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".

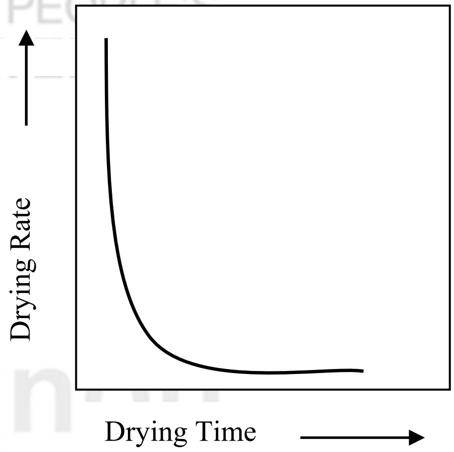
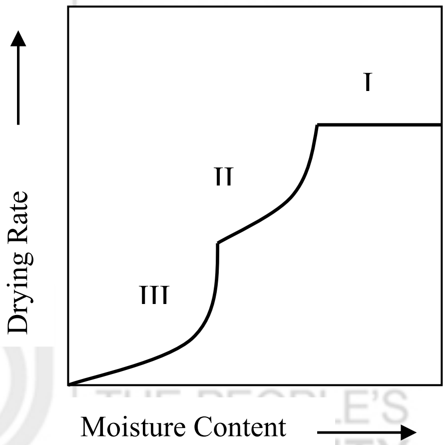


Figure 12.1: Drying time vs. drying rate

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.

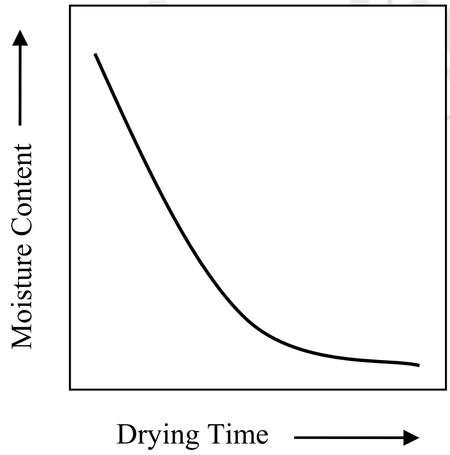


Figure 12.3: Drying time vs. moisture content

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.

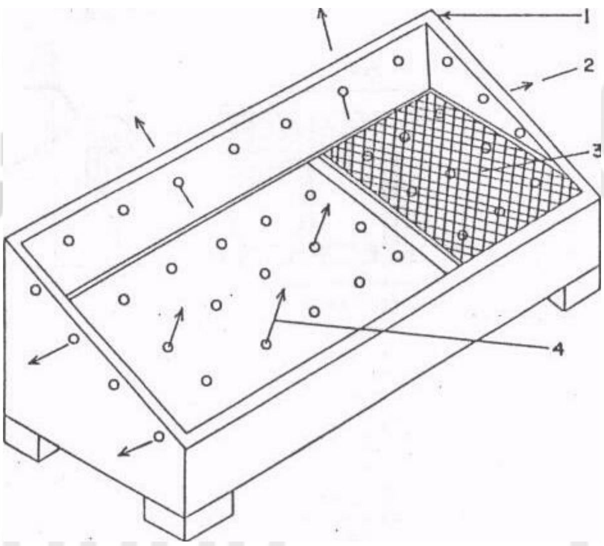

Figure 12.5: Solar cabinet driers: 1) Frame, 2) Exit air, 3) Drying tray, and 4) Air intake

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.

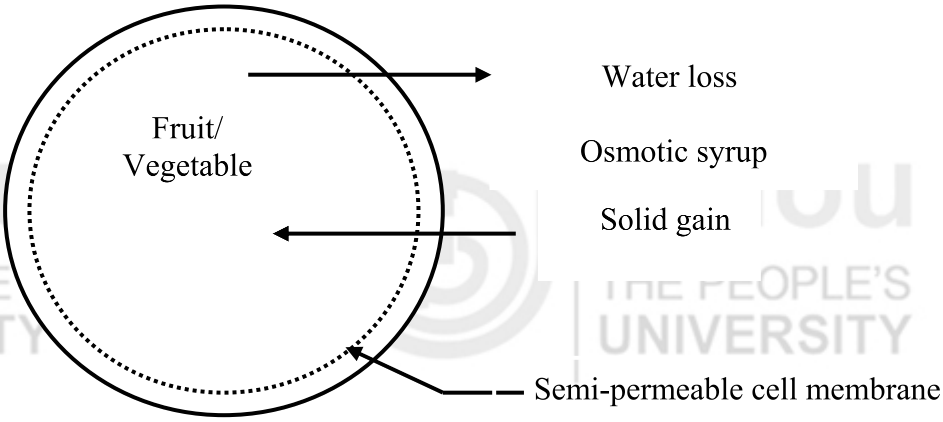

Figure 12.6: Principle of osmosis

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.

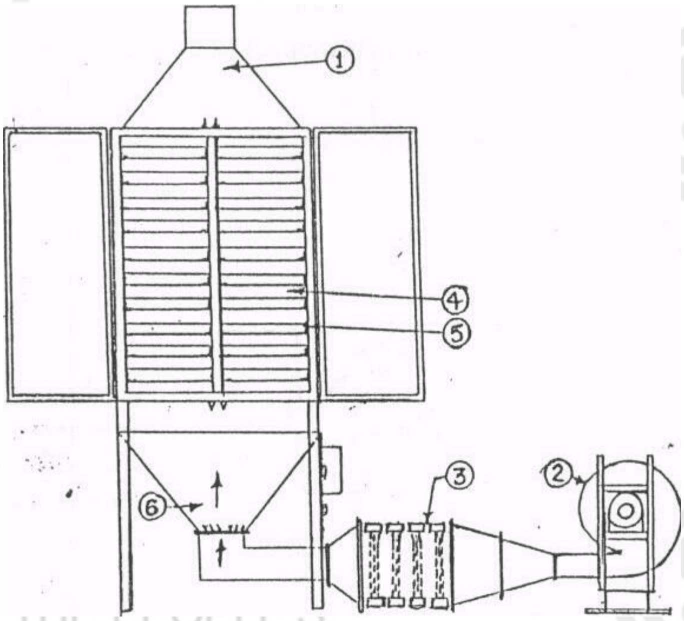

Figure 12.7: Schematic diagram of a typical tray drier: 1) Exit air, 2) Blower, 3) Heater, 4) Inter space between trays, 5) Trays, and 6) Plenum chamber

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.

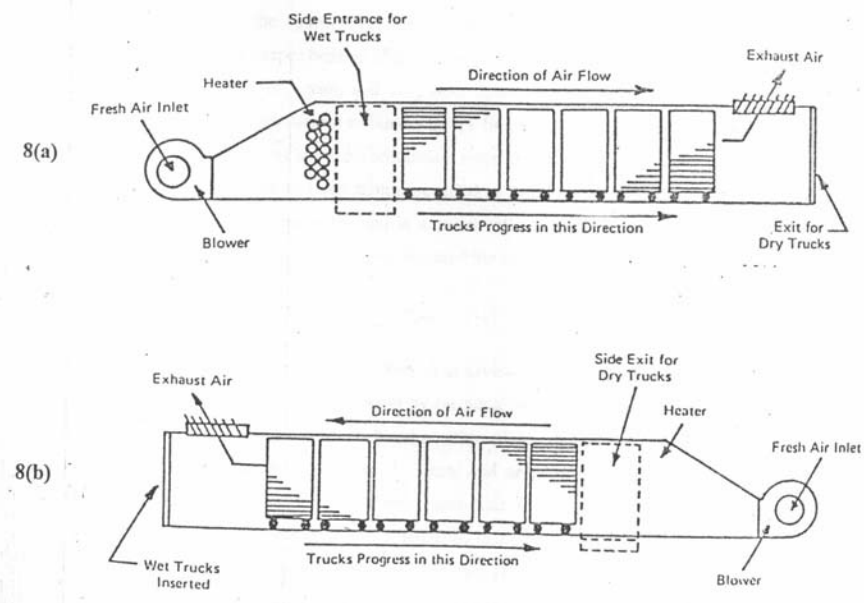

Figure 12.8: Schematic of tunnel driers: a) Concurrent flow drier, b) Counter-current flow drier

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.

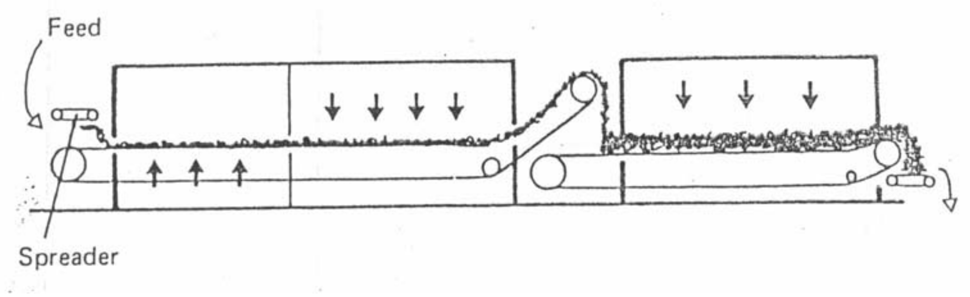

Figure 12.9: A typical two stage conveyor drier/belt drier

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.

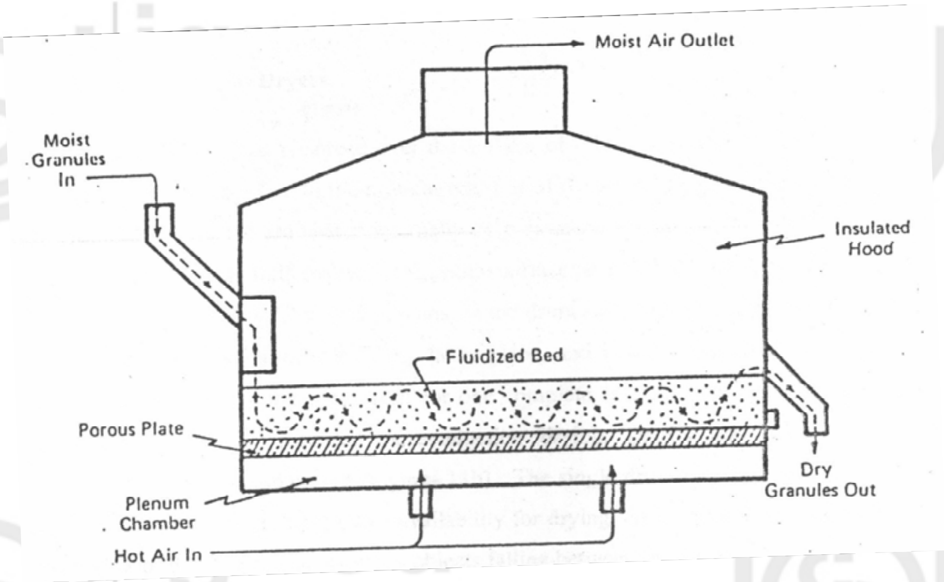

Figure 12.10: Schematic illustration of fluidized bed drier

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°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.

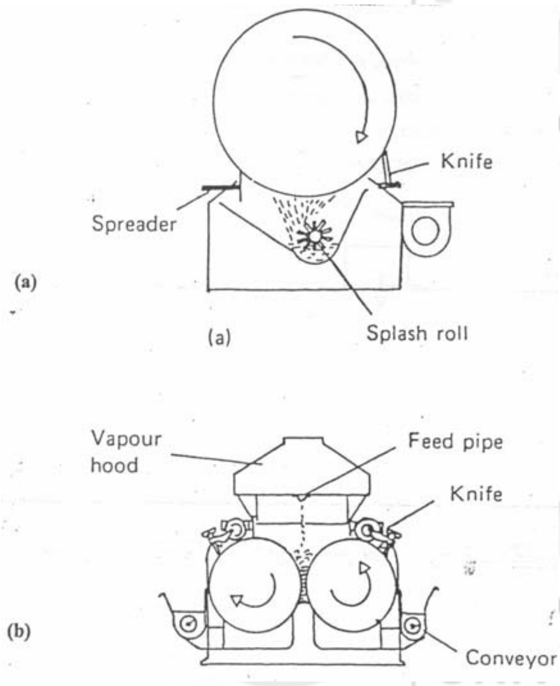

Figure 12.11: Drum driers: a) Single drum, b) Double drum

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 °C). 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.

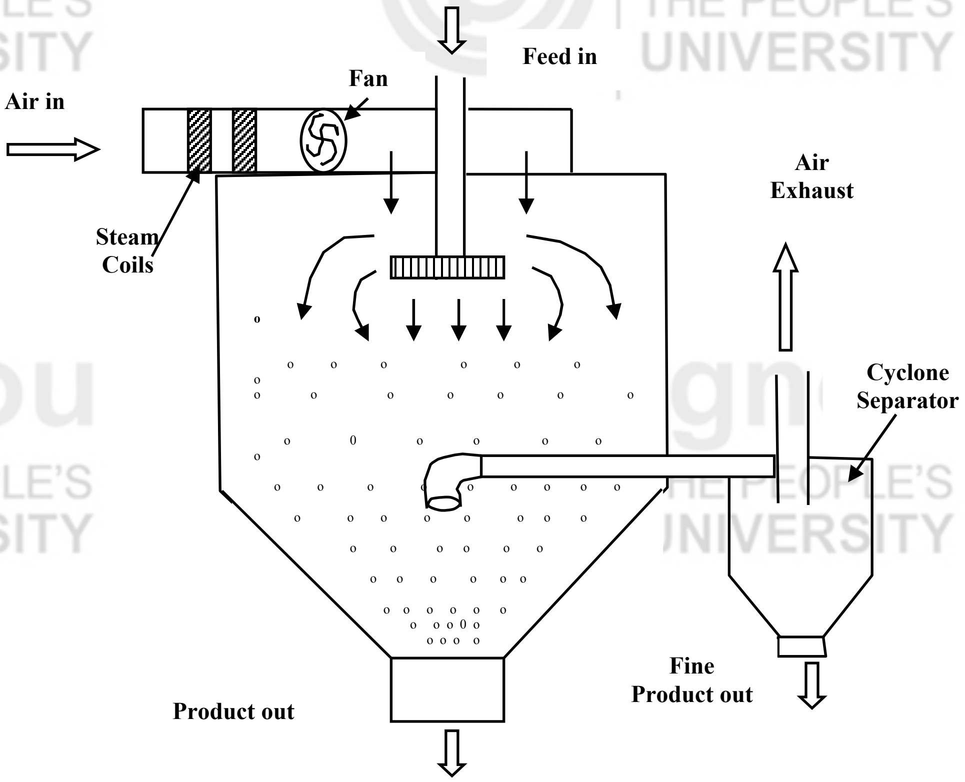

Figure 12.12: Typical schematic arrangement of a spray dryer

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.

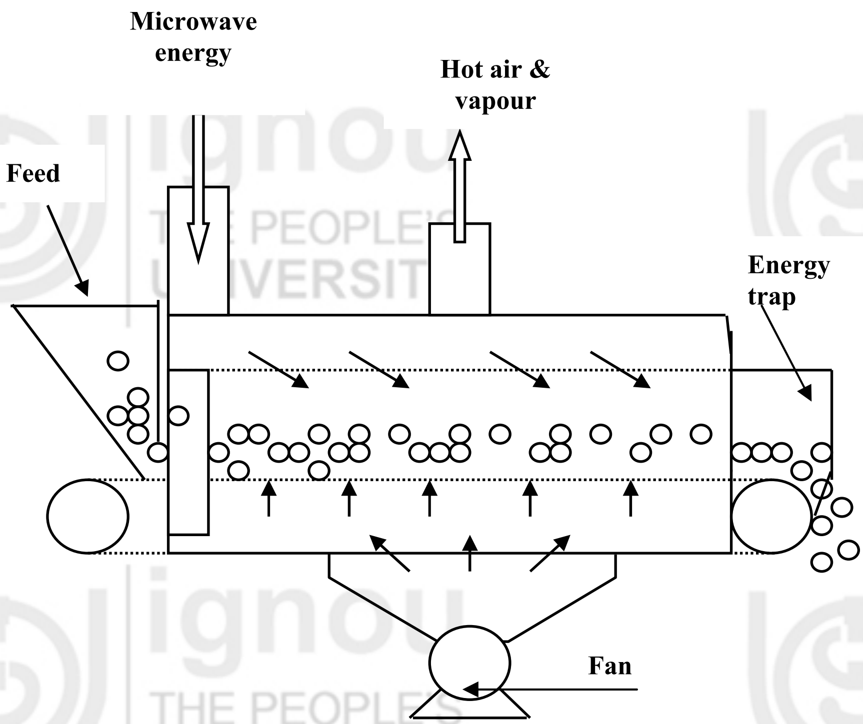

Figure 12.13: Schematic of a continuous microwave drying equipment

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).

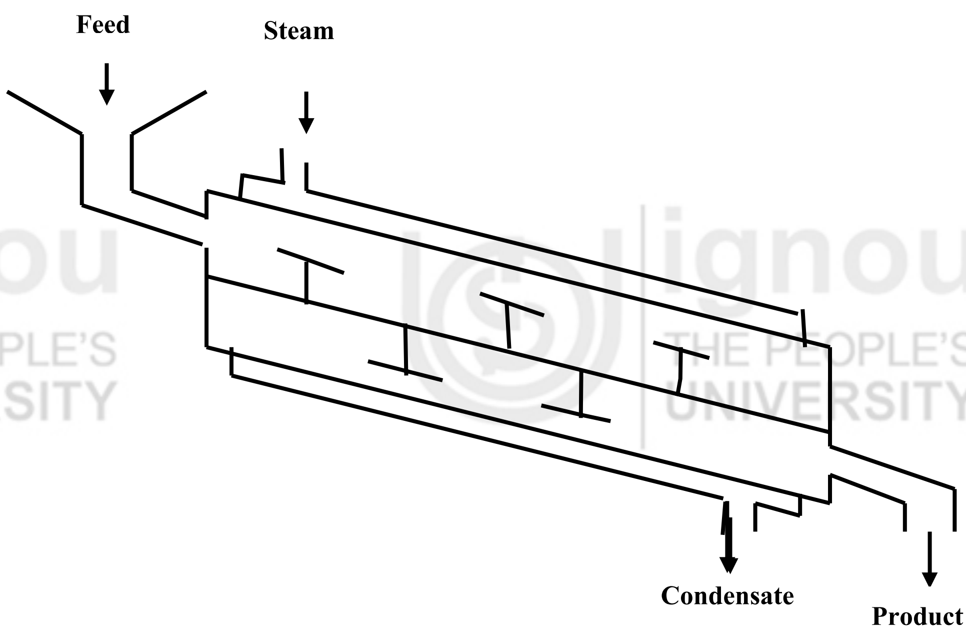

Figure 12.14: Rotary dryer

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.

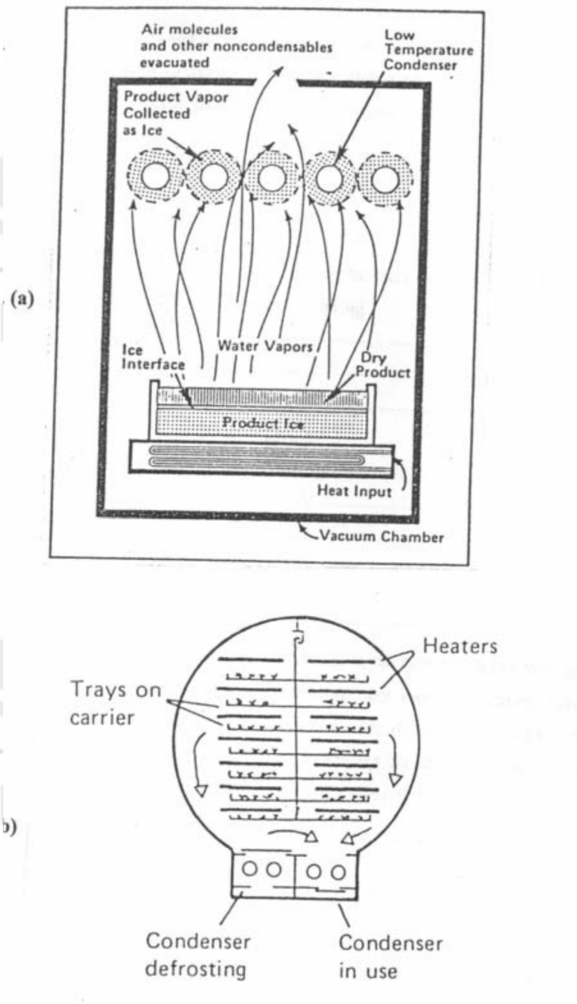

Figure 12.15: Freeze drying: a) Schematic illustration of freeze drying system; b) Cross-sectional view of a continuous freeze drier.

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^{o}C will keep for approximately one year. At 27^{o}C to 32^{o}C the food begins to deteriorate within several months. In general, for every 10^{o}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.