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Thermal performance of a solar tunnel dryer for drying of farm crops

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Abstract: ***A solar tunnel dryer of 16 meter long and 2 meter width was designed and constructed to analysis its thermal performance. The half of the tunnel base was considered to be used as the flat plate air heating solar collector and the remaining half as a dryer. The drying air was forced by a 30 watt fan from the collector region to the drying region of the half circled tunnel where the product was considered to be dried. The drying air temperature could be easily raised by some 5 - 30 degrees centigrade above the ambient temperature at an air flow rate of 0.09 – 0.11 m/sec inside the tunnel. The highest temperature 69 degrees centigrade was observed at around 1 PM while considering two days drying period. There was almost no temperature gradient in the vertical direction but 2-5 degrees centigrade was observed in horizontal directions of the whole tunnel. It was also observed that the highest temperature inside the tunnel became 75 degrees centigrade when the fan was not in operation. This indicated the operation of the dryer without fan would cause over drying of the product particular during 11:30 AM - 3:30 PM. The efficiency of the flat plate solar collector was found as 34.02% while the available solar energy in two days was 576 MJ and the available energy content of the dying air was 195.97 MJ at an average air flow rate of 0.1 m/s inside the tunnel. The energy utilization efficiency of the available energy in drying was found as 70% considering two days drying period for dates and the drying efficiency of dryer was found 36.4%.***

Keywords: **thermal performance, solar tunnel dryer, energy, temperature.**

I. INTRODUCTION

Many of the freshly harvested high moisture content and perishable farm crops are still dried by traditional method of open air natural sun drying in the developing countries. (Basunia et al., 2011) The traditional open air natural sun drying methods often yield poor quality dried products. In most cases the drying yard is not properly protected. The solar drying facilities combine the advantages of traditional and industrial methods, namely low investment costs and high product quality (Basunia et al., 2012, 2013). Drying is very important because it is the cheapest, easiest and most common method of preserving and storing of perishable agricultural products. Dried products are becoming highly alternative to marketing than the freshly harvested products because of many advantages (Lutz et al., 1987).

This solar tunnel dryer is classified as a solar dryer that have been successfully tested under field conditions in about 30 countries under different climatic conditions in drying various agricultural products (Basunia and Abe 2001a, 2001b). This new dryer design eliminated the dependence on grid electricity since the power consumption of the fan could be supplied by batteries or solar PV panels. The original designed of the dryer (20 × 2 m) (Lutz et al., 1987, Esper et al., 1996). However with a capacity that is suitable for use in a large farm. In order to adapt its design for small and medium scale rural farmers, a scaled down (16 × 2 m) prototype of the tunnel dryer was designed and fabricated for the detail thermal performance analysis at the Department of Soils, Water and Agricultural Engineering, Sultan Qaboos University, Oman.

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II. MATERIALS AND METHODS

The solar tunnel dryer consists of a flat plate air heating solar collector and drying tunnel, fabricated as a single unit (Fig. 1). The tunnel is 2.0 m wide, with a collector and dryer length of 8.0 m, respectively. The light weight aluminum frames were used as the upper structure for the entire tunnel to support the transparent plastic cover. The tunnel was placed on concrete block substructures 700 mm above the ground surface. The ply wood planks (0.9 × 2.0 m) of thickness 4 mm were used as the bed both for the dryer and collector parts of the tunnel to make the base of the tunnel almost air tight. Over the wooden base, black painted metallic sheets (0.9× 2.0 m) of thickness 0.25 mm was used as the absorber plate in the collector section of the tunnel. The entire tunnel became almost air-tight except the inlet opening (south side) for fixing a fan and the exit side (north side) for the moist air.

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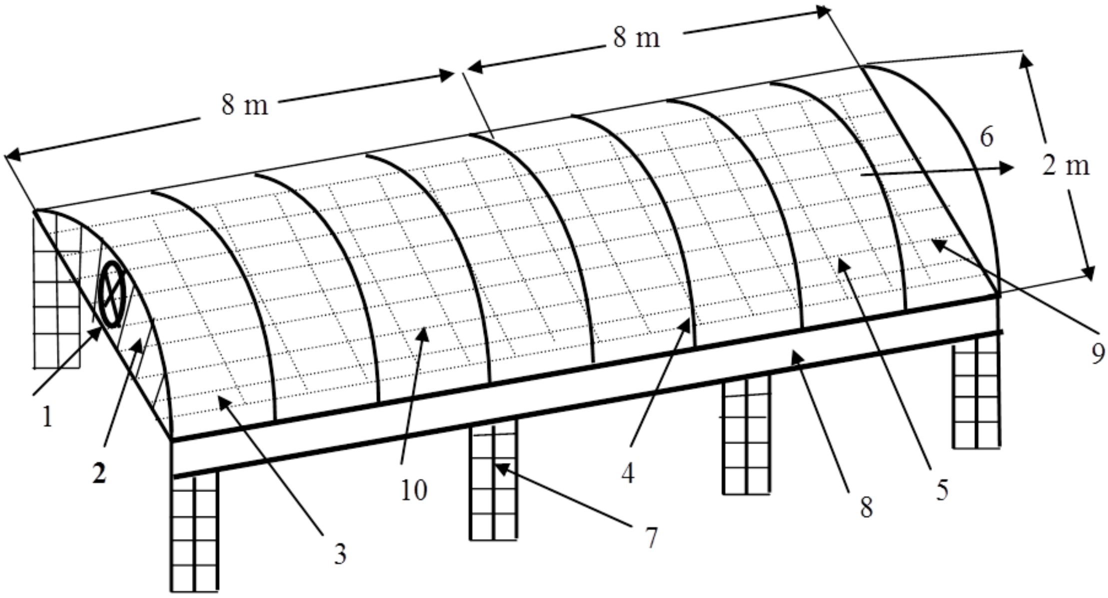

Fig. 1 A rough sketch of a solar tunnel dryer used in this study without plastic cover and part of wooden base of the tunnel (1- Air inlet to the collector, fan, 2- South side wooden cover, 3- Collector part (16 m^2), 4- Light weight aluminum frame, 5- Dryer part (12 m^2) 6- Air outlet from the dryer, 7- Concrete block sub-structures, 8- Wooden frame to support bends and base of the tunnel; 9- Metallic wire mesh net over wooden base in the dryer part, 10- Absorber plate (black painted metallic sheet over wooden base, not visible in figure, 16 m^2)

A solar powered fan of 30 watt capacity was installed at the holes made on the wooden cover plat, 150 mm above the absorber metallic sheet at the air input side of the tunnel. Thus the drying air was forced from the collector region to the dryer region where the product is to be dried. To measure the temperature profiles from morning to evening, thermocouples were installed to record the temperatures at different locations within the tunnel. Nine thermocouples were connected within the tunnel and two outside to record the dry bulb and wet-bulb temperatures. A pyranometer of Moll – Goregynstic type was used to measure the solar radiation incident on a horizontal surface. The thermocouples probes, anemometer and pyranometer were connected through an interface of an AD (analog to digital) converter then to a personal computer for data collection. The temperatures, air velocity and solar radiations data were recorded simultaneously at an interval of 30 minutes.
The collector efficiency of the flat plate solar collector of dryer was calculated from the measured solar energy at measured sun shine hour per day and the energy available for drying inside the tunnel. The following equation was used to calculate the available solar energy collected by a (8 ×2) m flat plate solar collector.

$$I_s = C \times I_c \times A_c \times t \quad (MJ) \tag{1}$$

where I_s the measured total (beams and diffuses) solar radiation incident on a horizontal surface (MJ), C is the unit conversion factor (0.0036), I_c the measured total (beams and diffuses) solar radiation incident on per unit area of a horizontal surface (w/m^2), A_c is the area flat plate solar collector (m^2) and t is the sun shine hour or drying period per day (h).
The potential available energy for drying carried by the drying air from the collector to the drying region was calculated from the flowing equation.

$$I_a = 3.6 \times A_t \times V_a \times \rho_a \times c_p \times (T_d - T_a) \times t \ (MJ) \tag{2}$$

where I_a is the amount of available energy inside the tunnel for drying (MJ), 3.6 is the constant for unit conversion, A_t is the cross sectional area of the half-circle tunnel (m^2), V_a is the average velocity of drying air inside the tunnel (m/s), ρ_a is the density of the drying air at the measured average drying air temperature (kg/m^3), c_p is the specific heat capacity of the drying air at measured average drying temperature (kJ/kg.^{o}C), T_d

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is the average drying air temperature inside the tunnel (°C), T_a is average measured ambient temperature on the drying day (°C) and t is the sun shine hour or drying period per day (h).

The drying efficiency of the dryer was calculated based on total energy input and the actual energy used in removing the moisture from product, and the energy utilization efficiency was calculated from the energy available in drying and actual energy utilized in drying dates.

III. RESULTS AND DISCUSSION

The difference between the drying air temperature and ambient temperature gradually increased from morning till mid-day then gradually fall in the afternoon (Figs. 2 and 3). The highest temperature 74^{0}C was observed at around 12:30 PM. The maximum difference between the average temperatures of the dryer and collector parts was about 5^{0}C in five seven days recording of temperature (Fig. 2). This indicated the uniformity of temperatures inside the entire tunnel. There was almost no temperature gradient in the vertical direction of the whole tunnel, both in the dryer and in the collector parts of the tunnel. Figure 3 shows the variations of ambient, collector and dryer temperatures with time of the day from recording of temperature for two days.

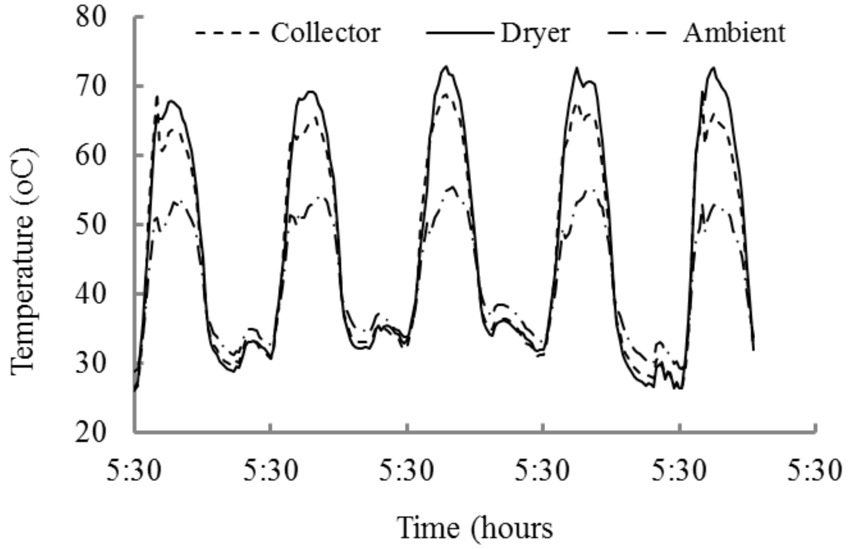

Fig. 2 Variations of ambient, dryer and collector air temperatures with time for five days .

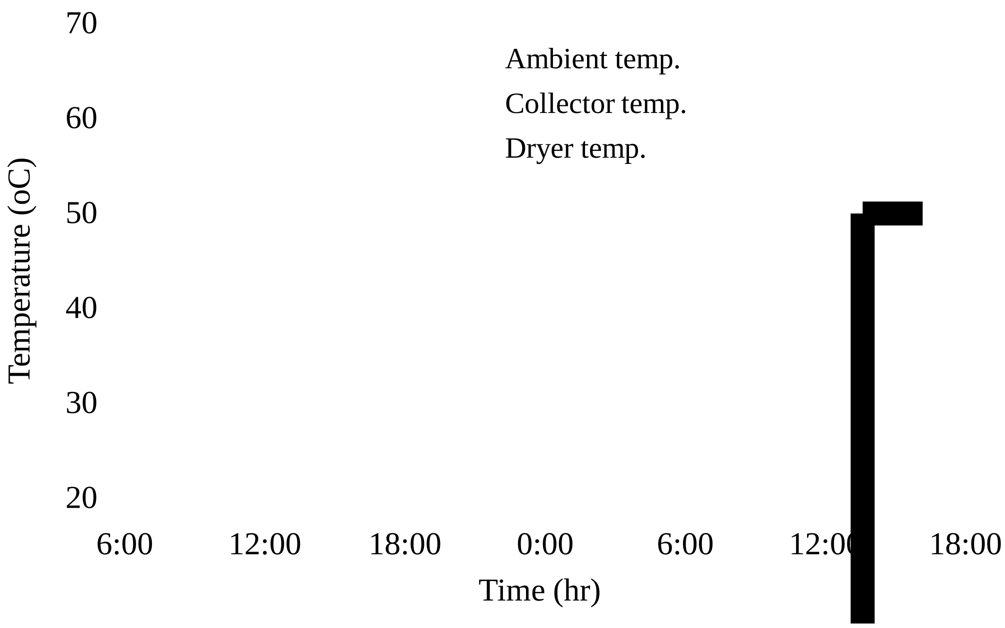

Fig. 3 Variations of ambient, dryer and collector air temperatures with time of the for two days.

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The average drying air temperature could be easily raised by some 5-30 ^{o}C above the ambient temperature at an average air flow rate of 0.1 m/sec. The highest temperature 69 ^{o}C was observed at around 1 PM. The maximum difference between the average temperatures of the dryer and collector parts was about 2 ^{o}C. This indicated the uniformity of temperatures inside the entire tunnel continuously recording temperature both for five days (Fig. 2) and for two days (Fig. 3), respectively. There was almost no temperature gradient in the vertical direction of the whole tunnel, both in the collector (Fig. 4) and the dryer parts of the tunnel (Fig. 5).

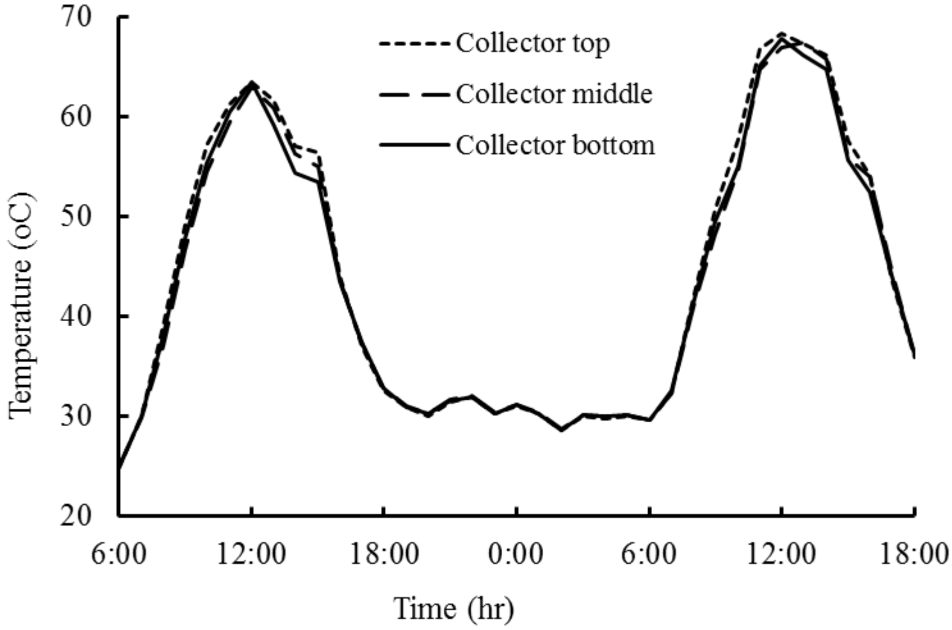

Fig 4 Variations of temperatures at the bottom, middle and top of the collector center along the length with time.

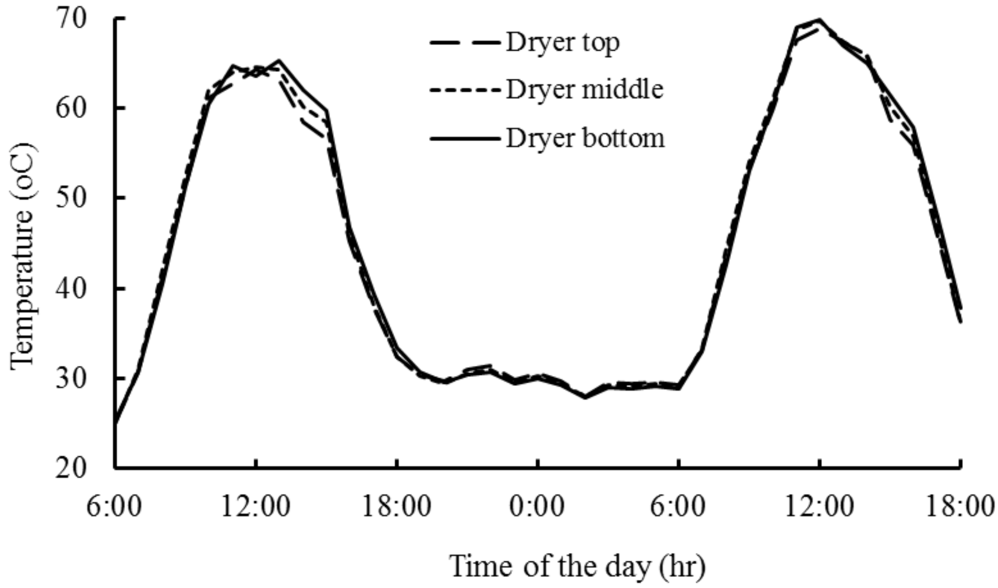

Fig. 5 Variation of temperatures at the bottom, middle and top of the dryer center along the length with time.

A test was also conducted keeping switch-off the fan. It observed that the highest temperature inside the tunnel became 75 ^{o}C when the fan was not in operation (Figs. 6 and 7). The difference between the average temperatures inside the tunnel without and with fan was about 10 ^{o}C. This indicated the operation of the dryer without fan would cause over drying of the product particular during 11:30 AM-3:30 PM.

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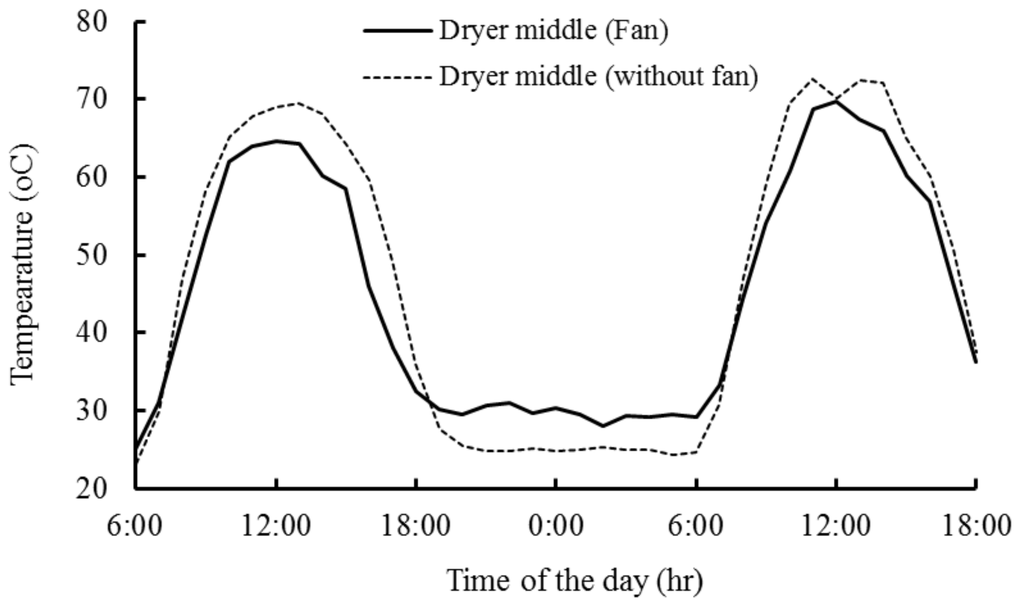

Fig. 6 Variations of temperatures in the dryer part of the tunnel with and without fan with time .

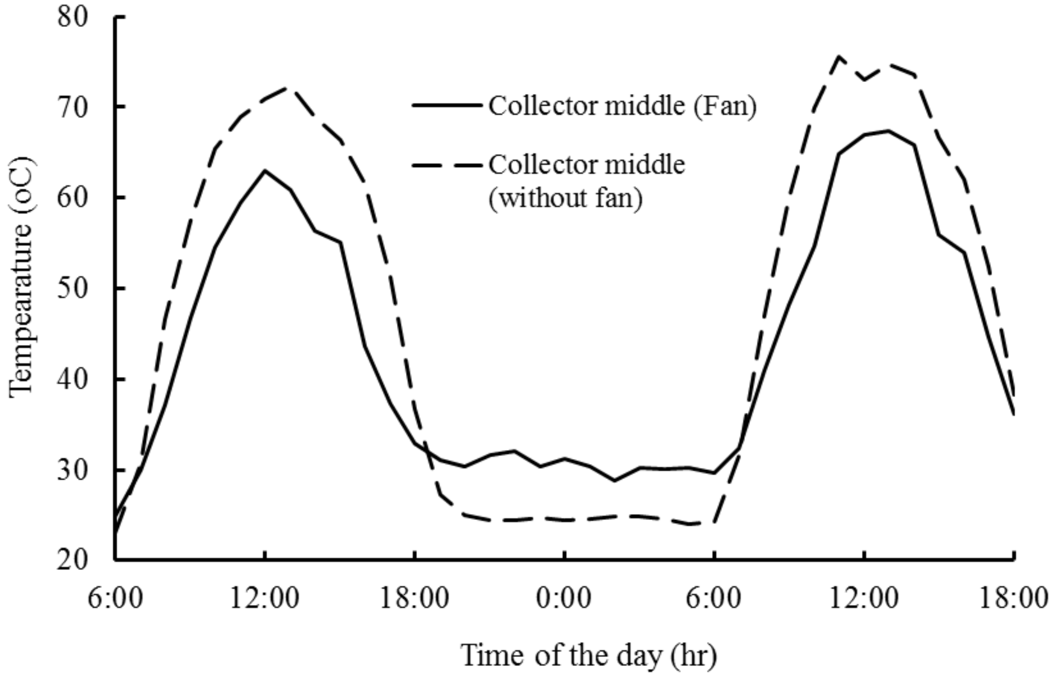

Fig. 7 Variations of temperatures in collector part of the tunnel with and without fan under no-load conditions with time

An average 500 w/m^2 solar energy was incident on the horizontal surface which can be easily utilized in drying agricultural products. The efficiency of the flat plate solar collector was found as 34.02% while the available solar energy in two days was 576 MJ and the available energy content of the dying air was 195.97 MJ at an average air flow rate of 0.1 m/s inside the tunnel. The energy utilization efficiency of the available energy in drying was found as 70% considering two days drying period for dates and the average energy requirement in removing per kg of moisture from the farm product is 3.5 MJ. The drying efficiency of the dryer was found as 36.4%. It is worth here to mention that a good performance of the dryer was also obtained in drying 300 kg freshly harvested limes within 7 days (Basunia et al., 2013).

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IV. CONCLUSION

This paper describes the thermal performance of a solar tunnel dryer. The tests clearly indicated that the drying temperature can be easily raised to 5-30 ^{o}C above the ambient temperature in Omani weather conditions while the average air flow velocity inside the tunnel was 0.1 m/s. The average drying air temperature could be easily attained 50 -55 ^{o}C, which is suitable for drying farm crops commonly harvested at high moisture contents. A considerable reduction in drying time in comparison with natural open air sun drying was obtained in drying both limes and dates. The efficiency of flat plate solar collector was found as 34% approximately. These results show that solar tunnel dryer can be used for low temperature drying of dates, limes and other agricultural products in the rural areas of the developing where electricity is not available.

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