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Experimental studies on the performance of a large-scale Solar Greenhouse dryer for banana in India – A case study

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ABSTRACT

Solar greenhouse drying is useful in conserving energy utilizing natural source of energy from sun and to speed up the process of drying crops. The main problem with unsold crops with farmers is addressed by solar drying and preserving. In this case study, a large scale solar greenhouse dryer for banana is studied. The dryer was installed at Thottiyam, Tiruchirapalli, Tamil Nadu, in India. The floor area of parabolic dryer is 6.1 m x 8.4 m. Because of protected drying environment, a good quality dried banana is obtained free from dirt and pests. Bananas each of approximately 50 g mass are dried in two days in this location.

Indexing terms/Keywords

Solar greenhouse dryer, Banana, Segmental baffles, Performance.

Academic Discipline And Sub-Disciplines

Mechanical Engineering, Chemical Engineering.

SUBJECT CLASSIFICATION

Heat transfer, solar Energy conversion technology.

TYPE (METHOD/APPROACH)

Experimental Investigation

INTRODUCTION

Solar drying is an ancient technique to preserve crops and it is practiced all over the world. In natural open sun drying, the wet food products are kept open to atmosphere which leads to contaminations like dirt, pests, and loss by birds.

Greenhouse dryers are classified based on structure into dome shape and roof even types [1]. Dome type maximizes the utility of global solar radiation while roof even type enhances proper of air inside the dryer. Based on the mode of heat transfer, Greenhouse solar drying is carried out by natural convection mode or force convection mode. In natural convection or passive mode, humid air is ventilated by thermosyphon effect while in forced convection or active mode, humid air is ventilated by an exhaust fan provided at the ventilator.

El-Awady et al. [2] studied an Integrated Solar Green House (IGSH) for solar desalination, plantation and waste water treatment in remote Arid Egyptian communities. It was concluded from experimental investigations that IGSH is a low cost solution for fresh water need in arid areas. It also provides desalinated water, cool environment and humidification.

Elsamila Aritest and Dyah Wulandani [3] studied the performance of the rack type greenhouse effect solar dryer for wild ginger and reported a drying efficiency of 8 % at its fullest capacity of 60 kg. Drying time increases with increase in dried mass, because of insufficient energy and insufficient air flow for drying.

Aymen Elkhadraoui et al. [4] carried out experimental studies on a mixed mode solar greenhouse dryer to dry red pepper and grapes. It was reported that moisture in red pepper was reduced to 16 % on wet basis in 24 hours by open sun drying while it took only 17 hours only by greenhouse dryer. Similarly, moisture in sultana grape was reduced to 18% on wet basis in 76 hours by open sun drying while it took only 50 hours by greenhouse dryer. A payback period of 1.6 years was reported while the life of the dryer was estimated to be 20 years.

Janjai et al. [5] carried out experimental and simulation studies on a PV-ventilated solar greenhouse to dry peeled banana and longan at Silpakorn University, Thailand. Increase or decrease in air velocity inside the greenhouse was directly proportional to the solar radiation. PV-ventilation system enables its usage in remote areas in the absence of electricity grid. Estimated payback period was 2.3 years.

Kaewkiew et al. [6] carried out experimental investigation on a large-scale solar greenhouse dryer to dry chilly in Thailand. The dryer was 8 m x 20 m in size, parabolic shaped, covered with polycarbonate sheet, and ventilated using nine fans powered by three photovoltaic panels of 50 Watts. 500 kg of chilly with 74% Wet Bulb Temperature (WBT) were dried in three days when compared to five days of natural sun drying. Estimated payback period was 2 years.

Ahmed A. Hassanain [7] experimentally compared the performance of a simple solar air dryer for banana with vertical and horizontal chambers in both passive and active modes. Horizontal drying chamber was found to dry banana faster than that with vertical chamber in both passive and active modes. System efficiency decreased on successive days as the moisture content in banana decreased with drying.

Vinay Narayan Hegde et al. [8] designed, fabricated and studied the performance of a solar dryer for banana. The dryer had a solar air heater with three layers of insulation Air flow allowed between glass cover and absorber plate was referred to top flow while that between absorber plate and bottom insulation was referred to bottom flow. Bottom flow was found to give 2.5^oC higher chamber temperature than that with top flow. System efficiency was found to be 38.21% with bottom flow and 27.5% with top flow. Wooden skewers used instead of conventional trays increased the drying rate. Air flow rate of 1 m/s was found to be the best when compared with 0.5 and 2 m/s for better colour, shape and taste.

Sharma et al. [9] has elaborated the details of moisture content in various crops before and after drying and the maximum allowable temperature for drying. Rate of drying depends on the type of agricultural product, its initial moisture content, size and solar insolation it is exposed to.

Gupta et al. [10] reported that loss of solar fraction through the northern wall of green house is predominant. Jain D. [11] proposed a packed bed thermal storage in the northern wall of greenhouse to minimize losses. Sethi, V.P., & Arora, S. [12] used an inclined northern wall reflection in solar greenhouse to minimize losses, increase drying rate and reduce drying time. Berrouga et al. [13] used $CaCl_2.6H_2O$ phase change material in the northern wall of greenhouse and reported an increase in inside temperature by 6 to 12^oC during off sunshine hours. Prakash and Kumar [14] used mirror as northern wall of solar greenhouse to improve the performance of the dryer. Ronoh et al. [15] studied a solar tent dryer with two rocks, one at the top and another at the bottom to dry amaranthus cruentus grain (called mulaikKirai in Tamil Nadu) and the drying time was found to be lower than others. The dried crop was more nutritious and hygienic.

In this manuscript, the real time performance of a large-scale solar greenhouse dryer for banana installed and being operated at Thottiyum, Tiruchirapalli, Tamil Nadu in India has been tested to rate the performance in this part of the world and the results have been presented.

2. MATERIALS AND METHODS:

2.1 Experimental setup:

The solar greenhouse dryer for banana in operation at Thottiyum, Tiruchirapalli, Tamil Nadu in India, installed in 2014 at a cost of Rs.3,50,000/- INR has been used for experimental studies. The floor area of the greenhouse dryer is 6.1 m x 8.4 m in dimension. The roof is parabolic in shape to minimize wind load and made of transparent polycarbonate cover having a transmissivity of 0.8. It has a capacity of 4000 full bananas at a time for processing. Poovan, elakki, Pisang, and karpooravalli are the traditional banana varieties mainly dried in the solar dryer. Fully matured bananas procured directly from the farmers are maintained at 18 to 20^oC in the scientific ripening chamber. Ethylene gas at desired parts per million is passed through the chamber. Ripening process is completed in 24 hours. Ripened bananas are pealed manually and rolled down on diluted honey which improves softness, sweetness and also acts as a natural preservative. The maximum light hours required for drying banana is 40 light hours. In each batch, 1000 to 1500 kg of dehydrated fruits are produced in summer while it is only 400 to 500 kg in winter.

The schematic diagram of the solar greenhouse dryer is shown in figure 1. Ventilators and door are shown in front view of the solar greenhouse dryer shown in figure 2. Figure 3, Figure 4 and Figure 5 show the right end view, left end view and rear end view of the solar greenhouse dryer respectively. Solar radiation that passes through the polycarbonate parabolic roof heats the air, food products and concrete floor. Air is drawn inside the dryer through the openings at the bottom of the front side and humid air is let out through the ventilators. Figure 1 shows the location at which temperatures are measured inside the solar greenhouse dryer T1, T2, T3, T4, T5, and T6 respectively. M1, M2, M3, M4, M5, M6, M7, M8, M9, and M10 are locations at which samples are weighed periodically to check the rate of change of mass due to drying of banana.

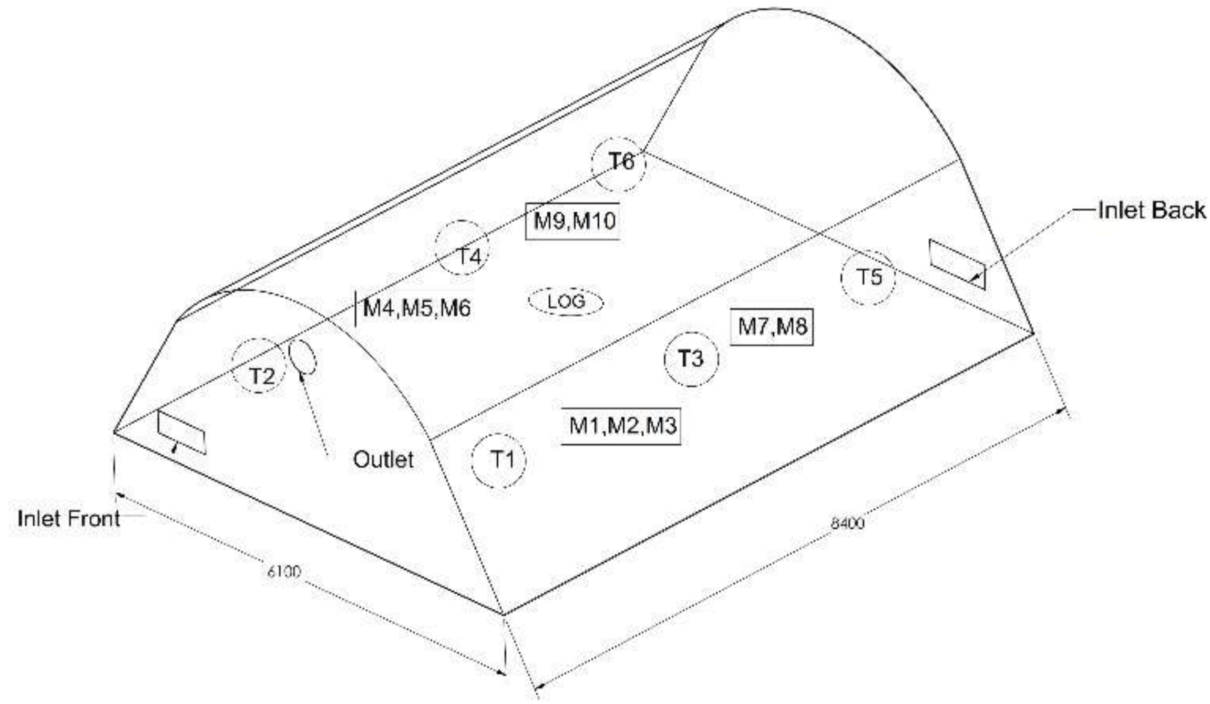

Figure 1 Schematic diagram of Solar Greenhouse Dryer

Figure 2 Front end view of the Solar Greenhouse dryer

Figure 3 Right end view of the solar greenhouse dryer

Figure 4 Left end view of the solar greenhouse dryer

Figure 5 Rear end view of the solar greenhouse dryer

2.2 Experimental procedure:

2.2.1 Measuring equipment and their characteristics:

A digital anemometer (MS6252B model) with built-in high quality temperature and relative humidity sensor is used to display simultaneously the air flow, velocity, ambient temperature and relative humidity and stored in the internal memory. A USB data logger (MIC 98583 model) is used to capture temperature and air humidity over a desired period programmed with adjustable time interval between 1 second and 6 hours. Recorded data is stored in an internal memory and transferrable to a personal computer. The range of temperature recorded is -40°C to +85°C. The range of air humidity recorded is 0.1 - 99.9 % relative humidity.

2.2.2 Effect of uncertainties and errors on the parameters measured:

The accuracy of anemometer is ±3%, its inbuilt temperature sensor is ±1°C, and that of relative humidity sensor is ±3%. The accuracy of USB data logger for recording temperature is ±0.6 °C and for recording is ±3 %. A series of temperatures were measured with the temperature sensors used and a digital thermometer to compare the errors. Relative uncertainty is the difference between the temperature sensed by the sensors and that by digital thermometer divided by the temperature sensed by digital thermometer. The average value of uncertainty of temperature measurement is 64%. Data logger channels were brought to calibration mode. Fractional variations if any were nullified in the data logger to ensure that the sensed parameters are accurate, reliable, and the uncertainties have negligible effect on the results.

3.0 RESULTS AND DISCUSSION

3.1 Variation of ambient temperature and solar insolation:

Figure 6 shows the variation in solar radiation and ambient temperature recorded on 22.08.2016 and 23.08.2016 in the day time. Sudden drop in solar radiation due to cloud covers are reflected in the graph along with drop in ambient temperature in response to it.

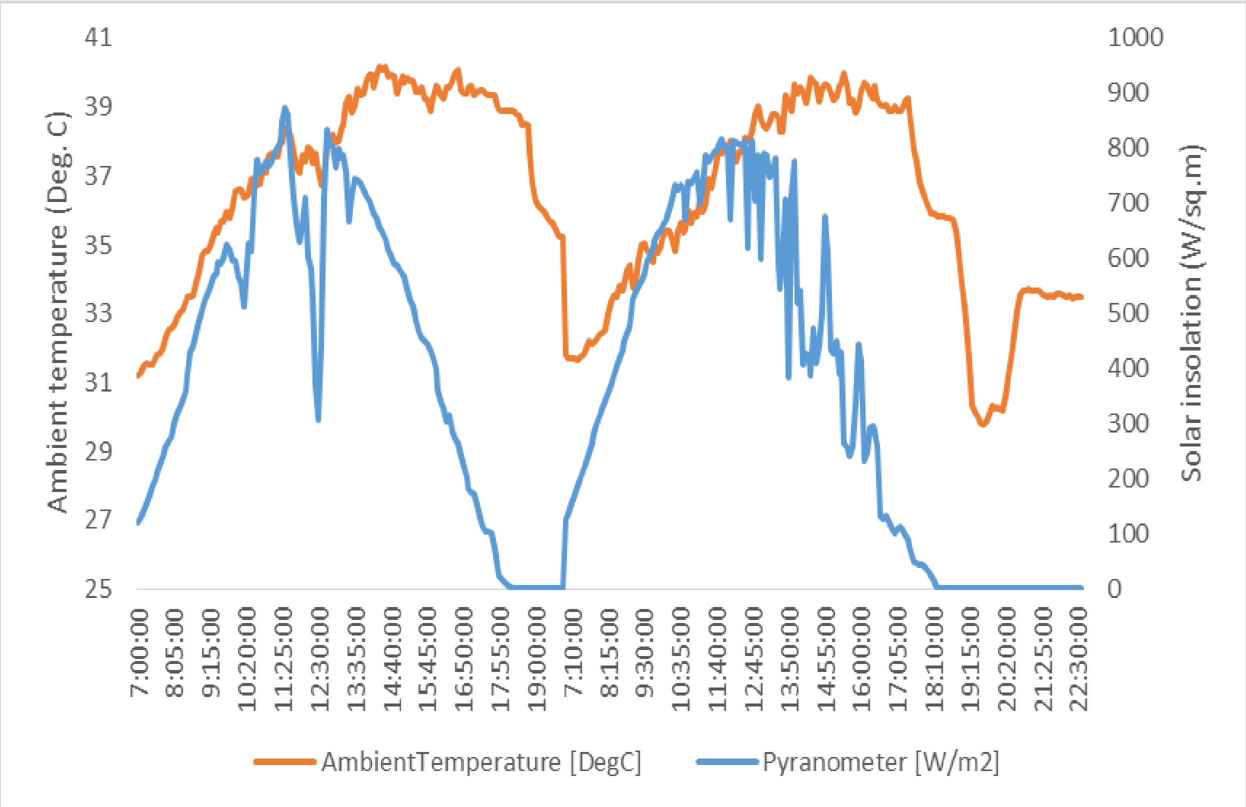

Figure 6 Variation of solar radiation and ambient temperature

3.2 Variation of air temperature and relative humidity in the Solar Greenhouse dryer:

Figure 7 shows the variation in temperature and relative humidity inside the solar greenhouse dryer on 22.08.2016 and 23.08.2016. It is observed that the temperature increases during the sunshine period till noon and then decreases in the afternoon. During night time, the temperature drop is little with time till early next day morning. Relative humidity decreases during day time with increase in solar radiation, because of the thermal potential that drives air flow that carries away the humid air. On the other hand, the relative humidity increases during night time, because of evaporation from bananas inside the drier without effective fresh air entrainment.

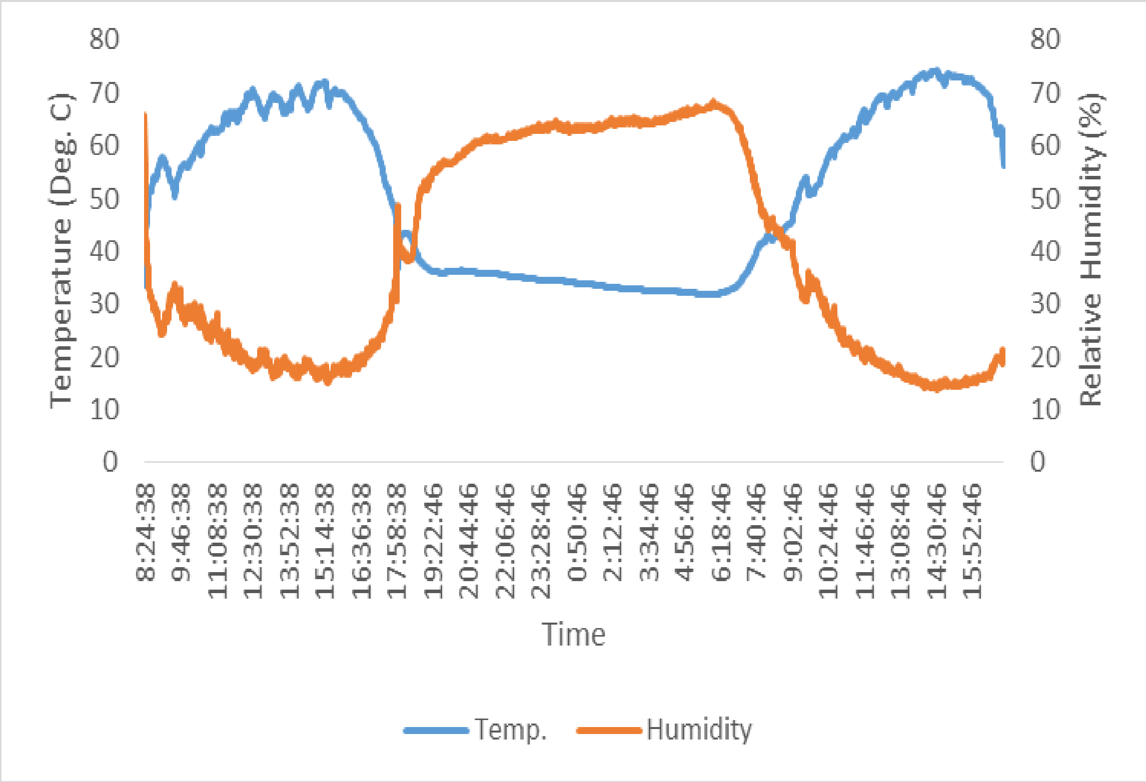

Figure 7 Variation in temperature and relative humidity inside the Solar Greenhouse dryer

3.4 Variation in air temperature in the solar greenhouse dryer:

Figure 8 and figure 9 show the variation in air temperature inside the solar greenhouse dryer at different locations as specified in figure 1 on 22-08-2016 and 23-08-2016 respectively. It is observed that the temperature increases with distance travelled as air gets heated up receiving solar energy, and carries away the evaporated vapor from bananas. Figure 10 and figure 11 show the variation in air temperature at the outlet, front, back and ambient in the solar greenhouse dryer. The air that enters the dryer gets heated as it passes through and finally leaves with maximum temperature and humidity at the outlet. Along the flow direction, the temperature at the back is greater than that at the front.

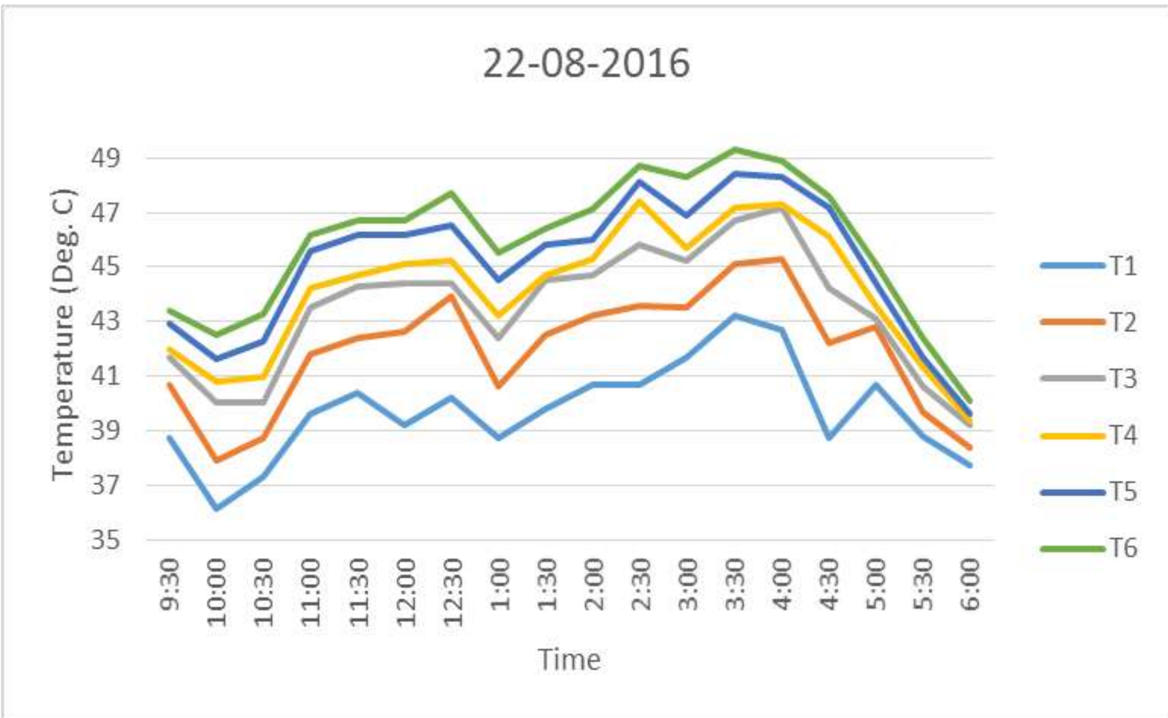

Figure 8 Variation in air temperature at different locations inside the solar greenhouse dryer on 22-08-2016

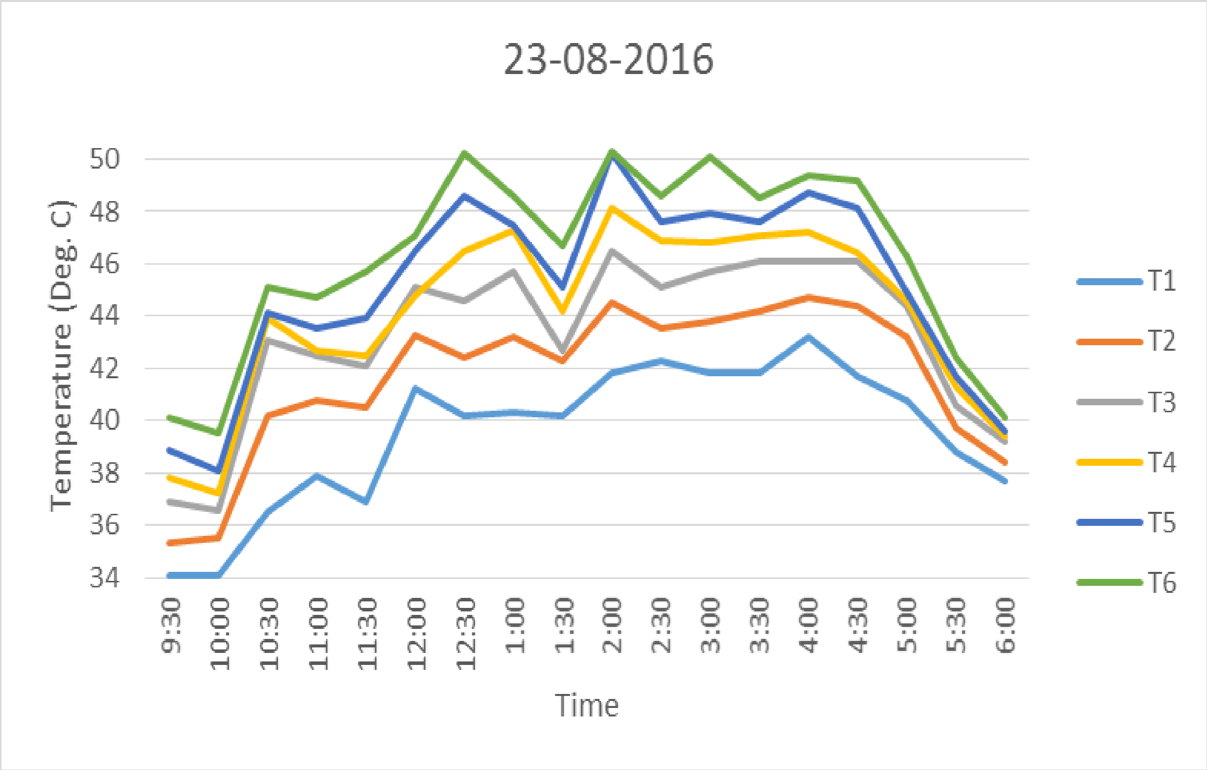

Figure 9 Variation in air temperature at different locations inside the solar greenhouse dryer on 23-08-2016

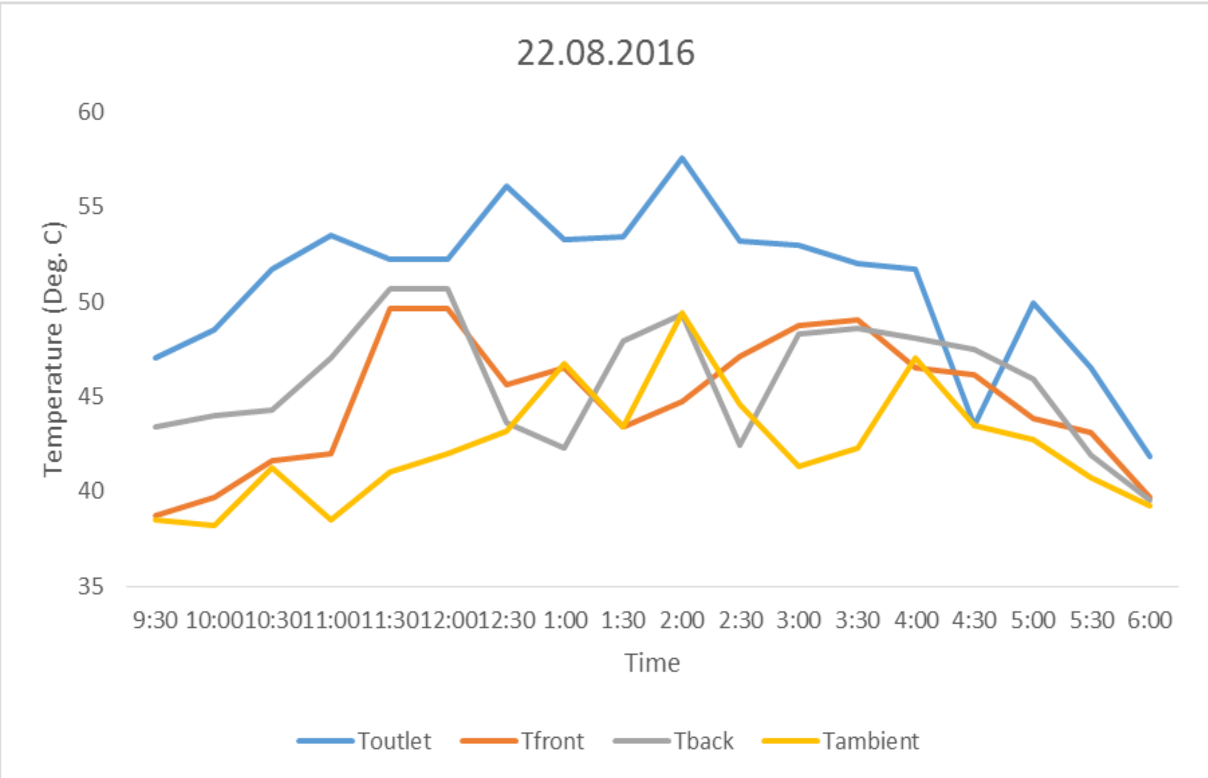

Figure 10 Variation of air temperature in solar greenhouse dryer on 22.08.2016

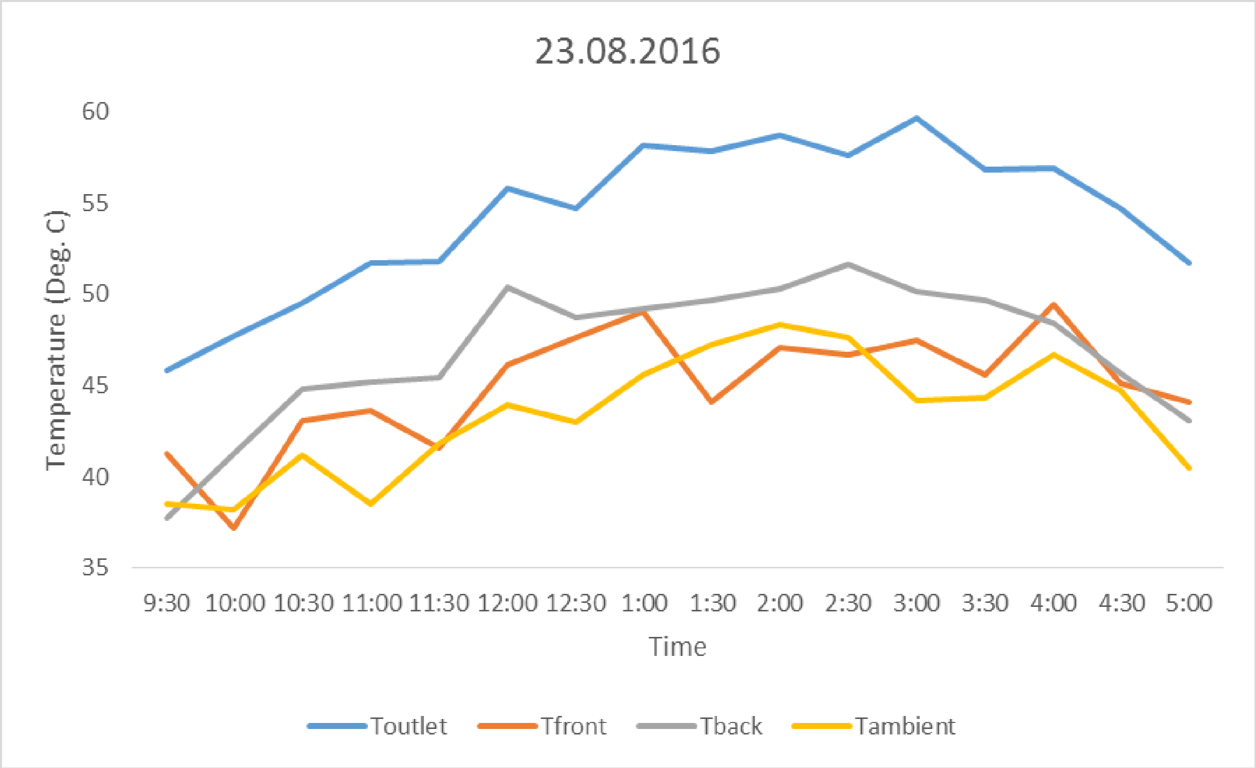

Figure 11 Variation of air temperature in solar greenhouse dryer on 23.08.2016

3.5 Variation in air velocity in solar greenhouse dryer:

Figure 12 and 13 show the air velocity variation at outlet, front and back of solar greenhouse dryer on 22.08.2016 and 23.08.2016 respectively. It is observed that the outlet velocity is the maximum because of fans in the ventilator sucking the air from inside the dryer. The velocity variation is proportional to the temperature variation observed in the dryer. According to this temperature variation the velocity at the front end is less than that at the back end of the dryer.

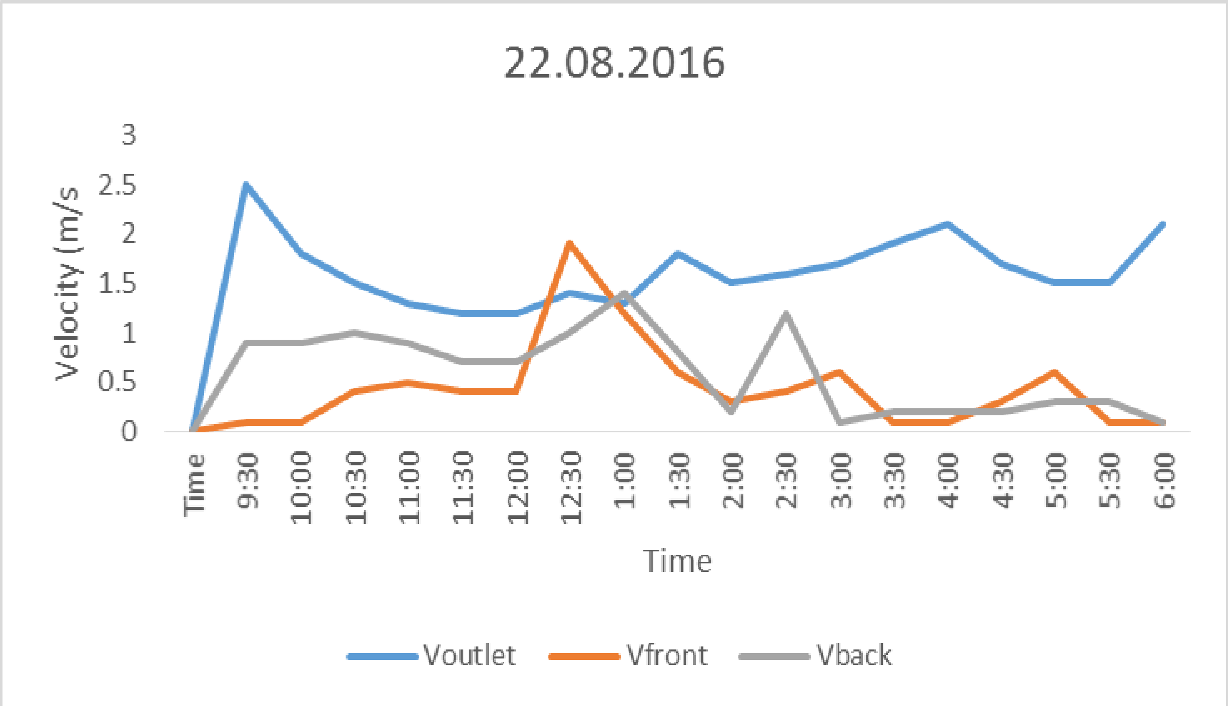

Figure 12 Variation in air velocity in solar greenhouse dryer on 22.08.2016

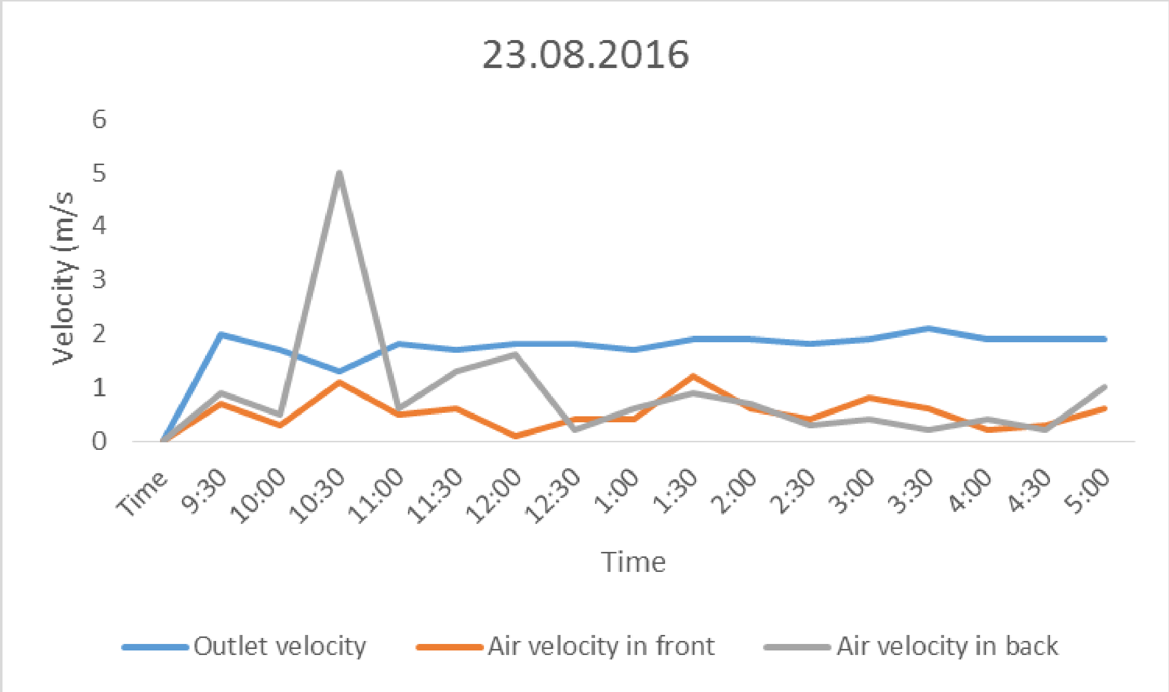

Figure 13 Variation in air velocity in solar greenhouse dryer on 23.08.2016

3.6 Variation in mass of water dried and removed in solar greenhouse dryer:

Figure 14 and figure 15 show the mass of water dried and removed from different banana samples with time inside the solar greenhouse dryer at different locations on 22-08-2016 and 23-08-2016 respectively. It is observed that more water is evaporated and removed on the first day than that on the second day. The curves are steeper on first day than that on the second day. The water removed is almost negligible in last 3 hours on the second day indicating that the process of drying is complete.

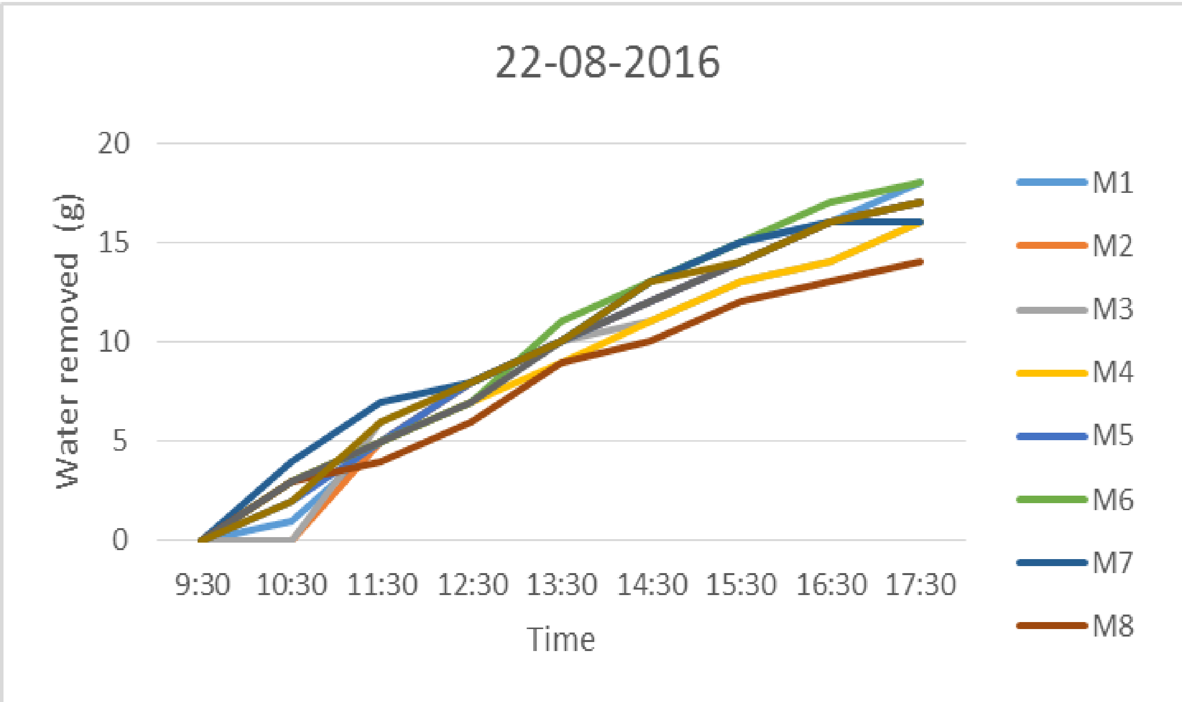

Figure 14 Water evaporated and removed from banana samples on 22-08-2016

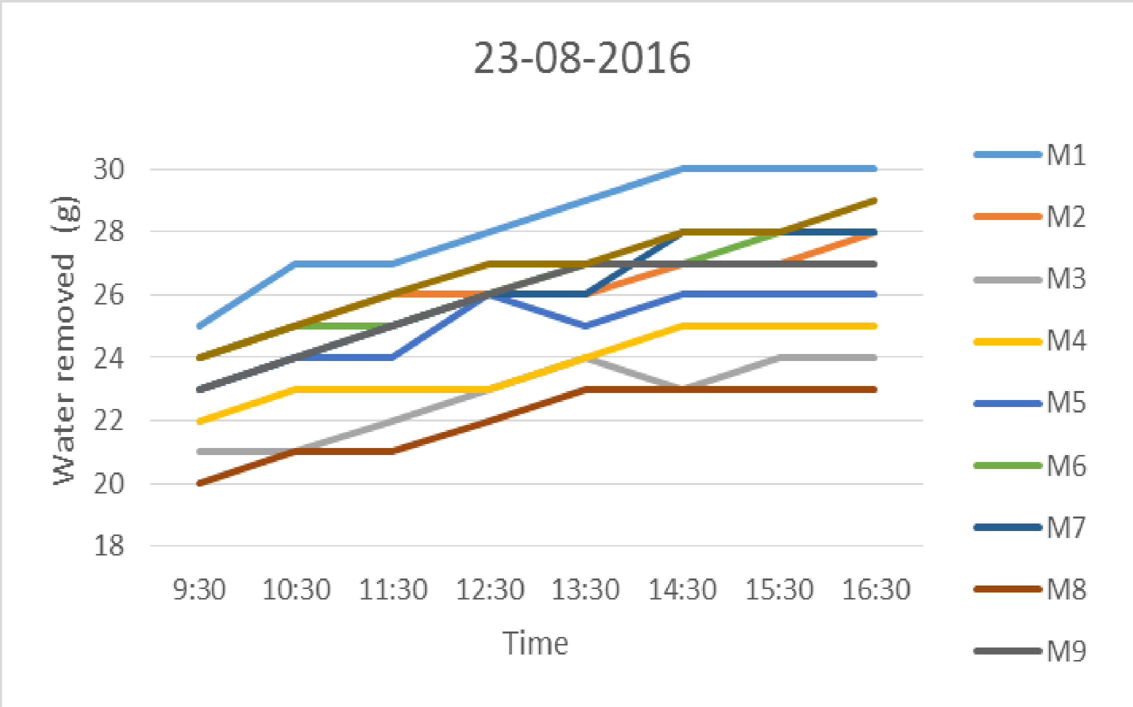

Figure 15 Water evaporated and removed from banana samples on 23-08-2016

4.0 CONCLUSION

In this case study, a large-scale solar greenhouse dryer to dry banana was studied. The performance of the system was studied. Approximately bananas of 50 g each are dried in two days while that of bigger sizes are dried in 3 days. On an average, 59% of total mass is removed by drying and evaporation of water from bananas. About 60 % of moisture content is removed on the first day while the remaining 40 % is removed on the second day in the solar greenhouse dryer.

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