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Solar Dryers for Post-harvest Processing: An Alternative Approach for Conventional Drying Methods

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Abstract

Fossil fuels and electricity are widely used as energy sources in most drying systems which results in high operational costs and environmental problems by increasing greenhouse gas (GHG) emissions. As a result, food producers have shifted towards clean energy-based technologies such as solar thermal energy in both direct and indirect form. Post-harvest losses are one of the major livelihood challenges for farmers. The use of drying technologies to preserve agricultural products has been promoted as a particular solution to overcome this challenge. Solar drying is one of the most efficient and cost-effective, renewable, and sustainable technologies to conserve agricultural products. This paper presents the different types of solar dryers that are widely used and details of construction and operational principles of the wide variety of practically-realised designs of solar-energy drying systems. Compared to open sun drying, the passive indirect solar dryer reduced drying time and increased the thermal efficiency. This study evaluates the performance of a solar dryer, a sustainable alternative to conventional food preservation technologies.

Keywords: solar thermal, solar dryer, open sun drying, post-harvest losses, drying systemIntroduction

Agriculture is the primary source of food for humans. As the population is increasing day by day most of the people are malnourished hence extra crops needs to be cultivated to meet the increasing demand. One of the alternative solutions to guarantee food safety is to minimize losses during harvest and post harvest. Post harvest loss occurs mainly due to microbial degradation

of crops. Microbial growth depends on storage conditions and moisture content. Drying is the one of the main method of food preservation to minimize post harvest losses. This process can be used for preserving various types of agricultural products in order to maintain product quality, texture and color. Pre and post processing of products before and after drying leads to the maximum advantage of

drying. This have major role in preserving products for long time. Based on the products to be dried preprocessing method varies. In recent year's renewable sources gaining much attention hence solar drying emerging technology an alternative method to conventional drying methods. Solar energy has been used for the preservation of agricultural produce since generations all over the world. Recent research on drying reveals the shortcoming of the open sun drying. In order to minimize the shortcoming of the open sun drying, various drying techniques are proposed [14].

Uncertain price rise and rapid depletion of fossil fuels accelerated the development of renewable energy sources in the form of alternative power sources. Solar is an abundant, renewable and sustainable energy source that attracted many eminent researchers across the world to work in the field of solar energy applications [10]. Shifting from fossil oil-generated electrical power to green energy has been a topic of greatest interest due to its huge negative impact on the environment and human well- being. Any step taken toward reducing pollution fingerprints would have a great contribution to saving the environment. Using solar energy in the food industry sector and precisely crop drying is one steptoward a clean environment. Several solar drying processes use various strategies to produce dry crops [2].

Solar drying assumes to be one of the alternatives to traditional drying method to improve post harvest management. Crop drying is essential for preservation in agricultural applications. It is performed either using fossil fuels in an artificial mechanical drying process or by placing the crop under the open sun. The first method is costly and has a negative impact on the environment, while the second method is totally dependent on the weather. By contrast, using a solar dryer is comparatively cheaper and more efficient [13]. In this paper emphasis has been given to understand drying principal, solar drying techniques and its importance.

Post-harvest processing

Postharvest processing involves cooling, cleaning, drying, sorting and packing. It is an important operation for decontamination of surface of fresh fruits and vegetables [9]. The postharvest processing increases the shelf life of fruits and vegetables [20]. Drying and cleaning is very important for maintaining high-quality grain. Problems with grain drying will vary from year to year depending on weather conditions. Grain moisture of 10–12% is optimum for storage
without further drying. It is important to harvest the grain when the plants are as dry as possible. Postharvest processing such as drying methods and storage conditions determine the stability of crops, which directly affects the market value of the product. The following flowchart gives the operation involved in postharvest processing. Drying is the final stage of processing.

Fig. 1: Operation involved in postharvest processing

Significance of Solar Drying

As 16% of agricultural product is wasted at post harvest level. Table 1 shows the post harvest losses of various agricultural commodities in India. It is therefore very important to minimize post harvest loss with minimum investment of
energy and economy. Efficient drying method should be adopted to minimize post harvest loss as it is complex process because it involves various changes in the product ultimately it affects the quality of product. Drying consumes 10-20% of total energy consumption hence it is necessary to develop energy efficient drying technology. Renewable energy sources such as solar energy is considerable source of energy for drying to minimize post harvest loss at sufficient level.

Table 1: Post harvest losses of various agricultural commodities in India (CIPHET, 2022)[6]

S.N.	Commodities	% loss
1	Grains	4.65 - 5.99
2	Pulses	6.36 – 8.41

3	Fruits and vegetables	4.58 - 15.88
4	Floriculture	30-35
5	Oilseeds	3.08- 9.96

Working Principle of Drying

The four principles of drying include excess water removal, evaporation, dehumidification and temperature control. Drying involves both heat and mass transfer operations. This process can be expressed as in following figure 2. The drying kinetics is used to describe the combined macroscopic and microscopic mechanisms of heat and mass transfer during drying, and it is affected by drying conditions, types of dryer and characteristics of materials to be dried. The various drying terms used in drying are illustrated in table 2.

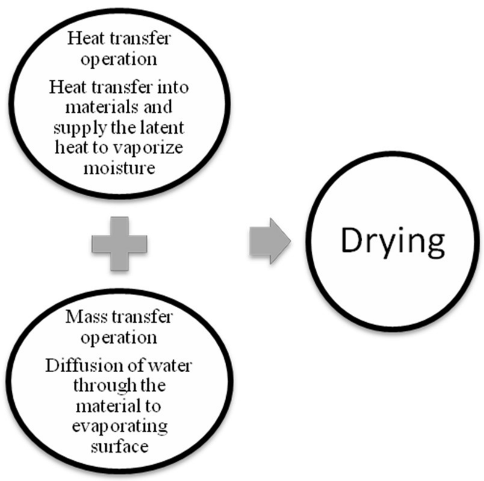

Fig. 2: Theory of drying

Table 2: Commonly used terms in drying [15]

S.N.	Term	Meaning/ Definition

Critical moisture content

Equilibrium moisture Content

Dry-Weight basiscontent corresponding to saturation humidity.
is the average moisture content when the constant-rate period ends
is the limiting moisture to which a given material can be dried under specific conditions of air temperature and humidity.
expresses the moisture content of wet solid as kilograms of water per kilogram of bone-dry

Moisture content

Bound moisture

Unbound moisture

of a solid is usually expressed as moisture quantity per unit weight of the dry or wet solid.
is that in a solid liquid, which exerts a vapor pressure less than that of the pure liquid at the given temperature.
in a hygroscopic material, is that moisture in excess of the equilibrium moisture

Wet- weight basis

Constant rate period

Falling rate periodsolid.

expresses the moisture in a material as a percentage of the weight of the wet solid.
is that drying period during which the rate of water removal per unit of drying surface is constant.
is a drying period during which the instantaneous drying rate continually decreases.

Solar Drying System

The schematic illustration of the drying system with the input and output terms is shown in Fig. 3. The figure shows the four major portion to consider, namely,
input of drying air to the drying chamber to dry the products, (2) input of moist products to be dried in the chamber, (3) output of the moist air after removing the evaporated moisture from the products, and
output of the dried products. The moisture contents are reduced to the level required for each commodity of the product.

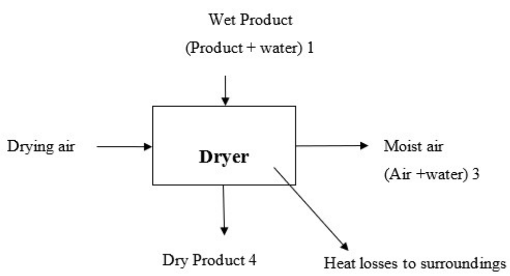

Fig. 3: Systematic illustration of drying system Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. Solar energy dryers can broadly be classified into direct, indirect and hybrid solar dryers (Fig.4). On the basis of the mode of drying, e.g. direct or indirect, solar dryers may be classified as passive and active ones: (a) Passive dryers, where crops are dried by direct impingement from the sun's radiation with or without natural air circulation, and (b) Active solar dryers,where hot drying air is circulated by means of a ventilator (forced convection).

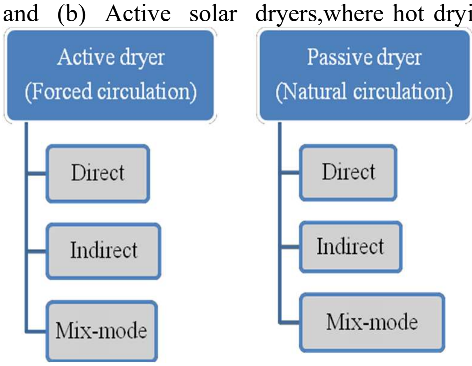

Fig.4: Classification of the solar drying systems The working principle of these dryers mainly depends upon the method of solar- energy collection and its conversion to useful thermal energy for drying. Open Sun Drying (OSD) Figure 5 shows the working principle of open sun drying by using only the solar energy [19]. Thecrops are generally spread on the ground, mat, cement floor where they receive short wavelength solar energy during a major part of the day and also natural air circulation [20]. A part of the energy is reflected back and the remaining is absorbedby the surface depending upon the colour of the crops [21,22]. The absorbed radiation is converted into thermal energy and the temperature of the material starts to increase. However, there are losses like the long wavelength radiation loss from the surface of crop to ambient air through moist air and also convective heat loss due to the blowing wind
through moist air over the crop surface [23]. The process is independent of any other source of energy except

sunlight and hence the cheapest method however has a number of limitations. In general, the open sun drying method does not fulfill the required quality standards and sometimes the products cannot be sold in the international market [24]. With the awareness of inadequacies involved in open sun drying, a more scientific method of solar-energy utilization for crop drying has emerged termed as solar drying [21].
A part of the transmitted radiation is then reflected back from the crop surface and the rest is absorbed by the surface of the crop which causes its temperature to increase and thereby emit long wavelength radiations which are not allowed to escape to atmosphere due to the glass cover. The overall phenomena causes the temperature above the crop inside the cabinet to be higher. The glass cover in the cabinet dryer thus serves in reducing direct convective losses to the ambient which plays an important role in incresing the crop and cabinet temperature [.

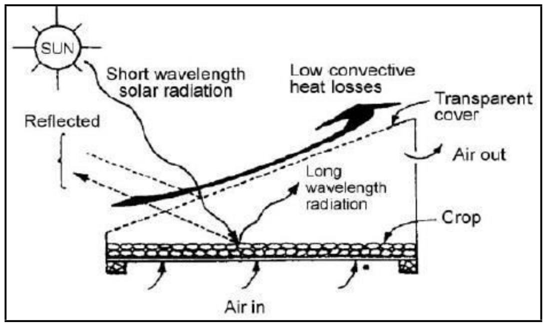

Fig. 5: Working principle of open sun drying The working principle of direct solar crop drying is shown in Figure 6 [19], also known as a solar cabinet dryer. Here the moisture is taken away by the air entering into the cabinet from below and escaping through at the top exit as shown in Figure. In the cabinet dryer, of the total solar radiation impinging on the glass cover, a part is reflected back to atmosphere and the remaining is transmitted inside the cabinet.Fig. 6: Working principle of direct solar drying These differ from direct dryers with respect to heat transfer and vapor removal. Figure 7 [19] describes the working principle of indirect solar drying. The crops in these indirect solar dryers are located in trays or shelves inside an opaque drying cabinet and a separate unit termed as solar collector is used for heating of the entering air into the cabinet. The heated air is allowed to flow through/over the wet crop that provides the

heat for moisture evaporation by convective heat transfer between the hot air and the wet crop. Drying takes place due to the difference in moisture concentration between the drying air and the air in the vicinity of crop surface [21].

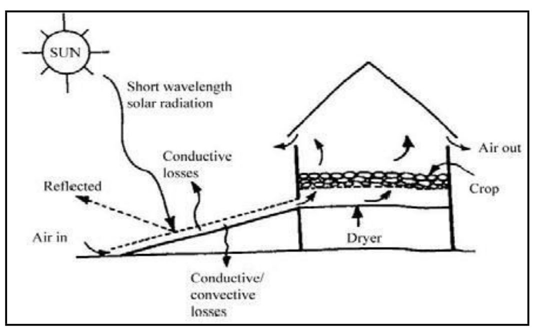

Fig. 7: Working principle of indirect solar drying

Evaluation of Solar Dryer

Solar food dryers are available in a range of size and design and are used for drying various food products. It is found that various types of driers are available to suit the needs of farmers. Therefore, selection of dryers for a particular application is largely a decision based on what is available and the types of dryers currently used widely [19]. Hence following figure 8 gives preliminary criteria considered while evaluation and selection of dryer.

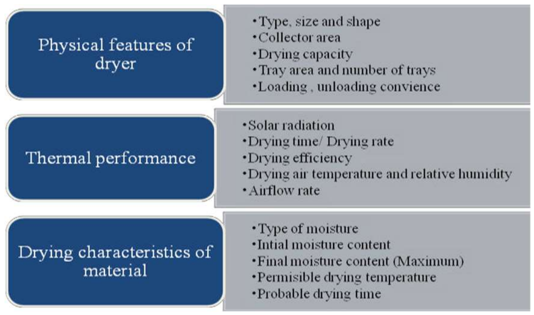

Fig. 8: Preliminary evaluation of solar dryer

Energy Analysis of Solar Dryer

Solar dryers take into application of energy conversion from solar to useful thermal energy for drying process. For this purpose, numerous methods and processes were developed and their effectiveness can be evaluated on many merits, such as energy efficiency, time to dry and product quality. In solar drying, thermal performance is a reliable indicator to study the system merits and can be quantified using energy analysis. Energetic performance is based on the first law of thermodynamics, which takes in to account the quantity of energy and the energy change in respect to the change in surroundings [18]. However, the drawbacks of energy analysis is that it only considers energies at inlet and outlet of the system, and sometimes is redeemed as insufficient for system optimization as it neglects the irreversibility and thermodynamic losses [4,5,11]. In general, energetic analysis on solar dryers can be done on two main components; the drying systems and the drying materials [7]. Drying systems of solar dryers includes the solar absorber unit, drying chamber, and movement of heated drying air throughout the system [8]. In short, energy analysis of solar dryer components is commonly done by applying
heat transfer and energy balance based on the principle of energy conservation of the first law of thermodynamics. Determination of thermal performance of solar dryers are important to achieve maximum moisture removal while using minimum amount of energy [9]. In literature, there are several indicators that are commonly used to evaluate the thermal capacity of solar dryer components, especially for solar collector unit. The amount of useful heat that can be harness from solar collector can be calculated using heat removal factor and the incident solar radiation [3].

Thermal efficiency of solar collector is the ratio of heat gain by air passing through the collector to the energy gained due to solar irradiation. Another indicator commonly used in energetic analysis is the thermal efficiency of solar dryers [10]. Essentially it is the ratio of energy required to evaporate product’s moisture to the energy consumed for the drying process. In short, thermal efficiency of the drying system is the ratio of the energy used for moisture evaporation to the energy input to the drying system [12].

In passive convection dryers, dryer efficiency calculation is based on the air movement due to natural buoyancy, whereas active dryers takes into account the energy input through electrical fans or blowers,given by respectively [1], [17]. Depending on the type of solar drying system, the energy consumed for drying process would need to account for all source of energy generated in the system. In hybrid system, usually photovoltaic-thermal (PVT) hybrid dryers, electrical efficiency of solar collector is quantified as the system takes electricity into energy generation.

The relationship between energy input to solar dryer and amount of water evaporated can also be used to define the performance of the dryer and to compare performance of the dryers. is Specific moisture extraction rate (SMER) in kg kWh-1 relates how much moisture can be removed per unit of energy, whereas specific energy consumption (SEC) is the reciprocal of SMER with units of kWh kg-1 [16].

Development in solar dryers

With future research in consideration some advance dryers needs to be developed as per design considerations. Heat storage medium is an advance step towards long drying hours also the dryer assisted with reflectors gives exposure of dryer to the sun with enhancement in drying efficiency and reduced drying hours. Above section gives the working principle of dryers but with some modifications in conventional methods
improves solar dryer performance as discussed above.

Conclusion

The development and introduction of solar drying as post-harvest technologies are significantly important in improving
fulfilling the increasing demand of healthy, low cost natural foods and need for sustainable income. Solar dryers used for agricultural product drying can be proved to be most useful device from energy conservation point of view that not only save energy but also saves a lot of time, occupying less area and improves product quality.

Conflict of Interest:

The author declares that there is no conflict of interest associated with this research. The study was conducted independently, and no financial or other support was received from any external sources that could potentially influence the results or conclusions.

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