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RECENT DEVELOPMENTS AND COMPREHENSIVE REVIEW ON GREENHOUSE DRYERS

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Abstract

Use of solar energy for drying the food items is a very common way used throughout the world. Different types of solar dryers has been developed by a number of researchers for drying different agricultural produces. Greenhouse solar dryers are very helpful in drying various commodities in large volumes in a controlled manner and in very economical way. In this review article basics of various types of solar dryers and recent advancements in greenhouse dryers have been presented. The use of solar collectors, solar air heater and heat storage materials with greenhouse dryer have also been reviewed.

Keywords:*Drying, Solar dryers, Greenhouse drying.*

1. Introduction

Food is a very basic need of every living one. Crops are harvested to fulfill the food requirements.It is difficult to consume all the food at one time. In other words, if the production is higher than the consumption, the need for storing the food items arises. A number of techniques have been used for storage of food commodities. Drying is one of the oldest and most widely used methods of food preservation. Drying can extend the shelf life of the food and canavoid the losses during the storage period (Sivakumar and Rajesh, 2016). The high moisture crops are prone to fungus infection and attacks by insects and pests (Tiwari, 2002).Drying reduces the available moisture of the product to a certain level. With this reduced moisture level, the product can be stored for a period of time i.e. "Safe storage period".Drying is a combination of two processes; the first one is the heat transfer from the heating source to the product and the second is the mass transfer in the form of moisture from the interior of the food or product to its surface (Ekechukwu and Norton, 1999). Drying with the help of solar radiation is a very economical procedure for agricultural products and on the other side it is very friendly to the environment.

2. Solar drying

Drying with the help of solar radiations in an open space is the most commonly used preservation technique for agricultural products in most developing countries.The various types of solar drying techniques are shown in figure 1.

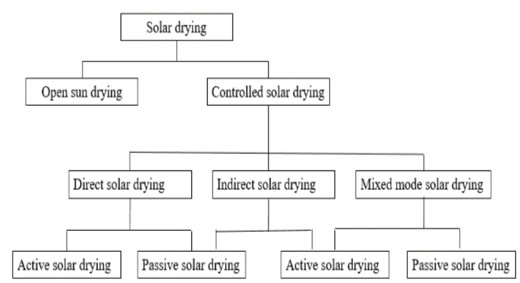

Figure 1 Classification of solar drying (Ekechukwu and Norton, 2012)

The open space condition of this drying process is very antipathetic to the food products and leads to severe losses in the quantity and quality. So, controlled solar drying was developed to reduce or eliminate these losses and enhance the quality of the dried product (El-Sebaii and Shalaby, 2012). In direct type controlled solar drying the product to be dried is placed in achamber called "drying chamber" which is either made of wood or a metal. The top of the chamber is enclosed with the help of a transparent cover such as plastic or glass etc. The product and internal surface of the drying chamber get heated up by absorbing solar radiation directly falling on them.In Indirect type controlled solar dryingthere is no direct contact between the solar radiations and the product to be dried. Solar collectors are used to receive the solar energy and tosupply it in the form of hot air to the drying chamber to dry the productby convection and diffusion. The mixed mode controlled solar drying is a combination of both direct and indirect type solar drying processes.

On the basis of method of air flow solar drying techniques can be classified as passive solar drying and active solar drying. In passive solar drying,the heat transfer fluid, i.e., air moves either due to buoyancy force, pressure differences or combination of these two. It is also known as natural convection solar drying. In this type of process the drying rate is slow because the air circulation is very slow but in case of active solar drying an additional device such as a pump and blower etc. is used to circulate the hot air. Figure 2 shows active and passive solar drying with some technical arrangements (direct, indirect and mixed mode type) of dryers.

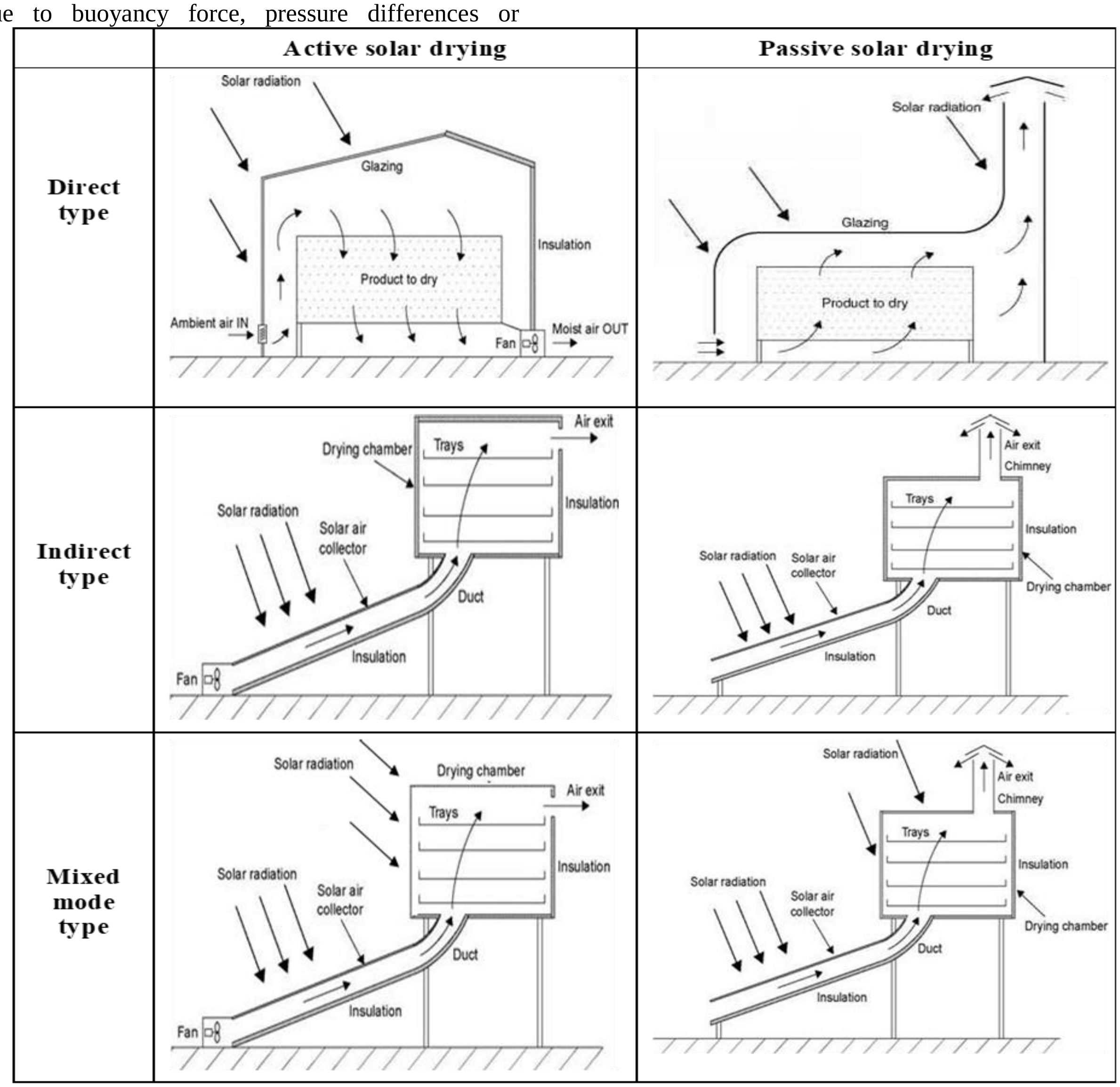

Figure 2 Schematics of typical solar drying arrangements (Ekechukwa and Norton, 1999)

3. Greenhouse drying

Greenhouses are being used for the purpose of cultivation of the crops from a long time but from the last two and half decade, greenhouse structures are also being used for the purpose of low temperature drying with the help of solar radiation (Singh and Shrivastava, 2017). In greenhouse structure the longer wavelength radiations get trapped due to the opacity of the cover to them. This cause's temperature rise in the greenhouse structure and this effect of temperature rise is known as greenhouse effect (Sahdev et al., 2016).Greenhouse drying is a type of direct solar drying and can be of an active or passive type depending upon the mechanism of air flow through the system. An enclosed structure of transparent roof and walls made up of glass and polyethylene film *etc.* is known as a greenhouse. The crop or product to be dried is placed inside the greenhouse. The solar radiations reach the crop through a transparent cover and moisture of the product is removed either by natural convection or forced convection. The greenhouse technology improves the product quality and reduces the drying period to a noticeable extent (Prakash and Kumar, 2014c). Figure 3 shows the classification of greenhouse based on different parameters. Various studies conducted on greenhouse drying are summarized in table 1.

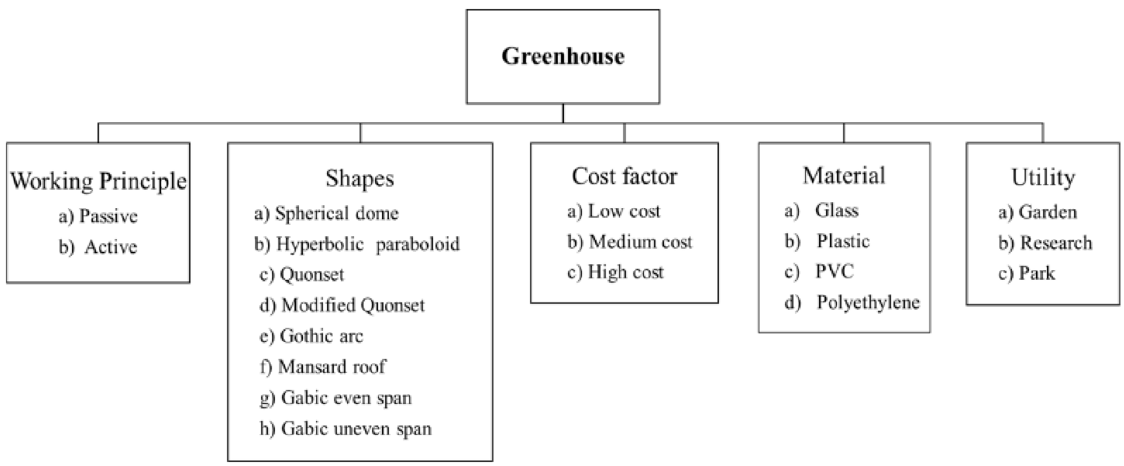

Figure 3 Classification of greenhouse based on different parameters (Sahdev, 2014)

Table 1 Studies on various greenhouse dryers

S. No.	Researchers	Year	Remarks
1	Kumar and Tiwari	2006	Shape and size of the commodity plays a very significant role in the variation of convective mass transfer coefficient.
2	Janjai et al.	2009	The drying time was reduced by 2 days for both peeled longan and banana using active mode greenhouse dryer.
3	Bennamoun	2012	Variation in the received solar radiation, ambient temperature, and surface area of the collector greatly affects the energy and exergy efficiencies of a solar dryer.
4	Almuhanna	2012	Loss of 39.89% of solar radiation with 60.11% average overall thermal efficiency was reported for the solar greenhouse.

5	Kumar	2013(a)	Convective and evaporative heat transfer coefficients were ranges from 0.739 W/m2 °C to 0.786 W/m2 °C and from 21.37 W/m2 °C to 25.42 W/m2 °C respectively.
6	Kumar	2013(b)	Convective heat transfer coefficient ranges from 1.08 W/m^2 °C to 1.40 W/m^2°C with an average value of 1.23 W/m^2 °C.
7	Janjai et al.	2014	Greenhouse solar dryer took 5 days for complete drying of the given commodity.
8	Prakash et al.	2016	The exergy efficiency ranges from 29% to 86% and 30% to 78% respectively for passive and active modes.
9	Kumar and Shrivastva	2017	Proposed that greenhouse with opaque north wall as the best modification to reduce heat losses.

4. Studies on Modified Greenhouse dryers

In a commercial greenhouse drying system the product quality and the drying time are of major concern. If the temperature inside the greenhouse increases in a controlled manner then both of these major concerns can be solved up to a great extent. Solar collectors or solar air heaters are the devices which can be used to increase the normal greenhouse temperature. Solar collectors can be used to supplement the inside air temperature of the greenhouse dryer. Flat plate solar collectors was generally used for this arrangement. Chauhan and Kumar (2016) studied a north wall insulated greenhouse dryer with and without solar collector and found that the unit with the solar air collector was more effective for drying applications. Azaizia et al. (2017) used a chapel shaped greenhouse dryer for pepper drying. A flat plate solar air collector was attached to the greenhouse as a modification. They developed a mathematical model to predict the behavior of drying kinetics with the help of TRNSYS. An increase in efficiency was observed with proposed modification. Elkhadraoui et al. (2015) studied a flat plate solar collector enabled chapel-shaped forced convection greenhousedryer for red pepper and sultana grape drying. The results showed that the greenhouse dryer took 17 h to reach the moisture content to 16% wet basis (w.b.) for red pepper, whereas it takes 24 h in open sun drying. The moisture content of Sultana grape was reduced to 18% (w.b.) in 50 h for greenhouse drying, whereas it takes 76 h in case of open sun drying. Chauhan et al. (2017) uses a solar air collector as a modification in the greenhouse drying system and compared the predicted and experimental results for the drying of bitter gourd flacks under open sun, natural and forced convection modes. It was concluded that the modified greenhouse dryer under forced convection is best among open sun and natural convection drying modes.

Chauhan and Kumar (2016) observed in a study that the north wall plays a significant role in the performance of a greenhouse. Berrouga et al.(2011)observed that the efficiency of greenhouse get increased when the north wall was made up of phase change material. A 6 – 12 °C rise of temperature with lesser fluctuations was reported. Prakash and Kumar (2014c) used a mirror as the north wallas an improvement and to enhance the use of solar radiation in the greenhouse dryer. Prakash and Kumar(2013) also obtained similar results about performance improvement in a study on greenhouse dryer with the north wall made up of mirror using Adaptive Neuro Fuzzy Inference system (ANFIS).Sethi and Arora (2009) used an inclined north wall reflection as a modification in a conventional greenhouse drying for higher drying rates.It was observed that this improvement produces the significant positive results by reducing the drying time for bitter gourd drying. Prakash and Kumar(2014b) observed a very significant reduction in heat losses in a study on greenhouse dryer with the application of opaque north wall. An increase in the inside greenhouse airtemperature and reduction in relative humidity was also reported in case of the application of a black sheet on the floor area of the greenhouse.

The use of thermal heat storage devices in greenhouse dryers is another improvement studied and suggested by a number of researchers. Sensible heat storage and latent heat storage devices are generally used for thermal energy storage in greenhouses. Ayyappan et al.(2015) studied agreenhouse dryer under natural convection using different sensible heat storage materials (concrete, sand, and rock-bed). Results revealed that the moisture content of coconuts was reduced from 52 to 7 % (w.b.) in 78h, 66h and 53h using concrete, sand and rock-bed as heat storage material respectively as compared to open sun drying which takes 174 h for doing the same. Ayyappan et al., (2012) in a study compared the performance of a solar tunnel dryer with and without a sensible heat storage material (rock-bed) under natural convection mode. An increment of 2 – 3% was observed in the efficiency of the dryer with sensible heat storage.Prakash and Kumar (2016) studied a greenhouse with a north wall made up of mirror in case of the dryer floor with and without a black PVC sheet. Lower heat losses was observed in the case where the floor of the greenhouse dryer was covered. To overcome the demerit of lack of perpendicular solar radiation on the dried items in a simple greenhouse dryer an inclined roof and drying tray was studied experimentally and numerically using Computational Fluid Dynamics (CFD); and a positive result was reported. Jain (2005) conducted a study on an even shaped greenhouse for drying of onions. A black painted north wall made up of bricks was used to reduce the north wall losses. A tray type crop dryer was created next to the north wall throughout with thermal energy storage system of packed bed type. The hot air was forced to the drying section with the help of blowers placed at the junction of greenhouse and crop dryer to maintain the forced convection. A greenhouse with crop dryer is shown in figure 4.

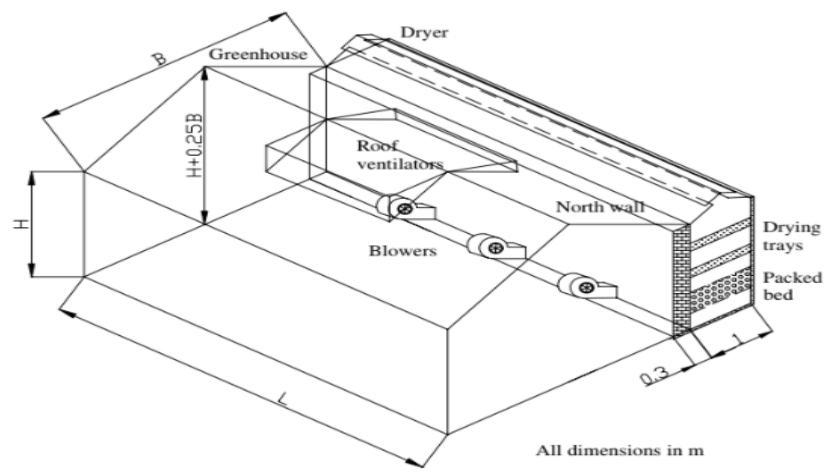

Figure 4 Greenhouse with crop dryer (Jain, 2005)

Table 2 Studieson various modified greenhouse dryer

S. No.	Researchers	Year	Type of Greenhouse	Modification	Remarks
1	Jain	2005	Even shaped forced convection.	Black insulated North wall, adjoined tray type crop dryer and packed bed thermal storage.	Lesser heat losses from the system and a significant reduction in the drying time was recorded for onion drying.
2	Sethi and Arora	2009	Even span natural and forced convection.	Inclined North wall reflection.	A significant reduction in the drying time was recorded for bitter gourd.
3	Berrouga et al.	2011	Even span natural convection.	PCM North wall	A 6-12°C rise of temperature with lesser fluctuations was observed.
4	Ayyappan et al.	2012	Natural convection	Rock bed as sensible heat storage.	A 2 – 3 % increment in the efficiency of the dryer was recorded.
5	Prakash and Kumar	2013	Even span forced convection.	Mirror North wall.	Adaptive Neuro Fuzzy Inference system was used to predict the behavior of the system.
6	Prakash and Kumar	2014a	Even span roof type natural convection.	Opaque mirror North wall with PVC covered floor.	A significant rise in the greenhouse temperature was recorded.
7	Prakash	2014b	Even span	Opaque	Higher

	and Kumar		roof type forced convection.	North wall and concrete covered floor.	inside temperature and reduced heat loss was observed in no load condition.
8	Ayyappan et al.	2015	Natural convection.	Concrete, sand and rock bed as sensible heat storage.	The rock bed SHS system takes the shortest time period for the drying of coconuts.
9	Chauhan and Kumar	2016	Natural convection.	Insulated North wall with solar collector.	System with North wall and solar collector proved to be much more efficient.
10	Jitjack et al.	2016	Parabolic shaped forced convection.	Additional area - enhanced panels.	The modification of enhancing the area proved out to be best with respect to more heat gain, less drying time and higher thermal efficiency.

5. Summary and recommendations for future work

Crop drying is one of the most important processes done after harvesting. It is estimated that about 80% of farmers across the globe uses open sun drying for long preservation of crops. It is observed from the available studies that the passive or natural convection greenhouse dryers are much suitable for low moisture crops drying and active or forced convection greenhouse dryers are more suitable for high moisture crop drying. Greenhouse dryers are of great importance in remote areas where electric supply is not available and the places where there is a need for drying a huge amount of products. Opaque north wall and black sheet coated floor are proposed to be the best modification to reduce heat losses by a number of researchers. Flat plate solar air heaters are also being used to enhance the overall performance of a conventional greenhouse dryer. So, solar collector should be studied and investigate more for improvements. Double sided flat, V -corrugated,finned and porous plate type solar air collectors should be studied as improvements in flat plate collector.The use of thermal energy storage as a modification for the expansion of the working period of the dryer is also suggested by a number of researches. Possibilities in improvement and enhancement in this technology is still required. A little consideration on the use of external energy sources, energy storage materials, geometries of the greenhouse can enhance the performance of the drying system.

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