Forced convection type solar tunnel dryer for industrial applications

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Abstract: A semi-cylindrical forced convection type solar tunnel dryer (STD) was designed and commissioned at M/s Miraj Products Pvt. Ltd., Nathdwara for drying processed tobacco. Essentially it is based on the mixed mode with direct and indirect type of heating mechanism i.e. the heated air from different solar flat plate collectors is passed through drying cabinet. At the same time, the drying cabinet absorbs solar energy directly through the transparent walls and roofs. It consists of 16×3.75 m^2 area, tunnel equipped with 12 solar flat plate collectors of 2 m^2 each propelled with 2 exhaust fans of 1 kW capacity placed on both ends of the tunnel. The dryer was tested at no-load and full-load conditions. During no-load, without flat plate collectors, temperatures inside the dryer were about 18-20℃ higher than the ambient temperature during summer day-light, where as in no-load with flat plate collectors, it was about 30℃ higher than the ambient temperature. A batch of processed tobacco of 500 kg with an initial moisture content 138% d.b. were successfully dried in full load condition to have final moisture content of about 8.7% d.b. in 8 h. It has been observed that STD has many other advantages i.e. getting rid of toxicant gas to labours during opening drying due to lime presence in material, avoidance of product expose to fly contamination and dust concentrations etc.

Keywords: Solar tunnel dryer (STD), natural convection, forced convection, mixed mode

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1 Introduction

Solar drying is a continuous process where moisture content, air and product temperature change simultaneously along with the two basic inputs to the systems: the solar insolation and inlet air at ambient temperature. The drying rate is affected by ambient climatic conditions. This includes temperatures, relative humidity, sunshine hours, solar insolations, wind velocity, frequency and duration of rain showers during the drying period etc. (Sevda, 2003). A solar tunnel dryer is essentially a poly house having tunnel like framed structure covered with ultra-violet (UV)-stabilized polythene sheet, where agricultural and industrial products could be dried under at least partially control environment, in which loading and unloading is quite easy (Sevda, 2007). A mixed-mode solar dryer allows the heated air from a separate solar collector to pass through a grain bed, and at the same time, the drying cabinet also absorbs solar energy directly through the transparent walls and roof. The performance evaluation of such a dryer revealed that the temperatures inside the dryer and solar collector were much higher than the ambient temperature during most time of the day-light (Bukola, Bolaji and Ayoola, 2008).

M/s Miraj Products Pvt. Ltd., Nathdawara process chewing tobacco and pack it in small pouches for sale. The initial moisture content of the processed tobacco is about 138 %-150% d.b. That reduced to a level of 8.5%-11.0% d.b. for further usages. Open sun drying and mechanical methods are used for drying the material. Open sun drying is quite a cumber due to presence of

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lime in products, which ultimately produces toxicant gases in environment. Due to the high power requirement and cost of existing mechanical dryer, a solar tunnel dryer was designed and commissioned at the factory site. The micro-climatic variations inside a solar tunnel dryer throughout the year were studied, which helps to maintain the desirable thermal conditions and relative humidity inside the tunnel dryer for drying.

2 Design of the solar tunnel dryer

A mixed-mode type forced convection solar tunnel dryer was designed to dry 0.5 t of processed tobacco from 138% d.b. to 11% d.b. moisture content with flat plate air heating collectors, a tunnel drying unit and blowers to provide the required air flow rate over the product. The design parameters were decided on the basis of amount of moisture to be removed, specific gravity of material, and flow rate required for removing moisture in stipulated time. Accordingly the length and width of tunnel, size of flat plat collectors, exhaust fans and area of north wall required for minimization of losses were calculated. The drying unit was covered with transparent UV stabilized semi-transparent polythene sheet of 2×10^{-4} m thickness. Low cost materials possessing high rigidity, long life and superior thermal characteristics were used for construction of floor, super structure and solar collectors. Cement concrete floor was painted black for better absorption of solar radiation. 5 cm thick glass wool insulation was provided to reduce heat loss through the floor. It was based on the theoretical calculation for critical insulation thickness for this dryer. The orientation of solar tunnel dryer was in east-west direction, so the sun covers the south side and the north side of the dryer act as an absorber. The north wall has a metallic cover of height of 1.5 m and glass wool sandwich in metallic cover for insulation. The products to be dried were placed in a thin layer on a stainless steel wire screen trays that are sliding on ball bearing for easy loading. Efforts were made for continuous and automatic loading of material inside the dryer. Various strategies for increasing work efficiency of system were developed during test of the system in actual use, like the loading of product in layer of constant thickness by the hopper, below the hopper the trays moves with constant speed by the motor, and trays can easily loaded in dryer by sliding on the ball bearing on rail from outside of the dryer.

The salient features of the solar tunnel dryer commissioned at the M/s Miraj Products Pvt. Ltd., Nathdawara, were as follows, semi-cylindrical poly house having base area of 16 m×3.75 m and with maximum ceiling height of 2 m, the metallic frame structure covered with polythene sheet. Incoming air through 12 numbers of flat plate collectors of size 2 m×1 m and forced over the products by two exhaust fans of 1 kW capacity of duct size 450 mm placed at each end of tunnel. The processed tobacco spread in thin layers of 2 cm thickness in the sliding trays of 15.9 m×3.6 m, 15.9 m×2.5 m, and 15.9 m×1.6 m size. Trays were loaded with 500 kg of material. Upper end of the tunnel was provided with a door 1.60 m×0.75 m size to facilitate movement in the dryer for loading and unloading.

The dimensions and other design parameters of the solar tunnel dryer are presented in Table 1. The schematic illustration of the solar tunnel drier is given in Figure 1.

Table 1 Dimensions and design parameters of the solar tunnel dryer

Parameters	Specifications
Floor area of solar tunnel dryer/m^2	60
Exhaust fans, duct size /mm	450
Area of semi-cylindrical shape of solar tunnel dryer/m^2	100.56

Figure 1 Solar tunnel dryer at M/s Miraj Products Pvt. Ltd., Nathdawara

3 Experimental procedures

The performance of the dryer was evaluated by conducting tests during no-load and full-load with processed tobacco, by measuring the following parameters: solar radiations incident on the dryer, air temperatures at various locations in the dryer and moisture content variation of material (Jain, Kothari and Mathur, 2004).

To measure the variation in temperature of air at various location of the dryer, five sensors inside and one outside of the tunnel were placed for recording. Sensor number (T_1), (T_2), (T_3), (T_4) and (T_5) were placed in tunnel at bottom, center, top, towards south from center and towards north from center respectively, and sensor (T_0) was kept outside of the dryer as shown in Figure 2. All temperature readings were registered at interval of 1 h, starting from 8:00 am to 6:00 pm. Under full-load condition processed tobacco were spreaded in 2 cm thickness in trays of size 15.9 m×3.6 m, 15.9 m×2.5 m, and 15.9 m×1.6 m size at bottom, center and top respectively in three levels to accommodate 500 kg of material in one batch.

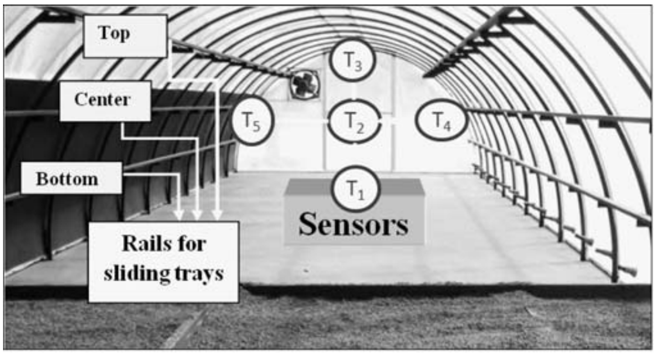

Figure 2 Schematic diagram of sensors for temperature measurement

4 Performance analysis

The performance of a dryer depends on the duration of drying and its temperature, besides some factors such as collector performance and quality of end products (Hussain and Bala, 2007). A detailed analysis of the solar tunnel dryer was carried out under no-load and full-load conditions during month of April, 2010 for drying processed tobacco at the factory level.

4.1 No-load test in natural convection mode without solar collectors

No-load test in natural convection mode was conducted with a view of finding temperature profile, relative humidity and solar insolation at different places in solar tunnel dryer. The test during no-load without connecting solar flat collectors to the tunnel dryer was made in the month of April, 2010 shown in Figure 3. It was observed that the maximum temperature inside the tunnel was 60℃ at 1:00 pm while the minimum inside temperature was 26.3℃ at 8:00 am in the month of April. Correspondingly, the maximum ambient temperature was 40℃ at 1:00 pm while minimum ambient temperature was 23.5℃ at 8:00 am. Thus, there is increment of about 20℃ as compared to the outside air ambient temperature. It was also observed that the maximum and minimum solar insolation in this month was 953 W/m^2 at 12:00 pm and 248 W/m^2 at 6:00 pm respectively were measured by digital solarimeter of capacity 0-2,000 W/m^2.

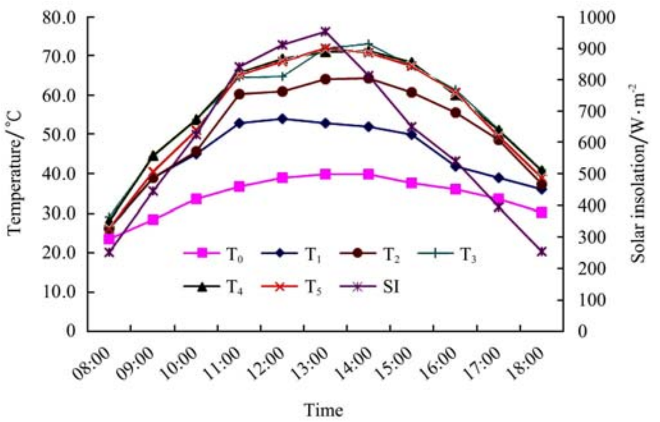

Figure 3 Variation of temperature in natural convection mode of the solar tunnel dryer under no-load condition.

4.2 No-load test with forced convection mode using solar collectors

No-load test in the forced convection mode was also conducted with a view of find temperature profile, relative humidity and solar insolation at different places in solar tunnel dryer in the month of April, 2010. As shown in Figure 4, it was observed that the maximum temperature inside the tunnel was 75.29℃ at 1:00 pm while the minimum inside temperature was 26.1℃ at 08:00 am in April. Correspondingly, the maximum outside of air ambient temperature was 41.9℃ at 1:00 pm while minimum outside of air ambient temperature was 23.7℃ at 8:00 am. It was also observed that the maximum and minimum solar insolation in this month was 952 W/m^2 at 12:00 pm and 251 W/m^2 at 08:00 am respectively. The forced convection mode is in position to boost up temperature to a level of 28℃ as compared to outside air ambient level.

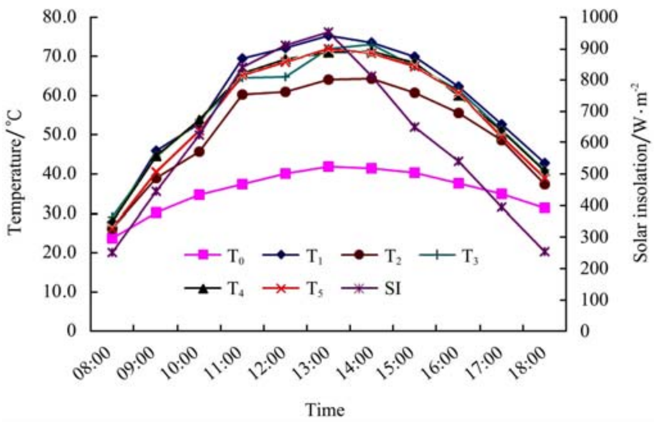

Figure 4 Variation of temperature in the solar tunnel dryer with forced convection mode under no-load condition

4.3 Full-load test

The full-load test of forced convection solar tunnel dryer was made for evaluating the performance in actual use for drying processed tobacco having 138% d.b. initial moisture content. Three trays were loaded containing 500 kg of material, Figure 5 showing inside view of STD in full-load condition. The loading was made at 8:00 am in the morning and corresponding readings were recorded up to 6:00 pm at one hour interval. As shown in Figure 6, the maximum temperature inside the solar tunnel dryer was 66.67℃ at 1:00 pm, while minimum temperature inside solar tunnel dryer was 28.25℃ at 8:00 am in typical day in the month of April, 2010 against the maximum and minimum outside air ambient temperature

Figure 5 Inside view of solar tunnel dryer during loading

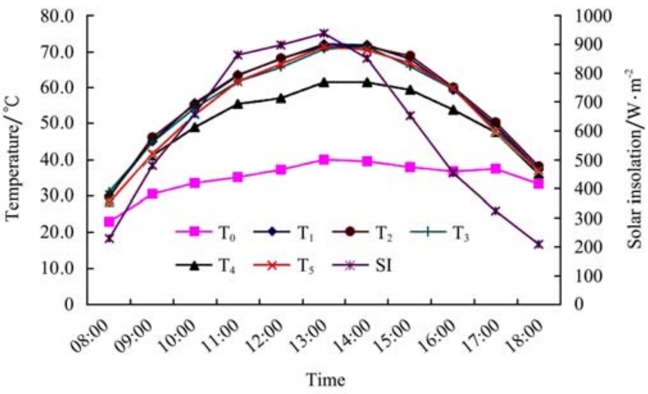

Figure 6 Variation of temperature in the forced convection solar tunnel dryer under full-load condition

of 40.11℃ and 23.1℃ respectively. It was observed that the maximum and minimum outside ambient solar insolation in this month was 900 W/m^2 at 12:00 pm and 221 W/m^2 at 6:00 pm respectively.

4.4 Moisture content variation

The comparison of variation of moisture content of processed tobacco in the solar tunnel dryer with conventional sun drying was conducted in a typical run in April, 2010. Processed tobacco was dried from a moisture content of 138.11% d.b. to 8.69% d.b. in 8 h of drying in solar tunnel dryer as compared to 12 h of drying in open sun drying. The moisture content of the product was determined by oven drying method. After every 2 h, sample of the product were taken and weighed. Then they were placed in the moisture boxes that were placed in the oven at temperature of 105℃ for 24 h.

It was observed that the initial moisture content of material in upper-tray, middle-tray, lower-tray and open-tray in ambient air was 140.97%, 143.91%, 138.1% and 132.56% d.b. respectively. Whereas, at the end of

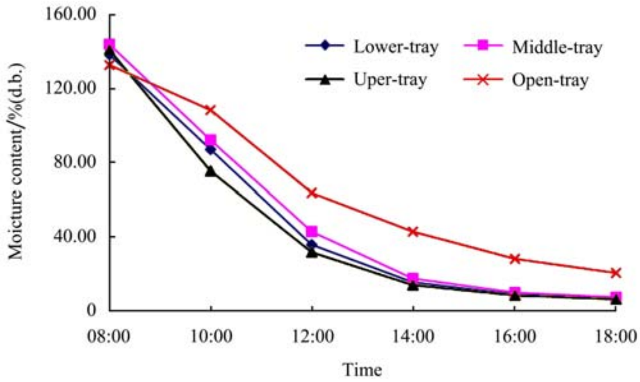

Figure 7 Variation of moisture content with time for drying of processed tobacco

day, the moisture content of material in upper-tray, middle-tray, lower-tray and open-tray was reduced to 6.61%, 7.53%, 6.72% and 20.49% d.b. respectively. The graphical representation of moisture content and time inside the solar tunnel dryer is as shown in Figure 7.

5 Conclusion

During no-load test in natural and forced convection mode, the air temperature in the tunnel was higher than outside by 20℃ and 33.4℃ respectively, the temperature difference of 13.4℃ during no-load test in natural and forced convection mode was due to 12 solar flat collectors connected during forced convection mode. During full-load test, air temperature in the solar tunnel dryer was higher than outside by 26.56℃. The moisture content of 500 kg processed tobacco loaded in the solar tunnel dryer in forced convection mode in one batch was reduced from an initial value of 138% d.b. to 8.7% d.b. in 8 h. However, in order to reduce approximately the same moisture content in the open air drying, 12 h are required. Dryness of processed tobacco and overall appearance of dried tobacco at the end of drying process were found to be good. Thus system can be successfully implemented for industrial production. The earlier problem of exposure of labour with toxicant gases and exposure of material with fly and dust concentrations was also minimized.

Acknowledgments

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