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Recent Developments in Renewable Solar Energy based drying Systems: A Review

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Abstract

India is the largest producer of fruits and vegetables, but still about only 2% of the produced fruits and vegetables are processed and safely preserved. The remaining is lost because of poor processing and post harvesting techniques. The intent of this article is to provide an summary of new technologies adapted for safe storage of food products by solar drying. New drying technologies not only preserve food products by drying but also it is cost effective, reduce energy consumption and improve the quality of dried product. In this article the recent design variations, performance of different dryers and various modeling techniques carried out in solar drying of food products have been discussed.

Keywords: *Post harvesting techniques, modeling techniques, solar drying*

I. INTRODUCTION

Drying is mainly done to remove the moisture content from the product to enhance the shell life of the product. Nowadays the demand for agricultural products, marine products and medicinal plants has increased considerably. Naturally dried products are the cheapest whereas their quality is far below the international standards.

Solar drying is one of the oldest ways for preserving crops in which crops are put on earthen floor in sunny days for drying. The main drawback in open sun drying under solar drying is the product exposed to contamination. Kumar et al. [1] presented a comprehensive review on the design, development and performance of various solar dryers and reported that indirect mode forced convection dryer is having higher drying speed and drying quality because of its higher drying rates and energy effectiveness. Different drying techniques and different modes of drying was analyzed by Setontakke et al. [2] and found that time taken for drying in mixed mode solar dryer is comparatively lower than other type of dryers. Phadke et al. [3] have done a review on various technologies and identified indirect solar dryer to improve the efficiency and to reduce drying time. Fudholi et al. [4] performed an energy and exergy analysis of solar drying process on red chilli and found that 49% of drying time is saved when compared to sun drying and identified the minimum and maximum values of exergy losses during the drying process. Chouicha et al. [5] conducted an experimental investigation on forced convection indirect solar dryer for drying sliced potatoes and found the best operating conditions to get higher efficiency and lower duration time. Padmanaban et al. [6] discussed the various types of dryer and compared the advantages of solar dryer over open sun drying. Bakhtyar et al. [7] analyzed the design and performance of different solar drying system with air solar collector

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presented by different authors in terms of capacity, drying time and energy consumption. Christinal et al. [8] analyzed the different drying methods on seed quality in chilli and found that seed quality and nutrition content is good in sun and oven drying.

Greenhouse drying is one of the drying methods where the product is dried inside a closed setup covered by a glazing sheet like polyethylene, polycarbonate etc. Kumar et al. [9] presented a detailed classification of greenhouse drying based on modes of heat transfer in to active mode, passive mode and mixed mode. Aliyu et al. [10] designed and developed a greenhouse dryer for drying cassava chips and found that drying time reduced by 30% under greenhouse drying compared to open sun drying. Aritesty et al. [11] obtained the drying performance of a greenhouse effect solar dryer for sliced wild ginger. Dong et al. [12] investigated the effects of different environmental condition on the wheat growth on greenhouse dryer.

In the present work the design variations, new modeling techniques used and the various products dried recently by various researchers have been presented.

II. NEW MATERIALS AND DESIGNS

Solar dryers are classified depending upon the mode of air circulation as shown in Fig.1.

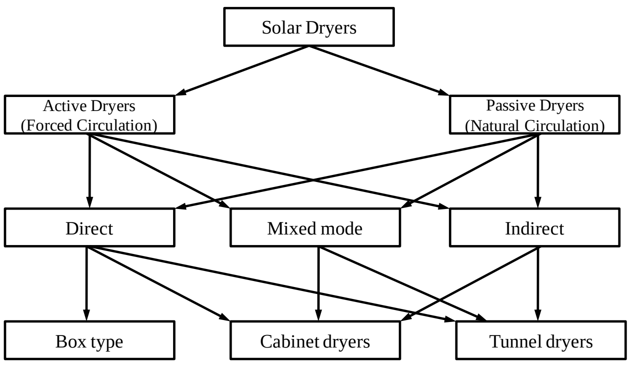

Figure 1 Classification of solar dryers

Subahana and Natarajan [13] developed an indirect type solar dryer shown in Fig. 2.The plate is made of and is inclined at 17° to the floor. To improve the heating capacity of the equipment, the lower part of the plate is treated with black paint. Solar drying is done using two solar dryers, one having flat plate collector and other having collector with fins to increase area of absorption of solar radiation.

Figure 2 Forced Convection Solar Dryer

Kinetic Modeling of the drying of chickpea with solar energy was created by Lopez et al [14]. The equipment used in this work is presented in Fig. 3. The chimney-type solar collector operated in natural convection. The trapping surface inclination was inclined at 40° with respect to the horizontal plane and was oriented south-north to capture the maximum solar energy.

A Desiccant Integrated solar dryer for drying of cocoa beans proposed by Dina et al. [15]. The normal solar dryer is integrated with the desiccant bed to absorb moisture content. Desiccant is a hygroscopic substance that sustains a state of dryness by absorbing moisture. The green pea is placed in the drying tray. Flat plate collector is placed facing south tilted at an angle of 30° to ensure maximum utilization of solar radiation. An experiment was conducted in both sunshine and off sunshine hours. In sunshine hours the desiccant bed is placed at top of the dryer, between bed and tray a gap is provided for ventilation. In off sunshine hours the desiccant bed is placed below to avoid the heat loss and 2-way fan is provided for air circulation. The results show that the product is dried uniformly. Fig. 3 shows the desiccant integrated solar dryer.

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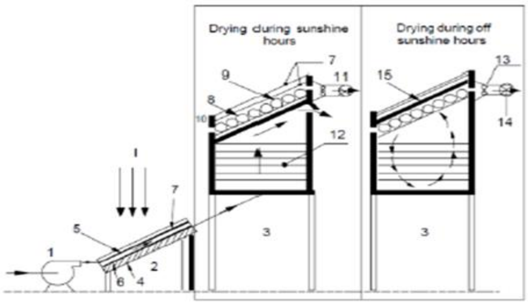

Figure 3 Desiccant integrated solar dryer

1. Blower; 2. Flat plate collector; 3. Drying chamber; 4. Insulation; 5. Absorber plate; 6. Bottom plate; 7. Transparent cover; 8. Desiccant bed; 9. Plywood; 10. Air inlet; 11. Duct for air exit; 12. Drying trays; 13. 2way fan; 14. Valve; 15. Plywood

Aliyu et al. [10] have proposed an indirect passive solar dryer for drying cassava chips. The frame which consists of a 30 mm square angle iron with a clear space of 50 cm above the ground. Its internal volume is 100 cm long x 10 cm wide x 120 cm high. The absorber plate which consists of 1.5 mm mild steel sheet metal inclined at an angle of 19^{o} and painted black with black paint. The bottom and sides of the absorber plate are lined with 25 mm insulating particle board. To preserve the collector from damage due to rain fall, it is made detachable so that at the end of drying period, the whole collector can be detached and kept safely for further use. The Transparent Cover is a 5 mm thick clear transparent glass sheet 15 cm above the absorber plate. A cylindrical chimney of 5 cm diameter and 10 cm high is positioned at the top of the drying chamber for ventilation. Cool air coming in through the aperture is heated up at the absorber plate surface and rises through the drying chamber to the exit opening at the top.

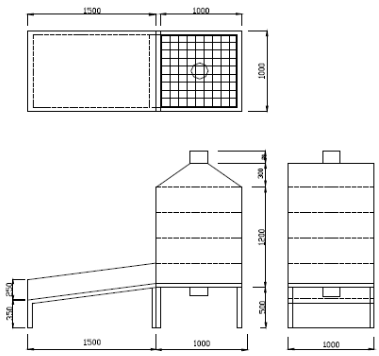

Figure 4 Orthographic views of the solar dryer

Navale et al [16] have proposed cabinet Solar dryer for drying of Fenugreek leaves. The cabinet solar dryer consists mainly of two parts such as cabinet and chimney. The cabinet and chimney was made by waterproof plywood. The front sides of cabinet and chimney were covered with transparent glass. The schematic diagram is shown in Fig. 5. The temperature inside the cabinet can be set according to drying temperature of vegetables by adjusting the width of chimney mechanically. For fenugreek leaves required temperature for drying was 45°C to 60°C.

Chillee et al. [17] has proposed spouted bed drying of papaya seeds for oil production.

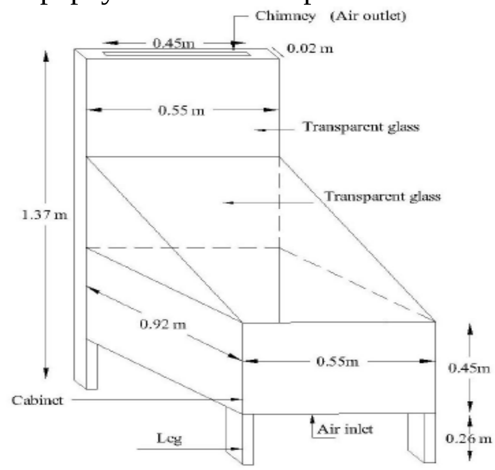

Figure 5 Cabinet solar dryer

Spouted bed dryer unit consists of a radial blower a bypass system consisting of gate discharge, thermo anemometer with propellers to measure the air velocity, a set formed by three resistors each power of 1000 W controlled by a control system, a manometer U tube, the bed, particulate collector, a cyclone psychrometer to measure the moisture and potentiometer to regulate the air flow.

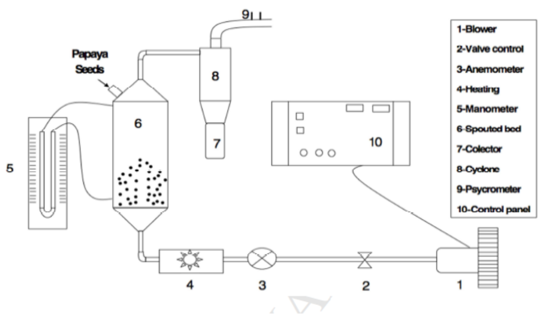

Figure 6 Spouted bed dryer

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Spouted bed has 60° in the conical base and 45° in the conical top. A hot air Infrared assisted vibratory bed dryer for drying of green pea was proposed by Marvasti et al [18]. The dryer was equipped with a provision to vibrate the drying tray on which the green peas were placed. The reciprocating motion was created by crank and slider mechanism. The thickness of drying beds was equal to a single, double and triple green peas diameter for different treatments.

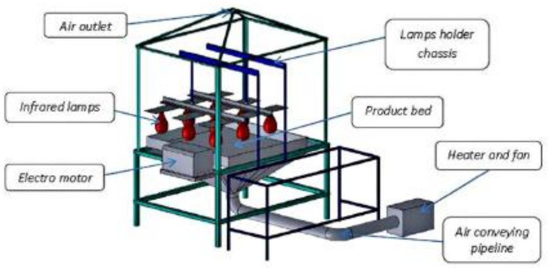

Figure 7 Infrared assisted vibratory bed dryer

Patil et al [19] has proposed solar tunnel dryer. In the solar tunnel dryer the food product is dried under the sun light. The dryer has a drying chamber which is covered by the transparent cover usually made up of polyethylene, polycarbonate sheets. The drying chamber is usually shallow and insulated box and has a hole for the air circulation. Solar collector is placed on the roof to provide a suitable temperature at off sunshine hours. The chilli is placed in the wire mesh tray that allows the free air circulation. Fig. 8 shows the schematic representation of Solar tunnel dryer. External fan is provided to exhaust the air inside the drying chamber enables a new air circulation. The results show that the quality of chilli dried in the Solar Tunnel dryer is far superior than the conventional drying.

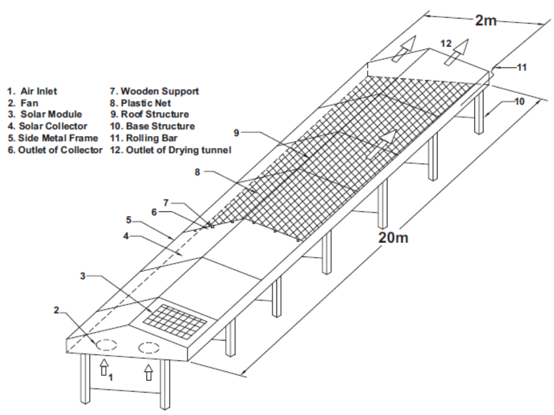

Figure 8 Solar tunnel dryer

Omprakash et al[20] performed a energy and exergy analysis on modified greenhouse dryer with thermal energy storage using poly carbonate sheet as glazing material operating under active and passive mode. The experimental result reveal that for high moisture content crops, modified green house dryer is found to give better performance under active mode. But, the pay back period of active mode of modified green house dryer is slightly higher than passive mode green house dryer because of additional components in active mode dryer.

Rasaq O et al [42] has proposed a Hybrid drying method to dry the food products. In those drying the food products were dried in Solar-Biomass hybrid dryer. Fig.9. shows the construction of Hybrid dryer for drying maize. The principle behind the dryer is greenhouse effect and also uses solar powered PV fan to provide Forced Convection. The dryer was capable of drying 12,923 bags of maize per year and had a payback period of 2 years.

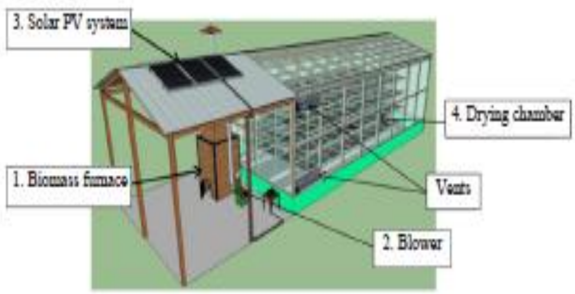

Figure 9 Solar-Biomass Hybrid Dryer

III. NEW MATERIALS FOR PRODUCTS

Bemamoun et al. [21] analyzed the different drying methods affecting the physical and chemical properties of algae and identified that freeze drying showed better quality of lipids and β – carotene. The quantity of protein was found higher in case of convective drying. Navale et al. [16] studied the drying performance of a fenugreek leaves on a cabinet solar dryer and open sun drying. It was found that drying time was reduced in cabinet solar dryer. The temperature inside the cabinet is 20 - 22°C more than the outside temperature and the overall efficiency is 68.12% greater than open sun drying. Yuan et al. [22] designed a solar drying system using a solar air heater for drying carpet and found that drying

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time is considerably reduced. Navale et al. [23] fabricated a cabinet solar dryer to dry fenugreek leaves and found that drying rate, nutrition content of the products dried like protein and fat is higher in cabinet dryer. Chielle et al. [24] studied spouted bed drying of papaya for oil production and found that air temperature of 70°c and air velocity of 10.50 m/s gave a better oil content in the seeds. Chen et al. [25] made a comparative study to dry Jujube fruit under hot air drying method and short, medium wave infrared radiation and concluded that SMIR drying showed minimum drying time, high drying efficiency and gave a better quality product. Sallam et al. [26] developed two identical solar dryers for drying mint under natural and forced convection. The result showed that drying rate was higher under forced convection. Fudholi et al. [27] worked on with performance improvement of a solar drying system for drying palm oil fronds to reduce the floor space and dependent condition on availability of sunshine. They performed energy and exergy analysis for drying palm oil fronds and found considerable improvement in drying. Yilmaz et al. [28] monitored the drying kinetics of pomegranate under vacuum, cabinet and open air. From the study it was concluded that drying was quicker and samples gave a higher bioactive content when dried under vacuum drying. Djaeni et al. [29] studied the effect of air temperature, humidity and velocity on drying. Better quality of dried seaweed is obtained at temperature 70°c and below. Ferreira et al. [30] evaluated the drying of solid waste in an integrated solar dryer to remove moisture after treatment of effluents till the moisture content reaches to 30% wet basis to reduce the transportation cost. Subanana et al. [13] investigated the drying characteristics of chilli leaf in open sun drying and solar forced convection drying. It was found that the drying rate was more and moisture content was less when the temperature of drying air increased in forced convection drying. The chick pea is a type of pulse dried by Lopez et al.[14] under natural convection, It took 40 hours in April to reduce the moisture content from 0.52 kg.water/kg.dry mass to 0.02 kg.water/ kg.dry mass and the numerical model that best represented was exponential one. Pastrana [31] conducted an experimental analysis for drying Nopal under Indirect solar dryer and found that indirect solar dryer give better result than cabinet dryer in the basis of drying rate and quality of the product. Seidu et al. [32] conducted a study with five different panels on the effects of nutritional content of Ayyolo leaves, Moringa leaves and Bitter leaves by solar drying covering the panel with black polythene sheet partially and found that weight loss was more in blanched samples and there was increase in carbohydrate in the dried product.M.M.Morad et al [33] made a thermal analysis on solar tunnel green house dryer for drying pepper mint leaves and peppermint plants. The results revealed that at the optimum flow rate of 2.10 m^3 / min and loading the green house by 4 kg/m^2 and with continous operation of fan increased the drying rate.Francisco et al [34] developed a methodology to study and analyze the drying behavior in an oil mill waste rotary dryer. The results revealed that the efficiency of the drier was less because of the in filtered air flow and poor combustion of biofuel used in oil mill.Nafiye Adak et al [35] analysed the different drying conditions such as infrared power, drying air temperature ,velocity etc and found that drying time decreases with increase in infrared power, air temperature and velocity. D.K.Rabha et al [36] fabricated a forced convection solar tunnel dryer and performed energy and exergy analysis for drying ghost chilli pepper and sliced ginger. The exergetic efficiency increased with advance in drying time.

The products dried by recent researchers and the application of those products after drying is shown in Table 1.

Table 1. Application of various dried Products by recent researchers.

Author	Dried Product	Application
Lyes Bemamoun et al.[20] (2015)	Algae	Sources of food supplement and feed stock for Biofuels.
S.R.Navale et al.[16] (2015)	Fenu greek leaves	An effective nutrition supplement and good for diabetes, skin and cholesterol.
Guofeng Yuan et al.[21]	Carpet	Dried to protect it from unpredicted

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(2015)		rain and wind brone dirt caused in open sun drying in carpet factory.
S.R.Navale et al.[22] (2015)	Fenu greek leaves	An effective nutrition supplement and good for diabetes, skin and cholesterol.
Chielle D.P et al.[23] (2015)	Papaya seeds	Oil production
Qinqin Chen et al.[24] (2015)	Jujube fruit	Rich in nutrient content, anti oxidant and immune enhancing.
Y.I.Sallam et al.[25] (2015)	Mint	Medicine for cold, flue,sinus and also act as a flavouring agent.
Ahmad Fudholi et al.[26] (2015)	Palm oil Fronds	Human consumption
Fatin Mehmet Yilmaz et al.[27] (2015)	pomegranate	Human consumption
Mohamad Djaehi et al.[28] (2015)	Seaweed	Raw material for food and additives.
Andre Guimaraes Ferreira et al.[29] (2014)	Solid waste	waste in steel wire industry and dried to reduce transportation cost.
Subanana K.R et al.[13] (2014)	Chilli leaf	Bio oil production by fast pyrolysis of chilli leaf.
Raymundo Lopez et al.[14] (2014)	Chick pea	A type of pulse produced for human consumption.
Adolfo G.Finck – Pastrana [30] (2014)	NOPAL(Cactus)	Human consumption, prevent diabetes, gastric ulcers and it regulates bad cholesterol.
Seidu J.M et al.[32] (2012)	Ayyo leaves,Moringa leaves and Bitter leaves	Rich in micro and macro nutrients to reduce nutrition deficiency.

IV. OPTIMIZATION TECHNIQUES

There are various Optimization techniques used by the researchers to check the performance of various solar energy based drying system and its characteristics of products that dried. Some of the Optimization techniques are as follows: 1.Artificial Neural Network (ANN) 2.Analysis of Variance (ANOVA) 3.Color Space (CIELAB) 4.Computational Fluid Dynamics (CFD) 5. Linear Regression Analysis 6. LAB View.

An Artificial Neural Network (ANN) model was created and validated the model for Hot Air Infrared-Assisted Vibratory Bed Dryer for drying Green Pea by Marvasti et al. [18]. The gathered data set was divided into three parts in the first step of ANN modeling; one used to train the network, the second part was applied to validate the model and the third one was used to test the model. The results showed that application of a vibratory bed during hot air-infrared drying of green peas decreased drying time, specific energy consumption and enhanced the quality of dried product in terms of color parameters, roundness and shrinkage. Considering both quality and energy factors, the optimum drying condition was obtained to have drying air temperature of 500C, infrared radiation of 4000 W.m-2.

A Root Mean Square (RMSE) model was created and validated the kinetics Modelling of drying of Chickpea with solar energy by Lopez et al. [14]. The results observed in this work show that it is possible to dry chickpeas using an indirect-type solar dryer. The empirical model that best represented the process was the exponential one, with the three imposed conditions, namely, r close to the unit, a very small $\chi2$, and small values of the deviation between the predicted and experimental dryer (RMSE).

Samu et al. [37] optimized different fruits and vegetables using CIELAB(Color Space Lab) model. Based on measured values they created each color on the calibrated LCD monitor by using the four 'rendering agents' of the color management system. Comparing the values between four intent types and found that no significant difference between perceptual, relative calorimetric and saturation intents.

Savas et al. [38] have optimized the infrared drying of bulgar production. Infrared drying shows great promise in bulgur production by reducing drying time without causing any deterioration in bulgur quality.
Advanced computational modelling for drying process was done by Thijis Defraeyeet al[39].This paper deals with emerging advanced computational methods for modelling dehydration of porous materials, which was approached from a combined multiphysics, multiscale and multiphase viewpoint.
A Lab view model was created to validate different techniques of Greenhouse remote monitoring system. This includes WSN technology and virtual instrumentation technology into greenhouse environment
supervisory systems. Using virtual instrumentation technology software develop platform lab View combine with zigbee based WSN protocol technology, designed remote monitoring platform to achieve control plc via OPC server.[40]

Seyed-Hassan et al. [41] analyzed the drying kinetics and modeling of peppermint leaves and found that RMSE was the most effective model for predicting the characteristics of peppermint leaves.

V. CONCLUSION

It is necessary to decrease the water content present in the product to reach a safe moisture content of less than 8% for fruits and vegetables to increase its shelf life. In the present article various dryer used, various products dried and the optimization techniques followed by recent researchers for drying have been summarized. The application of various dried products in our day to day life also has been discussed in the present work.

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