Fabrication and Experimental Analysis of Solar Tunnel Dryer using Thermal Storage Materials

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Abstract— A natural convection solar drier was developed to test its performance for grapes (Vitis vinifera) drying. The experiments were carried out without the integration of heat storage material. The drier reduces the moisture content of grapes from 85% (w.b.) to 10% (w.b.) in 71 hrs respectively the open sun drying is 85% (w.b.) to about 10% in 121 hrs. The average solar drier thermal efficiency was estimated to be about 41%.

Key words: Greenhouse, Solar Drier, Grapes, Moisture Content

I. INTRODUCTION

India, the world's second largest Producer of fruits and vegetables, is also one of the biggest food wasters in the world wasting Indian Rupees 440 billion worth of fruits, vegetables and grains every year. The India billion more people are not really about agriculture and food production but getting the lowest food to the peoples. The biggest contributors to waste are the lack of refrigerated transport and adequate high quality cold storage facilities for both food harvester and food retailers.

The most Vulnerable food category to a lack of cold storage is fruits and vegetable where annual wastage is estimated to be 18% of the total Production. The level of food waste in India and highlights where, wastage occur and its effect on food cost, production and safety. It focuses on fruits and vegetables not only that fruits and vegetable in India waste of other food product. The challenge faced by the cold chain sector in India and a roadmap for improvement, including greater use of establish technologies.

A greenhouse is essentially an enclosed structure which traps the short wavelength solar radiation and stores the long wavelength thermal radiation to create a favorable micro-climate for higher productivity. A greenhouse heating system is used to increase the thermal energy storage inside the greenhouse during the day or to transfer excess heat from inside the greenhouse to the heat storage area. This heat is recovered at night to satisfy the heating needs of the green house.Various investigators have studied the greenhouse for crop drying Condori et al. [1], Condori and Saravia[2], Garg and Kumar[3]. Fohr and Arnaud [4], studied a solar dryer with a greenhouse as a collector for drying grapes. Farhat et al.[5],conducted experiments on pepper drying in the greenhouse with natural ventilation. Rachmat and Horibe [6], have studied solar energy collection characteristics of a fibre reinforced plastic drying house for paddy drying. Jain and Tiwari [7], evaluated the convective mass transfer coefficient as the function of drying time in a greenhouse under natural and forced convection. Jain and Tiwari[8] conducted an experimental study on crop drying in a greenhouse and presented the thermal model for predicting the crop temperature and rate of moisture evaporation.

Dehydration is a common technique for preservation of agricultural and other products, including fruits and vegetables. In developing countries, the traditional method of dehydration is by open air, which often results in food contamination and nutritional deterioration (Ratti and Mujumdar,[9]. Some of the problems associated with open-air drying can be solved through the use of solar drying.

Solar crop drying involves the transport of moisture to the surface of the product and subsequent evaporation of the moisture by thermal heating. Thus, solar thermal crop drying is a complex process of simultaneous heat and mass transfer. Nevertheless, one disadvantage of solar drying is that the dehydration process is interrupted at night or under low insolation, resulting in a poor quality of the dried product.

Several attempts have been made to overcome the problem of intermittent drying in natural convection solar drying. One approach has been the use of thermal storage. Ayensu and Asiedu-Bondzie[10], constructed a dryer with thermal storage, from locally available materials. The system was capable of transferring 118 W m-2 of heat to the drying air. Ayensu [11], designed and constructed a solar dryer with a rock storage system. It was found that the rock pile stored enough energy to enhance nocturnal drying. The duration of crop drying in the solar dryer was shorter than that in the open air. Aboul-Enein et al. [12] developed a solar air heater and tested it with and without thermal storage for drying agricultural products. They found that the drying process would continue at night when a thermal mass was used. El-Sebaii et al.[13] developed a solar dryer with a thermal storage system. The dryer was tested with and without thermal storage and they found that the storage material reduced the drying period. Madhlopa and G.Ngwalo [14] developed an indirect natural convection solar dryer with thermal storage and biomass-back up heater and tested its performance for drying fresh pineapples. They found that the dryer reduced the moisture content of pine apple slices from about 669% to 11% (db) and yielded a nutritious dried product. Thermal energy could be stored, in general, in the form of either sensible or latent heat. Common systems used in storing thermal energy include water tanks or gravel beds, rock beds, sand, concrete etc., where energy is stored in the form of sensible heat. The thermal performance of solar drier with sensible heat storage materials is considerably higher than that without storage.

This paper presents development of a natural convection solar drier integrated without thermal storage for Grapes drying.

A. Materials and Methods:

The experiments were carried out under the meteorological conditions of Pollachi (latitude of 10.39ºN; longitude of 77.03ºE) in India during Jan.2015 – Feb.2015 from 9.00 a.m. in the morning to 5.00 p.m. in the evening.

B. Miniature Model Solar Drier:

A pictorial view of solar greenhouse drier used in the experiment is depicted in "Fig. 1." A community model solar greenhouse drier of size 912 mm (W) × 2134 mm (L) × 609 mm (H) at miniature model was designed and constructed. The semicircular portion of the drier was covered with UV (200 micron) stabilized polyethylene film. No post is

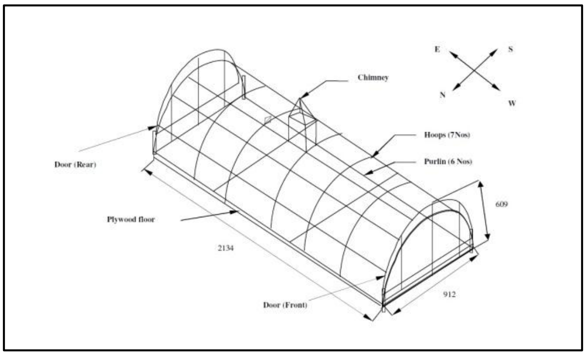

Fig. 1: Miniature Model Solar Drier

Fig. 1(B):

used inside the greenhouse, allowing a better use of inside space. One exhaust vents with adjustable chimney operated manually have been provided at the top of the roof for removing the humid air from the drier. The drier is provided with metallic movable tray for keeping the grapes in layers for drying. The front and back door used to keep the product inside solar drier easily. The capacity of the drier was to dry 5 Kgs of grapes per batch.

C. Instrumentation:

Eight calibrated thermocouples (PT 100) with uncertainty ± 0.5oC were fixed at different locations inside the drier to measure the temperature. Four humidity sensors with uncertainty ±1% were placed at different locations inside the drier for measuring the humidity of air. Ambient humidity was calculated based on measured values of wet bulb and dry bulb temperatures, using two calibrated thermometers with uncertainty ± 0.5oC, one covered with wet cloth. A solar intensity meter (Delta Ohm, Italy) with an uncertainty of ± 10% was used to measure the instantaneous solar radiation. All temperature sensors, humidity sensors and solar intensity meter are connected to a computer through a data logger (Simex, Italy). Air velocity at drier exit was measured by using a vane type thermo-anemometer (Equinox, Germany) having ± 0.5% uncertainty.

A digital electronic balance (Precision Scientific Company, India) of 1 kg capacity having an uncertainty of ± 0.1% was used to weigh the samples.

D. Experimental Procedure:

Experiments were conducted in the months of January 2015 to February 2015 under the meteorological conditions of Pollachi, India. The grapes (N.S. Rathore , N.L. Panwar) were procured from market. The fruit of commercial maturity having uniform size were selected for experiments. Each fruit separated from bunch before placing in dryer. Furthermore, fruit having crakes or skin injuries were rejected. The selected fruit washed with water to remove extraneous matter adhering to fruit. No chemical treatment was given before drying. Only water washed fruit were spread over trays. The sensors were put inside several locations to record temperature inside the tunnel. The moisture reduction in each day was calculated on wet basis.

II. DATA ANALYSIS

A. Determination of Moisture Content:

About 50 g samples were chopped from randomly selected and kept in a convective electrical oven, maintained at 105 ± 5°C for 5 hrs. Initial (mi) and final mass (mf) at time (t) of samples were recorded using electronic balance and repeated every 1 h interval till the end of drying. Moisture content on wet basis ( ) was calculated using the "Eq.(1)."

$$M_{wb} = (m_i - m_f)/ m_i \text{ ------ } (1)$$

B. Determination of Drier Thermal Efficiency:

Thermal efficiency of the solar drier was estimated using the "Eq.(2)."

$$\eta = \frac{m_w h_{fg}}{A * I} \times 100 \text{ ----- } (2)$$

III. RESULTS AND DISCUSSION

About 5 Kgs Grapes with 85% average initial moisture content was taken for study and loaded in the trays of solar dryer. The variation of solar radiation with time is shown in the "Fig.2." During the experiment the sky as clear and the maximum solar radiation observed was 710 W/m²

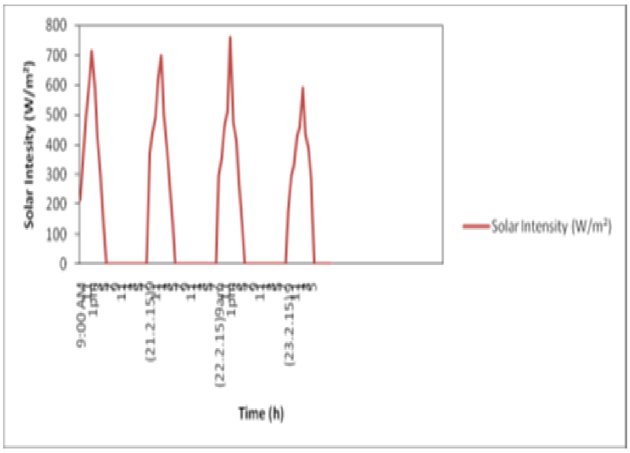

Fig. 2: Variation of Solar Intensity with Time

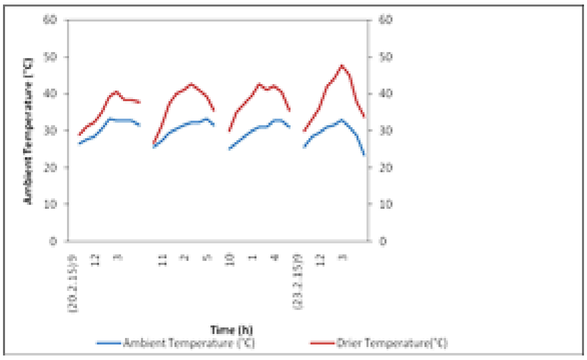

Fig. 3: Variation of Temperature with Time

"Fig.3." shows the variation of ambient and drier temperature. The maximum temperature attained inside the solar drier was found to be 58.25°C. Absorption inside the drier and therefore a higher temperature (7-12°C) was attained in the solar drier which helps in faster drying of grapes (Vitis vinifera).

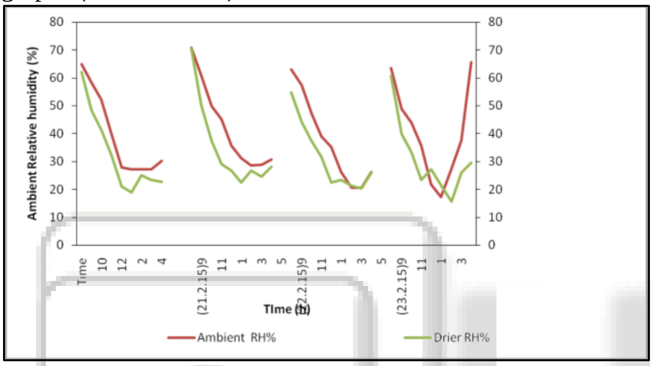

Fig. 4: Variation of Relative Humidity with Time

The variation of ambient and drier relative humidity was illustrated in "Fig.4." It was observed that the average relative humidity inside the solar drier was around 25% compared to the average ambient air humidity of 50%. The low air humidity inside the solar drier indicates that the air inside the drier was having higher drying potential compared to the ambient air and therefore the grapes (Vitis vinifera)

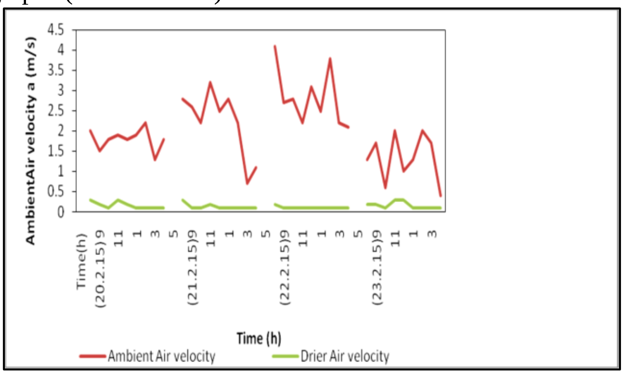

Fig. 5: Variation of Air Velocity with Time

Placed inside the drier was dried much faster compared to open sun drying. 'Fig.5" The air velocity varies between 0.1 m/s to 0.6 m/s during the drying period under natural convection. "Figure 6" shows the variation of moisture content (wet basis) with drying time. The solar drier takes 71 hours for reducing the moisture content of grapes (Vitis vinifera) from about 85% to about 10% without using

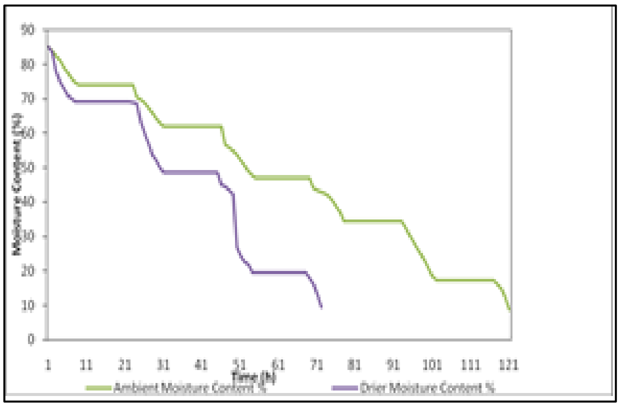

Fig. 6: Variation of Moisture Content with Days

The heat storage material, whereas the drier takes 71 hours for reducing the moisture content to the same level.. In open sun drying, the moisture content of grapes (Vitis vinifera) was reduced from 85% to 10% in 121 hours. However the moisture content has increased by 1-2% during the night due to de-absorption.

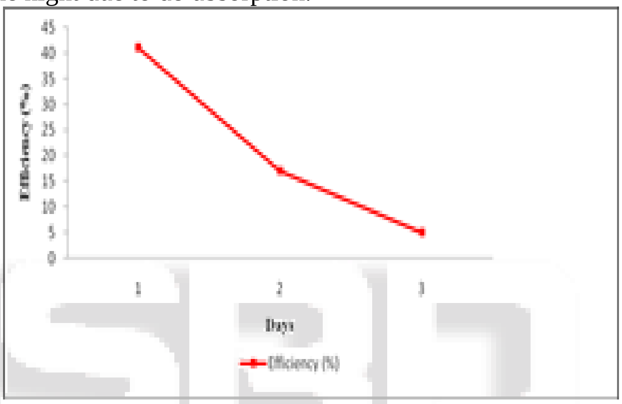

Fig. 7: Variation of Drier Efficiency with Time

The thermal efficiency of the solar drier was calculated using the "Eq.(2)" and was shown in the Fig. 7. The average thermal efficiency of the drier was found to be around 40%. Inside the drier and the drying takes place more 3-5% effectively compared to open sun drying.

IV. CONCLUSION

The developed natural convection solar drier is capable of producing the air temperature between 55 and 60ºC which was optimum for dehydration of most of the agricultural products. From the experimental work conducted for the drying of grapes (Vitis vinifera) in the natural convection solar drier, it was found that the grapes (Vitis vinifera) can be dried from initial moisture content of 85% (w.b.) to the required moisture level

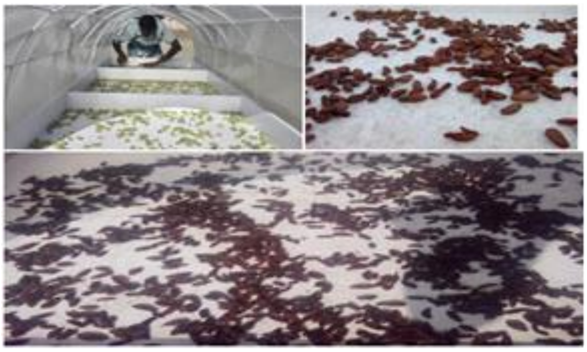

Fig. 8: Comparison with Open and Solar Drier

of 10% (w.b.) in 71hours respectively without using the heat storage material. The open sun drying takes 121 hours for reducing the moisture content of grapes (Vitis vinifera) to the same level. “Fig.8” reduced the drying time considerably compared to open sun drying. Also, the grapes (Vitis vinifera) obtained from the solar drier is of high quality, fetching more market price for the farmers. It can be concluded that this type of solar dryer is more suitable for the Fruits and vegetables farmers for producing high quality grapes (Vitis vinifera).

1) Nomenclature
- m_i initial mass of sample, kg
- m_f final mass of sample, kg
- M_{wb} moisture content on wet basis,%
- m_w mass of water evaporated, kg
- h_{fg} latent heat of vaporization of water, kJ/kg
- A area of solar drier, m^2
- I solar intensity, W/m^2

2) Greek Symbol
- η drier thermal efficiency

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