INTRODUCTION & REVIEW OF LITERATURE
1. INTRODUCTION AND REVIEW OF LITERATURE

1.1. History of Drying

Preservation of foods by drying is one of the oldest methods practiced by man. The early man mainly depended on nature as a means of drying foods to sufficiently low moisture to preserve them. Preservation of vegetables, fruits and meat by drying was in vogue, even during the Biblical times. Samples of, dried foods have been discovered even in 4000 years old settlements in Jericho and Egyptian tombs. Sun drying has been widely practised in India since ancient times. Drying, which depends on natural conditions, yields an inferior quality product, because of the variations in the weather conditions and inability to control the same. In order to avoid these difficulties dehydration equipments and methods were developed. In 1795 a hot air dehydration room was invented and by the end of the 19th century varieties of driers had been developed to dehydrate a variety of foods.

For the past 100 years the mechanism of drying has been the subject of many scientific studies. The out break of the First World War gave impetus to the studies on drying mechanism and since then a considerable amount of research has been conducted in this area as well as the production of dehydrated foods.

In the Second World War dehydrated foods, particularly dehydrated vegetables, meat and meat products gained considerable popularity due to several logistic advantages like saving in storage space, transport,
convenience and utility. After World War II food dehydration industry expanded greatly and reliable quicker dehydration methods were developed. By the end of 19th century, these innovations were gradually adopted by the industry for production of dehydrated foods. Today dehydrated foods are being produced and marketed for the general public and still continue to be an important consideration in military food supplies and use.

Drying is a complex process involving simultaneous heat and mass transfer accompanied by various physical and structural changes. The heat raises the vapour pressure of the water present in food material and helps in its evaporation from the surface. Surface water thus removed is replaced with water from within by diffusion or capillary movement. In case of diffusion mechanism the driving force is concentration gradient, as a result of either liquid or vapour movement.

Osmotic pressure is the main force for water movement in the liquid diffusion mechanism. In capillary mechanism the moisture moves due to surface tension. Based on the above principle two types of dryers have been designed and fabricated, mainly direct and indirect heated ones. In, direct heated dryers, hot gas are passed through or around the product to be dried. The heat in the gas provides latent heat of evaporation for water present in the food material and cooled gas conveys the vapour away from the product. In, indirect driers either the steam heats the air or electrical energy is used to supply the required heat of evaporation by radiation, conduction, convection or a combination there of. Water may also be removed from the solid food
products by means of mechanical force through pressing/compressing or centrifugal force. This is known as mechanical dewatering. Normally this technique is used as a pre-processing step before thermal drying. In this technique quality of the final product is affected due to the loss of soluble solids.

1.2. Classification of Drying

Drying processes are broadly classified on the basis of water removal mechanism:

- Thermal drying
- Osmotic dehydration
- Mechanical dewatering

1.3. Thermal Drying

In thermal drying a gaseous or void medium is used to remove water from the material. When hot air is blown over a wet food, heat is transferred to the surface and latent heat of vaporisation cause water to evaporate, water vapour diffuses through a peripheral film of air and is carried away by the moving air. This creates a region of lower water vapour pressure at the surface of the food and water vapour pressure gradient is established between the moist interior of the food and the dry air. This gradient provides the driving force for water movement from the food to the surface through liquid movement, by capillary force, or by diffusion. Thermal drying is divided further depending upon the mode of drying:

- Air drying
- Low air environment drying
- Modified atmosphere drying
1.3.1. Air Drying

Conventional air-drying is one of the most frequently used operations for food dehydration. The drying parameters, usually examined for food quality mainly depend on the temperature, relative humidity as well as velocity of air. Further the mechanisms of moisture transfer depend mainly on the type or physical state of food material and the drying process.

There are many types of air driers used in the dehydration of foods. The type selected being governed by the nature of the commodity to be dried, the desired form of the finished product, and labour and operating conditions.

1.3.2. Cabinet Dryers

Cabinet dryers are highly suitable for drying fruits and vegetables. This type of dryers consists of an insulated cabinet fitted with shallow mesh or perforated trays, each of which contain food product to be dried. Hot air is circulated through the cabinet at 0.5 – 5 m s\(^{-1}\) per square meter tray area. A system of ducts and baffles is used to direct air over and/or through each tray, to promote uniform air distribution. Heaters are placed above or alongside, the trays to increase the rate of drying. This type of driers is used for small or for pilot scale production. They have low capital and maintenance costs but have relatively poor control and produces more variable product quality.
1.3.3. Solar Drying

Both solar and sun drying are simple, in-expensive technologies, in terms of both capital input and operating costs. Apart from this energy inputs and skilled labour are not required. This technique of drying food products is the most widely practised for agricultural products like food grains and fruits. The main drawback of this technique is requirements of large surface area, chances of uncontrolled drying and cross contamination Cohen (1994).

1.3.4. Bin Dryers

This type of drier is used to remove the final moisture content from the food materials after initial drying being carried out using other drying techniques. These driers have a high capacities and low capital and running cost. Bin driers are cylindrical or rectangular in shape, fitted with a mesh base. Hot air is passed through a bed of food at relatively low speed of 0.5m$^3$ s$^{-1}$ per square metre of the bin area.

1.3.5. Conveyor Driers

In this type of drier food is dried on a mesh belt in beds of 5 – 15 cm deep. The airflow is initially directed upwards through a bed of the food and then downward in later stages to prevent dried food from blowing out of the bed. These types of driers have control over drying conditions and high production rates (yields). Generally foods are dried to 10 – 15 % moisture content and then transferred to bin driers for finishing.
1.3.6. Fluidised Bed Driers

These types of driers are used mainly for final drying of foods. The drier consists of a suitably housed, porous refractory plate. The hot gas is introduced from the bottom of a preloaded cylindrical bed of porous refractory plate, causing the food to become suspended and vigorously agitated. The air thus acts as both the drying and the fluidising medium, exposing the maximum surface area of the food for drying. The direction of movement of food particles resembles the convection currents observed when a container of water is heated from the bottom. The material thus behaves like a liquid and is discharged over a weir at the outlet of the dryer.

1.3.7. Kiln Driers

These are sometimes called as evaporators and used mainly for drying apples and hops. This type of driers consists of two-storey arrangement, the lower floor or cellar being provided with a stove or furnace and a fume pipe. The heating pipes of the furnace are arranged so that the warm air is equally distributed underneath the ceiling of the cellar. The ceiling consists of narrow slats and the air passes between the slats into the first floor. The material to be dried is spread evenly to a depth of 4 to 8 inches on the slatted floor. To facilitate air movement, intake ducts are cut into the lower part of the cellar walls on the first floor. The saturated air is passed out leaving the dried product. This type of drying, takes long time and there is only limited control possible over drying conditions. Apart from this high labour costs are incurred due to the necessity to turn the product regularly.
because of manual loading and unloading. However the driers have a large capacity and are easily constructed and can be maintained at low cost.

1.3.8. Pneumatic Driers

This type of drier is mainly used to dehydrate powdered or particulate foods in continuous vertical or horizontal metal ducts. A cyclone separator is used to remove the dried products. The moist food with usually less than 40 % moisture is metered into the ducting and suspended in air. The air flow is adjusted to distribute the particles in such away that lighter and smaller particles dry more rapidly than heavier and wetter ones. The dried particles are carried to a cyclone by air current. Air current pneumatic drier have relatively low capital cost, high drying rates as well as close control over drying conditions and are thermally effective. Mainly this type of driers are used after spray drying to bring down the moisture content to safe and less than the levels presented in milk powder, egg powder and potato granules.

1.3.9. Rotary Driers

This method of drying is generally suitable for foods that tend to mat or stick together in belt or tray driers. They consist of slightly inclined rotating metal cylinder fitted internally with flights to cause the food to cascade through a stream of hot air as it moves through the drier. Airflow is adjusted parallel to agitate the food. This creates large surface area for drying, resulting in uniform drying at a rate faster than other drying techniques.
1.3.10. Spray Drier

This type of drying is highly suitable for non-fibrous liquid foods like solutions, suspensions, slurries or sludges. The fluid that is to be dried is first atomised by pumping it through either a nozzle or a rotary atomizer into a gaseous heating medium such as air. The air transmits its heat to the individual particles of spray, and the moisture is evaporated instantaneously leaving behind the solids as a powder floating in the air stream. The method of atomising mainly depends on the type of food material to be dried. The purpose of atomising the liquid foods is to obtain a mist of the material. The position of the atomiser may be at the top, middle or bottom of the drying chamber. Seltzer and Settelmeyer (1949) have classified all spray driers into five principal categories, in accordance with the direction of spray, dispersal and relative direction of the drying air as:

- Horizontal co-current
- Simple vertical – downward co-current
- Complex vertical-downward co-current
- Vertical upward-current and vertical counter current. All of these have their own advantages and disadvantages.

The dry powder is collected at the base of the drier and removed by a screw conveyor or a pneumatic system with a cyclone separator. Depending on the type of food materials to be dried large number of designs has been fabricated for atomiser, drying chambers, air heating and powder collecting systems.
1.3.11. Drum Drier

Drum driers are suitable for drying the food materials like milk, vegetable juices, pectin and other fibrous liquid/semi solid foods. Drums are slowly rotating hollow in shape and made up of steel, heated internally by pressurized steam at 120 – 170°C. Thin layer of food is spread uniformly over the outer surface by spraying or spreading. Before the drum completes one-revolution, the products become dried and are scrapped off by a doctor blade, which contacts the drum surface uniformly along its length.

Drum driers have high drying rates and high-energy efficiencies. These types of drier are highly suitable for slurries with large particle size which are difficult to spray dry.

1.4. LOW AIR ENVIRONMENT DRYING

1.4.1. Smoking

This is one of the oldest techniques used to preserve the foodstuffs. Smoking has been mainly used to preserve meat and fish. This technique is not mainly used to dehydrate the foodstuff, however the heat associated with the generation of smoke gives a drying effect. Some of the compounds generated during smoking have a strong preservative effect along with partial dehydration. More than 400 volatile organic compounds have been identified during wood smoke (Melveen and Vallely 1996). Certain herbs, spices and cones are also used during smoking process to produce unique aromatic Smokey flavours Hughes et.al.(1993). Use of wood smoke in preventing lipid oxidation in meat and fish products has been widely investigated. Beedie
(1995). Synthetic smokes produced are used to eliminate harmful compounds and also to get desirable product quality Guillen (1996).

1.4.2. Vacuum Drying

Vacuum drying of foods is considered as low air environment and low temperature drying. Since the drying process takes place in the absence of air reduces the oxidation reaction. Thus the colour, texture and flavour of dried products are improved. Narsimham and John (1995) studied the product quality of bread-fruit dried using both vacuum and freeze drying techniques. They reported that the quality parameters like shrinkage, rehydration, taste, and textural qualities were equivalent to those in conventionally freeze dried (FD) product. In controlled low temperature vacuum drying, the product was preheated in a through flow drier at 60°C for 1 hour and dried at 0.5 mm Hg pressure. The product temperature during drying decreased from 50 to -5°C, vacuum allowed the water to vaporise at a temperature lower than that under atmospheric conditions. The foods can be dried without exposure to high temperature hence the heat-induced alterations and quality changes are minimum. This technique is highly suitable for heat sensitive food products.

1.4.3. Freeze-Drying

Freeze drying is one of the most sophisticated methods used for drying biological components through sublimation. This technique is similar to ordinary vacuum distillation but with one very essential difference that the material to be dried must be frozen before being subjected to a very low
absolute pressure and controlled heat input. Under these conditions the water (in the form of an ice matrix) is selectively removed via sublimation, i.e. ice transforms directly to vapour by-passing the intermediary liquid phase. Hence freeze-drying is a process of freezing a product and removing the water content while the product is still in frozen state. Four conditions found to be essential for proper freeze drying process are:

- Product must be frozen below its eutectic point
- Condensing surface must be at a temperature lower than that of the product temperature (-40°C)
- The system must be capable of evacuating to an absolute pressure between 5-25μ.
- Controlled Heat Supply For Sublimation

i. Product Pre-Freezing

The basic reason for pre freezing a product is to lock its solid particles firmly in to position to facilitate sublimation process and also to avoid chemical and physical changes during drying. Hence any product to be considered for freeze-drying should therefore be examined for its lower eutectic point. If the product is not frozen beyond its eutectic point, small amount of water may yet be in the liquid state. This will create improper drying and thawing during drying. Hence freezing is an important and critical step for proper and efficient freeze-drying.

ii. Condenser

Condenser is an important and essential part of a freeze drier. Generally it is placed in the direct path of migrating water vapours. During
drying through sublimation water vapours/ molecules leave the product and migrate towards the condenser due to temperature gradient or vapour pressure difference. On contacting the condenser, migrating vapours give up their heat energy and get converted into ice. This can be removed effectively from the system during drying or after drying. To improve the efficiency of the condenser, ice can be scraped off during the drying process.

iii. Vacuum

The main purpose of the vacuum system is to evacuate non-condensable gases from the chamber and also to increase the mean free path of the system for efficient sublimation. Apart from this, vacuum acts as an insulator, so that the product will not melt during drying operation. The absence of air in the system prevents oxidation during the drying process. Hence sufficient vacuum (100-150\(\mu\)) is essential for sublimation process to take place during the drying operation.

iv. Controlled Heat Supply for Sublimation

Heat is supplied to the frozen product under vacuum and refrigeration to maintain the migration of water vapours from the product towards the condenser. The application of heat either by convection or conduction supplies the necessary energy (i.e. latent heat of sublimation) to drive off these vapours. Hence freeze drying is an operation involving both mass transfer and heat transfer and the rate of drying depends on the magnitude of the resistance of these transfers.
In freeze-drying process, material remains frozen and drying takes place at low temperature hence heat induced alterations are minimum. In addition, there is a little or no loss in quality of the product because the removal of ice crystals leaves a porous honeycomb type structure rendering the product to re-hydrate rapidly. However freeze-drying is slow and expensive process due to the requirement of additional energy to run compressor and refrigeration units. Hence this technique of drying is highly suitable for high-value products. Cohen and Yang (1994).

1.5. Osmotic Dehydration

Osmotic dehydration is a process of water removal by immersion of water containing cellular solid in a concentrated aqueous solution. The driving force for water removal in this process is chemical potential between the solution and the intra cellular fluid. If the membrane is perfectly semi permeable, solute is unable to diffuse through the membrane into the cells. However it is difficult to obtain a perfect semi permeable membrane in food system due to their complex internal structure and there is always some solute diffusion into the food and leaching out of the foods own solute. Hence in this process mass transfer is due to combination of simultaneous water and solute transfers.

1.6. Effect of Pre-Treatment on the Quality of Dehydrated Foods

Pre-treatments like blanching, dipping and sulfiting are given to foods to improve the quality and process efficiency.
1.6.1. Blanching

Blanching is a process of preheating the product by immersing in water or steam. Blanching step is generally used in the freezing or drying process to reduce the initial microbial load and inactivate the enzymes responsible for chemical spoilage during storage. It also helps to remove the gases from the intercellular spaces to avoid oxidation related changes in dehydrated foods. Colour loss, flavour alterations, loss of soluble solids and textural alterations are the main drawbacks of this pre-treatment. Alzamora et al. (1985) studied the effect of static and agitated blanching on the retention of water soluble vitamins as well as soluble solids in peas and reported that leaching loss was less in static water blanching and blanching of peas at higher temperature reduced the leaching loss. Biekman et al. (1996) studied the effect of time and temperature on the retention of manitol during blanching of mushrooms and reported that the decrease in mushroom mass and increase of manitol concentration in blanching fluid was mainly dependent on time and temperature. Blanching brightens the colour of some foods by removing air and dust on the surface which alters the wavelength of reflected light Fellows (1997). Use of certain additives like salt and sugar to improve the rehydration properties of dehydrated vegetables have been suggested by Jayaraman et.al. (1990). Maharaja and Sankat (1996) studied the effects in blanching pre-treatments and drying conditions on the quality changes of dasheen leaves. They reported that blanching in water or in 0.06 % magnesium carbonate at 100°C for 10 seconds followed by sucrose infusion prior to drying improves the texture, aroma and rehydration properties of dasheen leaves.
compared to steam blanching at 96°C for 6 min. Increased water holding capacity of dehydrated fruits and vegetable slices was mainly due to blanching pre-treatment. Mate et al. (1988) have mentioned that blanching increased exposure of macro molecular complex to the aqueous phase enhancing the inter-particulate water binding. Mohamed and Hussein (1994) used low temperature-long time (LT) blanching along with calcium treatment to improve the textural properties of rehydrated carrots. They mentioned that during low temperature long time blanching of carrots, de-etherification of pectin methyl esterase took place which reacted with calcium to form a salt bridge. This helped to improve the textural quality of product. Increased rate of drying, due to blanching treatment was studied in carrot by Mazza (1983). Hence blanching pre-treatment is an essential and important treatment to get a quality end product.

1.6.2. Freezing

Freezing or cold shock treatment is generally given to certain food materials prior to drying to facilitate easy drying and also to obtain quality end products. Freezing the foods beyond their eutectic point, damage the cellular structure. The rate of freezing and type of freezing has been found to affect the cellular structure which in turn affects the drying rate. This is mainly due to tissue damage caused by large ice crystals. Eshtiaghi et al. (1994) showed that freezing had a significant influence on increasing the drying rate of green beans and potatoes. Kompany et al. (1995) studied the effect of freezing pre-treatments during air, vacuum and freeze drying of fruits and vegetables and
found that the rehydration rate of dried products increased to a level comparable to that for freeze-dried products.

1.6.3. Dipping Pre-Treatments

Dipping treatments with certain additives and chemicals have been used to increase the drying rate and also to improve the quality of dehydrated products with respect to rehydration, colour, texture and appearance. Haas et al. (1974) studied the effect of certain surfactants on the rehydration quality of dried foods and reported that surfactant improves the rehydration properties. Bolin and Safford (1980) used fatty acids, esters and carbonates to increase drying rate of grapes and suggested that dip-treatment of 2 % methyl-oleate and 2 % carbonate in the ratio of 1:1 increase the drying rate substantially by 30 % compared to control samples. Weitz et al. (1989) studied the surface dipping treatment of prunes for solar drying and reported that dipping prunes in 4 % methyl-oleate was an effective treatment to increase drying rate and also to get a better quality product with respect to appearance. A substantial increase in the drying rate of corn by the addition of ethyl-oleate dipping solution was observed by Suarez et al. (1984). Dipping treatment with esters was found to affect the waxy surface of fruits by altering the physical arrangements of the surface wax palettes, thus allowing moisture to remove readily evaporated from the fruit (Harrington et al.1978).

1.7. Quality Changes in Dehydrated Foods

Primary purpose of food dehydration is for preservation. During dehydration certain physico-chemical changes occur. The texture, wetability,
rehydration capacity, hygroscopicity, colour and nutrient retention are some of the physico chemical change which affects the quality of dehydrated foods. Various factors have been found to be responsible for these changes, like quality of raw material used, type of pre-treatments given and dehydration method employed. During drying shape and size of the products change appreciably, influencing their physical properties such as bulk density, particle density and porosity, this in turn modifies final texture, rehydratability and transport properties of the foods Ratti, (1994). Physical and structural changes are apparent in any dehydration process. Various workers have studied the effect of drying technique and the quality of raw material on the structural changes in fruits and vegetables. (Balaben 1989; Lozano et al. 1980; Krokida and Maroulis 1997; Madamba et al. 1994a). Most of biopolymers including food stuffs are dried from high moisture content to very low moisture content. Hence the mechanism of moisture transport during drying plays a major role with respect to physical changes in dried foods. Apart from this, heat induced chemical alteration like flavour; colour and nutrient retention affect the quality of foods.

Structural properties are an important quality attribute of dehydrated foods and it has a profound effect on the transport properties of foods like diffusivity, permeability and thermal conductivity. Hence food structure is of fundamental importance in the developing field of food material science. Generally the structure of food materials is characterized by its apparent solid and bulk densities, pore size distribution and specific volume.
Apparent density ($P_a$) is mainly of concern for powdered and porous food materials. This is determined by the mass of the sample and its apparent volume. Bulk density and bulk volume are also used for granular materials.

True density ($P_p$) is also used for granular foods. It is defined as the density excluding all pores and it is determined from the mass and its true volume values of the samples.

Porosity is nothing but overall open structure of a dehydrated material. It is usually estimated from the apparent and the true densities using the following equation.

$$\varepsilon = 1 - \frac{P_a}{P_p}.$$  

The extent of shrinkage and the density of the final product mainly depend on the mobility of moisture in the material and the rate at which the material is dried. A linear relationship between shrinkage and moisture content has been demonstrated for different food material (Lonzano et al. 1980; Madamba et al. 1994a, 1994b.).

1.8. Rehydration Properties of Dried Foods

Rehydration properties like rehydration time, rehydration ratio and rehydration co-efficient are some of the important quality parameters for dried products. Theoretically, if there are no adverse effects on the integrity of the tissue structure, it should absorb water to the same level as the initial product before drying. However, the nature of internal porous structure and elastic properties of the dried materials influence the moisture uptake during rehydration.
Lozano et al. (1980) explained that rehydration properties of dehydrated foods mainly depend on the porous structure, which may be affected due to structural collapse during the drying process.

1.9. Water Holding Properties of Dried Foods

Water holding capacity of rehydrated foods is one of the major quality attributes of dehydrated foods. During dehydration process the damage to cytoplasmic membrane of the cell takes place, resulting in leakage of intracellular and cellular components during rehydration. This affects the water holding capacity. Drying of foods below their mono-layer moisture content has been found to affect the water holding capacity (Kuts and Tutora 1983).

1.10. Crust Formation

Crust formation is a common phenomenon during drying of food polymers. Crust formation may be desirable or undesirable depending on the end use of the product. Crust formation takes place due to phase transition from rubbery to glassy state during rapid removal of water from the food materials. During this process the internal moisture diffusion is not enough to replace the moisture loss from the surface which favours the crust formation.

1.11. Stress Development and Cracking or Breaking

During drying food materials shrink at the surface, creating tensile stress at the surface and compressive stress inside. When the tensile stress on the material surface exceeds material breaking strength, the material
cracks. This causes undesirable changes like loss of valuable components and reduced consumer satisfaction.

1.12. Caking and Stickiness

Caking and stickiness of powders is an undesirable quality change and a time temperature dependent phenomenon, often encountered during their production and storage. The term stickiness refers to both particle-particle stickiness called cohesion and particle-wall stickiness called adhesion. Cohesion is an internal property of the powder and a measure of the force holding the particles together. Particles upon coming into contact stick together and agglomerate, unless the bond between them is broken by applying force greater than the cohesive one. Adhesion is an interfacial property and the measure of the force holding the powder to the surface of another material. Particles will stick to the surface unless the bond between them and the structure is broken by applying a force greater than the adhesive one. Cohesion gives rise to the phenomenon of caking or lump formation in a powder bed usually after exposure to high temperature and humidity. Dry hygroscopic foods such as instant fruit and coffee powders tend to form hard cake due to the excessive temperature and uncontrolled moisture migration when they are subjected to storage for a long time. The dry products can be categorized into two major groups as non-sticky and sticky. Non-sticky products can be dried using simple dehydration methods and are less hygroscopic and free flowing. The sticky products are difficult to dry and exhibit high degree of hygroscopicity during handling and storage (Jaya et al. 2002). The fruit powders, which contain amorphous sugars, fall
under sticky category. The stickiness of powders depends on the physical characteristics of the individual particles and the nature of the physical process by which these particles interact. Aguilera et al. (1995), indicated that a strict definition of caking is difficult to formulate, because changes in a particulate system depend on time, temperature, moisture and position within the powder. Various forces responsible for the stickiness of powdered foods are classified as:

- Immobile liquid bridges
- Mobile liquid bridges
- Electrostatic force
- Solid bridges and mechanical interlocking.

The force responsible for the stickiness of amorphous food materials like freeze dried juice powders is the immobile liquid bridges which are formed, when thin layer of viscous binders, adhering to the solids are introduced between the particles. If an immobile adsorbed liquid film is present on the surface of the particles, the magnitude of the vanderwals attractive forces is increased due to the decrease in effective inter particle distance. When the liquid bridge formation is increased, the adhesive forces at the solid liquid interface and the cohesive force with in the binder are utilized up to the point, where the weaker one is overcome. Another type of immobile liquid bridge is formed between the dry particles of spray dried amorphous soluble materials at temperature and humidity higher than the sticky point of the powders. The mechanism of bridge formation is the viscous flow driven by surface energy (Downton et al. 1982; Wallack and King 1988). There are three forms of mobile liquid bridges that occur with in the
amorphous powder. They are pendular, capillary and fenicular states. In pendular state wet agglomerates are formed by the forces resulting from the presence of mobile liquid between the particles. The void space between the particles is partly filled with the liquid which forms bridges between the individual particles. Whereas in capillary state, the void space between the particles is completely filled with liquid, which extends approximately to the edge of the pores. In fenicular state mobile liquid bridges are present as a continuous net work and interact with all other molecules present in the system.

Electrostatic force occurs between the molecules, which bear a charge. The potential energy of interaction between the molecules is inversely proportional to the distance between the molecules. This electrostatic force is the potential contributor to the adhesion phenomenon. Solid bridges are formed by sintering, chemical reactions, melting, hardening, and bonding agents as well as crystallization of dissolved materials while the mechanical interlocking occurs between needle shaped particles. The lumps formed are generally very strong and can be broken only by breaking the particles.

1.13. Textural Quality of Foods during Drying

Texture is one of the most important parameters connected to product quality. Textual properties are usually related to mechanical tests, which examine the viscoelastic behaviour of the material like stress-strain behaviour for solid food materials and flow property of powdered foods. The viscoelasticity is strongly related to complex quality characteristics.
Viscoelastic properties of foods are generally measured by compression, stress relaxation, creep and dynamic mechanical analyses tests. Among these compression test is one of the most common techniques used for the estimation of texture.

Textural behaviour of foods is mainly related to the structure of foods (Ramana and Taylor 1994) as well as chemical and biophysical characteristics (Thiagu et al. 1993). The rheological behaviour of dehydrated products has been studied through both compression and relaxation stresses. Various factors like drying method, drying conditions initial moisture content, pre-treatment have been found to be responsible for structural changes during dehydration process.

1.14. Volatile Development or Retention during Drying

In addition to physical changes, drying not only vaporise water but also causes loss of volatile compounds and formation/generation of flavours. The extent of volatile loss depends on the temperature, solid concentrations of the food and the vapours pressure of the volatiles as well as their solubility in water vapour. Volatiles which have high relative volatility and diffusivity are lost at an early stage in drying. Fewer volatile components are lost at the later stage. Hence control of conditions during each stage of dehydration is important to minimise the flavour loss. The second important cause of aroma loss is oxidation of the pigments, vitamins and lipids during dehydration and storage. This may be due to presence of open porous structure in dried foods, which allow access to oxygen. Luning et al. (1995) studied the aroma
of fresh and hot air-dried bell peppers. They found that hot air drying decreases the levels of odour compounds. Retention or loss of volatile compounds during spray drying is very important with respect to the quality of the products. A substantial volatile loss occurred during the first three stages of spray drying and afterwards, the loss was minimum or zero during the fourth stage due to selective diffusion. Apart from this during atomisation volatile loss was noticed. Several factors have been found to affect the retention of volatiles during spray drying, including the control of atomiser pressure or rotator speed, choice of spray angle, configuration of air input, alteration in air temperature profile, feed concentration, presence of oil phase, foaming of the feed, feed composition and steam blanketing of the atomizer.

Kompany and Rene (1995) studied the effect of freezing methods on the retention of aroma during freeze drying of mushrooms, and found that slow freezing resulted in higher aroma in the freeze dried samples.

1.15. Colour Change/Development during Drying

Drying changes the surface characteristic of food and hence alters the refractivity and colour. Chemical changes in carotenoid and chlorophyll pigment are caused by heat and oxidation during drying. In general, longer drying times and higher drying temperature produce greater pigments losses. Premavalli et al. (2001) studied the effect of blanching and air drying temperature on the retention of chlorophyll content in leafy vegetables. They found that total chlorophyll content decrease during drying but the chlorophyll was stable through out drying process. Sharma et al. (2000) studied the
effect of cooking, flaking and drying on the retention of carotenoids in red
gram and reported that cooking, flaking and drying caused loss in total
carotenoid content. Lower water activity favours the retention of chlorophyll in
dried foods due to non availability of water to react with chlorophyll to form
pheophytin. Biekman (1996) observed that pheophytin content of the dried
spinach decreased as the moisture level was lowered for preservation of
green colour. Another cause of colour degradation may be enzymatic
browning causing rapid darkening, mainly in the leafy portion. The formation
of dark pigment via enzymatic browning is initiated by the enzyme polyphenol
oxidase. Another reason for discoloration is photo oxidation of pigments,
caused by light in combination with oxygen leading to severe discoloration.
This phenomenon has been reported to occur in meat, Anderson et al. (1990).

1.16. Nutritive Value of Food during Drying

Large differences in reported data on the nutritive value of dried foods
are due to wide variations in the preparation procedures, drying temperature,
time and the storage conditions. In fruits and vegetables, losses during
preparation usually exceed those caused by the drying operation. Effect of
different drying methods viz., sun drying, oven drying and freeze drying on the
nutritional composition of seaweed (Sargassum) was studied by Chan et al.
(1998) and revealed that the nutritional composition of the seaweed was
greatly affected by different drying methods.
1.17. Factors Responsible for Quality Changes

Various factors have been found to affect the structural properties of foods like moisture content, drying method and drying conditions. During drying, significant changes in structural properties were observed (Krokida et al. 1970). In the early stage of drying, the cellular tissues are elastic enough to shrink into the space left by the evaporated moisture. As the drying process proceeds, structural changes in the cellular tissues result in a more rigid network, thus favouring the development of porosity.

1.18. Effect of Moisture Content on Structural Properties of Foods

Structural properties of foods are strongly affected by the moisture content. Diffusion of water molecules during drying form cracks to the solid structure, causing structural damage and significant changes to all the structural properties. The rate of drying is directly proportional to the true density of the product. As the water is removed from the food material true density reaches the value of dry solid density of the material while apparent density of the product decreases with moisture content. Porosity of the product also increases along with moisture decrease during drying. However the final porosity of the product depends on the structure of raw material and drying conditions. Karthanos et al. (1993) studied the effect of drying temperature on the porosity and rehydration properties of dried foods and mentioned that the low temperature drying produced porous structured product as compared to high temperature drying.
1.19. Effect of Drying Methods on Structural Properties of Foods

Structural properties of foods are greatly affected by the drying method. The true density of the product is not affected by the drying method however in osmotic dehydration true density is affected due to mass transfer phenomenon. During all types of drying methods true density increases as water is removed from the food material, while apparent density is highly affected by the dehydration process. Apparent density of vacuum dried products is lower than that of conventionally dried products while for freeze-dried products the apparent density is the lowest as compared to vacuum and conventionally dried products. Osmotic dehydration increases the apparent density. Porosity of freeze-dried foods is always higher as compared to all other dehydration processes.

Krokida and Maroulis (1997) studied the effect of five drying methods like hot air, vacuum, microwave, freeze and osmotic on shrinkage of banana, apple, carrot and potato, and reported that shrinkage was the highest in hot air dried and lowest in freeze dried products.

Khaloufi and Ratti (2003) studied the various combinations of freezing and freeze drying temperature on various quality parameters like volumetric shrinkage and pore size of pears and apples. They mentioned that volumetric shrinkage was not affected by freeze drying conditions but higher freezing and freeze drying temperature caused more shrinkage than lower ones. Shrinkage behaviour of carrots during drying in an inert medium fluidised bed
dryer was studied by Hatamipour and Mowla (2002). According to their investigation shrinkage of carrots during drying was found to be correlated positively with moisture content and there was no significant relationship between shrinkage and drying conditions like air velocity and temperature. Donsi et al., (1996) also found less shrinkage in freeze dried apple and potato. This was mainly due to non-collapse of empty pores during the sublimation process. However for conventional and osmotically dried material shrinkage phenomenon is very intensive compared to vacuum and microwave dried materials.

1.20. Effect of Drying Conditions on Structural Properties of Foods

Drying conditions such as temperature and pressure have been found to affect the structural properties of dehydrated foods. Thus the same raw material dried with the same drying method may end up in a completely different product under different drying conditions. This suggested that the rate at which the material was dried and its structural properties were interrelated. Pressure affected significantly the percentage of air pore formation in the final dry products. During vacuum drying apparent density and porosity were affected by the pressure. Linear relationship between pressure and apparent density was noticed during vacuum drying. Lower pressure prevented the structural collapse of foods, while the porosity of the products increased as the vacuum decreased indicating that shrinkage could be prevented by controlling pressure, resulting in high porosity in the final products.
Effect of temperature, air velocity and relative humidity on area shrinkage and volume of whole sour cherry fruit during air drying was studied by Oehoa et al. (2002). They observed linear relationship between dimensionless volume change and moisture content of the fruit. They mentioned that volume and area changes did not depend on drying variables.

Influence of processing parameters on the spice paprika was studied by Ramesh et al. (2001) and they mentioned that higher air velocity and lower relative humidity were desirable for reducing drying rate and improving the quality of the product with respect to structural property.

In case of freeze-drying eutectic freezing drying below the collapse temperature and high vacuum were found to be necessary to prevent structural changes during drying. Krokida et al. (1998) studied the effect of freeze-drying conditions on shrinkage and porosity of dehydrated agricultural products. They mentioned that porosity of the product decreased as the drying temperature increased.

1.21. Effect of Raw Material on the Quality of Dehydrated Foods

Raw material quality particularly variety, maturity, size, colour and raw material preparations like cleaning, shortening and peeling play a major role in determining the final quality of the products. Phanindra Kumar (1989) studied the effect of variety and seasonal variations on the quality of freeze dried
pineapple juice powder and reported that the giant Kew variety fruits available in the middle and the end of the season were found to have all the desirable characteristics with respect to juice yield, total soluble solids and other sensory characteristics. Maturity of the fruits and vegetables are also an important factor which affect the quality of dehydrated foods. Immature vegetables require more time for dehydration due to high water content. On the other hand fully matured vegetables yield poor quality products. Harvesting of fruits and vegetables is also an important factor for the potency of vitamins in dehydrated products.

Composition of vegetables and fruits are mainly depends on agronomical variations and variety. Certain varieties are highly suitable for processing and yield satisfactory dry products. Certain varieties grown in specific areas have been found to yield good quality products while same variety when grown in another area yielded poor quality products. Hence variety, climatic conditions, agronomical variations are some of the critical factors for good quality dehydrated products.