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Performance analysis of solar grape dryer with Thermal Energy Storage by PCM

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ABSTRACT

In this work efforts have been made to develop the mixed mode forced convection solar grape dryer for grapes drying with thermal energy storage. The performance of the dryer has been investigated experimentally. Dryer is designed for capacity of 25 kg and consist of the flat plate collector based air heating system integrated with thermal energy storage which utilizes Paraffin wax (PCM) as phase change material. Effect of mass flow rate of air on moisture content, drying rate and drying time with and without incorporation of thermal energy system has also been evaluated. Grapes are dried with developed solar dryer to check effect of air flow on drying time. The thermal efficiency of dryer has been evaluated with and without use of thermal energy storage system for grapes at different air flow rates. The raisins are tested for final moisture content and its nutrition value with the commercially available resins in the market.

The result shows that drying of grapes is technically feasible in accordance with international norms for moisture content and nutrition value for raisins with reduced drying time. The moisture reduction of grapes obtained with developed dryer is from 80% to 20% in 24 sunshine hours with thermal energy storage system. Incorporation of thermal energy storage system reduces drying time from 30 sunshine hours to 24 sunshine hours for grapes with mass flow rate air 0.01484 kg/sec. Drying time reduction is observed with decrease in mass flow rate of air for grapes.

Keywords— **Thermal Energy storage, PCM, Drying rate**

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I. INTRODUCTION

Fruits and vegetables constitute a major part of the food crops in developing countries. From the limited data available on post-harvest losses in fruits and vegetables, it is understood that the actual losses are much higher. The minimum reported loss is 21%, while some references indicate estimates of above 40–50%. The most notable feature is that many varieties of fruits are seasonal and many of them are consumed in their dried form to a large extent which has been made possible by the process of drying.

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. Variation of solar radiation in Maharashtra, India in which the research was carried out. 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.

The term drying, as used in this thesis, refers to the process of extracting moisture from fruits utilizing the sensible heat content of drying air. The removal of the moisture from the crop is accomplished by moving air through the fruit bin.

The efficient alternative energy utilization must invariably involve energy storage to be able to cater to fluctuation demand and at the same time to obtain a higher performance from energy sources. Energy storage system also assumed greater significance in the context of waste heat utilization or in the situation dealing with intermittent supplies of input energy like solar energy. Phase change material (PCM) is one of the most preferred from to store thermal energy. The results from previous studies indicated that PCMs can be adjusted to have a melting within the ranges which are most suitable for fruits and leaves drying applications

II. LITERATURE REVIEW

Jairaj et al.[1] presented paper which attempts to review various solar dryers developed exclusively for grape drying on a normal scale. Many popular varieties of solar dryers, certain typical models as well as traditional methods practiced for drying grapes are presented in this paper. There has been a remarkable achievement in solar drying of grapes due to sustained research and development associated with the adoption of advanced technologies. A review of various solar drying models for grapes is thus necessitated.

Among the indirect type solar dryers functioning in natural convection mode, the dryer designed by **Pangavhane et al.[2]** is technically superior because all the important parameters have been taken into consideration while designing the collector and drying chamber The initial cost of this dryer is quite high when compared to its capacity. The dryer developed by **El-Sebaii et al.[3]** is technically sound and economical. Provision is made for sensible heat storage which facilitates the dryer to be used beyond sunshine hours .The initial investment is moderate and affordable by farmers.

In the forced convection mode solar dryers, there is provision for controlling the temperature and humidity inside the drying chamber. This makes it possible to produce raisins of superior quality with much reduced drying time. The forced convection mode solar dryer developed by **Yaldiz et al.[4]** is technically sound and economical. The use of obstacles in the path of air passing through the air heater before entering the drying chamber enhances the drying rate of grapes thereby reducing the drying time to a large extent. The above mentioned method shows a notable reduction in the drying time of grapes but the quality of raisins produced is poor.

Gallali et.al.[5] presented paper titled "Preservation of fruits and vegetables using solar drier: a comparative study of natural and solar drying, chemical analysis and sensory evaluation data of the dried samples (grapes, grapess, tomatoes and onions)". An indirect type natural convection locally made solar dryer, consisting of a flat-plate solar air heater connected to a drying chamber, was investigated experimentally and theoretically by **El-Sabaii et al [6]**, with the drying of fruits and vegetables such as seedless grapes, grapess, green peas, tomatoes and onions.

Sharma et al. [7] 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.

Morrison, Abdel Khalik and Jurinak [8] in their different studies evaluated the performance of air-based solar heating systems utilizing phase change energy storage unit. The main objectives of their work were: (i) to determine the effect of the PCM latent heat and melting temperature on the thermal performance of air-based solar heating systems and (ii) to develop empirical model of significant phase change energy storage (PCES) units. The main conclusion was that the PCM should be selected on the basis of melting point rather than its latent heat and also found that air-based system utilizing sodium sulfate decahydrate as a storage medium requires roughly one-fourth the storage volume of a pebble bed and one half the storage volume of a water tank

Ghoneim and Klein [9] compared theoretically the performance of phase change and sensible heat storage for air and water based solar heating systems. Sodium sulphate decahydrate and paraffins were used as phase change materials and noted the similar results as by **Jurnik and Adbel Khalik [10].**

Buddhi et al.[11] have discussed both advantages and disadvantages of various experimental techniques used to determine the behavior of these materials in melting and solidification, including their thermo physical properties such as melting point, heat fusion, thermal conductivity and density. Recently, several works have been carried out in order to study the thermal characteristics of paraffin during solidification and melting process, their studies found that paraffin based PCMs have very low thermal conductivity leading to slow charging and discharging, hence heat transfer enhancement techniques are required in order to bring paraffin based PCMs to the successful applications.

Enibe [12] had undertaken design, development and performance evaluation of a natural convection solar air heater with phase change material energy storage. The daytime performance of the system under no-load conditions was tested under natural environmental conditions involving ambient temperature variations in the range 19–41 0C and daily global irradiation in the range 4.9–19.9 MJ m2. Peak temperature rise of the heated air was about 15 K, while peak cumulative useful efficiency was about 50%. The system is suitable for use as a solar cabinet crop dryer for aromatic herbs, medicinal plants and other crops, which do not require direct exposure to sunlight.

M. M. Alkilani et al. [13] presents a theoretical investigation of output air temperature due to thermal energy discharge process from a phase change material (PCM) unit consists of inline single row of cylinders contain a compound of paraffin wax with aluminium powder. This system consists of a single-glazed solar air collector integrated with a PCM unit which is divided into cylinders as an absorber-container installed in the collector in a cross flow of pumped air The heat transfer in PCM is by conduction. To overcome the low thermal conductivity of paraffin wax they added a powder of material which has a good conductivity property such as copper or aluminium powder and paraffin wax with aluminium powder is used to decrease the system cost. A Matlab computer program has been developed to compute the air temperature; cylinder by cylinder along the duct, freezing time for each cylinder, and the time required to discharge all the thermal energy. Output air temperatures due to a discharge process in a solar air heater integrated with a phase change material have been predicted for eight different values of mass flow rate, and reached the maximum temperature (42°C), with mass flow rate (0.05kg/s). The phase change material consists of paraffin wax with mass fraction 0.5% aluminium powder to enhance the heat transfer, the freezing time for the phase change material unit has been predicted for each mass flow rate, The freezing time of the phase change material cylinders related inversely to the mass flow rate, and take longer time approximately (8 hours) with flow rate of 0.05 kg/s.

Concluding Remarks:

- It is observed that grapes dried in solar dryers take lesser time to reach the safe level of moisture content for storage when compared to open sun drying and the quality of raisins produced are far more superior
- An indirect type of solar dryer with forced air circulation can be used to produce superior quality raisins acceptable in the international market.
- Drying time can be further reduced using the same system with heat storage material
- Economically sound farmers capable of moderate investments can choose solar dryers according to their individual requirements.
- 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.
- The introduction of heat storage material in the air heater enhances the rate of drying and reduces drying time (Sunshine Hour)
- 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.

III.DESIGN & DEVELOPMENT OFcEXPERIMENTAL SETUP

The developed solar dryer consist of the different components like flat plate collector based solar air heater, 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 flat plate collector, dryer cabinet and PCM storage) were calculated..

Figure 3.1 Actual Experimental set up.

The overall project is designed for drying of 25 kg of grapes. Taking into consideration the drying area required for 25 kg of grapes the drying chamber is designed. Then total energy required for drying is calculated based on the desired final and initial moisture content of grapes. Then the design of PCM storage was calculated for TES storage.

3.1 Dryer Chamber:

The dryer chamber is designed for the mixed mode method purpose. The overall dimensions of dryer chamber are:

Length* Width * Height = 80cm * 80cm * 250cm

3.2Thermal Energy Storage using PCM:

Thermal energy storage is implemented by use of phase change material. PCM material used is paraffin wax. Overall dimensions of the collector used for thermal energy storage.

Length * Width * Height = 1m * 0.8m * 0.15 m

PCM storage type: Using pipes
Material of pipes used: Aluminium
Dimension of aluminium pipes:
Outer diameter (OD) = 51mm
Inner diameter (ID) = 45mm
Length of pipe (L)= 1m
Properties of Paraffin Wax (P60)
Melting temperature: 560 C to 640C ≈ 600C
Boiling temperature: 370^0C
Latent heat of storage (Fusion heat) = 210KJ/kg
Density: 900kg/m3

3.3 Flat Plate collector:

The Flat Plate collector is used for heating air is which further supplied to the chamber using blower.

Specifications of the Flat Plate collector are:

Reflecting material used = Aluminium
Dimensions of collector:
Effective aperture area = $0.8m^2$
Aperture width =0.8m

3.4 Blower:

Blower is implemented for carrying out forced convection.

The specifications of the blower are:

Volume flow rate: 500CFM
Pressure head: 200 mm of water
Motor power: 2HP

3.5 Testing Methodology

Test methodology have been planned and executed in order to find the drying time with and without incorporation of thermal energy storage in developed solar dryer. The effect of mass flow rate of air on moisture content, moisture loss, drying rate, drying time and dryer efficiency has to be evaluated and accordingly test have been executed.

1. As pre treatment of grape remarkably affect on drying time hence it is decided to complete whole experimentation with pre treatment of grape by dipping it in to calcium carbide and dipping olive oil for three minutes.
2. Experimentation has been carried out for drying of grape from initial moisture content of 80 % to final moisture content up to 20% with and without incorporation of thermal energy storage system for variable mass flow rate of air.
3. Mass flow rate of air kept for the individual set of experimentation as 0.01484, 0.01569, 0.01650 and 0.01729 kg/sec though dryer cabinet with the help of orifice plate .
4.With selected mass flow rate of air , time to time reduction in weight of the sample grapes , flat plate collector air inlet, outlet temperature, dryer cabinet exit temperature ,intensity of solar radiation are noted till final moisture content reduced to 20 %.
5. With incorporation of TES, inlet and outlet temperatures of air passing through the thermal storage system have also been recorded, additionally with the parameters mentioned above.

3.6 Formulae Used

1. Head of air

$$h_a = h_l \times \frac{\rho_l}{\rho_a}$$

2. Velocity of air

$$A = \frac{(C_d A_1 A_2 \sqrt[2]{2 * g * h_a}\ )}{\sqrt[2]{A_1^2 - A_2^2}}$$

3. Volume flow rate of air

Q=VA

Amount of moisture = $(m_p\ (m_i - m_f) / ((100 - m_f)$

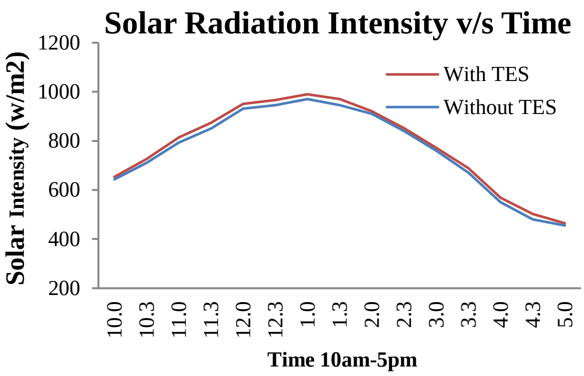
Amount of heat required to evaporate H_2O

$= Q = m_w * h_{fg}$

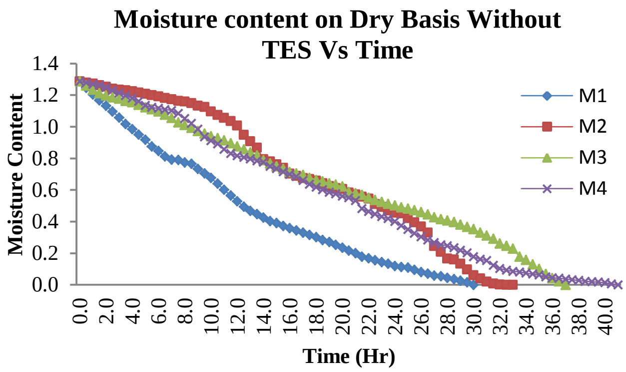
$h_{fg\,w} = 4186\ (597 - 0.56 * T_p)$

IV.IV. RESULTS AND DISCUSSION

The results obtained from the experimentation carried out on the solar dryer by the mentioned testing methodology are presented in the this section. Various graphs are plotted for the study of variation of moisture with respect to time, variation of intensity of solar radiation, study of effect of mass flow rate on drying time, variation in the efficiency of Flat Plate Collector etc.

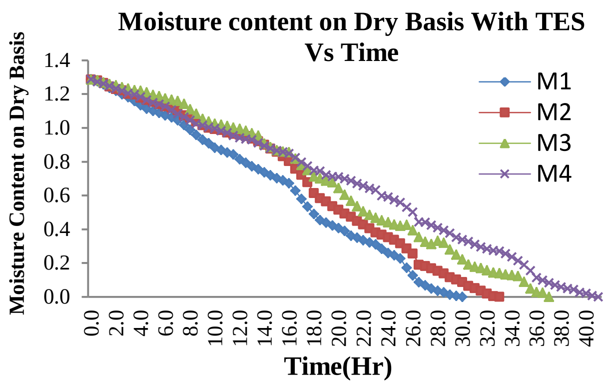


4.1.Variation of Intensity of solar radiation with time:

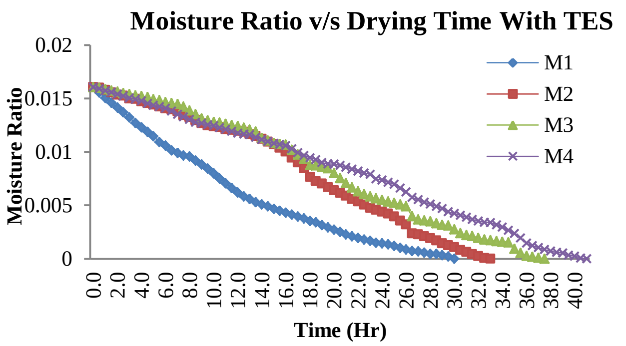


4.2.Variation of the moisture content on dry basis for grapes without TES:

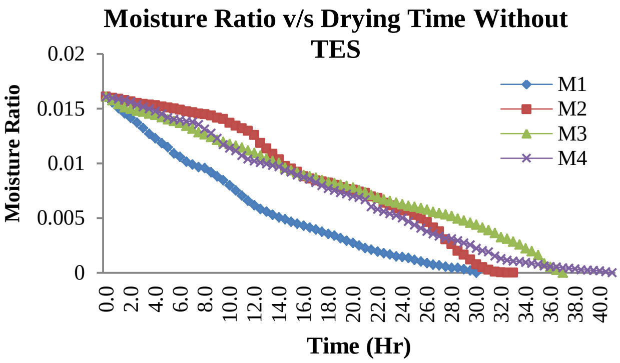
From the above graphs of moisture content on dry basis grapes, with and without TES versus time for the four mass flow rates, it is easily depicted that the moisture content decrease considerably with increase in the mass flow rate of air. The minimum drying time required for grape is 30 hours for the minimum mass flow rate of 0.01484 kg/sec. and the maximum required drying time is 41 hours for the highest mass flow rate of 0.01726kg/sec.



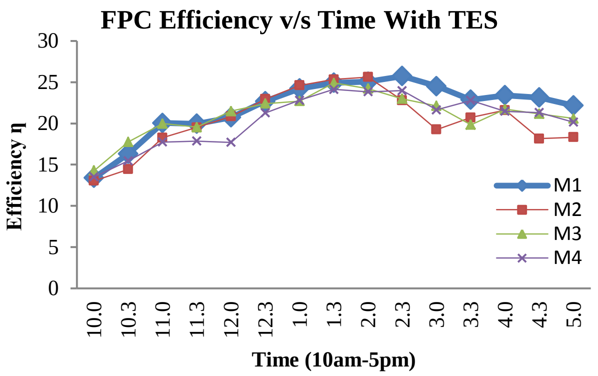
4.3.Variation of the moisture content on dry basis for grapes with TES:



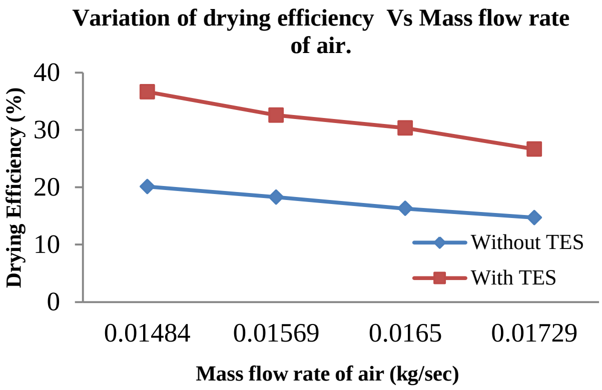
4.4Moisture Ratio versus drying time for grapes with TES:



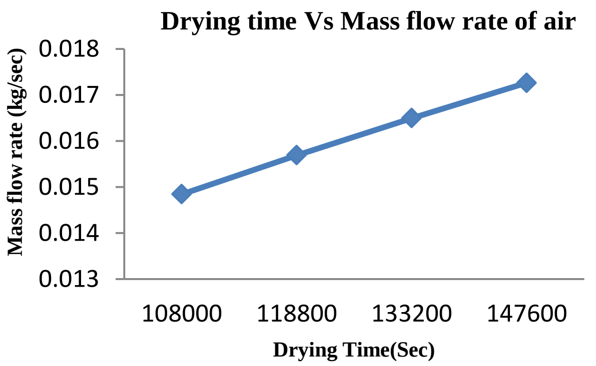
4.5Moisture Ratio versus drying time for grapes without TES:



4.6 Variation of Flat Plate Collector efficiency with time:



4.7 Variation of drying efficiency with and without TES:



4.8 Variation of drying time for different mass flow rates of air:

IV.CONCLUSION

In this work mixed mode forced convection solar grape dryer with thermal energy storage has been developed and tested experimentally. The grapes with pre treatment have been dried with developed solar dryer. 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.

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 increases the quantity of products dried. With increase in mass flow rate of air the collector outlet temp of air gets reduced. Hence drying time increases the outlet air temperature of collector is going to decrease which reduces the drying temperature required and thus increases drying time.

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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