GRINREY

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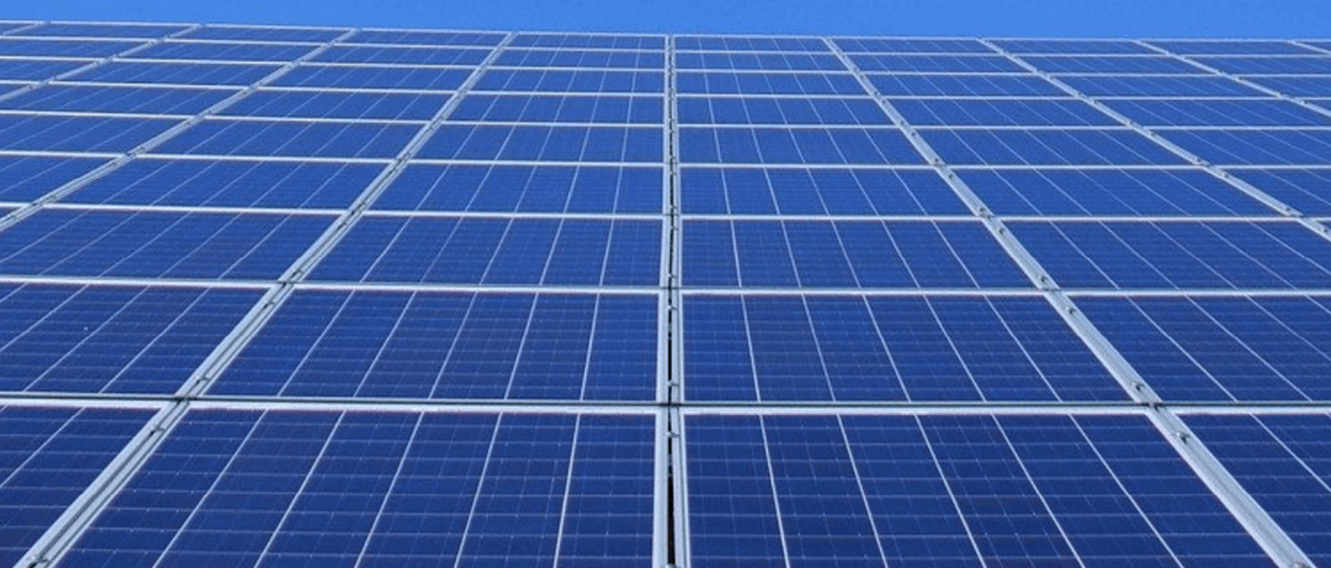

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Experimental Studies on Developed Direct Solar Dryer for Conversion of Grapes into Raisins with Temperature Control

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ABSTRACT

This chapter presents the experimental studies of the temperature variations in developed direct solar dryer while conversion of grapes into raisins. Optimum temperature of solar drying of grapes is in the range 28°C to 55°C so a small DC fan and speed control device running with solar PV panel is attached to the dryer to control the temperature in the dryer. The solar dryer is a flat plate solar collector with an aperture area as 2972.65cm^2. Experiments were performed without and with load, and the temperature profiles are reported. During load experiments with the developed solar dryer, the weight of 1kg of grapes reduced to 0.260 kg in five days and raisins were developed. The efficiency of the system was found to be in the range 4% to 7%. The efficiency of the system can be further improved with load optimization and slight modifications to make it suitable for households and cottage industries.

Keywords: Grapes, Raisins, Solar dryer, Temperature profile

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1. INTRODUCTION

Drying is one of the oldest techniques for preservation of food and agricultural products. The main objective of drying is to reduce the moisture content up to the safe storage level so that the products can be stored for a longer period without any spoilage. The low moisture content prevents the growth of microorganisms such as moulds, bacteria, and yeasts in the food products.

Solar energy is the most widely used renewable energy source in the drying process. The traditional open sun drying is the largest application of solar energy as it is a cheap drying technique, but some problems are associated such as longer drying time, difficulty in controlling the drying process, losses of the natural colours and minerals, losses of products due to insect, bird, weather changes, requirement of large drying area. To reduce these problems solar dryers are developed for use in drying the agriculture products and fruits. Solar dryers utilize the principle of conversion of solar radiation into thermal energy which heats the air and food products in the dryer and aids in removal of moisture from the food [1]. There are different types of dryers such as direct solar dryer, indirect solar dryer, hybrid solar dryer, mixed solar dryer, cabinet solar dryer, greenhouse solar dryer etc. [2]. Grapes are widely popular as a fruit world over. Grapes are main part for wine production, are used for preparing the raisins, the food industry uses grapes for various purposes like making jam and juice. Drying grapes either by open sun drying, shade drying or mechanical drying produces raisins. The grapes in India are used for making wine, jams, raisin and raw eating. Maharashtra is the India's largest producer of grapes and Nasik leads the list of grape producing areas in Maharashtra [3]. Open sun drying is oldest technique for drying the grapes and produces raisins but in this method drying rate is very slow. The drying time required for natural grapes is 20 days and for pre-treated grapes is 8–10 days. In this method there is possibility of contamination of the dried grapes. The direct exposure to intense sun radiation may also result in colour deterioration. [4]. The open drying process using sun can take a period of 9–15 days depending upon the climatic conditions of the location and dryer used [5-8]. For effective drying of grapes the temperature range 28^{o}C to 55^{o}C is considered optimum [9].

Though a number of studies have been carried out for solar dryers, the present work aimed at specific study of the temperature profile of each component of the solar dryer while conversion of grapes into raisins with control of temperature. The study is important from the point of view of understanding the temperature variations inside the dryer and for controlling the temperatures for optimum drying of the grapes through a small fan and speed control device running with solar PV panel. The present work reports the experimental observations related to the temperature variation of the dryer component with ambient air temperature and solar radiation values and estimates the efficiency of the system for drying. This work will form a basis for the development of an efficient temperature controlled solar dryer in future for households or cottage industries.

2. DESIGN DETAILS OF DEVELOPED SOLAR DRYER

The solar dryer is a flat plate solar collector with aperture area as 2972.65cm^2. The absorber plate (tray) is placed directly behind the transparent cover. Solar radiation trapped by glass heats up the air and heated air then circulates in whole system. Exhaust chimney is provided in the dryer to allow the hot air to move out from the dryer. The chimney is of length 53cm. Copper tubes are fixed at side walls of dryer so that whole system remains hot for long time, copper tubes is of 1125cm in length and having diameter 1.27 cm. The whole system is made up of GI sheet and insulated by polystyrene sheet and plywood.

Fig. 1. Complete experimental setup of solar dryer at University of Kota

The rolling wheels are attached for easy movement of the dryer. The whole dryer is painted black from inside so that more heat is absorbed by the system. The system is kept south facing to maximize the solar radiation incidence on collector. The solar dryer was initially developed as a passive solar dryer and tested for drying of ginger [10]. Some modifications were done in the dryer after the study to improve handling and convenience of operation. A fan with speed control device operated by PV panel was attached to control the temperatures inside dryer. The speed control device can increase and decrease the speed of exhaust fan. The designed dryer is tested at roof of University of Kota. The complete set up of direct type solar dryer is as shown in Fig. 1 and the schematic diagram of the solar dryer indicating the measurement positions of the thermocouple channels during load test is shown in Fig.2.

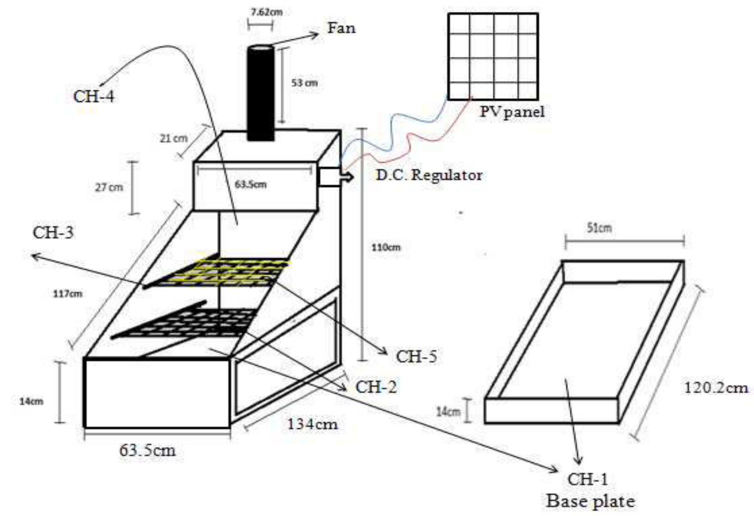

Fig. 2. Schematic diagram of developed solar dryer indicating measurement positions of thermocouple channels for load test

3. EXPERIMENTAL OBSERVATIONS

The performance tests of solar dryer presents the experiments without load and with load on the developed solar dryer and observations related to the temperature inside the dryer, drying rate and efficiency.

3.1. Experimental observations without load

The without load test was carried out to understand the trends of various operating parameters with respect to time. The positions of various thermocouple channels of the temperature data logger for the experiment without load for recording temperatures are presented in table 1.

Table 1: Details of thermocouple channels

Channel 1	Temperature of dryer base plate
Channel 2	Temperature of middle (second) tray inside dryer
Channel 3	Temperature of first tray inside dryer
Channel 4	Air temperature inside dryer
Channel 5	Ambient air temperature

The temperature profile without load at various positions inside dryer is as shown in fig. 3. It was observed that the solar radiation increased up to 1:00 PM and then decreased. Similarly, the ambient temperature increased with the day time and begins to fall in the afternoon hours. The maximum temperature was attained inside dryer at 12:55pm. Maximum base plate temperature attained inside dryer was 87°C, when the radiation was 975W/m^2 while the minimum temperature was 43ºC at 5 pm when the radiation was 323W/m^2. The maximum ambient temperature was recorded 35ºC at 12:55 pm, while the minimum ambient temperature was at 10am. From fig. 3 and 4 it can be inferred that the temperature rise is the function of solar radiation and ambient temperature.

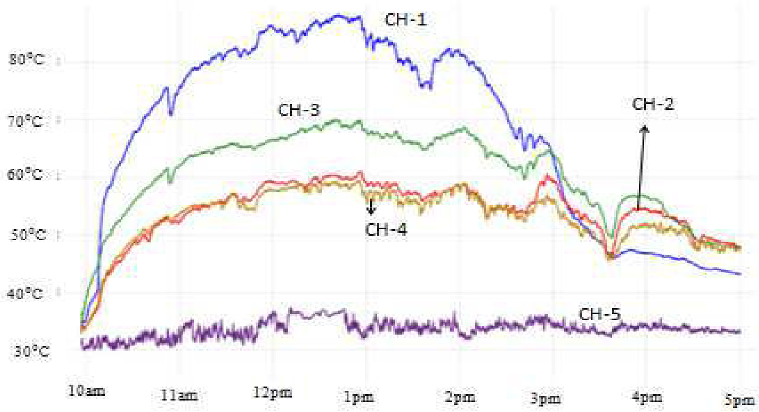

Fig. 3. Thermal performance curve for solar dryer without load test (Temperature plotted with time 27-03-2019)

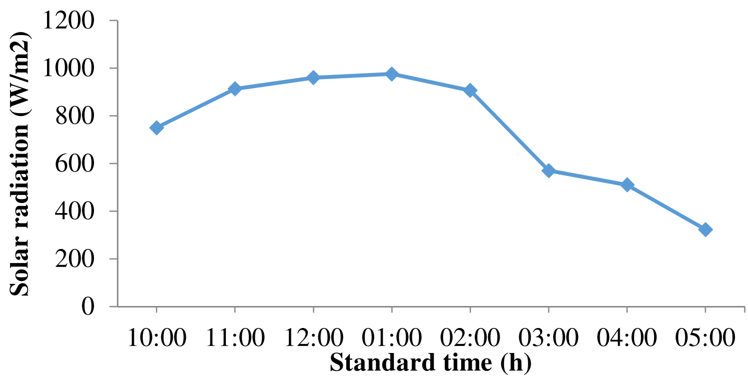

Fig. 4. Solar radiation (W/m^2) with standard time (27-03-19)

3.2. Experimental observations with load

Experiments were performed to evaluate the thermal performance and efficiency of the dryer for drying of grapes. The experiment was conducted with one kg load of grapes. The observations were recorded for the temperature profile of the various parts of the dryer, ambient temperature and variation of solar radiation with standard time. Five thermocouple channels of the temperature data logger were placed inside the dryer and one was placed outside to record ambient air temperature. The details of the channels are shown in table 2.

Table 2: Details of thermocouple channels

Channel 1	Temperature of dryer base plate
Channel 2	Temperature of middle (second) tray inside dryer
Channel 3	Temperature of first tray (upper tray) inside dryer
Channel 4	Air temperature inside dryer
Channel 5	Temperature of mesh with grapes placed on first tray
Channel 6	Ambient air temperature

3.2.1. Day 1

One kg grapes were put on upper tray (first tray) on a wire mesh inside dryer. Weight of the grapes was recorded at the starting and at the end of the day around 5 p.m. The temperature profile corresponding to the data logger channels and the solar radiation variation are shown in fig.5 and 6.

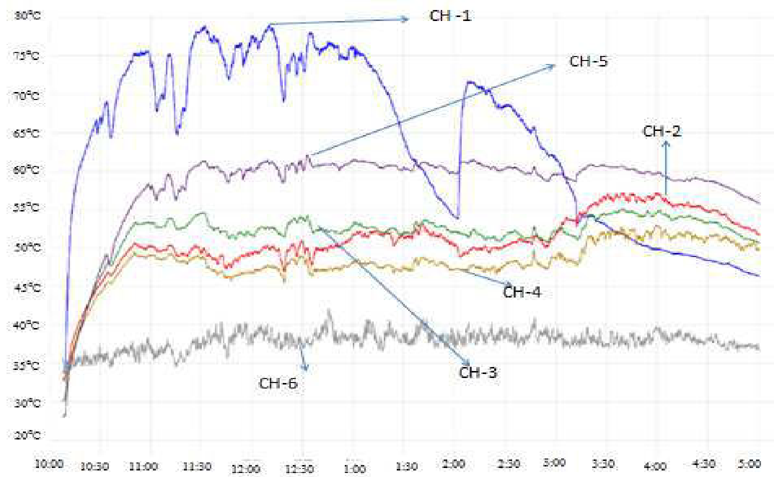

Fig. 5. Temperature profiles of various channels with standard time during load testing of solar dryer (1-04-19)

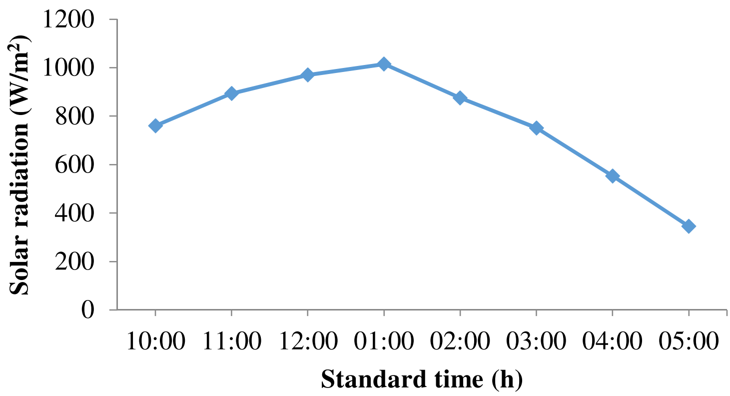

Fig. 6. Solar radiation (W/m^2) with standard time (1-04-19)

After drying process at 5 pm, the weight of grapes has been recorded as 854 grams. Thus, 146 grams of moisture was removed in 7 hours of effective drying process. With the help of exhaust fan the inside temperature of the dryer was controlled. CH-5 shows the maintained temperature of the grapes tray around 50-60°C. Humidity measured inside dryer was 23% at 10am and 10% at 5pm. For maintaining temperature inside dryer the fan was started at 11:00am with speed 1.3m/sec. CH-1 shows the decrease in the base plate temperature from 1 to 2 pm by shadow effect of dryer walls and by decrease in the solar radiation. CH-1 shows the increase of the base plate temperature at 2:00pm by tracking of dryer. Fan is put off at 3:00pm to maintain the inside temperature.

3.2.2. Day 2

Weight of the grapes was recorded at the starting of the second day and found to be 810gm at 10am. The grapes were put inside dryer for drying and at the end of the day the weight was around 709 gm at 5p.m. The temperature profile corresponding to the data logger channels and the solar radiation variation on second test day are shown in fig.7 and 8. CH-5 shows the maintained temperature of the grapes tray around 55-65°C. Humidity measured inside dryer was 21% at 10am and 10% at 5pm. For maintaining the temperature inside the dryer, the fan was started at 11:00am with speed 1.3m/sec. CH-1 shows the increase of the base plate temperature at 2:30pm by tracking of dryer. Fan was put off at 3:00pm to maintain the inside temperature. After drying process at 5 pm weight of grapes was found to be 709 grams as 101 grams of moisture was removed in 7 hours of effective drying process.

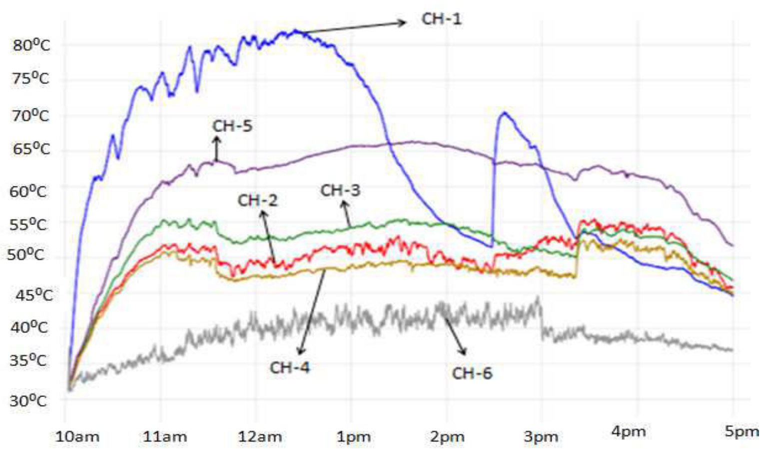

Fig. 7. Temperature profiles of various channels with standard time during load testing of solar dryer (2-04-19)

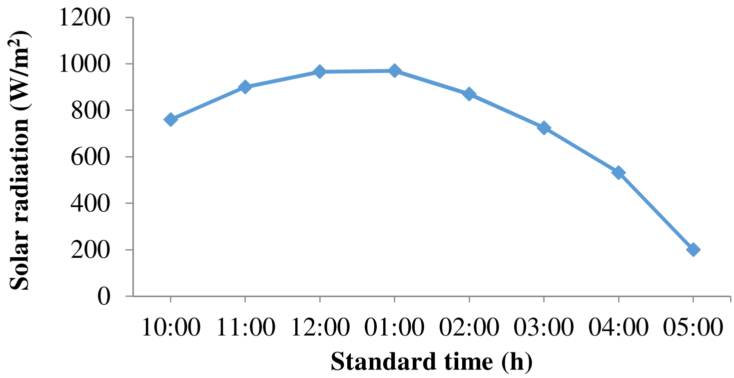

Fig. 8. Solar radiation (W/m^2) with standard time (2-04-19)

3.2.3. Day 3

On third day at 10 am 676 grams grapes were put in the dryer upper tray. CH-5 shows the maintained temperature of the grapes tray around 55-65°C. Humidity measured inside dryer was 24% at 10am and 10% at 5pm. For maintaining temperature inside dryer the fan starts at 11:00am with speed 1.3m/sec. CH-1 shows the increase of the base plate temperature at 1:35pm by tracking of dryer. Fan is put off at 3:00pm to maintain the inside temperature. After drying process at 5 pm weight of grapes was 516 grams as 160 grams of moisture was removed during the drying process.

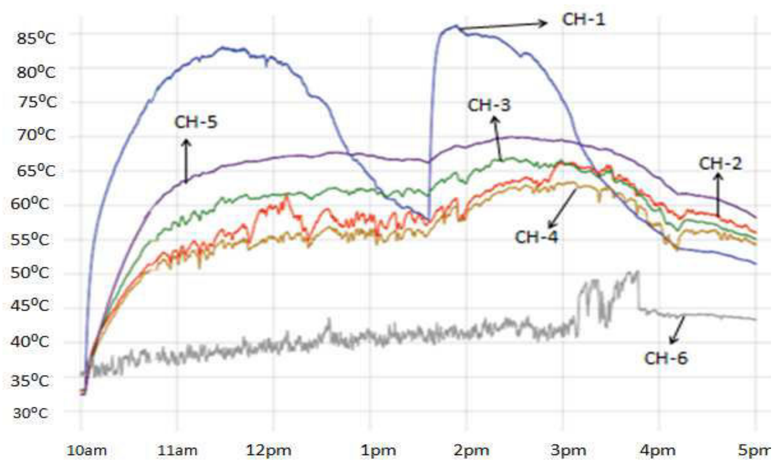

Fig. 9. Temperature profiles of various channels with standard time during load testing of solar dryer (3-04-19)

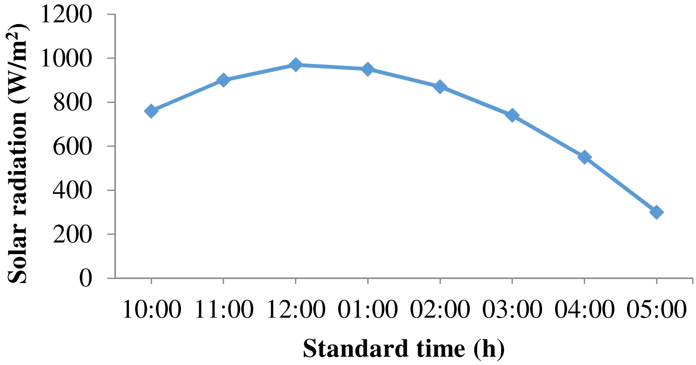

Fig. 10. Solar radiation (W/m^2) with standard time (3-04-19)

3.2.4. Day 4

On 4th day at 10 am 490 grams grapes were put in the dryer upper tray. Ch-5 shows the maintained temperature of the grapes tray around 55-65°C. Humidity measured inside dryer was 22% at 10am and 10% at 5pm. For maintaining temperature inside dryer the fan was started at 11:00am with speed 1.3m/sec. CH-1 shows the decrease in the base plate temperature after 2:10pm by shadow effect of dryer walls and by decrease in the solar radiation. Fan is put off at 2:00pm to maintain the inside temperature. After seven hours of drying process at 5 pm weight of grapes was found to be 388 grams as 102 grams of moisture was removed.

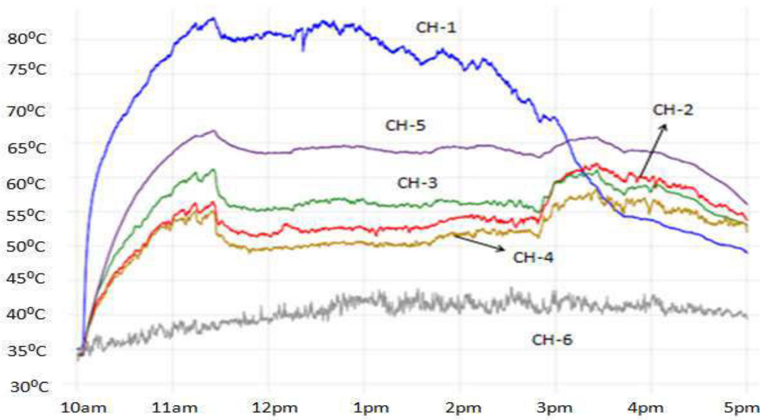

Fig. 11. Temperature profiles of various channels with standard time during load testing of solar dryer (04-04-19)

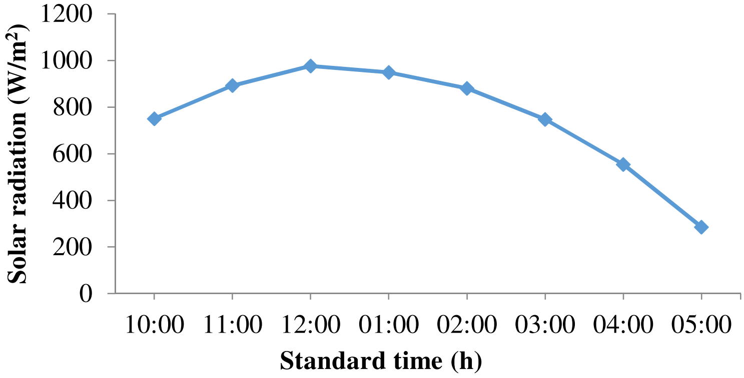

Fig. 12. Solar radiation (W/m^2) with standard time (04-04-19)

3.2.5. Day 5

On 5th day at 10 am 367 grams grapes were put in the dryer upper tray which has area of 2856 cm^2. Humidity measured inside dryer was 21% at 10am and 10% at 5pm. For maintaining temperature inside dryer the fan was started at 11:30am with speed 1.3m/sec. All channels show the temperature decrease inside dryer from 12:45pm to 1:45pm by decrease in the solar radiation. Fan is put off at 12:45pm to maintain the inside temperature. After seven hours drying duration at 5 pm the weight of grapes was recorded 260 grams as 107 grams of moisture got removed.

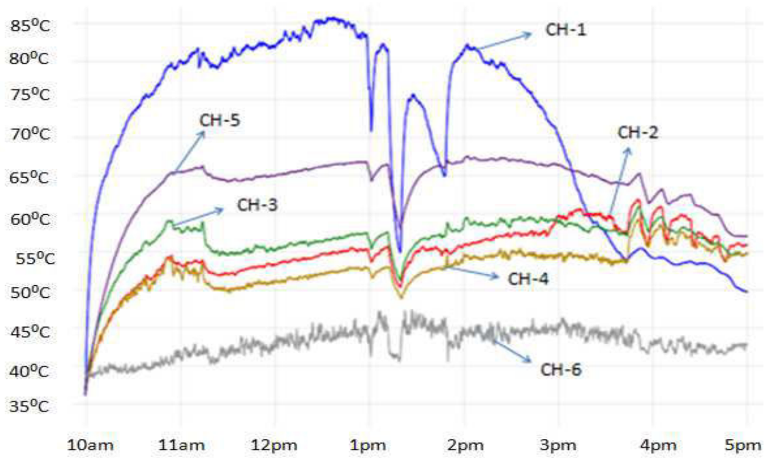

Fig. 13. Temperature profiles of various channels with standard time during load testing of solar dryer (05-04-19)

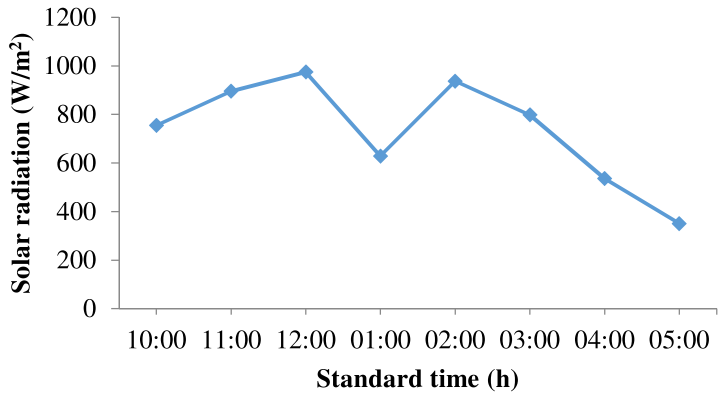

Fig. 14. Solar radiation (W/m^2) with standard time (05-04-19)

4. PERFORMANCE EVALUATION AND DISCUSSION

4.1. Moisture content

Moisture content of grapes was determined by calculating weight of grapes before drying and after drying for each day. The difference in weight is divided by initial weight and percentage is taken.

4.2. Drying rate

Drying rate is calculated by dividing the weight loss from the grapes due to moisture removal by the time period.

4.3. Efficiency

The thermal efficiency is defined as the ratio of thermal energy utilized for drying to the thermal energy available for drying [11].

$$\eta = \frac{m_v L}{I_{av} A_{in} t} x100 \qquad (1)$$

where, η = thermal efficiency, m_v is mass of moisture evaporated in total drying time, A_{in} is effective area of collector, I_{av} is the daily average solar radiation on the dryer surface area, t is the time in second and L is the latent heat of water (for moisture).

Table 3: Efficiency and drying rate of grapes in the developed solar dryer

Day	**Initial weight (kg)**	**Final weight (kg)**	**Solar radiation I_{av} (W/m^2)**	**Moisture removal (%)**	**Efficiency (%)**	**Drying Rate (kg/hr)**
1	1	0.854	0.770	14.6	5.71	0.020
2	0.810	0.709	0.740	12.46	4.07	0.014
3	0.676	0.516	0.755	23.66	6.34	0.022
4	0.490	0.388	0.754	20.81	4.03	0.014
5	0.367	0.260	0.734	29.15	4.35	0.015

From the above figures 3-14 and table 3, it can be seen that the dryer was able to achieve the required temperatures for drying of grapes. The weight of 1kg of grapes reduced to 0.260 kg in five days and raisins were developed. The daily basis reduction in moisture content has been observed as on day one it was 14.06%, on day two 12.46%, on day three 23.66%, on day four 20.81% and on day five 29.15%. The humidity levels inside dryer were generally in the range 21-24% in the morning when solar drying was started, by the evening the humidity levels observed inside dryer were around 10%. The grapes were again placed inside dryer after weighing at 5 p.m. to make use of the remaining heat inside dryer during the night. As a result slight decrease in mass is observed when the experiment was started next day.

During the experiments solar radiation remained on an average around 700 W/m^2 with clear sky except for cloud cover on 5th April for short duration at 1:00 p.m. It can be seen from fig. 13 and 14 that due to cloud cover the temperature corresponding to different channels fell down, major change in temperature was for base plate temperature (25-30^{o}C). The temperature of other components reduced just by around 5-7^{o}C. It is interesting to observe that there is a time lag of around 15 minutes between decrease in solar radiation and the observed decrease in temperatures of the various channels. This short term cloud cover did not have any major impact on overall performance, 29% of moisture reduction was observed with 4.35% efficiency on this day. Drying rate and the efficiency are observed to be highest on the third day. The efficiency of system lies within 4% to 7% for the conducted experiments. The reason for low efficiency is that the load is not optimized. Further works will be taken up to optimize the load for this developed system.

This developed solar drying system is a compact system which can be easily manually tracked and air speed can be controlled. This solar drying system holds promise to become a useful device for domestic drying applications and to be beneficial for cottage industries.

5. CONCLUSIONS

The grapes were converted in raisins within five days with the help of direct type solar dryer. Temperature variations in various system components were observed along with ambient air temperature, air temperature inside the dryer and global solar radiation on daily basis. Temperature control appropriate for grape drying was maintained between 55-60^{o}C with a small DC fan coupled with solar PV panel. The efficiency of system was found to be in the range 4% to 7% for drying of one kg grapes. There is scope of future studies to optimize the load and improve the efficiency of the system with slight modifications.

This system can be a useful aid in domestic drying applications and can be promising for use in cottage scale industries.

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