iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: IV Month of publication: April 2018

DOI: http://doi.org/10.22214/ijraset.2018.4531

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue IV, April 2018- Available at www.ijraset.com

Indirect Solar Dryer: A Review

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Abstract: Various agricultural products such as Fruits, Vegetables, Grains, and medicinal Herbs etc. requires drying to make them available for long period of time. Usually the methods being used for preservation of these products requires fossil fuel and open sun drying which has its own disadvantages. In developing countries fossil fuel availability still remains a big issue therefore solar drying can be a viable alternate solution for fossil fuels. Also the solar drying technique is not only dependent on solar energy for its functioning, rather its performance can be enhanced by incorporating various systems and techniques. In this paper various types of indirect solar drying techniques have been reviewed and emphasis is given to the dryers integrated with latent heat storage unit. Design and Analysis of Indirect solar dryer used for miscellaneous applications such as water heating, space heating and other industrial purposes have been presented in this paper.

Keywords: Solar Dryer, Desiccant material, indirect mode, mixed mode, phase change material.

I. INTRODUCTION

Studies from around the world suggest that 12-15% of the total world population still remains undernourished. The rate at which the population is increasing will add to the gap that already exists between the population & food supply. World population is estimated to reach 8 billion by 2025, to cater the needs of this population solely increasing the food supply won't help, reducing the losses during production, harvest & postharvest period can be considered as a viable option [1]. As per investigations, in developing and industrialized countries alone the post harvesting losses were found to be as high as 25-30% of the total production [1].

One of the most common method of food preservation is through drying. The principle of drying generally includes 2 stages, first stage takes place at the surface of the material at constant drying rate & is similar to the vaporization of water. The second stage takes place at constant drying rate and is determined by properties of material being dried [2]. However drying is one of the most energy consuming process in all the industrial processes. It requires almost 2.4 MJ of energy to evaporate one liter of water. To dry 1 ton of fruits it requires approximately 100 liters of oil. So this type of drying using fossil fuels is generally not used [3].

Most commonly used drying method is open sun drying for food products like grains, fruits & vegetables in developing countries. This type of drying leads to loss in quantity and quality of food because of bad environmental as well as climatic conditions. Main reason of these losses being insects, dust, dirt, birds etc. Hence Solar Dryers could be of great help in reducing the food loss and providing significant increase in quality over the conventionally open dried products. Solar Drying is mainly classified into 4 types:

1) *Open Sun or Natural Dryer:* The products to be dried are kept in open under the climatic conditions like humidity, radiation, air temperature, wind-speed etc.
2) *Direct Solar Dryers:* The product to be dried is kept inside an enclosed container, with transparent cover to absorb radiations. Drying takes place with the help of absorption directly by the products as well as by the internal surface of the chamber.
3) *Indirect Solar Dryer:* In these types of dryers, air is first heated in a separate solar collector and is then sent to the drying chamber.
4) *Mixed Solar Dryer:* It is a combination of Direct & Indirect type of dryers [2].

R.J. Fuller et al. in its paper had studied various types of dryers such as direct, indirect, mixed mode with variations and suggested the optimal practice for drying of agricultural products. Further author had also suggested the selection parameters for selections of these techniques as per place, type, quantity of product, etc. [1].

II. INDIRECT SOLAR DRYING TECHNOLOGIES

A. *Indirect Solar Dryers without Phase Change Material*

Romero et al. designed indirect solar dryer of 50 kg capacity for drying of vanilla pods. This research was aroused for the problem of drying the vanilla pods conventionally under sun which was both laborious and time taking. The suggested design included the solar absorber made of galvanized sheet metal and chamber. The research found that the drying of vanilla pods with indirect type took one month whereas the conventional method took three months [4].Bhattacharyya et al. had made a comparative study of indirect solar collector having metal fins of different dimensions viz. 0.05, 0.07 and 0.1m in height and 2mm in thickness. The findings concluded that the use of fins in absorber can enhance the collector efficiency and the fin with size of 0.07m height and 80 in number showed the highest efficiency of all [5]. D.H. Kokateet et al. A case study of Tangram technology was done for energy efficiency in plastic processing and it was found that a 5kW heater used for drying purpose was used and out of total 1kW energy was lost into transportation. Thus the attempt was made to reduce this loss by utilizing the solar collector, the results included that the nylon product dried in 6 hours with highest temperature 70ºC [6].

Figure 1: Schematic view of indirect solar dryer by Amina Benhamou et al. [7].

Garima Tiwaria et al. had designed the cheap indirect solar tunnel dryer and hybrid dryer to dry chillies. The results showed that the chillies were dried in 9 days with overall efficiency of 63.2% where as it took 15 days for direct drying [8]. Another similar solar dryer was developed by B.A. Ezekoye et al. for drying of pepper and ground nut, the dimensions of the dryer were 100cm x 50cm x 84cm operating temperature of dryer was 67^{O}C with corresponding ambient temperature of dryer 31^{O}C. The dryer efficiency was found to be 22%/day. The volume of air needed for the drying of the system is 0.24m^3 and it was estimated to be even faster by use of descent material [9]. Further on more specific concern in 2003 G. MULOKOZI et al. at Tanzania University experimented various techniques .i.e. chemical plus various drying technologies for successful drying and retaining the vitamin A in Green Leafy Vegetables [10]?

B. Indirect Solar Dryer with Phase change Material

A.K. Bhardwaj et al. carried out experiment for drying valeriana jatamansi (medicinal herb) using Indirect solar integrated with phase change material as Paraffin RT-42 in Himachal Pradesh. The experiment was carried out for five days and the final moisture content of the product was decreased to 9% which was 89% initially. The drying time required was less than shade drying when compared [11]. V.V.Pakhare et al. performed experiment on solar dryer using PCM material as paraffin wax for drying red chilli. Various experiments were carried out at different mas flow rates and the author came to conclusion that mass flow rate of 0.008kg/s was the most suitable mass flow rate for high temperature absorption. Weight of the chillies were reduced to 0.24kg which were initially of 1kg and the temperature of the drying chamber was 2.5ºC to 7.5ºC more than the ambient temperature for at ;east 5 hours after sunset because of PCM chamber [12].

A.K. Srivastava et al. designed flat plate collector in which the author used PCM material as Lauric acid foe drying purpose of potatoes and carrot. Potatoes and carrot used were of 15 mm diameter and thickness of two types 3mm and 5mm. The author came to conclusion that the drying time for 3mm thickness food product is less than that of 5mm food product [13]. Sreerag T.S et al. performed an experiment with and without phase change material, the phase change material used was paraffin wax near the inlet of the collector and glauber salt near the outlet of the collector for drying of green banana. Corrugated Aluminium sheet was used as an absorber plate and the PCM was kept in aluminium tubes which were welded under the absorber plate. At the end of the experiment it was found that one kg of green banana were dried in 1 day and it was noted that drying rate of setup with PCM was more than that of without PCM [14]. Amol Wadhawan et al. analyzed the setup after running experiments on it which was consisting lauric acid as phase change material, also a computational domain of solar air heater with TESD was analysed in CFD code FLUENT using various turbulence model. The experimental observation revealed that as the mass flow rate decreases, the time for which energy stored in TESD decreases. Drying time of 22 min is obtained for mass flow rate of 0.035 kg/s and time of 72 min at the mass flow rate of 0.021 kg/s [15].

An indirect forced convection solar dryer was designed, built and tested by Shanmugam and Natarajan. The setup was consisting of four main parts that are flat plate collector, latent heat storage device, solar collector and centrifugal blower. The experiments were conducted in two modes, off sunshine hours and sunshine hours with latent heat storage device and without latent heat storage device. Experiments with reflectors were also carried out to check the potential of the latent heat storage device for drying, and the results showed that with the use of reflective mirror the regeneration of the latent heat storage device becomes faster [16]. Sreerag T.S. and Jithish K.S. designed and tested the setup of solar dryer for drying 1kg of banana which sliced to 3mm in which Gaubler salt and Paraffin wax was used as phase change material and these phase change material were kept in aluminium tubes which were welded below absorber plate. The experiment was conducted from 9 a.m. to 8 p.m. with and without phase change materials and it was found that the drying rate for the setup without PCM is 0.047 kg/h and the drying rate for the setup with PCM is 0.055 kg/h. The final weight of the banana was 0.580 kg without PCM and the weight of banana was 0.385 with PCM [17].

Aymen El Khadraoui et al. performed experiment on solar dryer with phase change material as paraffin wax of 60 kg which was filled into the aluminium cavity below absorber plate. The drying chamber was insulated with polyurethane of 0.03m thickness and the result showed that he relative humidity inside the drying chamber was in between 15.88 to 66.7% for the case with phase change material and in between 16.14 to 78.6% for the case without phase change material it was also concluded that Use of the phase change material decreased the consumption of electricity between 40 and 70% [18]. Ramin Moradia et al. built and tested a double glazed SAH (Solar active house) in which paraffin wax was used as a phase change material the setup. The air flows between the first glazing and the absorber plate and then exits from the other side of the collector as a single pass. Aluminium powder was mixed with pure paraffin wax in the ratio of 0.5% to improve the heat transfer coefficient. At the end of the experiment the author concluded that the total thermal efficiency was varying between 35% and 45% and during the discharging period the thermal efficiency was between 13% and 15%, the results also showed that incorporating the PCM of 4cm resulted into the best optimum performance for SAH [19]. Drying of Vitis vinifera and Momordica charantia was carried out by N. Karunaraja et al. and the dryer was of tunnel type in which the chimney was placed in the mid-section of the solar dryer. The dryer was 2134mm in length and 912mm in width and 609mm in radius. The setup was operated with three different heat storage material viz. sand, aluminium and rock in which the author founded that at the end of experiment the thermal efficiency of the solar tunnel was 15.46%, 14.75% and 13.7% for WTSM, sand bed, rock bed and aluminum [20].

José Vásquezet et al. built a solar dyer was having solar panel and accumulator which was used PCM(paraffin wax) to accumulate energy, along with that the setup was also having fuzzy logic control which was controlling the solar accumulator, solar panel and recirculation valves. 15kg of peach were sliced in quarters and dried for 9 hours resulting into the reduction of moisture level 55% which was initially 86%, after that mushroom was also sliced(0.008m) and dehydrated up to the moisture level of 10% which was 85% initially when dried for 10 hours[21].

R. Arul kumara et al. performed experiment on solar dryer in which paraffin wax was used as phase change material. The efficiency of the solar dryer was calculated for four different types of absorber plate that is flat place collector, pin fin absorber plate packed with phase change material, Triangular tube absorber plate packed with phase change material and Circular tube absorber plate packed with phase change material. At the end of the experiment it was concluded that Pin fin absorber plate packed with phase change material was having the highest efficiency [22].

An indirect forced convection solar dryer was designed and tested by Shanmugam and Natarajan in hot and humid conditions of Chennai for the drying purpose of green beans. The solar dryer was mainly consisting of dryer chamber, flat plate solar collector and latent heat storage unit. The mass shrinkage ratio, pickup efficiency, dimensionless mass loss and specific moisture extraction rate of the setup were discussed [23].

C. Mixed Mode Solar Dryer

Ehsan Baniasadi et.al constructed a solar dryer that consisted of solar collector, drying chamber and a drying fan that works on photovoltaic cells. A battery storage system was also attached to the photovoltaic cells, which charges the batteries during the sunshine hours so that the power can be used during non-sunshine hours. Aluminum black plates were used as an absorber. The drying chamber was of the size 70x60x15 cm. A Copper coil filled with granulated paraffin was used as an energy storage unit at the bottom plate of drying chamber. It was observed that the difference in drying rates of upper and lower trays was lowered with the help of energy storage system. Use of paraffin material as energy storage unit decreased the drying time by 50% [24]. Simate et.al. Constructed, analyzed and compared two types of natural convection dryers. The two types of dryers used were an indirect dryer and a mixed mode dryer. A transparent cover was used for the drying chamber of mixed mode dryer & this was replaced by an opaque cover for the indirect type of dryer. Based on numerical calculations it was suggested to keep the length of solar collector as 1.8 m for the mixed mode drying, whereas for indirect drying process it was found to be 3.34 m for the same capacity of 90 kg. Total dried grain obtained from the indirect dryer at the end of the year was 3.30 tones, which was 17% more than that of the mixed mode dryer [25].

Tarigan & Tekasakul designed and fabricated a mixed mode type of solar dryer for drying of agricultural products with an integrated biomass burner system. Two tests were carried out on the system, one integrating the heat storage system and the other without it. After the tests were carried out, it was found that the system without heat storage performed better in the two. The efficiency of the dryer without heat storage system was 40% whereas with the heat storage system was 23%. The drying of food product was found to be uniform across all the trays [26]. Basunia et al. constructed and evaluated a mixed mode natural convection type of a dryer. The main aim was to study the characteristics of thin layer Solar drying of the Rough Rice used in their area also known as Oryza sativalinnaeus. The Drying was carried out in various ambient conditions like the varying drying air temperature from 22.3 to 34.9ºC, relative humidity varied in range of 34.5 to 57.9%. The initial moisture content on dry basis was found to be approximately between 37.07 and 37.69%. Product to be dried were stacked in trays inside the drying chamber [27].

III. MISCELLANEOUS APPLICATION OF INDIRECT SOLAR DRYER TECHNIQUES

Indirect solar dryer techniques finds its application not only in crop drying but also in other miscellaneous applications like water heating, space heating and other industrial application also. Xing la et al. presented an experiment investigation of a solar dryer system for drying carpet based on principle of active energy solar air heater field. The system was designed and constructed in Lhasa chengguan district carpet factory for production capacity of 150 kg of dry blanket and wool per day. The dryer system employs 28 pieces of plate solar air heater which has rectangular structure to reduce the local resistance. The modern feature of the system consists of water heating, water/air heat exchanger for drying system in evening and raining days. From the results drying time estimated for 320 kg wet wool was 7.5 hours [28].

Di Su et al. designed a numerical model of water based PV/T equipped with PCM developed using one dimensional energy balance equation. The objective of system was to harness both heat and electrical energy using PV and PCM from the experiment it was concluded that for every 1°C rise in temperature of PV cell the efficiency drop by 0.45%, which mainly occur by overheating of PV cell. To overcome this problem PCM were incorporated to maintain optimum temperature of PV. The designed system was tested on different thickness of PCM with different melting temperature out of that PCM with thickness 3.4cm and 40°C suitable for overall maximum efficiency [29].

IV. CONCLUSION

The best alternative to overcome the disadvantages of conventional open sun drying and use of fossil fuels is through use of solar dryers. Solar dryers not only overcomes the disadvantages but also enhances the efficiency of the product drying.

The following observation were made from the above reviewed papers:

A. Different designs of indirect solar dryer were reviewed.
B. Special attention was given to solar dryers integrated with heat storage materials which helped in drying of products in off sunshine hours.
C. The research related to the mixed mode solar drying techniques were satisfactorily reviewed with their design, analysis and conclusion.
D. Solar dryers used for purposes other than food product drying such as water, space, etc. were analyzed and reviewed.

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