UNIT 5 DRYING, DEHYDRATION AND EVAPORATION

Structure

5.0 OBJECTIVES

After reading this unit, you should be able to:

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

5.1 INTRODUCTION

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

5.2 DRYING PHENOMENA

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

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

Check Your Progress Exercise 1

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

1. Differentiate between drying and dehydration.

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2. Define evaporation.

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3. What are the main objectives of drying?

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

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5.3 FACTORS AFFECTING DRYING

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

i) Temperature

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

ii) Surface area

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

iii) Air velocity

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

iv) Dryness of the air

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

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

Check Your Progress Exercise 2

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

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

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2. Describe the role of temperature in drying.

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

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4. How the product size affects the drying rate?

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5. What is the role of air in drying?

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6. Define ERH.

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5.4 DRYING AND RECONSTITUTION RATIO

5.4.1 Drying Ratio

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

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

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

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

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

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

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

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

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

5.4.2 Reconstitution Ratio

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

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

Examples of such calculations are as follows:

i) Rehydration ratio

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

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

Coefficient of rehydration

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

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

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

Per cent of water in rehydrated material

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

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

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

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

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

5.4.3 Rehydration of Dried Fruits and Vegetables

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

5.5 SPOILAGE OF DRIED FRUITS AND VEGETABLES

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

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

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

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

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

Preventive measures for spoilage

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

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

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

Check Your Progress Exercise 3

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

1. Differentiate between drying and reconstitution ratios.

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

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3. What do you mean by spoilage of food?

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5.6 DRYING METHODS AND EQUIPMENT

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

5.6.1 Hot Air Driers

i) Sun and solar drying

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

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

ii) Kiln driers

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

iii) Cabinet driers (tray driers)

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

iv) Conveyor or belt driers

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

v) Tunnel driers

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

vi) Belt though driers

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

vii) Bin driers

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

viii) Fludised bed driers

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

ix) Spray driers

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

5.6.2 Heated Surface Driers

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

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

i) Drum or roller driers

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

ii) Vacuum band and vacuum shelf driers

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

5.6.3 Freeze Drying

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

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

5.6.4 Osmotic Drying

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

5.6.5 Microwave Drying

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

5.6.6 Foam Mat Drying

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

Check Your Progress Exercise 4

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

1. What are the important methods of drying?

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2. Explain what you understand by freeze drying?

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3. What is microwave drying?

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5.7 EVAPORATION/CONCENTRATION METHOD AND EQUIPMENT

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

5.7.1 Methods of Evaporation

i) Solar evaporation

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

ii) Open kettles

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

iii) Flash evaporators

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

iv) Thin-film evaporators

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

v) Vacuum evaporators

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

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

vi) Freeze concentration

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

vii) Ultra filtration and reverse osmosis/hyper filtration

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

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

viii) Plate evaporator

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

ix) Membrane concentration

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

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

x) Centrifugal evaporators

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

5.7.2 Types of Evaporators

Several types of evaporators are used in the food industry.

i) Batch-type pan evaporator

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

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

ii) Natural circulation evaporators

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

iii) Rising-film evaporator

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

iv) Falling-film evaporator

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

v) Rising/falling-film evaporator

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

vi) Forced-circulation evaporator

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

vii) Agitated thin-film evaporator

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

Check Your Progress Exercise 5

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

1. Explain evaporation and concentration of fruit juices.

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

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

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4. What are drawbacks of centrifugal evaporator?

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5. What are types of evaporator?

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

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

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5.8 LET US SUM UP

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

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

5.9 KEY WORDS

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

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

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

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

ERH : Equilibrium relative humidity.

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

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

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

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

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

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

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

5.10 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1. Your answer should include the following points:

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

2. Your answer should include the following points:

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

3. Your answer should include the following points:

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

4. Your answer should include the following points:

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

Check Your Progress Exercise 2

1. Your answer should include the following points:

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

2. Your answer should include the following points:

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

3. Your answer should include the following points:

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

4. Your answer should include the following points:

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

5. Your answer should include the following points:

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

6. Your answer should include the following points:

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

Check Your Progress Exercise 3

1. Your answer should include the following points:

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

2. Your answer should include the following points:

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

3. Your answer should include the following points:

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

Check Your Progress Exercise 4

1. Your answer should include the following points:

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

2. Your answer should include the following points:

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

3. Your answer should include the following points:

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

Check Your Progress Exercise 5

1. Your answer should include the following points:

   - Removal of water from the liquid substances.
   - Removal of water to concentrate soluble solids.

2. Your answer should include the following points:

   - Solar evaporation is used for salt concentration.
   - Kettle evaporation is used for maple syrup.

3. Your answer should include the following points:

   - Osmosis means movement of water through a membrane from higher concentration to lower concentration.
   - Reverse osmosis means movement of water through the membrane by applying pressure on the solute side of the membrane in excesses of the osmotic pressure.

4. Your answer should include the following points:

   - Low capacity
   - High capital cost

5. Your answer should include the following points:

   - Batch type evaporator
   - Natural circulation evaporator
   - Rising film evaporator
   - Falling/film evaporator
   - Rising/falling film evaporator
   - Forced circular evaporator

6. Your answer should include the following points:

   - Falling film evaporator is used for high viscous liquids, while rising film evaporator is used for low viscous liquids.
   - High heat sensitive products are more suited to falling film evaporator while low heat sensitive products used in rising film evaporation.

7. Your answer should include the following points:

   - High capital and maintenance cost.
   - Low processing capacity.

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