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A REVIEW

Applications of solar energy for drying of agricultural commodities

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Abstract : Drying is a simultaneous heat and mass transfer energy intensive operation, widely used as a food preservation technique. In view of improper postharvest methods, energy constraint and environmental impact of conventional drying methods, solar drying could be a practical, economical and environmentally reliable alternative. Open air solar drying method is used frequently to dry the agricultural products. But this method has some disadvantages. Therefore, to avoid disadvantages it is necessary to use the other solar drying methods. Different solar drying methods are direct solar drying, indirect solar drying and mixed mode solar drying. The device used for drying process with application of solar energy called the solar dryer. Solar dryer are also classified with mode of air circulation. In this paper, we studied the various modes of solar drying and classification of solar drying techniques.

Key Words : Solar drying, Natural circulation, Forced circulation, Food sector, Medicine sector

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INTRODUCTION

Globally the human population is expected to grow beyond 9 billion by the year 2050 and about 70% extra food production will be required to feed them (Godfray, *et al*., 2010). The population rise is expected to be more in developing countries and the demand for food is increasing due to population explosion, urbanization, climate change and land use for non-food crop production etc. Besides, the post-harvestlosses of agricultural products are also high in the developing countries due to poor infrastructure and resources available to use the modern storage techniques and lack of awareness about the usefulness of the techniques. Globally about one-third of the food produced (approx.1.3 billion ton), worth about US $1 trillion, is lost during post-harvest operations every year and it also predicts that if the current practices continue then the loss would be around 2.1 billion metric tons by 2030. India is one of the largest producers of fruits and vegetables in the world (Gustavsson *et al*., 2011). The cumulative wastages of fruits and vegetables in India are estimated to be 5.8% to 18%. As per the study, post-harvest losses of major agricultural products including fruits and vegetables in India alone were estimated to the tune ofabout Rs. 44,000 crore per annum (Kumari *et al*., 2015). The availability of low cost and

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effective storage structures can motivate farmers to store their agricultural products like cereals, vegetables and fruits etc., instead of selling right after harvesting at lower price. Proper storage will retain normal colour, nutritive value and gives opportunity to sell at higher prices during lean period besides giving sustainable food security.

Preservation of agricultural products is essential for keeping them for a long time without further deterioration in the quality of the product. Several process technologies have been employed on an industrial scale to preserve food products, among that. Drying is the efficient and reliable method. It offers a highly effective and practical means of preservation to reduce postharvest losses and offset the shortages in supply. Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an energy intensive operation. The prime objective of drying apart from extended storage life can also be quality enhancement, ease of handling, further processing and sanitation and is probably the oldest method of food preservation practiced by humankind (Balasuadhakar *et al.*, 2020).

The advancement of sun drying is solar drying systems in which products are dried in a closed system in which inside temperature is higher. Major advantage includes protection against flies, pests, rain or dust. Several significant attempts have been made in recent years to harness solar energy for drying mainly to preserve agricultural products and get the benefit from the energy provided by the sun. Sun drying of crops is the most widespread method of food preservation in most part of India and world because of solar irradiance being very high for the most of the year. As this technique needs no energy during day time, it is more beneficial to the small scale farmers who can't afford the electricity or other fuel for drying. If it is necessary to dry product in night or in bad weather, an additional bio-fuelled heater can be used for heat supply (Tiwari, 2016).

Drying:

In drying phenomena the psychometric is of importance as it refers to the properties of air-vapor mixture that controls the rate of drying. When an adequate supply of heat is provided for drying, the temperature and rate at which liquid vaporization occurs will depend on the vapor concentration in the surrounding atmosphere (Hii *et al.,* 2012). Drying is commonly described as the operation of thermally removing water content to yield a solid product. Moisture held in loose chemical combination, present in the product matrix or even trapped in the microstructure of thesolid, which exerts a vapour pressure less than that of pure liquid is called bound moisture. Moisture in excess of bound moisture is called unbound moisture. When a solid is subjected to thermal drying, two processes occur simultaneously (Sontakke and Salve, 2015).

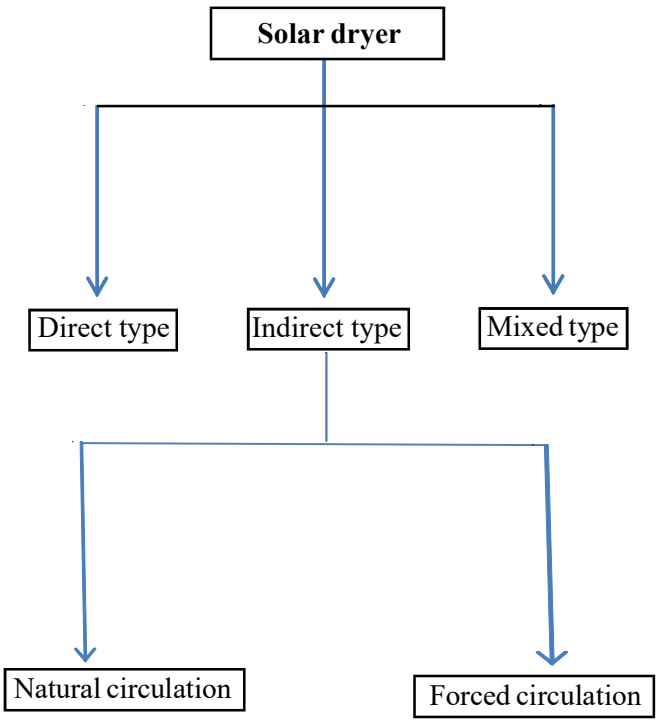
– Transfer of energy from the surrounding environment to evaporate the moisture from the surface.

– Transfer of internal moisture to the surface of the solid and its subsequent evaporation due to application of energy.

The removal of moisture as vapour from the material surface, depends on the external conditions such as temperature, air humidity and flow, area of exposed surface, and pressure Apart from weather conditions the drying behaviour of agricultural crops during drying depends on the:

– Product type
– Size and shape
– Initial moisture content.

Classifications of solar dryers



Classifications of solar dryers direct solar drying:

Direct solar drying is a general method of drying the product by means of solar energy. In this process

the energy which is obtained from sun is directly used for drying purpose. This is one of the convenient methods of drying, because energy is obtained from one of the cheaper source called as sun or renewable source of energy. It is the continuous operation of heat and mass transfer. This technique involves the thin layer of product spread over large space to expose to solar radiation. This process for a long time until the products will dry to a required level. The surface floor made from the concrete or particular area of soil is making applicable for Outdoor direct sun drying. This type of drying method is useful for grains. Material is led on outdoor floor for a long time, usually 10-30 days. This process is going on till

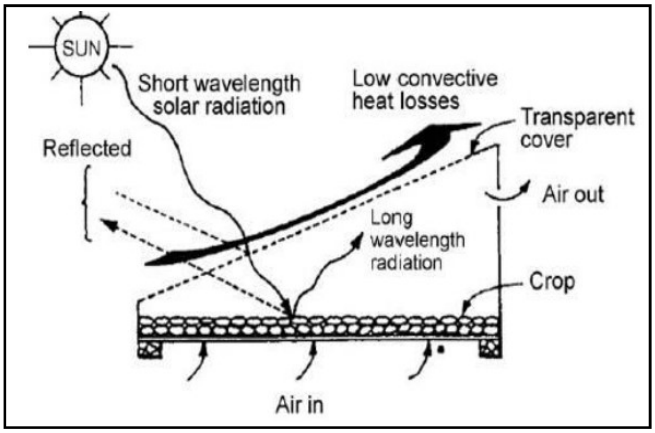
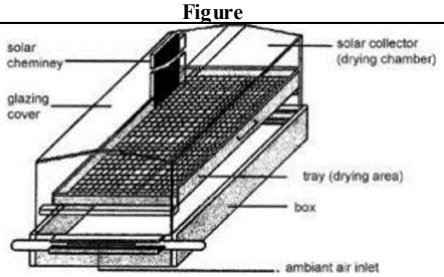
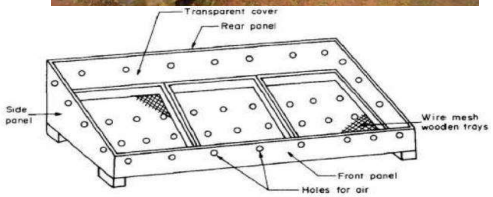
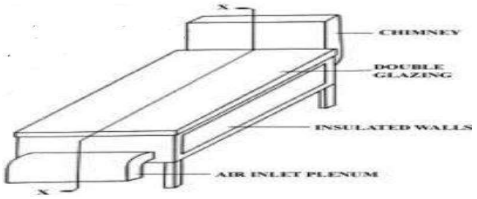
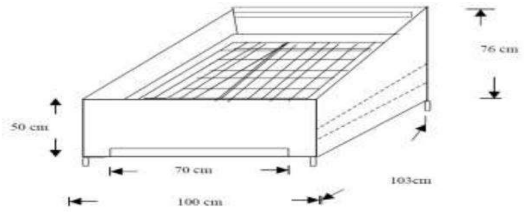


Fig. 1 : Direct type solar dryer

Direct solar driers

Author and product	Key findings	Figure
H. Yobouet Andoh *et al* (2007) Cassava and sweet banana	Moisture content was reduced from 80% to 13%. They concluded that the drying rate increases with drying air temperature and drying air mass flow.	
Ben Akachukwu et al.(2014) Tomato, okra and carrot	For tomato, okra and carrot dryers achieved 54.55, 52.88 and 50.98 percent gain in drying time and 21.80%, 21.18% and 24.95% system drying efficiencies respectively	
Sodha *et al.*(1985). Mango	Moisture content reduced from 95% to 13% in 12 sunshine hours.	
Ezekwe Food products	Dryer equipped with wooden plenum and chimney which were accelerated the drying rate 5 times over the un drying	
EL- Amin Omda Mohamed Akoy *et al.* (1999) Mango	Dryer had a collector area of 16.8. They dried 195.2 kg of fresh mangoes from 81.4% to 10% wet basis.	

then when the product is dried to a required level. According to the Sontakke and Salve (2015) drying is very important process applicable for agriculture and industrial product. Drying reduces the bacterial growth of the product and helpful for preserving the product for long period of time. But this conventional process have some disadvantages therefore in that case it is very essential to use other methods of drying such as active, passive and mixed solar drying.

Indirect solar drying:

Indirect or convective solar drying it is more efficient than direct type of solar drying. In an indirect solar dryer, the sun's heat is first collected by the solar collectors and is then passed on to the dryer cabinet, where the drying occurs. The air heaters are connected. The basic concept of reverse flat plate collector is used to dry food products in a solar cabinet-type dryer. Here, a solar air heater is used to heat the air that enters the chamber. The heated air then turns in to warm humid air, which passes through an outlet. This kind of dryer is better

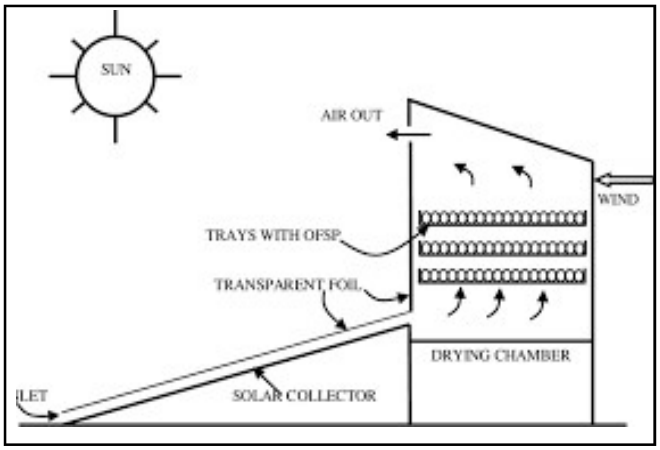


Fig. 2 : Indirect solar drier

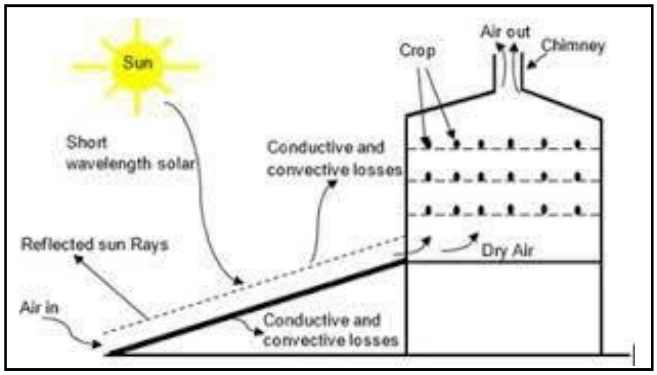


Fig. 3 : indirect solar drier

than other dryers in terms of solving various equations based on energy balance. It also has better performance than other conventional cabinet type of dryers. According to the Prof. A.G.M.B. Mustayen, method of drying is used to avoid direct exposing to the solar radiation. This method mainly reduces the disadvantages of direct solar drying Mustayen and Mekhilef (2014).

Mixed mode solar drying:

Mixed mode solar drying is one another advanced form of solar drying technique, in which both direct and indirect solar drying are performed simultaneously. This method also called as passive drier. The mixed-mode solar dryer has no moving parts, which is why it is called the passive dryer. This type of dryer acquires energy from the rays of the sun that enters through the collector lustering. The inside surface of the collector is painted black, and the sun's rays are harnessed by trapping the heat of the air that is collected inside the chamber. A previous study that examined the design and performance of this kind of solar dryer verified the accelerated drying process and its ability to dry agricultural products by quickly reaching better conditional moisture level, thus making it ideal for food preservation. A.G.M.B. Mustayen and Saad Mekhilef found that the mass flow rate effect and discharge rate of crop drying are good. Moreover, this system gives satisfactory result in terms of drying efficiency and moisture content. The maximum efficiency of the system was recorded at 21.24%, and the energy consumed during the drying process was 6–8%. Final moisture content was 13% at ambient temperature (25 degree Celsius) Mustayen and Mekhilef (2014).

Forced convection and natural convection solar dryer:

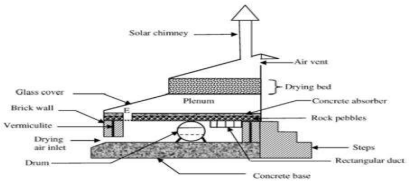
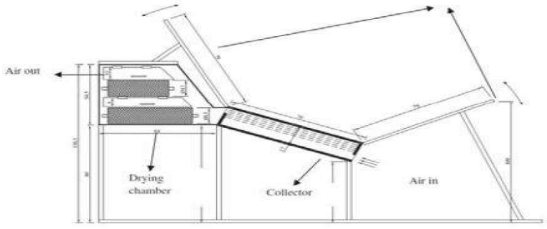
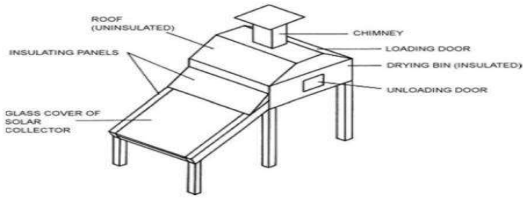
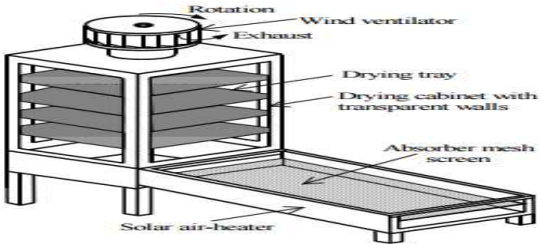
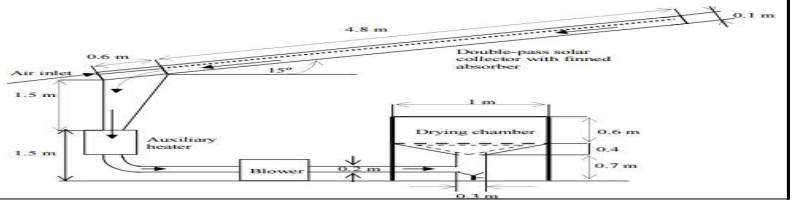
Natural convection :

This type of convection the circulation of air is take place in natural way. The flow of heated air has transfer by temperature gradient. When flow of fluid is due to buoyancy forces created by density differences are caused by temperature gradient in the fluid, the heat transfer in this action is called free or natural convection.

Forced convection :

Is a process in which we have used an external source to transport the air present in surroundings by using the fan. In this system natural convection, thermal conduction and thermal radiation occurs to transfer heat

Indirect solar driers

Author and product	Remarks	Figure
A. Madhlopa *et al.*(2007) Sliced pineapple [9]	Solar dryer integrated with collector storage and biomass-backup heaters. Moisture pickup efficiency was 13% in solar-biomass modes of operation	
Subarna Maiti *et al.* (2011) Papad [10]	Collector efficiency without load was enhanced from 40.0% to 58.5%. They dried 'papad' to a moisture content of 12 in 5 h. dryer has collector area of 1.8m^2 and loading capacity of 3.46 kg.	
Othieno *et al.* (1981) Maize [11]	The dryer consisted of a single glazed passive solar air heater with 1m2 single flat-plate collector. Moisture content reduced from 20% to 12% within 3 days and has capacity 90 kg.	
Bukola O. Bolaji.*et.al.* (2008) Pepper, yam chips	Average air velocity and daylight efficiency was 1.62 m/s and 46.7%. The maximum drying air temperatures was found to be 64oC inside the dryer. The weight losses were obtained 80% to55% in the drying of pepper and yam chips, respectively.	
R.K. Aggarwal (2012) Hill products	The solar dryer of 25kg capacity was attached with a solar cell for running the fan. Bulbs were also provided in the solar collector for heating air during cloudy days, evenings and mornings for faster drying, thereby reducing the drying time	
Fudholi *et al.* (2011) Marine products	The collector, drying system and pick-up efficiencies are found to be 35, 27 and 95 %, respectively. Moisture reduced from 90 % to 10 % in 15 h.	

by a very good rate in this system. The heat transfer co-efficients associated with forced convection are much greater than those associated with free convection.

Advantages of solar dryer :

– The higher temperature, movement of the air and lower humidity increases the rate of drying.

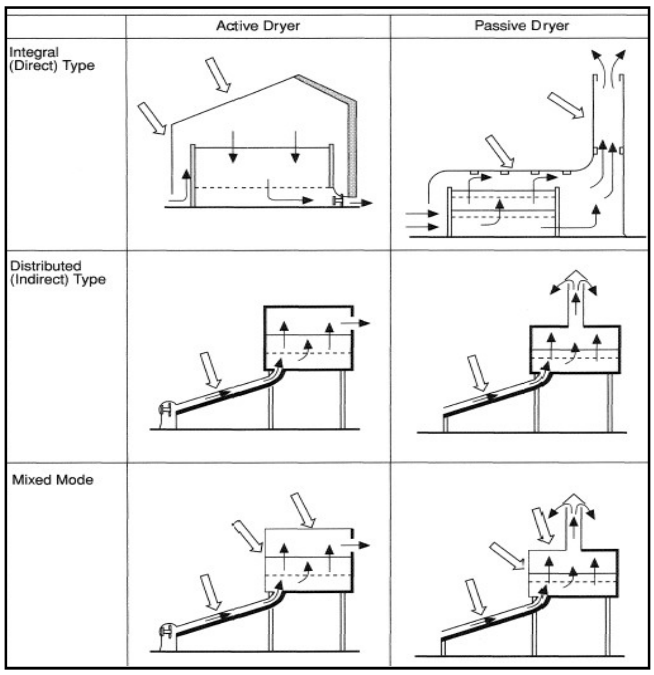


Fig. 4 : Solar dryer types according to mode of action

– Food is enclosed in the dryer and therefore protected from dust, insects, birds and animals.

– The higher temperature deters insects and the faster drying rate reduces the risk of spoilage by microorganisms.

– The higher drying rate also gives a higher throughput of food and a smaller drying area (approximately one third).

– The dryers are water proof, therefore, the food does not need to be moved during raining.

– Dryer can be constructed from locally available materials and are relatively low cost.

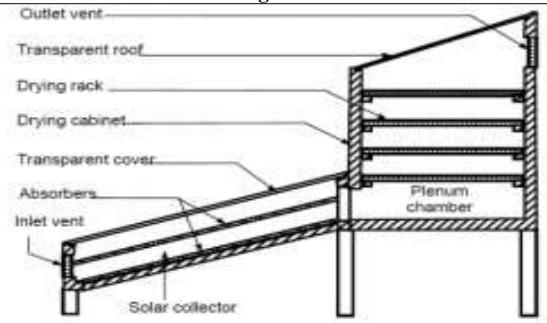
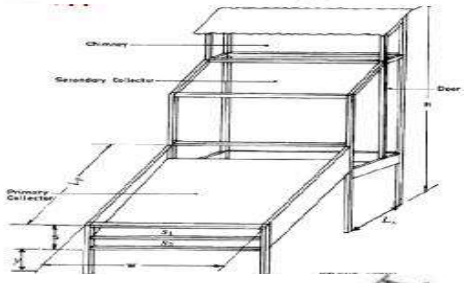
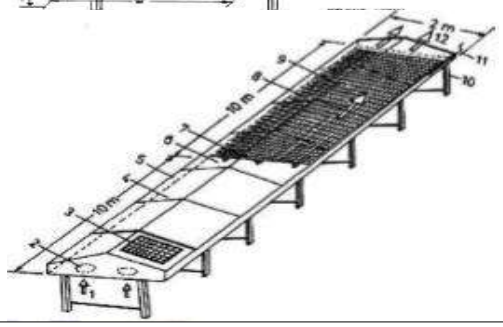
Limiting issues with solar dryer :

– 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.

Mixed mode solar driers

Author and product	Remarks	Figure
Bukola O. Bolaji and Ayoola P. Olalusi: (2008) Yam chips	The drying rate, collector efficiency and percentage of moist removed (dry basis) for drying yam chips were 0.62 kgh-1, 57.5 and 85.4%, respectively. The temperature rise inside the drying cabinet was upto 24° C	
F.K. Forson.*et.al* (2006)	Collector area of 42.4m^2 and expected drying efficiency of 12.5%. Under average ambient conditions of 28.2 and 72.1% relative humidity with solar irradiance of 340.4 W/m2, a drying time of 35.5 h was realized and the drying efficiency was evaluated as 12.3%.	
M.A. Hossaina and B.K. Bala (2005) Red chilli	The dryer consists of (1. air inlet 2. fan; 3. solar module; 4. solar collector;5.side metal frame;6.outlet of the collector7.wooden support; 8.plastic net; 9.roof structure 10.base structure for supporting The dryer;11.rolling bar; 12, outlet of the drying tunnel).Moisture content was reduced from 2.85 to 0.05 kg/kg(db) in 20 h.	

– A backup heating system is necessary for products require continuous drying.

Conclusion:

Solar drying of agricultural products is one of most important potential application of solar energy. In developing countries it is estimated about 30 to 40% of production of fruits and vegetables are losses during drying. The postharvest losses of agricultural products in the rural areas of the developing countries can be reduced drastically by using well-designed solar drying systems. Use of heat storage material in drying system will improve the efficiency of dryer and also dryer can be used after sunshine hours. Farmers should use solar dryers for drying their own agro produce and the use of solar dryers should be promoted by the respective Government authorities in the particular country. If we think of raisins production in India, still the 95% of the raisins are produced by the traditional open sun drying and shed drying, this inferior quality produce can be overtaken by superior quality produce by solar dryers. But to happen so, some steps should be taken to aware the farmers about the use solar dryers for their own fruits and vegetables produce.

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