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THERMAL PERFORMANCE ASSESSMENT OF GREENHOUSE SOLAR DRYER UNDER PASSIVE MODE

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ABSTRACT

In this paper, thermal performance assessment of greenhouse solar dryer is being carried out in a no-loadcondition. The greenhouse solar dryer was operated under passive mode. The performance of greenhouse is evaluated in different conditions first uncovered floor, second when floor is covered with blue tarpaulin to prevent the heat loss to the ground, and the third when concrete floor is used. The data obtained during the experiment is used to evaluate the thermal performance of the greenhouse solar dryer by calculating various thermal parameters. The average room temperature inside the greenhouse solar dryer was 52% higher than the average ambient temperature in the case of concrete floor while it was 45% higher in tarpaulin covered floor as compared to 23% higher in without covered floor condition.

Nomenclature

A_{gd}	*Area of ground (m^2)*
A_{vt}	*Area of vent (m^2)*
B_d	*Breadth of dryer (m)*
C_p	*Specific heat at constant pressure (J/kg°C)*
C_d	*Coefficient of diffusivity*
Gr	*Grashoff Number*
g	*Acceleration due to gravity (m/s^2)*
h_{conv}	*Convective heat transfer coefficient (W/m^2°C)*
h_{grm}	*Convective heat transfer coefficient for ground to room (W/m^2°C)*
h_{rad}	*Radiative convective heat transfer coefficient (W/m^2°C)*
h_{eva}	*Evaporative convective heat transfer coefficient (W/m^2°C)*
$h_{conv,c}$	*Convective heat transfer coefficient for canopy (W/m^2°C)*
I	*Intensity of solar radiation falling on greenhouse (W/m^2)*
K_{cd}	*Thermal conductivity (W/m°C)*
L_d	*Length of dryer (m)*
n	*No. of air exchange*
P_T	*Partial vapour pressure at temperatute T (N/m^2)*
t	*Time (seconds)*
T_{gd}	*Ground temperature (°C)*
T_{rm}	*Roomtemperature (°C)*

T_o	*Ambienttemperature (°C)*
T_i	*Mean temperature (°C)*
U_o	*Overall heat transfer coefficient (W/m^2°C)*
V_a	*Velocity of air (m/s)*
X	*Characteristic Length (m)*
UCF	*Uncovered Floor*
TCF	*Tarpaulin Covered Floor*
CF	*Concrete Floor*

Greek letters

β	*Coefficient of volumetric expansion (1/°C)*
ϕ	*Relative humidity of air (%)*
ε	*Emissivity*
σ	*Stefan–Boltzmann Constant (W/m^{2}K^4)*
μ_a	*Dynamic viscosity of air (kg/m)*
ρ_a	*Density of air (kg/m^3)*
η_{itl}	*Instantaneous thermal loss efficiency factor*

Keywords: greenhouse solar dryer, passive mode, heat loss, performance, no load

I. INTRODUCTION

Drying is the energy intensive process, in which moisture is reduced up to a safe limit by evaporation from solid, semi-solid or liquid product. The drying of crop results in better product quality, longer safe storage period and reduction in post-harvest losses [1]. Solar drying is one of the oldest and economic ways of crops preservation. In solar drying process, heat transfer takes place in the form of conduction, convection, thermal and radiation [2]. Greenhouse structure is a multipurpose structure, which can be used for crop cultivation, low-temperature thin-layer drying, soil solarization, poultry farm, and aquaculture [3]. From more than last two and half decades, greenhouses are used as a dryer for drying various agricultural (fruits, vegetables, etc.) and non-agricultural (rubber, jaggery, etc.) products. Greenhouse basically operates either in passive (natural convection) or active mode (forced convection) [4]. In the passive mode of greenhouse dryer, humid air gets ventilated through ventilator provided at the roof or through the chimney of the dryer. While in the case of the active dryer, humid air is ventilated by the help of an exhaust fan provided at the ventilator. Heat loss through the greenhouse effects its performance. Various researchers have tried to reduce the heat loss by implementing some modifications on the greenhouse like

(i) making north wall opaque [5],[6].

(ii) using various floor conditions [7],[8]

(iii) using reflecting and inclined north wall [9]

In the present study, the attempt is made to assess the thermal performance of developed low-cost greenhouse solar dryer under different floor conditions. So that the farmers can afford it for drying their crops and to get a better return from the dried crops by storing it for a longer time. In this study, the greenhouse solar dryer is being tested to achieve following objectives-

(i) To test the dryer in passive mode with three different floor conditions.

(ii) To determine the various thermal parameters like overall heat transfer coefficient, heat utilization factor, dimensionless numbers relating to natural convection

(iii) To determine the potential of the dryer so that proper crop can be chosen during its use under load condition.

II.MATERIAL AND METHODS

2.1 Experimental set up

The even span roof type greenhouse solar dryer has been developed and installed at the solar energy park of Lakshmi Narain College of Technology (23.25° N, 77.5° E), Bhopal, India. This low-cost green house solar dryer can be easily afforded by farmers. The pictorial view of developed greenhouse solar dryer is shown in Fig. 1. The dryer has a floor area of 2.94 m^2 and central height is 2 m. The side walls are 1.7 m high and the roof is inclined at 23.2°. The greenhouse dryer is covered with polycarbonate sheet having thickness 6 mm. The east-west orientation of the dryer is taken during an experiment. Two square shaped openings having dimension 0.15 m × 0.15 m are provided at the top for maintaining air circulation inside the dryer. The test has been conducted from 1st May – 3rd May 2017 for different floor condition. On day 1, dryer was tested with uncovered floor; on day 2 of experimentation, blue colored tarpaulin is used to cover the floor and on day 3, concrete floor was used.

Fig. 1 Pictorial View of Greenhouse solar dryer

2.2 Instrumentation

The global and diffuse radiation is measured by solar power meter. The range is 0–1999 W/m^2. The temperature and relative humidity are measured by hygrometer. The range of hygrometer is 10–95% and its accuracy is

0.1%. The various k type thermocouples used to find the temperature on digital temperature indicator. The range of temperature measurement is –20°C to 60°C and its accuracy is 0.1°C.

III. NUMERICAL COMPUTATION

3.1Overall Heat Transfer Coefficient

The values of various thermal parameters are calcuated by using formulastated below from Equ. 1 to 8 [10]

The overall heat transfer coefficient (U_O) can be calculated as follows:

$$\frac{1}{U_O} = \frac{1}{h_1} + \frac{X}{K_{Cd}} + \frac{1}{h_{conv,cp}} \quad (1)$$

Value of h_1 and $h_{conv,cp}$ are calculated with the help of Equ. 2 and 3

$$h_1 = h_{grm} + h_{rad} + h_{eva} \quad (2)$$

$$h_{conv,cp} = 7.2 + 3.8V_a \quad (3)$$

$$h_{grm} = 0.884\left[(T_{gd} - T_{rm}) + \frac{(P_{T_{gd}} - \varphi P_{T_{rm}})(T_{gd} - 273)}{(268.9\times10^3 - P_{T_{gd}})}\right]^{\frac{1}{3}} \quad (4)$$

$$h_{rad} = \frac{\sigma\epsilon[(T_{gd}+273.15)^4 - (T_{rm}+273.15)^4]}{(T_{gd} - T_{rm})} \quad (5)$$

In no-load conditions, evaporative losses are very less so it is neglected i.e. putting h_{eva}= 0.

3.2 Instantaneous thermal loss efficiency factor

The instantaneous thermal loss efficiency factor is calculated asfollows:

$$\eta_{itl} = \frac{U_o \sum A_i (T_{rm} - T_0)}{IA_{gd}} \quad (6)$$

3.3 Coefficient of diffusion

$$C_d = \frac{(1-\eta_{itl})IA_{gd}}{n A_{vt} \sqrt{\frac{2\Delta P}{\rho_a}} \Delta P} \quad (7)$$

3.4 Heat lost through dryer

$$Q_l = C_d A_{vt} \sqrt{\frac{2\Delta P}{\rho_a}} \Delta P \quad (8)$$

IV. RESULT AND DISCUSSION

4.1 Variations in ambient parameters

Greenhouse orientation and roof inclination are chosen as per the regional environmental conditions. Variation in observed ambienttemperature and solar radiation on consecutive days with time is shown in Fig. 2. It is observed that during all consecutive days, environmental conditions remain approximately same. During experimentation, the maximum ambient temperature on day 1, day 2and day 3 were 37.6 °C, 41.7 °C and 40.1°C respectively.Solar radiation was in the range of 418 W/m^2 to 1003 W/m^2 . The value of maximum solar radiation during all days was 1003 W/m^2 at 1 p.m.

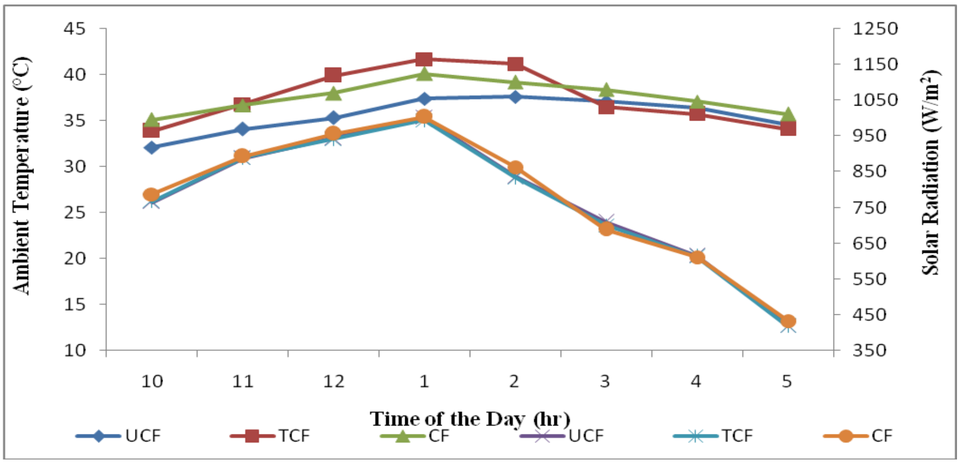

Fig. 2 Variation in ambient temperature and solar radiation with time of the day

Fig. 3 shows the variation in the ambient relative humidity of air inside and outside of the greenhouse solar dryer with time of the day. Observation shows that inside relative humidity varies in the range of 28 % to 44 % while outside relative humidity varies from 24 % to 35 % for all consecutive days.

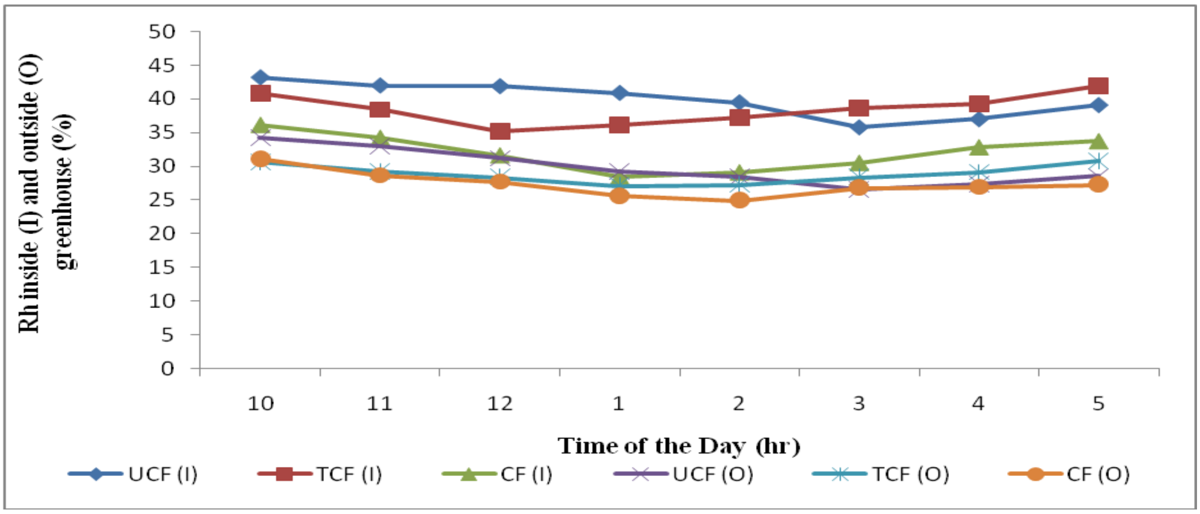

Fig. 3 Variation in relative humidityinside (I) and outside (O) of the greenhouse versus time of the day

4.2 Variation on parameters inside greenhouse

Fig. 4 shows the variation in room and ground temperature of greenhouse with time of the day for all days of experimentation. Room temperature and relative humidity inside the greenhouse is a crucial parameter for the drying of any crop. Higher be the room temperature, lower be the relative humidity and faster be the drying of crops. It is observed that room temperature inside greenhouse reaches to highest value of 64.2 °C on concrete floor condition at 1 p.m. While the maximum value of greenhouse room temperature in case of taurpolinn floor and uncover floor is 60.1°C and 46.9 °C respectively. Similarly, ground temperature on concrete floor condition

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were higher as compared to other and it varies between 37°C to 62°C.The average value of ground temperature of three days during experimentation was recorded as 47.71°C.

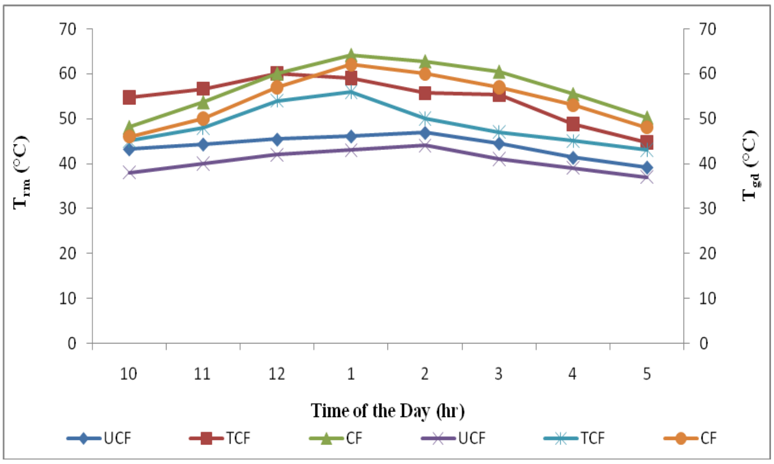

Fig. 4 Variation in room and ground temperature with time of the day

4.3 Effect on thermal parameters

Variation in convective heat transfer coefficient for heat transfer between ground to room air (h_{grm}), radiative heat transfer coefficient (h_{rad}) and overall heat transfer coefficient (U_o) were calculated using Eq. 1-5 and obtained results were plotted on the graphs to observe the variations. Fig. 5 shows the variation in convective and radiative heat transfer coefficient from ground to room with time of the day. On uncovered floor condition, the average value of convectiveheat transfer coefficient from ground to room (h_{grm}) and radiative heat transfer coefficient twere 5.95 W/m^2°C and 6.4W/m^2°C respectively. When floor was covered with tarpaulin, the average value of convectiveheat transfer coefficient (h_{grm}) from ground to room and radiative heat transfer coefficient were 6.95 W/m^2°C and 6.98W/m^2°C respectively. On concrete floor condition, the average value of convectiveheat transfer coefficient (h_{grm}) from ground to room and radiative heat transfer coefficient were 6.77 W/m^2°C and 7.253W/m^2°C respectively. The higher values of h_{grm} and h_{rad} was observed on all three floor conditions during noon time, it is due to higher value of ground temperature and higher value of room temperature of green house at that time.

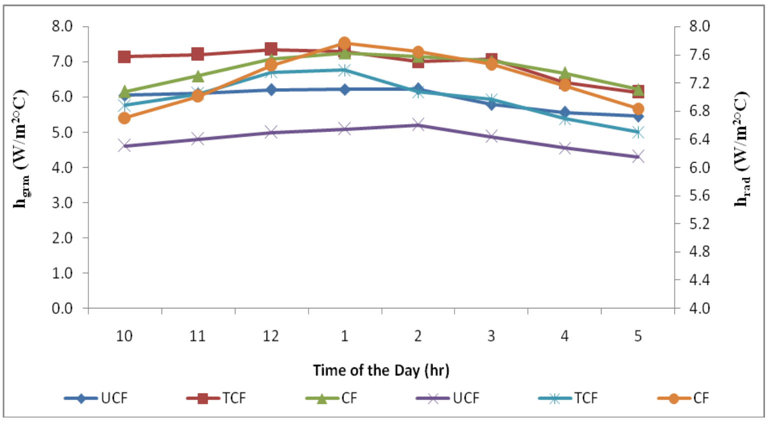

Fig. 5 Variation in convective and radiative heat transfer coefficient of ground to room with time of the day

Fig. 6 shows the variation in overall heat transfer coefficient with time of the day for all consecutive days of experimentation. Analytical results show that overall heat transfer coefficient was observed higher on concrete floor condition. It is due to increase in the heat gain and inside temperature of greenhouse air. On three concecutive days with different floor conditions the average values of overall heat transfer coefficient were 2.33W/m^2°C, 2.41 W/m^2°C and 2.43 W/m^2°C respectively.

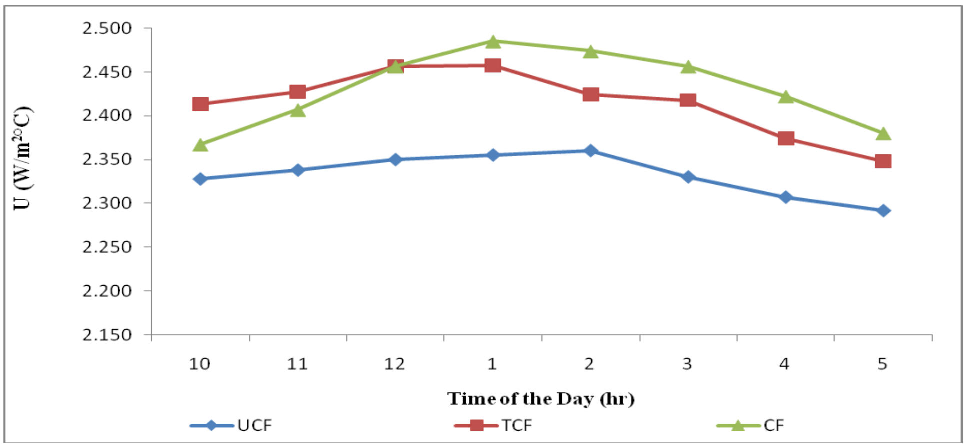

Fig. 6 Variation in overall heat transfer coefficient with time of the day

Fig. 7 shows the variation in coefficient of diffusion (C_d) and heat loss through greenhouse solar dryer with time of the day. Heat loss through dryer increases with increase in room temperature of the dryer.Under without covered floor condition, C_d varies between 0.074 to 0.097. Coefficient of diffusion (C_d) varies in the range of 0.021 to 0.036 under tarpaulin covered floor condition. On concrete floor condition, C_d varies between 0.02 to 0.042. Covering of floor leads to increase the temperature difference between the room and ambient, which increases the density difference between room air and cold surrounding air. This results in increased natural convection of air which is shown by lower value of C_d in covered floor condition as compared to values in without covered floor condition.

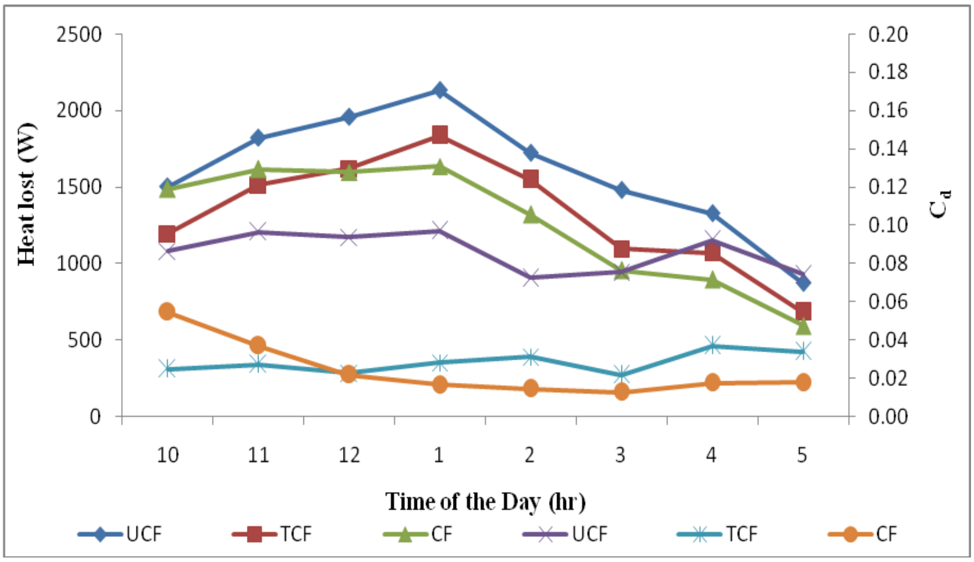

Fig. 7 Variation in coefficient of diffusion and heat loss through dryer with time of the day

V. CONCLUSION

In this paper thermal performance evaluation of greenhouse solar dryer is being carried out in no-load condition. The greenhouse dryer was tested under passive mode with three floor different conditions Experimentation gives the following results :-

- Concrete floor and floor covered with tarpaulin prevents the heat loss to the ground resulting in higher ground temperature as compared to uncovered floor.
- Higher room temperature was observed maximum upto 64.2 °C in case of concrete floor as compared to maximum temperature of 60.1 °C and 56.9 °C in case of tarpaulin covered floor and uncovered floor respectively.
- Lower relative humidity were found in case of tarpaulin covered and concrete floor.
- Maximum value of overall heat transfer coefficient of tarpaulin covered floor and concrete floor is 2.41 W/m^2°C and 2.48 W/m^2°C in respectively.
- Experimental results in case of tarpaulin covered floor was almost close to concrete floor condition and much better than uncovered floor condition. As tarpaulin is easily available in rural area so it can be used for low-cost greenhouse drying.
- These experimental values helps in selection of suitable crops for such dryer.

VI. APPENDIX [1]

$$C_p = 992.2 + 0.1434(T_i) + 1.101 \times 10^{-4}(T_i)^2 - 6.7581 \times 10^{-8}(T_i)^3 \quad (9)$$

$$K_{cd} = 0.0244 + (0.7673 \times 10^{-4})T_i \quad (10)$$

$$\rho_a = \frac{353.44}{T_i + 273.15} \quad (11)$$

$$\mu_a = 1.718 \times 10^{-5} + (4.620 \times 10^{-8})T_i \quad (12)$$

$$\beta = \frac{1}{T_i + 273.15} \quad (13)$$

$$T_i = \frac{T_{gd} + T_{rm}}{2} \quad (14)$$

$$X = \frac{L_d + B_d}{2} \quad (15)$$

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