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PERFORMANCE ANALYSIS OF FORCED CONVECTION EVACUATED TUBE SOLAR COLLECTOR USED FOR GRAPE DRYER

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Abstract

In the present experimental study an evacuated tube solar collector is designed, fabricated and its performance is tested in the force convection mode of heat transfer. The solar collector is designed for the grape dryer of capacity 10kg per batch. Experiments are carried out in the month of April to produce raisins for Thomson Seedless grapes, with initial moisture content of 77 (kg per kg on wet basis)% to final moisture content of 19 (kg per kg on wet basis)% in 36 hours. Raisins produced from this system are tested for varies parameters to check its quality and found satisfactory results. The average collector efficiency is found to be 23.4%.

Keywords: Evacuated tube, Forced convection, Grape dryer, Raisins.

1. Introduction

The growing concern of environmental pollution and energy crisis has created a new awareness towards sustainable development by switching to renewable energy sources. It is essential to find the solution for existing systems which has zero emission. Use of solar energy is quite attractive and feasible solution. In the recent past it has received considerable attention.

During last two decades many researchers have developed efficient solar collectors. Most of the designs were demonstrated to improve the structure of solar collector, latest coating techniques. Some researchers have developed heat storage mechanism for absorber and reduced the losses of absorber and collector.

Nomenclatures

C_p	Specific heat of air, J/kg °C
I_G	Total solar global radiation, W/m^2
L_w	Latent heat of the vaporization, J/kg
M_i, M_f	Initial and final moisture content of grapes, kg/kg (W.B.)
M_p	Mass of grapes, kg
M_w	Mass of water in grapes, kg
m_a	Mass flow rate of air required to dry grapes, kg/s
$\dot{Q}$	Discharge of hot air, m^3/s
Q_{abs}	Heat absorbed by the collector, W
Q_{cond}	Heat loss by conduction, W
Q_{conv}	Heat loss by convection, W
Q_{refl}	Heat loss by reflection, W
Q_u	Useful heat gain by air, W
R_e	Reynolds number
T_a	Ambient temperature, °C
T_{co} , T_f	Collector and dryer outlet temperature, °C

Greek Symbols

Δt	Total drying time, s
$\eta_{Coll-Th}$	Solar collector thermal efficiency
η_{opt}	Optical efficiency of the evacuated tubes
ρ	Density of air, kg/m^3
σ	Kinetic viscosity of air m^2/s

Similarly Solar drying for the various foods and agricultural products has been demonstrated by many researchers. This is a cost effective and economical alternative to the conventional drying procedures.

In the traditional grape drying the ambient temperature, natural wind and relative humidity of air plays an important role. Many a times these sources are disproportionate and unpredicted. Practical adaptability of the past research work was kept at high priority during the study of literature. Most of the times it is observed that the experiments carried out are under known and controlled environment. But in practice those conditions can varied with time hence it generates the errors while commercializing the research work [1].

There is a need of farmers to dry grape by using economical and modern technology. The traditional way of drying is less efficient and time consuming or some time does not produce quality product. Solar drying system consist two parts as solar collector and dryer chamber [2].

The main part of the drying system is the solar collector which converts and stores the solar energy in the form of heat energy; this heat is sued to remove the moisture from the product. In the past research it is observed that lot of work is done on natural and forced convection type flat plate solar collector. Pangavhane et al. have designed and developed a solar flat plate collector dryer for grapes and checked the performance of drying with natural convection mode [3].

But very little work is available in the open literature on evacuated tube type solar collector used for fruit dryer in forced convection mode. Mahesh et al. [6] have studied the performance of the evacuated tube solar dryer, whereas Umayal et al. have tested the performance of similar type dryer for drying Amla [15]. Hence an evacuated tube solar collector is designed, fabricated and tested using forced convection for drying the grapes. Analysis on the solar collector is done with the help of computational fluid dynamic technique and results are validated with the experimental results. Detail discussion on this part is out of scope of this paper. The experiment is carried out in early month of April when no raisin production is started this reason.

Some aspects must be considered while designing a system like locally available materials and skills. Also purchase and maintenance costs play an important role with drying capacity of particular dryer.

The solar dried grapes are compared with traditional drying method of Shade drying. The advantages of the newly designed solar drier are quick drying, good quality, less chances of getting infected by fungi and have more market value for dried grapes.

2. Materials and Methods

2.1. Design procedure

If unsaturated hot air is passed over the fresh grapes, the air will take up the moisture from them. When the hot air of volume 'V_{air}' is made to pass over the grapes with temperature 'T_{co}' (solar collector outlet temperature), it evaporates 'M_w' mass water from grapes, with 'T_f' as final temperature of air leaving dryer. Then the energy balance equation can be written as [4],

$$M_w L_w = \rho C_p V_{air} \left(T_{co} - T_f\right) \tag{1}$$

The density of air is considered at constant pressure and at mean temperature, for moderate temperature difference. The important task in designing the dryer is therefore to determine suitable values of 'T_{co}' and 'V_{air}'. The temperature must not be too high; otherwise it may deteriorate the quality and colour of the grapes.

In present work the solar collector is designed based on the dryer load. While calculating the dryer load it is considered that 10 Kg of grapes from initial moisture content of 78% wet basis to final moisture content of 17% wet basis is dried in total 35hours. In actual setup based on these design considerations 10 kg of grapes are dried in 36 hours from initial to final moisture content of 77% to 19% wet basis. In most of the past literature it is found that the collector outlet air temperature is considered as dryer inlet temperature. But in practice it differs and it is observed 1-3 °C less. This leads to generate some errors in calculating thermal efficiency of the system. So in this work collector outlet and dryer inlet temperatures are separately measured and considered while calculating the performance. Loss of the air velocity in the passage from collector to dryer is very small and hence neglected.

The heat absorbed by the evacuated tube collector is given by [5],

$$Q_{abs} = A_C I_G \eta_{opt} \tag{2}$$

Ten evacuated tubes are arranged at an angel of 45° to horizontal with facing due south. Hence the total exposed area of the collector (A_c) is [6],

$$A_C = \frac{\pi}{2} DLn \tag{3}$$

where, D and L $are -$ Diameter and length of the tube in m, and $n -$ is number of tubes.

The total heat absorbed by the absorber cannot be utilized completely to heat up the working fluid. Some part of the heat is going to loss due to reflection of the incident rays from tube surface, conduction of the heat by the tube to the fixture and convection loss due to atmospheric air flowing around the setup.

Let Q_{loss} is the total heat loss in W which is expressed as [7],

$$Q_{loss} = Q_{cond} + Q_{conv} + Q_{refl} \tag{4}$$

Hence total useful heat or net heat gain by the collector is expressed as [8],

$$Q_u = Q_{abs} - Q_{loss} \tag{5}$$

This useful heat is going heat up the working fluid, i.e., air from ambient temperature $T_a{}^\circ C$ to collector outlet temperature $T_{oc}{}^\circ C$. If m_a is the mass flow rate of air in Kg/s flowing through the 60 mm diameter pipe through the system then the heat gain by fluid is given by [5, 9,18],

$$Q_u = m_a C_p (T_{oc} - T_a) \tag{6}$$

This amount of heat is available to remove the moisture content from the grapes. In most of the previous research it is found that the same amount of heat is considered as an input to dryer chamber. But in actual practice the temperature of hot air entering to the dryer chamber is always less than the temperature at the outlet of the collector thought proper insulation is provided to the passage in between solar collector and dryer.

The discharge flow rate of the hot air is expressed as in [10],

$$\dot{Q} = \frac{V_{air}}{\Delta t} \tag{7}$$

Also the area of the fan A giving forced air is calculate with air velocity v m/s as,

$$A = \dot{Q}/v \tag{8}$$

Reynolds number is calculated as viscous force to inertia force in [11],

$$R_e = \dot{V}D/\sigma \tag{9}$$

If M_p is total mass of grapes to be dried with initial moisture content M_i to final moisture content M_f on wet basis then mass of water to be evaporated from the grapes is given by [12],

$$\dot{M}_w = \frac{M_p(M_i - M_f)}{100 - M_f} \tag{10}$$

Drying rate D_R depends on the total mass of water to be evaporated to the time required in seconds as in [13],

$$D_R = \frac{M_w}{\Delta t} \tag{11}$$

The solar evacuated tube collector thermal efficiency using forced convection is termed as in [14],

$$\eta_{Coll-Th} = \frac{Q_u}{A_C * I_G} \times 100\ \% \tag{12}$$

2.2. Experimental setup

As shown in Fig. 1, ten evacuated tubes of the dimensions as, 55mm diameter and 1800 mm length, are arranged, which are inclined to horizontal on steel frame. At any instant the collector exposed area to direct sun light is measured as 1.618 m^2. The point of contact of the evacuated tube to frame is insulated with polyethylene foam sheet with thermal conductivity of 0.04 w/m k to minimize the heat loss by convection. The output of all tubes is collected and passed through the dryer chamber from a 60mm diameter pipe. Forced air is provided by 12 V/1A five fans run on the 15 watt solar panel as shown in Figs. 2 and 3. Dryer chamber is designed on the basis of Collector surface to volume of dryer ratio, i.e., $R = \frac{SA}{V} > 3$ which is found as 4.4 [15]. The dryer chamber is made up of 0.6 mm thick aluminium alloy sheet with divergent and convergent section to observe uniform flow of the hot air on bottom and top side respectively. The dryer chamber is also insulated with 12 mm polyethylene foam sheet to avoid the heat loss from the hot dryer air to surrounding.

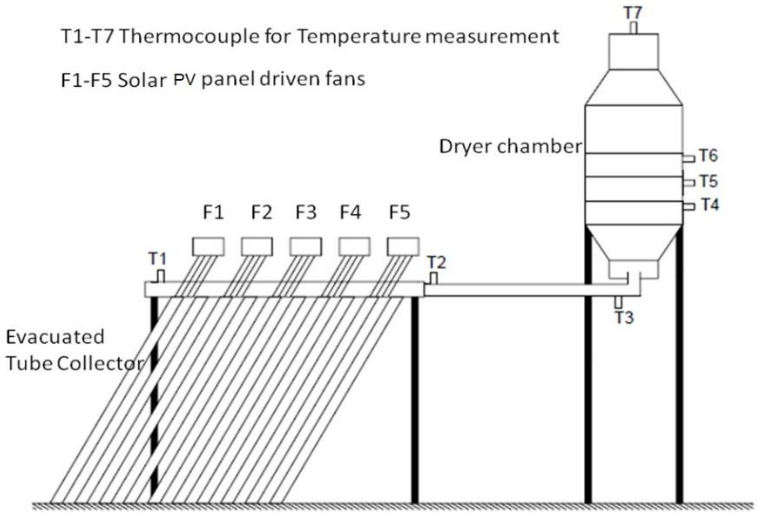

Fig. 1. Schematic view of evacuated tube solar collector and dryer.

10 kg of fresh Thompson seedless grapes are selected and sorted for infected berries. These are washed with tap water to remove dirt dust. Conventional alkaline pre-treatment is done to increase the water permeability. Deeping oil 2.5% and 2% Na_2CO_3 is used as agents [16-17, 19]. Grapes bunch are dipped for two minutes and equally spread on the three trays in dryer chamber made up of stainless steel mesh.

Fig. 2. Evacuated tube solar collector.

Fig. 3. Inside view of solar dryer.

2.3. Measuring instruments

The relative humidity, temperature of ambient air and in the vicinity of each tray is monitored on every hour basis during entire test time. One bunch from each tray is made as sample to weight after every hour with a weigh balance of accuracy ± 1grams from morning 9 am to evening 6 pm [17, 20]. RTD Pt-100 sensors (accuracy ± 0.1°C) with microcontroller reading facility having 12 channel selector switch is used to record the temperature reading at Ambient condition , air outlet to collector, inlet to dryer chamber. Also two thermocouple sensors are put on each tray of dryer chamber and dryer outlet temperature is also monitored per hour. Air velocity is measured for all reading with anemometer (accuracy 0.1m/s) in dryer and at exit of dryer. Solar pyranometer of accuracy ±3% is used to measure solar radiation. All the equipment are branded equipment and are calibrated.

2.4. Experimental Uncertainties

The measured data consist of several uncertainty sources such as solar radiation measurement, measurement of temperature at various locations in dryer and collector, relative humidity velocity and of air, current and voltage measurements etc. In this analysis, it is assumed that there is negligible loss of heat to the surrounding from the dryer. Further the heat losses due to convection and radiation from evacuated tubes are not significant in the current setup hence not calculated separately. The pressure drop of the working fluid in the collector is also not considered as the air velocity is measured at inlet and out let of dryer. Successive measurements under identical operating conditions give different results with small change. This variation is of the order of 2–5%. The temperatures of the working fluid at various locations were measured using PT-100 type RTD sensors. The instrument used for the temperature measurement has an accuracy of 0.1°C. Also the humidity measuring instrument and anemometer used are accurate with ±2% error considerations which is acceptable.

3. Results and Discussions

Tests are conducted in the month of April 2014 at the Symbiosis Institute of Technology, Pune campus with geographical data as, 18.5203° N, 73.8567° E. Table 1 shows readings of the solar radiation, temperature and relative humidity at ambient, collector and dryer for a typical day. Readings are recorded from morning 9 am to evening 6 pm on all test days at an interval of one hour for calculation purpose. The air velocity at the inlet to dryer is observed in the range of 2.1 to $2.7 m/s$. In the month of May the solar radiation and temperature goes high but efforts are made to start dryer system operative early, in the month of April to get more batches of production. This way more time will be available so it will reduce the requirement of higher capacity dryers for same amount of the raisins production.

Table 1. Solar radiation, temp, relative humidity reading of day one.

Time	solar rad.	Ambient Temp.		Collec outlet Temp.	Dryer tray 1		Dryer tray 2		Dryer tray-3	
am to pm	W/m^2	°C	% RH	°C	Tem °C	% RH	Temp °C	% RH	Temp °C	% RH
9	508	24.3	32	33.1	32.2	66	31	67	30.6	69
10	726	31.5	25	55.7	54.1	61	52.6	64	50.4	62
11	860	33.7	22	64.1	62.5	58	61.8	59	58.2	59
12	960	34.5	21	77.7	76.3	53	73.8	56	68.6	55
13	1050	36.2	21	80.5	79.2	40	75.6	42	69.8	41
14	1035	37.3	19	81.9	80	35	76.3	38	69.9	36
15	900	34.8	22	78.8	77.1	42	72.8	45	64.5	43
16	680	32.5	25	70.4	69.4	47	67.2	49	62.7	48
17	540	30.1	28	63.5	61	49	56	50	51	50
18	400	26.7	31	45.6	43.1	53	39.4	52	38.2	55

Figures 4 and 5 represent the climatic conditions of solar radiation and temperature variation with respect to time. Solar radiation varies from 380 to 1050w/m^2 with average radiation of 730w/m^2 during drying period. The maximum ambient temperature ranges from 35.8°C to 38.3°C and minimum average temperature range is 24.3°C to 25.9 °C. Whereas maximum collector output temperature reached to 82.3 °C to a mass flow rate of air 0.00817 Kg/s with average collector out let temperature of 65.1 °C.

Figure 6 represents heat gained by solar collector to solar radiation falling on the collector and the solar collector efficiencies are plotted against the drying time which is shown in Fig. 7.

The average heat required to dry the grapes is 234 W and the average heat gained by the air is 269 W. The average solar collector thermal efficiency is observed to be 24.3%.

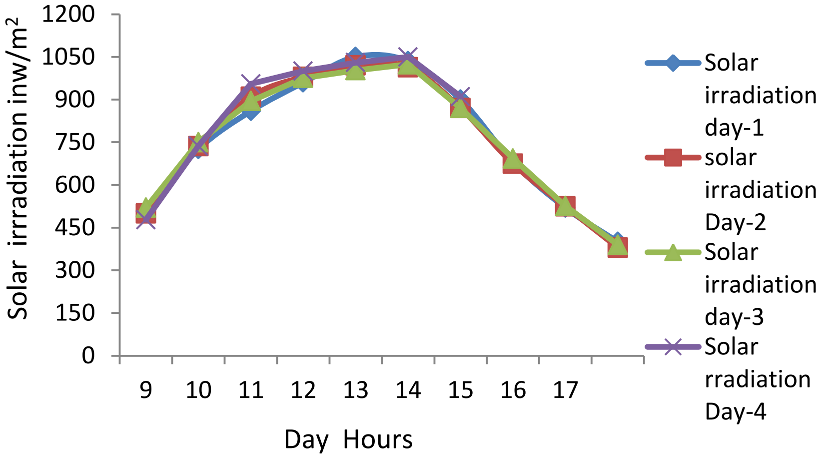

Fig. 4. Solar radiation vs. test time.

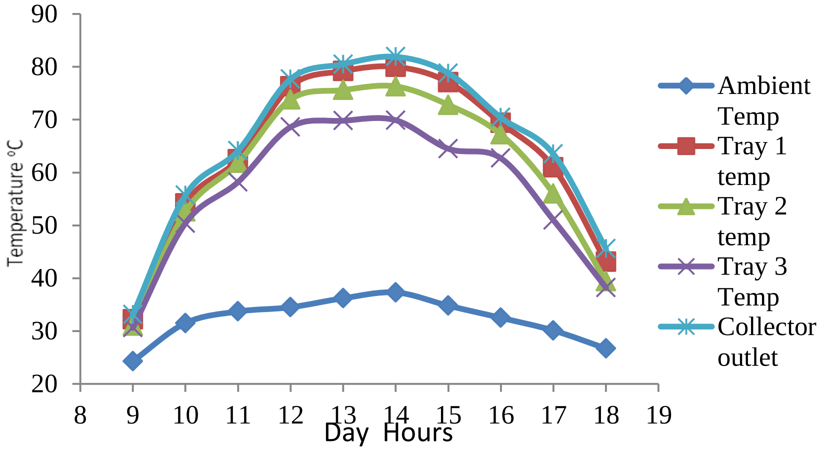

Fig. 5. Temperature variation.

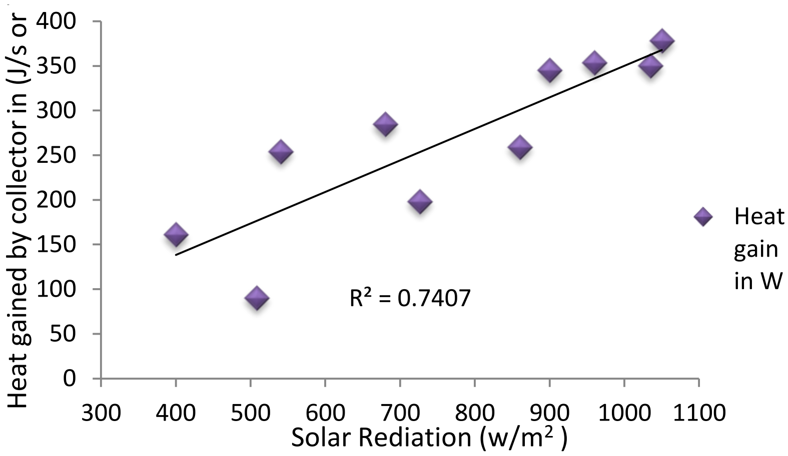

Fig. 6. Heat gained by collector vs. solar radiation.

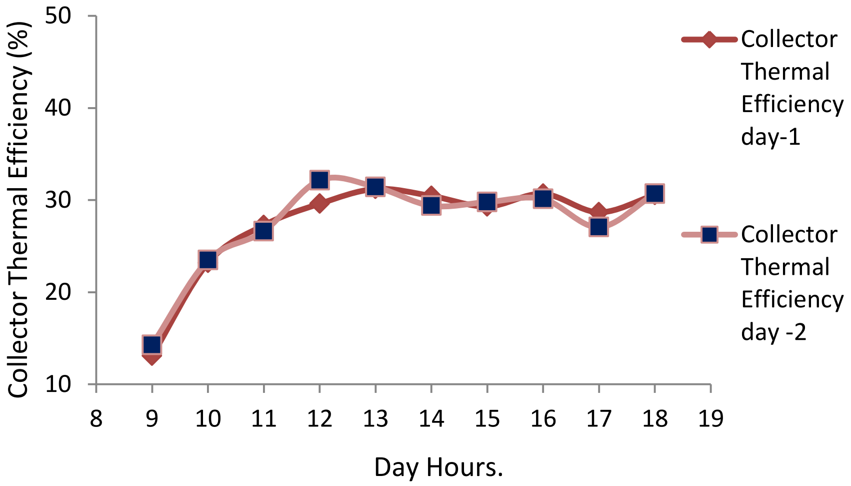

Fig. 7. Solar collector efficiency vs. drying time.

Figure 8 shows when mass flow rate is in between 0.0074 to 0.0085 kg/s and solar intensity is in the range of 700- 1000W/m^2 then heat gain by the air is observed maximum. This also relates to optimum solar collector efficiencies which are in the range of 24 to 29%. Corresponding air velocity in the dryer chamber is 0.7-1 m/s.

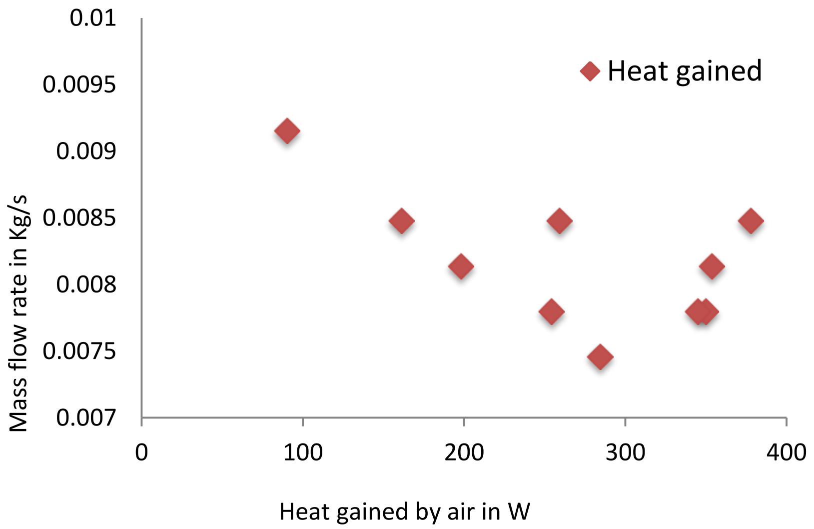

Fig. 8. Mass flow of air vs. heat gained.

As the temperature in the dryer chamber is higher than ambient temperature hence relative humidity of dryer is lower than ambient. From Fig. 9 it is observed that higher drying ratio during the initial stage of drying process. Moisture removal rate falls in the latter part of process. The drying rate of 0.45 kg of moisture to kg of dry matter per hr. is reported as highest during the early stage at 12 noon to 3 pm on first day with average drying rate as 0.21 kg of moisture to kg of dry matter per hr. At the end of the 36 hours the raisins are taken out from the dryer and checked for its moisture content which is found 19% (Wet Basis). Sensory test on the colour coding paper and glucose content of the raisins is also carried out and found satisfactory.

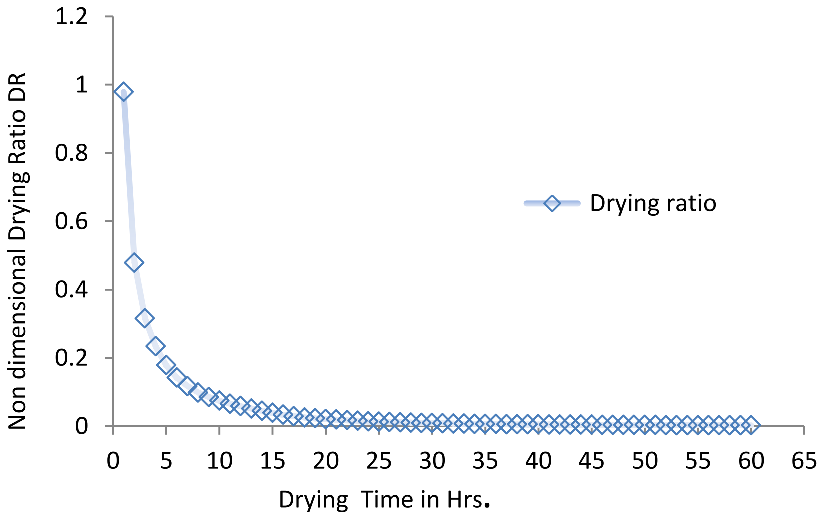

Fig. 9. Drying ratio vs. drying time.

4. Conclusion

Performance of evacuated tube solar collector for grape drying is studied by designing, fabricating and testing it in the force convection mode of heat transfer. A batch of 10 kg Thompson seedless grapes are dried from initial to final moisture content of 77% to 19%(wet basis) in just 36 hours with moisture removal rate of 0.21 kg per hour. Overall thermal efficiency of solar collector is found to be 24.3% in the first week of April where as in case of flat plate collector it is reported 16-22%. This could reduce the installations cost of dryer as more drying run can be carried out from April to end of May.

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