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Performance Evaluation of PV Ventilated Hybrid Greenhouse Dryer Under no Load Condition

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ABSTRACT

The PV ventilated hybrid greenhouse dryer was designed and fabricated for drying of food grains. The greenhouse dryer with 446.7 X 213.4 cm size and central height of 259 cm was constructed using 50.8X25.4 mm MS pipe and 19X30.2 mm MS angles. Clear twin wall polycarbonate sheet with 6 mm thick was used insulate the greenhouse dryer structure. Performance evaluation was conducted under no load test condition. It was observed that, the average temperature inside the dryer was 6.3-13.2 °C (22-43%) higher and average relative humidity was 23-40% lower than ambient temperature and relative humidity during the month of December. Exhaust air flow rate varied in the range of 28-63 m^3/min. Elevated greenhouse dryer air temperature and reduced relative humidity would reduce the drying time considerably.

Key words: Greenhouse dryer, Forced ventilation, Performance Evaluation, Photovoltaic.

Solar radiation in the form of solar thermal energy is an alternative source of energy for drying of food grains. Drying by solar energy is a rather economical procedure for agricultural products, especially for medium to small quantities of product. It is still used at domestic level up to small commercial size drying of agricultural products contributing thus significantly to the economy of agriculture at micro level. Sun drying has the problems such as unreliability, uncontrolled heating of grains, thermal stresses leading to grain fissures and breakage during milling, thus reducing its value, vulnerability to infestation and losses due to birds, rodents, etc (Kadam and Samuel, 2006; Dwivedi *et al*., 2003). The problems are further aggravated by rains, floods, and cyclones, to which farmers in the vast Indian coastal belt are most prone (Shankar *et al*., 1989).

Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods (Forson *et al*., 2007). A greenhouse dryer is a unique and cost efficient method of drying agricultural products on commercial scale, It consists of a drying chamber, an exhaust fan. In hybrid greenhouse dryers, photovoltaic module generates DC electrical power to drive a DC fan for maintaining the desired temperature inside the chamber used (Barnwal and Tiwari, 2008). Compared to conventional dryer, the solar greenhouse dryer had low cost and it was helpful in decreasing the time consumption by 50-70% for drying. Keeping in view all these facts, a study was initiated to develop and evaluate a hybrid greenhouse type drier under no load rest condition.

MATERIAL AND METHODS

The PV ventilated hybrid greenhouse dryer was developed for paddy drying at College of Agricultural Engineering, Bapatla is shown in the Fig.1. The foundation was laid in east- west orientation. A single standing greenhouse dryer with 446.7 X 213.4 cm size and 259 cm central height has been selected for construction. Greenhouse structure was constructed using 50.8X25.4 mm MS pipe and 19 X 30.2 mm MS angles. Clear twin wall polycarbonate sheet with 6 mm thick was used insulate the greenhouse dryer structure. The drying chamber of the solar greenhouse dryer is divided into multiple tires. The trays were used for holding the paddy inside the drying chamber of the designed greenhouse dryer. Each tray is having 142.5X80X17.5 cm size. Tray frame was fitted with good quality stainless steel woven mesh having specifications of 0.8 mm diameter, 2.83 mm aperture and open area 61%. Forced ventilation was provided with 9 inch diameter, 1200 rpm, 40 watt powered DC power operated exhaust fan (Fig. 1). The two no. 150 watt power capacity solar photovoltaic panels with 18.5 V rated voltage and 8.10 A rated current was used to drive the DC Exhaust fans.

The performance of PV ventilated hybrid greenhouse dryer was evaluated under no load mode during crop harvesting month of two kharif seasons with a view of finding temperature, relative humidity and solar radiation profiles at different positions inside and outside the hybrid greenhouse dryer. About six representative points were selected inside the hybrid greenhouse dryer, among the six points each two points located at lower, middle and top tiers of the dryer. Average of two points in each tier represented corresponding position values. Experiments were carried out between 9.00 AM and 5.00 PM. Solar radiation, greenhouse air temperature, relative humidity and exhaust air velocity was recorded at every one hour interval.

INSTRUMENTATION

Greenhouse dryer air temperature and ambient temperature was measured with T-type thermocouples (Range: -200 to 350 ^{p}C). The relative humidity was measured using hygrometer which has measuring range of 0-100%. Sixteen channel data logger (Process precision instruments (PPI), India) was used to record the readings at 1 minute interval. First 8 channels are connected to thermocouples, which are used to measure the greenhouse air temperature at six locations, ambient and exhaust air temperature. Channels from 9-16 are connected to relative humidity sensors, which are used to measure the greenhouse air relative humidity at six locations, ambient and exhaust air relative humidity. Anemometer (Lutran 4201) was used to measure the exhaust air velocity. Pyranometer (Apogee SP 110) was used to measure global solar radiation.

RESULTS AND DISCUSSION

Solar radiation, greenhouse air temperature, relative humidity and airflow rate variation during no-load testing on different days of December 2015 at different locations inside the dryer, namely, bottom, middle, and top positions and the outside the dryer was studied and reported.

Variation of greenhouse air temperature

Temperature variation in hybrid greenhouse dryer was studied on clear sunny days during the month of December and shown in the Fig. 2. It was observed that the greenhouse air temperature and ambient temperature was increased till 1.00 PM later decreased till 5.00 PM. The greenhouse air temperature varied in the range of 35.25-48.58 ^{p}C; during the same period ambient temperature varied between 25-36 ^{p}C. The average greenhouse air temperature was 6.3-13.2 ^{p}C (22-43%) higher than the ambient temperature under forced ventilated condition. It was also observed that the solar radiation varied in between 291.84-562.13 W/m^2.

The second order polynomial relationship was established between the greenhouse air temperatures (T_G) as function of ambient air temperature (Ta) as shown in Fig. 4 and equation 1 for the month of December.

$$T_G = 0.022\,Ta^2 - 0.228\,Ta + 26.85 \qquad (1)$$

Variation of greenhouse air temperature at different portions within the greenhouse dryer was studied and presented in the Fig. 4. It was observed that, there was considerable variation among the different points of the greenhouse dryer. It was found that the temperature at upper layer was always higher than corresponding to lower layer. This was due to shading effect of upper tray on corresponding bottom trays.

The average air temperature rise at the top layer (Tt) over ambient temperature was found to be 9-21 ^{p}C (31-59%) where as in bottom layer 5-10 ^{0}C (14-32 ^{p}C) rise was observed (Fig.4). Similar results were also reported by Rathore and Panwar (2011), Seveda (2012).

Variation of greenhouse air relative humidity

The change in relative humidity during day time was studied and shown in the Fig. 5. It was observed that the relative humidity decreases with time in solar greenhouse dryer and in ambient conditions during the first half of the day. For the later half of the day, relative humidity was increased as the temperature in both the cases was decreased. Furthermore, the relative humidity of air inside the greenhouse dryer is always less than that of ambient air since the temperature inside the solar greenhouse dryer was higher than the ambient air at any point of time.

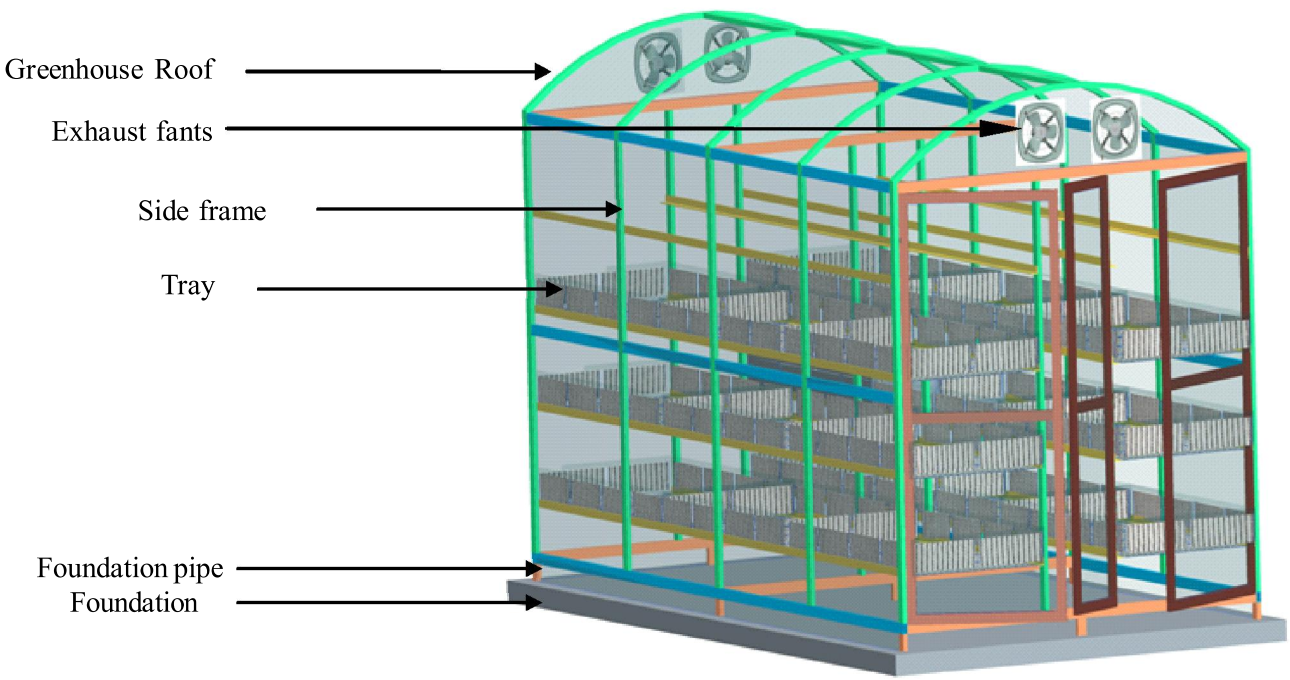

Figure 1. Details of PV ventilated hybrid greenhouse dryer

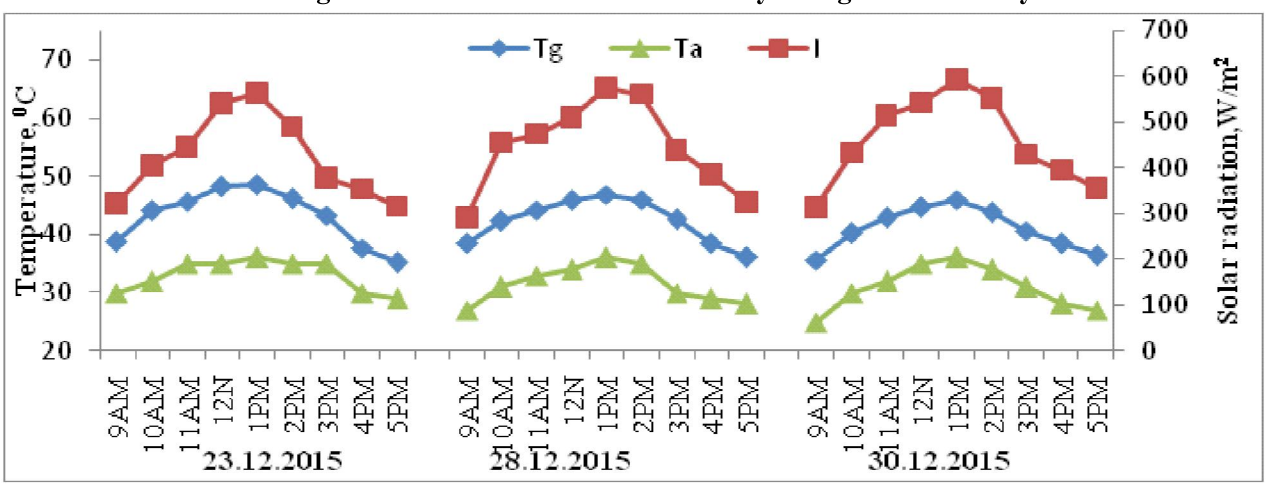

Fig.2. Variation of average greenhouse temperature, ambient temperature and solar radiation with respect to time during December month.

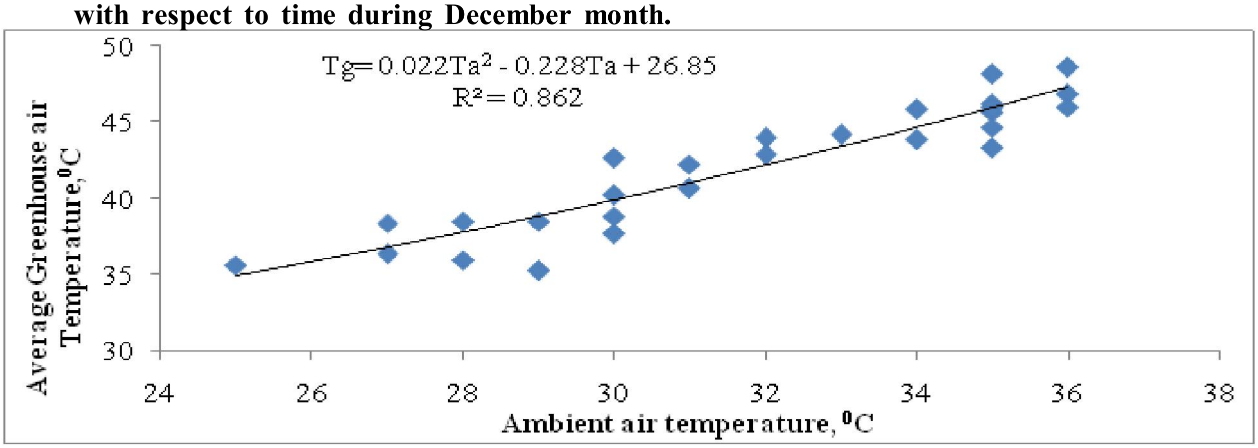

Fig. 3. The correlation between greenhouse air temperature and ambient air temperature during December month.

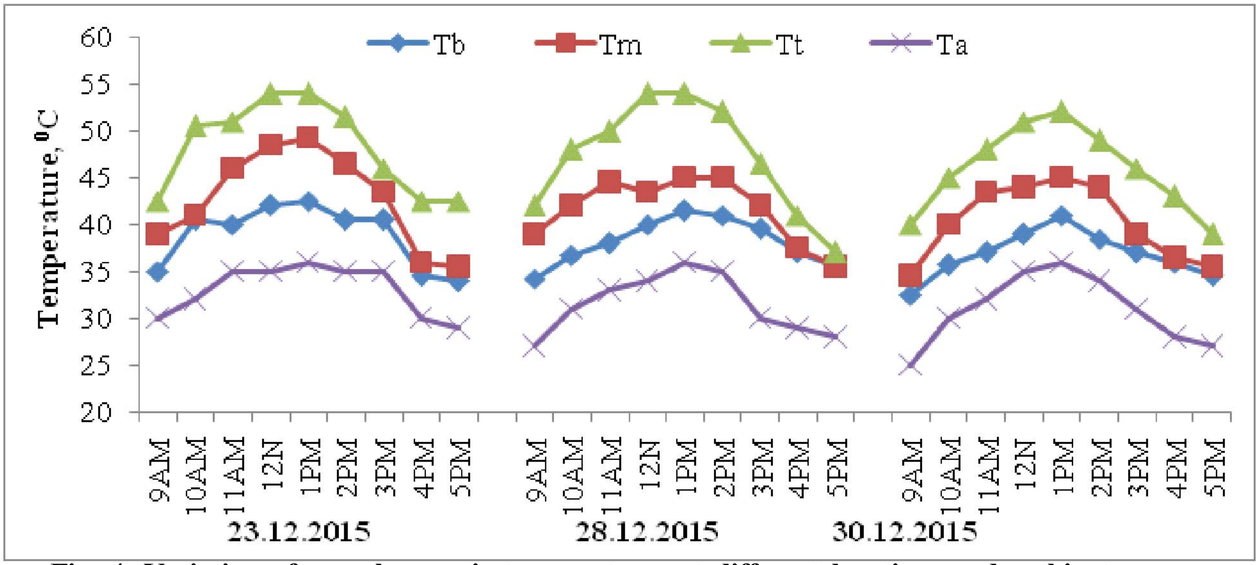

Fig. 4. Variation of greenhouse air temperatures at different locations and ambient temperature with respect to time during December month.

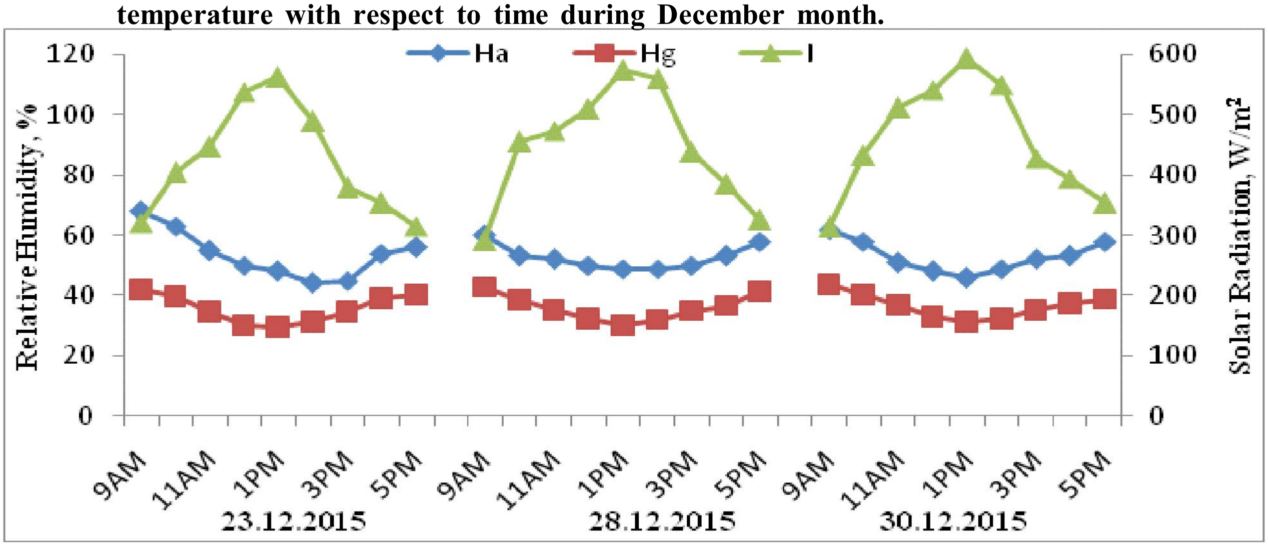

Fig.5. Variation in average greenhouse air relative humidity, ambient temperature and solar radiation with respect to time during December month.

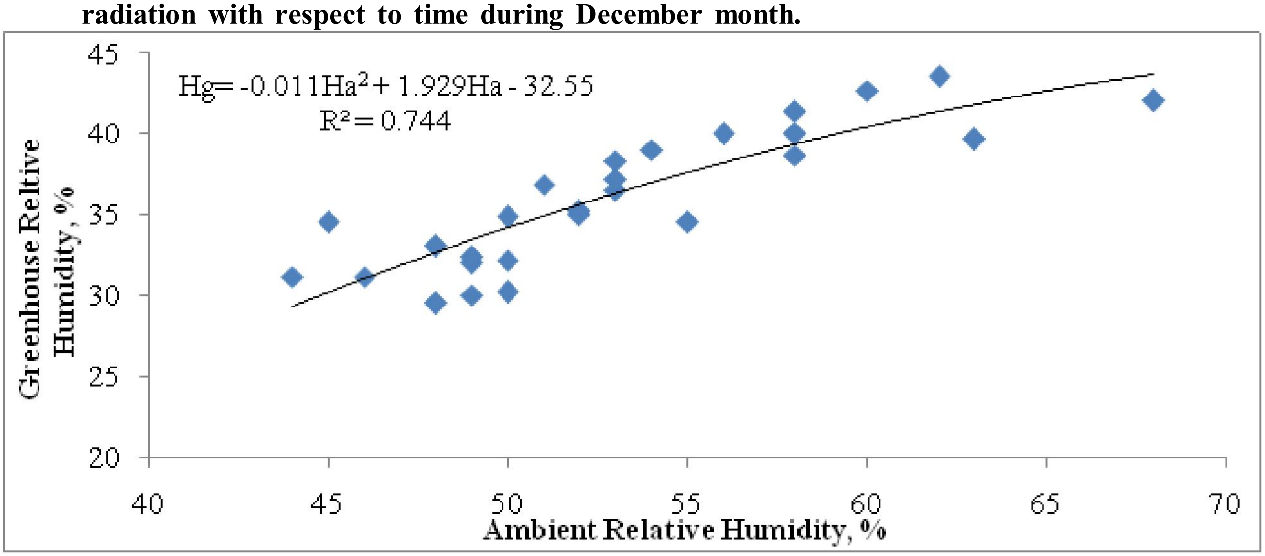

Fig. 6. The correlation between greenhouse relative humidity and ambient air relative humidity during December month.

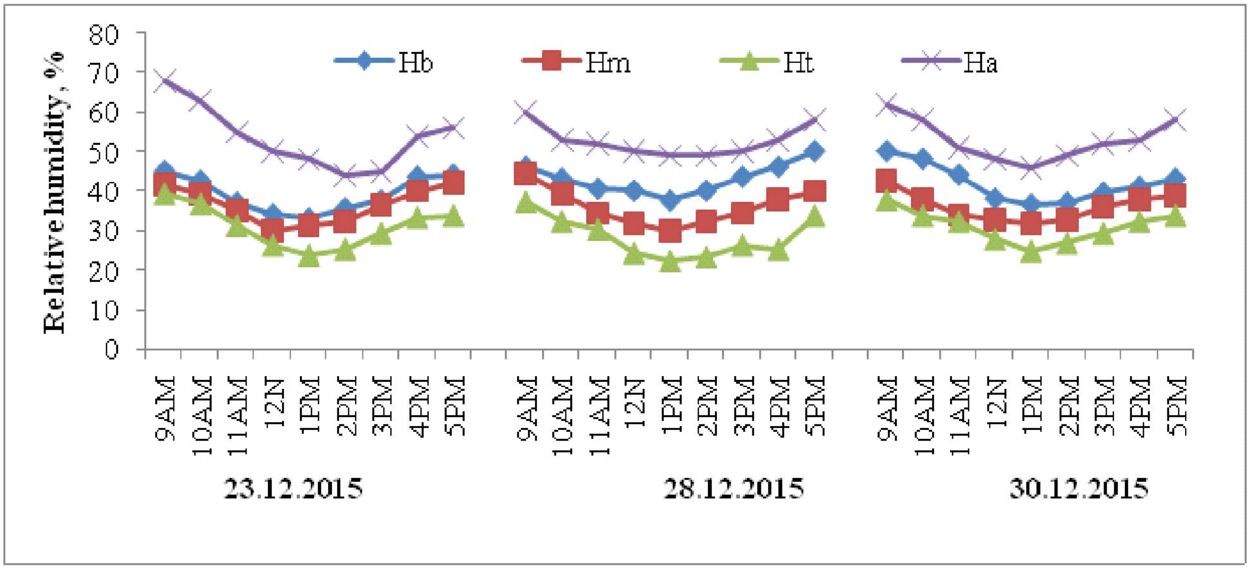

Fig.7. Greenhouse air relative humidity at different locations under no load condition with forced ventilation .

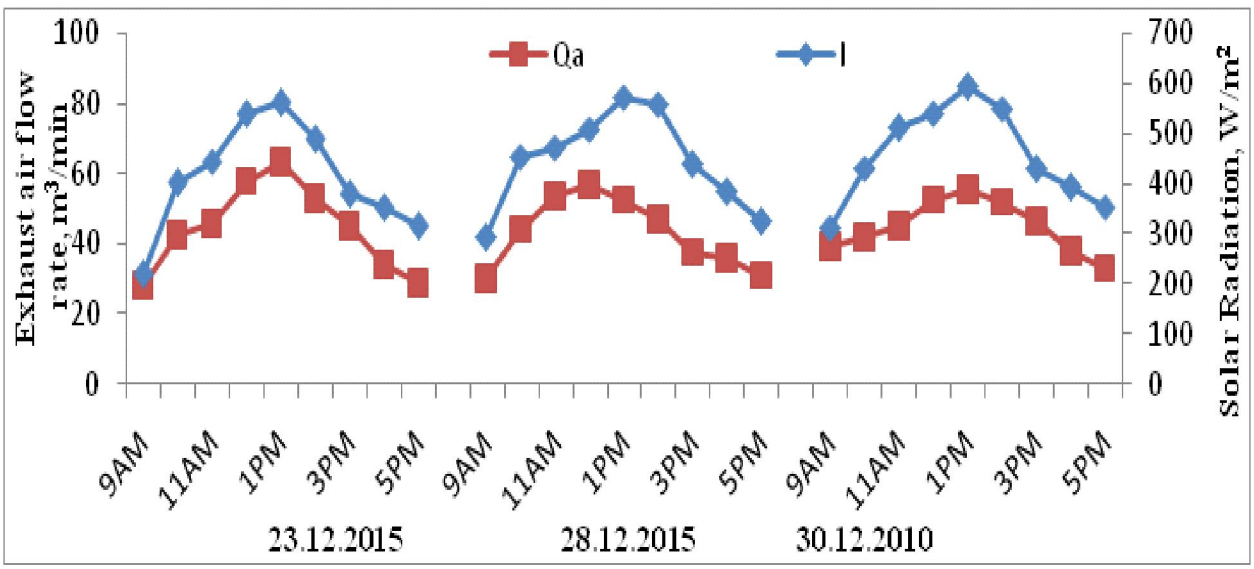

Fig.8. Exhaust air flow rate from the greenhouse under no load condition with forced ventilation.

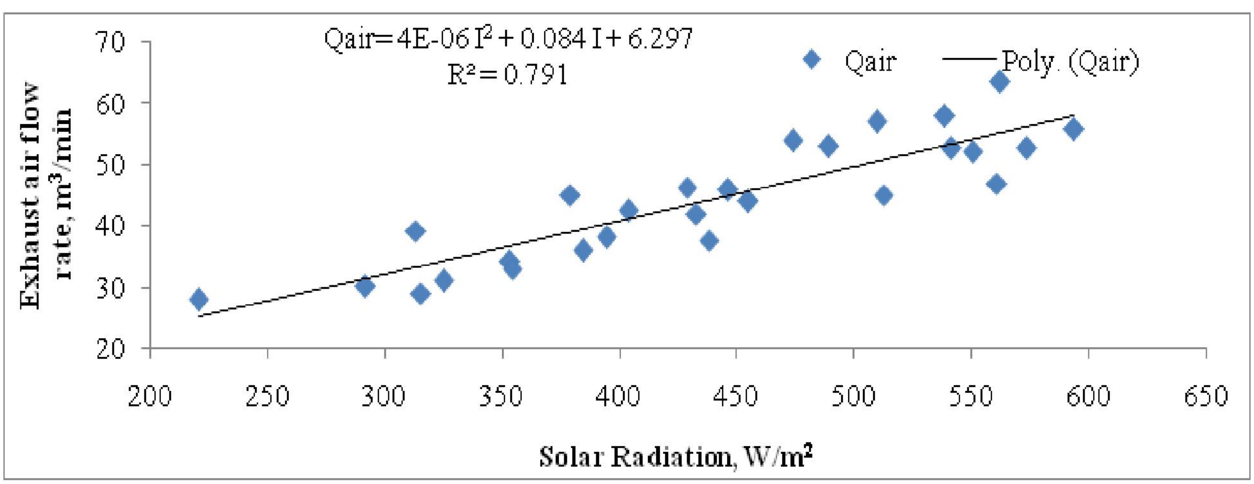

Fig. 9. The correlation between exhaust air flow rate and solar radiation.

The average relative humidity of the solar greenhouse dryer (Hg) varied between 29.5% - 42.67%. It was also observed that, the average relative humidity of the green house dryer was 23-40% lower than the ambient relative humidity (Ha) during same period. There was much variation among ambient and greenhouse relative humidity under forced ventilated condition. The second order polynomial relationship was established between the greenhouse air temperature (H_G) as function of ambient air temperature (Ha) (Fig.6) with the equation 2.

$$Hg= -0.011\ Ha^2 + 1.929\ Ha - 32.55 \quad \text{\_\_\_\_\_\_(2)}$$

Variation of greenhouse air relative humidity at different locations (layers) within the greenhouse was studied and presented in the Fig. 7. It was observed that, there was considerable variation among the different locations of the greenhouse dryer. It was also found that the relative humidity at upper layer was always lower than corresponding to lower layer. This was due to relatively less temperature in lower layer due to shading effect of upper tray. However relative humidity profile followed similar cyclic pattern at all three layers along the length of the day.

Among the three locations, the average relative humidity down at the top layer (Ht) over ambient relative humidity (Ha) was found to be 16-29% (34-54%) during December month. Lower layer relative humidity (Hb) found to be 7-20% (13-34%) lower than ambient relative humidity. Low relative humidity is more favourable for drying due to the increase of the evaporating capacity of the air. These results are in accordance with the results reported by Kumar *et al.,* (2013), Rathore and Panwar (2011).

Variation of greenhouse air flow rate

The ventilation rate depends on intensity of solar radiation. The Fig. 8 shows the variation of exhaust air volume and solar radiation during the month of December. The airflow rate increases sharply in the early part of the day, then becomes fairly constant and then drops sharply in the afternoon. The pattern of changes in airflow rate follows the pattern of the changes in solar radiation, since the airflow is regulated by three fans powered by a PV module. The variation of the air flow rate helped to regulate the drying air temperature.

Exhaust air flow (Qa) rate varied in the range of 28-63 m^3/min during December (Fig. 8). The relationship between air flow rate and solar radiation was studied and shown in the Fig.9. The polynomial relationship was established between the solar radiation and air flow rate is shown in equation 3 for December month. These are in alliance with the results of Kumar *et al.* (2013), Shahi *et al.* (2011).

$$Q= 4E\text{-}06\ I^2 + 0.084\ I + 6.297 \quad \text{\_\_\_\_\_\_(3)}$$

SUMMARY AND CONCLUSION

Performance evaluation of PV ventilated hybrid greenhouse dryer under no load condition revealed that the average greenhouse air temperature was 6.3-13.2 ^{0}C (22-43%) higher, average relative humidity 23-40% lower than the ambient temperature under forced ventilated condition. Increase in greenhouse air temperature, decrease in relative humidity would increase the water holding capacity of the greenhouse dryer air, hence drying time would be less as compared to open sun drying.

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