UNIT 2 MOISTURE CONTENT AND EQUILIBRIUM MOISTURE CONTENT

Structure

2.0 OBJECTIVES

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

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

2.1 INTRODUCTION

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

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

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

2.2 CHEMISTRY OF WATER

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

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

2.3 PROPERTIES OF WATER

2.3.1 Specific Heat

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

2.3.2 Latent Heat

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

Latent heat of Fusion

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

Latent Heat of Vaporization

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

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

2.3.3 Vapour Pressure

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

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

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

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

2.3.4 Boiling Point

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

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

2.3.5 Water as a Dispensing Medium

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

Solution

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

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

Colloidal Dispersion

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

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

Suspension

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

2.4 TYPES OF WATER AND WATER ACTIVITY

2.4.1 Types of Water

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

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

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

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

2.4.2 Water Activity (A_w)

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

$$A_w = \frac{P_s}{P_w} \qquad (2.1)$$

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

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

Properties of Food that Control the Water Activity

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

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

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

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

where,

γ_s = surface tension of liquid in a pore,

θ = wetting angle,

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

r = capillary radius,

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

T = °K.

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

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

Check Your Progress Exercise 1

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

1. Describe the importance of water in food systems.

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2. Write short notes on the following:

a) Vapour pressure

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b) Boiling point

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3. Differentiate between the following

a) Ionic and molecular solution
b) Colloid and suspension
c) Free and bound moisture

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4. Define water activity (A_w).

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

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

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

2.6 WATER HARDNESS AND TREATMENTS

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

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

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

2.7 MOISTURE MEASUREMENT TECHNIQUES

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

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

2.7.1 Direct Methods

Air Oven Method

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

Vacuum Oven Method

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

Brown-Duvel Fractional Distillation Method

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

Infra-red Method

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

2.7.2 Indirect Methods

Electrical Resistance Method

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

Dielectric Method

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

Chemical Method

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

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

2.8 EMC AND ITS RELEVANCE TO FOOD PRESERVATION

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

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

2.8.1 Importance of EMC

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

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

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

iii) EMC helps to determine drying characteristics.

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

2.8.2 Hysteresis Effect

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

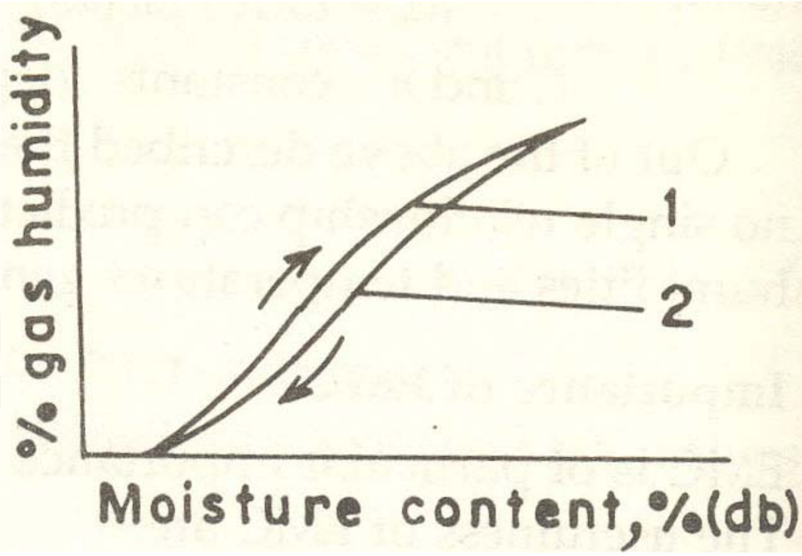

Figure 2.1: Hysteresis effect: 1) Adsorption EMC curve, 2) Desorption EMC curve

2.9 EMC DETERMINATION METHODS

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

2.9.1 Static Method

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

2.9.2 Dynamic Method

Desorption Method

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

Isotenoscopic Method

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

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

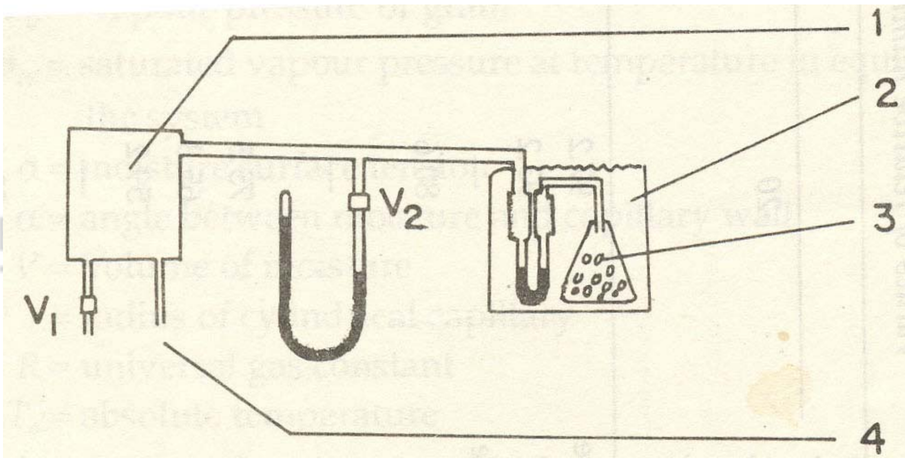

Figure 2.2: Schematic diagram of an isotenoscope: 1) Vacuum storage jar, 2) Constant temperature water bath, 3) Sample flask and 4) Vacuum pump

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Check Your Progress Exercise 2

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

1. What is hardness of water and how can it be removed?

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2. Define EMC and hysteresis.

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

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2.10 LET US SUM UP

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

2.11 KEY WORDS

Moisture content	:	It indicates the amount of free moisture in any material.
Water activity	:	Water activity or A_w, is a ratio of the vapour pressure of water in a solution (P_s) as compared to the vapour pressure of pure water (P_w) at a given temperature.
Hygroscopicity	:	It is the property of gaining or loosing of moisture (due to vapour pressure difference) as per the atmospheric conditions.
Specific heat	:	Specific heat is the energy required to raise the temperature of unit quantity of water by unit temperature and is the same whether heating water or ice.
Latent heat of fusion	:	It is the energy required to convert unit quantity of ice to water at freezing point and the unit is J/g of ice at the freezing point.
Colloidal dispersion	:	Molecules that are too big to form true solutions can be dispersed in water, depending on their size and the mixture is called as colloidal dispersion.
Suspension	:	Particles that are larger than 100 nm are too large to form a colloidal dispersion. Those form a suspension when mixed with water. The suspended particles settles down if the suspension is left undisturbed.
Free water	:	Water that can be extracted easily from foods by squeezing, or cutting or pressing.
Bound water	:	Water that cannot be extracted easily is termed bound water.
Entrapped water	:	Water bound by food constituents so that they cannot be easily removed and they do not behave like liquid water.
EMC	:	The moisture content attained by foods with respect to the set of atmospheric temperature and relative humidity
Hysteresis	:	The difference between the adsorption and desorption EMC at any given temperature and relative humidity.
Isotenoscope	:	Equipment used for measuring dynamic EMC

2.12 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

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

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

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

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

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

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

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

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

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

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

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

Check Your Progress Exercise 2

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

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

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

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

3. Different moisture measurement techniques are:

   Direct methods:

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

   Indirect methods:

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

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

4. Different EMC measurement techniques are:

   i) Static method
   ii) Dynamic method

      a) Desorption method
      b) Isotenoscopic method

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

2.13 SOME USEFUL BOOKS

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

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