Consortium for Educational Communication

Module on

Basic Concepts Of Dehydration Of Foods

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Text

Basic terminology in dehydration:

There are some terms that need to be understood in order to understand the process of dehydration. These include:

1. **Moisture sorption isotherm:**

The moisture sorption isotherm of a food material is a curve obtained by plotting its moisture content (usually expressed as mass of water per unit mass of dry material) versus the water activity of the vapour space surrounding the material, or the percent equilibrium relative humidity in the environment at constant temperature (Figure 1).

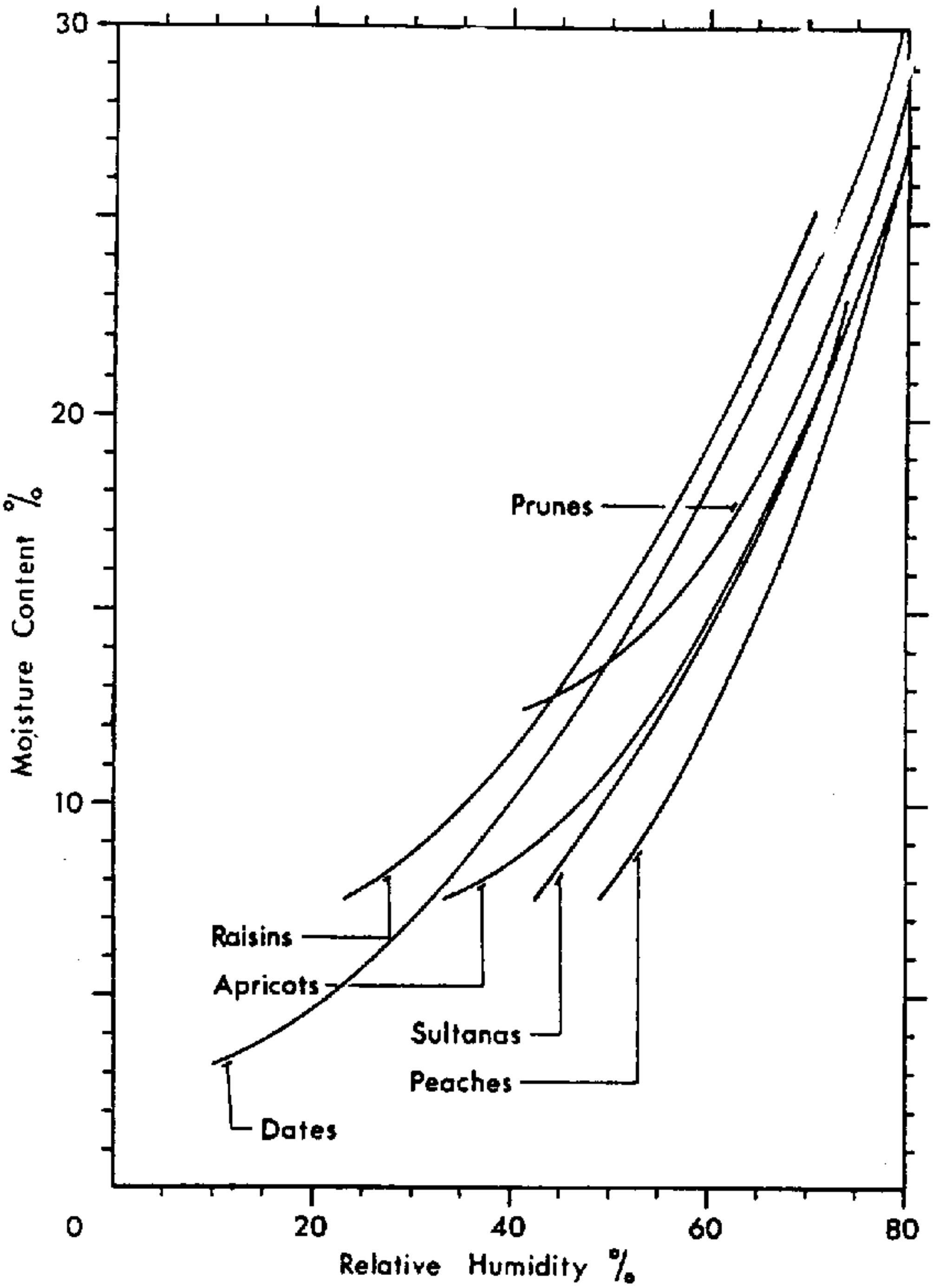

Figure 1: Moisture sorption isotherms for various dried fruits at 25°C

According to the adsorption isotherm classification of Brunauer, Emmett and Teller made in 1938, food materials usually present Type II isotherms which are manifested by a nonlinear, sigmoidal curve or Type III behaviour which is manifested by a concave shape (as shown in figure 2). The later is, however, the characteristic pertaining to foods rich in soluble components. Brunauer classified adsorption isotherms into five types (Figure 2) based on their shape where Type I is Langmuir and Type II is the sigmoid shape. No special names were given for Type III, IV and V.

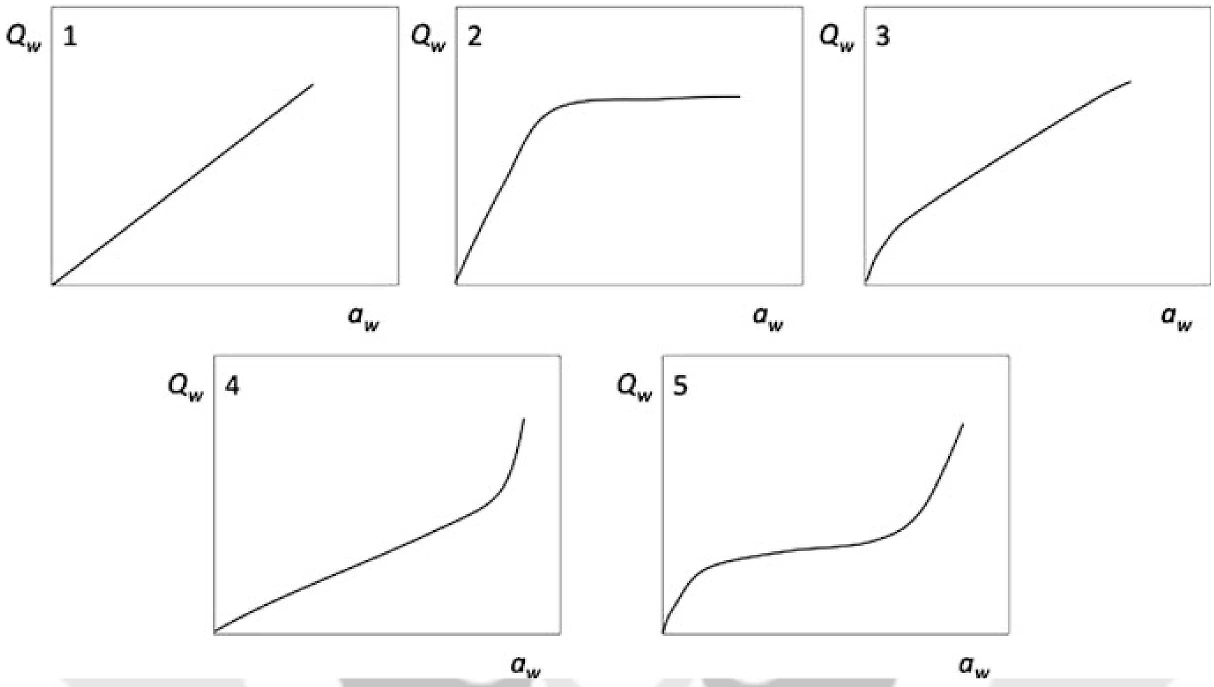

Figure 2: Types of isotherms described by Brunauer

2. **BET monolayer model:**

For better interpretation, moisture sorption isotherm in Figure1 may be divided into three regions. In region I, water is slightly bound to the polar sites of food material via the different interactions like water-ion, dipole-dipole and hydrophobic. Thus, it is the proportion of water in foods that is most strongly sorbed, least mobile, and unfreezable even at temperatures as low as -40 ^{o}C. It is unavailable for chemical and microbial reactions, and has an enthalpy of vaporization greater than that of pure water. In boundary regions I and II, water is considered to form a monolayer over each accessible highly polar group of dry food called “BET monolayer”. Region

II corresponds to the adsorption of additional layers over the monolayer, mainly by hydrogen bonding to neighbouring water molecules and solute molecules. This water is less firmly bonded than the first layer, slightly less mobile than bulk water, and available to dissolve solutes. In addition, it may take part in accelerating the rate of many chemical reactions although most of it is unfreezable at -40 ^{o}C. This water has a plasticizing action on glassy solutes, lowering their glass transition temperature and swelling the solid matrix.

Water at the beginning of region III is enough to complete a monolayer hydration shell for the macromolecules. As water content increases, molecular solubility and reaction rates significantly increase, and viscosity decreases. This water is freezable, available for chemical reactions and for the growth of micro-organisms within the food. It exhibits the properties comparable to those of the free water. Basically, it is held in the voids, crevices and pores of the material by physical forces related to surface tension. In high moisture foods, water in region III or “free” water constitutes more than 95 percent of the total water content, while water in regions I and II or “bound” water accounts for less than 5 percent of the total water content.

3. **Water activity (a_w):**

Water is known as most important and abundant substance on the earth and one of the most important components in foods and human body. The amount of water in food and agricultural products affects the quality and perishability of these products. However, perishability is not directly related to moisture content. In fact, perishability varies greatly among products with the same moisture content. A much better indicator of perishability is the availability of water in the product to support degradation activities such as microbial action. The term water activity is widely used in the food industry as an indicator of water available in a product. The term 'availability' of water is a measure of how 'freely' water molecules participate in chemical reactions or how easily water molecules diffuse to the site where chemical reaction is taking place and participate in it.

Mathematically, water activity is given by the ratio of fugacity of water in the system (i.e the escaping tendency of water from solution) to the fugacity of pure water, i.e.,

$$a_w =$$

Where, 'f' is the fugacity of water in the system and 'f_o' is the fugacity of pure water. At low pressure, the difference between f/f_o and p/p_o (the ratio of partial pressure of water in the food to that of the partial pressure of pure water) is less than 1 percent and are tending to equality, i. e.,

$$a_w =$$

Where 'p' is the vapour pressure of water in the substance, and 'p_0' is the vapour pressure of pure water at the same temperature.

4. **Psychrometry:**

Hot air is used both to supply the heat for evaporation and to carry away the evaporated moisture from the product. However, the notable exceptions are freeze and vacuum dryers, which are used almost exclusively for drying heat-sensitive products because they tend to be significantly more expensive than dryers that operate near to atmospheric pressure. Psychrometry or hygrometry is used to describe the field of engineering concerned with the determination of physical and thermodynamic properties of such gas-vapour mixtures.

5. **Dew point temperature:**

The temperature at which a given unsaturated air-vapour mixture becomes saturated is called dew point temperature. Any further decrease in this temperature from this point leads to the condensation of water from the air.

6. **Dry bulb temperature:**

Temperature measured by a (dry) thermometer immersed in vapour-gas mixture is called dry bulb temperature.

7. **Wet bulb temperature:**

If the thermometer is surrounded by a wet cloth, heat is removed by the evaporation of the water of the cloth. As a result, the temperature of the thermometer falls. This (lowered) temperature is called wet bulb temperature.

Mechanism of drying:

Hot dry air is used for commencing dehydration. Heat from the dry air is absorbed by the food which provides the moisture content present in it the latent heat of vaporization. The moisture begins to evaporate from the surface of the food. It develops the vapour pressure gradient between the interior of the food and its exterior surface. This gradient acts as a driving force for the removal of the moisture content from the food to a greater extent. The removal of moisture content from the food follows a series of drying rates i.e.,

- Constant rate period.
- Falling rate period.

Under constant drying conditions, the drying period during which evaporation rate per unit drying area remains constant is called constant rate period. Heat is transferred convectively from the warm air to the cooler wet surface through the boundary layer at the interface that induces evaporation. Mathematically, the equations for heat and mass transfer for this process can be given as under:

For heat transfer:

$$q = hA\,(Ta - Ts)$$

For mass transfer:

$$-\,dW/dt = kg\,A(ps - pa) = kg\,A(Hs - Ha)$$

Where:

$- dW/dt$ = rate of water transfer, $kg.s^{-1}$

h =coefficient of convective heat transfer, $w.m^{-2}.K^{-1}$

K_g and K'_g = coefficients of convective mass transfer, $kg.m^{-2},s^{-1}, Pa^{-1}$ and $kg.m^{-2}\,s^{-1}$ respectively

A =area of active transfer, m^2

p_a and p_s =partial pressure of water vapor in the air and on the wet surface respectively,

Ha and Hs = humidity in the air and on the wet surface, respectively (dimensionless).

Constant rate period is observed in foods in which the moisture content is greater than critical moisture content. Critical moisture content is that moisture content at which the drying rate first begins to drop under constant drying conditions. Below the critical moisture content, the rate of water transfer from the interior of the product to its surface decreases continuously, decreasing the drying rate of the foods. When the supply of water to the surface drops below the rate of evaporation, the moisture content of the surface begins to decrease rapidly. As a result the product becomes drier. Since the surface of the food is no longer water saturated, the temperature of the food rises during the falling rate period and approaches asymptotically the dry bulb temperature of the air. From that moment, internal transport of moisture content and not the evaporation becomes the rate limiting factor and the falling rate period begins. Theoretically, drying stops (i.e. the drying rate becomes zero) when the moisture content everywhere in the food has been reduced to the equilibrium moisture content. Figure-3 given below gives a representation of constant and falling rate period.

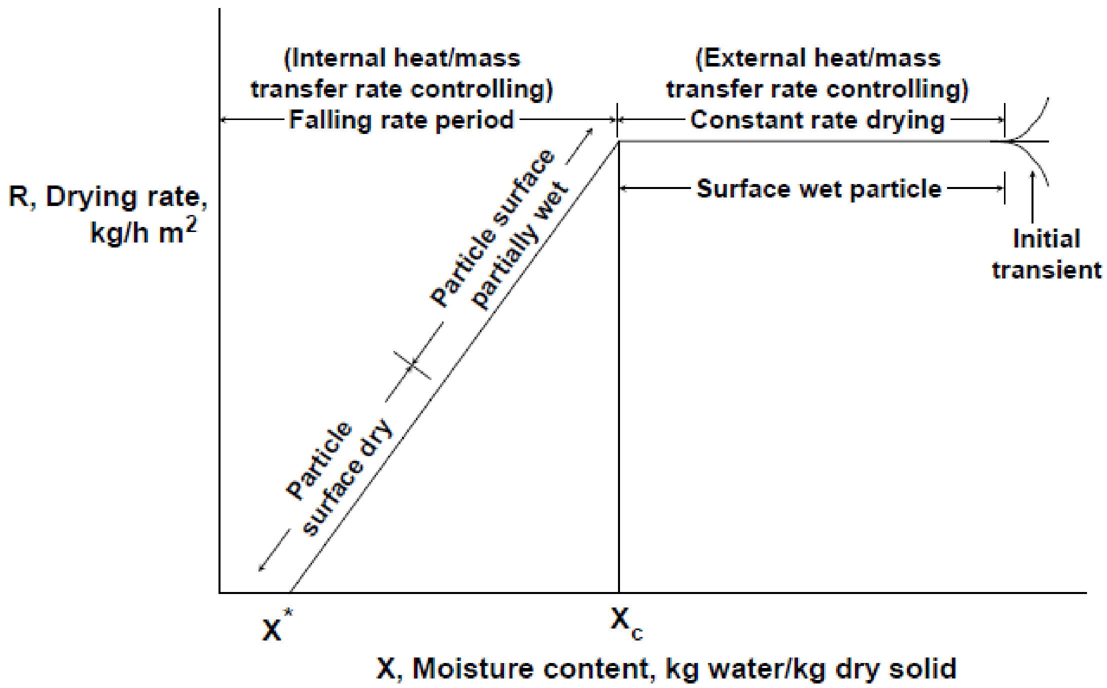

Figure 3: Constant and falling rate curves of the foods during dehydration

Factors affecting rate of drying:

Factors affecting the rate of drying vary with the type of drying system used depending upon weather the drying is commenced using heated surfaces or hot dry air. As the later is used in most of the equipments available for carrying out the process of dehydration, the factors that affect the rate of drying of foods using hot dry air are listed below:

- **Temperature:** The temperature of the drying air is one of the most important factors for the drying. The higher the temperature of the drying air, more is the rate of heat transfer and more is the rate of drying. The ideal temperature for drying or dehydrating foods is 60-70 ^{o}C. The use of higher temperatures, however may lead to cooking of foods rather than drying.

- **Humidity:** The moisture content already carried by the air used as a drying medium has an impact on the rate of drying. The lesser the humidity of the air, more is its capacity to carry the moisture content evaporated from the food.

- **Air velocity:** The velocity (or speed) at which the hot air moves over the product to be dehydrated influences the rate of dehydration as it forms a boundary layer near the surface of the food that hampers the rate of heat as well as mass transfer. The higher the velocity of the air, smaller is the thickness of this barrier layer and lesser is the hindrance to the heat and mass transfer. Further, the velocity of the air must be sufficiently high to evaporate the moisture from the surface of the food in the dryer and sweep this moisture-rich air out of the drying space (dryer).

- **Type and size of food:** The rate of drying also depends upon the type and size of the foods as there are the natural differences in the extent of moisture content present in them. Besides the differences in the moisture content of different foods, the transfer of moisture from the interior towards the external surface occurs quickly in some foods than others. Further, the foods with a lesser thickness of slices dry rapidly as compared to those with greater thickness. This is because in the former, moisture content takes lesser time to migrate from inner most layers towards periphery from where the evaporation occurs.

Methods of drying:

Foods may be sun-dried with or without a solar dehydrator, or dried in a gas or electric oven or with a portable electric dehydrator. Unlike sun drying, dehydrators are not affected by weather conditions and allow better control over food quality than sun-drying does. A brief description of some of the methods of dehydration is given as under:

- **Sun drying:**

Sun drying is usually used in case of fruits due to their high sugar and acid content which makes them safe for this process. Vegetables (with the exception of vine-dried beans) and meats are not recommended for sun drying. It is best to dry meats and vegetables indoors using the controlled conditions of an oven or food dehydrator. Drying the fruits on hot, dry and breezy days with a minimum temperature of 85ºF is normally optimum for this process. However, the hotter the day the better is it for the dehydration operation. Relative humidity should be below 60 percent. As the weather is uncontrollable, sun drying the fruits can be risky and it can take several days to complete the process. Often ideal conditions are not available when the fruit ripens and an alternative method of drying the food is needed. Sun-dried fruit must be covered or brought under shelter at night. Cool night air condenses, adding moisture back to the food, thus slowing the drying process. In actual practice, prepared foods are placed on drying trays that are usually made up of stainless steel screening or a thin wood lath. The trays are placed away from dusty roads and yards and kept elevated at about 1 inch above the table with spools or bricks to allow good air circulation below the food. It is covered with a muslin or cheesecloth tent to protect from insects. Fruit is dried in direct sunlight and trays are moved periodically to ensure direct sun exposure.

- **Bin Drying**

Bin drying systems are common in on-farm grain drying operations. The bin is filled with grain and drying air is forced up through the grain from a plenum chamber beneath the perforated floor of the bin. The grain on the bottom is dried first. As drying progresses a layer of drying grain separates the dried grain from the undried grain. This region of drying grain is called a drying front. This drying front progresses upward through the bin of grain until all grain is dried. Figure-4 given below shows a representation of this process.

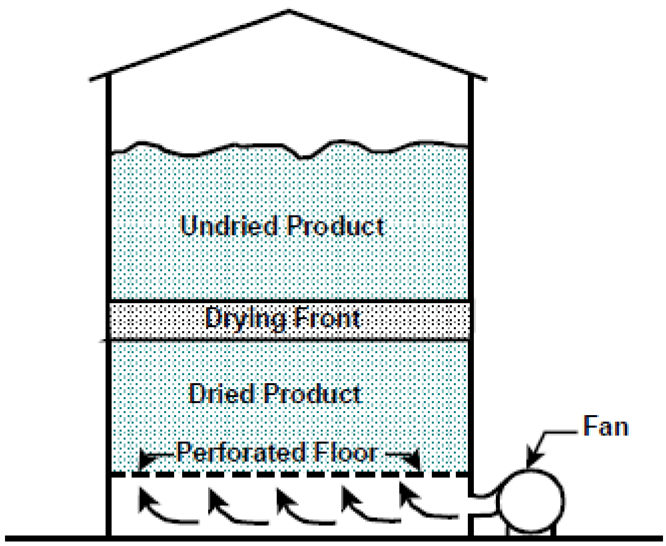

Figure 4: Bin drying diagram showing the drying front after half of the product is already dried.

- **Cabinet Drying**

Cabinet dryers are usually small, insulated units with a heater, circulating fan, and shelves to hold the product to be dried. The small dehydration units sold for home use are small-scale examples of this type of dryer. Figure-5 shows the basic operation of a cabinet dryer with recirculation.

- **Tunnel Drying**

Tunnel dryers are a large-scale modification of the cabinet dryer concept. The drying chamber is a tunnel with multiple carts containing trays of the product being dried. New carts of the undried product are loaded at one end of the tunnel as carts of dried product are removed from the other end. Air flow in these dryers may be parallel or counter to the movement of carts in the tunnel.

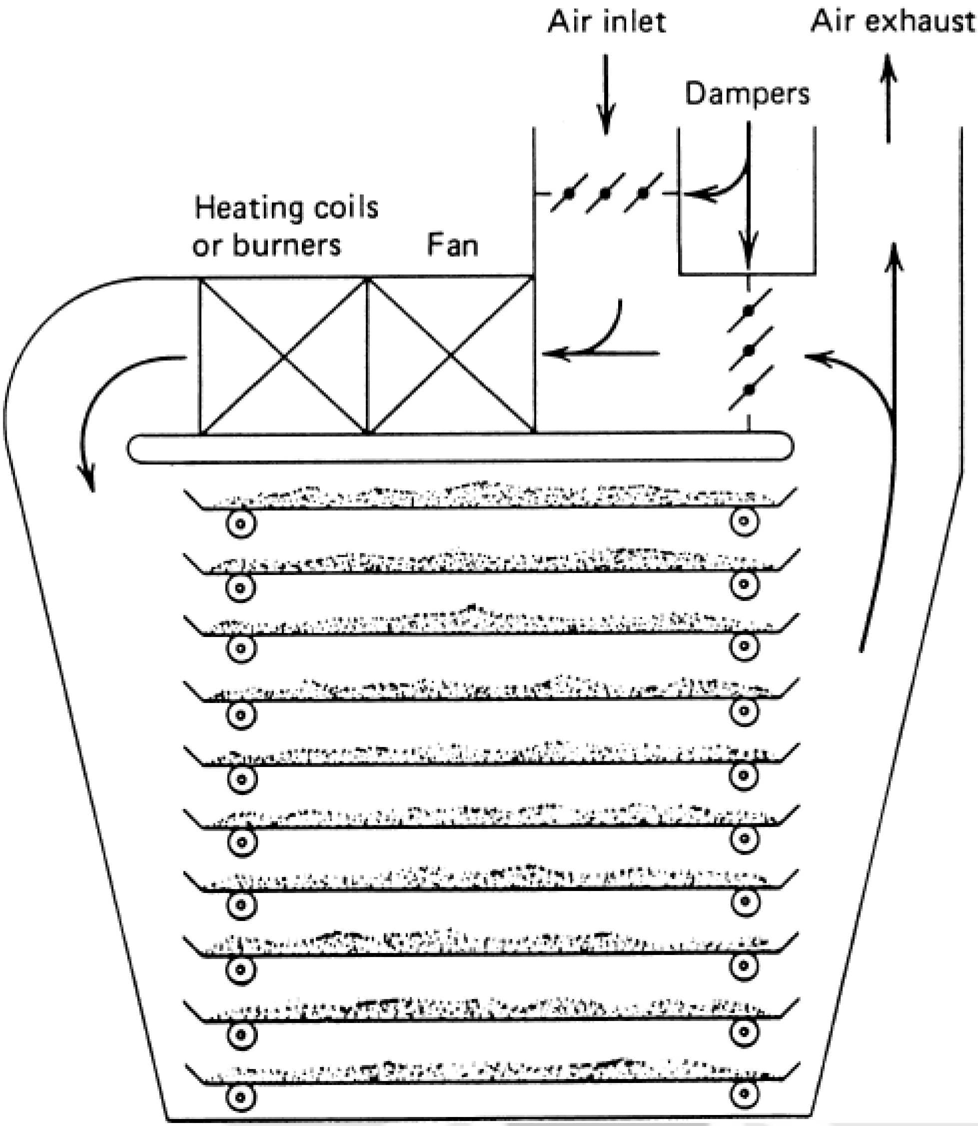

Figure 5: Representation of a cabinet dryer.

- **Drum Drying**

Large rotating drums are used for drying slurries (liquids with high solids content). A thin film of the slurry is deposited on the bottom of a rotating drum as it passes through the slurry. The slowly rotating drum is heated and sometimes held under a vacuum. The dried product is scraped from the drum before the rotating surface re-enters the slurry.

- **Other drying techniques:**

Numerous other air drying techniques are also used. The major function of all such systems is to move air over the product in such a manner that the product is dried as economically as possible without damage.

Effect of dehydration on foods:

Consumer demand has increased for processed products that keep more of their original characteristics. In industrial terms, this requires the development of operations that minimize the adverse effects of processing. The effect of food processing on finished product quality ultimately determines the usefulness and commercial viability of that unit process operation. In the case of food drying operation, several changes are noted in the dehydrated products that affect their quality. These include loss of volatiles and flavours, changes in the colour and texture, decrease in nutritional value, residual enzyme activity and microbial activity in dried foods. These not only affect the quality but also the shelf life of the final product. Some important changes in the food article during the process of dehydration include:

- **Browning reactions:**

  These include enzymatic and non-enzymatic browning reactions. Browning is considered to be desirable if it enhances the appearance and flavour of some food products in terms of tradition and consumer acceptance as in case of coffee, maple syrup, beer, and in toasting of bread. However, in many other instances, such as fruits, vegetables, frozen and dehydrated foods, browning is undesirable as it results in off-flavours and colours. Another significant effect of browning is the lowering of the nutritive value of the food article. Rate of browning reactions depends on temperature of drying, pH and moisture content of the product, time of heat treatment, and the concentration and nature of the reactants. Rate increases with increasing temperature, and the increase is faster in systems high in sugar content.

- **Lipid oxidation**

Lipid oxidation is responsible for rancidity, development of off-flavours, and the loss of fat soluble vitamins and pigments in many foods, especially when dehydrated. Factors that affect the oxidation rate include moisture content, type of substrate (fatty acid), extent of reaction, oxygen content, temperature, presence of metals, presence of natural antioxidants, enzyme activity, ultraviolet light, protein content, free amino acid content and other chemical reactions. Moisture plays an important part in the rate of oxidation. The elimination of oxygen from foods can reduce oxidation, but the oxygen concentration must be very low to have an effect.

- **Colour loss**

Drying changes the surface characteristics of food and hence alters the reflectivity and colour. Carotenoids are fat soluble pigments present in green leaves and, red and yellow vegetables. Chemical changes to carotoneoid 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.

- **Aroma loss**

There is often decrease in the quality of the dried products because most conventional techniques use high temperatures during the drying process. Processing may also introduce undesirable changes in appearance and will cause modification of the natural "balanced" flavour and colour. Heat treatment of fruits and vegetables often reduces the number of original volatile flavour compounds, while introducing additional volatile flavour compounds through the autoxidation of unsaturated fatty acids and thermal decomposition, and/or initiation of Maillard reactions. This highly affects the sensory attributes of the dehydrated product.

- **Nutrient losses**

In drying, a food loses its moisture content, which results in increasing the concentration of nutrients in the remaining mass. Proteins, fats, and carbohydrates are present in larger amounts per unit weight in dried foods than in their fresh counterpart. In fruits and vegetables, losses in nutritional attributes during preparation usually exceed those caused by the drying operation. The water-soluble vitamins can be expected to be partially oxidized and are diminished during blanching and enzyme inactivation.

- **Changes in texture:**

Many drying techniques or pre-treatments given to food before drying are aimed at making the structure more porous so as to facilitate mass transfer thereby speeding up the drying rate. Porous sponge-like structures are excellent insulating bodies and generally will slow down the rate of heat transfer into the food. Porosity may be developed by creating steam pressure within the product and a case hardened surface through rapid drying. On the other hand, as moisture is removed from fruits or vegetables, their cellular structure begins to collapse and the cells become smaller. The result of this is the shrinking of the product as it dries.