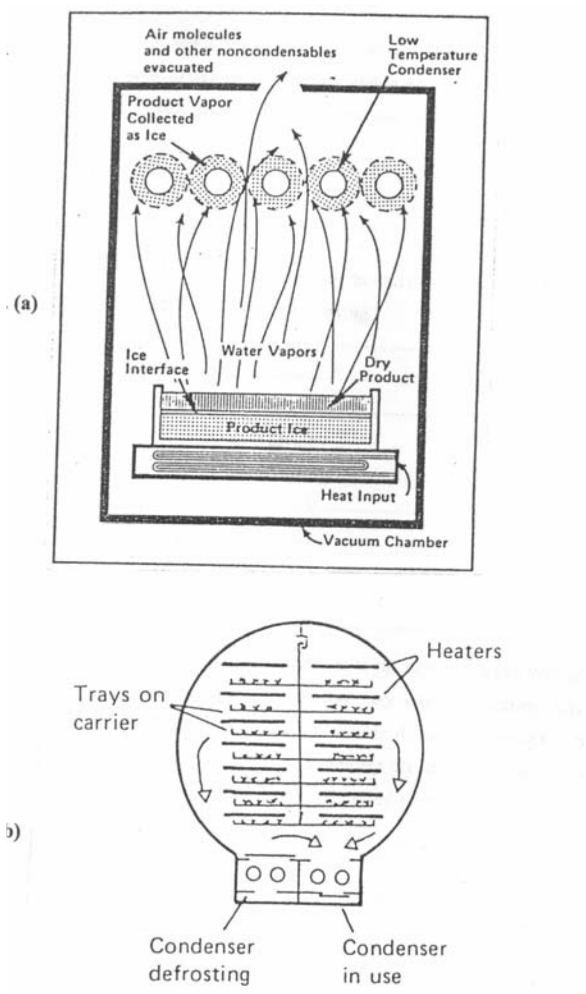

Figure 12.15: Freeze drying: a) Schematic illustration of freeze drying system; b) Cross-sectional view of a continuous freeze drier.

The advantages of freeze drying are high flavour retention, maximum retention of nutritional value, minimal damage to the product texture and structure, little change in product shape and colour, and a finished product with an open structure that allows a fast and complete rehydration. Disadvantages include high capital investment, high processing costs, and the need for special packing to avoid oxidation and moisture gain in the finished product.

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 advantages of using freeze drying?

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2. Explain the principle of microwave drying?

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12.10 POST-DEHYDRATION TREATMENTS

Treatments of the dehydrated product vary according to the type of fruit or vegetable and the intended use of the product. These treatments may include sweating, screening, inspection, and packaging. Sweating involves holding the dehydrated product in bins or boxes to equalize the moisture content. Screening removes dehydrated pieces of unwanted size, usually called 'fines'. The dried product is inspected to remove foreign materials, discoloured pieces, or other imperfections such as skin, carpal, or stem particles.

12.11 PACKAGING

It is commonly done for most of the dehydrated products and has a great deal of influence on the shelf life of the dried product. Packaging of dehydrated fruits and vegetables must protect the product against moisture, light, air, dust, micro-flora, foreign odour, insects and rodents. It should provide strength and stability to maintain original product size, shape and appearance throughout storage, handling, and marketing. The packaging materials used should be approved for contact with food. Cost is also an important factor in packaging.

Package types include cans, plastic bags, bins, and cartons, and depend on the end-use of the product. The details of packaging materials and its advantages are explained under the unit 1. It is better to pack dried foods in small amounts, since opening of a package can lead to moisture absorption and deterioration of its quality. Technical solutions for maintaining a low dehydrated products moisture are:

- Use packages that are water vapour proof. The most efficient packages are tin boxes or drums (mainly for long term storage periods); combined packages (boxes, bags, etc.); from complexes (carton with metallic sheets, plastic materials, etc.) mainly for small packages.
- Modern solutions are oriented not only to maintain the product moisture during storage but also to reduce the moisture by the use of desiccants (substances which absorb moisture) introduced in hermetically closed packages.
- Another factor that can deteriorate dried/dehydrated vegetables is atmospheric oxygen through the oxidative phenomena that it produces. In order to eliminate the action of this agent some packing methods under vacuum or in inert gases (carbon dioxide or nitrogen) are in use. Such packaging systems are used for packing dried carrots in order to avoid beta-carotene oxidation. To avoid the action of oxygen it is also possible to add ascorbic acid as antioxidant (for example in carrot powder).
- Sun or artificial light action on dehydrated vegetables generally causes discolouration which can be avoided by using opaque packaging materials.
- Store in a place with relative humidity below 78%.

12.12 STORAGE

The containers of dried foods are stored in a cool, dark, dry area such as a basement or cellar. Exposure to humidity, light or air decreases the shelf life of foods. Storage temperature has an important role because this reduces or inhibits the speed of all physico-chemical, biochemical and microbiological processes, and thus prolongs storage period. The lower the temperature, the better will be the shelf life of the product.

Foods stored at temperatures below 15°C will keep for approximately one year. At 27°C to 32°C the food begins to deteriorate within several months. In general, for every 10°C drop in temperature, the shelf life of fruits increases three to four times. The storage temperature should be below 25°C (and preferably 15°C); lower temperatures (0-10°C) help maintain taste, colour and water rehydration ratio and also, to some extent, vitamin C.

12.13 SUITABILITY AND ACCEPTABILITY OF DIFFERENT FRUITS AND VEGETABLES FOR DEHYDRATION

Fruits and vegetables selected for drying should be of the highest quality – fresh and ripe. Drying does not improve the quality. Immature produce will lack flavour and colour. Over mature produce may be fibrous or mushy. If the food is not perfect for eating, it is not suitable for drying. Different foods requiring similar drying times and temperatures can be dried together. Vegetables with strong odours or flavours (garlic, onion and pepper) should be dried separately. Don't dry strong-smelling vegetables outside in an electric dehydrator, because dehydrators are not screened and insects may invade the food.

Blanching is essential for all vegetables except onions, peppers, okra, herbs, and some new types of corn that get sweeter as they mature. Most fruits such as berries, cherries, seedless grapes, melons, prunes and plums does not require blanching before drying. Sulfuring has to be done for light-coloured fruits, especially apples, apricots, peaches, nectarines and pears, which tend to darken during drying and storage

Vegetables are sufficiently dried when they are leathery or brittle. Leathery vegetables will be pliable and, spring back if folded. Edges will be sharp. Sufficiently dry green peas shatter when hit with a hammer.

Fruits are adequately dried when moisture cannot be squeezed from them, and if tough and pliable when cut. Fruit leathers may be slightly sticky to touch, but should separate easily from the plastic wrap.

12.14 EFFECTS OF DRYING ON PRODUCT QUALITY

12.14.1 Nutritional Quality

The nutritive value of food is affected by the dehydration process. Large differences in the nutritive value of dried foods are due to wide variation in the preparation procedures, the drying temperature and time, and storage conditions. In fruits and vegetables, loss during preparation usually exceed those caused by the drying operation. Vitamins A and C are destroyed by heat and air. Sulfite treatment prevents the loss of some vitamins, but causes the destruction of thiamin. Blanching vegetables before drying results in some loss of Vitamin C, B-complex vitamins and some minerals because these are all water soluble. On the other hand, the loss of vitamins A, C and thiamin during dehydration and storage is reduced by blanching process.

Oil- soluble nutrients (vitamins A, D, E & K) are mostly contained within the dry matter of the food and they are not therefore concentrated during drying. However, water is a solvent for heavy metal catalysts that promote oxidation of unsaturated nutrients. As water is removed, the catalysts become more reactive, and the rate of oxidation accelerates. Fat soluble vitamins are lost by interaction with the peroxides produced by fat oxidation. Losses during storage are reduced by low oxygen concentration, low storage temperature and by exclusion of light.

There are more calories in dried foods on a weight-for-weight basis because of the concentration of nutrients. For example, 100 grams of fresh apricots have 51 calories, while 100 grams of dried apricots have 260 calories. Nutritive value, as well as flavour and appearance, is best protected by low temperature and low humidity during storage.

12.14.2 Texture

Changes in texture of solid foods are an important cause of quality deterioration. The nature and extent of pre-treatments, the type and extent of size reduction, peeling, affect the texture of rehydrated fruits and vegetables. In foods that are adequately blanched, loss of texture is caused by gelatinisation of starch, crystallization of cellulose, and localized variations in the moisture content during dehydration, which set up internal stresses. These stresses will rupture, compress and permanently distort the relatively rigid cells, to give the food a shrunken shriveled appearance. On rehydration, the product absorbs water more slowly and does not regain the firm texture associated with the fresh material.

The rate and temperature of drying have a substantial effect on the texture of foods. In general, rapid drying and high temperature cause greater changes than do moderate rates of drying and lower temperatures. In powders, the textural characteristics are related to bulk density and the ease with which they are rehydrated. These properties are determined by the composition of the food, the method of drying and the particle size of the product. Low fat foods (e.g.: fruit juices) are more easily transformed into free flowing powders than those rich in fat (e.g.: whole milk).

12.14.3 Flavour and Aroma

Heat not only vaporizes water during drying but also causes the loss of volatile components from the food. The extent of volatile loss depends on the temperature and solid concentration of the food and on the vapour pressure of the volatiles and their solubility in water vapour. Volatiles which have a high relative volatility and diffusivity are lost at an early stage in drying. Fewer volatiles components are lost at later stages. Control of drying conditions during each stage of drying minimizes losses.

A second important cause of aroma loss is oxidation of pigments, vitamins and lipids during storage. The open porous structure of dried food allows access of oxygen. The rate of deterioration is determined by the storage temperature and the water activity of the food. Flavour changes due to oxidative or hydrolytic enzymes are prevented in fruits by the use of sulphur dioxide, ascorbic acid or citric acid, by pasteurization of fruit juices and by blanching of vegetables.

Other methods which are used to retain flavours in dried foods include

- Recovery of volatiles and their addition to the product during drying.
- Mixing recovered volatiles with flavour fixing components, which are then granulated and added back to the dried product.
- Addition of enzymes, or activation of naturally occurring enzymes, to produce flavours from precursors in the food.

12.14.4 Colour

Drying changes the surface characteristics of food and hence alters the reflectivity and colour. Chemical changes to carotenoid and chlorophyll pigments are caused by heat and oxidation during drying. In general, longer drying times and higher drying temperatures produce greater pigment losses. Oxidation and residual enzyme activity cause browning during storage. This is prevented by improved blanching methods and treatments of fruits with ascorbic acid or sulfur dioxide.

12.14.5 Rehydration

Rehydration is the process of adding water to the dried products and is restored to a condition similar to that when it was fresh. This enables the food product to be cooked as if the person was using fresh fruits or vegetables.

Factors that affects rehydration process of the dehydrated or dried products are time, temperature, air displacement, and pH. Rehydration rate can be accelerated by ultrasonic treatment of the product to be rehydrated. Gamma radiation increases the rehydration rate of freeze dried products.

The level of reconstitution or rehydration is evaluated by using rehydration coefficient and rehydration ratio. *Rehydration ratio* is the ratio of the weight of the drained rehydrated sample to the weight of the dehydrated sample.

Rehydration coefficient is calculated by the following equation.

$$\text{Rehydration coefficient} = \frac{\text{DRW}\,(100 - \text{MC}_1)}{(\text{WD} - \text{MC}_2) \times 100}$$

where, DRW is the drained weight of the rehydrated sample.

MC_1 is the moisture content of the sample before drying.

WD is the weight of dried sample taken for rehydration.

MC_2 is the amount of the moisture present in the dried sample taken for rehydration.

12.15 SPECIAL CARE TO BE TAKEN DURING DRYING

There aren't many problems in food drying. However, here are some things to watch for.

Case Hardening – If the drying temperature is too high or the humidity too low, the food may harden on the surface. This makes it more difficult for the moisture inside to escape and for the food to dry properly.

Scorching – When black streaks or areas appear on the food, it has scorched. This is most common in sun drying and is why we recommend you to move the food into the shade when it is about two-thirds dry.

Souring – At the beginning of drying, if the temperature is too low or if the humidity is high,, the food may sour or ferment. It may even mould if conditions are too cold. Overloading the trays can also cause this problem.

Mould – Mouldy dried food should always be discarded. Check stored dried foods frequently to be sure that they remain dry. The presence of moulds demands either removal of more moisture in subsequent trials or storage of the dried food in the freezer.

Insects – All sun-dried foods should be pasteurized before storing to destroy insects or their eggs. Heat fruit and vegetables on trays in a 66°C oven for 30 minutes or put in freezer for 48 hours. Store food in insect-proof containers.

12.16 LET US SUM UP

Drying is an important and oldest preservation method in food processing. The main purpose of dehydration is to extend the shelf life of foods by a reduction in water activity. It also saves energy, money and space in shipping, packaging, storing and transportation. Due to these advantages the dried fruit or vegetable is known as high value low volume food.

In this section, we have detailed the procedure of dehydration which includes various pre-treatments, methods of dehydration and post treatments. The comparative advantages and limitations of the drying techniques are also discussed. You have also studied the different factors affecting drying and the suitability of commodities for drying. The importance of packaging, storage and rehydration of dried commodities are also briefed in this unit.

The future prospects of the drying industry seems to be quite encouraging since the dried/concentrated products are nutritionally good and easy to handle. 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 market.

12.17 KEY WORDS

Sulphuring	:	Pre-treating fruits with the fumes of burning sulfur.
Rehydration	:	Process of restoring moisture to a dried food.
Blanching	:	It is the process of inactivation of enzymatic activity in vegetables and in some fruits, prior to further processing.
Concurrent/Co-current flow dryer	:	Hot dry air and wet material enter at the same end and travel through the dryer in the same direction.
Counter flow dryer	:	Air flows in a direction opposite to the direction of travel of material through the dryer.
Sweating	:	Keeping the dehydrated product in bins or boxes to equalize the moisture content
Water activity	:	It is the water in a system available to support biological and chemical reactions
Bound water	:	This is the water bonded to the cell solutes or cell sap.
Fluidization	:	When the air velocity becomes higher than the critical velocity, the bed (drying product) progressively expands until it reaches a state of

boiling or bubbling. This phenomenon is called fluidization.

Osmosis : It is process of diffusion of water from dilute solution to concentrated solution through a semi permeable membrane.

12.18 SELF TEST FOR THE COMPLETE UNIT/ ASSIGNMENT

1. Define drying?
2. Where should the dried foods be stored?
3. Does the calorie content of foods change during drying?
4. What are the common quality changes that may occur when foods are dried?

12.19 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Water activity (a_w) is defined as the ratio of the vapour pressure on the aqueous solution to that of pure water at the same temperature. Quantitatively, water activity is a measure of unbound, free water in a system available to support biological and chemical reactions. The a_w has a major role to play on microbial spoilage and chemical changes produced in the food. The energy required to remove a molecule of water from a food increases as the water activity decreases. This is important for drying operations, since energy is required to provide sufficient driving force for drying.
2. Various factors that effect the rate of drying of fruits and vegetables include: i) The Composition of raw material, ii) Size, shape and arrangement of stacking of the produce, iii) Temperature, relative humidity and velocity of air, iv) Pressure, and v) Heat transfer to the surface.
3. Blanching is the process to inactivate the enzymes present in the fruits and vegetables, prior to further processing. These enzymes cause deterioration of colour, vitamins, odour and flavour during storage.

Check your Progress Exercise 2

1. The advantages of freeze drying are high flavour retention, maximum retention of nutritional value, minimal damage to the product texture and structure, little change in product shape and colour, and a finished product with an open structure that allows a fast and complete rehydration.
2. As the microwaves passes through the material such as fruits, the molecules within the food attempt to align themselves with the electric field direction. As they oscillate around their axis, heat is produced by the intermolecular friction within the product. This heat is responsible for the moisture removal from the fruits and vegetables.

Answers to Assignments

1. Drying or dehydration means the process of removal of moisture by the application of artificial heat under controlled conditions of temperature, humidity and air flow.

2. Store dried foods in a dry, cool, dark place. The higher the temperature, the shorter the storage time. Use clean, dry, insect-proof, moisture/vapour proof containers and package in small amounts to avoid constantly opening a container and exposing it to air.

3. The calorie content of foods does not change but is concentrated into a smaller mass as moisture is removed during drying. Therefore, on a per kg basis, dried foods contain considerably more calories than do the same foods fresh.

4. The various quality factors affected by the dehydration process includes nutritive value of food, fat oxidation, colour changes, texture changes, flavour and aroma changes.

12.20 SOME USEFUL BOOKS

1. David Arthey and Collin Dennis (1991). Vegetable Processing, Blackie Publication, New York.

2. Fellows, P. (1990). Food processing technology – Principles and practices. VCH Ellishorwood Publishers.

3. Fennemma, O.R. (1989). Principles of food science. Part 2–Physical principle of food preservation. Marcel Dekker, New York.

UNIT 9 JUICE AND BEVERAGES

Structure

9.0 OBJECTIVES

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

- prepare various fruit beverages;
- learn principles of various preservation techniques;
- know equipment used in the processing of fruit beverages;
- explain quality aspects and standards of product; and
- describe packaging requirements and types of packaging material.

9.1 INTRODUCTION

Fruit beverages are easily digestible, highly refreshing, thirst- quenching, appetizing and nutritionally far superior to synthetic and aerated drinks. The fruit beverage include natural and sweetened juices, squash, syrup, fruit juice concentrate and fruit juice powder.

In this unit we will study the various steps in the preparation of fruit beverages, and their preservation methods for extending their shelf life. Measures taken to improve the quality of the final product by Fruit Products Order (FPO) is also given in this unit. Apart from this, you will learn the importance of packaging and different packaging materials used in the processing industry.

9.2 FRUIT JUICE

The concept of fruit juices has gained immense consumer popularity. Fruit juices are products for direct consumption and are obtained by the extraction of cellular juice from fruit, this operation can be done by pressing or by diffusion. The fruit juice processing technology employed for different fruits and the various equipments required during different stages of processing has been covered here.

9.2.1 Preparation of Fruit Juice

Fruit juices must be prepared from sound, mature fruits only. Soft fruit varieties such as grapes, tomatoes and peaches should only be transported in clean boxes, which are free from mould and bits of rotten fruit. The flow chart for fruit juice production is given in Figure 9.1.

Fruits
↓
Receiving the material
↓
Washing
↓
Sorting
↓
Crushing/Grinding/Disintegration
↓
Enzyme treatment
↓
Extraction/ Expression
↓
Straining/Filtration
↓
Clarification (Optional)
↓
De-tartarisation (Optional)
↓
Preservation of fruit juice
↓
Filling in sterilized bottles
↓
Corking
↓
Pasteurization
↓
Labelling and Storage

Figure 9.1: Flow chart for fruit juice production

Washing: Fruit must be thoroughly washed. Generally, fruits are submitted to pre-washing before sorting and a washing step just after sorting. Washing can be done either by water or by dilute hydrochloric acid (1 part acid : 20 part water).

Sorting: Removal of partially or completely decayed fruit is the most important operation in the preparation of fruit for production of first quality fruit juices; sorting is carried out on moving inspection belts or sorting tables.

Crushing/Grinding/Disintegration: This is applied in different ways and depends on fruit types: Crushing for grapes and berries; Grinding for apples, pears; Disintegration for tomatoes, peaches, mangoes, apricots etc. This processing step will need specific equipments, which differs from one type of operation to another.

Enzyme treatment: The enzyme treatment of crushed fruit mass is applied to some fruits by adding 0.2-0.8% pectolitic enzymes at about 50° C for 30 minutes. This optional step has the following advantages: extraction yield will be improved, the juice colour is better fixed and taste of finished product is improved.

***Expression/extraction**:* Generally juice is expressed from the crushed/disintegrated fruit pulp. During expression, juices should not be unnecessarily exposed to air as it will spoil the colour, taste and aroma and also reduce the vitamin content.

The equipments used for the juice extraction are screw type juice extractors, basket presses or fruit pulpers (shown in figure). All equipments used in the preparation of fruit juices and squashes should be rust and acid proof. Copper and iron vessels should be strictly avoided as these metals react with fruit acids and cause blackening of the product. Machines and equipments made of aluminium, stainless steel, etc can be used.

***Straining/Filtration**:* The extracted juice contain some amount of suspended matter. The suspended matter consists of broken fruit tissue, seed, skin, gums, pectic substances and protein in colloidal suspension. These materials can be removed by straining through a thick cloth or sieve. Removal of all suspended matter improves the appearance but often results in disappearance of fruity character and flavour. The present practice is to let fruit juices and beverages retain a cloudy or pulpy appearance to some extend (Figure 9.2).

Clarification: It is the process of complete removal of all suspended material from the juice**.** This can be performed by many methods viz. centrifugation, enzyme treatment, settling, filtration, freezing(-18^{o}C), use of high temperature (nearly 82^{o}C) and low temperature(-2 to –3 ^{o}C). The chemical treatments like addition of gelatin, albumin, casein, or a mixture of tannin and gelatin are also used for the removal of suspended particles.

Centrifugation is carried out in centrifugal separators with a speed of 6000 to 6500 rpm. Enzyme clarifying is based on pectic substance hydrolysis; this will decrease the viscosity of juice and facilitate their filtration. The treatment is the addition of pectolitic enzyme preparations in a quantity of 0.5 to 2 g/l. This will last for 2 to 6 hours at room temperature, or less than 2 hours at 50° C, a temperature that must not be exceeded.

De-tartarisation is applied only to raisin juice and is aimed to eliminate potassium bi-tartrate from solution. This step can be performed by the addition of 1% calcium lactate or 0.4% calcium carbonate.

9.2.2 Preservation of Fruit Juices

Fruit juice is preserved to prevent the decay/spoilage and to extend the shelf life of the juice in a good condition for future use. This is generally done by the use of high temperature (pasteurization and flash pasteurization), use of low temperature (refrigeration and freezing), preservation with chemicals (sulphur dioxide and benzoic acid), drying, filtration, carbonation, and by using sugar. The methods used for the preservation are follows:

Pasteurization

Preservation by heat is the most common method. It is the process of heating fruit juice at boiling temperature or slightly below it for a sufficient length of time to kill the microorganisms that cause spoilage. The juice is hermetically sealed in containers before being pasteurized. Usually the fruit juices are pasteurized at about 85°C for 25 to 30 minutes according to the nature of the juice and size of the container.

Flash Pasteurization

In this method, fruit juice is heated for a short time at a temperature higher than the pasteurization temperature and held at that temperature for about a minute and then filled into containers which are sealed air tight under cover of steam to sterilize the seal and then, cooled. For the maintenance of the product quality, the rate of heat transfer in these pasteurizers are kept high. The heat transfer depends on the viscosity of the juice, specific heat of the juice and temperature difference. This method has many advantages viz., minimum loss of flavour, preservation of vitamins, economy of time and space, uniformity in body of juice, and minimum cooked flavour.

Preservation by Chemicals

Microbial spoilage of fruit beverages is also controlled by using chemical preservatives. The inhibitory action of preservative is due to their interfering with the mechanism of cell division, permeability of cell membrane and activity of enzymes. Pasteurized fruit beverages undergo spoilage once opened. To avoid this it is necessary to use chemical preservatives. Chemically preserved beverages can be kept for a fairly long time even after opening the seal of the bottle. The two important chemical preservatives permitted in our country by FPO are sulphur dioxide (including sulphites) and benzoic acid (include benzoates).

Sulfur dioxide: It is widely used throughout the world in the preservation of fruit juice and other beverages. It has good preserving action against bacteria, moulds and inhibits enzymes. In addition, it acts as an antioxidant and bleaching agent. It is generally used in the form of it's salts such as sulphite, bisulphite and metabisulphite.

The advantages of using sulphur dioxide are:

1. It has better preserving action against bacterial fermentation
2. It helps to retain colour
3. It ensures better mixing and hence their preservation

4. It helps in preserving the surface layer of juices.
5. Excess amount can be removed by heating or by vacuum

The limitations of sulphur dioxide are:

1. It can't be used in some coloured juices like those of jamun, strawberry etc on account of its bleaching action.
2. It corrodes the tin containers.
3. Some consumers may be sensitive to sulphur dioxide.

Benzoic acid: It is only partially soluble in water and hence it's salt, namely sodium benzoate is used as preservative. Pure sodium benzoate is tasteless and odourless. The antibacterial action of benzoic acid is increased in the presence of CO_2 and acid. Benzoic acid is more effective against yeast than against moulds. The quantity of benzoic acid depends on the acidity of the products. In case of fruit juices with pH of 3.5-4, addition of 0.06% of sodium benzoate is recommended.

By Addition of Sugar

Syrups containing 66 % or more of sugar do not ferment. Sugar absorbs most of the available water with the result that there is very little water for the growth of microorganisms. This reduction in water will inhibit the multiplication of microorganisms and gradually they die out from the product.

By Freezing

Microbial growth and enzymatic reactions are retarded in juice stored at low temperatures. The lower the storage temperature the slower will be the rate of a chemical or enzyme reaction. Freezing is the process in which the temperature of a food is reduced below the freezing point, and a proportion of the water undergoes a change in state to form ice crystals. Under the usual condition of storage of frozen foods, microbial growth is prevented completely and the action of food enzymes greatly retarded. The best way of preserving pure fruit juice is by freezing. Properly frozen juice retains its freshness, colour and aroma for a long time. This method is particularly useful in case of juices whose flavour is adversely affected by heating. Preservation by freezing is carried out at about −30° C, after a preliminary de-aeration. Then storage is done at −15 to −20° C.

By Drying

Drying is the processes of removal of moisture to a pre determined level. You know that the growth of microorganisms is directly dependent upon the concentration of water present in the food. So a reduction in moisture will reduce the growth of microorganisms. Moisture can be removed by the application of heat. The details regarding the methods of drying are given in the Unit 4.

By Carbonation

It is the process of dissolving sufficient carbon dioxide in fruit juice so that the product when served gives off the gas as fine bubbles and has characteristic taste. Carbonation is done at a concentration of 1.5% CO_2 under a pressure of 7 kg/cm^2. Another advantage of carbonation is the removal of air from the fruit juice, which reduces the oxidation of ascorbic acid, prevents browning and microbial growth. High carbonation should be avoided as it usually destroys the delicate flavour of the juice. The keeping quality of carbonated fruit beverages is enhanced by adding about 0.005 % of sodium benzoate.

By Filtration

In this method, the juice is first clarified through ordinary filters and then passed through special filters. These special filters retain yeast and bacteria. Various types of germ-proof filters are used for this purpose. This requires elaborate precautions to ensure complete sterility in the bottled product.

By Irradiation

The irradiation process involves passing of fruit juice through a radiation field allowing the juice to absorb desired amount of radiation energy. The juice itself never comes in contact with radioactive material. The gamma radiations from the radioactive material will disinfest, sterilize and preserve the fruit juice. The dose required to provide stability is partly determined by the solid content of the juice. Generally irradiation lightens the colour of the juice. On storage, however, darkening occurres and stored irradiated apple juice shows little difference from the original colour. Flavour changes caused by the irradiation are less. The dose required to obtain stability may be reduced by heating the juice to a higher temperature (50^oC) prior to irradiation. In this way, a dose of 3 kilo Grey is adequate to secure stability at ambient temperature for more than a year.

9.2.3 Bottling

Bottles are thoroughly washed with hot water and drained before filling. A 1.5 to 2.5 cm head space is left during filling. They are then sealed either with crown corks (by crown corking machine) or with caps (by capping machine).A typical corking machine is shown in Figure 9.2.

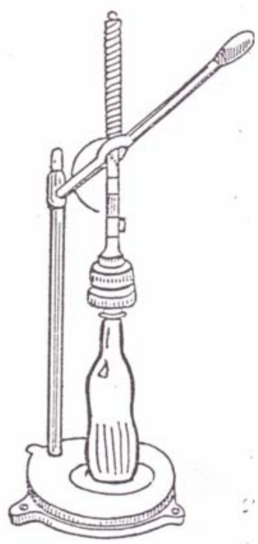


Figure 9.2: Crown corking machine

9.3 EQUIPMENTS FOR THE PRODUCTION OF JUICE AND PULPS

Different types of equipments are used in the juice processing plant, starting from equipments for washing, sorting, extracting to pasteurizers. While selecting an equipment the material of construction is very important. Glass-lined equipment, or equipment made of metals like stainless steel, monel metal, nickel, aluminium or bronze should be used because such equipment is not readily acted upon the fruit or vegetable juices. A unit of machinery made of different metals should also be avoided because is similar metals in the system or unit will lead to the setting up of small electrical couples and consequently corrosion will take place. Use of rubber in the equipments should be avoided as far as possible.

9.3.1 Washing Equipments

Different types of equipments are available for washing of fruits and vegetables. Tender fruits are usually washed with a fine overhead spray of water, while the fruits travel on a continuous woven wire belt. On small scale processing plants washing is carried out in cement or galvanized iron tanks.

9.3.2 Sorting Equipments

In large factories, a continuous broad belt, made of woven metal, is generally employed for sorting the fruits. In smaller factories, however, batch sorting will be sufficient. A schematic diagram of belt and roller sorter and screen sorter are shown in Figure 9.3a and 9.3b.

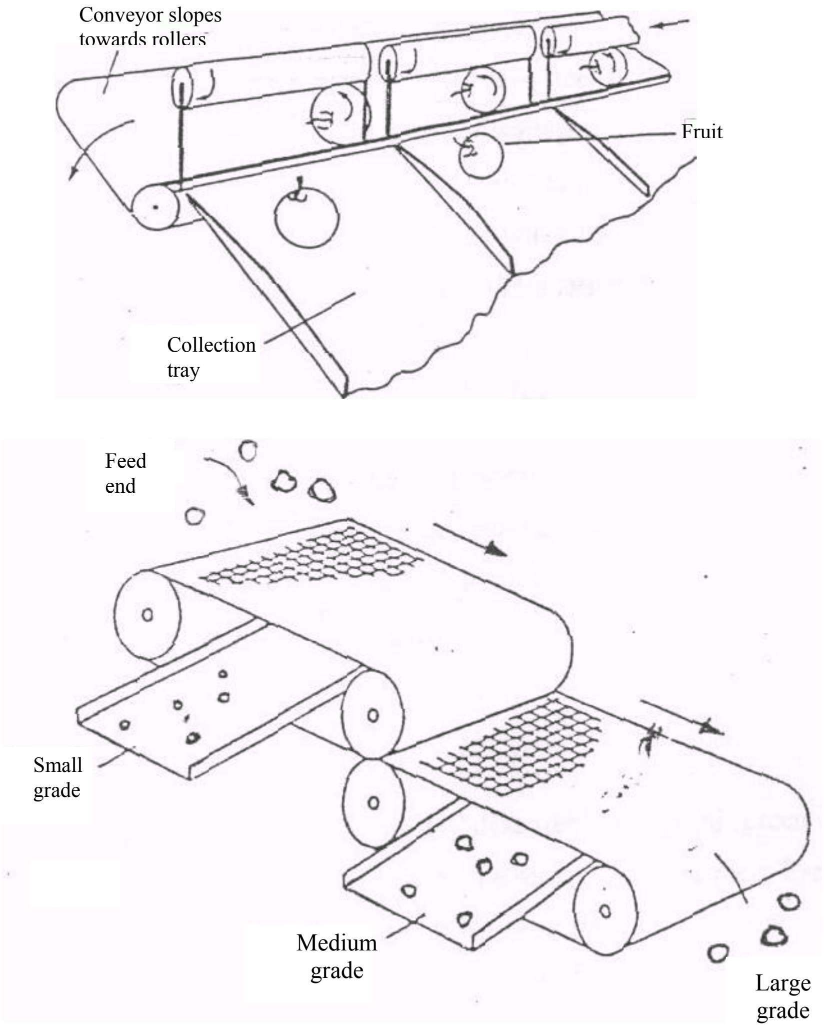
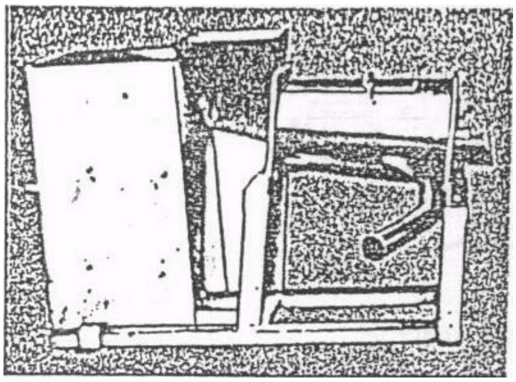


Figure 9.3: Sorting machines: a) Belt and roller sorter; b) Screen grader

9.3.3 Pulping/Grinding Equipments

There are two types of extractions. In the first case, the fruits are crushed and pressed continuously in one operation (Figure 9.4). In the second case, the fruits are crushed or cut into small pieces or comminuted in a mill, and these are subsequently pressed in a suitable press. Some of the crushing/ extraction equipments are discussed here.



Pulper

Figure 9.4: Fruit pulper

Hammer mills: These are devices to pulp/crush the whole fruit in preparation for extraction. Hammer mills consist of heavy stainless steel bars spinning from a common axis under a high speed of rotation. The fruit is disintegrated until it will pass out through a screen of specific size mounted in the bottom of the mill (Figure 9.5). The mash will be of finer particle size and the smaller particle size will allow greater yields in case of firm fruits. Softer fruit presses with more difficulty, and a larger particle size in the mash will enhance ease of pressing.

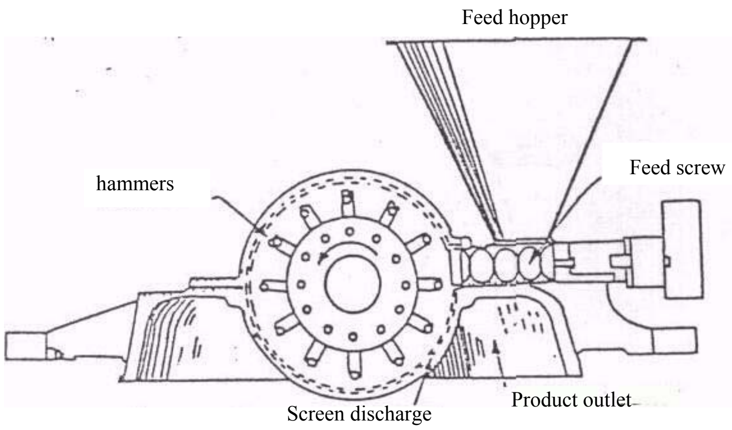


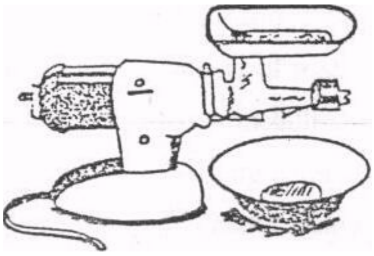
Figure 9.5: Sectional view of hammer mill

Grating mills: These offer an alternative method for disintegrating fruits. In grating mill, the fruit is drawn past fixed knifes mounted on a cylinder. Control of the grind is accomplished by adjusting the depth of the knifes and thus the size of cut from the fruit

Crusher: In grape juice processing, a stemmer/crusher removes residual stems, leaves, and petioles from the grapes and does the initial crush of the fruit after arrival at the plant. This unit is designed around a rotating drum perforated with holes of approximately 2.5 cm diameter. In the process of traversing the rotating drum, grapes are caught by the perforated drum and knocked from the stems. The individual grapes are broken open or crushed in the process and drop through the drum.

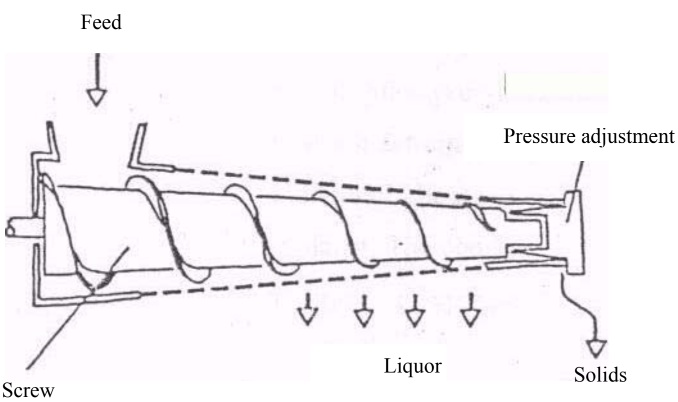
9.3.4 Screw Press

A typical screw press consists of a reinforced stainless steel cylindrical screen enclosing a large bore screw with narrow clearance between the screw and the screen. Breaker bars are located between the screw intervals in order to disrupt the compressing mash. Working principle of a typical screw extractor is shown in Figure 9.6a and Figure 9.6b. Back pressure is provided at the end of the chamber and is usually adjustable. The segments of the fruit are fed through a hopper at one end of a feeding screw, revolving inside the perforated screen. The juice flows out through the perforations and the pomace comes out through the other end. Capacities for screw press with a 30.5 cm and 41 cm diameter are 5,080 kg and 15,240 kg per hour.

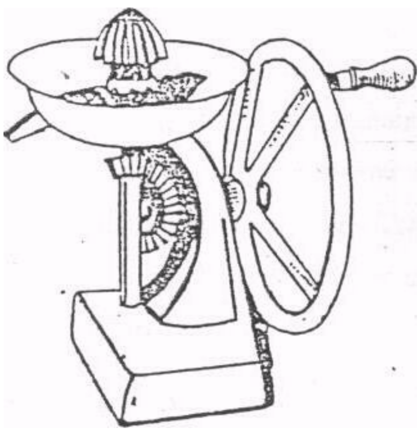


Screw Type Juice Extractor

(a)



(b)



Lime Juice Extractor

(c)

Figure 9.6: a) Screw extractor; b) Working principle of screw press; and c) Lime juice extractor

9.3.5 Basket Press

These are of various designs and capacities and are worked manually by hydraulic pressure. The manually operated press consists of a strong cylindrical basket which is made of wooden slates. It rests on a wooden or metallic base. There is strong screw at the top of this frame. The mash is folded in a strong cloth and placed inside the basket. By turning the screw by hand or with a hydraulic pump, the juice is pressed out. A schematic diagram of basket press shown in Figure 9.7.

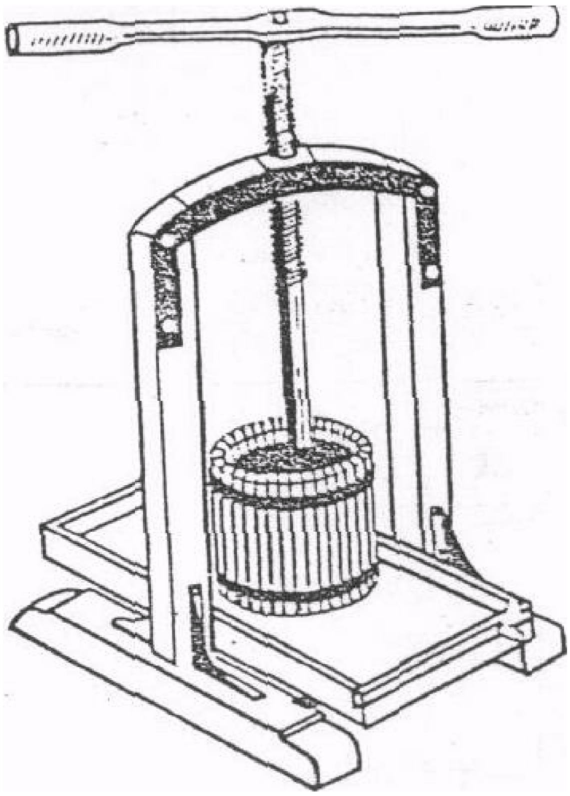


Figure 9.7: A typical basket press

9.3.6 Rack and Frame Hydraulic Press

The hydraulic rack and frame press is a very common press system found in small juice operations. It was the primary method of fruit juice pressing operations for many years. Heavy cotton or nylon cloths are filled with a set amount of mash and then folded to produce what is called a cheese. The individual cheese is stacked and separated by a wooden, stainless steel, or plastic spacer platen. The combined stack is then compressed using a hydraulic ram, during which the juice is expressed. A typical hydraulic juice press is shown in Figure 9.8.

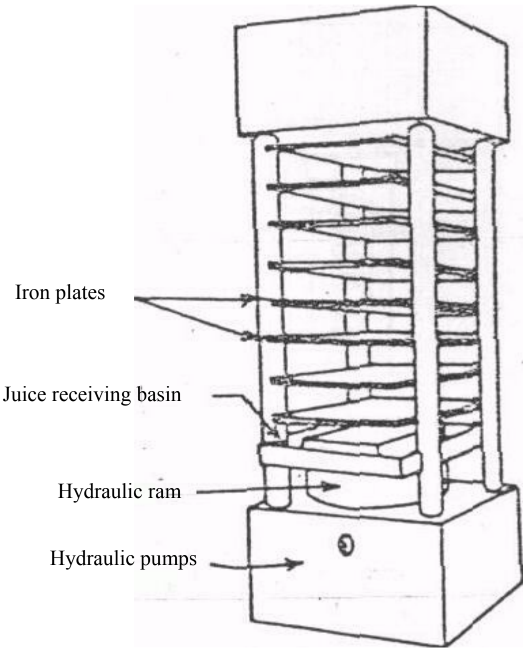


Figure 9.8: Schematic diagram of a hydraulic juice press

9.3.7 Decanter

A high solid stream can be partially clarified using decanters and finishers. Both pieces of equipment operate on the principle of a spinning central cone, drum, or set of paddles pushing the juice through a screen of some type. The unit is typically mounted horizontally, and throughput is relatively high. Total suspended solids may be reduced to 1% or less during operation, depending upon characteristics of the feed stream and operating conditions of the separator.

9.3.8 Filtration Equipment

Finely suspended particles in the juice are removed with a special equipment known as filter press. Filter presses are available with various designs and capacities. The filtering media may be finely woven cloth, canvas, fibre, asbestos pads, cotton or wood pulp discs, porous porcelain wares etc. The frame and filter press is highly effective for clarification of lime juice required for the preparation of lime juice cordial. A schematic diagram, explaining the working principle of frame and filter press is shown in Figure 9.9a and Figure 9.9b.

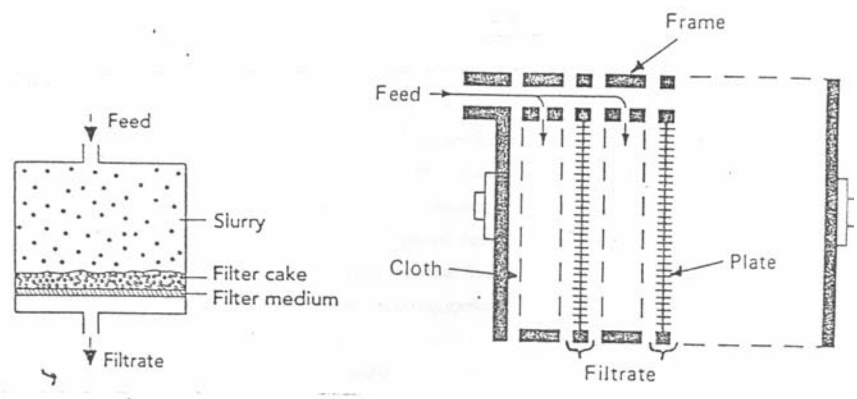


Figure 9.9: Filters: a) Schematic representation of filtration; b) Plate and frame filter press

9.3.9 Deaerator

Freshly extracted and screened juice contain large amount of oxygen, which should be removed before packing. Most of the air is present on the surface of the juice and some is dissolved in it. The air as well as other gases are removed by subjecting the fresh juice to a high vacuum. This method is highly expensive due to the vacuum creation. The equipment used for the removal of oxygen from the fruit juice is called deaerator. The deaerated juice is heated in a flash pasteurization equipment.

9.3.10 Flash pasteurizer/Rapid Pasteurizer

In this equipment, the juice is heated rapidly to a temperature of about 5.5°C higher than the pasteurization temperature and kept at this temperature for about 10-60 second. By this technique, the loss of flavour and vitamin destruction is minimum and the juice keep a uniformly cloudy appearance. A schematic diagram of flash pasteurization equipment is shown in Figure 9.10.

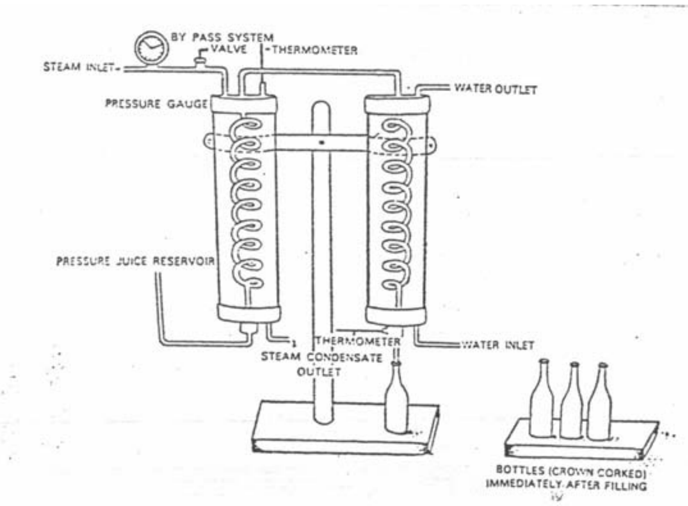


Figure 9.10: Schematic representation of a flash pasteurizer

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. Explain clarification process.

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2. What is the role of enzymes in juice processing?

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3. What is the difference between pasteurization and flash pasteurization?

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4. What are the methods used for the preservation of juice?

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9.4 SQUASHES

Squash essentially consists of juice containing moderate quantity of fruit pulp to which cane sugar is added for sweetening. According to FPO this type of fruit beverage should contain at least 25% fruit juice or pulp and 40-50 % total soluble solids on weight basis. It also contains about 1.0 % acid and 350-ppm sulphur dioxide or 600 ppm sodium benzoate. It is diluted before serving.

Juice or pulp of fruits is extracted in different ways as discussed earlier. This juice is used for the preparation of squash. Sugar, citric acid, flavouring materials, colour and preservatives are added to the juice in correct proportion. Sugar, citric acid and water are mixed and heated. The dirt is skimmed-off. The clean syrup is blended with the juice. After mixing all the ingredients, a calculated amount of chemical preservative, namely, sodium benzoate or potassium metabisulphite (KMS) is added. Colour and essence can be added to the squash, but should be fairly resistant to the action of preservatives.

The bottles should be cleaned and well sterilized before filling. There should be about 1.2-2.5 cm of head-space in bottles. Bottles are closed with pilfer proof closures, which should be dipped in 1% potassium metabisuphite solution. The bottles are washed, dried and labelled. The product keeps well for more than one year without much change in colour, taste and flavour.

9.5 CORDIAL

This is a sparkling, clear sweetened fruit juice from which pulp and other suspended materials have been completely removed. It contains at least 25% juice and 30% total soluble solids. It also contains about 1.5% acid and 350ppm sulphur dioxide. This is very suitable for blending with wines.

Juice is stored in barrels which are lined with microcrystalline wax. KMS is added as preservative during storage. During storage, the sediment settles and forms a compact layer at the bottom and clear juice remains at the top. Clarification process takes 2-3 months. The clear juice is siphoned off. This method is slow. To make it fast, gelatin and tannin can be added. In clear juice, sugar, water, colour and preservatives are added and the mixture is filtered by means of a filter press. The clear cordial is then bottled.

9.6 SYRUPS

This type of fruit beverage contains at least 25% fruit juice or pulp and 65% total soluble solids. Since the syrup strength is very high, to avoid crystallization, sugar is inverted by adding a small quantity of citric acid and heating in water. It also contains 1.3-1.5% acids and is diluted before serving. Syrups with 65 ^{o}Brix TSS can retain their fresh flavour for over four years. The condition required for this is that a juice should be filtered to a brilliant condition for making the syrup.

9.7 CARBONATED BEVERAGES

The use of fruit juices in the preparation of carbonated drinks is practically unknown in our country. Mostly, artificially flavoured drinks which have no nutritive value are prepared by this method. The use of fruit juices would increase the nutritive value of carbonated beverages.

One of the most important factors that relates to the taste of the bottled fruit juice beverage is carbon dioxide gas content or degree of carbonation. Carbonation is the process of dissolving or incorporating carbon dioxide in a beverage so that when served, it gives off the gas in fine bubbles and has the characteristic pungent taste suitable to the carbonated beverage.

In beverage manufacture, CO_2 not only provides the distinctive taste of carbonated drinks but also inhibits the growth of certain microorganisms. Fruit juices can be carbonated directly or preserved in the form of concentrates for subsequent carbonation. Clarification of such juice is essential prior to carbonation. Carbonated beverage can keep well for about a week without addition of any preservative. For longer storage of carbonated drink, use of preservative (0.05 % sodium benzoate) is necessary.

9.8 FRUIT JUICE CONCENTRATES

Fruit juice concentration offers significant advantages to the processor. Juices obtained by removal of a major part of their water by vacuum evaporation or fractional freezing is termed as “concentrated juices”. By concentrating the juice, the processor reduces the bulk of the juice, thereby reducing storage volume requirement and transportation costs. The process starts with pressing fruits and obtaining pure fruit juice. This is then stabilized by heat treatment which inactivates enzymes and micro-organisms. The next processing step is concentration under vacuum up to 40-65° Brix or 4-7 fold. The concentrates are then blended for standardisation and stored. Many methods are adopted for concentrating fruit juice. They are discussed below:

Evaporation: Evaporation is the most important process for concentration of fruit juices. Production of concentrated juices by evaporation is performed under vacuum (less than 100 mm Hg residual pressure) up to a concentration of 65-70% total sugar which assures preservation without further pasteurization. Modern evaporation installations recover flavours from juices which are then reincorporated in concentrated juices.

Evaporator generally consists of a heat transfer surface, a feed distribution device, a liquid vapour separator and a condenser. A schematic diagram of an evaporator is shown in Figure 9.11. With most of the juices, it is desirable to heat the juice for as short time as possible and rapidly cool the product. This minimizes the effect on flavour, aroma, and sugar components.

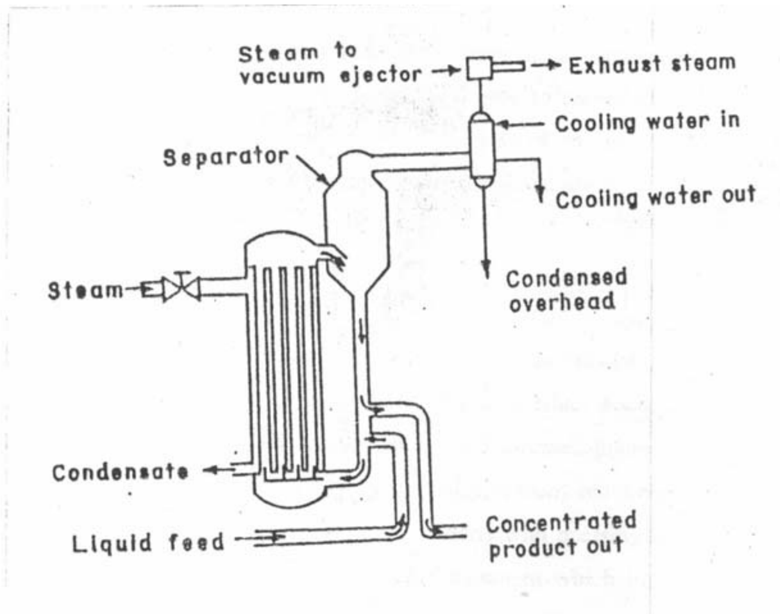

Figure 9.11: Diagram of a typical evaporator

Membrane concentration: Membranes are available that can effectively separate water molecules from other food constituents. Concentration of juice is also possible by using combination of reverse osmosis and evaporation. Specific membranes are used for this purpose. The principle involved is the interposition of a membrane between the feed stream and a transfer stream, and the establishment of conditions providing a driving force for the transport of water across the membrane from the feed to the transfer stream. A schematic diagram explaining the working principle of membrane concentration is shown in Figure 9.12.

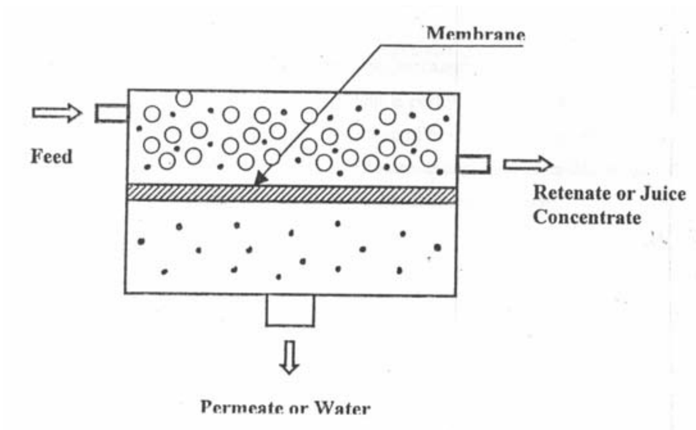

Figure 9.12: Schematic representation of ultrafiltration process

The reverse osmosis technology is effective in concentrating a low solid juice (7-8 ^{o}Brix) two or three fold. From there, use of evaporation technology would be appropriate. Recently, a new reverse osmosis design has claimed effectiveness in achieving a 50-60 ^{o}Brix concentrate. These fruit juice concentrates are often further stabilised by the addition of sodium benzoate and potassium sorbate and are usually stored away from light and are refrigerated or frozen.

Membrane concentration has many advantages over the other concentration techniques. Since the temperature of the processing is less, product quality is maintained. Lower energy requirements, lower labour costs, lower floor space, and wide flexibility are other advantages.

Freeze concentration: This process is based on freezing point depression. Pure water freezes at a temperature of 0^oC. However, if dry solid is dissolved, freezing take place at further low temperatures. In this process a freezer is used to produce ice crystals out of fresh juice and a device is used for separating these ice crystals. The separation of ice crystals from the juice slurry is done by using a centrifuge or filter press.

Freeze concentration avoids the problems associated with evaporation methods that depend upon the heat. It is capable of concentrating most juices to 50^oBrix without appreciable loss of taste, aroma, colour or nutritive value.

9.9 FRUIT JUICE POWDERS

In this method juices are preserved in the form of powder. The juice is sprayed as mist into an evaporating chamber and the flow of air is so regulated that dried juice falls to the floor of the chamber in the form of dry powder. The powder is then separated and packed air tightly. The powder, when dissolved in water makes a fruit drink almost similar to its original fresh juice.

Many fruit juices can be dehydrated to powders or crystals for reconstituting into beverages and are available at prices comparable with quality frozen concentrates. These powdered products are available in several sizes of package. Additives which are permitted by FDA are usually included. These powdered products are also considered as “sports drink”, which requires mixing by the individuals and avoids the inconvenience of transporting large volume of liquid.

These powders are highly hygroscopic in nature and hence require proper packaging. Fruit juice powder from fruits like oranges, mangoes, jackfruit, guava etc. are prepared from strained fruit juices either by spray drying or puff drying and pulp can be used as the base material for baby foods. The powders can be made by vacuum drying, spray drying, freeze drying, drum drying or by foam-mat drying. The moisture content of powdered juice varies from 3-5%. The methods and principles of these drying processes are explained in unit 4 (Section 4.9).

9.10 QUALITY

The term ‘quality’ is one of the most defined terms in use in the food industry today. Quality may be defined as ‘The totality of features and characteristics of a product that bear on its ability to satisfy a given need’. The first part, ‘The totality of features and characteristics of a product…..’concerns objective factors related to the product. The second part, ‘……to satisfy a given need’, concerns subjective factors related to the user or the consumer of the goods.

9.10.1 Factors Influencing Product Quality

To produce high-quality products, the processor needs to be aware of the quality attributes which the consumer discerns as most important and which are most relevant in determining acceptability. Most consumers would initially judge the acceptability of products on their appearance, flavour, texture and perceived nutritional benefits. Each of these attributes is a function of the bio-chemical and physico-chemical composition of the fruit or vegetable. This is influenced by various factors viz:

1. The quality and composition of the raw materials,
2. The effects of processing,
3. The effects of environmental factors, such as temperature, oxygen, light and moisture, encountered during storage and distribution,
4. Customer handling and use, and
5. The barriers to these factors provided by the packaging.

9.10.2 Measurement of Product Quality

One obvious way of measuring product quality is to monitor sales and customer complaints; the higher the sales and the fewer the complaints, the more likely one is to be satisfying the consumer requirements. However, no responsible food manufacturer would rely on this as their only method of quality control. Various methods used for the evaluation are:

1. Instrumental,
2. Immunoassay,
3. Near infrared spectroscopy, and
4. Sensory evaluation.

9.10.3 Quality Control Measures

Some of the important points to be considered for maintaining good quality products are as follows:

1. Only sound fruits or vegetables of sufficient maturity are to be used for processing.
2. Adequate hygienic practices should be followed during the processing of the product.
3. The inspector must be aware of the pesticides and other chemicals used in the production of the raw materials. Necessary laboratory analyses can then be arranged to ensure residue levels in the final product.
4. At the commencement of and during processing, the inspector should pay attention to the state of raw materials, the preparation of raw materials for processing (peeling, slicing, dicing, blanching, etc.), preparation and density of packing medium (sugar syrup, salt brine, etc.), the state of containers to be used (cleanliness and strength), the pasteurization or freezing process (time/temperature relationship), bottle filling and capping and bottle/container storage.
5. The people who work in the processing plant must maintain a high degree of personal cleanliness and conform to hygienic practices while on duty.
6. Persons who are monitoring the sanitation programs must have the education and/or experience to demonstrate that they are qualified.

7. Plant construction and design shall provide enough space for sanitary arrangement of equipments. The equipments must be self-cleanable as far as possible. Cleaning operations must be conducted in a manner that will minimize the possibility of contaminating foods or equipment surfaces that contact food.

8. Check the final product to ensure the vacuum and headspace, packing medium strength and container conditions. Statistically based sampling plans should be adopted for the examination of final product to ensure that it meets the requirements of the export regulations.

9. Each processing unit should have its own sufficiently equipped laboratory and staff to carry out physical, chemical and microbiological quality examinations of the goods.

10. Practice proper sanitary handling procedures. Cleaning operations must be conducted in a manner that will minimize the possibility of contaminating foods or equipment surfaces that contact food

9.10.4 Labelling

Customers and consumers expect the labelling on food to be a true description of what they are buying. Misleading or fraudulent labelling is an unfair trade practice that cannot be tolerated. The important requirements of a label are as follows:

1. A statement of identity,
2. A declaration of net contents (weight or volume),
3. The name and address of the manufacturer, packer, and
4. A list of ingredients (in descending order of volume or weight).

In addition, labels may also be required to include, amongst other things, the country of origin, date of manufacture or packing, a use-by or expiry date, nutritional qualities or values of the food, storage directions, a quality grade and directions for consumption.

9.11 STANDARDS

Government of India has made statutory provision for the control of quality. This has been made to maintain the quality of food, to prevent exploitation of the consumer by the sellers, to safeguard the health of consumers and to establish a criteria for the quality of food products. By this provision we can easily identify the quality of the processed products.

Fruit Products Order (FPO) – 1955, promulgated under Section 3 of the Essential Commodities Act – 1955, aims at regulating sanitary and hygienic conditions during the manufacture of fruit products. It is mandatory for all manufacturers of fruit and vegetable products to obtain a license under this Order. This act regulates the manufacture, storage and sale of fruit and vegetable products.

The FPO 1955 was issued by the Department of Food, Ministry of Food Processing Industries under the powers vested in the government under the Essential Commodities Act to ensure the quality of fruit and vegetable products. This order controls the production, distribution and quality of the fruits and vegetable products manufactured in the country as well as registration, licensing and operation of manufacturing units.

The FPO mark is given to the processor after the grant of license for manufacturing fruit or vegetable product, after the inspection of factory for hygiene and sanitation. FPO mark and license number is required by law to be exhibited on labels of each processed item along with the other information as laid down in the FPO rules.

The FPO specifications includes methods of preservation, permissible colours in the preparations and also the minimum quality requirements of the final products. Fruit and vegetable products which do not conform to the FPO specifications are considered adulterated.

FPO specifications for fruit beverages are as follows:

Sl. No.	Particulars	Specifications	
		Minimum % of TSS in final product	Minimum % of fruit juice or prepared fruit in final product
1.	Fruit Syrup	65	25
2.	Squash	40	25
3.	Cordial	30	25
4.	Unsweetened Juice	Natural	100
5.	Sweetened Juice	10	85
6.	Fruit Juice concentrate	32	100

Permissible limits of preservatives in fruit beverages:

Sl. No.	Fruit beverage	Preservative	Maximum level permitted (mlp)
1.	Fruit juice concentrate	Sulfur dioxide	1500
2.	Squashes, fruit syrups, cordials, fruit juices	Sulfur dioxide or Benzoic acid	350 600

9.12 PACKAGING

Packaging is an integral part of food processing. It performs two main functions: to protect the processed product from surroundings and to advertise the product at the point of sale. The main factors that cause deterioration of product during storage are as follows.

1. Mechanical forces (Impact, vibration, compression etc.),
2. Climatic influences that cause physical or chemical changes (UV light, moisture, oxygen, temperature changes),
3. Contamination (by microorganism, insects, or soil), and
4. Pilferage, tampering or adulteration.

9.12.1 Requirements and Functions of Packaging Materials

The following are among the more important general requirements and functions of food packaging materials/ containers:

1. They must be non-toxic and compatible with the specific foods.
2. Sanitary protection and light protection.
3. Moisture, gas, odour and fat protection.
4. Resistance to impact or other external forces.
5. Transparency.
6. Ease of opening and ease of disposal.
7. Pouring features and reseal features.
8. Size, shape, weight limitations.
9. Appearance and printability.
10. Low cost and other special features.
11. Eco-friendly.

9.12.2 Types of Packaging Materials

There are two main groups of containers: i) Shipping containers, and ii) Retail containers. Shipping containers are containers which contain and protect the contents during transport and distribution (e.g. Wooden, metal or fibreboard cases, crates, barrels, drums and sacks). Where as the retail containers are consumer units which protect and advertise the food in convenient quantities for retail sale and home storage.(e.g.: metal cans, glass bottles, jars, rigid and semi-rigid plastic tubs, collapsible tubes, paperboard cartons and flexible plastic bags).

Wooden containers: Wood offers good mechanical protection and good stacking characteristics. The bottles of fruit beverages are transported by the use of wooden crates. Boxes, crates, casks, kegs, pallets, and few other types of containers made of wood are used on a limited scale to package food products.

Textiles: Cotton bags, sacks and bales are also used in the shipping of food products. They have limited use in the packaging of larger quantities of some products. Open mesh bags are frequently used to pack products such as fresh vegetables, which require complete ventilation in transport and storage.

Metal Can: Metal cans have a number of advantages over other types of containers. These includes protection, convenience for ambient storage and tamper proof. However the cost and weight of metal containers are relatively high. The usual metal cans used are three piece cans, two-piece cans, aerosol cans and aluminum cans.

Tinplate is the common material used for metal cans. It is a rigid and impervious material, consisting of a thin sheet of low carbon steel coated with a very thin layer of tin. Tin is not completely resistant to corrosion but its rate of reaction with many food materials is considerably slower than that of steel. Some organic coatings are provided to protect the tin surface. The FDA approved coating used for the fruit beverage is known as "Beverage can enamel" The coatings not only protect the metal from corrosion by food constituents but also protect the foods from metal contamination.

Glass: There is more use of glass in food industry. Glass containers are chemically inert and do not react with or migrate into food products. They are resealable, recyclable, reusable and are transparent to microwaves. They are transparent to display the contents and impervious to moisture, gases, odours and microorganisms. The principal limitation of glass is its susceptibility to breakage, which may be from internal pressure, impact, or thermal shock, all of which can be greatly minimised by proper matching of the container to its intended use and intelligent handling practices. Main classes of glass receptacles are:

1. Jars which are resistant to heat treatments,
2. Jars, glasses, etc. for products not submitted to heat treatment (marmalades, acidified vegetables, etc.),
3. Glass bottles for pasteurized products (tomato juice, fruit juices, etc.) or not pasteurized (syrups), and
4. Receptacles with higher capacity.

Flexible Films: Flexible packaging describes any type of material that is not rigid. In general they are heat sealable, suitable for high speed filling, suitable for printing and add little weight to the product. They fit closely to the shape of the food, thereby wastage of space is less during transportation and storage. In most cases, such films are used in the construction of inner containers. Since they are non-rigid, their main functions are to contain the product and protect it from contact with air or water vapour. Their capacity to protect against mechanical damage is limited, particularly when thin films are considered.

Flexible films includes single films (e.g.: poly ethylene, poly ester, etc.), coated films (e.g.: films coated with aluminium), laminated films (lamination of two or more films) and co-extruded films.

Paper and paper board: Paper and paper board are used in a variety of package types and forms. Paper from wood pulp and reprocessed waste paper will be bleached and coated or impregnated with such materials as waxes, resins, lacquers, plastics, and laminations of aluminium. This is to improve water vapour and gas impermeability, flexibility, tear resistance, burst strength, wet strength, grease resistance, sealability, appearance, printability, 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. Differentiate between fruit juice and squash.

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2. How is syrup different from cordial?

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3. What are the different methods to produce juice concentrate?

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4. How is juice powder made?

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9.13 LET US SUM UP

The fruit beverage industry is gaining popularity because of nutritional superiority of these beverages to synthetic and aerated drinks. We have discussed in detail about the preparation of a variety of fruit beverages viz., juices, squash, syrup, fruit juice concentrate and fruit juice powder.

The various methodologies adopted in preservation and the working principles of different equipments used in processing of fruit beverages are briefly described in this unit. In addition, the packaging requirements, types of packaging materials, quality aspects and standards of fruit beverages are explained in detail.

9.14 KEY WORDS

Disintegration	**:**	Size reduction of fruit
Enzyme	**:**	Enzymes are organic biocatalysts which govern, initiates and control biological reactions important for life processes.
Expression	**:**	Separation of liquids from solids by applying pressure.
Filtration	**:**	Separation of solids from liquids by passing the mixture through a bed of porous material.
Brix	**:**	Unit for the measurement of Total Soluble Solids present in fruit beverage.

TSS	**:**	Total Soluble Solids is the amount of sugars and water soluble substances present in fruit and vegetables.
Clarification	**:**	It is the process of complete removal of all suspended material from the juice
Centrifugation	**:**	The separation of immiscible liquids, or solids from liquids by the application of centrifugal force.
De-tartarisation	**:**	Elimination of potassium bi-tartrate from fruit beverage.
Pasteurization	**:**	It is the process of heat treatment used to reduce the total microflora, especially pathogenic bacteria.
Flash pasteurization	**:**	It is the process of heating fruit juice for a short time at a temperature higher than the pasteurization temperature and held at that temperature for about one minute.
Carbonation	**:**	It is the process of dissolving sufficient carbon dioxide in fruit juice
Decanter	**:**	It is the process of removal of suspended material from the juice.
Deaerator	**:**	The equipment used for the removal of oxygen from the fruit juice.
Squash	**:**	Fruit beverage which contain at least 25% fruit juice or pulp and 40-50 % TSS.
Cordial	**:**	Fruit beverage which contain at least 25% juice and 30% TSS.
Syrups	**:**	Fruit beverage which contains at least 25% fruit juice or pulp and 65% TSS.
Evaporation	**:**	It is the partial removal of water from liquid foods by boiling.

9.15 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Clarification is the process of complete removal of all suspended material from the juice**.** This can be performed by many methods viz. centrifugation, enzyme treatment, settling, filtration, freezing(-18^{o}C), use of high temperature (nearly 82^{o}C) and low temperature(-2 to –3 ^{o}C). The chemical treatments like addition of gelatin, albumin, casein, or a mixture of tannin and gelatin is also used for the removal of suspended particles.

2. The enzyme treatments during crushing process will enhance the extraction yield, the juice colour is better fixed and finished product taste is improved.

3. Pasteurization is the process of heating fruit juice at boiling temperature or slightly below it for a sufficient length of time to kill the microorganisms which cause spoilage. Whereas flash pasteurization is the process of heating fruit juice for a short time at a temperature higher than the pasteurization temperature and held at that temperature for about one minute.

4. Preservation of fruit juice can be done by addition of sugar, pasteurization, flash pasteurization, freezing, drying, carbonation, filtration, irradiation and by adding chemicals like sulfur dioxide or Benzoic acid.

Check Your Progress Exercise 2

1. Fresh fruit juice contain 100 % fruit juice, where as fruit beverage which contain at least 25% fruit juice or pulp and 40-50 % TSS is known as squash.

2. Cordial is a fruit beverage which contain at least 25% juice and 30% TSS, where as syrups contains at least 25% fruit juice or pulp and 65% TSS.

3. Various methods used for fruit juice concentration are: Evaporation, Freeze concentration and Membrane concentration.

4. Fruit juice powders are prepared from strained fruit juices by spray drying, vacuum drying, freeze drying, drum drying or by foam-mat drying. However spray drying is the most common method. The juice is sprayed as mist into an evaporating chamber and the flow of air is so regulated that dried juice falls to the floor of the chamber in the form of dry powder.

9.15 SOME USEFUL BOOKS

1. Mahadeviah, M. and Gowramma, R.V. (1990). Food Packaging Materials, Tata McGraw Hill Publishing Company Ltd. New Delhi.

2. Somogyi, L.P, Barrett, D.M. and Hui, Y.H. (1996). Processing of Fruits: Science & Technology (Vol. II) – Major Processed Products, Technomic Publishing Co. Inc., Lancaster, USA.

3. Srivastava, R.P. and Kumar, Sanjeev (1998). Fruits and Vegetable Preservation – Principles and Practices, International Book Distributing Co., Lucknow.

UNIT 13 SITE SELECTION AND LAYOUT

Structure

13.0 OBJECTIVES

After studying this unit, you should be able to:

- understand the importance of proper plant layout for efficient and optimum working environment;
- describe the general guidelines for layout of a fruits and vegetables processing plant; and
- explain various steps that can be taken for maintenance of clean working environment and workers' safety in a fruit and vegetable processing plant.

13.1 INTRODUCTION

In this unit we shall study about the various aspects of plant layout, which is nothing but the arrangement of different facilities and equipment in a plant. It begins with the importance of proper plant layout followed with the general principles of a plant layout. We will also discuss how a proper plant layout helps in saving of manpower and energy, and maintaining efficient and optimum working environment. And as you know, all of these parameters lead to the maximisation of profits.

This unit also covers different considerations for maintenance of clean working environment and safety of workers, which are very important for the survival of any industry. You will be able to comprehend that the working environment of the food processing plant and ultimate sustainability of the plant do not depend only on the plant operation management; rather a major part of it is also dependent on the plant layout, design and installation of different equipment and the safety measures. You will also know about the guidelines for placement of different equipment and other facilities in a fruit and vegetable processing plant.

13.2 SITE SELECTION

Suppose you want to establish a mango processing industry in a particular area, what type of questions would immediately come to your mind?

The first set of questions you would ask yourself is:

- Is sufficient quantity of good quality raw material available in the locality, or what will be the transportation cost for bringing raw material from another locality to the proposed processing site?
- Whether the auxiliary facilities such as electricity, water, labour, etc. are available in the locality?
- Is there any other associated problem for establishment of industry in the particular place?

The answers to all these questions should be favourable. These are some of the factors, which affect the site selection for any type of manufacturing industry. In fact many such factors have an effect on the site selection for any industry. If we don't give a realistic consideration to all these factors, we may face problems in running the industry in future.

In general, a proper site for a fruits and vegetables processing plant should have the following features.

- Adequate quantities of good quality raw materials should available in the nearby locality, because fruits and vegetables are highly perishable and deteriorate in very long distance transport.
- The fruits and vegetables processing plant requires a huge amount of water for processing, cleaning and other operations. Hence the area should have a good source of quality water supply, or a permanent water source should be created for the purpose.
- The environment should be as far as possible clean and free from debris and dust. The site should be at a considerable distance from other industrial factories, which may affect adversely the quality of processed product by spreading smoke, disagreeable odours, etc.
- There should not be any problem for availability of electrical power in the area. A standby generator will help in maintaining operation during power failures.
- There should exist proper transport facilities for the movement of raw materials and finished products.
- There should be easy availability of labour in the area.
- There should also be facilities for disposal of the waste, as this is becoming a matter of growing concern these days.
- There should be scope for future orderly expansion of the factory.

After we have selected an area or region for locating the plant, the next job is to select a specific site. The final site selection requires a careful scrutiny of experts. We should shortlist some probable sites and test their soil condition. If the soil doesn't have good bearing capacity, there will be more investment on foundation costs. Good natural drainage is another desirable feature. If the site is located near a stream or other body of water, we should check the flood history. In addition, consultation with officials of the neighbouring plants on the various nature of locations in the area and attitude of the local community is also helpful for deciding a suitable location for the plant.

13.3 IMPORTANCE OF PROPER PLANT LAYOUT

13.3.1 What is Plant Layout?

We may consider any food processing operation as a transformation process. In a fruit and vegetable processing plant, the raw materials (raw fruits and vegetables) are transformed into finished product (processed fruits and vegetables) by a series of operations, whose sequence and numbers are specified for the input. For example, the sequence of operations that are carried out in an onion dehydration plant, can be shown as in Figure 13.1.

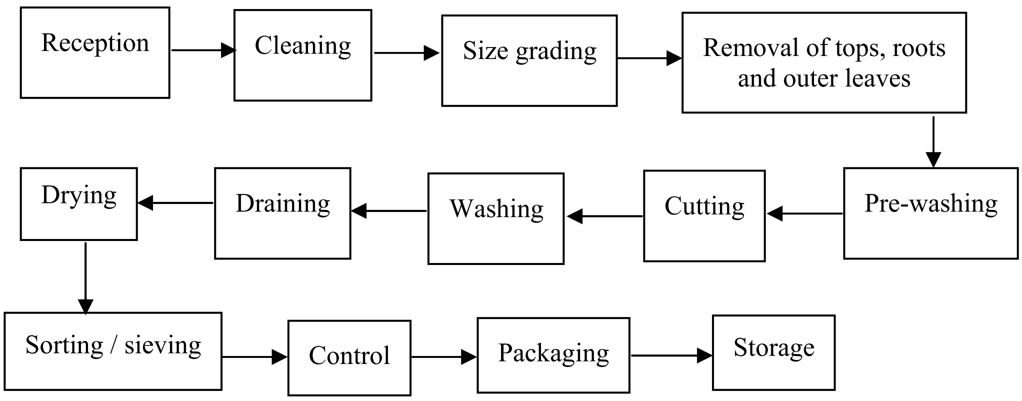

Figure 13.1: Processing of dehydrated onions

We can not change the sequence of these operations as per our desire. In this case, after receiving, the dust and dirt sticking to the surface of the onion bulbs must be cleaned first. Then the bulbs should be graded for size, then the tops and roots be removed, and so on. Therefore, for efficient utilisation of energy, labour (these are the other inputs than the raw materials), and of course money, the cleaning section should be kept adjacent to the receiving section followed by the grading section, and so on.

Now, suppose we place the size grader between the receiving yard and the cleaning section or the drying section between the packaging section and storage section, what do you think will happen? It will unnecessarily increase the materials handling cost and time, and reduce overall performance. In addition, it will also cause collision between the workers and wastage of manpower and energy. Hence, we should arrange the work areas, equipment and auxiliary facilities judiciously in the processing plant such that the operation will be economical and the employees will feel safe and satisfying.

Thus, the arrangement of the different facilities and equipment in a food processing plant plays an important role in the overall viability of the project. This physical arrangement of the industrial facilities is known as **plant layout**. The arrangement also includes the space needed for material movement, storage, indirect labour and all other supporting activities, or services, as well as for operating equipment and personnel.

13.3.2 Advantages of Good Plant Layout

In general, a good plant layout will permit simple and forward movement for the product and containers through the plant. Let us take a simple example.

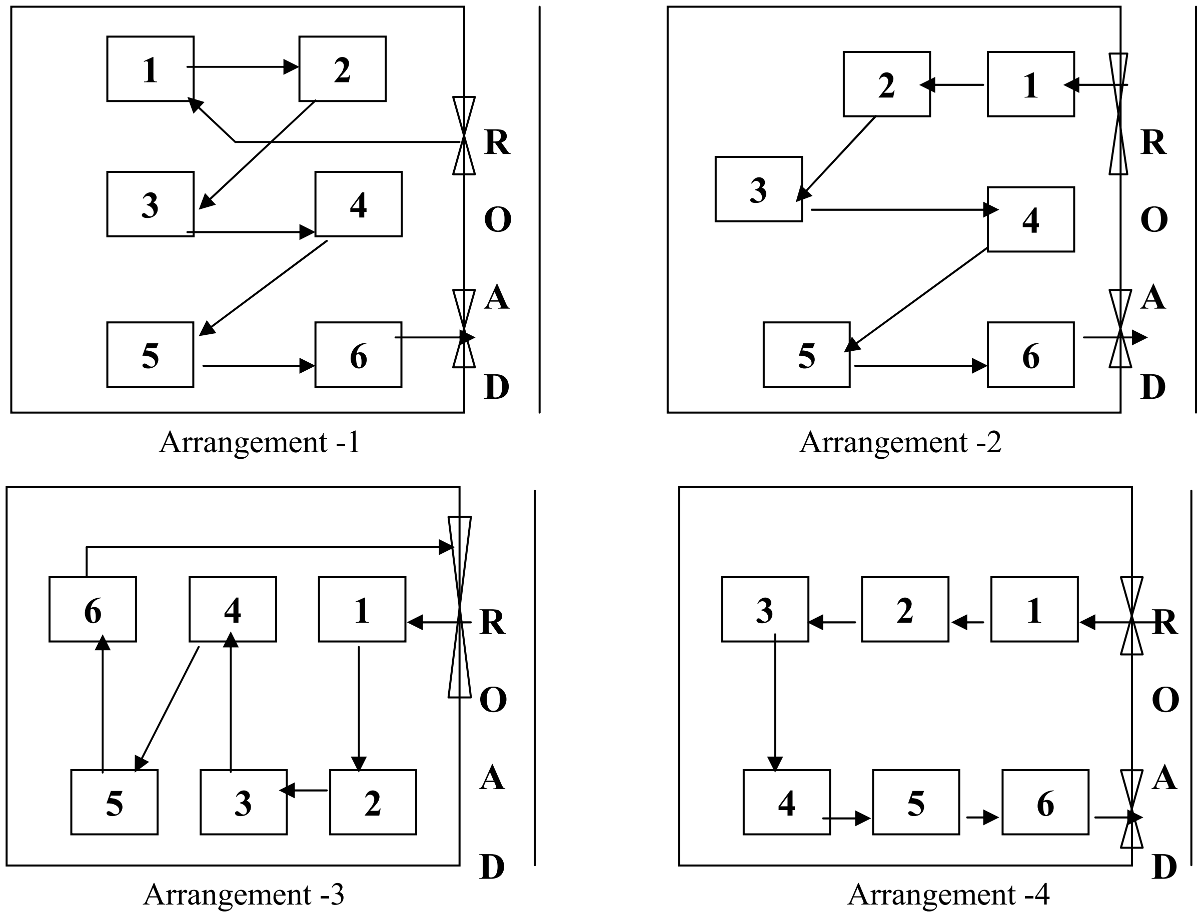

Figure 13.2: Understanding what plant layout means

In Figure 13.2, we have shown you some equipment in boxes, in which the numbers show the sequence of operations. Say, the first operation (may be cleaning) will be done by the Equipment-1, the second operation by Equipment 2 and so on. The Equipment 6 does the packing and then the product has to be taken out of the factory. I have shown you four possible arrangements for these equipment. Which pattern or arrangement do you think will be the best to reduce the cost of operation and improve performance?

Obviously Arrangement No. 4 will be the most ideal one. Remember, we are yet to learn the general guidelines for a good plant layout. However, you will definitely agree that if the machines are not properly arranged, as in the cases 1, 2 or 3, the total material movement inside the plant is unnecessarily increased. Besides, there is also crossing of the flow paths, which would interrupt a smooth operation.

The sequence of operations is one of the major criteria, but not the only criteria for designing plant layout, which we will discuss later in the unit. But as we are discussing about the advantages of a good plant layout, we wee that a proper plant layout helps us in reducing cost of operation, which is very important for survival of any industry.

A good plant layout, in general, has the following advantages.

- Saving in floor space;
- Better utilisation of machine and man power, and services;
- Reduced material handling, thus saving in labour and cost, less production delays;
- Reduced inventory in process, thus saving in investment and working capital;
- Increased output/ production per unit time, labour, money and energy; and
- Easier and better supervision.

In addition to the above, a properly designed layout helps to maintain proper sanitation and safety standards in a plant. It reduces confusion between different sections of workers, and improves moral of the workers. All these factors directly affect the output. Careful layout planning can identify and remedy bottlenecks and trouble spots before the plant is built, and thus prevents troubles later.

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 major factors for selection of site for a fruits and vegetables processing plant?

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2. What are the main advantages of a good plant layout?

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13.4 GENERAL PLANT LAYOUT

In this section, we will discuss about the different requirements and general guidelines for a good plant layout. As we go on discussing the general guidelines, you will discover that a careful planning is very essential for the health of any industry, and in particular the industries processing fruits and vegetables.

13.4.1 Requirements/Factors in Planning Layouts

As we have already discussed, the basic objectives of a good plant layout are smooth operation and reduced cost in handling and processing. Further good layout must include arrangement of specified areas for processing, storage and handling in efficient coordination. This should also consider the following factors.

- ***Proper placement of equipment and conveying machines*** – All the equipment and conveying machines should be arranged in proper coordination depending on the flow sequence and characteristics of equipment. Depending on requirements, the layout can be single level, multi storied, or combined designs.

- ***Economic distribution of services*** – The layout, in addition to proper placement of important equipment, should also have provision for efficient and economic distribution of water, process steam, power, and gas, etc. The distribution lines for these utilities should not interrupt the normal working of the people.

- ***Suitable use of floor and elevation space*** – This will depend on the type of food processing plant and the special facilities and equipment used for the system.

- ***New site development or addition to a previously developed site*** – If we want to plan the plant on a site, which already has some installed equipment, office rooms and storage godowns, etc., then the layout should consider these amenities. Our objectives will be to see that minimum alterations or modifications are made to the existing facilities without affecting the overall objective of the layout.

- ***Future expansion*** – The layout should have sufficient provision for future expansion. Suppose at this stage we are interested in a 1 tph (tonne per hour) dehydration plant for ginger. But after some years, we want to increase the capacity to 4 tph or want to prepare dehydrated onion and garlic from the same plant. It requires installation of some more equipment. We will also need more space for godown and processing operations. In that case, we will be in trouble if the present arrangement doesn't have sufficient provision for expansion. Another alternative is to install a completely new plant in another location. It will involve some unnecessary cost and further it will also be difficult to manage two plants at two different locations. To overcome such type of difficulties, the layout should have provision for future expansion.

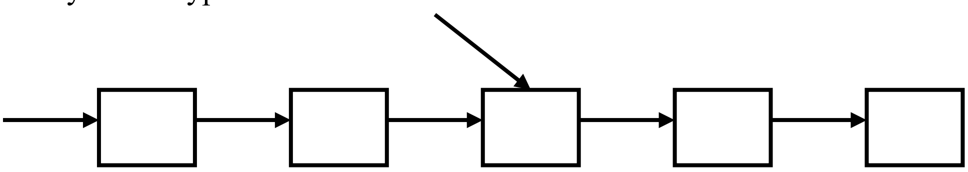
- ***Waste disposal problems*** – The layout should have adequate provision for disposal of solid, liquid and gaseous wastes. Or else, the project may not be even passed by the pollution control authorities.

- ***Safety considerations*** – We should keep the equipment or areas having chances of hazards like fire or explosion away from normal working of the people. For example, we should isolate the boiler room.

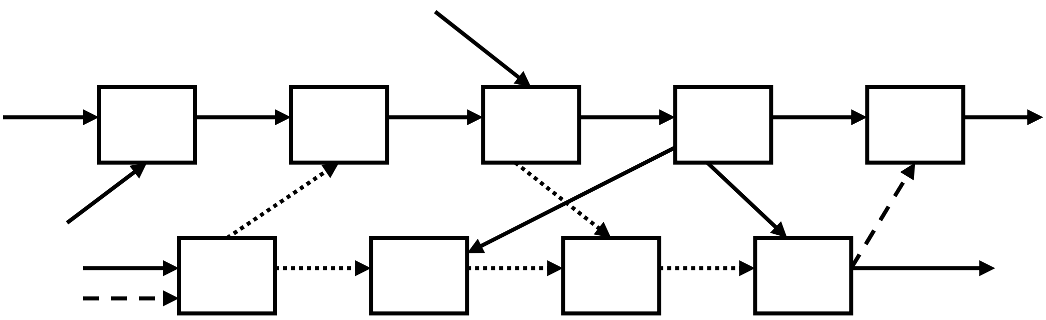
- ***Other factors*** – The building code requirement, weather conditions like extreme high or low temperatures, maximum wind speed in the area, etc. are some other factors which need to be considered during planning the layout.

13.4.2 Types of Layouts

There are generally two types of product flow in food processing industry, namely, **line flow process** and **intermittent flow process.** In the line flow process, the product flows from one operation to the next in a prescribed sequence as in the preparation of homogenised and pasteurised milk in an automatic dairy plant. The individual work tasks are closely coupled. There may be side flows, which impinge on this line, but they are integrated to achieve a smooth flow. In an intermittent flow process the production is carried out in batches at intermittent intervals. In this case, we can organise the equipment and labour into different work centres by similar types of skill or equipment. The product can be sent to any of the work centres as per requirement. For example, in a mango processing plant, the mango slices can be sent to a dehydrator for preparing dried mango slices or sent to the canning section for getting canned mango slices, or may be filled with syrup and frozen to prepare frozen mango slices. Similarly mango pulp can be processed in different work centres to get frozen mango pulp, mango squash, mango nectar, mango bar, mango powder or mango cereal flakes. Or, say the particular squash manufacturing section can be used for different commodities like mango, pineapple, lime or watermelon at different times. This often results in a jumbled pattern of flow. The volume of product handling can be changed easily in this type of flow.



LINE FLOW- PRODUCT FORM OF LAYOUT



INTERMITTENT FLOW-PROCESS FORM OF LAYOUT

Figure 13.3: Product form and process form of layout

Based on the above classification of flow processes, the layouts also differ. The intermittent process is also known as a **process form of layout** as similar equipment and processing operations are grouped together. It is also known as 'layout by function'. The line flow is also called a **product form of layout** because various process equipment, and labour skills are put into sequence according to the way the product is made.

When a product lacks standardisation or the volume of product is low, the intermittent operation is economical and involves least risk. If an industry produces high volume of one or a few products, then layout by product or flow-line layout can be used. The equipment are placed in sequence, either on a straight line, or in shapes like U, L or convoluted or serpentine shape. As the raw material is processed, some products and by-products may move away from the principal direction of the flow.

Many modifications to above flow patterns are possible. A **hybrid layout** is one, where some portions may be layout by process and some portions by product. Generally the small food processing plants have process form of layout, whereas bigger industries have hybrid layouts.

Another type of classification of layout is single level, multi-storey or combined layout.

13.4.3 General Guidelines for Layout of a Fruit and Vegetable Processing Plant

After obtaining some idea on the factors affecting the layout planning and the different types of layout plans, in this section, we will give a closer look at different aspects of layout of a fruit and vegetable processing plant.

Layout of different sections / buildings

After a complete study of the requirements of the plant, the selection of the building or buildings must be considered. The building should be designed around the process, not a beautiful structure into which the process must fit.

Different products may each have their own processing room or area, or they may be housed in a single room with different allocated area. The primary rooms should be planned larger than necessary, for possible future expansions. We should keep in mind that the height is also equally important as the floor space requirement for layout planning.

The office room needs to be accessible to suppliers, customers and visitors. In large plants it can be kept at the main entrance as a separate building. The office accommodation should also contain a reception room and a demonstration room for study groups, etc. For small plants such offices are contained in the main building. The main laboratory can be conveniently put on an upper floor of the administrative building or next to the office room so that manager can easily control both administrative and technical services.

Reception and dispatch rooms should be situated on the ground floor having good access to main gate. The reception platform should be at a height to suit the vehicles concerned. In small plants loading and unloading, and conveying within the plant are done manually, In large plants, if mechanical conveyors or hydraulic conveyors are to be used, then the conveying section has to be planned simultaneously with the reception section.

Storage facilities for raw materials and intermediate and finished products may be located either in isolated areas or in adjoining areas. While considering for storage, the amount of handling involved for carrying the materials from reception to the storage section or from the storage to the processing section should be considered. However, sometimes storage of materials in adjoining areas to reduce materials handling may create problem for future expansion of the plant. Hazardous materials, if stored in large quantities, should be isolated.

Areas involving dust, dirt, oil and fumes, which may contaminate the products must be separated from processing or storage areas. The boiler room, fuel store, repair shop, compressor rooms are such types of areas.

The orientation of prevailing winds, the polluting potential of the air, topography of the site and access to roads must be considered when fixing the position of different rooms. Direct exposure of certain areas of the plant to the summer sun may be undesirable.

Layout of equipment

The information on exact space needed for installation of each equipment is very important for planning. The design and capacity of equipment will determine the floor space. Manufacturers normally give the dimensions of their equipment including floor space required. Besides, there should be adequate space for convenience in operation and maintenance, while still practising economy of floor space and good housekeeping in the plant. Allowances for working space should be five times the floor space occupied by the equipment. Floor area for dry store and office spaces should each be 25% of the plant floor area. The floor areas should also include space for possible additional equipment.

The equipment that need frequent servicing needs special care. There should be space for lowering the overhead equipment for maintenance. Besides, it is not wise to fit the equipment too closely in a building. A slightly larger building that appears unnecessary will cost little more than the one that is crowded, but this will help in maintenance of proper sanitation, safety and comfort of the operators.

We must consider the relative levels of several pieces of equipment and their accessories before placement. For gravity flow, the materials are first lifted to a higher level, and hence, a multi-storey layout is often necessary. The cost of mechanical transportation is greatly reduced in single storey plant.

In most of the cases, a group of operations are carried out simultaneously, for example, in a canning plant the can filling, exhausting, and can closing are such type of operations. So we can group the necessary equipment in proper sequence in a single room. It helps us in division of operating labour so that some specialised operators can be trained to attend all equipment of the group.

Suppose at any point of time we need to bypass a machine or a section, then the plant layout should be such that it allows that with minimum of alterations.

Layout of materials handling equipment

As we have discussed previously, considerations for materials handling should accompany the equipment and buildings layout. Suppose the materials are to be carried by crates on a chain conveyor from the receiving yard to storage, then the layout should have provision for that, in addition to working space for the labourers. Wherever possible, we should take advantage of the topography of the site location. The working surface of the conveyor must be at a height to facilitate the operations, which may be involved.

Lay out of service facilities

The important service facilities for any type of food processing plant are water, steam, power, electricity, gas and air. Proper placement of the distribution lines for the above services help in ease of operation, orderliness, and reduction in costs of maintenance. For example, we must not lay any pipe on the floor or up to a height of 7 ft level, where the operator is expected to move during the work. Chaotic arrangement of piping invites chaotic operation of the plant.

The service lines should be as short as possible to reduce capital investment and running costs. In small plants it is practicable to provide accommodation for steam production, refrigeration and electricity within the main building. In large plants, this is often not possible, and the service rooms are grouped in a separate building. The switch room may be as central as possible, to economise in wiring. In large plants more than one switch room may be necessary. The generator room should be adjacent to the switch room.

The boiler house must provide accommodation for the steam boilers and auxiliary equipment, such as feed water tank, feed water treatment plant etc. The type and capacity of the boilers greatly influence the space required. A working space of 1-2 m should be allowed between boilers and other equipment or wall of the building to give access for maintenance. The space in front of boiler must be much higher than this for cleaning of flue tubes and their replacement. The room or house for the boiler is usually separated from the main plant building in compliance with legal requirements.

The refrigeration machinery should be grouped in one room, but if separate compressor(s) are used for direct refrigeration, they must be placed close to the room, which they cool. Longer service lines need more cost of refrigerant required to charge the system, and thus higher will be the running costs.

Layout of waste disposal system

The disposal of wastes, which include liquors, fumes, dusts and gases, need special attention. The wastes should not affect the local community. If the wastes are not disposed properly, they will attract local dissatisfaction and prosecution by law, which will harm the unit in long run. The special equipment installed for ventilation, fume elimination, and drainage should not interfere with the flow of materials in process.

Other considerations

We should locate the windows / doors/ ventilators to allow maximum possible thermal circulation of air. Proper orientation of the buildings in respect to the solar position and prevailing wind direction is also important.

The local and national safety and fire code requirements are important factors while arranging the equipment and buildings in a plant. Different fire protection devices must be incorporated to protect costly plant investment and reduce insurance rates.

Existing or possible future rail roads and roads adjacent to the plant should be considered for placing the layout of building and auxiliary facilities. There should be proper access to all parts of the plant. Sufficient free space should be kept in the initial planning for future expansion.

13.4.4 Steps of Layout Planning

The steps involved in layout development are as follows:

First we have to decide the process and the type of layout design. The factors affecting process selection are capital, market conditions, labour, management, raw materials and viability of technology. As mentioned before, a complete understanding of the different unit operations involved in the process is essential. Layout has to be done for individual sections, and for individual equipment inside each section.

Then the preparation of the product flow charts is the next step in planning. The product flow chart shows 'how the product is processed', in addition to the transportation and storage activity. An example of a simple flow chart is shown in Figure 13.4 for manufacture of tomato sauce.

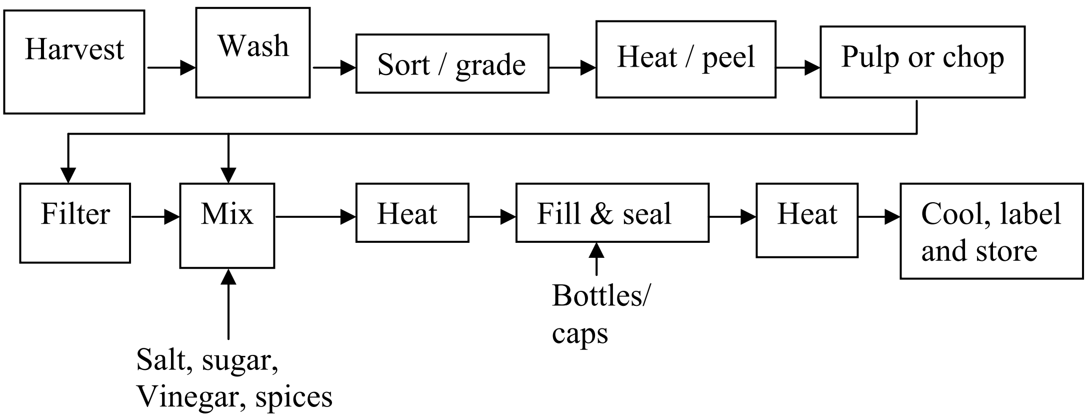


Figure 13.4: Product flow chart for tomato sauce

After preparing the product flow chart, we have to decide the principal equipment; the flow lines are then converted to machine lines. The designer must have a complete knowledge on the space requirements for individual pieces of equipment, for processing, storage of products and by-products, and for the working of people. At a later stage of process planning, the make or capacity of certain item may be changed when the particular details of the equipment become fully available, or we find better equipment during the planning process.

As the layout design develops it should be drawn on paper. After appropriate revisions, detailed drawings can be made to show the exact location of equipment and distances. Scale drawings are widely used in layout planning. We arrange the basic blocks or sections and arrange them in plot plans. Thus, the shape and extent of any area/section is described and the interrelationship between each area is shown. This is also known as 'Unit area concept' of planning.

Two dimensional scaled templates or small cutouts of unit areas and equipment within each area are placed on crosshatched scale paper. After repeated investigations and with different combinations/alterations, a basic plot plan is prepared with detailed two-dimensional diagrams, and is shown in a series of drawings.

Three dimensional scale models prepared from blocks of wood and cardboard give a better representation than the two-dimensional drawings. In bigger models, the piping and utilities can be shown. Now-a-days softwares are available for layout planning of process facilities using computers.

13.4.5 Example of Plant Layout

In Figure 13.5, we have shown you a typical example of fruit processing plant layout. Check how the raw materials receiving and storage and processed product storage are isolated from each other. See that the raw material enters

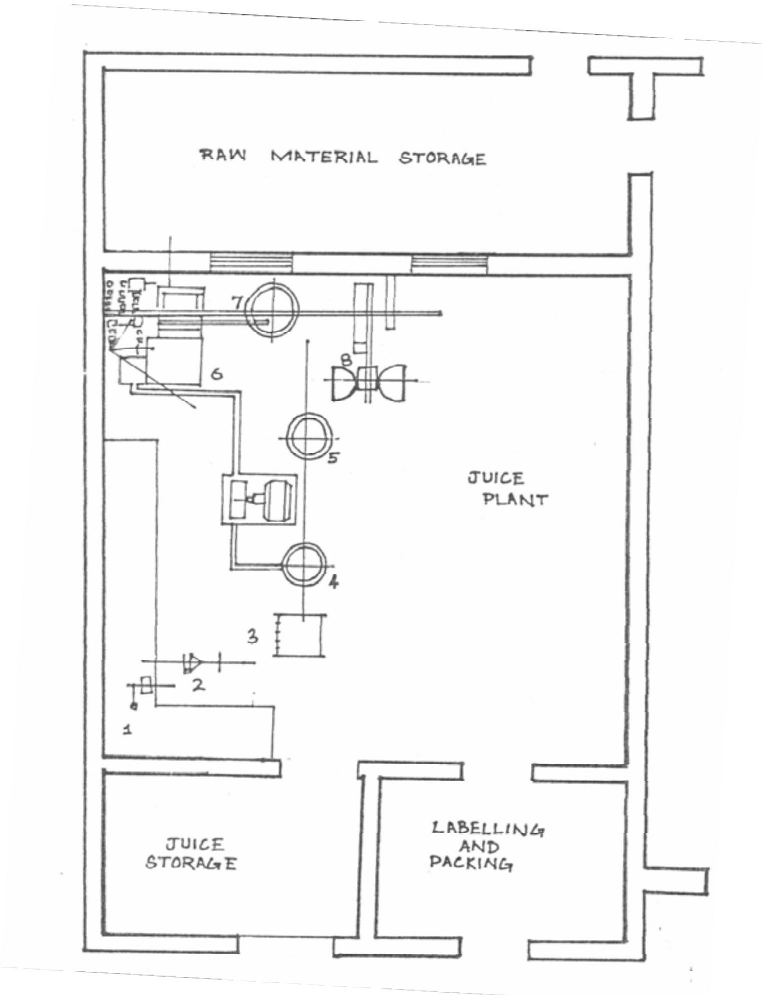


Figure 13.5: Layout plan of a fruit juice plant: 1) Capsular, 2) Corker, 3) Filler, 4) Syrup agitator, 5) Syrup maker, 6) Pulping M/C, 7) Pump, and 8) Pulp extractor

the processing room from one side and exits from the other. In the processing section, all the equipment are arranged in sequence so as to avoid criss-crossing of the flow lines. Besides, also observe that sufficient working space is kept in the processing room, which will avoid collision between workers and avoid accidents, and also help in maintenance of the equipment. Many arrangements or alternate layouts are possible for this kind of plant. But the basic features that we have studied in the previous section should be carefully incorporated in the system for optimum working conditions.

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 is the basic objective of a good plant layout?

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2. Why considerations for future expansion is important during designing of a plant layout?

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3. What are the different types of plant layouts?

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4. What are the advantages of 3-dimensional scale models over two-dimensional representations?

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13.5 ANALYSIS OF MAN AND MATERIAL MOVEMENT

In a fruit and vegetable processing plant, in addition to the cost of raw material and its processing, the other major costs involved are the cost of labour, storage, transport and distribution. Hence we must try to minimise the material handling cost as well as employee travelling time, which also affect the viability of the project. Similarly, mechanical handling equipment consume a lot of power and by generously planning the layout, a considerable saving is possible with this aspect.

The total cost involved in a plant for transportation can be expressed as follows:

$$C = \sum_{i=1}^{N} \sum_{j=1}^{N} T_{ij} C_{ij} D_{ij}$$

where C = Total cost

T_{ij} = Trips between section i and section j

C_{ij} = Costs per unit distance per trip travelled from i to j

D_{ij} = Distance from i to j

N = Number of sections

Here C can be considered in rupees or time units to accommodate materials handling or travelling time criteria. The trips between any two sections will depend on the quantity of materials handled, and hence, once the plant capacity is decided, the number of trips between sections becomes apparently constant. The cost per trip is regulated by the labour rates or power utilised in the conveying machines, and for the purpose of this analysis, may be assumed constant. Hence to minimise the total cost due to man and material movement, the sections need to be arranged in such a manner that the distance travelled by the people or product between the time it enters the processing plant till the time it is dispatched will be minimum. The same approach can be thought of the movement between equipment in a particular room or department. In other words, our objective will be to find out particular D_{ij} combinations for minimising C.

Generally we proceed as follows:

- Determine the number of trips between each pair of sections per unit time such as a day, week, month or year, and with this information draw the ***trips matrix***.
- Ascertain the costs of material handling per unit of distance and draw the ***cost matrix***.
- Draw the ***distance matrix*** with the knowledge of distance between each pair of sections. These distances will depend on layout chosen.
- Compute the total materials handling cost per each pair of sections with the help of above three matrices.

The following example of Figure 13.6 will help you understand how this can be done.

Let us take the example of a small food processing plant, which has only five sections. In the first matrix, I have shown the number of trips required per week between each pair of section for a fixed quantity of raw material (Figure 13.6). Say for example, there will be 23 trips between sections 2 and 3, and 26 trips between sections 3 and 5.

I have put the costs of material handling per unit of distance between each pair of sections in the 2nd matrix. Subsequently on the basis of the layout plan, I found the distance between each pair of sections, and substituted the values in distance matrix.

It will be interesting for you to see that the **total cost matrix** is computed by multiplying the corresponding figures in the trips matrix, cost matrix and the distance matrix. Observe in Figure 13.6 that for sections 2 to 4 the cost of materials handling is (22)(23)(5) = Rs. 2530. After I have calculated all costs, I added all cells in the total cost matrix to get the total cost as, C = Rs. 38561 per week. This completes the evaluation of the equation for a particular layout plan.

Sections	1	2	3	4	5
1		24	25	27	24
2			23	22	24
3				25	26
4					27
5					

Trips matrix

Sections	1	2	3	4	5
1		32	23	34	42
2			30	23	21
3				18	23
4					20
5					

Cost matrix

Sections	1	2	3	4	5
1		5	7	8	4
2			6	5	4
3				7	8
4					5
5					

Distance matrix

Sections	1	2	3	4	5
1		3840	4025	7344	4032
2			4140	2530	2016
3				3150	4784
4					2700
5					

Total cost matrix

Figure 13.6: Computation of total cost of man and material movement for a layout plan

After this step, we may think of improvements by exchanging pairs of sections, and recalculating the total cost again. Alternate combinations of the locations, i.e. every possible layout are evaluated to find out the optimal solution.

In the above example of Figure 13.6, we have only 5 sections, and hence, we have only 4! combinations, i.e. only 24 arrangements are possible. However, as the number of sections increases the possible combinations would increase. For example with a plant having 8 sections the number of possible combinations will be 7! or 5040. You calculate yourself what will be the possible combinations for a plant having 20 sections. In such cases the use of a computer becomes inevitable.

13.6 MAINTENANCE OF CLEAN WORKING ENVIRONMENT

Cleanliness is very essential in any food processing establishment. It aims at protecting the food safety as well as improving and maintaining the quality of food. It is also the key to good health and efficient work. It is not only the responsibility of the plant manager to take care of sanitation aspects during operation, but proper layout, suitable placement of equipment, proper construction of building, doors, windows, selection of building materials etc. are also vital in maintaining a clean working environment during the plant operation. What do you do to remove bad gases or odours during cooking? The answer will be to switch on the exhaust fan or open the windows. But if the kitchen has no provision of exhaust fan/ventilator or windows, then what shall you do? It is the fault of planning the kitchen that the cook will suffer.

So, we should think about sanitation from the preparation stage of building plan. Provision of built-in sanitation in the construction design as well as in every piece of equipment, fittings, fixtures and utilities help us in maintaining a clean working environment. If the work area is not properly planned, the employee may tend to overlook hygienic practices while handling food. For example, if the wash basin is at a considerable distance from the working table, the worker may tend to skip proper washing of hands when required. There should be sufficient space to provide convenience and comfort to workers.

While selecting a site, we must have taken care that the area should be at a considerable distance from other industries, which might cause pollution. But after selecting the site also, we must be very careful for maintenance of clean environment within the industry and its vicinity. As discussed previously, we should isolate the areas/equipment producing dust, fumes, etc., so that they would not pollute the other working places. The processed food area should be kept away from the raw food area, receiving and cleaning sections. For example, if ginger or turmeric is collected directly from the field, then the washing operation should be carried out in a separate room or in an open yard away from the main room. The drying yard should not be kept near to the road or dusty areas. We should install the grinding mills or cyclones collecting powders in a separate room, or else, it will make the whole environment dusty.
In the ceiling if there are exposed beams or girders of iron or reinforced concrete, they would harbour dust and dirt. These dust and dirt get into the plant atmosphere and contaminate both equipment and products. The best ceiling is therefore one with a plain smooth horizontal surface. Light fixtures embedded or inset into the ceiling are more sanitary than the suspended ones. Windows must be properly constructed and maintained to provide adequate light and ventilation. The panes, frames, and screens must be easily and regularly cleaned. The doors and windows must be fly and rodent proof.

Smooth surfaces on the floor and glazed surfaces on the walls up to a height of at least 150-200 cm are satisfactory from sanitation point of view. Drains with proper slope should be provided in all rooms to carry away the liquid wastes promptly from the main working areas. Suitable slope of the floor helps easy cleaning. Garbage dumps and stagnant water in the vicinity encourage breeding of rodents, flies and mosquitoes, and hence should be at a considerable distance from the working areas.

13.7 WORKERS' SAFETY

Safety of workers is one of the prime concerns of any type of industry, and as mentioned in the preceding section, safety considerations start even from the stage of layout planning. Some of the important points that can be considered for workers' safety during designing of a food processing plant are as follows:

- There should be adequate space around all working equipment including those used for material handling to avoid collision between workers and the equipment and between workers themselves. This is more important for equipment, which need frequent servicing.
- The foundation and structure of the floor must be capable of supporting equipment, especially large storage tanks, work load and traffic.
- In the processing plant, fruit juices may fall on the floor throughout the processing area. If the floors have pores, cracks, joints then these get deposited on the floor and ferment to produce acid. The acids react chemically with the floor materials, corroding and damaging the floor. Hence, all parts of the food processing plant should have suitable acid resistant floors. The floors should also be able to tolerate physical abuse and thermal shock.
- The surface of the floors must not be slippery. However, rough surfaces are not preferred as they are difficult to clean; hence we should give a suitable slope to the floor for proper drainage. The design of the drains must permit quick flow of effluent. Drains should be covered with grills or perforated grate, which are inset and level with the floor. This allows normal traffic across a floor area without interference by the drains.
- We should assure proper lighting to all parts of the plant. The areas where there is more chance of water pouring onto the floors or the moist areas need special attention.
- The dangerous and moving parts of the machines need to be fenced. The places where the persons are likely to fall as dangerous pits, sumps, openings in floor, etc. should also be fenced. There should be provision for suitable safety devices in the moving machines so that they can stop immediately if any problem occurs.
- During operation, untrained and unskilled workers must not be allowed to operate any machine or equipment.
- There should be provision of emergency doors for escape in case of fire, necessary fire fighting equipment and training to workers.
- Proper maintenance measures should be taken for each and every machine and periodic routine checkups are essential to avoid accidents.

Safety is a matter of concern for all directly or indirectly involved in the industry, and small cares taken for maintenance of a better work place and during operation can help prevent major accidents and improve the performance of the food processing plant.

13.8 REGULATIONS AND STANDARDS

The Factories Act, 1948 is applicable to all types of food processing industries. The main objectives of the Factory Act are (i) to regulate working conditions in factories; and (ii) to ensure that basic minimum requirements of safety, health and welfare of the factory workers are provided. Besides, the Act envisages regulating the working hours, leave, holidays, overtime, employment of children, women and young persons, etc. The revision of the Act in 1987 included rules for use and handling of hazardous substances and procedures for setting up hazardous industries. The State Governments are empowered to make the rules for ensuring the administration of the provisions of the Act in their respective states. The occupier of a factory is required to get prior approval of the State Govt. for the site on which the factory has to be situated. The Chief Inspector of Factories is responsible for the approval. The occupier of the factory is also required to get the factory registered for obtaining a license for operating it and send a notice of occupation to the Chief Inspector of Factories, at least 15 days before it begins to occupy the factory.

Some important aspects of the Act as regards to health, safety and layout aspects are as follows:

1. Maintain all places of work in a condition that is safe and without risks to health.
2. Make arrangements for ensuring safety and absence of risks to health in connection with the use, handling, storage and transport of articles and substances.
3. Fencing of all dangerous and moving parts of the machinery while in motion or use.
4. Providing sufficient space for workers to operate self-acting machines; encasing and guarding of all machinery installed in the factory and every set of screw, bolt, spindle, wheel or pinion so as to prevent danger
5. Taking necessary steps to ensure that the maximum safe working peripheral speed of every revolving machine, etc. and the maximum safe working pressure of any pressure plant are not exceeded.
6. Keeping floors stairs, steps, free from obstructions and slippery substances and providing with substantial handrails, wherever necessary.
7. Providing suitable striking gear or such device for the movement of driving belts of any transmission machinery and proper locking of device which can shift inadvertently from ‘off’ to ‘on’ position.
8. Ensure that workers do not overcrowd the workplace. There should be a provision of minimum space of 14.2 m^3 per worker in a new factory and 9.9 m^3 per worker in an existing factory. Suitable provisions for lighting, drinking water, latrines, urinals and spittoons are also covered under the Act.

Besides, as I have mentioned previously, there are specific standards for ergonomical considerations for design of equipment or arrangement of workspace. Some more standards related to maintenance of clean working environment come under the Pollution Control Laws.

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. How does the analysis of man and material movement help in layout planning of a food processing industry?

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2. What is the need to have enough working space around the equipment?

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3. Write True / False:

a) In a fruit and vegetable processing plant, the processed food area and raw food area should be kept close to each other.

b) The drying yard should be kept close to the roads.

c) The floors of a food processing room should be made rough to avoid slipping of the workers.

13.9 LET US SUM UP

In this unit, we have studied the various aspects of site selection and layout of a fruit and vegetable processing plant. We began with the factors affecting site selection and plant layout and then discussed the general considerations for a food plant layout. We discussed some rules for layout of different buildings, equipment, service facilities and waste disposal systems. We also studied the different steps involved in a layout planning process. How the analysis of man and materials movement, cleanliness and safety affect the plant layout are also discussed here. The unit has acquainted you with the general principles of site selection and plant layout, which are the primary steps in planning any type of industry.

13.10 KEY WORDS

Plant layout	:	Physical arrangement of the industrial facilities
Line flow process	:	When the product flows from one operation to the next in a prescribed sequence

Intermittent flow process : When the production is carried out in batches at intermittent intervals. We can organise the equipment and labour into different work centres by similar types of skill or equipment

Process form of layout : The intermittent process is also known as process form of layout as similar equipment and processing operations are grouped together.

Product layout : The line flow is also called a product layout because various process equipment, and labour skills are put into sequence according to the way the product is made.

13.11 SELF TEST FOR THE COMPLETE UNIT/ ASSIGNMENT

1. Describe the different guidelines for layout of different buildings in a food processing plant?
2. Describe the different guidelines for layout of different equipment in a food processing plant?
3. Explain the different steps that can be taken during layout planning for maintenance of clean working environment and workers' safety?

13.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. The major factors for selection of site for a fruits and vegetables processing plant are availability of raw material and good quality water, good surroundings, availability of electrical power, good transport facilities, easy availability of labour, facilities for disposal of wastes and scope for future expansion.
2. A good plant layout has the following advantages: saving in floor space, better utilisation of machine, manpower and services, reduced material handling, reduced inventory in process, increased output/ production per unit time, labour, money and energy, easier and better supervision

Check Your Progress Exercise 2

1. The basic objectives of a good plant layout are smooth operation and reduced cost in handling and processing.
2. If during the preparation stage of a plant layout, possible future expansion is not considered, we will face problems in expanding our industry or business, either by addition of new products or by increasing the capacity.

3. The layouts can be process form of layout and product layout. Also hybrid layouts, which are a combination of the above two are possible. The layout can also be classified as single level, multi-storey or combined layout.

4. Three dimensional scale models give a better representation of relative positions of different equipments and spaces than the two-dimensional drawings. In bigger models, the piping and utilities can be shown, which give idea on the actual work area that will be available.

Check Your Progress Exercise 3

1. The analysis of man-material movement helps to select a layout among many possible alternatives, which will reduce the total cost of movement and materials handling within the plant. This helps in minimising the cost of operation of food processing industry.

2. There should be adequate space around equipment to avoid collision between workers and the equipment and between the workers themselves. This will also help in servicing of the equipment.

3. a) False
   b) False
   c) False

13.13 SOME USEFUL BOOKS

1. Reed, R. (1961). Plant layout-Factors, Principles and Techniques. Richard D. Irwin, Inc. Illinois.

2. Vilbrandt, F.C., Dryden, C.E. (1959). Chemical Engineering Plant Design. 4th Edition, McGraw Hill Tokyo.

UNIT 14 EQUIPMENT AND MACHINERY

Structure

14.0 OBJECTIVES

After studying this unit, you should be able to:

- know how the equipment are selected, installed and maintained in a food processing plant;
- visualise how the different ergonomical factors influence the design and arrangement of equipment and work area; and
- acquaint yourself with different managerial skills such as proper maintenance planning, management of inventory of spare parts and good manufacturing practices, which help in improving the performance of equipment and workers in an industry.

14.1 INTRODUCTION

In this unit we shall discuss about the different factors for selection of equipment for a fruit and vegetable processing plant. You will observe that the entrepreneur can himself decide the type of equipment with a proper understanding of different unit operations that are to be carried out in the processing plant. Then we will discuss how the human factors such as body posture, selection of tools, environmental factors, etc. affect the selection and installation of different equipment and improve the work efficiency. You will also know about the different maintenance and inspection schedules, workers' safety and spare parts management aspects. Our basic objective in this unit will be to understand the skills needed to upkeep the operational area and equipment, minimise the plant downtime, and to improve overall performance of the setup.

14.2 SELECTION OF EQUIPMENT

In the previous unit, we discussed about the plant layout and how a proper plant layout helps in maximisation of profits. After we have decided the process, prepared a good plant layout, and have constructed the building as per requirement, the next job is the selection of equipment and their installation. In fact these considerations start even before the civil construction work is started. We must remember that the equipment constitutes a major part of the initial investment and if not decided properly, may create problems in future. The problems could be of many types, such as low performance than rated capacity or frequent disorders. Sometimes the workers do not find the equipment comfortable to work with. Therefore, we must be very careful for selection of each individual equipment for the processing plant.

14.2.1 Selection Procedure

The selection of the types and sizes of equipment for the process plant requires considerable experience. However, as most of the food processing operation that we will be dealing with are established ones and are in operation elsewhere, the task becomes chiefly of comparative evaluation of standard equipment available from different manufacturers, scaling of the equipment and accessories up and down, and incorporating pertinent improvements that previous users have suggested.

First, we have to list the required equipment from engineering flow sheets. The next step is to make the necessary design calculations with the help of an expert and prepare the specifications for each equipment. The equipment not only include the major processing equipment and boilers, but also other accessories as suitable weighing scales, small hand tools, sieves, basins, buckets, and quality assurance equipment. If outside bids are required, detailed specification sheets must be presented to suppliers.

Standard vs. special equipment

We may use standard equipment already available in the market, or may design and fabricate equipment as per our need. However, use of the standard equipment is always better as it has the following advantages over the specially fabricated equipment.

- The initial investment for standard equipment will be significantly lower as compared to the special equipment.

- The duplication of equipment is easier.

- The repair and maintenance are easier and standard spares are easily available. Most often the equipment comes under a guarantee of satisfactory performance.

- Standard equipment has gone through long periods of experimentation and has been tested elsewhere. Usually it is the result of many modifications of its original design.

Hence, unless it is absolutely necessary, we should not be involved in the design of equipment. When we are sure that we have completely exhausted the trade literature for our requirements, then only we should think of design of a special equipment.

Specifications and competitive bidding

As we discussed earlier, a range of equipment for almost all types of operations in any food processing plant are available; our job is to specify our requirement for a particular duty and then select suitable machines from the above range. The specification should contain all essential information such as characteristics of the material handled, kind and quality of service requirements, delivery requirements and quotation. A comparison of the different machines available in the market often helps our decision with respect to principal components, materials of construction, service requirements, and accessories furnished along with the cost. Minor modifications may be suggested for an equipment for particular applications. We must also consider the delivery time, experience, and reliability of the supplier before final selection of the supplier.

14.2.2 Example of Selection of Equipment

Standard guidelines for selection of different types of process equipment are available in different *Chemical Engineers Handbooks*. For a general understanding of these guidelines, we will discuss about the selection of a dryer in the following paragraphs.

Drying equipment can be classified according to the following design and operating features.

1. Batch or continuous.
2. Physical state of feed: liquid, slurry, wet solid.
3. Method of conveyance of the solid: belt, rotary, fluidised.
4. Heating system: conduction, convection, radiation.

Dryers can be either batch type or continuous type. Batch dryers are normally used for small-scale production and where drying cycle is likely to be long. Continuous dryers require less labour, less floor space and produce a more uniform quality product.

The choice of suitable drying equipment cannot be separated from the selection of the upstream equipment feeding the drying stage. The main factors in the selection of drying equipment are the nature and concentration of the feed. For example the dryer to be selected for drying tomato paste will be different from the dryer for drying peas. For the first case a drum or spray dryer is considered suitable, and in the second case a fluidised bed dryer is better as it gives a more uniform product with higher drying rate for particulate solids.

In general with solids feeds, the material should be placed in the drying chamber in such a way that it will produce a bed of solids with an open, porous structure. For pastes and slurries, some form of pre-treatment such as extraction or granulation is often needed.

Besides the feed condition and the initial liquid content, the other product factors, the required quality of the end product such as its physical form and dryness, and the heat sensitivity of the product also play a major role in selection of the dryer. Hot air is mostly used as drying medium in industrial dryers. The air is directly heated by electrical heating coils, gas or oil, or indirectly heated, usually by banks of steam-heated finned tubes.

A range of dryers is available for use in a food processing industry, viz. tray dryers, conveyor dryers, rotary dryers, fluidised bed dryers, pneumatic dryers, spray dryers, drum dryers, infrared dryers. Our type of dryer should be picked from these available types depending on our requirement. After the type of dryer to be installed has been decided, the capacity of the dryer is decided based on the throughput required.

14.2.3 Other Considerations

After a brief discussion on some general guidelines, some more points that need consideration before making the final selection for any equipment are:

- How many operators are required to operate the equipment and the kind of technical knowledge they must possess?
- Whether servicing the equipment needs outside technicians or can it be serviced by available staff?
- What is the power consumption of the equipment?
- Whether the equipment can be easily cleaned and sanitised?
- What is the durability of the material used in the equipment?
- Whether the equipment is silent or noisy when operating?

14.3 MOVEMENT AND INSTALLATION OF EQUIPMENT

In our every day experience we observe many physical equipment and facilities, which are not suitable to use because of their installation features. Examples include kitchen sinks that are too low, uncomfortable chairs, narrow staircases, very little space near a equipment that needs repair, and so on. Therefore, installation of the equipment is as important as the selection of proper equipment.

In most of the cases the manufacturers take up the responsibility of proper packing of the equipment so that it does not damage during transit. The movement within the plant is done by labour or by trolleys or cranes. They may also take up the installation job with or without charging an extra amount. However the plant manager has the responsibility to check that the machine/equipment is properly installed for convenient working, cleaning and maintenance operations. The machine should have a proper foundation. In particular the machines which produce significant vibration and noise should have a proper base. Sufficient working space should be kept around the machine.

Almost all equipment are designed for standard people. But installation is very important for comfortable working for a special group of people. The physical location and arrangement of such items (and of their specific features) can affect the comfort of the users as well as physical well being. For example, the comfortable working height of the tables and control panels will differ for ladies and gents. Therefore, special care should be taken during installation of equipment, working tables, etc. which could ultimately affect the work performance.

14.4 ELECTRICAL WIRING

A factory generally needs 3 phase 4 wire supply. For motors whose ratings exceed 2 or 3 kW, 3 phase 3 wire supply is required; and for light and fan circuits single-phase supply is required.

For internal wiring for supply to motors, conduit system of wiring with vulcanised Indian rubber (VIR) or PVC insulated cables of suitable size are used. The conduits are usually run on surface rather than laying them in covered trenches to facilitate additions and alterations. Use of separate conduit for every motor is preferred. The conduit used in power wiring should be electrically continuous throughout and connected to the frame of the motor. The frame of the motor is to be earthed by two separate and distinct connections to earth. Under-ground cables are preferred for very large capacity motors.

In domestic installations single earthling is sufficient but in an industry double earthling of motors, medium voltage regulating or controlling equipment etc. is necessary. Circuits and sub-circuits to 400 V motors must be provided with fuses on all poles, i.e. on all three phases of the a.c. supply.

In a large industry, power distribution is made from a suitable location, known as distribution centre, through a switchboard. This switchboard consists of a set of insulated bus bars. Each incoming and outgoing circuit is controlled by an automatic circuit breaker (or linked switch and cutouts). The outgoing circuits feed different sub-distribution boards erected at convenient places, which further distribute power to a number of equipment. A line diagram, showing the tapping supply from bus bar chamber to the individual machine is shown in Figure 14.1. In small industries, sub-distribution boards are not needed and a switchboard or distribution board is used for distribution of power. All equipment used in power wiring should be of iron clad construction and wiring shall be of the armoured cable or conduit type. Every motor, regardless of its size, shall be provided with a switch fuse close to it, and with a suitable starter placed at a convenient place. The starters are used to limit the starting current to a desirable value. Electrical wiring diagrams must be prepared for all sections and a qualified/trained personnel should be given the responsibility of electrical wiring of the complete plant.

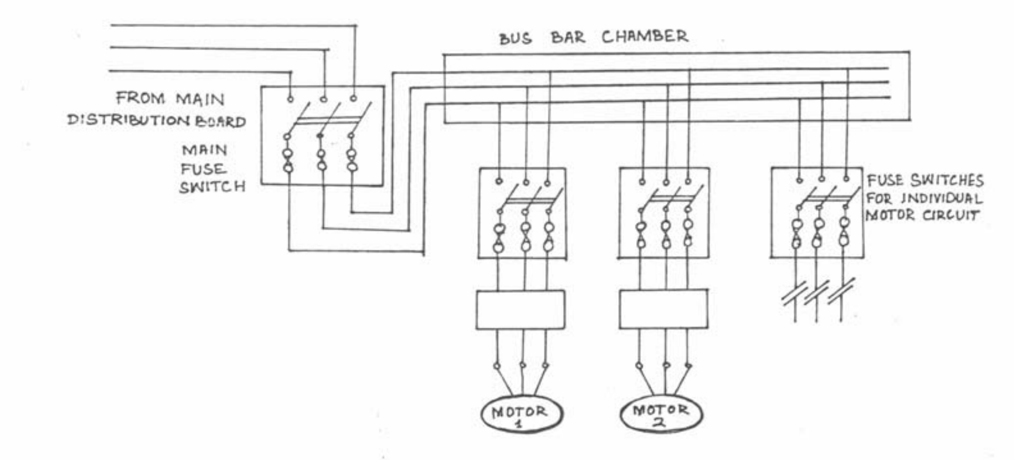

Figure 14.1: Supply from busbar chamber to individual machines

14.5 ERGONOMIC CONSIDERATIONS

The word ergonomics is derived from the Greek words 'ergon' (work) and 'nomos' (law). In the United States, the term 'human factor' is used for ergonomics. It is defined as the scientific discipline concerned with understanding the interactions among humans and other elements in a system, and the profession that applies theory, principles, data and methods to design, in order to optimise human well being and overall system performance. In other words ergonomics aims to design appliances, technical systems and tasks in such a way as to improve human safety, health, comfort and performance at work and everyday life. Motivating the man at work and making the work to suit him is the prime objective of ergonomics.

The application of ergonomics includes plant and workspace layouts, selection, training and placement of personnel, design of equipment, power tools, displays, jigs, fixtures, and even furniture, motivation of the worker, working conditions and environments, and computation of relaxation allowances.

The ergonomical factors include body posture and movement (standing, sitting, lifting, pulling and pushing), environmental factors (noise, vibration, illumination, climate, chemical substances), information on different machines and operational characteristics (information gained visually or through other senses, controls), as well as work organisation (type of task, nature of job, etc., whether the job is interesting or not?). Brief descriptions on these factors is given below.

14.5.1 Body Posture and Movement

Posture and movement play a vital role in ergonomics. Poor design or installation of equipment, technical systems and tasks has often reported to cause back pain, psychological illness (e.g. stress) and occupational disability. In addition, it also reduces performance and sometimes leads even to accidents. Some of the ergonomic considerations may be that the important components should be placed in convenient locations. The body size of the workers should be kept in mind for designing the working tables. Particularly the assembly tables and packaging section need special attention as in a food processing plant the workers need to stand or sit at a constant place for longer times. During movements, the body joints ought to be kept as far as possible in a neutral position. The workers should not be overloaded during conveyance of loads. Lifting accessories like lever, raising platforms and cranes and transport accessories such as conveyor, sack barrow, mobile raising platform, forklift, etc. should be used wherever possible.

14.5.2 Environmental Factors

The environmental factors such as noise, vibration, lighting, and climate can affect people's safety, health and comfort. The chemicals do also affect. The presence of high noise levels during a task can be annoying and prolonged exposure can result in impaired hearing. The noise level should be below specified levels; in most cases it is 80 decibels.
Ensure that floors are hard and even, and machines have proper foundation. It not only reduces vibration and noise, but also avoids other types of accidents. Well-maintained machines are quieter. There must be proper illumination in all parts of the factory. The air temperature, humidity and ventilation affect the comfort and productivity of the workers. The location of the building and its surroundings, convenience of transportation, size and number of rooms, design of ceiling heights and slopes, windows, style of architecture, type of building materials, colour, cleanliness, etc. are considered under environmental factors, which affect the work performance.

14.5.3 Information and Operation

The workers should be well informed about the work they are doing, with their important contribution in the work. They should feel responsible for their role in the final product development. This way they will be more involved in the work and their performance will increase. Suitable warnings at desirable places, display of the steps of operation and maintenance of the machines, putting different colours for different switches, etc. are some ways to improve the performance of equipment and workers, and reduce accidents.

14.5.4 Work Organisation

The worker must find the equipment comfortable, and he must enjoy the technical systems and tasks, which can be achieved by proper work organisation. Selection of the right kind of tool come under this category. Suppose we use a dull knife in cutting of vegetables, we expend a lot of extra energy that is, in effect, wasted. It is also important to train the workers on the proper way of using the tools. Further, the tools can not be designed in isolation. Often a redesign of the workspace, which includes the work envelope, work surfaces (such as desks, tables, etc.) and seats (if used) as well as the design and relocation of equipment used. The important components need to be placed at convenient locations.

You must bear in mind that safety can be improved by 3 E's, viz. education, engineering and enforcement. A range of ergonomic subjects is covered by international ISO standards, European EN-standards, as well as national standards. In addition, there are specific ergonomic standards, which are applied to individual companies and industrial sectors. These should be followed for the overall effectiveness of the industry.

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 advantages of standard equipment over special equipment?

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2. What are the main ergonomic considerations during arrangement of work space and design of tools?

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14.6 UPKEEP OF OPERATIONAL AREA

Proper upkeep of operational area improves performance of workers and increases production. A systematic and scientific maintenance of operational area assures instant operational readiness and optimal availability for production at all times without compromising on the safety of man and machine. It also reduces worker frustration and improves job satisfaction, which in turn improve the working life of personnel, and productivity.

The health and safety of both workmen and machines need careful maintenance. This is more important for a fruits and vegetables processing plant where they affect food safety. The orderliness and cleanliness of the workplace has to be assured to improve total productivity and the conditions of the labour force, and to avoid accidents. There should be proper light and aesthetic environment.

For most projects, a maintenance planning system is included in the preparation stage of the project to protect the investment in machinery, plant and buildings through regular and adequate maintenance. These all help in reduction in downtime, which is very significant in a food processing plant, as we have the responsibility to process the produces within the shortest possible time after harvest. Further, with ever increasing cost of labour and material, this is good economy also. It maximises the utilisation of labour and other resources and prevent waste of spares, tools and materials.

14.7 MAINTENANCE AND INSPECTION SCHEDULE

14.7.1 Maintenance Scheduling

You must have experienced the importance of scheduled maintenance for the performance of any machine. For example, we change the gear oil of our motorcycles after every 3000 km of running as a scheduled maintenance practice. A **maintenance schedule** is the sequential arrangement by which maintenance is done. In an industry, the schedule indicates, what is the work to be done, how often it is to be done, by which it is to be done, and the estimated time required to complete the work. Separate schedules have to be prepared for each type of maintenance activity, and for each equipment/machine.

The decision on a sequence is based on the priority, the availability of spares, materials and specific tradesman. It should be remembered that most critical equipment has to receive prompt attention in maintenance caring and should be the first items to be scheduled. The other priorities could be emergency breakdown, preventive maintenance, predictive maintenance, and/ or other maintenance systems prevalent in the organisation.

The guideline for the maintenance are often laid down by the manufacturer. But the actual conditions of operation, the severity of use, and the skill level of operators are also to be considered. Schedules must be made in two parts: the **long term schedule** to be made 8-12 weeks in advance, and the **short term schedule**, just a week or two in advance. This will help in preparing and planning in advance for materials, spares, tools, and test equipment. The short-term schedule is finally broken up into daily schedules for day-to-day implementation and for assuring that close control would be exercised. The supervisor assigns work individually to each worker and keeps him informed as to what work is expected of him within a small frame of time limit, may be the next morning. This allows the worker to plan his own activities. Revisions in schedules are expected, and hence, they must be kept flexible enough to accommodate any change.

14.7.2 Inspection Scheduling

Inspection is the examination of equipment and machines or their parts to determine their condition. Periodic inspection helps detect extent of deterioration and plan for its repairs and rectification, or if need be, even make replacements before an actual breakdown occurs.

Take for example the daily inspection routine for a fan or a pump would involve carrying out checks for:

a) any abnormal vibrations, or any abnormal noise;

b) the temperatures of all the bearings to ascertain that they are at acceptable levels and that there is no overheating;

c) leakages from the glands and gauge to see whether they are excessive;

d) oil levels in cups; and

e) grease nipples to ensure that they are not dry.

Different checklists are required for the same machine, depending on whether the machine needs a weekly, monthly or annual check up.

The frequency of inspection is affected by many factors, such as:

a) age of the machine or equipment, its condition and value;
b) severity and intensity of service;
c) hours of utilisation- are they prolonged- or intermittent;
d) susceptibility to wear and tear or any other damage;
e) susceptibility to losing adjustment during use- Will the maladjustment and non-alignment affect the accuracy or functioning? Will the lack of proper balancing affect performance?
f) safety requirements and considerations;
g) criticality of item- if the item is very critical, then it may need daily inspection.

14.8 PERIODIC MAINTENANCE PRACTICES

14.8.1 Classification of Maintenance System

The different maintenance systems can be classified as: a) Breakdown maintenance, b) Routine maintenance, c) Planned maintenance, d) Preventive maintenance, e) Predictive maintenance, f) Corrective maintenance, g) Design out maintenance, h) Total productive maintenance, and i) Contracted out maintenance.

Breakdown maintenance or repair maintenance is carried out only in case of a need of repair or when the machine ceases to work. **Routine maintenance** involves routine checks such as daily lubrication and inspection of the machines, monthly inspection of motors. **Planned maintenance** is maintenance organised and carried out with a predetermined plan depending on the machine's needs, expected requirement of the machines and manufacturer's recommendation.

Preventive maintenance system refers to the steps taken to reduce the likelihood of failures to the absolute minimum. **Predictive maintenance** can be defined as "methods of surveillance used to indicate as to how well the machine is, while performing its intended tasks". **Corrective maintenance** is defined as maintenance carried out to restore (including adjustment and repair on item) machinery, which have ceased to meet an acceptable condition. **Design out maintenance** (DOM) tries to eliminate or to minimise the need for maintenance to the lowest possible level.

The basic concept of **total productive maintenance** is to change the attitude and improve the skill of all personnel by using quality equipment. **Contract maintenance** is using specialised maintenance personnel on contract basis, mostly for specific equipment.

Each individual organisation, big or small, simple or complex, or using highly advanced or simple technology must choose the maintenance system that suits it best. Total maintenance planning includes: a) inspection, b) lubrication, c) planned maintenance, d) preventive maintenance, e) predictive maintenance,

f) corrective maintenance, g) modifications h) retrofits, i) refurbishing, j) overhaul, k) replacement of equipment, l) discarding of equipment, m) standardisation, n) material requirement planning, o) spares planning, p) documentation, q) spare parts manufacture, r) exercising of spare parts and sub-assemblies held under long term storage (Particular attention should be given to rubberised components).

14.8.2 Maintenance Steps in a Fruit and Vegetable Processing Plant

In general the maintenance steps for a general food processing plant includes following steps.

- Carry out a visual check of the equipment and all operational area for cleanliness.
- Check if safety devices are present and functional. If not, do not operate the equipment.
- Operate the machine and check for any unusual noise, vibration, friction and instruction.
- Check if lubrication cups are replenished to correct levels and grease nipples so that they are not dry; then operate the machine. This is mainly required for conveying machines and elevators.
- Never operate the machine beyond laid down conditions of speed and feed.
- Make sure that no tools or any smaller parts of containers, glass pieces, etc. have dropped inside any equipment.
- Follow the manufacturer's recommendations for maintenance of each individual equipment.

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 proper maintenance and inspection help improve performance of a food processing plant?

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2. What is a maintenance schedule?

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14.9 INVENTORY OF SPARE PARTS

An **inventory** is a stock of materials used to facilitate production or to satisfy customers. All idle resources other than materials are considered as capacity, e.g. equipment or idle workers. Capacity is used to produce, while inventories are the products at some point in conversion and distribution process.

Spare parts are those parts of machines, which because of wear and tear, use or breakage, need replacement. However, it is often not possible to obtain each and every spare in the market as and when needed. Besides, purchasing anything in small quantity is expensive also. There is also chance of getting improper spares. Hence it is necessary for any industry to carry inventories of frequently used spare parts. In particular, in a food industry when the work is in progress inventories of spares are an absolute necessity.

The finance department generally prefers to keep the inventory level low to conserve capital, marketing prefers high levels of inventories to enhance sales, while operations department prefer adequate inventories for efficient production and smooth employment levels. Inventory management must balance these conflicting objectives and manage inventory levels in the best interests of the factory as a whole.

The decision problems in inventory management are a) which items should be carried in stock, b) how much should be ordered, c) when should an order be placed, d) what type of inventory control should be used. Whether to buy a spare or make it in the workshop / local market is another criteria. This decision is dependent on the cost, assurance of availability, opportunity to control quality, availability of equipment and expertise, desire to preserve confidentially, and saving in transportation costs.

14.9.1 Optimisation of Total Cost of Inventory

What is the quantity to be purchased is one major decision in inventory management. The **economic order quantity (EOQ) model** is a tool, which helps to know the quantity that will optimise the total cost. The motivating factor to control inventory is the cost incurred by carrying it. The different costs involved in the calculation of the total cost are:

1. **Item cost** or the cost of buying or producing the items;

2. **Ordering** or **setup cost,** which is the cost of getting an item including the cost of transportation, and salary of personnel working in stores and stock verification department;

3. **Carrying** or **holding cost,** which includes capital cost, storage cost or rents, depreciation charges, cost due to deterioration of the part or obsolescence; and

4. **Stock-out cost**, which reflects the economic consequences of running out of stock, since the sale is lost if material is not on hand. The profit is lost on sale, and good will in the form of future sales.

The quantity, which optimises total cost, is known as **economic order quantity (EOQ)**. For a general case, EOQ is given by,

$$\text{EOQ} = \sqrt{2C_o M/(C_c p)}\,,$$

where, C_0 is the order cost or setup cost, Rs. per order,

C_C is the carrying cost, expressed as percent of Rs. values per year,

M is the annual consumption, units per year, and

p is the unit price, Rs. per unit.

We will see the applicability of this formula with the help of a small example. A fruit processing plant purchases 600000 bottles per year for handling juice. The order cost is Rs. 70 per order, and the carrying cost is 15% per year. If each bottle costs Rs.2 only, find out the economic order quantity?

Solution

$$\text{EOQ} = \sqrt{2\frac{(70)(600000)}{(0.15)(2)}} = 16733 \text{ units.}$$

It means that the plant should purchase 16733 bottles at a time. This will result in 600000/16733 = 36 purchases per year, i.e. one purchase almost in every 10 days. This quantity will involve minimum total cost for maintaining the inventory. Now, check that if the order cost is increased to Rs. 210 per order, the EOQ will be 28983, i.e. the plant has to purchase 28983 bottles in each order to minimise the total cost. In that case it will go for 20 purchases in the year.

We suggest you to change the unit price and other parameters and see how these changes affect the EOQ. You will observe a definitive change in the EOQ with changes in the above parameters. Even though the EOQ model has several limitations as it assumes a constant demand, a constant unit price, a constant setup cost, etc. throughout the year, still it is widely used in the industry as a standard tool for the inventory management.

14.10 MINIMISATION OF EQUIPMENT DOWNTIME

As we have already discussed, the downtime for any equipment or for the complete plant can be reduced by proper upkeep of operational area, by properly scheduling the maintenance and inspection, and judicious management of the inventory of spare parts. In this section we will give a closer look at this area.

14.10.1 What is Downtime?

Downtime in general may be considered as the time when the plant or any specific equipment is down or not performing. Thus the downtime directly affects the production. However, downtime does not always imply / cause a direct production loss. There are certain conditions under which downtime does not create a production loss, e.g. when the plant does not operate at full capacity utilisation level, or when the completely processed product is not lifted for delivery to customers but is stored.

14.10.2 Reasons of Downtime

The main reasons for downtime in an industry or a section are as follows:

- Breakdown of a machine due to any reason.
- Failure in power supply or load shedding.
- Non-availability of suitable raw material.
- Improper planning, scheduling or machine loading.
- Lack of proper tools, jigs or fixtures.
- Non-availability of calibrated test equipment.
- Shortage or absence of operator.

14.10.3 How to Reduce Downtime

Once we know the different possible reasons for downtime in our plant, the planning to reduce the downtime becomes much easier. Both the operator and the maintainer have to jointly make efforts to lower and control down time.

Simple dos and don'ts are to be specified for an operator, which if followed can eliminate a large number of breakdowns. For example, before the start of the machine the operator should check all the safety devices, lubrication points and cleanliness. Then he should operate the machine for a short time to check for the presence of any unusual noise, vibration, friction, etc. The management should have the responsibility to educate and train the workers on these aspects.

Some basis steps that are useful in reduction of downtime are as follows:

- Adopt proper maintenance planning, maintain and carry out repair of buildings, utilities and allied equipment.
- Ensure scheduled inspection and lubrication of all necessary points
- Adopt rapid fault-finding systems and the use of diagnostic charts
- Ensure and carry out faithful recording and documentation of all maintenance work, and review of the records. Analyse repetitive failures of any particular equipment and replace the faulty parts / redesign the machine.
- Standardise equipment for replacement and purchase.
- Monitor procurement of spare parts and material for maintenance.
- Design and enforce safety standards.
- Recruit and train personnel to carry out maintenance work.

It is very important to record all breakdowns with care and absolute accuracy, so that the parts that have failed may be segregated and analysed to find out the reasons for the failure. Every single person working in the maintenance department must know his or her exact function. Once the cause has been diagnosed, corrective actions are to be planned and taken. We must understand that it is a collective job and all persons associated in the plant operation have individual important responsibilities for reduction of downtime.

14.11 MAINTENANCE OF RECORDS

It is very important for an organisation to maintain different records and document them properly. This is quite beneficial. For example, if the job cards and history record cards are properly maintained, one can choose machine or equipment wise information about how much has been the annual maintenance cost on each of them.

Facility register: A facility register is a complete list of all the machinery, plant, equipment and buildings, which have to be maintained. If the number of such items is very large, then they can be maintained in different groups depending on their usage, technical practices, or by the maintenance methods which are being used. For example, a food processing plant can be divided into sections by their maintenance needs. The shut down can be done section-wise for maintenance. This can help in working at all other sections while a particular section is undergoing maintenance. Such types of information are maintained either by cards or by computers.

Equipment record card: An equipment record card or **Plant record card** keeps all information about each individual machine, such as the name and address of supplier, date of purchase, price, etc. It is very useful when a repeat order has to be placed for procurement after many years and the necessary information is not available from any other source.

History record card: A history record card or **Log card** carries information on all corrections, replacements, repairs, and other modifications that have been carried out on a particular equipment from the day it was inducted to the day it is scrapped, or disposed of. If an equipment is moved from one section to another, its History record card has also to move along with it. The card is quite helpful in analysing the total downtime, the frequency of occurrence of specific faults, and which parts or spares are frequently being replaced. Thus it will help in making standardisations and replacement decisions.

Defect analysis record: This is another type of record, where the focus is on defect analysis.

Besides, the food processing plant has to maintain several other records related to financial and marketing departments, operation departments, etc., which help in the analysis of raw materials status, production status, money flow and similar factors of interest to the plant manager.

14.12 CERTIFICATION

In India, the fruit and vegetable processing industry come under the **Fruit Products Order (FPO)** issued by the Govt. of India. No person shall carry on the business of a manufacture except under and in accordance with the terms of an effective license granted to him. A manufacturer using different manufacturing premises for manufacture of fruit products shall take out a separate license from each such premises.

The FPO has many quality standards relating to production, quality of processed products, and packaging aspects. It also covers the **Prevention of Food Adulteration (PFA)** Act. FPO has standards for the sanitary requirements of a factory manufacturing food products. The 2nd part of the 2nd schedule has specifications for different types of processed fruits and vegetable products. This is just to acquaint you with the FPO. For details, I suggest you to go through the draft of the FPO.

You must have also heard about **International Organization for Standardization (ISO)** certification. At present there are two series: ISO 9000 series and ISO 14000 series. ISO 9000 is concerned with "quality management". This means what the organisation does to enhance customer satisfaction by meeting customer and applicable regulatory requirements and continually improving its performance in this regard. ISO 14000 is primarily concerned with "environmental management". This means what the organisation does to minimise harmful effects on the environment caused by its activities, and continually to improve its environmental performance. The vast majority of ISO standards are highly specific to a particular product, material, or process.

ISO standards contribute to making the development, manufacturing and supply of products and services more efficient, safer and cleaner. They make trade between countries easier and fairer. ISO standards also serve to safeguard consumers, and users in general, of products and services. This certificate is very useful to industrial and business organisations of all types, and to suppliers and customers of products and services in both public and private sectors.

There are several methods and tools to help with the implementation of a Food Safety Management System, such as **HACCP (Hazard analysis and Critical Control Points)**, **Good Hygiene Practice (GHP)** and **Good Manufacturing Practice (GMP)**. Together with a Quality Management System, e.g. ISO 9001, they form the basis for an overall Food Safety Management System.

Hazard analysis is the identification of all ingredients, stages in progress, environmental features and human factors that can lead to hazards for the customers. The risks and likelihood of their occurring is estimated. Critical Control Points are the points at which control is essential to guarantee that potential hazards do not become actual hazards. A CCP is a location, a practice, a procedure or a process, which if not controlled, can result in an unacceptable risk. Examples include inspection of goods at delivery or before use, correct temperature ranges during sterilisation or blanching, etc. Thus HACCP is preventive in nature and it protects the consumers from exposure to potential food hazards. Thus HACCP should be the top priority in any food firm.

A HACCP certificate proves that our food safety system has been measured against a best practice standard and found compliant. Issued by a third party accreditation body/registrar, the certificate proves to customers that we have implemented the necessary routines to ensure food safety. It is a prevention-based food safety system. It provides a systematic method for analysing food processes, determining the possible hazards, and designating the critical control points necessary to prevent unsafe food from reaching the consumer. HACCP is based on the Codex Alimentarius developed by the Food and Agricultural Organisation of the United Nations and the World Health Organisation.

14.13 GOOD MANUFACTURING PRACTICES

A food processing industry has the responsibility to make safe and wholesome processed food available to the consumers. In addition, it has to take care of the sustainability of the industry. Hence, good manufacturing practice (GMP) should look at the above two factors.

The aim of good manufacturing practice in the food industry is to provide food that meets the consumers needs and wants, and also to give them the security of safety ad reliability. GMP is based on the knowledge and skills throughout the food system, from primary production of the raw materials, through processing of the industrial ingredients, manufacturing of the consumer products, distribution of the final retail products till the cooking and eating of the final food. The objectives of GMP are to control the changes in the food materials so as to develop desired qualities in the product, to ensure that the food is safe to eat, and to stop or slow down any deterioration in the food. GMP means understanding, analysing and controlling the manufacturing process.

GMP guidelines include location requirements, design of facilities, facilities to be provided such as supply of potable water and water standards, equipment selection, storage, pest control, packaging, transportation, personal hygiene, etc. It also includes training, maintenance of records, quality control, inspection and testing, verification, etc. It means it covers all aspects of food processing operation and management.

For example, GMP says that the food plant establishment should be located away from environmentally polluted areas and industrial activities, which pose a threat of contaminating food; areas subject to flooding unless sufficient safeguards are provided; areas where wastes can not be removed effectively; and areas prone to infestation of pests. GMP requires that the equipment should be located and installed in a manner that permits adequate maintenance and cleaning, functions in accordance with its intended use, facilitates good hygiene practices including monitoring. The equipment should be installed at a distance from the floor and walls to allow proper cleaning and avoid dirt accumulation (recommended minimum 30 cm from floor and minimum 60 cm from walls and other equipment). GMP requires that the conveyors in dry product area should be covered. Guidelines for plant layout, upkeep of operational area, electrical wiring, ergonomic considerations in arranging the work space and almost all the aspects that we have studied in this unit and previous unit come under the purview of GMP. Personal hygiene is a very important component of good manufacturing practice.

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 do you call the quantity of purchase, which optimise total cost in inventory management?

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2. What are the different costs involved in the analysis of inventory?

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3. What are the main reasons for downtime?

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4. Name some records that are maintained for equipment/machinery management?

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5. Expand the following abbreviations?

FPO – ………………………………………………………………………

ISO – ………………………………………………………………………

GHP – …..…………………………………………………………………..

GMP – ………………………………………………………………………

14.14 LET US SUM UP

In this unit we have discussed about the different guidelines for selection of equipment for a fruit and vegetable processing plant, and other commissioning features as movement and installation of equipment, electrical wiring. We also studied the ergonomic considerations for selection and installation of equipment for improvement in workers' performance. The different aspects of maintenance and inspection of equipment and inventory of spare parts are also covered which are very important for reduction of downtime. We also studied about the maintenance of different records, which are helpful in analysis of performance of specific equipment and make replacement decisions. Brief discussions on the certification aspects and Good Manufacturing Practice for a plant are also made at the end of the unit.

14.15 KEY WORDS

Ergonomics : The scientific discipline concerned with understanding the interactions among humans and other elements in a system, and the profession that applies theory, principles, data and methods to design, in order to optimise human well being and overall system performance.

Inventory : It is a stock of materials used to facilitate production or to satisfy customers

EOQ : It is the quantity, which optimises total cost in inventory management.

Downtime : It is the time when the plant or any specific equipment is down or not performing.

14.16 SELF TEST FOR THE COMPLETE UNIT/ ASSIGNMENT

1. Explain the different steps for upkeep of operational area and reduction of downtime?

2. Write short notes on (a) Ergonomics in a food plant design, (b) Inventory management, (c) Selection of equipment.

14.17 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. The initial investment for a standard equipment is lower and duplication of equipment is easier. The repair and maintenance are easier as standard spares are easily available. Standard equipment usually come under some guarantee and are usually the result of many modifications of its original design.

2. The ergonomical factors include body posture and movement, environmental factors (noise, vibration, illumination, climate, chemical substances), information and operation, and the work organisation.

Check Your Progress Exercise 2

1. Proper inspection and maintenance reduce the total downtime, ensure operational readiness, improve job satisfaction and improve safety of workers. Proper inspection helps detect the extent of deterioration of any equipment/machine or their parts, which helps repair/replacement before an actual breakdown occurs.

2. A maintenance schedule is the sequential arrangement by which maintenance is done.

Check Your Progress Exercise 3

1. Economic Order Quantity.

2. The different costs involved in the analysis are the item cost, ordering or setup cost, carrying or holding cost, and stock-out cost.

3. Zmain reasons for downtime are breakdown of a machine, failure in power supply or load shedding, non-availability of suitable raw material, and improper planning, scheduling or machine loading.

4. Facility register, Equipment record card or Plant record card, History Record Card or Log card and Defect analysis record.

5. Fruit Products Order
   International Organization for Standardization
   Good Hygiene Practice
   Good Manufacturing Practice

14.18 SOME USEFUL BOOKS

1. Dul, J. and Weerdmeester (2001). Ergonomics for Beginners 2nd Edition. Taylor and Francis, London.

2. Gopalkrishnan, P. and Banerji, A.K. (1997). Maintenance and Spare Parts management. 2nd Edition, PHI, New Delhi.

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4. Lal, G., Siddappa, G.S. and Tondon, G.L. (1986). Preservation of Fruits and Vegetables. ICAR, New Delhi.

5. Vilbrandt, F.C., Dryden, C.E. (1959). Chemical Engineering Plant Design. 4th Edition, McGraw Hill, Tokyo. pp.1-188.

UNIT 15 PLANT SANITATION AND EFFLUENT TREATMENT

Structure

15.0 OBJECTIVES

After studying this unit, you should be able to:

- know the importance of plant sanitation for a fruits and vegetables processing industry;
- know the properties of process water and different methods for treatment of process water as well as waste water;
- familiarise yourself with the methods for waste solids upgrading and methods to reduce the discharge volume from a fruits and vegetables processing plant; and
- acquaint yourself with the regulations relating to plant sanitation and waste disposal.

15.1 INTRODUCTION

Plant sanitation plays an important role in the overall work performance of any industry. In particular, in a fruit and vegetable processing industry as we are concerned with handling of food, plant sanitation plays a very vital role. It directly affects food safety. If the food produced by an industry is not safe, then the unit will ultimately loose customers, and may have to shut down. In this unit, we will discuss the various aspects of food processing plant sanitation and see how it affects food safety. Water is one of the major inputs in any fruit and vegetable processing plant as it is needed for a variety of operations such as cleaning, blanching, preparation of syrup or brine, as heat exchange medium or boiler feed, and many other uses. It also directly affects food safety and food plant sanitation. So we will discuss about the requirements of process water and its properties. Another important aspect for any type of industry is waste disposal, as it not only affects food safety, but also affects the surroundings and work environment. Hence, we will discuss about the waste disposal methods. Still more important are the methods that can be taken to reduce the discharge volumes and upgrade the waste solids for further uses, which are not only important for reducing environmental pollution, but also for the economy of operation in a plant. In addition, we will also discuss briefly about the waste and effluent disposal regulations.

15.2 IMPORTANCE OF PLANT SANITATION WITH RESPECT TO FOOD SAFETY, RISKS AND HAZARDS

The word "sanitation" derived from latin word '*Sanus*' means sound and healthy or clean and whole. Thus plant sanitation includes all possible activities to maintain a healthy environment.

Will you consume a food, which is very attractive in colour and aroma, but has a chance of some toxic or otherwise harmful material in it. Of course your answer will be 'No'; it means that the food plant sanitation principles are mandatory in the production of foods primarily for gaining public acceptance of the products. The processed food obtained from an industry should not only be attractive and nutritious, but also be wholesome and bacteriologically safe. The processed food, even though processed for killing pathogenic organism, is at a greater risk of contamination because it is prepared in large quantities and is handled by many people. Hence, along with proper control on the qualities of raw materials used in processing, proper hygiene at all the work places is very important for obtaining safe food. Since food sanitation has a direct effect on the health of individuals patronising the specific food processing industry, the management needs to lay down definite guidelines for implementation and maintenance of hygienic conditions. This is required even for the survival of the industry itself.

We must realise that sanitation affects every phase of food handling such as purchasing and receiving raw material, transportation and processing operations; and quality control should be maintained throughout. The major sources of contamination of food are air, water, plant, soil, food handler, machinery and equipment, sewage and trucks or cans during transport. The contamination can be in the form of visible contamination by insects, rodents, stones or other extraneous materials, or visible and invisible contamination by micro-organisms. The third type is potential chemical contamination. It means, if slight negligence is observed at any point that would directly bear a risk of food contamination. We should also bear in mind that all the above sources of contamination are directly related with many decisions as selection of a proper site, layout and orientation, ventilation, illumination, water supply and disposal of wastes.

Sanitation is every person's job in a food plant. It should be a part of everyday's policy of the food firm, as ultimately a good sanitation gives us a product free of risks and hazards. If properly practised, sanitation removes the concern about the spreading of communicable diseases or potential food poisoning. Further properly maintained sanitation gives us a product free of contamination and eliminates waste and spoilage. A food prepared under hygienic conditions commands respect in the market. From a legal obligation stand point also, it is important. If the food is prepared, packed, or held under unsanitary conditions, whereby it may become contaminated with filth, it invites legal action.

Sanitation is a responsibility that every person handling or working with food must constantly fulfill. The value of a planned sanitation programme utilising good manufacturing practice includes the following.

- A better product to meet the competition's demands and consumer's expectations.
- A more efficient food plant operation.
- Greater employee productivity.
- Fewer food plant employee accidents.
- Fewer consumer complaints.

Thus food plant sanitation is of prime importance, and several requirements such as adequate supply of potable water, proper sewage disposal facilities have to be fulfilled for maintaining sanitation. However, whatever may be the expense of maintaining a quality sanitation system, there is no point of compromise, as we are going to handle food and ultimately the health and life of the people.

15.3 PROPERTIES AND REQUIREMENTS OF PROCESSING WATER

Water is one of the major inputs in a fruit and vegetable processing plant. It is used in the preparation of brine or syrup, in blanching, in cleaning and washing of fruits and vegetables, different equipment and containers. The other important applications include its use as boiler feed and as heat exchange medium. More than 10,000 litres of water are required to process a tonne of fruits or vegetables.

The processing water must meet the health standards for potable (drinking) water and should be low in mineral salts (calcium, magnesium, sulphur and iron). Potable water is one, which is safe to drink, pleasant to taste and usable for domestic purposes. The water for food processing plants should also be chemically pure to prevent turbidity, off-colour, and off-flavour. The tap water may not be sufficiently pure for use in food products.

15.3.1 Water Hardness

Hardness of water is one of the major properties of water as regards to food processing industry. We all know that if water forms a lather with soap which lasts for at least five minutes, it is called **soft water**. If lather is not formed easily then it is termed as **hard water**. The compounds of calcium and magnesium ions dissolved in water mainly cause the hardness. These ions form precipitates with bicarbonates, sulphates or chlorides present in water instead of forming lather, which is known as hardness.

Hardness of water is further classified as **carbonate hardness** and **non-carbonate hardness**. The carbonate hardness is due to the presence of calcium and magnesium bicarbonate. This type of water is found in chalk and lime stone regions. Non-carbonate hardness is due to the presence of calcium and magnesium sulphates, chlorides, and nitrates. The water in areas having rocks containing these salts is of this type. The carbonate and non-carbonate hardness are also referred to as **temporary hardness** and **permanent hardness,** respectively.

Hardness of water is expressed in terms of milli-equivalents per litre (mEq/l). One mEq/l of hardness producing ion is equal to 50 mg calcium carbonate (50 ppm) in one litre of water.

Table 15.1: Types of hardness

Sl. No.	**Degree of hardness**	**Amount of dissolved compounds**	
		mEq/l	**mg/l**
1.	Soft water	Less than 1	Less than 50
2.	Moderately hard	1-3	50-150
3.	Hard	3-6	150-300
4.	Very hard	More than 6	Over 300

Disadvantages of hard water in processing industry

As hard water fails to give lather with soap, it creates a problem in cleaning operations.

Hardness causes scale on equipment, which acts as an insulating layer against efficient heat transfer and may eventually clog pipes and foul valves. When hard water is used as boiler feed, the growing layer of scale not only reduces boiler efficiency, but also tends to contaminate steam generated in the boilers. Such steam can become alkaline and corrosive to aluminium and tin cans. There is also danger of overheating of the boilers.

The life of pipes and fixtures is reduced as they may rust.

These deposits can harbour bacteria and add to the difficulty of equipment cleanup and may affect food products directly.

Calcium ions have firming effect on certain fruits and vegetables, which may be used to advantage under controlled conditions. But in excessive amounts, the calcium from hard water can cause various textural defects.

Advantages of hard water

As mentioned before, calcium ions have firming effect on certain fruits and vegetables.

The dissolved calcium salts in hard water increases the dietary intake of calcium.

Hard water is more suitable in brewing industries, as it produces better beer.

Methods of removing hardness in water

There are various ways to soften water, depending primarily on the nature of hardness.

Boiling: If water is boiled, temporary hardness only is removed. The bicarbonates are broken down into carbonates, water and carbon dioxide.

$$Ca(HCO_3)_2 \rightarrow CaCO_3\downarrow + H_2O + CO_2$$

The equation of magnesium bicarbonate is similar. The carbonates are precipitated and therefore have no action on soap, being out of solution.

Addition of slaked lime (Clark's process): Slaked lime also removes temporary hardness only. The lime must be added in calculated quantities so that it just neutralises the bicarbonate. Insoluble calcium carbonate is formed.

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\ CaCO_3\downarrow + 2\ H_2O$$

Addition of washing soda: The method removes both temporary and permanent hardness. Washing soda (sodium carbonate) reacts with the calcium and magnesium salts in hard water forming soluble sodium salts and insoluble calcium and magnesium salts, which remain as a precipitate. The equations are as follows:

For temporary hardness: $Ca(HCO_3)_2 + Na_2CO_3 \rightarrow CaCO_3\downarrow + 2\ NaHCO_3$

For permanent hardness: $CaSO_4 + Na_2CO_3 \rightarrow CaCO_3\downarrow + Na_2SO_4$

Ion exchange process: This method is used in domestic and industrial installations for removing both types of hardness. It involves the use of natural and synthetic resins such as '***permutit***' and '***zeolite***'. The hard water is passed through a column packed with resin and the calcium and magnesium ions in the water are exchanged for sodium ions in the resin. The resin is regenerated from time to time by flushing the column with a concentrated salt (sodium chloride) solution. This replenishes the sodium ions.

Use of sequestering agents: A sequestering agent such as '***Calgon***' (sodium hexametaphosphate), when added to hard water, encloses the calcium and magnesium ions in stable complexes, which are soluble but do not react with soap. *Calgon* is used extensively for domestic purposes, but has limited industrial use, as it is quite expensive.

15.3.2 Other Impurities

The water may have natural pollutants like suspended impurities (clay, silt, sand and mud), dissolved gases like carbon dioxide and ammonia, dissolved minerals like calcium and magnesium salts, lead and microscopic plants or animals. The artificial pollutants include sewage that contains decomposable organic matter and pathogenic agents, industrial wastes, agricultural pollutants, pesticides, fertilizers and physical pollutants such as radioactive substances. Occasionally, the well waters and municipal waters entering a plant will be contaminated with moderate numbers of proteolytic and lipolytic food spoilage organisms. Thus the water to be used for processing needs a critical analysis and remedial steps as required. The municipal water may have a pH as low as 5 or as high as 8.5. Higher pH corresponds to hard water. In-plant water softening or direct neutralisation rectifies it. Pure water has a pH of 7.

We know that chlorine disinfects water; but shall we like to consume water having a sharp chlorine smell? It implies, even though the water is safe from health point of view, still it may not be acceptable to food processing industries. A sharp detectable taste or odour of chlorine may be due to over-chlorination or due to the presence of traces of phenol in the water. Phenol reacts with chlorine to give a strong medicinal odour. Such type of odour can be removed by filtration of water through a bed of carbon or adsorbent clay. Materials such as hydrogen sulphide or organic impurities, if present in water, react with chlorine and inactivate it before chlorine can exert its germicidal effect. Therefore, the amount of chlorine required to disinfect water is dependent on other substances present in the water.

Decomposition of organic matter in water by non-pathogenic bacteria may produce off-flavours and off-odours. When water contains sulphates and reducing types of bacteria, production of sulphite odours may occur. These types of odours can be removed by filtering water through carbon. But prevention of formation of off-odour needs pipeline sanitation to destroy microorganisms.

Dissolved salts in water may impart some colour to the water. Iron salts, if present in water, can be oxidised to ferric hydroxide, which is red-brown in colour. Manganese hydroxides are gray-black in colour. The ion-exchange treatment removes the dissolved mineral impurities. Activated carbon or clay is used to adsorb the colouring pigments. Treatment with alum (aluminium and potassium sulphates) causes flocculation of suspended materials, which are then removed by filtration and centrifugation.

If the supplied water is not suitable for direct food processing applications due to one or more of the above reasons, they can still be used for other uses as heating canned food in a retort, in pre-chilling operations or as a heat exchange medium in evaporator. After the process water has been used, it can be recycled for cleaning of the processing plant and conveying of fruits and vegetables. However, if this recycled water poses threat to the overall sanitation and safety of food, then it is further purified or discarded depending upon the situation.

15.3.3 Disinfection of Water

Chlorination of water is done to kill or inhibit the growth of microorganisms. In addition, chlorinated water is used in the plant for disinfecting products and machinery. Effective chlorination must take into account the chlorine demand of water before a germicidal effect can be achieved. The **chlorine demand** is equal to the amount of chlorine added minus the amount of residual chlorine remaining at the end of 60 minutes of contact at a given temperature and pH. Therefore, it is the amount of chlorine required to destroy bacteria and oxidise organic matter. The break point is when the chlorine demand of water is met, after which further addition results in the formation of free residual chlorine.

For drinking purposes, the residual chlorine level should be less than 0.4 ppm. For cleaning of working equipment and conveyors water containing about 5 ppm of residual chlorine is used. Water to be used in general food plant cleanup may require a residual chlorine level as high as 25 ppm. This is because much of this chlorine will be used up in satisfying the chlorine demand of soil before it can have disinfecting properties. Chlorine is available in cylinders in the form of gas, which are discharged into the water. It may also be derived from hypochlorite preparations.

Ozone eliminates undesirable odour and taste, has a strong viricidal effect and is a powerful oxidising agent. The advantage is that it has no residual effect. **UV rays** are very effective against most viruses and microorganisms. However, the treatment is very expensive, and colour and turbidity of water reduces its effectiveness.

15.3.4 Water for Canning Industry

Chlorinated water should be used in a cannery to maintain hygienic conditions. As far as possible soft water should be used. The hardness of water, especially the temporary hardness, should be low for obtaining clear syrups (sugar solutions). The degree of hardness is still of greater importance in canning of vegetables, as the presence of lime in the blanching water or brine causes toughening of the skins of products such as peas and beans. The addition of sodium hexametaphosphate or sodium phosphate in desirable quantity overcomes the problems.

15.4 PROPERTIES OF WASTE WATER

The composition and contamination loads of the waste water obtained from a fruit and vegetable processing plant varies greatly as it may contain a wide variety of materials (e.g. pulp and peels, soil, detergents, etc.). The treatment of waste water is necessary for converting it into an acceptable final effluent and also to dispose off the solids removed in the process. The nature of the impurities and extent of pollution decide the suitable treatment methods and the degree of treatment, which will ultimately decide the design of the treatment plant.

15.4.1 Nature of Impurities in Waste Water

The wastewaters can be conveniently categorised according to their physical, chemical and biological natures of impurities.

The **physical characteristics** include appearance and odour. The materials in waste water from a fruit and vegetable processing plant are in solution and suspension, which are mostly organic with some inorganic matters. Water in-soluble liquids such as oils and certain solvents may also be present. The materials which remain as particles in the waste water must be removed before sending it to treatment plants or dumping, and should be treated separately. These materials, if discharged into streams and lakes, cause pollution and impart unaesthetic appearance. After removal of gross particulates, the wastewater may contain colloidal and dissolved impurities beyond the specified upper limit for discharge into streams or acceptable to sewage treatment plants. Therefore, further treatments depending upon the impurities are often required.

Under **chemical classification** of impurities, the colloidal and dissolved impurities in waste waters are divided into organic and inorganic materials. The peels, pulps, etc., which form a major part of the waste, are organic in nature. The ratio of nitrogenous constituents to carbohydrate materials present in the organic materials are very important from sewage treatment point of view. The nitrogen rich wastes accelerate the decomposition process by helping growth and activity of the sewage microorganisms, and hence sewage treatment plants are designed to receive wastes rich in nitrogen. Many vegetable wastes have higher nitrogen:carbohydrate ratio. As the fruit wastes have a high carbohydrate-low nitrogen content, they need supplementation with nitrogenous material before treatment in a sewage plant.

Very high and low pH waste water require neutralisation to bring down the pH to about 6-9 before discharging as it may kill aquatic life and essential microorganisms in sewage treatment plants or natural waters. The synthetic detergents and surface-active materials cause operating problems in sewage treatment plants, which can be easily avoided by using biodegradable detergents. If there is any bad odour from the wastewater, it needs an additional treatment.

The **biological nature** of impurities is very important. As previously discussed, the food plant wastes are generally organic, which are biodegradable. Mostly aerobic organisms are responsible for the degradation. In this process, carbohydrates are transformed into carbon dioxide and water, and nitrogen residues are converted to nitrates. Intermediate products such as alcohols, acids, amines, and ammonia are also produced during the process if the oxidation/ decomposition is incomplete. These intermediates often impart bad odour, and may be toxic to plant and fish life. These intermediates will undergo further degradation in nature.

15.4.2 Biological Oxygen Demand

Oxygen is required in the process of decomposition of organic waste by microorganisms. The amount of oxygen required is directly proportional to the amount of organic pollutants. This amount of oxygen, which is consumed for oxidation of organic contaminants is termed the biological oxygen demand (BOD).

BOD is an important measure of the dissolved organic wastes in water, and is of essential importance for the improvement of sewage and water. The BOD test measures the quantity of oxygen in ppm (parts per million) required by aerobic microorganisms to stabilise waste or polluted water under specific conditions (generally 20°C for 5 days). For example, the BOD of tomato processing wastes and citrus processing wastes vary between 80-4000 and 1000-5000 ppm. The BOD of milk processing waste water varies between 20-650 ppm only. When the BOD of waste discharged into a stream is excessive, there is fast depletion of the stream’s oxygen, which disturbs stream’s ecology, kills aquatic wild life and destroys beneficial microorganisms. The higher the BOD values, costlier will be the treatment before it is discharged into municipal wastes.

Sewage and waste treatment plants can be rated in terms of their BOD-removing capacity. The result of the BOD test determines whether a simple primary sewage treatment plant is sufficient or a complete treatment plant is required. The classification of streams by regulatory agencies is also often based upon BOD standards. Antipollution regulations are written to include maximum permissible BOD loadings into natural waters.

15.4.3 Chemical Oxygen Demand

The chemical oxygen demand (COD) is another useful test, which measures chemically oxidisable material in a liquid sample. This test is based upon the fact that all organic compounds, with a few exceptions can be oxidised quantitatively by strong oxidising agents, such as potassium dichromate, potassium permanganate, etc. under acid conditions. Thus it also measures chemically oxidisable inorganic materials.

15.4.4 Other Chemicals

The food plant wastes may sometimes be contaminated with highly toxic materials such as pesticides and disinfectants. Such toxic substances may kill the plant's normal microbial flora essential to sewage and waste treatment. Under such cases, it is advisable store it separately before discharging it into a convenient location or to dilute the wastes substantially and then send it to the treatment plant in very small quantities at a time.

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 disadvantages of hard water for a food processing industry?

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2. Name the different methods for removal of hardness of water?

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3. What are the major disinfecting agents of water?

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4. What will happen if a high BOD waste water is discharged into a sewage treatment plant?

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15.5 WASTE WATER TREATMENT

The extent to which the pollution load must be decreased before waste water leaves a food processing plant is highly variable. It depends on many factors such as whether the waste water will be discharged to a municipal sewage or commercial waste treatment plant, and if so what is the maximum pollution load this plant can treat; what will be the cost for such treatment and can it be done more economically by the food plant itself; what dumping privileges does the food plant have and what pollution laws apply, and so on. The waste water treatments may be classified under the following headings.

15.5.1 Primary Treatments

The primary treatments include screening, filtration, centrifugation and settling or sedimentation. Large solid matters and heavy sediments are removed by screening through vibrating sieves. This is essential to protect and safeguard the subsequent treatment units. Smaller particles may be removed by filtering or centrifuging. Mostly the slow sand or biological filters and rapid sand or mechanical filters are used for the purpose.

Suspended impurities are allowed to settle or rise in large sedimentation tanks and removed. The rate of sedimentation can be enhanced by the use of alum or ammonium sulphite, which produces a sticky flocculant precipitate. Scum or oil is readily skimmed from such tanks, and settled solids are concentrated. These primary treatments may remove some 40% of the wastewater's BOD and about 75% of total solids, depending on the nature of the waste.

15.5.2 Secondary Treatments

The primarily treated sewage in small food processing industries is discharged into municipal treatment plants. But in large plants, some additional treatments similar to those carried out in municipal sewage installations are carried out after the primary treatments. The basic purpose of these treatments is to reduce the BOD level of the wastes. These secondary treatments commonly involve the use of trickling filters, activated sludge tanks, and ponds of various types. Sometimes these are preceded by use of anaerobic digesters.

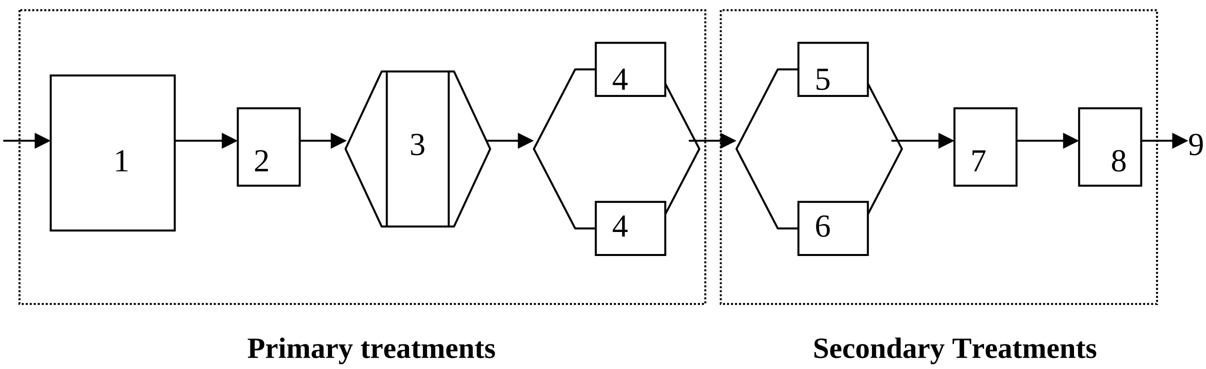


Figure 15.1: Waste water treatments: 1) Screen, 2) Shredder, 3) Grit chamber, 4) Primary sedimentation tank, 5) Trickling filter, 6) Activated sludge tank, 7) Secondary sedimentation tank, 8) Chlorination tank, and 9) final effluent.

15.5.3 Tertiary Treatments

The tertiary treatments or final treatments or advanced treatments applied to potable water for special food processing uses include water softening, ion exchange and carbon filtration. These treatments are also referred to as "polishing treatments". These are generally not needed or used to treat food plant wastewaters.

When a food plant has no means for disposing of treated waste waters, it may choose to discharge these waters into sewer lines for further handling by a municipal plant. The municipal plants usually chlorinate the waste waters before disposal into waterways or irrigation channels.

15.6 WASTE SOLIDS UPGRADING AND TREATMENT

You must have observed how a significant portion of the raw material is wasted during household processing of fruits and vegetables or cooking. Can you guess how much would be the amount of waste materials from a 10 tonne per day capacity fruit processing plant. If these wastes are not utilised properly, it affects the economic success of the industry. These wastes include crown, peel, core, seeds, pomace, trimmings, shells, stalks, etc. Table 15.2 gives an idea of the extent of waste during processing for different fruits and vegetables.

Table 15.2: Extent of wastes during processing for selected fruits and vegetables

Items	Waste as percent original raw material	Items	Waste as percent original raw material
Apples	30-35	Grapes	20-30
Mango	25-35	Peas	20-25
Guava	40-45	Beans	15-20
Pineapple	45-50	Carrots	5-7
Lemon	40-45	Tomato	8-10
Orange	50-55	Misc. vegetables	20-25

Most of the above wastes obtained from a fruit and vegetable processing industry are generally mixed with water. By suitable upgrading and treatment, they can be of several beneficial uses, as mentioned below.

- The by-products can be recovered from the waste water and spread out thinly on agricultural land for grazing of cattle. The unused material may be disposed off by burning.
- If the waste food are collected separately taking care that it does not mix with other refuse like broken glass, polythene pieces etc., they can be boiled, shredded, dried and enriched with minerals and can be used as poultry feed.
- Under favourable economic conditions most wastes can be processed or altered to a more useful and valuable material. Table 15.3 gives some beneficial uses of fruits and vegetables processing by-products. In fact, you will soon discover that no part is a waste during the processing of fruits and vegetables.
- Fruit and vegetable skins, pulp, and pits can be pressed to further remove water and be converted into compost for improving soils. Some wastes are ground into the plough as fill. Vermicomposting is one novel way for getting bio-fertiliser from bio-degradable wastes with the activities of earthworms.
- Sludge and residues remaining after waste water and sewage treatment have been dried and sold as fertilizer or used wet for this purpose. Sometimes they are incinerated, leaving only a small amount of ash, which can be disposed conveniently.
- Fruit and vegetable wastes are also used as a source of fermentable carbohydrate.
- All kinds of glass, solids, polythene, paper and metal can be recycled. Each of these materials should be collected separately for recycling.
- When none of these uses are feasible, then waste may be burned as garbage where law permits.

Table 15.3: Beneficial uses of fruits and vegetable wastes

Fruit	Nature of waste	Uses
Mango	peels, stones, pulping waste	starch, fat, pectin, vinegar, syrup, alcoholic beverage
Pineapple	peels, cores, trimmings	vinegar, syrup, citric acid, candied cores
Grapes	stem, seeds, seed hulls	cream of tartar, seed oil, tannin, vinegar, pectins, wines, stock seed
Apple	pomace, Cores cull	Pectin, cider, vinegar, soft drink, jelly base, Ingredient in cattle feed
Citrus	peels, pomace, seeds	pectin, essential oil and seed oil
Peaches, apricots and cherries	piths, kernels	oil, stock feed
Tomato	seeds, peels, and cores	animal feed, fertiliser, resin from peels, oil from seeds for soap making and edible use, peels

15.7 LOWERING DISCHARGE VOLUMES

Even though there are several ways to treat waste water, but you will agree that for minimising costs involved with waste water treatment and reducing the size of treatment plant, it is better to try to lower the discharge volume. The first step in lowering the discharge volume from a food plant is to reduce the amount of water used in the plant, which can be achieved by some modification in processing methods. Other means are recycling of the used water or treated waste water for some other non-priority areas.

15.7.1 Waste Water Treatment

For very large quantities of waste disposal, land treatment is the cheapest and best. The recovery of by-products from the wastes not only offers good economy, but also reduces pollution. However, these practices are viable only for big processing plants.

It is better to separate the solid wastes from the liquid. The coarse particulates and fine solids can be separated with different types of screens and settling tanks, as discussed in the previous section. The clear and problem free effluent can be drained.

Instead of segregating the different waste streams from a particular plant, the concentrated and high BOD wastes need to be handled separately. Thus large volumes of dilute waste water can be saved from high contamination. Some pre-processing ingredients are available which can reduce waste loads needing treatment.

15.7.2 Recycling and Modified Processing Methods

There are many modified processing operations, which can give lesser volumes of waste water as compared to conventional processing methods.

Reuse of water for less demanding operations is the most suitable one. The water obtained from heat exchangers or the boiler feed can be used for cleaning and conveying of fruits and vegetables. This decreases waste load to a considerable extent.

Recovery of salt by evaporation of the brine and crystallisation is possible. In addition to a potential saving in salt costs, it also avoids pollution that might have been caused due to discharge of the brine. However, the crystallised salt slurry may contain some organic matter, which has to be separated before the salt can be reused. This is done by incineration of the slurry, which leaves a trace of carbon. The salt can be reused after certain modifications such as adjusting the pH, and filtering to remove the carbon. Such processes, however, must also be considered in terms of benefit-cost ratio.

Loosening the skins of fruits and vegetables for peeling is usually done in dilute caustic solution. This method consumes a lot of water, which is ultimately wasted after peeling. Instead, we can achieve a considerable saving in water by peeling using concentrated sodium hydroxide (NaOH) solution combined with vigorous mechanical action. The BOD of the wastewater per weight of raw material obtained by this 'dry caustic method' is only about one-third that generated by the dilute caustic solution.

Similarly, steam blanching of vegetables saves considerable water from being polluted as compared to conventional hot water blanching. Further, as less amount of solids are dissolved in the blanching medium, the effluent has low BOD level. It is also reported to give better texture of the vegetables after freezing, thawing, and cooking as compared to the hot water blanching method.

Check Your Progress Exercise 2 ✍

Note: a) Compare your answers with those given at the end of the unit.

1. State True / False:

   a) The primary treatment of wastewater involves the use of activated sludge tanks.

   b) The secondary treatments of wastewater are also known as "Polishing treatment".

   c) In small food processing plants the secondary treatment of wastewater is not carried out.

   d) The amount of wastes from mango fruits is in the range of 5-10 percent of the raw material.

   e) Recycling of water in food processing plant reduces considerable wastewater.

15.8 PLANT SANITATION AND EFFLUENT TREATMENT AS A CONTINUOUS RESPONSIBILITY

The ever increasing population, increase in number of industries and vehicles, migration of the people from rural areas to cities and towns, and several other factors have added to the amount of wastes. Now there is more concentration of people in areas of processing than the areas of production. This has added to a growing problem of waste disposal, which has always meant expense to food processors. In particular, in fruit and vegetable processing industry huge amount of waste and effluents are released. Most often the wastes are more than the preserved edible materials. It must be disposed off regularly and efficiently to prevent contamination of any food product. In addition, it is very important to prevent pollution of atmosphere and water supplies by proper disposal of the waste and effluents from such plants.

The wastes obtained from a fruit and vegetable processing plant are mostly organic and biodegradable. Large quantities of inorganic impurities from fruit / vegetable washing process may also be obtained. Small doses of pesticide residues, nitrates and nitrites formed out of residual protein and ammonical compounds during processing may also occur. All of these, if disposed as such to the surrounding, will pollute the surface and ground waters used for drinking purposes. This will ultimately add to the ever-growing problems of the human being. Therefore, every necessary step should be taken for effluent treatment of a food processing plant to protect the environment. All of these are moral obligations also.

The major source of air pollution in a fruit and vegetable processing industry is fuel burning in boiler for steam raising and heating which mainly emits smoke/ particles/dust, sulphur oxides and oxides of nitrogen. The intensity of emission varies with the type of fuel and boiler used, and the boiler-firing practice adopted. Minor discharge of benzpyrenes and trace metals contained in coal may also be present. Provision of inadequate smoke stack (lower height) and / or existence of unfavourable meteorological conditions may result in increased ground level concentration of pollutions which can result in discomfort and respiratory complaints initially and impairment of lung functions in the long run.

Therefore, it is our responsibility to take a holistic approach of production and processing as well as for the minimisation of wastes disposed from a food plant. Besides, if a food plant pollutes the surrounding atmosphere, it ultimately earns bad reputation and looses customers.

15.9 WASTE / EFFLUENT DISPOSAL REGULATIONS

Setting of the project has a very important role to play in the control of pollution. While deciding the location of the project, the weightage has to be given to the availability of power and water. It is also necessary to know in advance whether no objection certificate from the pollution control angle would be admissible for the proposed industry.

There are several pollution control acts to protect and improve the natural environment including forests, lakes, rivers and wild life and have compassion for leaving creatures. The Pollution Control Law Series: PCLS/02/1992 has the details of these regulations. It also contains standards notified with respect to the important pollutants as well as rules governing hazardous wastes, hazardous chemicals, etc. notified under Environment (Protection) Act, 1986. The Environment Ministry / Department and the State Pollution Control Boards are responsible for giving clearance on these aspects to any industry.

The Act specifies the wastewater discharge standards for any food and fruit processing industry, as given in Table 15.4. Table 15.5 gives the specified emission levels from boilers as covered under the Act.

Table 15.4: Wastewater discharge standards for food and fruit processing industry

Category	Concentration not to exceed				Quantum
	pH	Suspended solids (mg/l)	Oil and grease (mg/l)	BOD at 27°C for 3 days (mg/l)	g/tonne of product
a) Above 0.4 tonnes/day	6.5-8.5	50	10	30	-
b) 0.1-0.4 tonne/day	6.5-8.5	-	-	300	-

Table 15.5: Limits of emission from boiler houses

Capacity of Boilers	Particulate matters emission (mg/Nm³)
Less than 2 ton/h	1200*
2 to less than 10 ton/h	800*
10 to less than 15 tons/h	600*
15 tons/hr and above	150**

(* To meet the respective standards, cyclone / multicycle is recommended as control equipment with the boiler. ** Bag filter/ESP is recommended as control equipment. In the above table, 12% of carbon dioxide correction shall be the reference value for particulate matter emission standards for all categories of boilers.)

There are several other schedules in the Pollution Control Act dealing with discharge of effluents, ambient air quality standards, standards for control of noise pollution, etc. The Bureau of Indian Standards (BIS) has also specified regulations for manner, condition and fees for grant and renewal license for environmental management system.

The Factory Act, 1948 has several clauses relating to health measures and waste disposal aspects in any type of factory. Under the Act, the occupier is required to keep the factory premises clean and free from waste and effluvia. He shall make arrangements for sweeping and removing dirt and refuse daily, cleaning with disinfectant, painting the walls, doors and windows at specified time intervals. Effective arrangement shall be made for treatment of wastes and effluents due to the manufacturing process carried on therein, so as to render them innocuous and for their disposal.

If any process or machine gives off dust/fumes or other impurity which are likely to be injurious or offensive to the workers, effective measures should be taken to prevent its inhalation and accumulation in any workroom. The exhaust appliance, if used, shall be applied as near as possible to the point of origin of the dust, fume or other impurity. Besides, such points shall be enclosed as far as possible. The factory premises should be adequately ventilated by circulation of fresh air and comfortable temperature should be maintained in every workroom.

15.10 ENVIRONMENT IMPACT

Now-a-days we have become very conscious of the environmental pollution and degradation aspects at all levels. Therefore possible environmental impacts are taken into serious consideration before and after setting up an industry in a particular location. For example, the discharge of solid and liquid wastes, smoke and polluted air will change the physical and chemical characteristics of surrounding environment and water body. Sometimes, it has so happened that due to deposition of solids and/or discharge of harmful chemicals, streams have become unfit for drinking water purpose, or even for bathing. Similarly you must have observed how the surroundings near a thermal power plant or stone crushers are heavily polluted, which affect the normal life of the people. Hence, preparation of environmental management plan is required for formulation, implementation and monitoring of environment protection measures during and after commissioning of the projects.

The environmental impact not only considers the changes in air or water qualities in the area, but it also considers the biological, cultural and socio-economic components of the environment. It is essential to assess these environmental impacts and the tool used for the purpose is known as **Environmental Impact Assessment** (EIA).

In recognition of the role that EIA could play, Ministry of Environment and Forests, has published a list of 29 industries, which are required to obtain environmental clearance from competent authority in addition to a NOC from Pollution Control Board. Even though, the food and fruit processing industry, at present, is not included in the list, still the environmental impact for such industry can not be ignored.

Environmental impact has a very wide scope in the formulation of a project. Even for site selection, the environmental attributes such as topography, geology, water resources (quantity and quality), soil characteristics, land productivity, flora and fauna, socio-economic conditions are considered. The proximity to water resources, raw materials, markets, availability of land and human resources etc. are other project attributes. An environmental management plan is formulated to ensure that the resources are used with maximum efficiency, waste generation is minimised, residuals are treated adequately and products are recovered and recycled to the maximum possible extent.

EIA consists of establishing quantitative values for selected parameters, which indicate the quality of the environment before, during and after the proposed development activity. EIA involves three steps, viz. identification, prediction and evaluation of impacts. First the environmental parameters to be investigated for possible impacts are listed. Then with the help of suitable models real impacts for proposed development are assessed. Though fairly good models are available for prediction with respect to air and water components, predictions of biological, socio-economic and cultural impacts are often subject to uncertainty. The degree of uncertainty could however be ascertained mathematically or indicated in qualitative terms while presenting prediction results. The evaluation step calls for conversion of predicted values for various environmental parameters to a comparable set of units using some system of normalisation. At present many consultancy firms are also doing EIA studies, which can be hired for the purpose.

Check Your Progress Exercise 3

Note: a) Compare your answers with those given at the end of the unit.

1. Fill in the blanks:

   a) The major source of air pollution in a fruits and vegetables processing industry is __________________.

   b) The extended form of EIA is ___________________________________.

15.11 LET US SUM UP

In this unit we studied about the importance of plant sanitation for a fruits and vegetables processing plant and we observed that sanitation is very important for the safety of food and overall performance of the industry. We discussed about the different properties of process water and steps for removal of hardness and disinfection of water so as to make it fit to be used as process water. We also discussed about the methods for waste water treatment and water solids upgrading and treatment. The different methods for lowering discharge volumes such as waste water treatment and recycling and modified processing methods are also covered in the unit. Thus we are now familiar with the general sanitation and waste disposal aspects of a fruits and vegetables processing plant.

15.12 KEY WORDS

Carbonate hardness : Hardness due to presence of calcium and magnesium bicarbonates; also known as temporary hardness.

Non-carbonate Hardness : Hardness due to the presence of calcium and magnesium sulphates, chlorides and nitrates; also known as permanent hardness.

Chlorine demand : It is the amount of chlorine required to destroy bacteria and oxidise organic matter.

BOD : The amount of oxygen consumed for oxidation of organic contaminants in water.

15.13 SELF TEST FOR THE COMPLETE UNIT/ ASSIGNMENT

1. Explain the different methods for disinfection of water?

2. Explain the importance of waste solids upgrading and treatment?

3. Explain the requirement of process water?

15.14 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Hard water creates a problem in cleaning operations. Hardness causes scale on equipment, which reduces heat transfer and contaminates steam produced in boilers. The life of pipes and fixtures is reduced as they may rust. The scales house bacteria and affect food products directly. Calcium present in hard water in excess amounts can cause various textural defects.

2. The methods for removal of hardness of water are boiling, addition of slaked lime, addition of washing soda, ion exchange process, and use of sequestering agents.

3. Chlorine, Ozone, UV rays

4. There will be fast depletion of the stream's oxygen, which disturbs stream's ecology, kills aquatic life, and beneficial micro-organisms for sewage conversion.

Check Your Progress Exercise 2

1. a) False
   b) False
   c) True
   d) False
   e) True

Check Your Progress Exercise 3

1. a) Boiler
   b) Environmental Impact Assessment (EIA)

15.15 SOME USEFUL BOOKS

1. Bhatia, S.C. (2001). Environmental Pollution and Control in Chemical process Industries. Khanna Publication, New Delhi.

2. Central Pollution Control Board (1992). Pollution Control Acts, Rules and Notifications Isued thereunder. Pollution Control Law Series, PCLS/02/1992, CPCB, Delhi.

3. Chatterjee, A.K. (1996). Water supply, Waste Disposal and Environmental Pollution Engineering. 5th Edition. Khanna Publication, New Delhi.

4. Gould, W.A. (1990) CGMP's/Food Plant Sanitation. CTI Publication, Inc., Baltimore.

5. Potter, N.N., Hotchkiss, J.H. (1996). Food Science. 5th Edition. CBS Publishers and Distributors, New Delhi.

6. Roday, S. (1999). Hygiene and Sanitation in Food Industry. 1st Edition. Tata McGraw Hill, New Delhi.

EXPERIMENT 1 PREPARATION OF FRUIT BEVERAGES – SQUASH, CORDIAL, RTS BEVERAGE, FRUIT NECTAR AND SHARBETS

Structure

1.1 INTRODUCTION

Tropical countries, like India, have a vast scope of providing delicious cold drinks during hot summer particularly the fruit beverages. Due to increased consumer awareness with respect of quality, safety and health, these fruit beverages are becoming more and more popular and are gradually acquiring a chunk of the market share of cold drinks.

Fruit beverages are easily digestible, highly refreshing, thirst quenching, appetizing and nutritionally far more superior to the synthetic aerated drinks. Fruit beverages can be classified as fermented and unfermented. In this practical, however, we will only deal with unfermented beverages which do not undergo any alcoholic fermentation.

Objectives

After going through this experiment, you should be able to:

- describe methods of preparation and preservation of unfermented fruit beverages; and
- know the difficulties, precautions to be taken and technical know-how of the final product quality.

1.2 EXPERIMENT

1.2.1 Principle

Fruit beverages are prepared from fruit juices or pulp and preserved by chemical preservatives or by heat application.

1.2.2 Requirements

Raw materials, equipment and apparatus

1. Fruit/vegetable, sugar
2. Peeler
3. Juicer
4. Pulper
5. Filter cloth / sieve
6. Pans of suitable size
7. Heaters
8. Thermometer
9. Crown corking / capping machine
10. Corks / caps
11. Sterilizer/Pasteurizer
12. Volumetric flask
13. Measuring cylinder
14. Weighing balance
15. Potable water

Chemicals and reagents

1. Hydrochloric acid
2. Citric acid / ascorbic acid
3. Potassium metabisulphite
4. Sodium benzoate

1.2.3 Procedure

General method for preparation of fruit juice

The general process for the preparation and preservation of unfermented fruit beverages is as follows:

- Select only fully ripe and quality fruits. Care should be taken not to include either over ripe or under ripe fruits as it affects the final product quality.
- Sort and reject/trim diseased, damaged or decayed fruits. Wash them properly with water or dilute hydrochloric acid (1 part acid: 20 parts water) to remove dirt and spray residues of arsenic, lead, etc.
- Extract juice from fresh fruits by crushing and pressing them by using suitable juice extractors, basket presses or fruit pulpers. Fruits, which require preheating, should be preheated before extraction.
- Strain and filter the juice to remove suspended matter consisting of broken fruit tissue, seed, skin, etc. Clarify the juice if required using a suitable method.
- Fortify the juices with vitamins to enhance their nutritive value, to improve taste, texture or colour and to replace nutrients lost in processing, if required.
- The preservation could be by physical methods (pasteurization, sterilization, etc.) or by chemical preservatives.
- Wash bottles thoroughly with hot water and fill them leaving 1.5-2.5 cm headspace. Seal with crown corks (by a crown corking machine) or with caps (by capping machine).

a) Squash

Squash should contain at least 25% fruit juice or pulp and 40 to 50% total soluble solids commercially. About 1% citric acid and 350 ppm Sulphur dioxide or 600 ppm sodium benzoate are added as preservatives.

Method of preparation

For the preparation of 10 litres of squash follow the procedure given below:

- Calculate the amount of juice required as per commercial specification

  Required juice = (25/100) × 10 = 2.5 lts.

- Measure the TSS using a refractometer (say the TSS is 30%)

  Calculate the total solids content of the juice i.e. 0.3 X 2.5 = 0.75 kg

- The final required TSS content in the product is to be say 50%. The TSS required to be added to obtain the final product is (0.5 × 10 – 0.75) kg = 4.25 kg

- The amount of soluble solids in the form of citric acid and KMS is

  Citric acid @ 1%, in the final produce is 100 g i.e. 0.1 kg.

  600 ppm SO_2 (1.5g/litre of KMS being equivalent to 1000 ppm) @ 0.9g KMS/litre. i.e. 0.9 x 10 = 9 g i.e 0.009 kg.

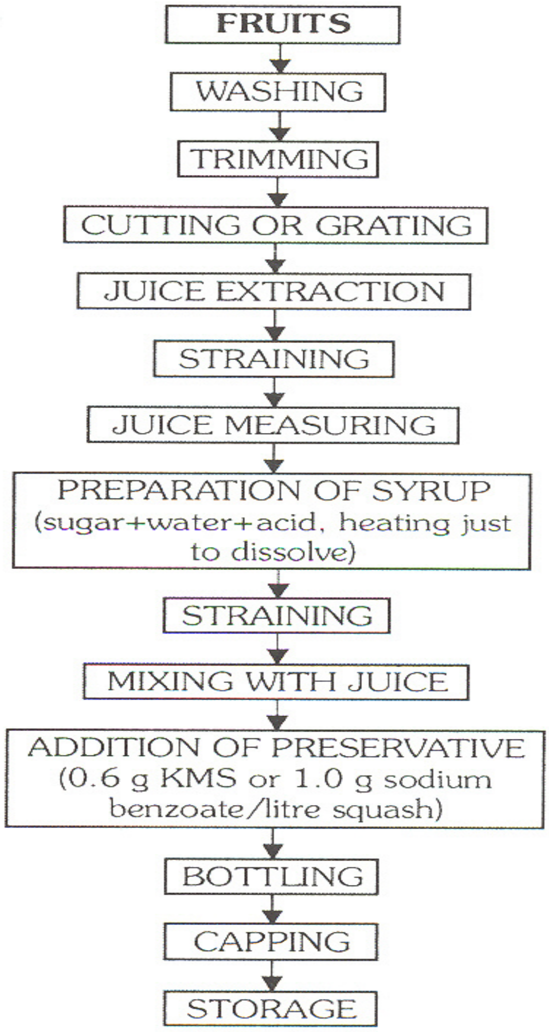
- Amount of solids to be added in the form of sugar is 4.25–(0.1+0.009)= 4.141 kg.

- Ingredients

Ingredients	Juice	-	2.5 kg	
	Sugar	-	4.141 kg	4.25 Kg
	Citric acid	-	100 g	
	KMS	-	9 g	
	Water	-	(10-2.5+4.25) = 3.25 Lts	

- As prescribe dissolve sugar in water, add citric acid and give a boil, strain through a fine muslin cloth. Cool the syrup completely. Mix the fruit juice with syrup. Add colour as required and then essence. Grind the preservative in a saucer with a spoon. Add little water. Pour into squash. Add more juice and transfer all the preservative to the squash.

Flow sheet



b) RTS Beverage

This is a type of fruit beverage containing at least 10% fruit juice and 10% total soluble solids besides about 0.3% acid. It is not diluted before serving and, hence, is known as ready-to-serve (RTS) beverage.

Method of preparation

For the preparation of 10 lts. of RTS beverage, follow the procedure given below:

- Calculate the amount of juice required as per commercial specification

  Required juice = (10/100) × 10 = 1.0 lts.

- Measure the TSS using a refractometer (say the TSS is 30%)

  Calculate the total solids content of the juice i.e. 0.3 × 1.0 = 0.30 kg

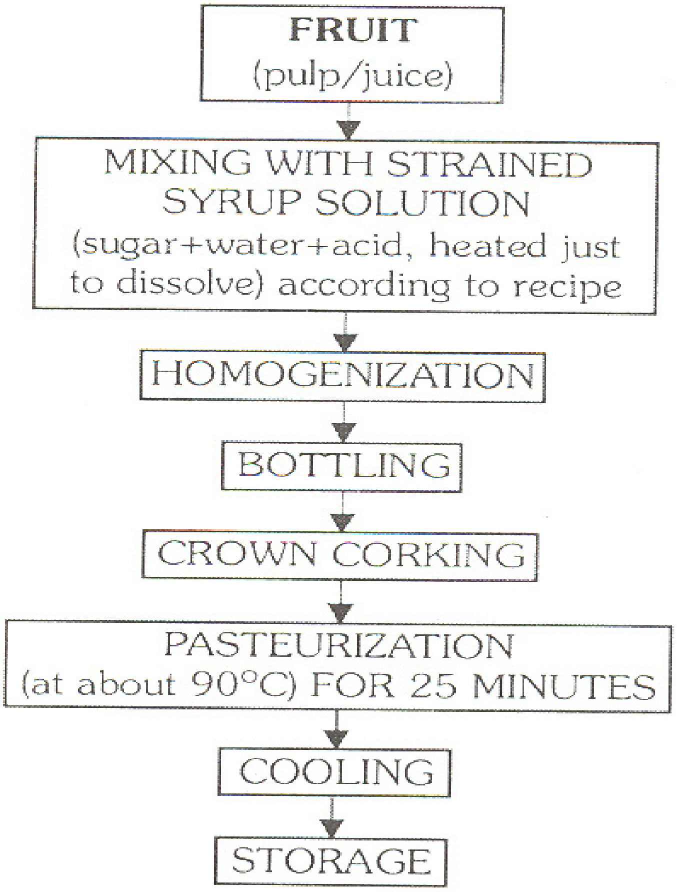
- The final required TSS content in the product is to be say 10%. The TSS required to be added to obtain the final product is (0.1×10–0.30)kg = 0.70 kg

- The amount of soluble solids in the form of citric acid and KMS is

  Citric acid @ 0.3%, in the final produce is 30 g i.e. 0.03 kg.

- Amount of solids to be added in the form of sugar is 0.70–0.03=0.67kg.
- Add calculated amount of sugar to about 2 lts of water and heat it till it dissolves completely. Add citric acid and juice to the sugar syrup and makeup the volume to 10 lts. Mix it well.
- Heat up to 90°C, fill hot in clean pre-sterilized glass bottles up to brim, seal and cool in the air or fill in bottle, seal and heat process (90°C for 25 min.).

Flow sheet



c) Fruit Nectar

This is a type of fruit beverage containing at least 20% fruit juice/pulp and 15% total soluble solids besides about 0.3% acid. It is also not diluted before serving.

Method of preparation

For the preparation of 10 lts. of fruit nectar, follow the procedure given below:

- Calculate the amount of juice required as per commercial specification

  Required juice = (20/100) × 10 = 2.0 lts.

- Measure the TSS using a refractometer (say the TSS is 30%)

  Calculate the total solids content of the juice i.e. 0.3 × 2.0 = 0.60 kg.

- The final required TSS content in the product is to be say 15%. The TSS required to be added to obtain the final product is $(0.15 \times 10 - 0.60)$ kg = 0.90 kg.
- The amount of soluble solids in the form of citric acid and KMS is

  Citric acid @ 0.3%, in the final produce is 30 g i.e. 0.03 kg.

- Amount of solids to be added in the form of sugar is 0.90–0.03=0.87kg.
- Add calculated amount of sugar to about 2 lts of water and heat it till it dissolves completely. Add citric acid and juice to the sugar syrup and makeup the volume to 10 lts. Mix it well.
- Heat the RTSB / Nectar up to 90°C, fill hot in clean pre-sterilized glass bottle up to brim, seal and cool in the air or Fill in bottle, seal and heat process (90°C for 25 min.).

d) Cordial (Lime)

- Extract the juice and strain through a fine muslin cloth to remove all pulp
- Add preservative (KMS) 2 gms per litre of lime juice
- Pour in bottles and keep for 1-2 months. All the sediment settle down and the juice becomes clear
- Pour all clear juice without disturbing the sediment. Use the recipe and proceed as for squash.

Flow sheet

Same as RTS Beverage

e) Sharbet

Sharbet should contain at least 65% total soluble solids, suitably acidified and may or may not contain fruit juice.

Method of preparation

For the preparation of 10 lts. of sharbet follow the procedure given below:

- Take about 6 lts. of water and add approx. 6.5 kg of sugar and dissolve it properly.
- Add the required flavour.
- Make up the volume to 10 lts. and adjust the TSS to 65%.

1.2.4 Observations

Determine TSS and acidity.

Note: The procedure for the calculation of TSS and acidity can be seen in the practical manual of BPVI-007 Course VII 'Food Quality Testing and Evaluation' and BPVI-003 Course III 'Food Chemistry and Physiology'.

1.2.5 Result

Acidity of the given squash, cordial, nectar, RTS beverage = % (w/v)

TSS of the given squash, cordial, nectar, RTS beverage = %

1.3 PRECAUTIONS

- All equipment used in the preparation of fruit juices and beverages should be rust and acid proof.
- Copper and iron vessels should be strictly avoided as these metals react with fruit acids, and cause blackening of the product.
- Avoid exposure of juice to atmosphere as it will spoil the colour, taste and aroma and also reduce the Vitamin content.

EXPERIMENT 2 PRODUCTION OF FRUIT JAM, JELLY, MARMALADE, FRUIT BUTTERS, CONFECTIONARY AND CHEESE, PRESERVE AND CANDIES

Structure

2.1 INTRODUCTION

Jam, jellies and preserves etc., are very common products made out of fruits and vegetables that permit consumers to taste the fruits of their liking even during lean periods or when the fresh produce is expensive. These products also permit the diversification of the fruit use to avoid distress sale during the production season and to minimize the post harvest wastages. These practices of preparing the processed products are simple and could be attempted at household levels even in rural settings if adequate food safety related precautions are put in place. Besides, there are several fruits that are not cultivated in large quantities to permit large scale processing. Still these fruits are novel enough to convert them into the processed products and present them to consumers as niche products.

Objectives

After going through this experiment, you should be able to:

- describe methods of preparation and preservation of jam, jelly and preserve etc.; and
- know the difficulties, precautions to be taken and technical know-how of the final product quality.

2.2 EXPERIMENT

2.2.1 Principle

Jam, Jelly and Preserve are prepared from fruit pieces or pulp and preserved by high sugar concentration/chemical preservative or by heat application.

2.2.2 Requirements

Raw materials, equipment and apparatus

1. Fruit/vegetable, sugar
2. Peeler
3. Pulper
4. Filter cloth / sieve
5. Pans of suitable size
6. Heaters
7. Thermometer
8. Crown corking / capping machine
9. Corks / caps
10. Sterilizer/Pasteurizer
11. Volumetric flask
12. Measuring cylinder
13. Weighing balance
14. Potable water

Chemicals and reagents

1. Hydrochloric acid
2. Citric acid / ascorbic acid
3. Potassium metabisulphite
4. Sodium benzoate

2.2.3 Procedure

a) Jam

- Jam is a product made by boiling fruit pulp with sufficient sugar to a reasonably thick consistency, firm enough to hold the fruit tissues in position. Apple, pear, sapota, apricot, loquat, peach, papaya, karonda, carrot, plum, strawberry, raspberry, mango, tomato, grapes and muskmelon are used for preparation of jams.

- It can be prepared from one kind of fruit or from multiple kinds. Commercial jams such as tutti-frutti can be prepared from pieces of fruit, fruit scraping and pulp adhering to cores of fruits, which are available in plenty in canning factories.

- Jam contains 0.5 - 0.6% acid and invert sugar should not be more than 40%.

Method of preparation

For the preparation of 10 kg of jam follow the procedure given below:

- Calculate the amount of fruit pulp required as per commercial specification

  Required pulp = $(45/100) \times 10 = 4.5$ kg.

- Measure the TSS using a refractometer (say the TSS is 50%)

  Calculate the total solids content of the juice i.e. $0.5 \times 4.5 = 2.25$ kg.

- The final required TSS content in the product is to be say 68%. The TSS required to be added to obtain the final product is $(0.68 \times 10 - 2.25)$ kg = 4.55 kg.

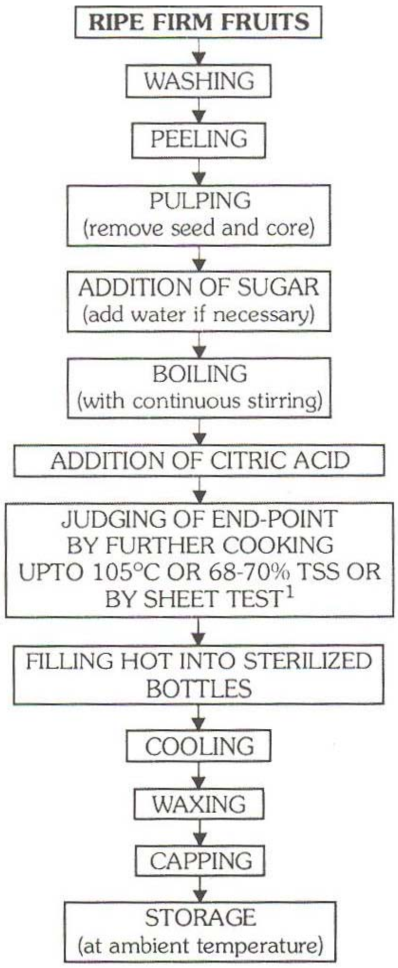
- The amount of soluble solids in the form of citric acid and KMS is

Citric acid @ 0.5%, in the final produce is 50 g i.e. 0.05 kg.

- Amount of solids to be added in the form of sugar is 4.55–0.05=4.5 kg.

- Add the calculated amount pulp and sugar to about 2 lts of water and boil it to 105°C so that the sugar dissolves completely. Add citric acid and juice to the sugar syrup and judge the end point by measuring its TSS or using sheet test.

Flow sheet



1. **Sheet or flake test:** A small portion of jam is taken out during boiling, in a spoon or wooden ladle and cooled slightly. It is then allowed to drop. If the product falls off in the form of a sheet or flakes instead of flowing in a continuous stream or syrup, it means that the end-point has been reached and the product is ready, otherwise, boiling is continued till the sheet test is positive.

b) Jelly

- A jelly is a semi-solid product prepared by boiling a clear, strained solution of pectin-containing fruit extract, free from pulp, after the addition of sugar and acid.

- A perfect jelly should be transparent, well-set, but not too stiff, and should have the original flavour of the fruit. It should be of attractive colour and keep its shape when removed from the mould. It should be firm enough to retain a sharp edge but tender enough to quiver when pressed.

- It should not be gummy, sticky or syrupy or have crystallized sugar. The product should be free from dullness, with little or no syneresis (weeping), and neither tough nor rubbery.

- Guava, sour apple, plum, karonda, wood apple, loquat, papaya, and gooseberry are generally used for preparation of jelly. Apricot, pineapple, strawberry, raspberry, etc., can be used but only after addition of pectin powder, because these fruits have low pectin content. Its acid content should be 0.5-0.75%.

Method of preparation

For the preparation of 10 kg of jelly follow the procedure given below:

- Take about 10 kg of fruit and boil in 15 lts of water for 20 – 30 min.

- Add to it about 20 g (@ 2g/kg) of citric acid and strain it.

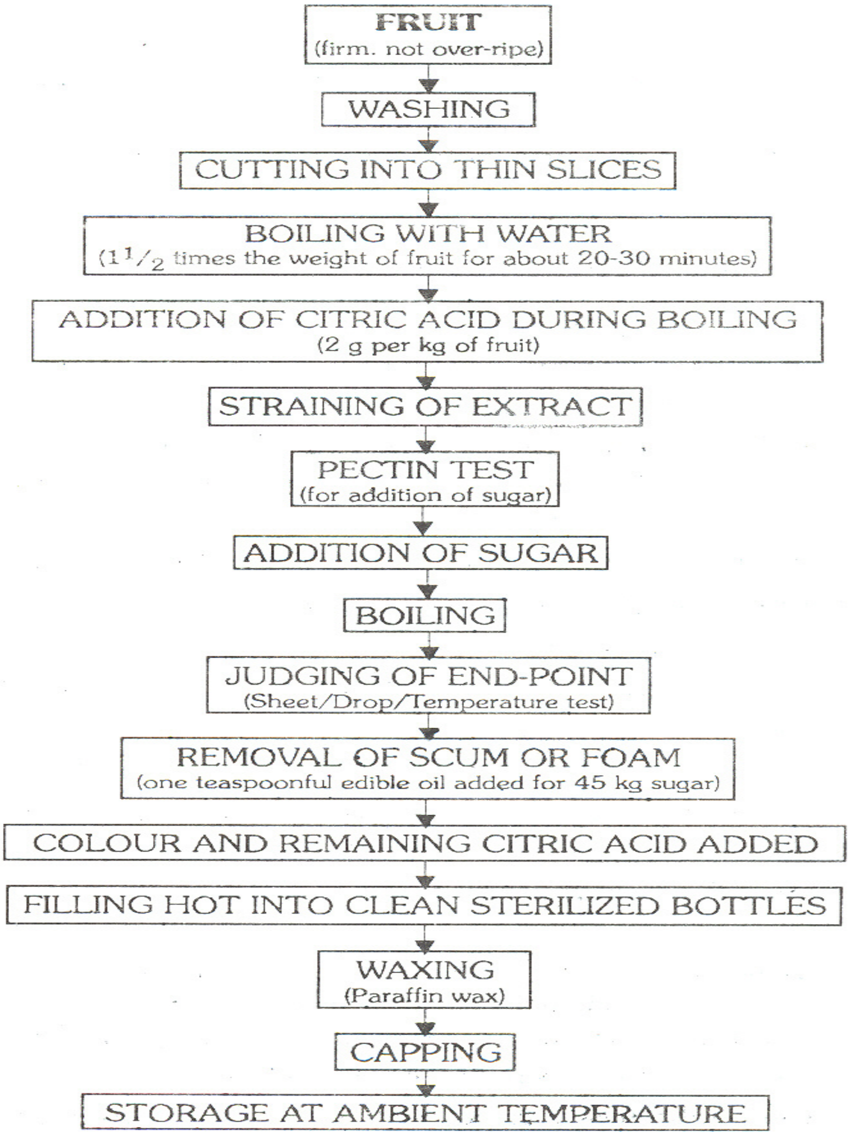
- Determine the pectin content using alcohol or Jelmeter test.

- Add the required amount of sugar (1:1 for extracts rich in pectin; 1:0.75 for extract moderate in pectin; and 1:0.5 for extract poor in pectin.

- Boil the mixture judge the end point using sheet test as mentioned in the preparation of jam.

- Add the calculated amount pulp and sugar to about 2 lts of water and boil it to 105°C so that the sugar dissolves completely. Add citric acid and juice to the sugar syrup and judge the end point by measuring its TSS or using sheet test.

Flow sheet



c) Preserve and its Method of Preparation

- A mature fruit/vegetable or its pieces impregnated with heavy sugar syrup till it becomes tender and transparent is known as a preserve.
- Aonla, bael, apple, pear, mango, cherry, karonda, strawberry, pineapple, papaya, etc., can be used for making preserves.
- It can be prepared using 1 kg of fruit, 1 litre of water and 1 kg of sugar. A. little quantity of acid (citric or tartaric) is added during the preparation to prevent crystallization of the syrup.

Method of preparation

The following steps are required in a good preserve:-

1. Pre-treatment
2. Leaching
3. Pricking
4. Penetration of Sugar
5. Finishing

1. Pre-treatment

After selecting good fruit, it is washed and given pretreatment for the following functions

a) To reduce bitterness
b) Softening and Maturity
c) Hardening the tissues
d) Storing for long period
e) Reducing the shrinkage of fruit

2. Leaching

Leaching is carried out in the following functions:

a) To remove salty taste from fruit
b) To soften the fruit so that penetration is quick
c) To remove bitterness in intercellular space

3. Pricking

a) Pricking is carried out for facilitating of the penetration of sugar.
b) This is usually done by piercing fork needles or stamp having painted nails or needle.

4. Penetration of Sugar

This is done to achieve the following:

a) Uniform penetration
b) Retention of natural colour and flavour
c) Retention of nutrition
d) Method should be quick

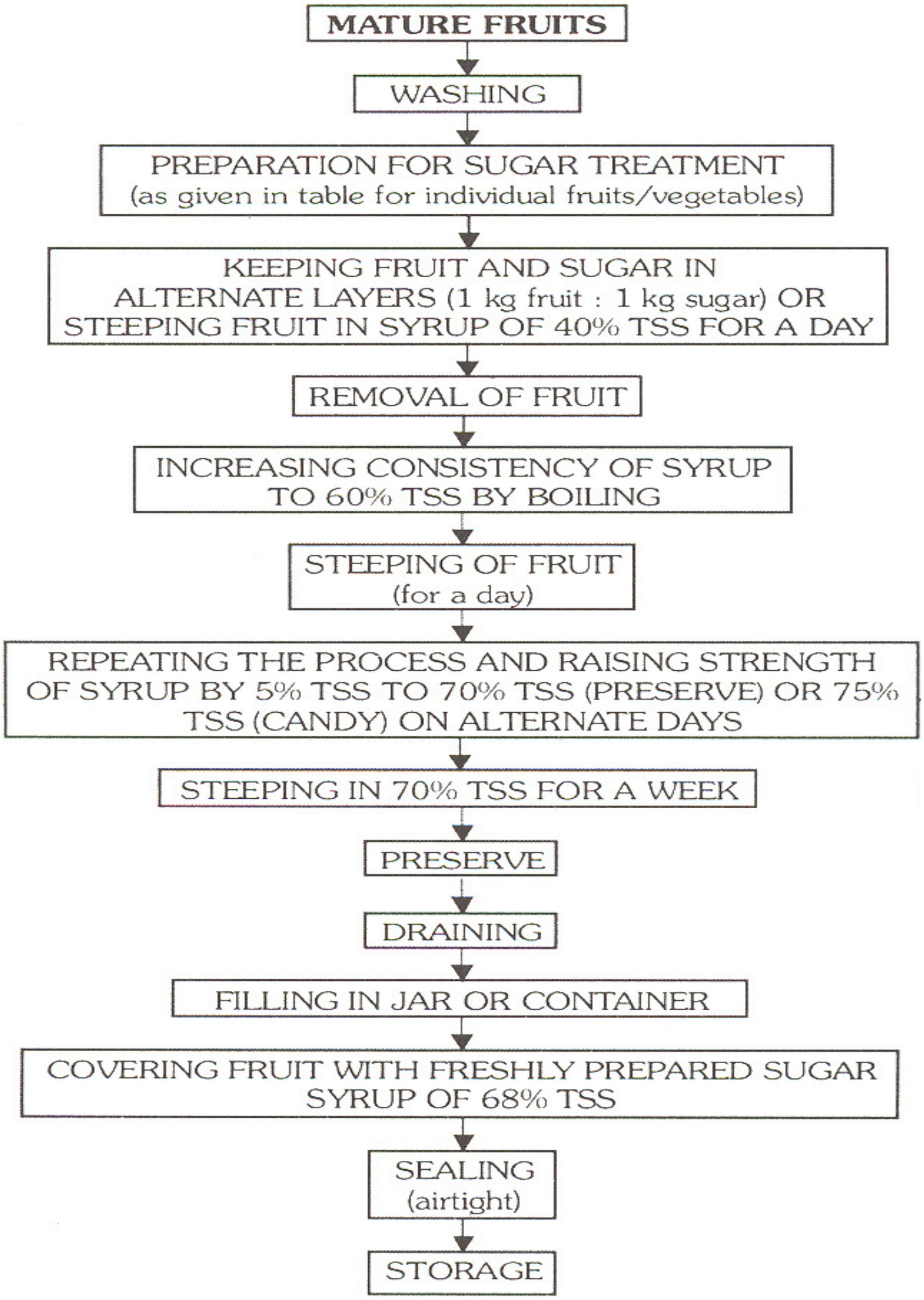
5. Finishing

Generally preserve is packed along with syrup covering 45% portion in the container.

For the preparation of 10 kg of jelly follow the procedure given below:

- Take about 10 kg of fruit and prepare it for sugar treatment as mentioned in the table in the following section.
- Make 10 lts of sugar solution of 40% TSS (Dissolve 4 kg of sugar in about 5 lts of water and make up the volume to 10 lts.).
- Dip the fruit in the sugar syrup for 24 hrs. Remove the fruit and boil the sugar solution to increase its consistency to 60%. Again steep the fruits in it for 24 hrs.
- Repeat the process on alternate days raising the TSS % of the sugar solution by 5% up to 70%. Steep the fruits in 70% TSS sugar solution for a week and the preserve is ready.
- The preserve should be stored in air tight jars with adequate sugar solution of 68% TSS to cover the fruits.

Flow sheet


MATURE FRUITS
WASHING
PREPARATION FOR SUGAR TREATMENT
(as given in table for individual fruits/vegetables)
KEEPING FRUIT AND SUGAR IN ALTERNATE LAYERS (1 kg fruit : 1 kg sugar) OR STEEPING FRUIT IN SYRUP OF 40% TSS FOR A DAY
REMOVAL OF FRUIT
INCREASING CONSISTENCY OF SYRUP TO 60% TSS BY BOILING
STEEPING OF FRUIT
(for a day)
REPEATING THE PROCESS AND RAISING STRENGTH OF SYRUP BY 5% TSS TO 70% TSS (PRESERVE) OR 75% TSS (CANDY) ON ALTERNATE DAYS
STEEPING IN 70% TSS FOR A WEEK
PRESERVE
DRAINING
FILLING IN JAR OR CONTAINER
COVERING FRUIT WITH FRESHLY PREPARED SUGAR SYRUP OF 68% TSS
SEALING
(airtight)
STORAGE

Preparation of fruits and vegetables for preparing preserve

Fruit/ vegetable	Steps of Process			
	Step I	Step II	Step III	Step IV
1	2	3	4	5
Aonla	Prick with fork, needle or gooseberry pricker (avoid iron needle as it causes browning due to tannin in fruit)	Steep in 2% salt solution for 24 hours to remove astringency	Wash and dip in 2% alum solution for 24 hours then wash thoroughly	Blanch until soft but segments do not break or crack
Apple and pear	Peel, prick with needle or fork (do not remove core and stem of whole fruit to be used otherwise peel and cut into halves or quarters, remove core and prick)	Steep in 2% salt solution for 24 hours to prevent browning and disintegration of fruit tissues during blanching	Wash and dip in 2% alum solution for 24 hours and wash again	Blanch in water containing small quantity of potassium metabisulphite to bleach or in water containing edible deep green or red colour
Bael	Remove shell, slice peeled fruit crosswise into 2.5 cm thick pieces and wash with water, prick on both sides	Steep in cold water for 24 hours	-	Blanch in water containing edible red colour until soft and sufficient colour absorbed
Ber	Prick whole fruit	Steep in 2% salt solution containing 0.2% potassium metabisulphite for a week and wash thoroughly	-	Blanch until soft
Mango	Peel and remove green portion (because it turns black during subsequent operations), cut fruit lengthwise into large pieces	-	-	Blanch until soft and then prick pieces
Karonda and Cherry	Cut into two pieces and remove seeds	Steep in 2% salt solution containing 600 ppm sulphur dioxide (in orm of potassium metabisulphite) for 24 ours to bleach, thereafter wash and prick with fork	-	Blanch in water containing 0.05% erythrosine and 0.25% citric acid to soften sufficiently and fix the artificial colour

Pineapple	Peel, cut into 1cm slices, remove core and eyes, prick slices on both sides	Steep in 2% salt solution for 24 hours	Wash and steep in cold water for 12 hours	Blanch until soft
Papaya	Peel, cut into rectangular pieces 4 cm long and 0.5-1.0 cm thick, remove seeds and prick	Steep in 2% salt solution for 24 hours	Wash thoroughly	Blanch until soft
Strawberry and Raspberry	Remove stems	-	-	Blanch for a minute
Petha (Ash gourd)	Cut lengthwise into large pieces, remove fluffy portion, peel, prick and cut into pieces of suitable size	Soak in dilute lime water for 24 hours to harden texture	Wash and soak in 2% alum solution for 24 hours and a wash again	Blanch (until tender) in water containing little potassium metabisulphite to bleach
Ginger	Scrape off skin from tender, fibreless, large sized rhizomes, and cut into pieces	-	-	Boil for an hour with 0.5% citric acid solution (to improve colour) in pressure cooker, then prick and wash
Carrot	From tender carrot having soft pith, scrape off thin peel and green leafy portion, prick and cut into suitable sized pieces	-	-	Blanch until soft
Citrus peel	Remove the rags from thick rind orange, citron, pummelo, etc.	Dip in 2% hot sodium bicarbonate solution for 30 minutes, then wash and prick	-	Blanch until tender and to remove bitterness

CANDIES – Glaced and Crystallized

Principles

Candy is fruit penetrated with sugar and dried to give a sugar coated solid fruit pieces. The glaced candy are coated with a thin transparent layer of heavy sugar syrup, while crystallized candy are derived from coating pure white crystallized sugar. In preparing candies all steps are same as that up preserve except that of finishing.

Fruit butters

This product is prepared by boiling the fruit pulp with or without the addition of sugar, fruit juices and spices to a semi-solid mass of homogeneous consistency. It differs from jam in being of higher concentration and finer consistency. It is usually heavily spiced. The appearance and texture look like butter. They are packed in can and sterilized in boiling water.

Fruit confections

This is a general term used to describe candies in which fruits are used. They are on the market a large number of products of the character which vary greatly in appearance, texture, flavour and the proportion of fruit used in their manufacture.

Guava jelly and cheese

Guava are available plenty and cheap during the season all over India. It is rich source of Vitamin C. You can prepare jelly and thereafter cheese from residue of fruit. Jelly is prepared from the extract of the fruit.

Recipe in cheese

Pulp 1 kg Sugar 1.25 kg Salt 3g Butter 20g	Cook sugar and pulp till it becomes very thick add salt, butter and continue cooking till it does not stick to bottom of the vessel. Smear a tea spoon of ghee on tray and spread cooked guava pulp. When it is cold roll out glass jar to make surface smooth. Next day cut into small pieces and wrap them into Butter paper.

2.2.4 Observations

Determine TSS, acidity, pectin (alcohol method/jelmeter test) and consistency of gel (sheet/flake test).

Note: The procedure for the calculation of TSS, acidity, pectin (alcohol method/jelmeter test) and consistency of gel (sheet/flake test) can be seen in the practical manual of Course III ‘Food Chemistry and Physiology’ and theory of course IV ‘Food Processing and Engineering – I’.

2.2.5 Result

Acidity of the given jam, jelly, preserve = % (w/v)

TSS of the given jam, jelly, preserve = %

2.3 PRECAUTIONS

- All equipment used in the preparation of fruit juices and squashes should be rust and acid proof.
- Copper and iron vessels should be strictly avoided as these metals react with fruit acids, and cause blackening of the product.

EXPERIMENT 3 PREPARATION OF PICKLES AND CHUTNEYS, RELISHES AND SAUCES

Structure

3.1 INTRODUCTION

Pickling is the result of fermentation by lactic acid-forming bacteria, which are generally present in large numbers on the surface of fresh vegetables and fruits. These bacteria can grow in acid medium and in the presence of 8-10 % salt solution, whereas the growth of a majority of undesirable organisms is inhibited. Lactic acid bacteria are most active at 30°C, so this temperature must be maintained as far as possible in the early stage of pickle making. When vegetables are placed in brine, the brine penetrates into the vegetable tissues and soluble material present in them diffuses into the brine by osmosis. The soluble material includes fermentable sugars and minerals. The sugars serve as food for lactic acid bacteria that in turn convert the sugars into lactic and other acids. The acid brine thus formed acts upon vegetable tissues to produce the characteristic taste and aroma of pickle. Pickles are consumed as minor item in food to make meals more a) appetizing, b) digestive, c) antiseptic due to the presence of spices, d) supplying protective food as vitamins and minerals. The commercial varieties of pickles can be divided into five classes.

1. Fermented Pickle
2. Oil Pickle
3. Acid Pickle
4. Mustard Pickle
5. Brine Pickle

Out of five classes only first four are sold in form of finished pickle where as the last one mainly brine pickle is generally not sold for consumer but is kept for further processing to make other types of pickle.

Objectives

After going through this experiment, you should be able to:

- know the pickling processes by pickling the available fruits and vegetables;
- describe the methods of chutney, relishes and sauces; and
- explain the precautions during the processes of product making.

3.2 EXPERIMENT

3.2.1 Principle

Pickles and chutneys are prepared with salt, vinegar, oil or with a mixture of salt, oil, spices and vinegar.

3.2.2 Requirements

Raw materials, equipment and apparatus

1. Fruit/vegetable, sugar
2. Peeler
3. Juicer
4. Pulper
5. Filter cloth / sieve
6. Pans of suitable size
7. Heaters
8. Thermometer
9. Crown corking / capping machine
10. Corks / caps
11. Volumetric flask
12. Measuring cylinder
13. Weighing balance
14. Potable water

Chemicals and reagents

1. Hydrochloric acid
2. Citric acid / ascorbic acid
3. Potassium metabisulphite
4. Sodium benzoate

3.2.3 Procedure

a) Pickles and its Method of Preparation

Pickles are prepared with salt, vinegar, oil or with a mixture of salt, oil, spices and vinegar. The general process for the preparation and preservation of is as under:

1. Preservation with salt

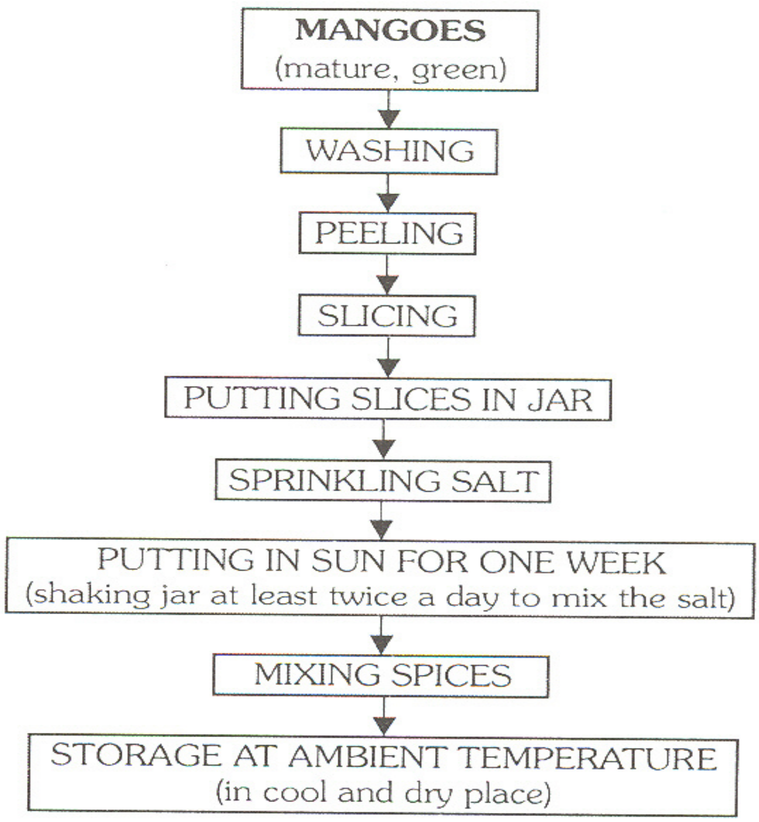
Salt improves the taste, flavour and hardness of the tissues of vegetables and controls fermentation. Salt content of 15 % or above prevents microbial spoilage. This method of preservation is generally used only for vegetables which contain very little sugar and hence sufficient lactic acid cannot be formed by fermentation to act as preservative. However, some fruits like lime, mango, etc., are also preserved with salt. The preparation of some pickles is described below:

i) Lime pickle: Lime 1 kg, salt 200 g, red chilli powder 15 g, cinnamon, cumin, cardamom (large) and black pepper (powdered) each 10 g, clove (headless) 5 numbers.

PROCESSING FLOW-SHEET FOR LIME PICKLE

ii) *Mango pickle:* Mango peeled and sliced 1 kg, salt 200 g, red chilli powder 109, asafoetida 5 g, fenugreek, black pepper, cardamom (large), cumin and cinnamon (powdered) each 109, clove (headless) 6 numbers.

PROCESSING FLOW-SHEET FOR MANGO PICKLE

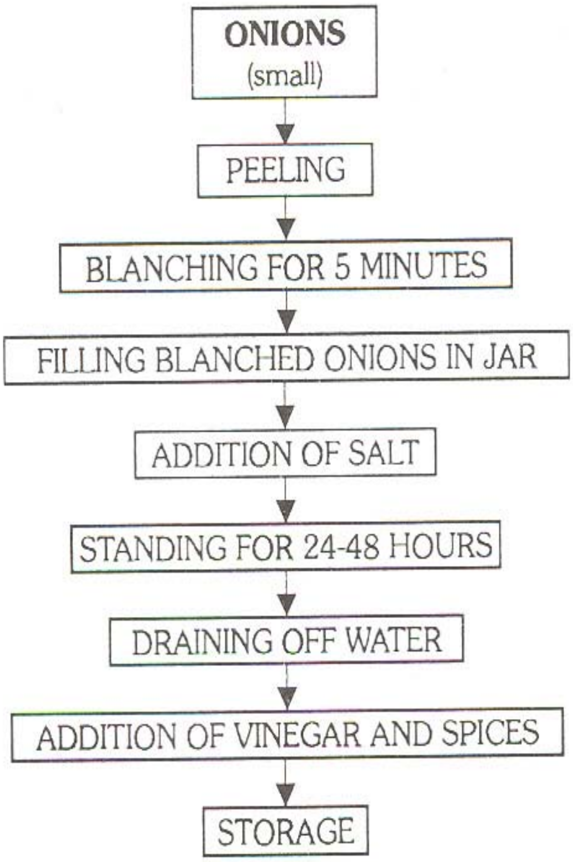


2) *Preservation with vinegar*

A number of fruits and vegetables are preserved in vinegar whose final concentration, in terms of acetic acid, in the finished pickle should not be less than 2 %. To prevent dilution of vinegar below this strength by the water liberated from the tissues, the vegetables or fruits are generally placed in strong vinegar of about 10 % strength for several days before pickling. This treatment helps to expel the gases present in the intercellular speces of vegetable tissue. Vinegar pickles are the most important pickles consumed in foreign countries. Mango, garlic, chillies, etc., are preserved as such in vinegar.

i) *Onion pickle:* Onions 1 kg, vinegar 1 litre, salt 250 g, red chilli powder 10 g, cardamom (large), black pepper, cumin (powdered) each 10 g, clove (headless) 5 numbers.

PROCESSING FLOW-SHEET FOR ONION PICKLE

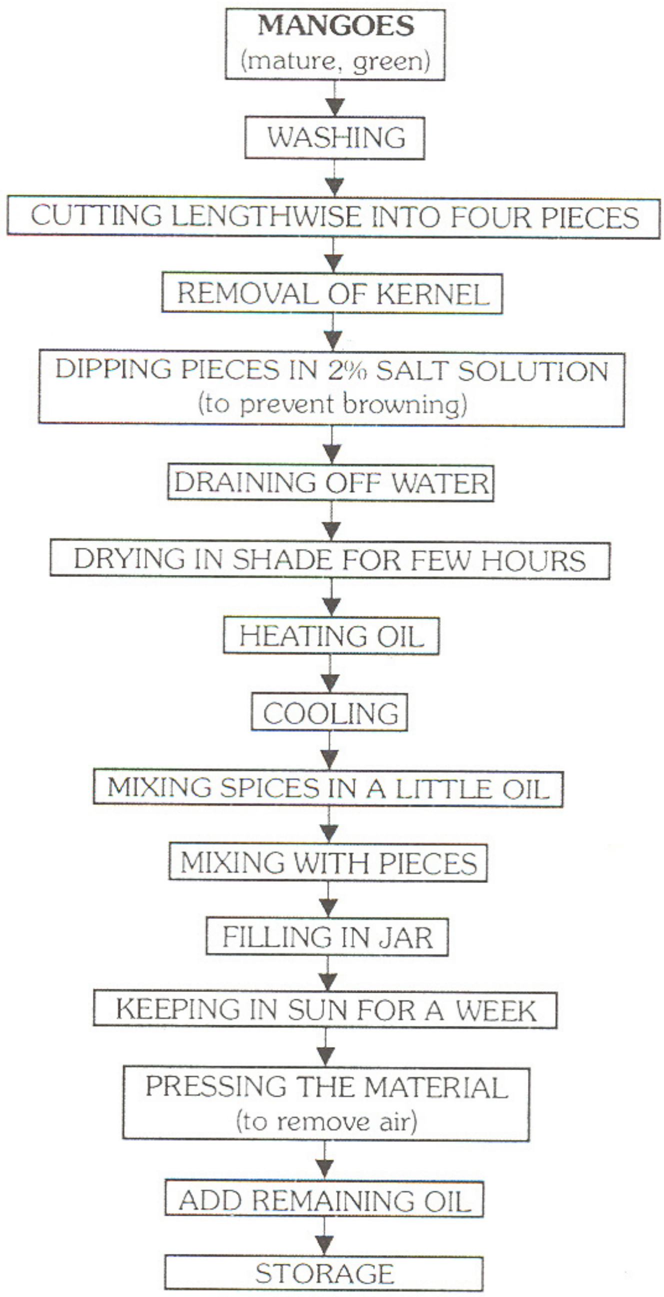


3) *Preservation with oil*

The fruits or vegetables should be completely immersed in the edible oil. Cauliflower, lime, mango and turnip pickles are the most important oil pickles.

i) *Mango pickle:* Mango pieces 1 kg, salt 150g, fenugreek (powdered) 25g, turmeric (powdered) 15 g, nigella seeds 15g, red chilli powder 10g, clove (headless) 8 numbers, black pepper, cumin, cardamom (large), aniseed (powdered) each 15g, asafoetida 2g, mustard oil 350 ml Gust sufficient to cover pieces).

PROCESSING FLOW-SHEET FOR MANGO PICKLE



b) Chutney and its Method of Preparation

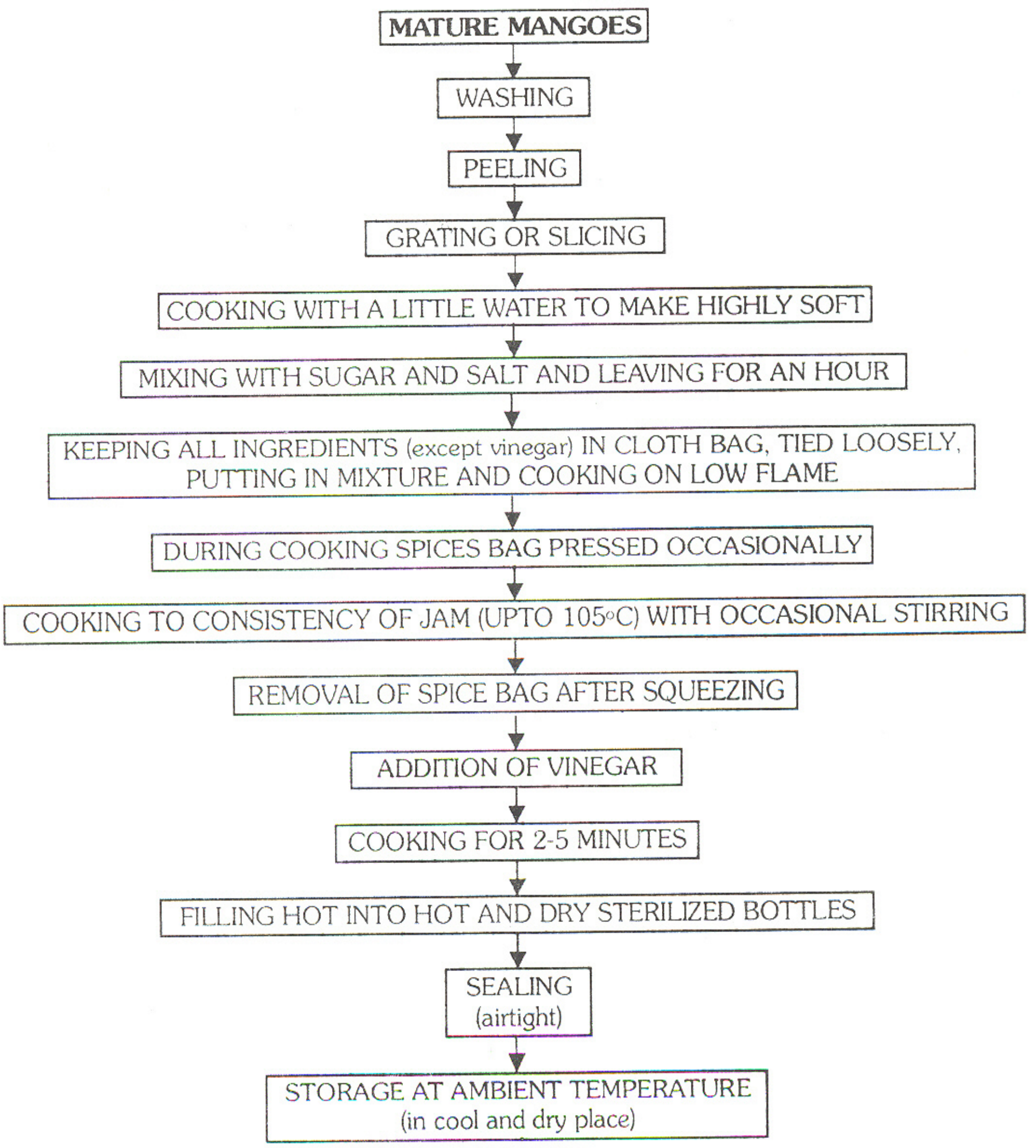
- The method of preparation of chutney is similar to that for jam except that spices, vinegar and salt are added.
- The fruits/vegetables are peeled, sliced or grated, or cut into small pieces and cooked in water until they become sufficiently soft.
- The quality of a chutney depends to a large extent on its cooking which should be done for a long time at a temperature below the boiling point.
- To ensure proper thickening, cooking is done without a lid even though this results in some loss of volatile oils from the spices.
- Chopped onion and garlic are added at the start to mellow their strong flavours. Spices are coarsely powdered before adding.

- Vinegar extract of spices may be used instead of whole spices. Spice and vinegar are added just before the final stage of cooking, because prolonged boiling causes loss of some of the essential oils of spices and of vinegar by volatilization.
- In mango and apricot sweet chutneys, where vinegar is used in large quantity, the amount of sugar added may be reduced because vinegar itself acts as a preservative.
- The chutneys are cooked to the consistency of jam to avoid fermentation. Some of the common recipes for preparation of chutney are given below.

1. *Sweet mango chutney*

   Mango slices or shreds 1 kg, sugar 1 kg, salt to taste, onions (chopped) 50g, garlic (chopped) 15g, ginger (chopped) 15g, red chilli powder 10g, black pepper, cardamom (large), cinnamon, cumin, aniseed (powdered) 10g each, clove (headless) 5 numbers and vinegar 170 ml.

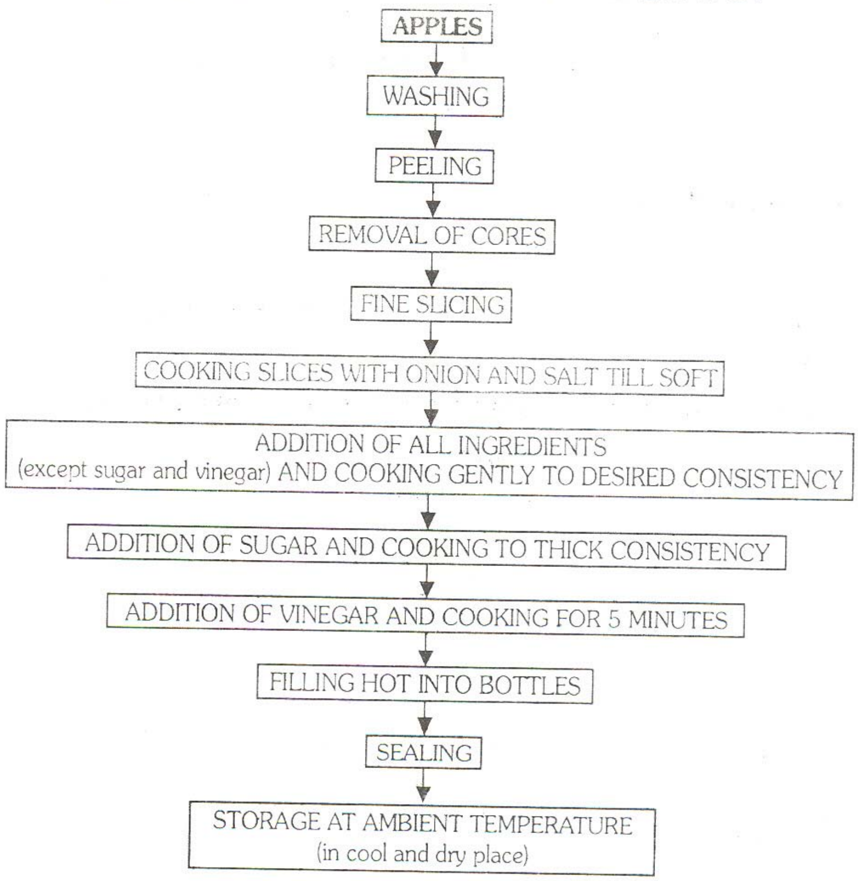
PROCESSING FLOW-SHEET FOR SWEET MANGO CHUTNEY



2. *Apple chutney*

   Apple slices 1 kg, sugar 750 g, dried dates (chopped) 100g, salt to taste, raisins 50g, ginger (chopped) 15g, red chilli powder 10g, black pepper, cardamom (large), cinnamon, cumin, aniseed (powdered) 10g each, clove (headless) 5 numbers, onions (chopped) 250g, garlic (chopped) 15g, and vinegar 200 ml.

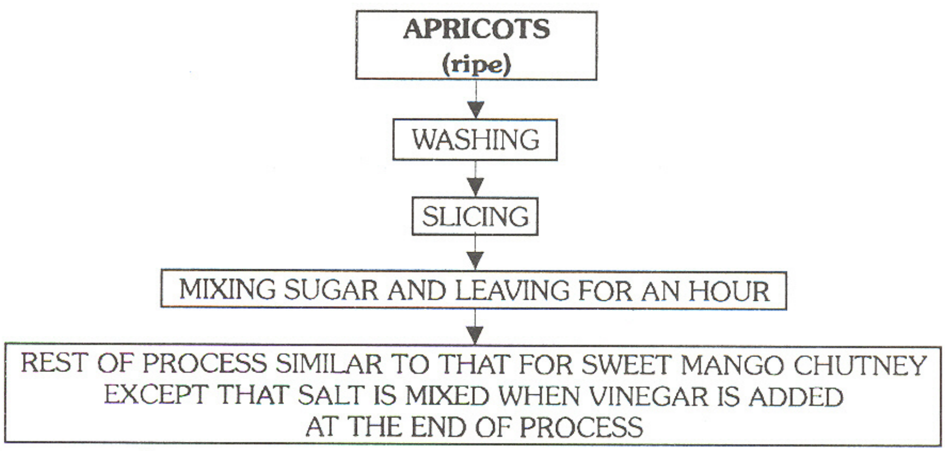
PROCESSING FLOW-SHEET FOR APPLE CHUTNEY



3. *Apricot chutney*

   Apricot slices 1 kg, sugar 1 kg, salt to taste, onions (chopped) 50g, garlic (chopped) 10g, ginger (chopped) 20g, red chilli powder 10g, black pepper, cardamom (large), cinnamon, cumin, aniseed (powdered) 10g each, clove (headless) 5 numbers and vinegar 150 ml.

PROCESSING FLOW-SHEET FOR APRICOT CHUTNEY



c) Relish

Relish is a semi solid or vinegar extract prepared by mixing fruit or vegetable pulp and used in making food more flavourful and relishing. It can also include the sauces and chutney.

In the preparation of relish mayonaise comes fore most. The next comes is mustard paste and third one is spice vinegar.

Mayonaise

Recipes	1kg Salad oil	Preparation Egg yolk and oil is beaten together and kept aside spiced vinegar is taken and mixed with the mixture of oil and egg yolk. Add sugar to the mixture. Gum tragcanth can be used as stablizer in immulsion.
	100g egg yolk	
	1 kg vinegar spiced	
	100 g sugar	
	Sod. Benzoat 200 ppm	

Mustard paste

The mustard paste is prepared by mixing mustard powder with spiced vinegar to make a smooth paste. It is preserved with 0.05% BHA and 250ppm sodium benzoat.

Spiced Vinegar is nothing but malt vinegar infused with spices and herbs. Whole spices are put in a muslin bag and suspended for 3-4 days. After that it is simmered and spiced oils are added.

d) Sauces

Sauces are made from fruit/vegetable pulps, flavoured with vinegar and spices. There are two types of sauces namely 1) Thin sauces and 2) Thick sauces.

Thin sauces: Thin sauces are those where the flavour of spices, grains fruits, vegetables are extracted in Vinegar. The most popular in this category are a) Worestershire Sauce, b) Soya Sauce, c) Walnut Ketchup.

Thick sauces: Thick sauces are those where spices, vinegar, sugar and starch are mixed with fruit and vegetable pulps. They are concentrated to desired consistency. Thick sauces are generally prepared from tomatoes or from vegetables.

Vinegar: It is one of the ingredient used in pickles its types are given in Annexure I.

3.2.4 Observation

Determine TSS, acidity and salt.

3.2.5 Result

TSS, acidity and salt = %

3.3 PRECAUTIONS

- All equipment used in the preparation of fruit juices and squashes should be rust and acid proof.
- Copper and iron vessels should be strictly avoided as these metals react with fruit acids, and cause blackening of the product.
- The spices should be free from foreign matter and microbial contamination.

EXPERIMENT 4 PRODUCTION OF TOMATO JUICE, KETCHUP, PUREE AND PASTE

Structure

4.1 INTRODUCTION

Tomato is grown in our country in abundance, both in summer and winter seasons, but those grown in winter are superior in quality because they contain more total solids. They are a good source of vitamin C. Often they are sold at distress prices during the peak harvest season and nearly 25% of the produce is spoiled due to mishandling. Such losses can be avoided by converting tomatoes into delicious products like paste, puree, juice, ketchup and sauce. This processing of tomato will not only minimize the chances of distress sale but also permit the growers/ their dependents to generate more income.

The quality of a tomato product is judged by its colour, which is dependent on the redness of the tomatoes used. In fact, the red pigment (lycopene) can be used as an index of the amount of tomato actually present in a product. High quality tomato products can be prepared only by: (i) using plant-ripened uniformly red tomatoes as the yellow and greenish portions not only mask the red colour but also cause browning due to oxidation; (ii) avoiding prolonged heating, and cooling the product quickly after preparation; and (iii) not using iron and copper equipment at any stage of processing. Lycopene (self-oxidizing isomer of carotene) turns brown when it comes into contact with iron. Iron also forms black compounds with the tannin in the tomatoes and the spices used. Equipment used should be glass-lined or made of stainless steel.

Objectives

After going through this experiment, you should be able to:

- understand the general concepts of tomato processing and those of processed products;
- know the flow charts of production methodologies; and
- explain experience in the production of tomato juice, ketchup, puree and paste.

4.2 EXPERIMENT

4.2.1 Principle

Tomato products are prepared from ripe tomatoes and preserved by chemical preservatives or by heat application.

4.2.2 Requirements

Raw materials, equipment and apparatus

1. Tomato, spices, etc.
2. Pulper
3. Filter cloth / sieve
4. Pans of suitable size
5. Heaters
6. Thermometer
7. Crown corking / capping machine
8. Corks / caps
9. Sterilizer/Pasteurizer
10. Volumetric flask
11. Measuring cylinder
12. Weighing balance
13. Potable water

Chemicals and reagents

1. Salt
2. Sugar
3. Citric acid/Vinegar
4. Spices

4.2.3 Procedure

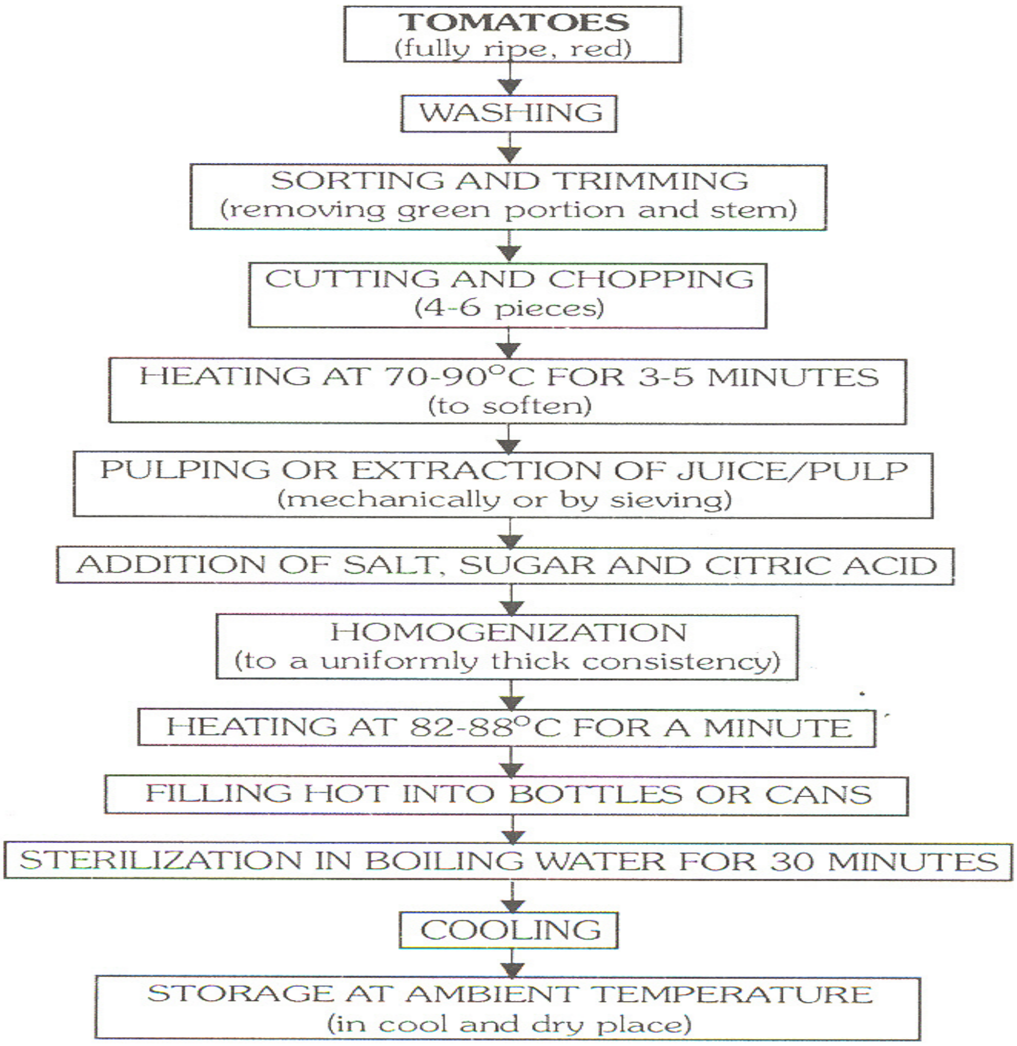
a) Tomato Juice

Plant-ripened, fully red fruits are selected, discarding all green, blemished and over-ripe fruits. A good quality juice should be of deep red colour, possess the characteristic taste and flavour of tomato, contain about 0.4 % acid (in terms of citric acid), be uniform in appearance and have high nutritive value. In addition the juice should contain 0.5% salt, and 1% sugar.

An average of 10 kg of tomatoes yields 7 litres of juice. Wash tomatoes, remove stems, and trim off bruised or discoloured portions. To prevent juice from separating, quickly cut about 0.5 kg of fruit into quarters and put directly into saucepan. Heat immediately to boiling while crushing. Continue to add and crush freshly cut tomato quarters to the boiling mixture. Make sure the mixture boils constantly and vigorously while you add the remaining tomatoes. Simmer 5 min. after you add all pieces. Press heated tomatoes through a sieve or food mill to remove skins and seeds. Heat juice again to boiling.

Hot pulping is superior to cold pulping because in the latter case, extraction of juice is somewhat difficult and its yield is less, vitamin C is oxidized more rapidly, the juice is lighter in colour and there are chances of microbial spoilage. On commercial scale, a pulper or continuous spiral press is used for juice extraction but in homes tomatoes are strained through a steel sieve. To one litre of juice add 10g of sugar, 5g of salt, 1g of citric acid and 1g of sodium benzoate. Herbs, onion, garlic, and spices may be added to meet individual's taste requirements.

PROCESSING FLOW-SHEET FOR TOMATO JUICE



b) Tomato Sauce/Ketchup

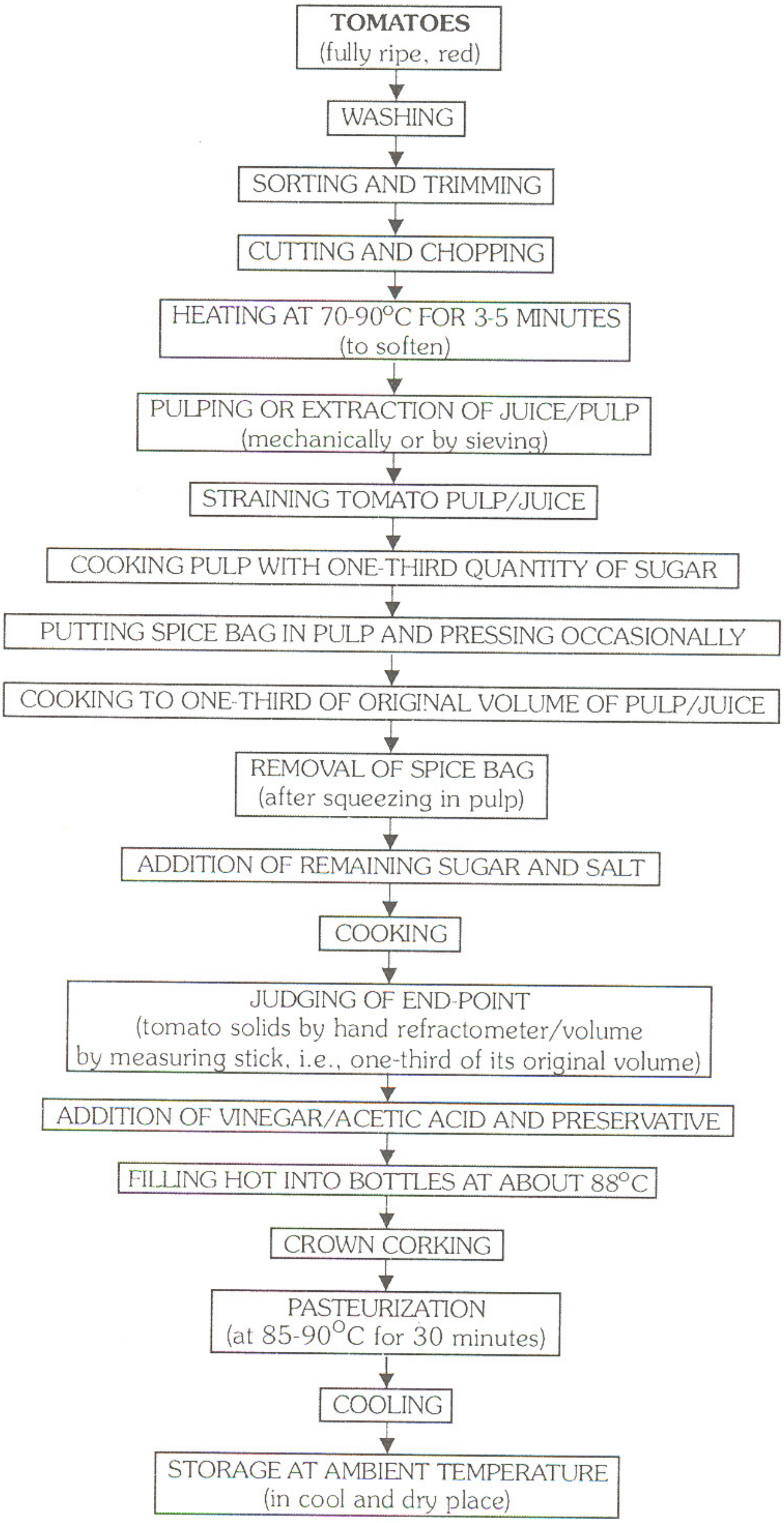
It is made from strained tomato juice or pulp and spices, salt, sugar and vinegar, with or without onion and garlic, and contains not less than 12% tomato solids and 25% total solids.

General considerations: About one-third of the sugar required is added at the time of commencement of boiling to intensify and fix the red tomato colour. If the whole quantity of sugar is added initially, the cooking time will be longer and the quality of pulp will be adversely affected. Generally, the sugar content in ketchups/sauces varies from 10-26%. On the other hand, salt bleaches the colour of the tomato product. It is, therefore, desirable to add it towards the end of the cooking process. Spices are generally added in powdered form to the product by spice bag method. Instead of whole spices, essential oils of spices, oleoresins and spice extract can also be used. Essential oils, however, do not give the characteristic true aroma of whole spice but oleoresins provide true aroma. At present, spice extract is used in many industries for sauce/ketchup preparations. These do not adversely affect the colour of the product and are generally added a few minutes before the end of cooking.

The salt content of the product should be 1.3-3.4%. Good quality vinegar is essential for the preparation of high quality sauce/ketchup. It should contain 5.0-5.5% acetic acid and should be added when the product has thickened sufficiently, so that the acid is not lost by volatilization. Tomato sauce/ ketchup generally contains 1.25-1.5% acetic acid. Sometimes glacial acetic acid (100% acetic acid) is used which is colourless and cheaper than vinegar. In order to increase the viscosity and prevent the separation of pulp form clear juice, pectin can be added to the extent of 0.1-0.2% by weight of the finished product. The ketchup should be filled hot (about 88°C) to prevent browning and loss of vitamins during subsequent storage. If it is made from tomatoes of good quality, using sugar, salt, vinegar and spices in the correct proportion, it does not spoil for a fairly long time, even after opening the sealed bottle, if the latter is kept in a cool and clean place. It is, however, advisable to add 0.025% sodium benzoate to the product before bottling and then pasteurize the bottles as a precaution against spoilage during the 3 to 4 weeks that the ketchup remains in the opened bottle before it is used up.

Recipe: Tomato pulp 1 kg, sugar 75g, salt 10g, onion (chopped) 50g, ginger (chopped) 10g, garlic (chopped) 5g, red chilli powder 5g, cinnamon, cardamom (large), aniseed, cumin, black pepper (powdered) 10g each, clove (headless) 5 numbers, vinegar 25 ml or glacial acetic acid 5 ml and sodium benzoate 0.25g per kg final product.

PROCESSING FLOW-SHEET FOR TOMATO SAUCE/KETCHUP



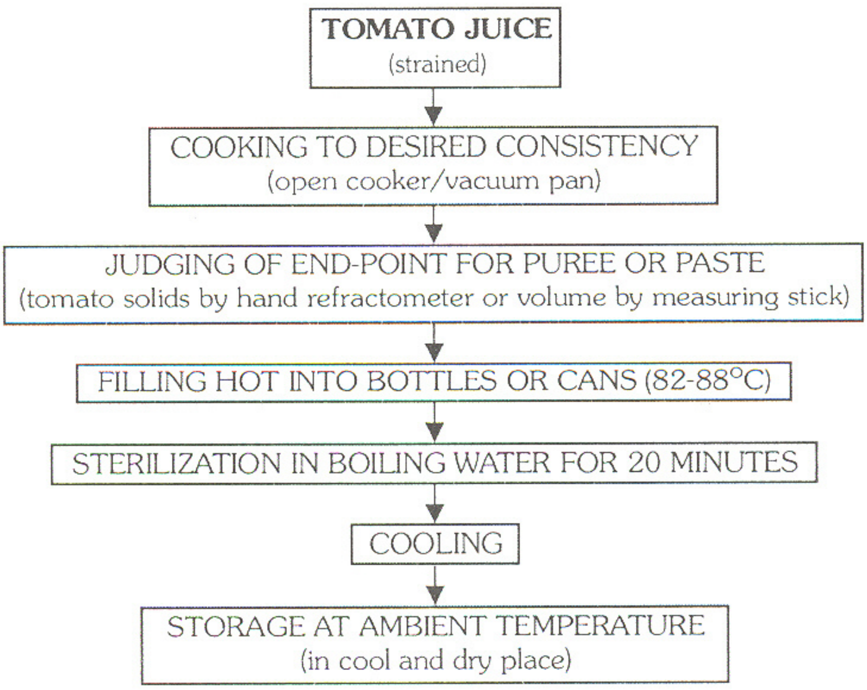
c) Tomato Puree and Paste

Concentrated tomato pulp without skin or seeds, with or without added salt, and containing not less than 9.0 % of salt-free tomato solids, is known as 'medium tomato puree'. It can be concentrated further to 'heavy tomato puree', which contains not less than 12% solids. If this is further concentrated so that it contains not less than 25% tomato solids, it is known as tomato paste. On further concentration to 33% or more of solids, it is called concentrated tomato paste.

Tomato pulp is prepared from plant ripened tomatoes in the same manner as tomato juice. Cooking for concentration of the pulp can be done either in an open cooker or a vacuum pan. In the former most of the vitamins are destroyed and the product become brown. On the other hand, use of vacuum pans, which are expensive, help to preserve the nutrients and also reduce the browning to a great extent. In vacuum pans the juice is boiled at about 71°C only. Ordinarily tomato juice can be concentrated to 14-15% solids in an open cooker, but for obtaining higher concentrations a vacuum pan is required. Moreover, sterilization of the product is also possible in a vacuum pan. While cooking in an open cooker, a little butter or edible oil is added to prevent foaming, burning and sticking.

If, after cooking, the total solids content of the juice is higher than required, more juice is added to lower it, if it is lower, cooking is continued till the desired concentration is reached. The end-point of cooking puree and paste can be determined either with a hand refractometer or by measuring the volume (a known volume of juice is concentrated to a known volume of final product) with the help of a measuring stick.

PROCESSING FLOW-SHEET FOR TOMATO PUREE/PASTE



d) Tomato Cocktail

Tomato cocktail is gaining popularity in many high class hotels and restaurants. It is prepared before serving and is also served from stock. The cocktail is preserved by pasteurizing it in bottles. The main constituent is tomato juice to which tobasco sauce, common salt, vinegar, lemon, worcestershire sauce are added in different proportions to suit the palate.

e) Chili Sauce

This is highly spiced product and is prepared from plant-ripened and peeled tomatoes. It is mostly used as a flavouring material in cooking and to some extent as a table relish also.

f) Tomato Soup

The main constituents of the soup are tomato juice, butter or cream, spices, arrowroot (a thickening agent), etc. These are added in various proportions to suit the table.

4.2.4 Observations

Determine TSS and acidity.

4.2.5 Result

Acidity of the tomato product = % (w/v)

TSS of the tomato product = %

4.3 PRECAUTIONS

- All equipment used in the preparation of fruit juices and squashes should be rust and acid proof.
- Copper and iron vessels should be strictly avoided as these metals react with fruit acids, and cause blackening of the product.
- Avoid exposure of juice to atmosphere as it will spoil the colour, taste and aroma and also reduce the Vitamin content.

EXPERIMENT 5 DRYING AND DEHYDRATION OF FRUITS AND VEGETABLES

Structure

5.1 INTRODUCTION

Dehydration is an age-old method of preservation of fruits and vegetables by removal of moisture. It is the process of removal of moisture by the application of artificial heat under controlled conditions of temperature, humidity and air flow. Various factors that affect the rate of drying of fruits and vegetables include the following:

i) Composition of raw materials
ii) Size, shape and arrangement of stacking of produce
iii) Temperature, humidity and velocity of air
iv) Pressure (barometric or under –vacuum)
v) Dehydration technique

Depending upon the type of dryers and drying environments available, the drying studies could be conducted.

The dried product could either be consumed directly or it needs to be rehydrated before use. For example, most vegetables need to be rehydrated. The practical will permit the study of rehydration behavior of the dehydrated products.

Their concentrated form, low cost, and convenient and easy transportability made dried products very popular among the armed forces.

Sun-Drying

Sun drying is practiced in tropical and sub-tropical regions where there is plenty of sunshine and almost no rain during the drying season. The equipment consist essentially of drying trays and few other items like knives, lye-bath, etc. Most of the work is done in a drying yard which is kept free from dust, flies, bus etc.

Packing and Storage

The dried products should be put into confectionary tins and sealed air-tight with tin or wax depending upon the length of the period of storage. Dried fruits and vegetables are subject to insect attack even when they have been properly dried and stored.

Sulphuring and Sulphitation

In order to obtain good results during drying and storage. Fruits are given sulphuring treatment before and sometimes after drying. In case of vegetables they are dipped in a solution of KMS (Potassium Meta bisulphite 0.1 to 0.5%) after blanching and then they are dried. This treatment will help in preventing non-enzymatic browning during storage.

Objectives

After going through this experiment, you should be able to:

- know the process of drying of fruits and vegetables; and
- demonstrate the computation of moisture content, drying rates, rehydration ratio.

5.2 EXPERIMENT

5.2.1 Principle

A sample of 'X' mass is dried to the final 'Y' mass in a period of T time.

Amount of moisture loss = X – Y

Percent moisture loss = 100 ((X – Y)/ X)
(wet basis)

Percent moisture loss = 100 ((X – Y) / Y)
(dry basis)

Rate of drying = (X – Y) /T

Dehydrated vegetables need to be rehydrated for consumption. The process of dehydration that results into highest rehydration in considered to be the best.

Rehydration ration = B/A

Where, B is the drained weight of the rehydrated sample. The initial weight of the sample is A.

5.2.2 Requirements

- Selected fruits and vegetable
- Knife
- Cutting board
- Water for washing
- Peeler
- Dry and wet bulb thermo meter
- Perforated drying trays
- Desiccators
- Petri dishes
- Weighing balance (Top pan, digital)
  - 100 g cap., 10 mg. Least Count
  - 5 kg cap., 1g least count

- Hot air oven with temperature control in the range of 50 C – 200 C.
- Selected dryers/ drying environments

5.2.3 Procedure

The steps for moisture content determination, drying experiment and rehydration experiment are being given below.

I) Moisture content determination

- Wash the fruit/vegetable and pat dry to remove surface moisture.
- Cut the fruit/vegetable into small pieces of desired size (**IS- 1708, 1734, 4332**).
- Weigh a sample of about 10 gm in a clean and dry Petri dish. (let the initial weight be X g).
- Heat the oven to the desired temperate and place the sample of fruit/vegetable for the desired time.
- Remove the sample after the desired time from the oven and place it in a desiccator till it cools down to room temperature.
- Weigh the dried sample (Let the final weight be 'Y' g).

II) Drying experiment

- Wash the fruit/vegetable to remove dust and other adhering objects. Remove surface moisture by pat drying or air jet drying.
- Cut the fruit/vegetable into small pieces of desired size using knife and cutting board.
- Spread the cut fruit/vegetable in the drying tray in a thin uniform layer.
- Note the initial weight of the tray with and without the fruit/vegetable sample.
- Place the tray in the selected drying environment (dryer).
- Weigh the tray periodically (1/6, ¼, 1/3, ½ hr, etc.) till the tray weight becomes constant.
- Note the final weight of the tray with dried fruit/vegetable.

III) Rehydration experiment

In rehydration, water is added to the product which is restored to a condition similar to that when it was fresh. The following rehydration test is used to find out the quality of the dried products.

Rehydration test

- Weigh out a sample of 35 grams from the dehydrated product.
- Put the sample into a small container (beaker) and add 275 ml of cold water (and 3.5 g salt).
- Cover the container (with a watch-glass) and bring the water to the boil.
- Boil gently for 30 minutes.

- Turn out the sample onto a white dish.
- At least two people should then examine the sample for palatability, toughness, flavour and presence or absence of bad flavours. The testers should record their results independently.
- The liquid left in the container should be examined for traces of sand/soil and other foreign matter.

Rehydration ratio

If the weight of the dehydrated sample (A) used for the test is 35g and the drained weight of the rehydrated sample (B) 210g, then

$$\text{Rehydration ratio} = \frac{B}{A} = \frac{210}{35} = 6:1$$

5.2.4 Observations

i) Moisture content determination

Weight of Petri dish. = a g.

Initial weight of Petri dish and sample = X g.

Final weight of Petri dish and sample = Y g.

ii) Drying rate

Weight of empty tray = a kg.

Initial weight of tray and the fruit/vegetable sample = X kg.

Periodic weight of tray and the fruit /vegetable sample = Y_i kg.

$i = 1,2,3,4$ time intervals

Final weight of the tray & the fruit/Vegetable = Y_f kg

Time duration of final drying = T hours.

Table 5.1: Observations for drying experiment

Sl. No.	Time	X	X−a	Drying rate (wet basis)
1.	0.0	X_0	$X_0 - a$	$(X_0 - X_{DT}) / DT$
2.	DT	X_{DT}	$X_{DT} - a$	$(X_{DT} - X_{2DT}) / DT$
3.	2DT	X_{2DT}	$X_{2DT} - a$	–
4.	–	–	–	–
5.	T-DT	$X_{(n-2)DT}$	$X_{(n-2)DT} - a$	–
6.	T	Y	Y−a	$(X_{(n-2)DT} - Y) / DT$

iii) Rehydration

Initial weight of sample to be rehydrated = A g

Final weight of the drained rehydrated sample = B g

5.2.5 Results

1. Moisture Content Determination.

   Moisture content (wet basis) = $((X-Y)/ (X-a)) \times 100$

   Moisture content (dry basis) = $((X-Y) / (Y-a)) \times 100$

2. Drying Rate

   Instantaneous drying rate is computated as given in column 5 of Table 5.1.

   Final drying rate = $(X-Y)/T$ kg/hr.

3. The rehydration ratio can be calculated as the ratio B/A

5.3 PRECAUTIONS

- All measurements of a type should be done uniformly and recorded to the same decimal point. For example, if temperatures are being measured to one decimal point, all values should be recorded to one decimal point only.
- All instruments used in the practical should be properly calibrated.
- The oven needs to be preheated to the desired temperature before the sample is put into it for moisture content determination.
- Petri dishes should be handled gently to avoid any spillage or breakage.
- The computed values need to be rounded off to just one more decimal point than that used for measurement.

EXPERIMENT 6 REPAIR AND MAINTENANCE OF MACHINES

Structure

6.1 INTRODUCTION

Good maintenance and repair procedures contribute significantly to the safety of the maintenance crew as well as that of machine operators and a reduction in the cost of production. Training and aptitude of people assigned to these jobs should make them alert for the intermittent electrical failure, the worn part, the inappropriate noise, the cracks or other signs that warn of impending breakage or that a safeguard has been damaged, altered, or removed. Sometimes all that is needed to keep things running smoothly and safely is machine lubrication or adjustment. Any damage observed or suspected should be reported to the supervisor; if the condition impairs safe operation, the machine should be out of service for repair. Safeguards that are missing, altered, or damaged also should be reported so appropriate action can be taken to insure against worker injury.

Objectives

After studying and performing these experiments, you should be able to:

- know the basic understanding of factory using the available energy utilities with emphasis on up-keep, safety and economy, organisation of the maintenance department; the staff; duties and responsibilities;
- impress upon the workers and managers in a food processing facility that prevention is better than cure;
- ascertain the practices of regular maintenance schedule along with record keeping have been introduced;
- highlight human and equipment safety concerns; and
- explain maintenance of an inventory of critical components is essential to avoid long down times.

6.2 EXPERIMENT

6.2.1 Principle

Machinery breakdowns are always costly. We must strive to avoid the breakdowns through preventive measures.

- Read the operator's manual and ensure proper installation and suggested periodic inspections.
- Maintain regular and complete schedule for greasing and lubrication.
- Ensure proper electrical connections and clean away dust and dirt in areas where connectors are located. Use compressed air instead of water to keep moisture away from the wires.
- Use the machine at its maximum performance level but not beyond it.
- Replace worn parts, and not just broken parts, to avoid frequent break-downs.
- Check for any misalignments and fix them.
- Proper storage of the machine when it is not in use by adequate cleaning and covering.
- Avoid high humidity or condensing environment during machine operation.
- Do not ignore warning signals such as low hydraulic pressure or if a shaft isn't turning on. The warning signals from the digital and analog displays must be taken seriously. Some operators not only ignore the signals but disconnect them completely to stop the signal from beeping or flashing. This too can result in breakdowns. Signals commonly disconnected include those for engine temperature, hydraulic oil, shaft speeds, or other parts that might not be turning at the correct speed.
- Provide adequate training to the machine operator (s).

6.2.2 Requirements

General hand tools required for the maintenance are as follows:

1. Set of open-ended spanners double ended.
2. Set of bihexagon ring spanners double ended.
3. Set of box/ tubular spanners.
4. Set of socket with extension and ratchet.
5. Set of screwdrivers regular and engineering pattern.
6. Set of allen key wrenches.
7. Set of pliers- combination, nose, circlip, adjustable, radio etc.
8. Set of punches.
9. Set of chisels.
10. Set of hammers.
11. Set of G-clamps.
12. Special tools, pullers etc.
13. Grease and oil guns.

6.2.3 Procedure

Daily maintenance

1. Cleaning of the machine so that there is no dirt or any other foreign material in the machine. The machine should usually be clean after the operation is over or after the day work is over. The cleaning operation should not be left over to the next working day. The cotton waste, cloth,

compressed air etc. may be used for cleaning of the processing machines and equipment.

2. Before switching on the machine inspect it externally and carry out the greasing and oiling as per manufacturers recommendation.

3. Check all the nuts and bolts and tighten them if required.

4. Check the belt tensions and adjust if required.

5. Switch on the machine and let it run idle for 5 minutes and observe the machine sound or noise. In case there is some unusual noise, identify it and take appropriate steps for repairs.

Weekly maintenance

In addition to daily maintenance check the oil levels of the various chambers and top them to required levels. Be sure that the recommended oil is used for topping the chambers.

Monthly maintenance

In addition to daily and weekly maintenance, drain the oil from the chambers, clean the chambers and refilled the oil. If the oil change is required may be done according to manufactures recommendations.

Yearly maintenance

1. In addition to daily, weekly and monthly maintenance, the cleaning of bearings and repacking of the grease may be done according to the manufacturers' recommendations.

2. The worn out nut and bolts may be replaced.

3. The belts checked and replaced if required.

4. Changing of the oil according to manufacturers recommendations. Cleaning of oil filters and replacing them if required.

5. Checking of the alignment of the machine and its adjustment if required.

6. Carrying out small repairs or replacement of worn out parts if required.

7. Carrying out all the maintenance as per manufacturers recommendations

6.2.4 Observations

It is recommended to mount a service record chart for each machine on the wall of the work area, with 10-, 50-, 100-, 250- and 500-hour maintenance intervals indicated so they can be performed regularly and the hours marked down. Recommended maintenance operations listed in the operator's manual should be attached to the chart to help operators do all required maintenance procedures.

Also useful is a large planning calendar with machine operating manuals stuck in pockets or hung in a vertical row on the left and columns for each of the months of the year to the right. Use this calendar for noting major repair and service operations to be carried out on each piece of machinery in the months.

Given below is a sample of weekly maintenance chart. Such record not only ensures daily compliance of the inspection/ maintenance work, it becomes a valuable record of the machine performance history.

Table 6.1: Weekly maintenance chart (Machine No.), Week No.
(Tick √ against the activity performed for the day)

Sl. No.	Activity	Mon	Tue	Wed	Thur	Fri	Sat	Sun
1.	Cleaning of the machine							
2.	External inspection before switching the machine							
3.	Greasing/ oiling as per manufacturer's instructions							
4.	Check all the nuts and bolts and tighten them if required							
5.	Check the belt tensions and adjust if required							
6.	Switch on the machine and let it run idle for 5 minutes and observe the machine sound or noise							
7.	check the oil levels of the various chambers and top them to required levels (**weekly**)							
Remarks								
Signatures: Operator								
Signatures: Supervisor								

A suggested service chart to be maintained in the office of the supervisor is given below:

Suggested Service Schedule Format

Service Schedule for ______________________________

Hours of Operation	HOUR METER READINGS																			
10 Hour Service																				
10 Hour Service																				
10 Hour Service																				
10 Hour Service																				
10 Hour Service																				
50 Hour Service																				
100 Hour Service																				
250 Hour Service																				
500 Hour Service																				
1000 Hour or Yearly																				

Place chart in a prominent place in the shop. Perform the required service and write down the hour meter reading. Continue down the column to the 50 hour level and move to the top of the next column after the next 10 hour interval.

6.3 PRECAUTIONS

- As a rule of thumb, spend one to two days in the slack season servicing equipment to avoid breakdowns during the service.
- Before attempting any maintenance, disconnect and lock out the machine from all of its power sources, whether the source is electrical, mechanical, pneumatic, hydraulic, or a combination of these.
- Energy accumulation devices must be "bled down." Open the circuit at the switch box and lock the switch in the "off" position.
- Notifying all affected employees (usually machine or equipment operators or users) that the machine or equipment must be shut down to perform some maintenance or servicing.
- Verifying that the machine or equipment is isolated from the energy source.
- When the servicing or maintenance is completed, inspect the machine or equipment to ensure that all guards and other safety devices are in place and functional,
- Check the area to ensure that energization and start up of the machine or equipment will not endanger employees.

- Remove the lockout devices.
- Re-energize the machine or equipment, and notify affected employees that the machine or equipment may be returned to service.
- All the right tools should be on hand and in good repair.
- Lubricating oils and other common supplies should be readily available and safely stored.
- Commonly used machine parts and hardware should be kept in stock.

ANNEXURE I

Vinegar

The name 'Vinegar' is derived from Latin word Vine-gry means wine-sour. The name itself indicates that vinegar is prepared by fermenting of wine into vinegar or alcohol into acetic acid, because during fermentation Alcohol is converted by micro-organism into acetic acid. Generally vinegar contain 4% Acetic Acid. Vinegar can be calssified into four groups according to the source of materials namely:

1. Synthetic Vinegar
2. Brewed Vinegar (Malt)
3. Spirit Vinegar
4. Distilled Vinegar

1. ***Synthetic Vinegar:*** Is self explanatory. It is prepared by diluting glacial acetic acid to 4% and colouring with suitable colour (caramel) to give appearance like brewed vinegar or natural fermented vinegar. According to FPO it must contain 4% acetic acid.

   Preparation: a) Boil water, strain and allow it to cool, b) Add acetic acid at the rate of 50ml/1Litre of water, c) Fill in bottles, cork, label and store. A little caramel colour is added to improve colour and flavour.

2. ***Brewed Vinegar:*** Is prepared by fermenting and food material which contain sugar into alcohol and from alcohol into vinegar by natural process of fermentation. It must contain minimum 3.75% acetic acid weight/volume.

3. ***Spirit – Vinegar:*** When vinegar is prepared directly from alcohol without any sugar, it is known as spirit vinegar. The source of alcohol could be any sugary material. It must also have 3.75% acetic acid.

4. ***Distilled Vinegar:*** It is colourless vinegar prepared by distilling any brewed or spirit vinegar. It must also contain 3.75% acetic acid weight/volume.

   It is easy to differentiate all the types of vinegar by analysis. Synthetic vinegar does not have any other volatile substance than acetic acid. While other three types of vinegar have volatile other than acetic acid in varying degree and from this one can easily find out whether vinegar has prepared synthetically, fermentation or distillation.

   In preparing vinegar any food containing appreciate quantity of sugar e.g. fruits and vegetables waste, dried fruits honey etc. can be used.

ANNEXURE II

Boiling Temperatures

Juice, sugar mixtures (Jam Boiling Temperature)

Boiling Point			
	Percentage sugar	At sea level	500' Above sea level
	50	216	215.2
	52	216.6	215.8
	54	217	216.2
	56	217.15	216.7
	58	218.1	217.3
	60	218.7	217.9
	62	219.4	218.6
	64	220.2	219.4
	66	221.2	220.1
Jam, Jellying Temperature	68	222.2	221.4
	70	223.5	222.7
	72	225.0	224.2
	74	226.8	226
Toffee Setting Temperature	76	229.1	228.3

Approximate Conversion of Measure

1 Tea spoon	= 5 ml
1 Table spoon	= 15 ml (3 tea spoon)
1 Oz	= 2 table spoons = 30 ml
1 Cup	= 8 oz = 230 ml
1 Soda Bottle	= 7 oz = 200 ml
1 Ketchup Bottle	= 12 oz = 350 mls
1 Sugar Bottle (big)	= 24 oz = 720 mls
1 Pint	= 568 mls
1 Litre	= 1000 mls = 7½ cups