International Journal of Engineering, Science and Mathematics
Vol. 6 Issue 8, December 2017 (Special Issue)
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

DESIGN, PERFORMANCE AND ANALYSIS OF EFFECTIVE SOLAR CABINET DRYER FOR NOCTURNAL USE BY USING TRANSFORMER OIL AND THERMAL ENERGY STORAGE MATERIAL.

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Abstract

Objective of the present study was to carry out detail experimentation and then analyze solar cabinet dryer. The loading capacity of the dryer was about 2kg of fresh product per batch. The dryer is of both natural and force mode type based solar cabinet dryer. The experiments were carried on both natural and force mode by using chili as the raw product. Various readings related to temperature and humidity at the desired points were measured with the help of thermocouples and hygrometer respectively, also air flow rate and solar intensity were measured with the help of anemometer and pyrometer. These experiments were carried in ITER, SOA UNIV Bhubaneswar (India), in this various parameters related to solar dryer was not only calculated but also natural and force mode was compared in terms of drying rate. The data are presented in terms of tables and graphs. It was found that the drying of chili in natural mode would take around 50-56 hrs and drying in force mode will take about 10-21 hrs depending on whether we are using heater as an external source of heat or not. It will take around 105 hrs in open drying of chili. The chili was reduced from the initial moisture content of 86.5(wb) to 7.3(wb).[23-24]Further, the dryer was modified by implanting evacuated tube above the black plate collector incorporating with PCM(Paraffin Wax) as the heat storage medium behind the black plate. This in turn has increased the performance of the dryer. After that, an oil was filled in the annular space between the copper and the glass tube by mixing it with carbon graduals. The mixture was a semi solid type of slug which acts as a conducting medium between glass and copper tube. The performance of the dryer was seen to be increased surprisingly. Design and various parameters have been discussed here for clear in-depth of the topic. [25]

Keywords:

**Solar Drier,
Solar Collector,
Pyrometer,
Anemometer,
Thermocouples and
Hygrometer.**

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1. Introduction

The future of solar energy is very bright, as the non-renewable resources of energy are in extinct. One day when all the resources may go on extinct then we have to rely upon our renewable resources. In India there is a huge scope of solar power/energy, as the solar radiations we are getting are greater than what China and Japan like countries are getting; but the fact is that much more research related to solar is going on in these countries.[70] Actually, Japan and China are in the top zone of solar equipment producing countries. Solar dryer is among one of the equipments or we can say a machine which is used for drying purpose, it can be

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either in natural mode or in forced mode. People are actually not very confident in using solar dryer because of its initial cost, but they are not thinking about its pay back periods and its effectiveness as compared to open drying. Actually we have to do a lot of research work related to solar energy, inspite of its abundantly availability and one of the oldest sources of energy to mankind it had not been given enough attention for its development. Almost all the old civilizations from Egypt to Inca have built solar temples and solar operated monuments to trace the position of stars and to set the flow of wind in their desired directions. If you have noticed then you could have seen that there is a network of energy points of pyramids of all civilizations over the globe, perhaps it may be used infor communication. Hossain and Bala[1] had dried chili using solar tunnel drier and showed the effectiveness of dryer than open drying, also they showed that there was a considerable reduction in drying time.Ceylan and Ergun[2] had studied the relation between the psychrometry working upon the thermo-dynamic analysis of humid air and drying at a timber dryer. The thin layer silk cocoon drying was studied by Singh[3] in a forced convection[21-22] type of solar dryer, the drying air temperature varied from 50 to 75 C and the cotton was dried from the initial moisture content[17-18-19] of about 60-12(wb). Akintunde[4] studied the four layer drying models. The page model was found to best describe the drying behavior of chili pepper for sun and solar drying. The kinetics of heat pump drying of cocoa beans was investigated by C.L Hii et al.[5]. Chowdhury et al. studied the exergy and energy analysis of jackfruit leather in solar tunnel dryer. The various drying curve characteristics of tomato were studied by Manna et al.[6].

2. Methodology

A. Experimental setup and approach

The solar dryer we had used in our experiment is of cabinet type solar dryer. The design of the solar dryer is based on the climatic conditions of the place, nature of the product and the quantity of the product to be dried. The indirect type of the solar dryer was designed and constructed and then it was coupled with already available solar collector. The dimension of the solar collector is 1.55 by 1.09 m. The dryer is of 0.6m height from the ground, the inlet ambient air enters through the inlet of the collector of square cross-section having dimension of 12cm by 12cm. After that the inlet air is heated up with the help of solar air collector and the outlet is connected to the solar dryer inlet, where the hot heated-up air carries out the moisture content of the product to be dried and the extra moisture carried by the air is then thrown by the outlet of the drier. The electric blower used here have a capacity of 379W, as already mentioned the capacity of the drier is of 2kg of raw product. Matt black paint is used on the absorber plate to increase the absorptivity to solar radiation. The collectors were oriented due south at an angle of 45°. More details on the solar air collector can be found out from Wankhade et al.[6] where they had discussed the drying characteristics of Okra slices.The drying of the materials involve the migration of water from the inner of the material to its surface, and then removal of the water from the surface; which in turns requires an equivalent of latent heat of evaporation of water.

The equilibrium equation thatpresents the heat required is supplied by the solar air collector is given by Equation (1):

$$m_w h_{fg} = m_a C_P (T_{oc} - T_{tc}) \quad \textbf{(1)}$$

The collector should deliver a quantity of heat which equals to Equation (2):

$$\boldsymbol{Q} = HR(\overline{\tau a}) t A_{C\eta C} \quad \textbf{(2)}$$

The values of m_a and A_C are selected as desired by the drying conditions. The quantity of moisture removed from the raw product is calculated from the following relation referred to as Equation (3):

$$m_w = \frac{m_i (M_i - M_f)}{(1 - M_f)} \quad \textbf{(3)}$$

The efficiency of the air collector may be calculated from the following relation as shown in Equation (4):

$$\eta_C = \frac{Q_U}{HR.A_C} \quad \textbf{(4)}$$

The efficiency of the dryer is given by the following Equation (5):

$\eta_d = \frac{P.h_{fg}}{(HR.A_c + W)t}$	**(5)**

For heater the efficiency is calculated as follows as shown by Equation (6):

$\eta_h = \frac{\dot{m}.C_P.\Delta T}{I.V}$	**(6)**

The efficiency of the drying system is calculated by multiplying the efficiencies of the individual components of the system. Several tests were carried on using the flow rates 0.0378, 0.05619, 0.0689, and 0.0793m^3/sec. Calibrated thermocouples are used to measure the temperatures at the desired points for each interval of time. The temperature measurements were taken at the inlet to the collector, outlet to the collector, inlet to the dryer, outlet to the dryer, dryer inlet temperature, absorber plate temperature. Equal quantities of product were taken both for natural and forced convection, and for drying the product was uniformly spread over the 8 shelves of the dryer. The sample of dried product were taken and weighted with the help of weight balance, then the sample was dried with the help of oven and again its weight was measured with the help of the same weight balance after the sample was completely dried off. The weight balance used here is of type PE-3600, range0-500g and accuracy $\pm$1.5%. The relation whom we had used to calculate the moisture content is shown by Equation [8-9-10-11] (7):

$\boldsymbol{M} = \frac{w_s - w_d}{w_s}.100$	**(7)**

B. Design approach

We had tried to represent the design and drying analysis of the solar dryer.

1) *Thermal analysis*: The performance characteristic of the collector [7] and solar dryer is described by the energy balance that indicates the conversion of incident solar energy into useful energy gain and various losses.[6].

The air properties that are considered here are taken for the average temperature of the of the dryer cabinet: $\rho = 1.1324kg/m^3, C_P = 1.0066kJ/kg$℃ ,$\mu = 1.9036 \times 10^{-3}$kg/m.s, ν=16.9616$\times 10^{-6}m^2$/s, k=0.02719W/m.℃, Pr=0.70524; these properties are used to calculate the thermal characteristics and performance of the system. Grashof Number, Gr is given by the Equation (8):

$\boldsymbol{Gr} = \frac{g\beta L^3 \Delta T}{\nu^2}$	**(8)**

Where $\nu=\mu/\rho$, $\beta=1/T$, $\Delta T = T_c - T_a$, $T = (T_c + T_a)/2$. L depends on the section of the cabinet under analysis.
The heat transfer coefficient is represented by the Equation (9):

$\boldsymbol{h} = \frac{kNu}{L}$	**(9)**

Where the following Nusselt numbers Nu were used depending on the section or area of the cabinet under consideration.
For horizontal plate:
Above heated plate, Equation conforms (10):

Nu=0.54$Ra_L^{1/4}$ **for** $10^4 \leq Ra_L \leq 10^9$	**(10a)**

Nu=0.15$Ra_L^{1/3}$ **for** $10^7 \leq Ra_L \leq 10^{11}$	**(10b)**

Below heated plate, Equation conforms (11):

Nu=0.274 $Ra_L^{1/3}$ **for** $10^5 \leq Ra_L \leq 10^{10}$	**(11)**

For vertical heated plate, Equation signifies (12):

Nu=0.68+ $\frac{0.67 Ra_L^{1/4}}{(1+(0.492/Pr)^{9/16})^{4/9}}$ **for** $Ra_L \leq 10^9$	**(12)**

Where $Ra_L = Gr \times Pr$.

Here the analysis is not shown in details, because the heat transfer is more important and is calculated from the above Nusselt Number. In all the cases air in the environment is assumed to be stagnant; that is the reason why the heat transfer coefficient outside the dryer is taken to bezero.

2) *Collector analysis [16]:* The properties of air which had been used are already discussed before.Heat absorbed by radiation in the collector is predicted by Equation (13):

$Q_{rad,in} = \propto A_C I,$	**(13)**

Where ∝the absorptivity of the metal is, $A_C$is the surface area of the collector. I is the total incident solar radiation [20] and is expressed as by Equation (14):

I= $\frac{hourlyradiation}{solarradiation} \times solar\ irradiation$	**(14)**

Heat loss by convection and conduction through the base of the collector$Q_{cb,loss}$is given by Equation (15):

$Q_{cb,loss} = \frac{\Delta T_{cb}}{\Sigma R_{cb}}$	**(15)**

Where ΔT_{cb} is the temperature difference between the collector and the environment.$\boldsymbol{\Sigma} R_{cb} = \frac{1}{h_{cb}A_{cb}} + \frac{x}{kA_{cb}}$ is the thermal resistance offered by the wall and the film at the inside of the collector taking the heat transfer coefficient at the outside of the wall as zero (still air). $A_{cb}$is the base area of the collector.

Useful heat in the collectorQ_u is given by Equation (16):

$Q_u = \dot{m} C_p (T_c - T_a) = Q_{rad,in} - Q_{cb,loss}$	**(16)**

Collector Efficiency $\eta_c$is given by Equation (17)

$\eta_c = \frac{Q_u}{Q_{rad,in}} \times$ **100%**	**(17)**

3) *Cabinet analysis:* The analysis for drying cabinet was evaluated for the properties of air at the bulk temperature.Heat absorbed by the radiation in the cabinet $Q_{rad,in}$is given by the Equation (18):

$Q_{rad,in} = \alpha A_d I$	**(18)**

Heat transfer through the walls of the collector body $Q_{gc,in}$is given by the Equation (19):

$Q_{gc,in} = \frac{\Delta T_{gc}}{\Sigma R_{gc}}$	**(19)**

Where ΔT_{gc} is $\Delta T_{ca} + T_d$ and $\boldsymbol{\Sigma} R_{gc} = {}^1/_{h_{gc}A_{gc}} + {}^1/_{kh_{gc}A_{gc}}$is the heat transfer coefficient at the inside wall of the cabinet and $A_{gc}$is the area of the portion of the vertical wall separating the collector and the cabinet case.

Heat radiated to the environment by the cabinet $Q_{rad,out}$ is given by the Equation (20):

$$Q_{rad,out} = \varepsilon_{in}\sigma A_d(T_d^4 - T_a^4). \quad (20)$$

Where ε_{in} is the emissivity of the metal, $\boldsymbol{\sigma}$=5.699× 10^{-8}W/m^2.$K^4$is the Stefan-Boltzmann constant and $A_d$is the total surface area of the cabinet through which heat is exchanged by radiation with the environment.
Heat Transfer from the cabinet through the side wall Q_{vc} is given by the Equation (21):

$$Q_{tc} = \frac{\Delta T_{da}}{\Sigma R_{tc}} \quad (21)$$

Where $\Delta T_{da} = T_d - T_a$ and $\boldsymbol{\Sigma} R_{tc} = {}^1/_{h_{tc}} A_{tc} + {}^x/_{kA_{tc}}$.Here A_{tc} is the area through which heat is transferred from the lower side of the cabinet to the ambient &$h_{tc}$is the heat transfer coefficient on the inside of the box about the desired area.
Heat transfer from the cabinet through the bottom wall Q_{bc} is given by Equation (22):

$$Q_{bc} = \frac{\Delta T_{da}}{\Sigma R_{bc}} \quad (22)$$

Where$\Delta T_{da} = T_d - T_a$ and $\boldsymbol{\Sigma} R_{bc} = {}^1/_{h_{bc}A_{bc}} + {}^x/_{kA_{bc}}$. Here A_{bc} is the area through which heat is transferred from the base wall of the cabinet to the ambient &h_{bc} is the heat transfer coefficient at the top surface of the base wall inside the cabinet around the desired area.
Total heat through the walls of the cabinet box $Q_{loss}$is given by the equation (23):

$$Q_{loss} = Q_{vc} + Q_{tc} + Q_{bc} + Q_{rad,out} \quad (23)$$

Useful heat in the cabinet is given by the equation (24):

$$Q_u = \dot{m}C_p(T_c - T_d) = Q_{rad,in} + Q_{gc,in} - Q_{loss} \quad (24)$$

Solar Dryer Efficiency is given by Equation (25):

$$\eta_s = \frac{Q_u}{Q_{rad,in} + Q_{gc,in}} \times 100\% \quad (25)$$

4) *Drying analysis:* Percentage of moisture removed from the product, M%

$$\frac{m_w - m_d}{m_w} \times 100\% \; on \; wet \; basis$$

Where $m_w$and $m_d$are the masses of wet and dried products respectively.
Average Dry Rate, m_{avg}

$$m_{avg} = \frac{m}{t}$$

Drying Time, T is given by the following Equation (26):

$$\frac{mh_{fg}}{3600IA_T t\eta_c\eta_s} \quad (26)$$

Where t is the daily sunshine hours.

3. Results and Analysis

1) ***Moisture content****:*This graph of Fig.1 (a) & Fig.1 (b) shows the rate of decrease of moisture content for different modified and unmodified modes of the dryer. As the graph is seen steeper from black plate free, black plate forced, evacuated tube with PCM free, evacuated tube with PCM forced to oil with PCM free and oil with PCM forced respectively, it is cleared that the rate of decrease of moisture content of the sample is higher for oil with PCM forced and is lowest for the black plate free mode, the moisture content was reduced from about 88.5 to 7 %. This is only due to reason of

high heat addition which in turn increases the drying chamber temperature, which leads to increase in moisture removal rate respective consequent cases.

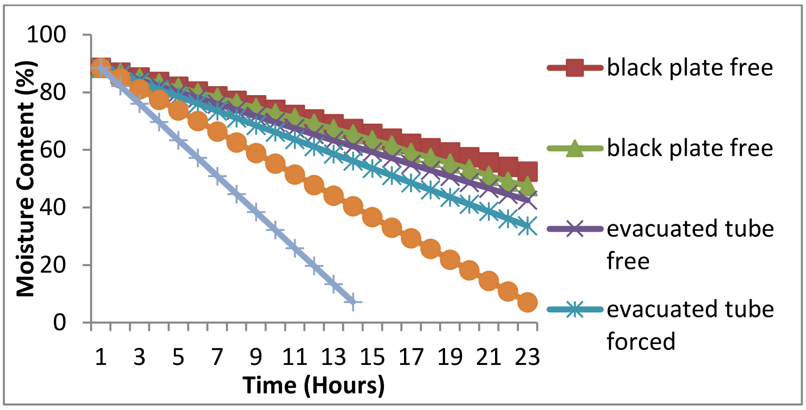

Figure1 (a). Shows the graph between moisture and time (hrs) for natural mode drying.

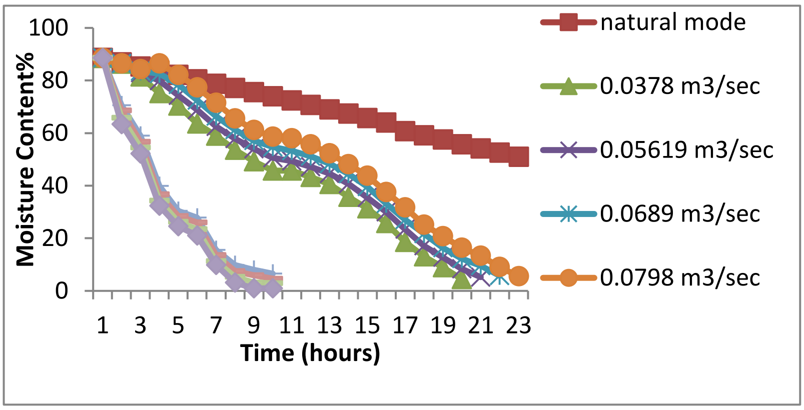

Figure1 (b). The graph between moisture and time (hrs) for natural and forced mode for different flow rates

2) ***Collector efficiency***: The collector efficiency is given by the graph; this graph shows the relation between the collector efficiency and drying time. The collector efficiency was seen to be first increasing and then decreasing. As the solar intensity of the radiation first increases and then decreases and this is due to this reason that the collector efficiency was seen to be monotonically increasing and then decreasing. The collector efficiency of the dryer was seen from the graph fig.2 to be higher for in case of Oil + PCM mode and it goes on decreased for Black Plate Free mode. The graph is seen to be monotonically increased up to 1 pm in noon and goes to monotonically decreased up to 6 pm in the evening, this happens only due to reason that solar intensity of the radiation goes on increasing from 8 am in the morning to the noon and is highest at 1 pm in the noon and again then goes decreased to 6 pm in the evening.

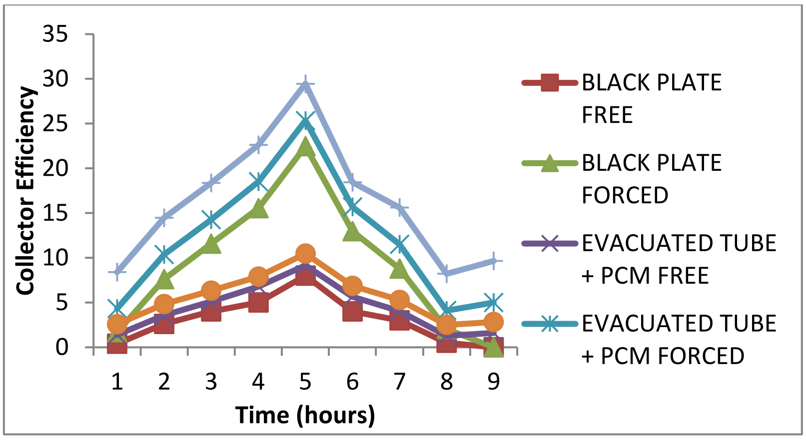

Figure 2. The variation of collector efficiency with time

3) ***Drying rate***: The drying rate was seen to be decreasing with the time and is shown by the given graph in fig4. In this graph of fig.3 the drying rate was seen to be higher for Oil+ PCM Forced and will be seen to be decreased to Black Plate Free. Drying Rate is the rate of decrease in moisture content, i.e. $\frac{\Delta W}{\Delta T}$ where ΔW is the decrease in sample weight and ΔT is the time taken for that sample weight to be decreased to the desired limit. The curves were seen to be staggered and modulated upon one another, this is due to the fact that at the latter stage of drying there will be very less moisture content in the drying sample and for that there will be almost no or very little differences in the drying efficiency of the dryer for different modes. This is because, for very less moisture content within the sample all the modified and unmodified versions have almost no effect on the drying rate.In this graph of Fig.3(a) & Fig.3(b) the drying rate was seen to be higher for oil with PCM forced and will be seen to be decreased to black plate free mode. The drying rates for the case of chilli for different cases were seen to be in the range of 12.4 kg/ hr, 13.55 kg/ hr, 15.45 kg/ hr, 17.9 kg/hr, 24.35 kg/ hr, and 35.4 kg/hr respectively; whereas for the case of ginger it was seen to be in the order of 14.05 kg/ hr, 14.6 kg/ hr, 15.3 kg/ hr, 18.05 kg/ hr, 28.5 kg/ hr and 40.15 kg/ hr for consequent cases. This was only due to reason of high heat addition to the drying chamber, which in turn had increased its temperature and hence the efficiency. Latter on the bars were seen to be staggered and modulated upon one another, this is due to the fact that at the latter stage of drying there will be very less moisture content in the drying sample and for that there will be almost no or very little differences in the drying efficiency of the dryer for different modes. This is because, for very less moisture content within the sample all the modified and unmodified versions have almost no effect on the drying rate.

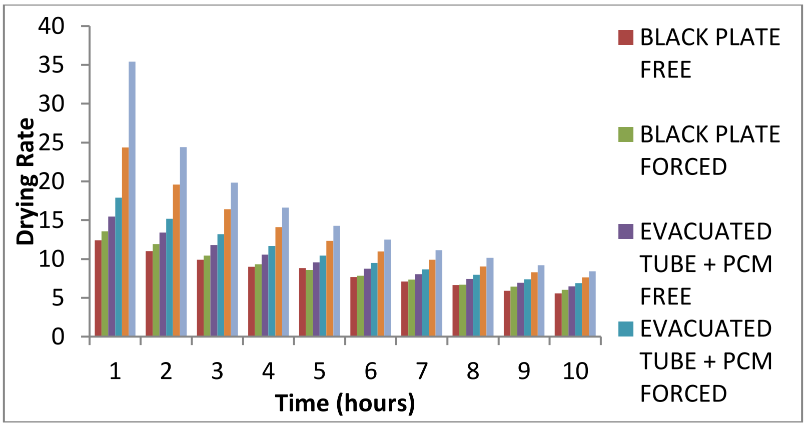

Figure3(a). The variation of drying rate with time.

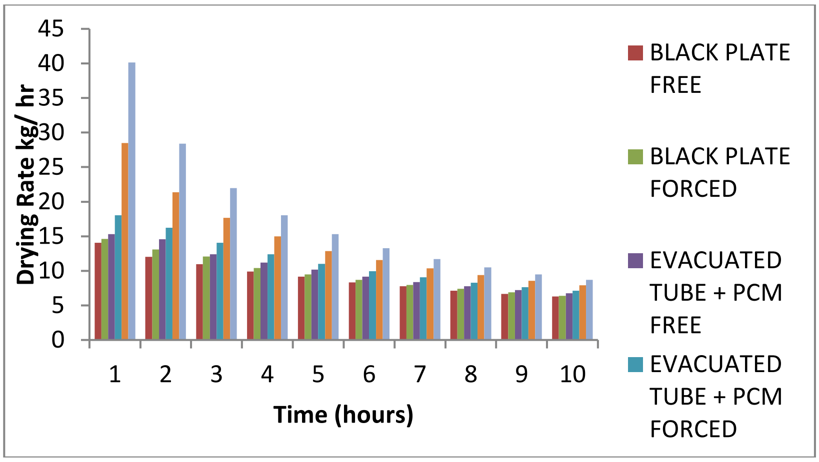

Figure 3 (b). Variation of drying rate with time for ginger

4) ***Drying efficiency***: The drying efficiency was seen to be decreasing with time and is shown in the fig4. There are some peaks and falls in the curve and the curve is not monotonically decreasing.The graph of Fig.5 (a) & Fig.5 (b) below shows that the efficiency of the oil with PCM forced mode version of the dryer is the highest and it goes decreased to black plate free version. The performance of the dryer was seen to be in the order of Black Plate Collector Free mode, black plate collector forced mode, evacuated tube with PCM free mode, evacuated tube with PCM forced mode, oil with PCM free mode, and oil with PCM forced mode. The drying efficiency was seen to be in the order of 25.52%, 27.88%, 31.78%, 36.83%, 50.102% and 72.838% respectively for chilli; where as in case of ginger it was observed in the order of 28.90%, 27.05%, 31.48%, 37.139%, 58.64% and 82.611% respectively. This was only due to reason of the fact that the conversion of energy from solar intensity to heat had been improved in the consequent cases. At the latter stage the curves are seen to be staggered and cover one upon the other, this happens due to the fact that at that stage the moisture content of the sample was so low that it doesn't matters over an interval of an hour for the increased in efficiency. This is because at the latter stage almost maximum % of the moisture has been evaporated.

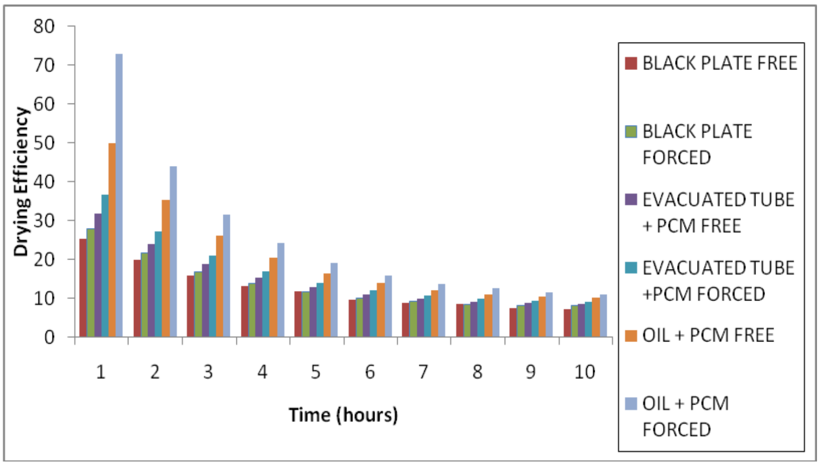

Figure4(a). The graph between drying efficiency with time.

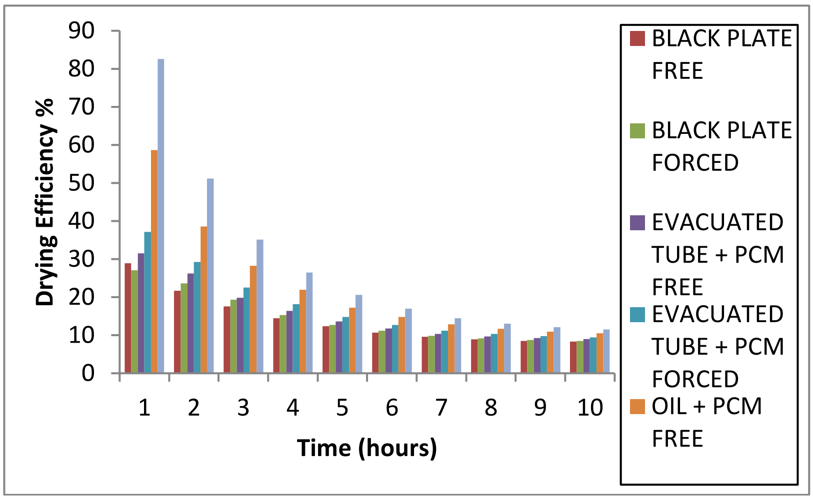

Figure4(b). Variation of drying efficiency with time for ginger

5) ***Relative humidity:*** The relative humidity at the desired points is shown in the fig5, and it was found to be first decreasing and then increasing. The relative humidity inside was found to be higher than relative humidity at outside.The Fig.5 shows that relative humidity at outlet is greater than relative humidity at inlet; this is due to the fact that moisture addition to the inlet humidity occurs inside the drying chamber. Also, the humidity at outlet for different consequent cases such as black plate free mode, black plate forced mode, evacuated tube with PCM free mode, evacuated tube with PCM forced mode, oil with PCM free mode and oil with PCM forced mode were seen to be increased at each instant of time, as 65.9%, 75.4%, 77%, 81%, 84%, 86% and 88% at 10 am respectively. This was only due to high moisture removal rate for consequent modified cases, as there had been an increase in the moisture content of air inside the drying chamber due to higher efficiency of the dryer.

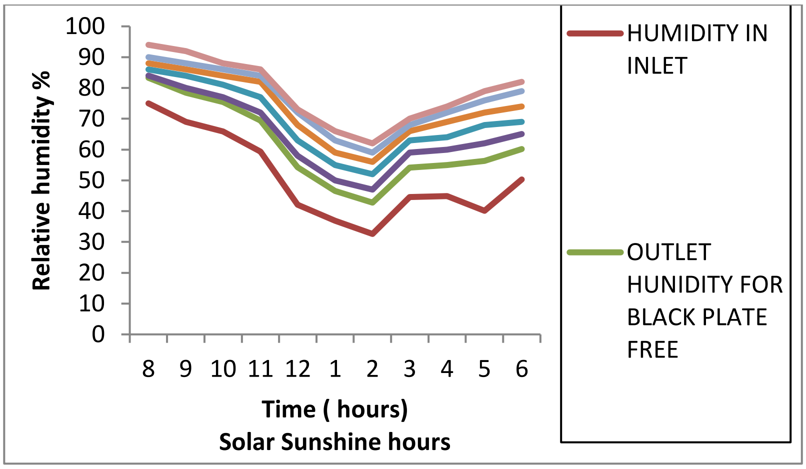

Figure5. The variation of relative humidity with time.

6) ***Temperature***: The temperature variations in the system are shown in the fig6 (a), and it was found to be first increasing and then decreasing. The reason for this monotonically increasing and then decreasing is due to available solar intensity which was seen to be increasing first and then decreasing.The given figures of temperature variation shows the various temperatures at the desired points in the dryer. Ambient temperature is the lowest and the collector plate temperature is the highest. The temperature at desired points was seen to increase in the order of increased performances. As the dryer chamber temperature were seen to be in the increasing order of 57℃, 58 ℃, 62℃, 63℃, 68℃ and 71℃ for black plate collector free mode, black plate collector forced mode, evacuated tube with PCM free mode, evacuated tube with PCM forced mode, oil with PCM free mode, and oil with PCM forced mode respectively. In the six above temperature graphs we can see that the temperature at the desired points will going to be increased for its each modified version, that means the temperature curves are seen to be increased from black plate free to forced then to evacuated tube free and then to forced and subsequently to oil free to its forced version. The

only reason to above statement is due to increase in drying efficiency, the conversion of radiant energy to heat energy had been increased which is a clear sign of increase in temperature at desired points for the consequent cases. From Fig.5.10 to Fig.5.14 we can see that the temperature at the desired points are remained to be almost constant from 5 pm to 6 pm and this was due to PCM used that tried to maintain constant temperature after the sunset.

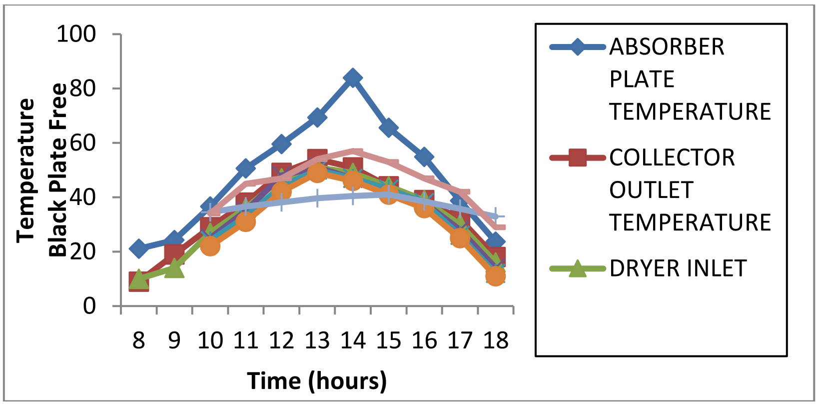

Figure6 (a) Shows the variation of temperature vs. Time

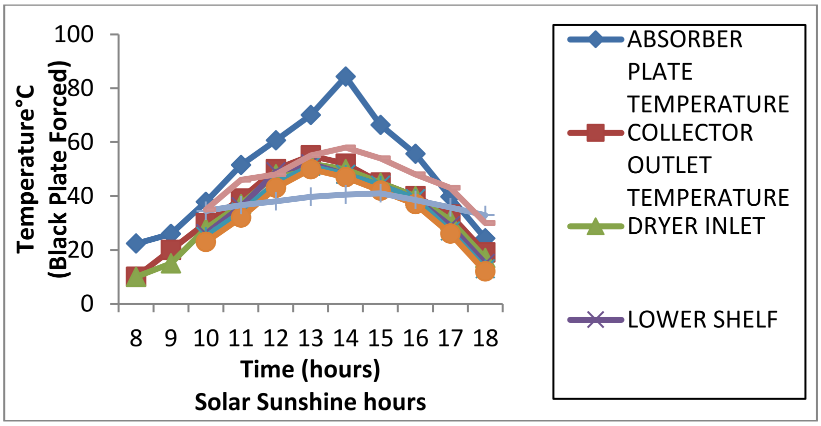

Figure6 (b) Variation of temperature of black plate in forced mode with solar sunshine hours

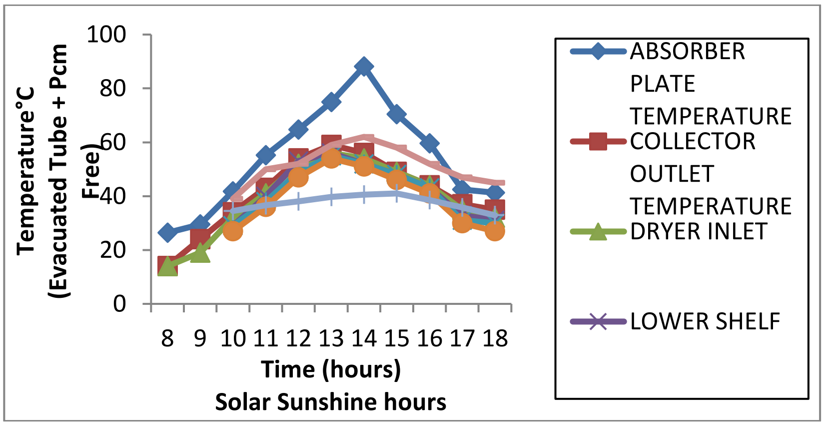

Figure6 (c) Variation of temperature of evacuated tube with PCM in free mode with solar sunshine hours

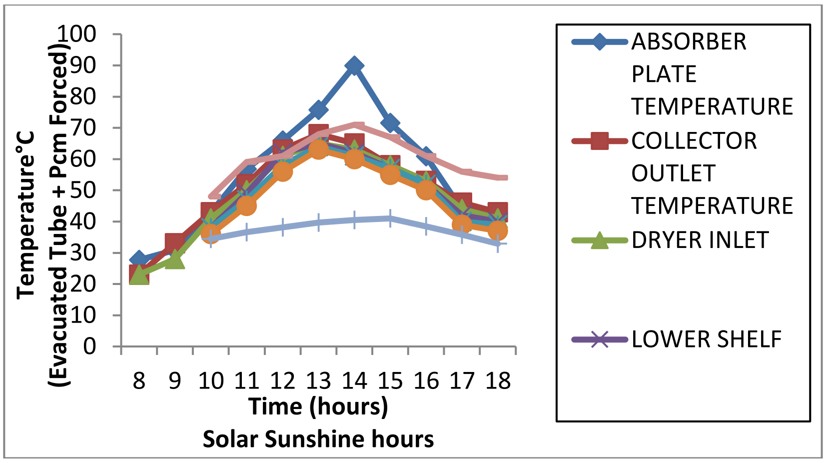

Figure6 (d) Variation of temperature of evacuated tube with PCM in forced mode with solar sunshine hours

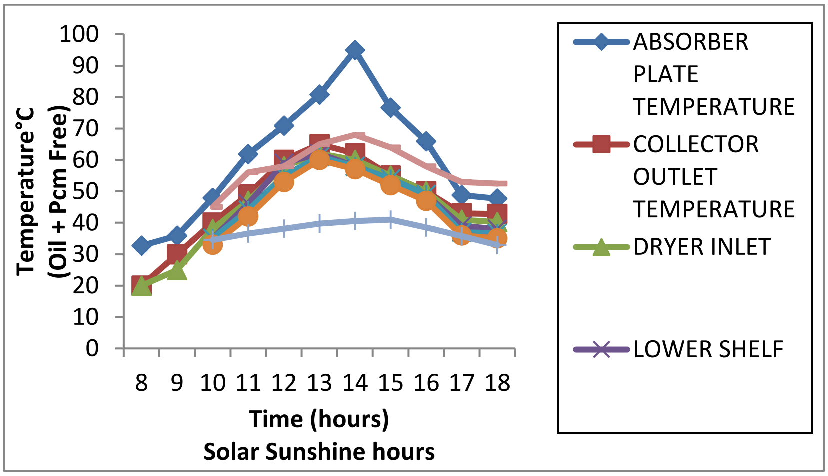

Figure6 (d) Variation of temperature of Oil with PCM in free mode with solar sunshine hours

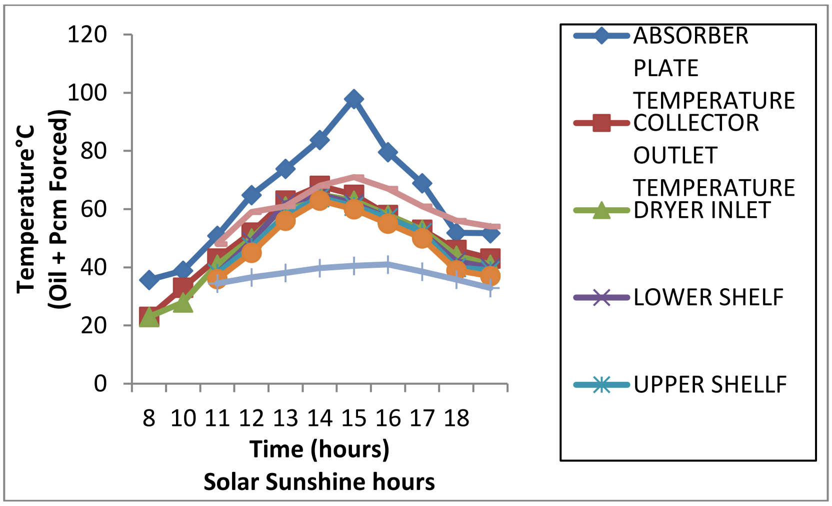

Figure6 (e) Variation of temperature of Oil with PCM in forced mode with solar sunshine hours

7) ***Solar intensity***: The variation of solar intensity with time is shown in the fig7, and it was first seen to be increasing and then decreasing.

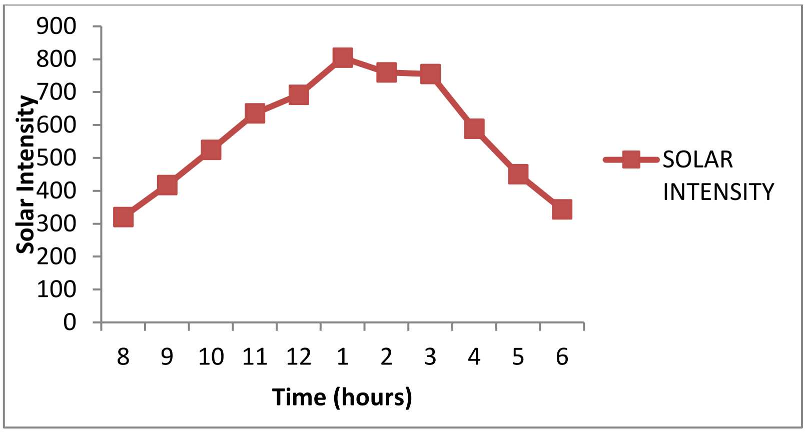

Figure7. Shows the variation of solar intensity vs. time

4. Conclusion

As it was seen that with the increase in flow rate there will be a considerable increase in the drying rate and moisture removal rate would be faster. Also it was seen that when heater was used there were almost negligible effect of flow variation in the moisture removal rate. Thus it was seen that it will be beneficial to use blower with different flow rates instead of using a completely natural solar dryer. It should be noted that using a blower may consume more energy but it adds to less time in drying the product and may lead to more net profit. The performance of the dryer was enhanced by the use of evacuated tubes incorporated with PCM and latter on its performance was increased by transformer oil filling in the annular space between the glass and the copper tube.

The performance of the dryer was seen to be in the order of Black Plate Collector Free mode, Black Plate Collector Forced mode, Evacuated Tube + PCM Free mode, Evacuated Tube + PCM Forced mode, Oil + PCM Free mode, and Oil + PCM Forced mode. Also, the temperature at desired points was seen to increase in the order of increased performance. The numbers of days are reduced from 5days to 1 and half day, where 5 days are required for Black Plate free mode where as 1 and half day is required for Oil +PCM forced mode. The temperature from 5pm to 6pm are seen to remain constant, this was only due to use of PCM (Paraffin Wax).The dryer was modified by keeping the collector area constant and then implanting evacuated tube above the black plate collector incorporating with PCM (Paraffin Wax) as the heat storage medium behind the black plate. This in turn has increased the performance of the dryer. After that, oil was filled in the annular space between the copper and the glass tube by mixing it with carbon graduals. The mixture was a semi solid type of slug which acts as a conducting medium between glass and copper tube. The performance of the dryer was seen to be increased surprisingly.

- The performance of the dryer was enhanced by the use of evacuated tubes incorporated with PCM and latter on its performance was increased by transformer oil filling in the annular space between the glass and the copper tube.
- The drying rate was seen to be higher for oil with PCM forced and will be seen to be decreased to black plate free mode. The drying rates for the case of chili for different cases were seen to be in the range of 12.4 kg/ hr, 13.55 kg/ hr, 15.45 kg/ hr, 17.9 kg/hr, 24.35 kg/ hr, and 35.4 kg/hr respectively.
- The performance of the dryer was seen to be in the order of Black Plate Collector Free mode, black plate collector forced mode, evacuated tube with PCM free mode, evacuated tube with PCM forced mode, oil with PCM free mode, and oil with PCM forced mode. The drying efficiency was seen to be in the order of 25.52%, 27.88%, 31.78%, 36.83%, 50.102% and 72.838 respectively for chilli; where as in case of ginger it was observed in the order of 28.90, 27.05, 31.48, 37.139, 58.64 and 82.611 respectively.
- The mean peak collector efficiency for black plate, evacuated tube with PCM mode and oil with PCM mode were seen to be in the increasing order of 8%, 9.15% and 10.467% respectively in free convection mode; where as it was seen to be in the order of 22.47%, 25.34% and 29.451% respectively in forced convection mode.
- Also, the temperature at desired points was seen to increase in the order of increased performance. As the dryer chamber temperature were seen to be in the increasing order of 57, 58,

62, 63, 68 and 71 for Black Plate Collector Free mode, black plate collector forced mode, evacuated tube with PCM free mode, evacuated tube with PCM forced mode, oil with PCM free mode, and oil with PCM forced mode respectively.

- The humidity at outlet for different consequent cases such as black plate free mode, black plate forced mode, evacuated tube with PCM free mode, evacuated tube with PCM forced mode, oil with PCM free mode and oil with PCM forced mode were seen to be increased at each instant of time, as 65.9%, 75.4%, 77%, 81%, 84%, 86% and 88% at 10 am respectively.
- The numbers of days are reduced from 5days to 1 and half day, where 5 days are required for black plate free mode where as 1 and half day is required for oil with PCM forced mode.
- The temperature from 5pm to 6pm are seen to remain constant, this was only due to use of PCM (paraffin wax).

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