

Design and Performance analysis of solar dryer with different mass flow rate of air for ficus carica (fig)

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ABSTRACT

In the recent years there has been a growing interest in agricultural products dryer from the point of view of the commercial value for farmers and reduction in the wastage. Dry fig stands at a highest position in dry fruit. Dried fig production has a great important in terms of foreign trade, farmer's income and employment. In India, its cultivation is mostly confined to western parts of Maharashtra and Gujarat, Karnataka. The largest area brought under the cultivation of fig is in the state of Maharashtra. Out of yearly total production of fig in India, near about 80% of fig production takes place in Pune (Maharashtra). Considering the commercial value of dried fig and concentrating on reduction in waste, if the renewable technology is available for local farmers then it will be economically benefited. At the same time to overcome the disadvantage of the intermittent nature of solar energy, if thermal energy storage system is integrated with solar dryer it could enhance the energy storage capacity and make the system suitable for continuous usage. Thermal energy storage and chemical pretreatment causes significant decrease in the drying time for all the investigated crops. The reduction rate of figs moisture content was increased with the increasing of drying air temperature and air velocity in all pretreatment of whole figs. The dryer thermal efficiency was increased with the increasing of drying air temperature and air velocity. The thermal efficiency of the PTC varies significantly with variation of mass flow rate of the air. The thermal efficiency of the PTC is on the higher side for the mass air flow rate of 0.027kg/sec than corresponding thermal efficiency obtained by mass air flow rate of 0.022kg/sec at any instance throughout the day.

1. Introduction

Preservation of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. 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 produce. It is a question of adopting it and designing the right type of solar dryer. Drying involves the application of heat to vaporize moisture and some means of removing water vapour after its separation from the food products. It is thus a combined and simultaneous heat and mass transfer operation for which energy must be supplied. The removal of moisture prevents the growth and reproduction of microorganisms like bacteria, yeasts and molds causing decay and minimizes many of the moisture-mediated deteriorative reactions. It brings about substantial reduction in weight and volume, minimizing packing, storage, and transportation costs and enables storability of the product under ambient temperatures.

1.1. Solar Drying

Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. In order to benefit from the free in recent years to develop solar drying mainly for preserving agricultural and forest products. However, for large-scale production the limitations of open-air drying are well known. Among these are high labour costs, large area requirement, and lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, and so on. The drying time required for a given commodity can be quite long and result in post-harvest losses (more than 30%). 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. In many rural locations in most developing countries, grid-connected electricity and supplies of other non-renewable sources of energy are unavailable, unreliable or, too expensive. In such conditions, solar dryers appear increasingly to be attractive as commercial propositions [2-3]. During the last decades, several developing countries have started to change their energy policies toward further reduction of petroleum import and to alter their energy use toward the utilization of renewable energies.

Solar radiation in the form of solar thermal energy is an alternative source of energy for drying especially to dry fruits, vegetables, agricultural grains and other kinds of material, such as wood. This procedure is especially applicable in the so-called "sunny belt" world-wide, i.e. in the regions where the intensity of solar radiation is high and sunshine duration is

long. Both the ambient temperature and the solar radiation can vary much from one year to another, and the distribution of temperature and solar radiation vary during different years. In

India, there exists significant potential for tapping solar energy due to more sunshine hours.

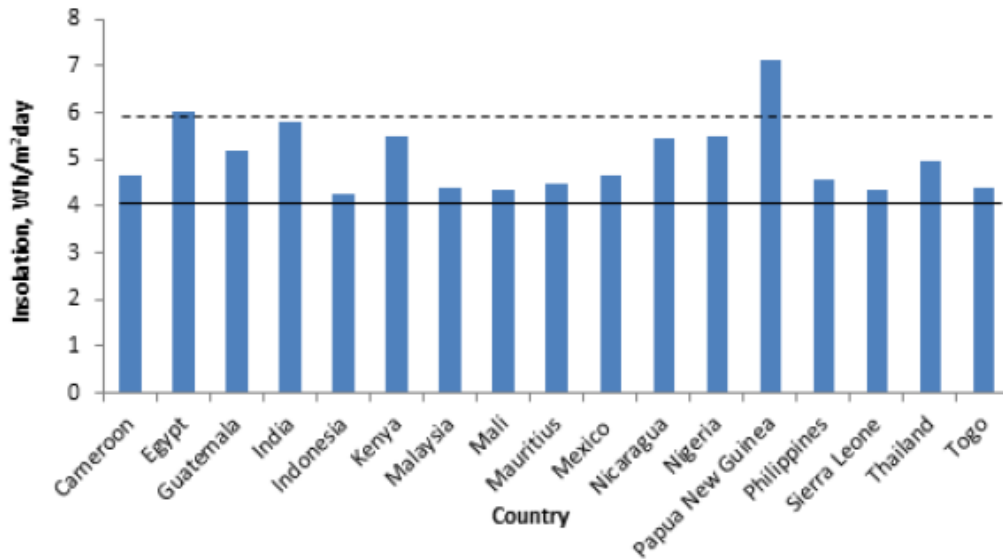


Fig. 1.1. Total horizontal solar insolation for some developing countries

2. PCM for fig drying

Drying is one of the most energy-intensive processes in agro-products industry. For this reason, using solar energy appears as an attractive not polluting alternative to be used in drying processes. However, the daily and seasonal fluctuations in the radiation level require using energy accumulators with phase change materials (paraffin wax), to have continuous drying processes. The dryer includes paraffin wax as phase change material. The input variables were ambient temperature and solar radiation, both not controllable. Optimizing the use of solar energy. The idea to use phase change materials (PCM) for the purpose of storing thermal energy is to make use of the latent heat of a phase change, usually between the solid and the liquid state. Since a phase change involves a large amount of latent energy at small temperature changes, PCMs are used for temperature stabilization and for storing heat with large energy densities in combination with rather small temperature changes.



Fig 2.1 Paraffin Wax

The successful usage of PCMs is on one hand a question of a high energy storage density, but on the other hand it is very important to be able to charge and discharge the energy

storage with a thermal power, that is suitable for the desired application. One major drawback of latent thermal energy storage is the low thermal conductivity of the materials used as PCMs, which limits the power that can be extracted from the thermal energy storage. As one of the goals of latent energy storage is to achieve a high storage density in a relatively small volume, PCMs should have a high melting enthalpy [kJ/kg] and a high density [kg/m³], i.e. a high volumetric melting enthalpy [kJ/m³]. Paraffin has an excellent stability concerning the thermal cycling, i.e. a very high number of phase changes can be performed without a change of the material's characteristics. The selection of the PCM for grape drying systems depends on the operating temperature range of the HTF which in turn is based on the application. A variety of PCMs exist, the temperature obtained by the HTF in flat plate collectors, and the desirable PCM properties, are the decisive factors in selecting the PCM. The test facility was meant for an application that demands hot air in a medium temperature range in between 50^oC to 60^oC.

The need to maximize the efficiency of the solar system restrains the selection of high melting temperatures of the PCM though higher storage temperatures could be advantageous for several applications. In such cases, the maximum heat gain can be obtained from the solar system and the fraction of high temperature energy requirement can be made available from other sources. The commercial phase change material (PCM), HS 60, which has a melting temperature of 56^oC to 64^oC was chosen considering the above factors. The disadvantages of the PCMs are their cost and degradation of properties when subjected to high thermal cycling at high temperatures in long term TES application.

3. Design and progress of solar fig dryer

The developed solar dryer is as shown in Fig 4.1 consist of the different components like concentrating collector (PTC),

thermal energy storage system, dryer cabinet and blower. On the basis of the criteria mentioned the design of the individual component was prepared and corresponding parameter (i.e. relative dimensions and material for solar concentrator, dryer cabinet and PCM storage) were calculated. The procedure of design and calculations for each component is mentioned below.

The overall project is designed for drying of 25kg of fig. Taking into consideration the drying area required for 25kg of fig the drying chamber is designed. Also the fact that the direct sunlight is to be considered the solar drying chamber is designed. Then from the calculations carried out the total energy required for drying is calculated based on the desired final and initial moisture content of fig. Then the design of PCM storage was done for TES storage. The energy required to dry the fig is the function of the moisture content to be removed. So, wet (raw) fig and the market purchased dried fig were taken for moisture contents. The reports resulted in the initial and the final moisture as 73.37g/110g and 11.83g/100g respectively. Using this data obtained the energy calculations were done.

A) Capacity of solar Dryer:- 25 kg
 Considering amount of moisture content: 75% for wet fig and 15 % for dried fig
 Amount of moisture to be removed from given quantity of fig to be dried Amount of moisture =
 $(m_p(m_i - m_f) / (100 - m_f)) = 17.64 \text{ kg of water}$
 Here, m_p = mass of product
 m_i = Initial moisture
 m_f = Final moisture
 Amount of heat required to evaporate water =
 $Q = m_w * h_{fg}$
 $h_{fg} = 4186 (597 - 0.56 * T_p) = 2.5 \text{ MJ/kg}$ T_p -initial temperature of the product
 Amount of heat required to evaporate water
 $Q = m_w * h_{fg} = 44 \text{ MJ}$
 Assume 10 % loss of heat in drying chamber
 Amount of heat required to be supply = $44 * 1.1 = 48.4 \text{ MJ} \approx 50 \text{ MJ}$
 Total energy to be supplied for drying of fig = 50MJ.

4. Thermal energy storage calculations



Fig. 4.1. Thermal energy storage system

The total heat energy to be supplied for the drying purpose will be the heat retracted from the thermal energy storage and supplied through the parabolic trough collector. But for knowing

the exact proportionate of energy supplied from the either energy sources it is necessary to carry out the calculations of thermal energy storage initially.

For the purpose of thermal energy storage Phase Change Material type is used. The material selected for PCM is paraffin wax.

Properties of paraffin wax :(Paraffin 60)
 Melting temperature: 560C to 640C ≈600C
 Boiling temperature: 3700C
 Latent heat of storage (Fusion heat) = 210KJ/kg
 Density: 900kg/m³

The PCM material is stored in the aluminium pipes. Depending on the dimensions of the storage pipes the quantity of PCM stored was determined. Further from the quantity of PCM stored the energy stored in it is calculated.

Dimensions of Aluminium Pipe:
 Outer diameter (D) = 51mm
 Inner diameter (d) = 45mm
 Length of Pipe L = 1.2m

Calculation for TES using PCM:

$$\text{Total volume of Aluminum pipe} = \pi/4 * d^2 * L = 1.9 * 10^{-3} \text{ m}^3$$

$$\text{Amount of PCM stored in single pipe} = m = \rho * V = 1.7 \text{ kg}$$

Total number of pipes= 12

Total PCM stored = 1.7 * 12= 20 kg

Amount of energy stored in per kg of PCM = 210 kJ/kg

Amount of energy stored in given PCM = 210 kJ/kg * 20 kg= 4200 kJ= 4.2 MJ

Considering efficiency of Thermal Energy Storage System = 80 %

$$\text{Actual energy retracted from PCM} = 4.2 * 0.8 = 3.36 \text{ MJ}$$

4.1. Determination of total collector area required:

The total energy required for drying purpose is 50MJ. From PCM 3.36MJ of energy is retracted. The remaining energy is to be supplied from the parabolic trough collector and the direct sunlight.

$$\text{So, the energy to be supplied by collector} = 50 - 3.36 = 46.64 \text{ MJ}$$

Total collector Area required;

Assuming the efficiency of collector (η) = 30%

Intensity of radiation (I) = 800 W/m²

The efficiency of the collector is calculated by,

$$\eta = E / (I * A), \text{ where A- area of the collector}$$

$$\text{Efficiency of Collector} = \eta = E / (I * A),$$

$$0.3 = (46.64(12 * 3600)) / (800 * A)$$

$$A_c = 4.49 \text{ m}^2$$

The collector area required for supplying the essential heat energy is 4.49m².

The total collector area is obtained from:

1.Parabolic trough collector

2.Upper surface of the drying chamber which contributes to direct drying and (i.e flat collector)

Now, the upper surface area of the drying chamber can be calculated from the dimensions of the upper surface:

$$\text{Area} = \text{Length} * \text{Width}$$

The total area with of the upper surface which results direct solar drying =2.1m².

(By considering the shadow effect caused by the chamber) So, the

remaining collector = 2.4m², this is obtained through parabolic trough collector.

Area of the parabolic trough collector is 2.4m²

5. Performance of developed solar fig dryer

The experiment was carried out using different method. The mass flow rate of air was varied and the subsequent effects on the drying time were calculated. Also study of effect of use of thermal energy storage on the drying time is studied by carrying out the experiment with thermal energy storage and without thermal energy storage. The experiment was carried out for whole as well as sliced fig.

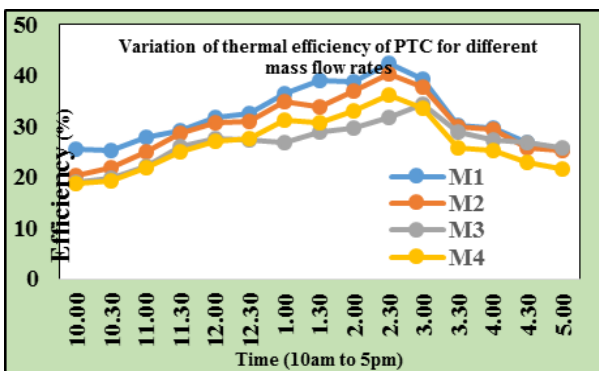
The mass flow rates of air were varied from 0.027kg/sec to 0.022 kg/sec. Study on pretreatment analysis showed considerable decrease in the drying time of figs. Hence, the figs were pretreated by dipping in the boiling water effecting in skin cracking of the figs and helping the cause of moisture removal.

6. Results and Discussion

The results obtained from the experimentations carried out on the solar dryer by the mentioned testing methodology are presented in the following section. Various graphs are plotted for the, study of effect of mass flow rate on drying time, variation in the efficiency of parabolic trough, etc.

6.1 Variation of Parabolic trough efficiency with time for the different mass air flow rates:

The variation of the parabolic trough efficiency is analyzed by plotting the thermal efficiency versus the time for the four mass flow rates of air, M1= 0.027kg/sec, M2= 0.025kg/sec, M3=0.024kg/sec and M4=0.022kg/sec.



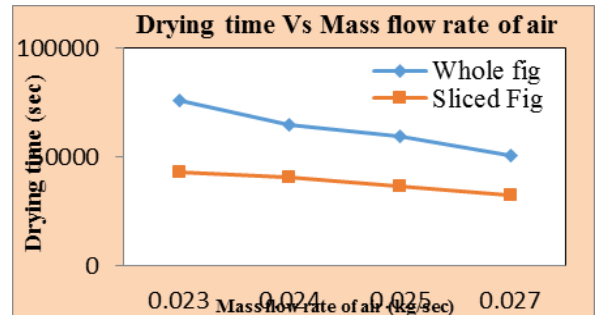
Graph 6.1. Variation in thermal efficiency of PTC with time for different mass air flow rates.

The above graph 6.1 shows the variation in the thermal efficiency of the PTC for the four mass flow rates of the air throughout the day from 10am to 5pm. The maximum thermal efficiency obtained during experimentation is about 43% at around 2.00pm to 2.30pm for the maximum mass flow rate of 0.027kg/sec. With decrease in the mass flow rate of the air to

0.022kg/sec the efficiency decrease to 33% for same period where maximum efficiency is obtained.

6.2 Variation of drying time for performed test methodologies:

The variation in the drying time for different mass flow rates of the air is computed in the below graph.



Graph 6.2. Variation in drying time for different mass flow rate of air.

The variation in the drying time for different mass flow rates in analyzed in the above graph 6.2 The drying time does not vary significantly with the use of TES, so the drying time with and without the use of the TES is almost the same. (Inclusion of the TES system increase the drying period for a particular day by prolonging it to the non-sunshine hours.) From the analysis of the above graph, the drying period decrease from nearly 76,000sec (21 hours) for mass air flow rate of 0.023kg/sec to approximately 50,000sec (14 hours) for mass air flow rate of 0.0027kg/sec. for whole figs. So, for whole figs with the increase in the mass flow rate of the air from 0.023kg/sec to 0.027kg/sec the drying time decrease by 7 hours.

For the sliced figs the drying is reduced to 32,500sec from 42,500sec with increase in the mass air flow rate from 0.023kg/sec to 0.027kg/sec.

7. Conclusion

Mixed mode forced convection solar dryer for fig drying has been developed and tested experimentally. The effect on drying time for sliced fig and dried fig with variation in mass flow rate of air has also be investigated.

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

- The thermal efficiency of the PTC varies significantly with variation of mass flow rate of the air. The thermal efficiency of the PTC is on the higher side for the mass air flow rate of 0.027kg/sec than corresponding thermal efficiency obtained by mass air flow rate of 0.022kg/sec at any instance throughout the day.
- The drying time varies significantly with variation in the mass flow rate of the air. With increase in the mass flow rate the drying time decreases and vice-versa
- 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.

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