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Review on Direct, Indirect and Mixed Mode Solar Dryer

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Abstract- **India is the agricultural dominated country. Food problem arises in most developing countries mainly due to the inability to preserve food surpluses rather than due to low production. Hence preservation of agricultural food/crop is very essential to avoid the wastage. Solar energy is abundantly available with us but because of frequently cloud, drying of agricultural product is not effective for special crop like grapes, fig, turmeric, etc. In order to preserve and protect food crop from bacterial growth solar dryer is to be designed. Drying is the process in which moisture of the product can be removed without hampering the nutrients. Mostly direct and indirect mode solar dryer is used to drying the agricultural product. Natural and forced convection solar dryers are used for so many agricultural products. There is tremendous research is going on in solar drying technology to improve the performance of solar dryer. Experimentally it is proved that solar drying technology is economical viable and possible. Thermal energy can be store in solar drying system to improve the performance of solar dryer using different phase change material. In this review paper, we revived direct mode, indirect mode and mixed mode solar dryer for various agricultural crop.**

Key Words: **Solar Dryer, Agricultural Crop, Thermal energy storage.**

I. INTRODUCTION

Food is a basic need for all human beings along with air and water. Food problem arises in most developing countries mainly due to the inability to preserve food surpluses rather than due to low production. Agricultural yields are usually more than the immediate consumption needs, resulting in wastage of food surpluses during the short harvest periods and scarcity during post-harvest period. Hence, a reduction in the post-harvest losses of food products should have considerable effect on the economy of these countries. Several process technologies have been employed on an industrial scale to preserve food products; the major ones are canning, freezing, and dehydration. Farmers dry food products by natural sun drying, an advantage being that solar energy is available free of cost, but there are several disadvantages which are responsible for degradation and poor quality of the end product. Certain variety of food products are not supposed to be dried by natural sun drying because they lose certain basic desirable characteristics. Experiments carried out in various countries have clearly shown that solar dryers can be effectively used for drying agricultural product. Solar drying has been used since time immemorial to dry grapes, turmeric, seeds, fruits, meat, fish, wood, and other agricultural products. Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods [1].

II CLASSIFICATION OF SOLAR DRYER

Solar Drying is classified in so many ways according to way of heat transfer, according to type of product and their moisture content and according to drying time required. Basically there are two types of solar dryer,

1. Natural convection solar dryer
2. Forced convection solar dryer

But solar drying methods are usually classified to four categories according to the mechanism by which the energy, used to remove moisture, is transferred to the product:

***1. Sun or natural dryers*:** The material to be dried is placed directly under unfriendly climate conditions like solar radiation, ambient air temperature, relative humidity.

***2. Direct solar dryers*:** In these dryers, the material to be dried is placed in an enclosure, with transparent covers or side panels. This heat evaporates the moisture from the drying product and promotes the natural circulation of drying air.

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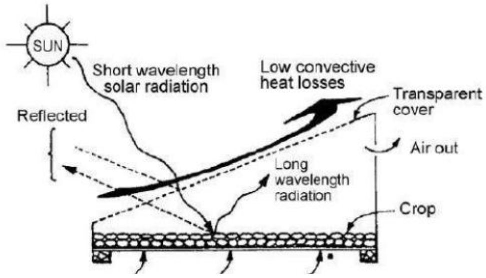

Fig. 1 Schematic of Direct mode solar dryers [2]

Here sun light fall on the surface of glass then things happen fist is some light is absorbed some light is Reflected back from glass some light is transmitted. Dimension of box used is 1 m length and 0.3 Width. Temperature recorded in this cabin dryer is 80^{o} C.

3. Indirect solar dryers: In these dryers, air is first heated in a solar air heater and then ducted to the drying chamber.

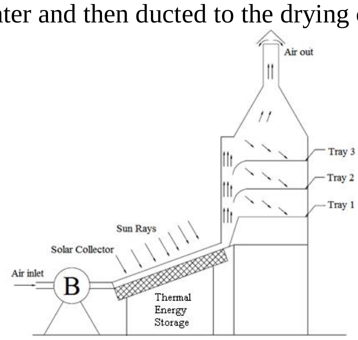

Fig. 2 Schematic of Indirect mode solar dryers

An indirect type of solar dryer with forced air circulation can be used to produce superior quality products acceptable in the international market.

4. Mixed-type solar dryers:

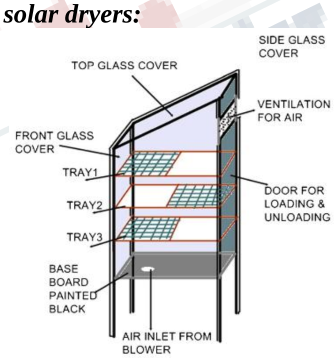

Fig. 3 Schematic of Mixed mode solar dryers [3]

The combined action of the solar radiation incident directly on the material to be dried and the air pre-heated in the solar air heater furnishes the energy required for the drying process.

III LITERATURE REVIEW

1. M. Mohanraj, P. Chandrasekar [4] the performance of an indirect forced convection solar drier integrated with heat storage material was designed, fabricated and investigated for chili drying. The drier with heat storage material enables to maintain consistent air temperature inside the drier. The inclusion of heat storage material also increases the drying time by about 4 hrs. per day. The chili was dried from initial moisture content 72.8% to the final moisture content about 9.2% and 9.7% (wet basis) in the bottom and top trays respectively.

Fig.4 Pictorial View of Experimental Setup.

They concluded that, forced convection solar drier is more suitable for producing high quality dried chilli for small holders. Thermal efficiency of the solar drier was estimated to be about 21% with specific moisture extraction rate of about 0.87 kg/kW h.

2. S.M. Shalaby et al. [5] evaluated thermal performance of an indirect forced convection solar dryer to dry mint and thymus (Figure-13). They tested fourteen mathematical models of thin layer drying & found that Midilli and Kucuk model is convenient to describe the thin layer solar drying of mint. However, the Page and modified Page models were found to be the best among others for describing the drying curves of thymus. Based on the results obtained for the solar drying of thymus and mint, they found that the drying times of thymus and mint depend on the mass of the drying product and temperature of the drying air.

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Fig.5 Pictorial View of Experimental Setup.

They also inferred that the abnormal drying behavior of thymus needs further study at different mass flow rates and various temperatures of the drying air.

3. Sharma et al. [6] presented a research paper titled "Review on thermal energy storage with phase change materials and applications." The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications. This paper also summarizes the investigation and analysis of the available thermal energy storage systems incorporating PCMs for use in different applications.

4. Avesahemad Husainy [7] designed and develops forced convection solar dryer for grapes with thermal energy storage by using paraffin wax. In this work indirect cum mixed mode forced convection solar grape dryer with thermal energy storage has been developed and tested experimentally. The grapes with pretreatment have been dried with developed solar dryer.


Fig.6 Pictorial View of Experimental Setup.

The designed dryer was integrated with a Phase Change Material to extend the use of dryer in the evening/night hours. The effect of air mass flow rate on moisture content, moisture ratio, drying rate, drying time and dryer efficiency has been evaluated for grapes. At the same time effect of thermal energy storage on drying time on grapes also evaluated with and without incorporation of thermal energy storage with variation in mass flow rate of air.

5. Mohamed Zayed, Abd elnaby Kabeel, Alsaied Khalil, S. M. Shalaby [8] In this research, the thermal performance of flat, finned and v-corrugated plate solar air heater is investigated experimentally. The solar air heater is designed to be easy to replace the absorber plates from one to another one. Comparisons between the temperature difference of air across the heater and thermal efficiency of the flat, finned and v-corrugated plate solar air heater were presented. Effect of change the mass flow rate of air on outlet air temperature and thermal efficiency of the heater were also studied at mass flow rates are 0.062, 0.028 & 0.009 kg/s. Experimental results showed that the maximum value of outlet temperature of the v corrugated plate solar air heater increased by 5 and 3.5^{0}C compared with flat and finned plate when the mass flow rate is 0.062 kg/s, respectively and it increased by 8 and 5.5^{0}C when the mass flow rate 0.009 kg / s.


Fig. 7 Pictorial View of Experimental Setup.

The average ambient conditions are 30ºC air temperature and 15% relative humidity with daily global solar radiation incident on horizontal surface of about 20MJ/m2/day. The weather conditions considered are of Khartoum, Sudan. A prototype of the dryer is so designed and constructed that has a maximum collector area of 1.03m2. This prototype dryer will be used in experimental drying tests under various loading conditions.

6. S. Dhanushkodi1, Vincent H. Wilson [9] Develops biomass dryer for cashewnut. The dryer is capable of producing hot air continuously with temperature ranging

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Vol 2, Issue 2, February 2017

between 70 to 75°C. Performance analysis showed that the moisture reduction from 9% to 4% was achieved within 7 hours in biomass drying and it had taken almost 15 hours in open sun drying. The system efficiency of the dryer was found to be 9.5%.

***Fig.8 Pictorial View of Experimental Setup*.**

The main features of the dryer are to maintain uniform temperature across the tray by using chimney effect and an acceptable system efficiency. The dryer has been designed as a substitute to the electrical and conventional dryers. It is simple in construction and it is suitable for small scale cashew industries present in both rural and urban areas of India.

7. M.A. Hossaina and B.K. Bala [10] were used a mixed mode type forced convection solar tunnel drier to dry hot red and green chillies under the tropical weather conditions of Bangladesh as shown in figure 8.which consists (1.air inlet 2.fan;3.solar module;4.solar collector;5.side metal frame;6.outlet of the Collector 7.wooden support; 8.plastic net; 9.roof structure for supporting the plastic cover; 10.base structure for supporting The dryer;11.rolling bar; 12,outlet of the drying tunnel.)The drier had a loading capacity of 80 kg of fresh chillies.

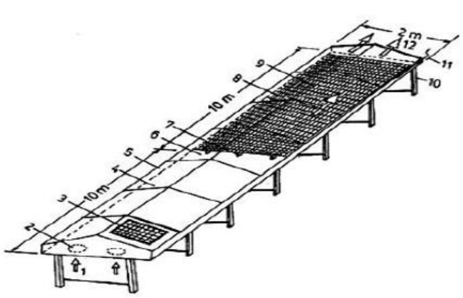

Fig. 9 Schematic of Mixed mode solar dryers

Moisture content of red chilli was reduced from 2.85to 0.05 kg/kg(db) in 20 h in solar tunnel drier and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg/kg (db) in improved and conventional sun drying methods, respectively. In case of green chilli, about 0.06 kg/kg(db) moisture content was obtained from an initial moisture content of 7.6 kg/kg(db) in 22 h in solar tunnel drier and 35 h to reach the moisture content to 0.10 and 0.70 kg/kg(db) in improved and conventional sun drying methods, respectively. Average air temperature rise in drier was about 21.62 ºC.

8. Arpita Mehta, Sudhir Jain [11] developed An indirect forced convection solar drier with thermal storage has been developed and tested its performance for drying ginger under the metrological conditions of Udaipur, India. Agricultural food materials can be dried at late evening, while late evening drying was not possible with a normal solar dryer. So that, solar dryer with storage unit is very beneficial for the humans and as well as for the energy conservation.

Fig.10 Pictorial View of Experimental Setup.

The system consisted of a flat plate solar air collector, heat storage unit, a drying chamber and a DC fan. Drying experiments have been performed at an air flow rate of 0.0025 kg/s. drying of ginger rhizomes in a forced convection solar drier reduces the moisture content from around 84 per cent (wet basis) to the final moisture content about 9.63 per cent in 36 h. Average drier efficiency was estimated to be about 30 per cent.

9. V. Shanmugam et al. [11] incorporated a CaCl2 based regenerative solid desiccant bed into the dryer for drying green peas (Figure-15). The results of their tests have shown that the integration of desiccant unit with solar dryer continues the drying of products in the off-sunshine hours and improves the quality of drying product. At a given air flow rate of 0.01, 0.02 and 0.03 kg/m^{2}s the product dries to its equilibrium moisture content at about 22, 18 and 14

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hours, respectively. Also, more uniform drying of product in all the trays is achieved during desiccant drying.

Fig.11 Pictorial View of Experimental Setup.

They modified the design further and incorporated a reflective mirror to improve the regeneration of the desiccant and tested it to dry green peas and pineapple. The test results were then conducted with and without the inclusion of the reflective mirror. They concluded that, with the inclusion of a reflective mirror on the desiccant bed the drying potential increases considerably. The useful temperature rise of about 10^0C was achieved with mirror, which reduced the drying time by 2 hours for green peas and 4 hours for pineapple slices.

IV CONCLUDING REMARK FROM LITERATURE REVIEW

1. The performance of an indirect forced convection solar drier integrated with heat storage material was designed, fabricated and investigated for chili drying. The chili was dried from initial moisture content 72.8% to the final moisture content about 9.2% and 9.7% (wet basis) in the bottom and top trays respectively. It could be concluded that, forced convection solar drier is more suitable for producing high quality dried chili for small holders.

2. Based on the results obtained for the solar drying of thymus and mint, it was found that the drying times of thymus and mint depend on the mass of the drying product and temperature of the drying air. Both thymus and mint are exhibit the constant and failing rate periods of solar drying of agricultural products. It was found that, Midilli and Kucuk model is convenient to describe the thin layer solar drying of mint. However, the Page and modified Page models were found to be the best among others for describing the drying curves of thymus.

3. This paper presents the current research in this particular field, with the main focus being on the assessment of the thermal properties of various PCMs. The heat storage applications used as a part of solar water-heating systems, solar air heating systems, solar cooking, solar green house, space heating and cooling application for buildings, off-peak electricity storage systems, waste heat recovery systems.

4. The following conclusions have been arrived at, from the experimental investigation carried out in the present work on solar grape dryer.

- Dried grape (Raisins) production is possible with developed solar dryer in much shorter time. An indirect type of solar dryer with forced air circulation can be used to produce superior quality raisins acceptable in the international market.
- The drying experiment conducted with grapes and it was found that the complete drying process could be attained with 30 hours, which is very less compared with open sun drying
- Incorporation of thermal energy storage system reduces drying time remarkably in terms of sunshine hours. With implementation of thermal energy storage the drying time for particular day can be extended from sunshine hours to non-sunshine hours. Hence it increase the quantity of products dried.
- With increase in mass flow rate of air the outlet air temperature of collector is going to decrease which reduces the drying temperature required and thus increases drying time
- After all this work put forward extension of renewable energy based drying technology in the field of grape drying so that small scale farmers can be economically benefited.

5. The v-corrugated collector was found to be the most efficient collector and the flat plate collector to be the least efficient. The v-corrugated solar air heater is 8 –14.5% more efficient than the flat plate heater and 6 – 10.5% more efficient than the finned plate heater, respectively under the considered configurations and operating conditions.

6. A biomass dryer was designed, constructed and tested at PRIST University, Puduchery Campus, India for drying cashew kernel. On the basis of the experimental results the following conclusions are drawn.

- The developed system is suitable for drying maximum of 40 kilograms of cashew in one batch.
- The required air temperature of 65-75°C was obtained with minimum fuel consumption of 0.5-0.75 kg/hr.
- The biomass dryer can dry cashew kernel from a moisture content of 9% w.b. reduced to 3% w.b.within 7 hours.
- Maximum biomass system/overall efficiency of 9.5 % was observed.
- The dryer does not depend on whether condition and can be operated maximum 3 batches per day.

7. The solar tunnel drier can be used to dry up to 80 kg of fresh chillies. In all the cases, the use of this drier led to considerable reduction in drying time in comparison to that of conventional sun drying, and the products dried using this drier were of better quality as compared to their conventional sun dried counterparts. This drier can be easily constructed using locally available materials. This can be operated by a photovoltaic module independent of electrical grid. The photovoltaic system has an advantage because the temperature of the drying air in the drier is automatically controlled by the solar radiation and photovoltaic combination. Blanching retained more colour than that of unbalanced samples for red and green chillies without reducing pungency. Hence, solar tunnel drier was found to be technically suitable for drying of red and green chillies.

8. The performance of an indirect forced convection solar drier with thermal storage was designed, fabricated and investigated for ginger drying. The drier with thermal storage mater ial enables to maintain consistent air temperature inside the drier. The inclusion of heat storage material also increases the drying time by about 2 h per day. The ginger was dried from initial moisture content 84 per cent to the final moisture content about 9.63 %. It could be concluded that, forced convection solar drier is more suitable for producing high quality dried ginger for small holders. Thermal efficiency of the solar drier was estimated to be about 24 per cent.

V. CONCLUSION

From above literature review it is concluded that, open sun drying method is very economical. However, there are numerous disadvantages to this method. This drying process exposes the product to unpredictable weather, dust, and swarm by insects. Many modifications have been done to eliminate above issues with traditional drying. Economically sound farmers capable of moderate investments can choose solar dryers according to their individual requirements. Mixed mode solar dryers are more efficient, but, they have disadvantage of exposing the products to solar radiation. Natural convection indirect mode is very much effective than mixed mode dryer but it requires more time for drying the vegetables. But indirect mode forced convection solar dryer is very effective than others because time required for drying is very less than others. The introduction of heat storage material like paraffin wax in the air heater enhances the rate of drying and reduces drying time. The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high-energy storage density. Drying time can be further reduced using the same system with heat storage material. The v-corrugated collector was found to be the most efficient collector and the flat plate collector to be the least efficient. Solar dryers have been reported to improve the taste, nutrition, and final value of produce compared to traditional drying method. Solar dryer is economical viable for all kinds of product/crops like grapes, fig, turmeric, chilli, ginger, mango, fish, leafy vegetables, etc.

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