Review on Different Drying Methods: Applications & Advancements

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Abstract - Drying or dehydration or dewatering is the oldest method of food preservation. Drying removes the moisture content up to extent so as to prevent microbial growth as microbial organisms become inactive for water amounts < 10%, in weight in food, thereby provides advantages like greater shelf life, reduction in weight, reduction in volume and space to storage, easier manipulation of product, thereby decreases transportation cost. Natural and artificial drying are two commonly used drying methods. Natural drying includes sun drying, solar drying, whereas artificial drying includes microwave, fluidized bed, spouted bed, infrared, solar, simple convective and desiccant drying, freeze, osmotic ,vacuum, Pulsed electric field, high hydrostatic pressure, The quality of product after drying for new , high quality and customer attractive dried product in terms of colour, taste, appearance and rehydration in some of the products has need to be addressed and monitored and. The literature review of some research paper has been studied which provide brief introduction on each drying technology. This Paper reviews different drying methods, their suitability, developments and Current Applications.

Keywords:- Drying technology, Natural drying, Artificial drying, Moisture,

I. INTRODUCTION

Drying is defined as simultaneous heat and mass transfer operation in which water from inner side of food brings to the surface and then evaporated into an unsaturated gas stream by either natural or artificial means. Agricultural products like vegetables and fruits are perishable. Moisture content cause spoilage over a time and create waste. Thus, removal of moisture content by drying which result in increase product life and avoid the spoilage and waste of excess agricultural products , thereby converting it into stabilized product . The suitability of drying method depends on various factors such as the type of product, availability of dryer, cost of dehydration and final quality of desiccated product. Energy consumption and quality of dried products are other critical parameters in the selection of a drying process. Natural drying like direct Sun drying is associated with limitations such as contamination by dirt, damage by rodents, birds, domestic animals. these methods based on conductive and convective methods for heat transfer, but result in poor quality and high possibility of contamination. The problem of contamination can be overcome by using closed transparent enclosure. Solar dryers with closed transparent enclosure are used since as efficient alternative option to the hot air and open sun drying methods, especially in locations with good sunshine during the harvest season Among these are lacks of ability to control the drying process Properly, weather uncertainties, high manpower costs, large area requirement, insect infestation, mixing with dust and other foreign materials and so on. Artificial drying methods include microwave , fluidized bed, spouted bed, infrared, solar, simple convective and desiccant drying, infrared drying , freeze drying , osmotic drying ,vacuum drying , Pulsed electric field, high hydrostatic pressure, superheated steam drying, heat pump drying and spray drying. These methods have advantages like shorter drying time, good quality of drying, Operational safety, Non-polluting, Higher capacity, Better process control, Better cost economics. Artificial drying use Different types of dryers that should possess the characteristics like low initial capital costs ,easy to construct and fabricate with available natural materials ,easy-to-operate with no complicated electronic/ mechanical protocol, effective in promoting better drying kinetics and product quality than the sun-drying method, easy to maintain all parts and components; and simple replacement of parts during breakdowns. The present review summarizes drying methods, applications and advancements on drying.

II. DIFFERENT DRYING METHODS

Fluidized Bed Drying

A layout of a simple FBD system is shown in Fig. 1.

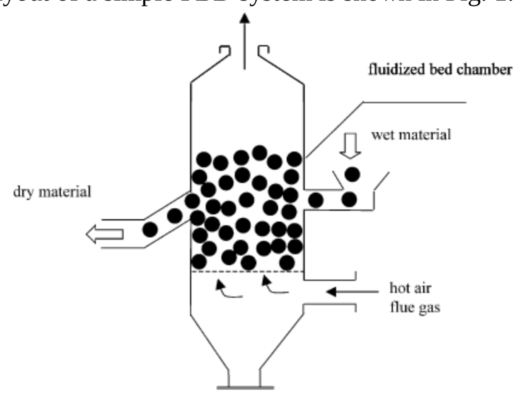


Fig.1 Longitudinal schematic of the Fluidized Bed System [1]

It is simple in construction with simple steel-frames, steel-sheets and wooden planks. The wet product enters from one side into the main drying zone. Hot air passes from the bottom through the perforated plate interacting with the wet product in a cross-flow causes the particles to fluidize, enabling efficient gas–particle contact to take place and resulting in the particles being dried effectively. The dried particles are then discharge through the exit port of the fluidized bed. [1] Dehydration occurs by convection and therefore, the warm air moves through the bed causing the food to become suspended and vigorously agitated (fluidized), exposing the maximum area for drying .[7] . Advantages include cheap and easy to design requiring low capital cost, High drying rates due to good gas-particle contact, leading to optimal heat and mass transfer rates, smaller flow area, high thermal efficiency, lower capital and maintenance costs and ease of control.[1] .Fluidized bed drying (FBD) has found many practical applications in the drying of granular solids in the food, ceramic, pharmaceutical and agriculture industries like peas, beans, diced vegetables, fruits granules, onion flakes and fruit juice powders.[1]

Spouted Bed Drying

The layout of simple SBD is shown in Figure 2.

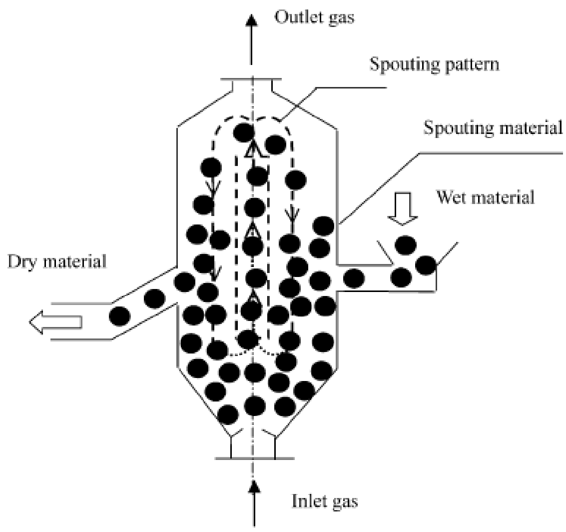


Fig.2 Schematic diagram of a spouted bed showing spouting pattern [1]

It consists of a cylindrical vessel with a conical bottom fitted with an inlet nozzle for introduction of the spouting air (drying medium). A draft tube is held in the center to enhance the height for which the granular particles can be spouted. The wet material enters from the side entrance port and undergoes spouting with the assistance of the draft The incoming drying air, introduced through a centrally located opening at the conical base, interacts well with the particles. tube. The particles, upon interaction with the air, rise rapidly through a hollowed central core, namely spout zone, within the vessel These particles, after raising a certain height above the bed surface, get separated from the air stream and drop into the annulus region where they move slowly downward due to the angular shape of the bed. As the particles undergo spouting motion, moisture is removed from the particle surface. Due to the good air–particle contact, high drying rates can be achieved leading to optimal heat and mass transfer rates.

SBD is suitable for drying of granular agricultural products that are too coarse like wheat, corn, oats, cereal seeds and also cattle feeds. Advantages include Higher drying rates, Lower drying temperatures, Can be used for drying processes that require coating, granulation and agglomeration operations, used for convert viscous paste and slurries into powdery form. Disadvantages include the problems of scale-up and control of the cyclic pattern.

Infrared Drying

It is suitable for employment in rural farming areas to foodstuffs such as grains, flour, vegetables, pasta, meat and fish. Fig. 4 shows a simple IR dryer. It consists of includes a manual-conveyor system whereby the food product enters from the inlet hoop and is dried as it moves parallel to the IR lamps. The level of irradiation can be adjusted via the voltage regulator while intermittent IR drying can be implemented by turning the timer relay knob.

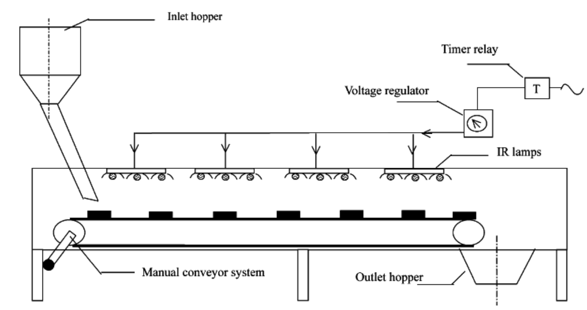


Fig.3 Schematic diagram of a conveyor IR drying system [1]

During IR drying, radioactive energy is transferred from the heating element to the product surface without heating the surrounding air. The radiation is target to the exposed product, penetrating it, and subsequently being converted into sensitive heat. advantages include Versatility, simplicity of the required equipment, fast response of heating and drying, easy installation to any drying chamber and low capital cost[1]. During the product drying process and due to a decrease in its water content, the absorbance ability of the dry material decreases while its reflectivity increases the transmissibility [7]

Sun Drying

It is cheapest method of drying among all existing method. In open sun drying, the food to be dried is left exposed to the sun for a number of days to achieve the desired moisture content. advantages include simple in construction only requires sunlight . Disadvantage include Insect infestation, dust and dirt contamination, long time for drying, over heating due to direct exposure, quality deterioration and low rate of transmission of heat due to condensation of the evaporated moisture are some the major problem faced during open air drying[4] This technique requires no equipment, since the raw materials are simply arranged in fields, roofs or other flat surfaces, being steered frequently until dry. This natural process requires ideal environmental conditions, which are achieved during the warmer months. [7]

Fruits posses high sugar and acid content make them safe to dry in the sun .Whereas, Vegetables and meats are not recommended for sun drying due to low in sugar and acid. A minimum temperature of 86 °F is needed with higher temperatures being better. Humidity below 60 percent is best for sun drying. Fruits dried in the sun are placed on trays made of screen or wooden dowels. The best screens are stainless steel, teflon coated fiberglass or plastic. Avoid screens made from “hardware cloth”. This is galvanized metal cloth that is coated with cadmium or zinc. These materials can oxidize, leaving harmful residues on the food. Also avoid copper and aluminum screening. Copper destroys vitamin C and increases oxidation. Aluminum tends to discolor and corrode. Outdoor drying rack most woods are fine for making trays. However, do not use green wood, pine, cedar, oak or redwood. These woods warp, stain the food or cause off-flavors in the food, it is best to place the racks or screens on a concrete driveway or if possible over a sheet of aluminum or tin. [8]

Solar Drying

The sun emits nearly 70,000 to 80,000 kW/m2. The solar radiation intensity outside the atmosphere is nearly 1,360 W/m2 [2] Solar drying is different from ‘‘sun drying’’ as it uses equipment to collect the sun’s radiation in order to harness the radioactive energy for drying applications. Good product quality can be achieved via control of the radioative heat. It is used to dry products like grains, fruits, meat, vegetables and fish.[1] the solar rays are collected inside a specially designed unit for keeping food, which contains an adequate ventilation system for the removal of moisture from the air. It consists of a transparent panel located above the manifold or camera, which is painted black to absorb the solar rays and contains a series of trays, where the prepared fruit samples are placed uniformly. The drying air flows through the solar collector where it is heated up. The temperature inside the unit is 100C to 300C higher than outside, which results in shorter drying times [7]. A foil surface inside the dehydrator helps to increase the temperature. Ventilation speeds up the drying time. Shorter drying times reduce the risks of food spoilage or mold growth [8]

Solar dryers are of two types: active and passive. In direct passive dryer, food is directly exposed to the sun’s rays. it is best for drying small batches of fruits and vegetables such as banana, pineapple, mango, potato, carrots and French beans.

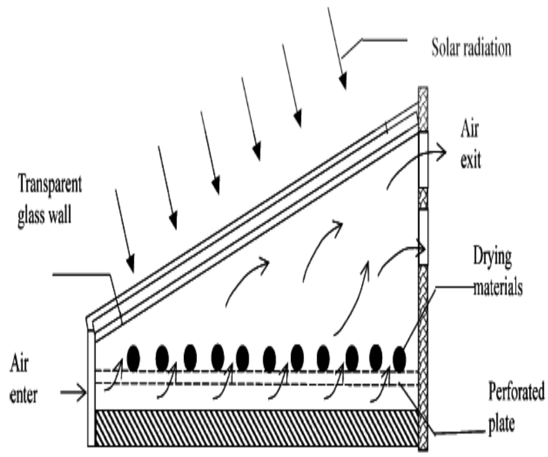


Fig. 4 Structure of a Passive cabinet food solar dryer [1]

It consists of a drying chamber is covered by a transparent cover made of glass or plastic. The drying chamber is usually a shallow, insulated box with air-holes in it to allow air to enter and exit the box. The food samples are placed on a perforated tray that allows the air to flow through it and the food. shows a schematic of a simple direct dryer. Solar radiation passes through the transparent cover and is converted to low-grade heat when it strikes an opaque wall. This low-grade heat is then trapped inside the box by what is known as the ‘‘greenhouse effect.’’ Simply stated, the short wavelength solar radiation can penetrate the transparent cover

Active solar dryers are designed incorporating external means, like fans or pumps, for moving the solar energy in the form of heated air from the collector area to the drying beds The collectors should be positioned at an appropriate angle to optimize solar energy collection. A gear system can be designed to manually adjust the angle of the collectors. Tilting the collectors is more effective than placing them horizontally, for two reasons.In an active dryer, the solar-heated air flows through the solar drying chamber in such a manner as to contact as much surface area of the food as possible. Thinly sliced foods are placed on drying racks, or trays, made of a screen or other material that allows drying air to flow to all sides of the food. Once inside the drying chamber, the warmed air will flow up through the stacked food trays. The drying trays must fit snugly into the chamber so that the drying air is forced through the mesh and food Trays that do not fit properly will create gaps around the edges, causing large volumes of warm air to bypass the food, and prevent the dryer from maximizing the potential of the drying air to remove moisture from the food.

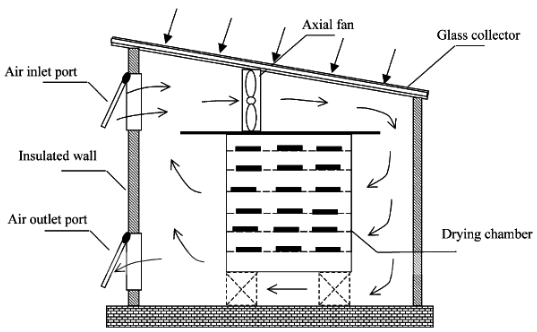


Fig. 5 Structure of an Active solar convective dryer [1]

As the warm air flows through several layers of food on trays, it becomes moisture laden. This moist air is vented out through the outlet port. Fresh air is then taken in to replace the exhaust air. Active solar dryers are known to be suitable for drying higher moisture content foodstuffs such as papaya, kiwi fruits, brinjal, cabbage and cauliflower slices.[1]

Advantages include It is faster due to shorter period of time, It is more efficient due to more quickly drying , less spoilage Prevent loss from marauding animals and insects since the food products are in safely enclosed compartments, It is hygienic as drying takes place in controlled environment, thereby controlling contamination, It is healthier as enables to retain more of their nutritional value such as vitamin C. It is cheap as it Uses freely available solar energy [1]. The dryers are waterproof, therefore, the food does not need to be moved during raining.[2]

Limiting issues with solar dryer that Can be only used during day time when adequate amount of solar energy is present, Lack of skilled personnel for operation and maintenance, Less efficiency as compared with modern type of dryers, A backup heating system is necessary for products require continuous drying.[2]

Microwave Drying

The microwave generator produced microwaves with varying power densities based on the supplied power. The generated microwaves guide using the waveguides into the microwave cavity to dry food [2]. Microwave drying uses electrical energy in the frequency range of 300 MHz to 300 GHz. The most commonly used frequency is 2,450 MHz. Microwaves are generated inside an oven. This is done with the help of the magnetron tube. When the material couples with microwave energy, heat is generated within the product through molecular excitation. The critical next step is to immediately remove the water vapour. A simple technique for removing water is to pass air over the surface of the material [5].The dehydration by microwave is caused by differences in vapour pressures between the interior and the surface of the food, which creates a driving force for the transfer of moisture. The dehydration occurs between a range of 915 MHz and 2450 GHz and the wavelengths vary between 1 mm and 1 m. The most important feature of this method is the volumetric heating, which means that food can absorb microwave energy directly or internally, being converted into heat. it is recommended to use of electromagnetic waves for food with 50 to 97% of water [7]

Desiccant Drying

It is used mainly in the air-conditioning industries to improve air quality for thermal comfort. Also, it is suitable for drying of herbs like Parsley, rosemary and thymes and flowers like roses, lavender, chamomile and clover, mushroom . Flowers dried via desiccant drying possess excellent product quality in terms of color, texture and lasting. Typical desiccants suitable for herbs and flower drying include silica gel, borax, cornmeal oralum. The advantages of a desiccant drying system include: the moisture-laden desiccant can be re-generated by passing it through a stream of hot air which absorbs the moisture; the system is easy to design and ensures years of maintenance-free operation; incorporating the desiccant with other drying systems such as solar and fluidized bed results in a significant reduction in energy consumption per kg of moisture removed; easy access of replacement of the desiccant media after cycles of operations.

It is found improved quality and reduced drying time, from 52 to 4 h, for the drying of apricot in combining a rotary desiccant wheel system with a solar-powered adsorption refrigeration system for the cooling of grain, found better performance in terms of energy savings and lower operating costs for this hybrid system compared to a purely adsorption refrigeration system. One of the most promising desiccant drying systems of recent years is the desiccant wheel , as shown in Fig 5.

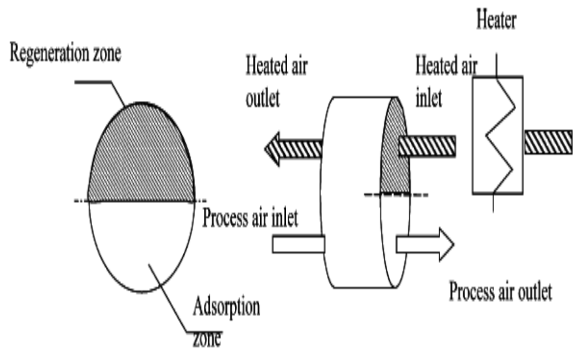


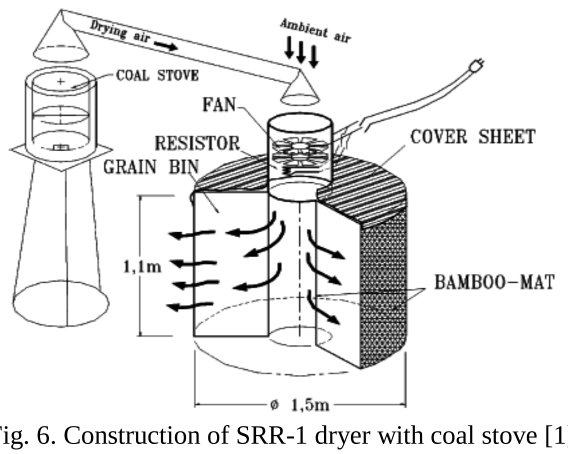
Fig.5 Desiccant drying system [1]

In the adsorption region, the desiccant adsorbs water vapor and the dehumidified air is then delivered through the process outlet directly into the drying chamber. Then, as the desiccant media rotates it switches the adsorption and regeneration zone, and the hot air entering into the regeneration zone inlet

drives off the moisture and exhausts it into the atmosphere. After regeneration the hot, dry desiccant rotates back into the process air stream where a small portion of the process air cools the desiccant so that it can begin the adsorption process all over again. To increase dehumidification capacity, farmers can either increase the diameter of the rotating bed to hold more desiccants, or increase the number of beds stacked on top of one another. It has advantages like low cost and reduced operating overheads, simple design, compact and easy to produce as well as install and maintain. It maintain germinalogy of Products like cereal grains and plant seeds The two factors that most influence the seed viability are temperature and moisture content. The moisture content of the seed is a function of the surrounding ambient relative humidity (RH). Therefore, to minimize fungal activity which can cause a decrease in seed viability, discoloration and possible production of harmful substances such as mycotoxins, proper storage conditions requires a RH of below 70%. The desiccant wheel system can then be utilized in storage facilities to produce the required RH to ensure optimal germinability of seeds, and longer shelf life of grains.

Convective Drying

Convective method of drying is employed to remove water from the food substances through the application of heat in equipment meant for drying. Hot air is allowed to pass through the product in a manner to transfer the heat to the food and moisture is removed [4]. It is suitable to use in small farming areas of less than 1ha, where electricity can be made available and in remote area where diesel generator is aalternative. Hot convective air dryers are generally used for drying pieces of banana, mango and pineapple slices, various tea leaves and some sturdy herbs such as basil, lemon balm ,bay leaves. The simple low cost convective dryer is the SRR-1dryer shown in fig.6



. Fig. 6. Construction of SRR-1 dryer with coal stove [1]

It consists of three basic components: an axial fan, an electric heater, and a bamboo-mat drying bin. The drying bin is made up of two concentric bamboo-mat fabricated cylinders to hold upto one ton of paddy. To improve the efficiency, a coal stove can be incorporated as an auxiliary heating system to the dryer. It burns pulverized-and compressed coal with a calorific value of about 25 MJ/kg. It is noteworthy that one unit-heat of this coal is approximately 7–12 times cheaper than one unit-heat of electricity. With the installation of the stove, the heated flue gas from the stove is sucked through a pipe to the fan inlet, and mixed with the ambient air. The stove consumes 0.9–1.0 kg of coal per hour. The time period for refilling of the coal is 3 h. By employing the stove allows the air temperature to be raised in the range of 5–9_C, with a correspondingly lower air humidity, from 95–100% down to 75–60%, resulting in a significant improvement in the drying potential of the air and hence, shortening the drying time to obtain the desired moisture content of the grain [1]. It was observed that the pre-treated strawberries had a higher drying rate and decreased drying time. The pre-treated samples also had better rehydrating properties as compared to the sample which had not been pre-treated.[4]

Freeze Drying

It uses freezing to dry products. and removal of solvents associated with direct sublimation. Unavailability of liquid water and low temperature results in the production of a good quality product by complete control of microbial growth. About 90% of the water present in the fruits is removed in the first phase of freeze drying. It has the ability of the fruits to rehydrate, Differences in the rehydration property of freeze dried fruits is due to salt concentration, desorption of water, break down of pectin cells in the membrane, size of water crystal and its porosity. The rehydration property of the freeze dried product is rapid and the organoleptic property of the rehydrated foods is almost similar to the fresh product. Advantages include minimum volume reduction, minute chemical change, minimum loss of volatile components, long storage period, stability, ability to be used as an antioxidants and colorants. The disadvantages include high cost and energy consumed during the freezing, drying and condensing process, high freeze drying time, collapse of the product can happen which may result in loss of aroma and yield tough product with low rehydration capacities [4].

Freeze-drying works by freezing the material and then reducing the surrounding pressure to allow the frozen water in the material to sublimate directly from the solid phase to the gas phase. [8]

Osmotic Dehydration (OD)

It is a partial dehydration process. It is suitable for Vegetables and fruits for a pre-treatment prior to drying by other methods. [6]. Foods to be dried is placed in a hypertonic solution which causes a difference in concentration and causes the water content of foods to be driven out from the sample to the solution. Diffusion of the solutes from the solution into the tissue of the fruits and vegetables also takes place . It changes physical, chemical, nutritional values, taste and structural properties of the final product [4] Although it does not remove enough moisture to be considered as a dried product, It works well as The application as a technique for production of intermediate moisture foods or as a pre-treatment prior to drying in order to reduce energy consumption or heat damage. Some aspects of osmotically.[6]

Monosaccharides, disaccharides and salts such as sodium chloride are the most commonly used osmotic ally active solutes [4].dehydrated fruits have been reviewed by various workers with reference to osmotic agents and their concentration , temperature, sample to solution ratio , agitation of fruit in syrup , sample size and shapes , osmotic agents , material type , pre-treatment , size and shape , temperature and concentration dehydration method and physico-chemical changes modelled the mass transfer process with respect to moisture loss and solids gain. It is observed that even though the moisture loss and solids gain occurred at the same time, the rate of moisture loss was much higher than the rate of solids gain. The advantages include lower energy use and lower product thermal damage, lower temperatures used allow the retention of nutrients. described sweeter taste of dehydrated product, reduction of 20–30% energy consumption and shorter drying time[6].

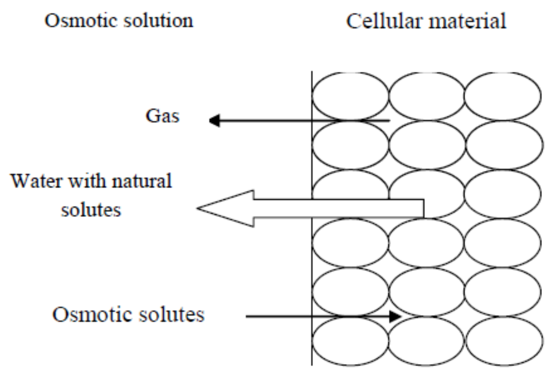


Fig.7 Pattern of mass transfer when cellular material is immersed in osmotic solution [4]

It is conducted at room temperature[4]. It is observed that in OD of guava slices found that higher sugar concentration (600B) and temperature (60°C) increase the water loss from the produce and solid gain into the osmosed guava slices. The driving force for the diffusion of water from the tissue into the solution is provided by higher osmotic pressure of hypertonic solution. The rate of mass transfer during OD is generally low. Techniques to improve mass transfer are partial vacuum ,ultra high hydrostatic pressure , high intensity electrical field pulses , super critical CO2 treatment and prior to OD processing and using centrifugal force. Vacuum - The reduction in pressure results the expansion and escape of gas . After pressure restoring, the pores can be occupied by the osmotic solution, increasing the available mass transfer surface area. The effect of vacuum application during OD is explained on the basis of osmotic transport parameter, the mass transfer co-efficient and the interfacial area Vacuum pressure (50-100 mbar) is applied to the system for shorter time to achieve the desired result [6]

Pulsed Electric Field

This treatment is particularly recommended to increase the permeability of plant cells. It is suitable to increase in permeability of potato and carrot tissues by PEF treatment. Due to applying PEF treatment , cell get damage that cause tissue softening, which in turn resulted in a loss of turgor pressure, leading to a reduction in compressive strength.. It is observed that the effective diffusion coefficients of water and solute increased exponentially with electric field strength. The increase in effective diffusion coefficient can also be attributed to an increase in cell wall permeability, which facilitated the transport of water and solute. It is observed that PEF treatment increased water loss, which was attributed to increased cell membrane permeability. The effect of PEF treatment on solid gain is minimal. so, it is not recommended for solid grain.[6]

High Hydrostatic Pressure

It is suitable for sugar. It is observed that application of high hydrostatic pressure applied which damages the cell wall structure result in significant changes in the tissue architecture cause cells more permeable. It is used at a sugar factory. It lower the dryer equipment and operational costs by about 15 %. While conventional drying results in problems such as browning, dust explosion and burning, better results in terms of product quality and operational safety can be obtained . [6]

Superheated Steam Drying

Superheated steam at atmospheric is suitable for dehydrating materials that can withstand temperatures above 100°C. It takes longer constant rate periods and lower critical moisture contents compared to conventional drying. The degree of superheating increases with lowered operational pressures since it act as predominant process parameter. The advantages of superheated steam drying include: high drying efficiency, no risk of oxidation, non-polluting, smaller equipment, better microbial control, insecticidal effects and lessened risk to fire and explosion.[11]

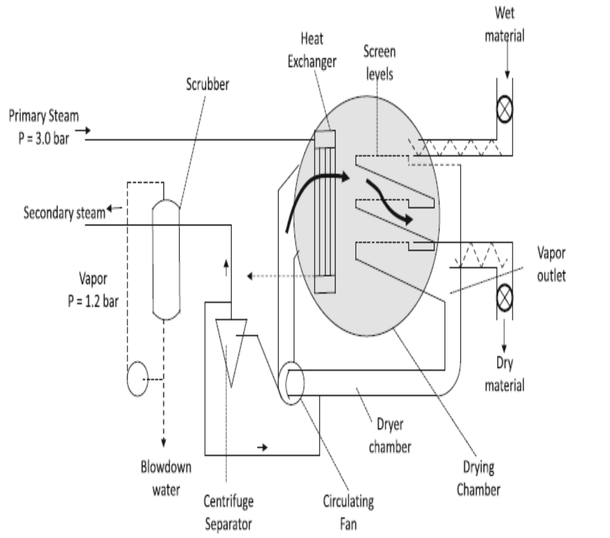


Fig .8 A schematic diagram of Superheated steam dryer[11]

Any convective dryer can be modified as a superheated steam dryer by use of superheated steam. forced over the food material results in boiling and steam evolution from the interior of the product. It is suitable for oil palm empty fruit bunches, cereals and selective snack-food. Superheated steam at 150°C used to dry distillers' spent grain. It have advantages that it does not have adverse effect on the protein and phenolic content, . reduced risk to oxidative reactions. With relatively shorter drying time, it is suitable for pepper seeds. There is good potential to use combined microwave-superheated steam as a hybrid system to produce products with low apparent density. Far-infrared radiation can be used in combination with superheated steam drying to overcome the problem of slow drying. Related studies conducted on banana have shown favorable results Limitations that require to be addressed in superheated steam-drying systems include the development of simpler superheated steam-drying systems and risk to deteriorative effects of condensation and glass transition [11]

Heat Pump Drying

Heat pump drying develop from existing refrigeration systems with some modifications. it acts as closed-loop systems. its working principle is vapour compression cycle. In Heat pump dryers, the latent heat of vapour condensation is converted into sensible heat of an air stream passing through the condenser. Fig. 8 shows the schematic layout of an air source heat pump drying system

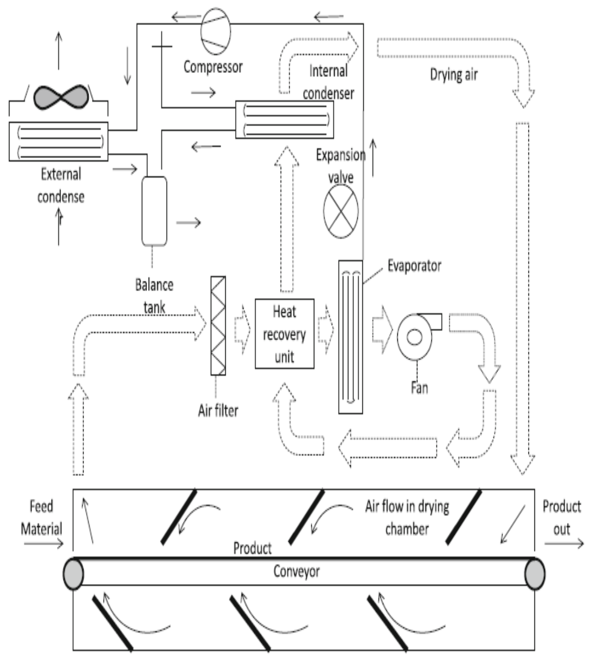


Fig.9 Heat Pump drying [11]

It consists of valve, two heat exchangers (evaporator and condenser), and a compressor and a dryer attachment. The evaporator acts as dehumidifier and the condenser act as heater. Now a days, chemical and hybrid heat pump plays important role into improve process efficiency. Controlling of drying temperature and air humidity is crucial to use it for both agricultural and pharmaceutical products. It is suitable for saffron, the most expensive spice. Heat pump drying system is the best method to produce intermediate moisture foods, particularly for applications in fish processing.

An best alternative to compression heat pumps with ozone-depleting fluids is chemical heat pump (CHP). A solar-assisted CHP is a feasible energy efficient option for the tropics. It consists of solar collector, storage tank, CHP units and drying chamber. In short, the system alters the thermal energy stored by chemical substances utilizing reversible chemical reactions. it is suitable for agricultural products[11]

III. CONCLUSIONS

1. The need to develop low cost but energy efficient drying technologies should be focused for village level to convert surplus crops into acceptable and marketable food items. thereby , making farmers economically strong.

2. The natural drying method is simple and easier to use, but associated with drawbacks such as more drying time, intermittent supply of sun energy and the conditions of drying cannot be manipulated as compared to the artificial method of drying. However, potential area of research is

to develop natural drying solutions with greater efficiency and drying models taking all the variables into consideration

3. New methods with characteristics such as increased rate of drying, enhanced final product quality and improved energy consumption need to be develop.

4. This paper reviews and highlights the developments in drying technologies covering suitability of each method, advantages and drawbacks.

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