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A Survey on the Design, Fabrication and Utilization of Different Types of Foods and Vegetables Dryer

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Abstract : *The demand for dried fruits and vegetables in various forms is increasing. For instance, the estimated world demand for dried, dehydrated, and freeze-dried fruits and vegetables increased from Rs 700 billion in 2001 to Rs 970 billion in 2011. Several preservation techniques can be applied to extend shelf life and add value to fruits and vegetables and one of them is drying and dehydration. Reported to be one of the oldest preservation technique, dehydration is continuously gaining significant interest among researchers, scientists, entrepreneurs and processors both in academia and industry. Dehydration is the process that involves the application of heat to remove moisture from the fresh fruit and vegetable product. This paper discussed the fundamental material properties related to food dehydration such as water activity, sorption isotherms, and glass transition temperature. Recent developments in dehydration of fruits and vegetables and their applications to fruit and vegetable products were reviewed. In this paper we will be surveying different types of dehydration techniques and their working operations and also proposed preliminary research on an advanced solar tunnel dryer for drying of different types of vegetables and fruits.*
Keywords: *Dehydration, Solar dryer, tunnel dryer, tray dryer.*

I. Introduction

Drying is one of the essential unit operations performed to increase the shelf life of agricultural / horticultural produce and it is one of the most practical methods of preserving food and the quality of horticultural produce. If the drying process is not completed fast enough, growth of microorganisms will take place as a result of the high relative humidity. This often leads to severe deterioration of the quality of the product. Traditionally, the food products are dried by spreading in open sun in thin layer. Though this method is economical and simple, it has the draw backs like; no control over the rate of drying, non-uniform drying, chances of deterioration due to exposure of products against rain, dust, storm, birds, rodents, insects and pests which results in poor quality of dried products. Whereas, solar drying system leads to fast rate of drying and exposure of products against rain, dust, storm, birds, rodents, insects and pests are avoided.

This method is practiced until today for certain products because of the advantages of simplicity and economy. However, open sun drying has some drawbacks. Open sun drying requires longer drying time and product quality is difficult to control because of inadequate drying, high moisture, fungal growth and encroachment of insects, birds and rodents and others. Open sun drying also requires a large space. Drying is usually conducted by vaporizing water in the product. Thus, the latent heat of vaporization must be supplied. Airflow is also required to remove the vapor away from the product. The lower the humidity of hot air supplied to the drying chamber is, the better the drying rate, as the less humid air can carry more moisture from the product surface than the more humid air. Generally, increasing the temperature and velocity shortens the drying time. However, for heat-sensitive products, such as food and pharmaceutical products, high temperature decreases product quality. In this case, drying at low temperature and humidity is required to maintain the fresh color of the product using the desiccant system. Without the use of the desiccant system, high temperature is required to obtain low humidity. The same product dried with different techniques produces different levels of product quality.

In this paper we are going to discussed about the different types of drying process and techniques for the drying of fruits and vegetables.

II. Historical Background

Dehydration was continuously gaining significant interest among researchers, scientists, entrepreneurs and processors, both in academia and in industry. Dehydration is a process that involves the application of heat to remove moisture from fresh fruit and vegetable products (Vega-Mercado et al., 2001; Jarayamanan & Das Gupta, 2006). Its primary objective is to reduce microbial activity and deterioration, and to extend the shelf life of the product. Other benefits of dehydration include reduction of weight, which greatly decreases the cost of packaging, handling, storage and transport (Singh & Heldman, 2009). Ezekoye and Enebe (2006) evaluated a domestic direct mode solar dryer with constructed components mounted on a skeleton and screwed such that the various components were detectable and dismantled for easy movement. Ajao and Adedeji (2008) fabricated and tested a motorized direct low temperature crop dryer consisting essentially of wood and double layered transparent glass which serves as a solar collector. Ikejorfor and Okonkwo (2010) developed an active solar dryer with adjustable airflow rates and heat storage unit with drying chamber made of three detachable perforated metal screens for spreading products and covered with a transparent material to allow direct solar radiation on products. Ojike et al (2011) investigated the influence of open-air sun drying, Green house passive solar dryer, Sun-tracking passive solar dryer and Latitudinal box passive solar dryer systems on the vitamin content of Pawpaw

(Carica papaya) experimentally. Jude et al (2013) fabricated and evaluated a direct absorption solar dryer using local materials. Ehiem et al (2009) designed and developed an industrial fruit and vegetable dryer consisting of a drying chamber, blower and heat exchanger unit for reducing vegetable wastage and improving their storage conditions. Lotfalian et al (2010) studied an indirect passive solar dryer for drying Lemon and Orange fruits using iron and aluminum solar collectors experimentally.

The development of various types of solar dryers, their principles and operations can be found in many publications elsewhere (Bansal & Garg, 1987; Imre, 1995; Parker, 1991; Muhlbauer, 2002; Wiess & Buchinger, n.d.; Jayaramayan & Das Gupta, 1992; Bolin & Salunkhe, 1982).

Several authors have published books and articles focused on different drying techniques and technologies (Barbosa-Cánovas & Vega-Mercado, 1996; Ekechukwu, 1999; Muhlbauer, et al., 2002; Kudra & Mujumdar, 2002; Jayaraman & Das Gupta, 1992; Mujumdar, 2006; Ratti, 2009). The present review describes some fundamental concepts related to food dehydration and developments in dehydration of fruits and vegetables.

III. Methodology

In this section we are discussed about the different types of the drying methods used in the agriculture field and also discus about their performance, working and usefulness.

Drying of fruits and vegetables offers a challenging task due to the different structural characteristics of these products. The removal of water from these products must be accomplished without compromising the physico-chemical properties and quality of the dried products. To obtain the desired quality products, some fundamental concepts associated with food dehydration such as water activity, sorption isotherms and glass transition temperature, among other concepts need to be understood. A selection of appropriate drying methods and systems must be analyzed based on the entire drying process. For example, there is a need to define the types and characteristics of raw materials to be dried, and the specifications of the finished product. Also, the desired production capacity, shape and particle size distribution, and drying characteristics of the product should also be critically assessed (Vega-Mercado et al. 2001).

Several dehydration methods and types of dryers are commercially available for drying a wide range of food products. Approximately 100 types of dryers of the more than 400 types reported in the literature (Strumillo, 2006) are being utilized in the industry. These dryers are classified into several categories, based on certain specific criteria. Vega-Mercado et al., 2001 divided dehydration technologies into four generations: first generation (i.e kiln, tray, truck tray, rotary flow conveyor and tunnel); second generation (i.e. spray and drum drying); third generation (i.e. freeze-dying and osmotic dehydration); and fourth generation (i.e. Rrefractance), high-vacuum, fluidization, microwaves, and RF). Mujumdar (2008) and Law & Mujumdar (2008) classified dehydration into four categories, namely, drying strategy, drying medium, method of handling of solids, and mode of heat input. Jarayamanan & Das Gupta (2006) suggested three basic types of drying processes for fruits and vegetables such as sun or solar drying, atmospheric and continuous, sub-atmospheric drying, and low-temperature and low-energy drying process.

Regardless of the classifications and categorization of dehydration technologies, the application of a particular drying technique for fruits and vegetables depends on the type of raw material and its characteristics and intended used of the dried material. In most cases, the acceptance of drying methods and designs is highly dependent on the capacity, efficiency, investment cost, operational drying cost, and impact on the environment.

3.1 Types of Dehydration Techniques

I. Sun drying

In sun drying, the heat from the surrounding air and diffused radiation from the sun is transferred to the material being dried (Fig. 1). The heat generated is used to increase the temperature of the product causing the moisture or vapor to migrate from interior to the surface of the crop (Muhlbauer, 2002). Part of the radiant energy provides the heat to evaporate the water from the product surface by convection and radiation, which is finally removed from the surrounding air by convection through the application of forced air. In an ambient condition, the equilibrium moisture content of the product is attained when the vapor pressure of the product is equal to the atmospheric pressure. Sun drying is a simple and inexpensive method for drying fruits and vegetables. However, this method is only useful when sun is available. Other limitations include uncontrollable drying conditions, possible contamination from dust and insects, and possible microbial and enzymatic degradation as a result of longer drying time. Non-uniform drying may also lead to deterioration during storage.

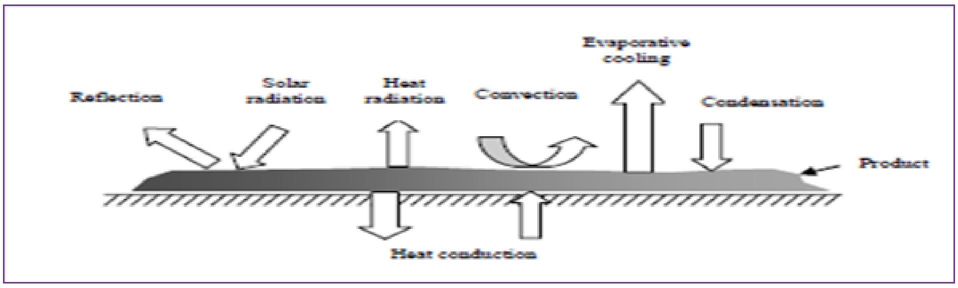

Fig. 1: Heat flow influencing in sun drying (Adapted from Muhlbauer, 2002)

II. Solar drying

In general, solar dryers are classified according to their utilization of heat generated from solar radiation to dry the product. These classifications include direct, indirect, hybrid, and mixed systems (Lawland, 1981).

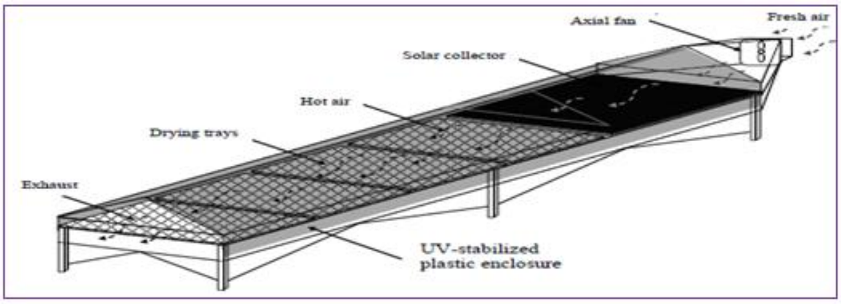

Fig. 2: Schematic diagram of multi-commodity solar tunnel dryer (Adapted from Miranda, et al., 2003)

III. Hot air drying

Drying of wet material using a hot air drying method is accomplished mainly by convective heat transfer process facilitated through direct contact of the heated air into the wet material to be dried. Mass transfer of water from the core to the surface of the product and removal of water vapor from the surface are the two main important mechanisms that facilitate the drying process. To obtain dried product at reasonable drying cost, the desired type and quality of dried product, raw material, economy of scale and drying efficiency must be considered.

Hot air drying designs are generally adopted in drying fruits and vegetables. These dryers include cabinet or tray dryer, tunnel dryers, pneumatic conveyor dryers, and belt conveyor dryers, fluidized, spray and drum dryers, among others.

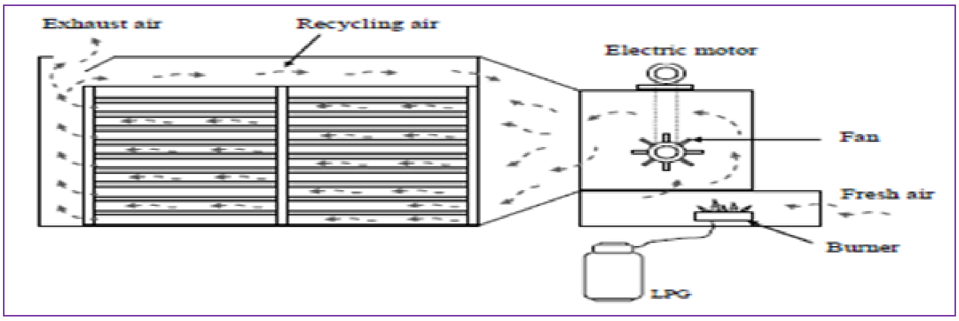

Fig. 3. Cabinet Easter dryer

a) Cabinet or tray dryers

Generally, cabinet dryers are designed for small-scale drying operation (100-2000 kg/day of dried product), normally used for laboratory or pilot-scale drying experiments (Tang & Yang, 2004). The dryer configuration consists of perforated trays located in an insulated chamber. It is equipped with blower and ducts to allow for a controlled circulation of heated air around or across the drying chamber. The heat source can be from a gas burner, electric heater, biomass furnace or by means of a heat exchanger. The energy is supplied from the air stream to provide the heat required to evaporate the water from the product surface, and carried away from the drying chamber (Tang & Yang, 2003; Barbosa-Cánovas & Vega-Mercado, 1996; Simate & Ahrne, 2006). An example of a cabinet dryer design is illustrated in Fig. 3.

b) Tunnel dryers

Tunnel dryer have the dryer dimension maybe up to 24 m long with a 2 x 2 m rectangular or square section. It consists of a cabinet equipped with mobile truck and trays with rails that move along a tunnel (Fig. 4).

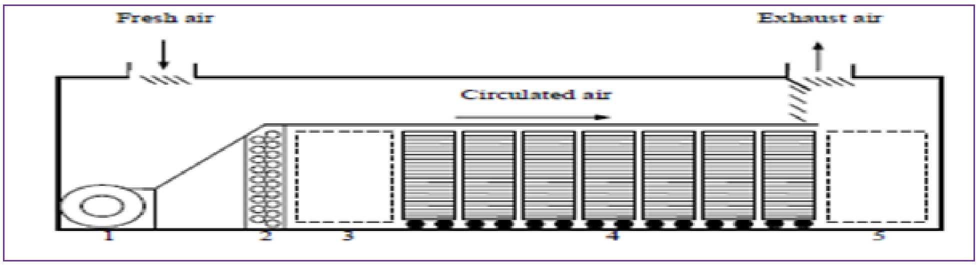

Fig. 4. Tunnel Dryer

Drying of material is done in continuous mode wherein trays of wet product are stacked in trolleys and periodically introduced into one end of the tunnel and then the dried materials are discharged at the other end at predetermined time intervals. The movement of the product to be dried can be in the opposite direction of the heated air (counter-current flow) or in the same direction (co-current flow). The drying capacity of the dryer depends on the size of the tunnel, number of trays, drying temperatures and airflow rates.

c) Belt conveyor dryers

A conveyor belt dryer consists of several sections in series. Each section contains an independent control system that allows for easy adjustment to a desired belt speed, airflow rate and direction of airstream. During the operation, wet products are conveyed using either a high tensile strength plastic belt or perforated metal. The heated air is introduced directly to the conveyor belt for maximum product exposure. To achieve a higher drying efficiency, the thickness of the material to be dried varied, ranging from 5- 6 cm for the first or second sections.

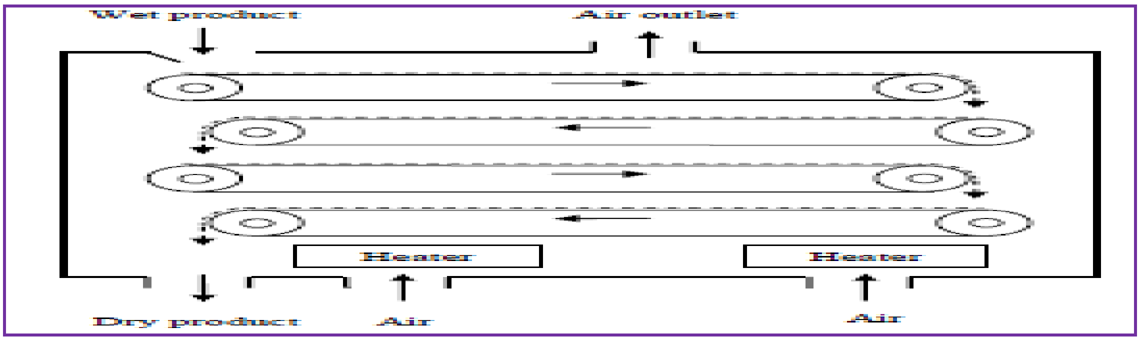

Fig. 5. Schematic diagram of multi-pass conveyor belt dryer (Adapted from Grabowski et al., 2003).

d) Pneumatic conveyor dryers

Pneumatic conveyor dryers are effectively used for powders or granulated products, specifically for potato granules. The drying process begins by feeding the material into a stream of heated air and then conveyed through a duct at a predetermined conveyor speed to attain the desired moisture of the material. The used air from the system is exhausted through a cyclone or filter, while the dried product is separated and conveyed to a discharge outlet. The semi-dried material that comes out from this type of dryer can be re-dried in a cabinet dryer at a faster rate. Jayaraman et al. (2006) reported that pieces of vegetables were dried down to 50 % wb in 8 min using a temperature of 160 180 °C. The semi-dried product was found to have increased porosity, which was facilitated during finish drying in a conventional cabinet type dryer.

e) Fluidized bed dryers

The fluidized bed dryer was originally designed for drying of potato granules (Jayaraman et al., 2006). This process requires a small drying space, but it is an effective technique to maximize the surface area of the material to be dried, which facilitates drying of the product. During the drying operation, the heated air is introduced through a bed of food particles at a high velocity which is enough to overcome the gravitational force of the material and thus allows it to be suspended in the air. As illustrated in Fig. 6, the movement of the product within the system is facilitated by the reduction of mass as moisture is removed.

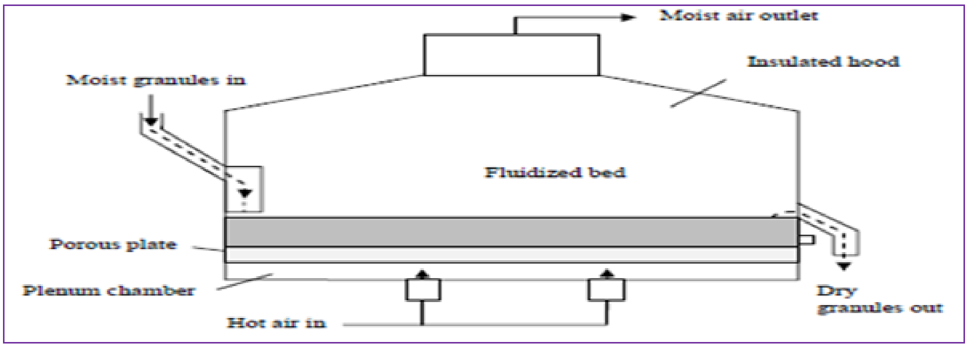

Fig. 6. Fluidized bed dryer

f) Spray dryers

Spray drying is a process wherein the feed such as paste, solution or suspension is sprayed in droplets in a stream of hot air using an atomizer to accomplish evaporation and produce a free flowing dry powder (Barbosa et al., 2005). A typical spray drying system consists of a large cylindrical drying chamber, feed atomizer, hot air supply and a cyclone to collect the dried particle product, and fan (Masters, 1985 & 1991) (Fig. 7a). The geometry of drying chambers depends mainly on the type of atomizer, which dispenses the liquid, slurry or paste-like material into fine droplets. A rotary wheel atomizer is used for a short and wide drying chamber (conical type), while a nozzle type atomizer is used for a long and narrow (tall type) chamber (Ramaswamy & Marcotte, 2006). Conversion of liquid to powder particle during spray drying takes place in two basic steps. The first step is referred to as a drying constant rate period. Basically, the drying process is controlled at the feed droplets. The heat transfer occurs from the droplet surface through the gas phase, while mass transfer of water vapor occurs from the droplet surface to the gas phase. The second step is the formation of a solid particle in which evaporation is controlled by the diffusion of moisture from the internal core of the particle toward the particle surface.

g) Drum Dryers

As A drum dryer is made up of a single-drum, double-drum, twin- drum or vacuum-drum dryer (Fig. 8) (Karel, 1975; Barbosa-Cánovas & Vega-Mercado, 1996). The single-drum dryer (Fig. 8a) consists of one cylinder, while the double-drum dryer (Fig. 8b) design consists of two cylinders rotating in opposite directions. The double-drum design allows adjustment of the thickness of the feed by changing the gap between the two drums. The twin-drum dryer (Fig. 8c) is also comprised of two drums similar to a double-drum, but they are positioned apart and rotating away from each other.

A vacuum-drum dryer (Fig. 8d) has similar configuration to the other types except that the entire system is enclosed in a vacuum-tight chamber. This system is normally used when handling heat-sensitive materials (Barbosa-Cánovas & Vega-Mercado, 1996).

During drum drying operation, the product to be dried in slurry, paste or puree form is spread in a thin layer onto the metal surface of the internally heated drums by means of a feeder mechanism. The dried product in the form of flakes is removed after rotating approximately three fourths of the revolution of the drums by a doctor blade (Saravacos, 2006).

h) Freeze drying

Freeze-drying or lyophilization is a drying process in which the food is first frozen and thereafter sublimed from the solid state directly into the vapor phase without passing through the liquid state, generally under reduced pressure (Ramaswamy & Marcotte, 2006; Athanasios & Bruttini, 2006; Barbosa-Cánovas & Vega-Mercado, 1996). Fig. 10 represents the phase diagram of water with conditions of atmospheric air pressure, vacuum and freeze drying. The point of intersection of the curves is called the "triple point" at which the three phases exist in equilibrium.

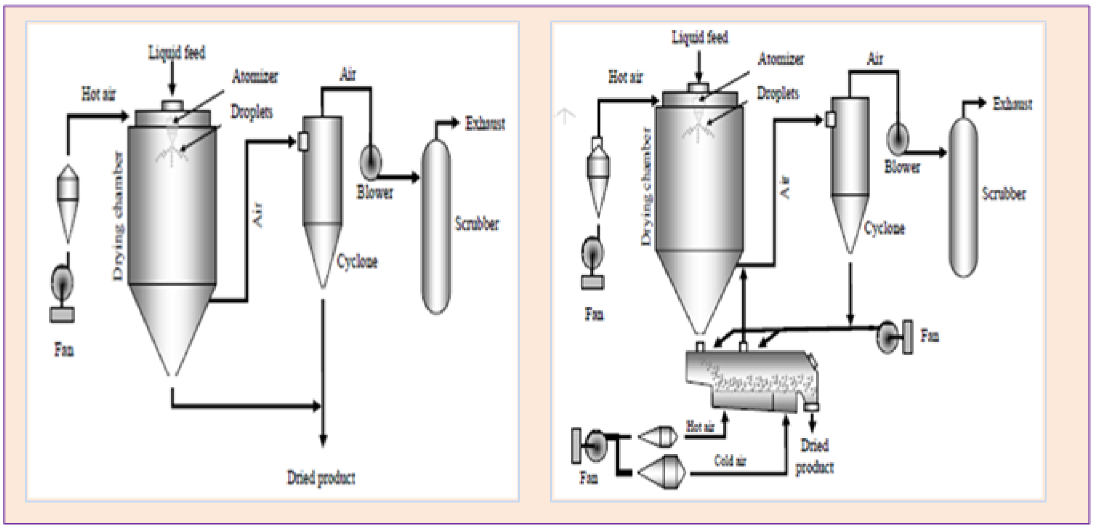

Fig. 7. Schematic of a typical spray dryer(a) and spray drying system with external vibrating fluidized bed. (Adapted from Barbosa-Cánovas & Vega-Mercado, 1996 and GEA-Niro, Inc.)

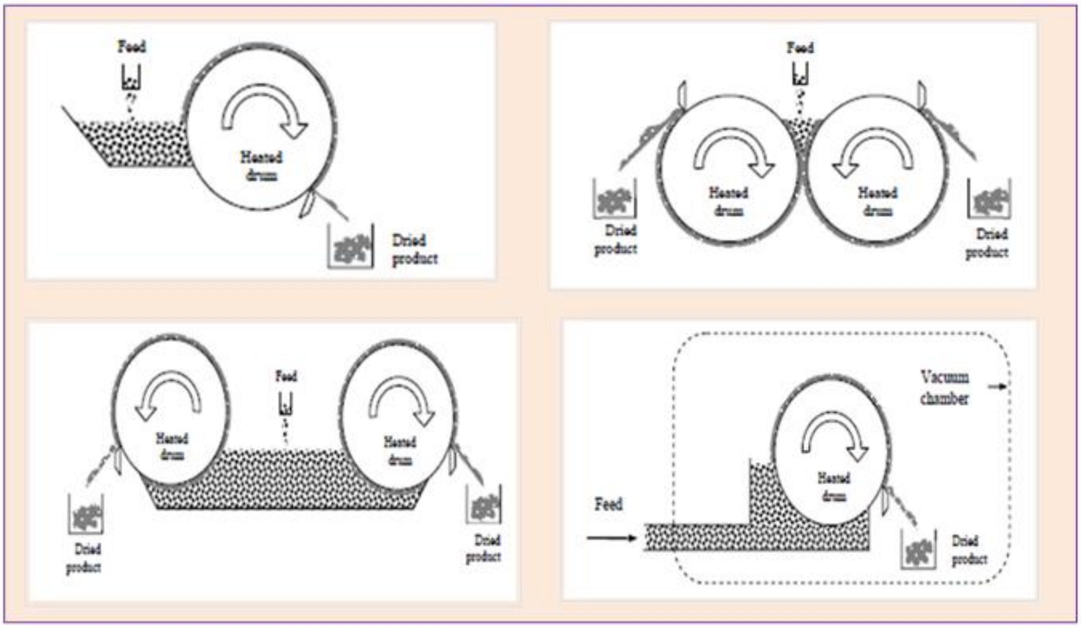

Fig. 8. Schematic diagram of a single drum dryer (a); a double drum dryer (b); a twin-drum dryer (c); and a vacuum drum dryer (d) (Adapted from Karel, 1975; Barbosa-Cánovas & Vega-Mercado, 1996).

IV. Proposed Methodology

In this section we are going to discuss about the proposed methodology of my current research. My proposed methodology is that design and fabricate a tunnel solar dryer for drying fruits and vegetables.

4.1 Solar Dryer

Solar dryer technology offers an alternative which can process the vegetables and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. Solar drying can be used for the complete drying process or as a supplement to artificial drying systems, in the latter case reducing the fuel energy required. Solar dryer technology can be used in small-scale food processing industries to produce hygienic, good quality food products. At the same time, this can be used to promote renewable energy sources as an income-generating option. Further, this solar technology is ideally suited for women since they can place a load in the dryer and then get on with their other numerous tasks.

Solar drying is often differentiated from ‘‘sun drying’’ by the use of equipment to collect the sun’s radiation in order to harness the radiative energy for drying applications. Sun drying is a common farming and agricultural process in many countries, particularly where the outdoor temperature reaches 30 8C or higher. In many parts of South East Asia, spice crops and herbs are routinely dried. However, weather conditions often preclude the use of sun drying because of spoilage due to rehydration during unexpected rainy days. Furthermore, any direct exposure to the sun during high temperature days might cause case hardening, where a hard shell develops on the outside of the agricultural products, trapping moisture inside. Therefore, the employment of solar dryer taps on the freely available sun energy while ensuring good product quality via judicious control of the radiative heat. Solar energy has been used throughout the world to dry food products. Such is the diversity of solar dryers that commonly solar-dried products include grains, fruits, meat, vegetables and fish.

Solar dryers can broadly be categorized into direct, indirect and specialized solar dryers. Direct solar dryers have the material to be dried placed in an enclosure, with a transparent cover on it. Heat is generated by absorption of solar radiation on the product itself as well as on the internal surfaces of the drying chamber. In indirect solar dryers, solar radiation is not directly incident on the material to be dried. Air is heated in a solar collector and then ducted to the drying chamber to dry the product. Specialized dryers are normally designed with a specific product in mind and may include hybrid systems where other forms of energy are also used.Although indirect dryers are less compact when compared to direct solar dryers, they are generally more efficient. Hybrid solar systems allow for faster rate of drying by using other sources of heat energy to supplement solar heat.

The three modes of drying are:
(i) open sun,
(ii) direct
(iii) indirect in the presence of solar energy.

The working principle of these modes mainly depends upon the method of solar-energy collection and its conversion to useful thermal energy.

4.2 Basic Principles of Drying

Drying depends upon:
a) Temperature, humidity and quantity of air used
b) Size of the pieces being dried
c) Physical structure and composition
d) Airflow patterns within the drying system

Heat is not the only factor which is necessary for drying. The condition, quality and amount of air being passed over and through the pieces to be dried determine the rate of drying. The amount of moisture contained in the air to be used for drying is important and is referred to as absolute humidity. The term relative humidity (RH) is more common and is the absolute humidity divided by the maximum amount of moisture that the air could hold when it is saturated. RH is expressed as a percentage and fully-saturated air would have an RH of 100%.

This means that it cannot pick up any more moisture. Air containing a certain quantity of water at a low temperature will, when heated, have a greater capacity to hold more water. The table below gives an example of air at 29^{o}C with an RH of 90%. Such air, when heated to 50^{o}C will then have an RH of only 15%. This means that instead of only being able to hold only an extra 0.6 grams of water per kilogram (at 29^{o}C), it is able to hold 24 grams per kilogram. Its capacity to pick up moisture has been increased because it has been heated.

When placed in a current of heated air, food initially loses moisture from the surface. This is the constant rate period. As drying proceeds, moisture is then removed from inside the food material, starting near the outside. Moisture removal becomes more and more difficult as the moisture has to move further from deep inside the food to the surface. This is the falling-rate period. Eventually no more moisture can be removed and the food is in equilibrium with the drying air.

4.3 Benefits of solar drying

The choice between alternative types of solar drier will depend on local requirements including scale of operation as well as the budget available. If intended for smallholder farmers drying crops for their own needs then capital cost may well be the main constraint and so low-cost plastic-covered tent or box driers may be the most suitable choice. However, commercial farmers with an assured market for their product may consider banks of fan-assisted, glass-covered solar dryers more appropriate for their needs.

Dried foods are tasty, nutritious, the nutritional value and flavor of food is only minimally affected by drying;
- Dried foods are high in fiber and carbohydrates and low in fat, making them healthy food choices
- Vitamin A is retained during drying
- Storage space is minimal, easy-to-store

- Transportation costs are reduced; dried Products weigh only about 1/6 of the fresh food product
- The energy input is less than what is needed to freeze or can
- easy-to-prepare; solar food drying is a very simple skill
- longer storage of dried products (because of more complete drying)
- Can open new markets and income and is a good start-up technology. It improves the bargaining position of farmers. Sometimes farmers sell at very low prices during the harvest season
- You can have up to 50% more productivity in agriculture
- For diabetics dried fruit prepared without adding sugar is a healthy choice instead of desserts.
- Dried fruit can be used in stews, soups and casseroles or enjoyed as snacks. It can also be added to cereals for breakfast or used in making ice cream and baked products
- It is an absolute safe technology. No high voltage is used; no risk of high Temperature not any harm could be generated by the dryer.
- The food is safe, although it could be contaminated before drying. Because of the pasteurization-effect due to "high" temperature in the dryer.

4.4 Design Considerations of Solar tunnel Dryer

The developed solar tunnel dryer consist of frame, tray, exhaust fan, polythene, thermo coal sheet, aluminum sheet wire mesh, stand, transported wheel, speed regulator, Insulator material etc which are explain below: The semi-cylindrical tunnel shape was formed by using iron angle and flat bar having required length. While making semicircular frame by bending squre pipes, sufficient diameter cylindrical tunnel was formed. The tray was prepared with angle iron and wire mesh.

The tunnel was covered with UV stabilized polythene sheet of 200 micron size.. One exhaust fan of 1 kW capacity were fixed at front end of the solar tunnel dryer in order to regulate the air flow rate and to maintain the humidity during drying process. Exhaust fan of the solar tunnel dryer (STD) used to remove the moist hot air. The frame consists of eight trays with aluminum sheet and wire mesh. Hoops were made of 9 gauge (3.8 mm) wires support a clear polyethylene film cover. We provide some height to the polyethylene cover in such a way that it reduced from mid to bottom in semi circular form above the drying trays. One edge of the polyethylene film is securely attached to the side of the frame while the other is attached to a polyvinyl chloride (PVC) pipe. The PVC pipe allows easy removal of the cover and drying tray access. The bottom of the dryer is insulated with 3/4 inch (19 mm) thick foil faced insulation board.

V. Conclusions

This survey paper is focused on the available renewable energy operated dryer's systems. We presented a comprehensive review of the various designs, details of construction and operational principles of the wide variety of practically realized designs of solar-energy drying system. This paper is also present a preliminary study of a solar tunnel dryer. Such low-cost food drying technologies can be readily introduced in rural areas to reduce spoilage, improve product quality and overall processing hygiene. The eventual objective of employing these appropriate drying technologies is to significantly improve the agricultural returns for farmers in appreciation of the hard effort they have devoted in crop cultivation.

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