Experimental Investigation of Drying Tomato in a Double Slope Solar Dryer Under Natural Convection

E. Elavarasan, Yogesh kumar, R. Mouresh, and Sendhil Kumar Natarajan

Abstract In this study, thin layer drying of tomato slices under open sun drying and double slope solar dryer was conducted. The drying effect on exergy loss, exergetic efficiency, dryer efficiency, pickup efficiency, energy utilized, thermal and drying chamber efficiency has been obtained. It has been observed that the solar dryer with double slope had more efficiency than the open sun drying. The exergy loss range from 1196.82 to 11,758.18 kJ/kg having an average value of 6302.47 kJ/kg, the exergetic efficiency varied from 67.19% to 81.17% with an average value of 70.20%, respectively. The value of pickup efficiency varied from 10.89% to 14.33% with an average value of 12.22% with the dryer efficiency varying from 11.58% to 44.76% with an average value of 25.76%, respectively. The energy utilized ranged from 19.23 to 76.73 kJ/s with an average value of 55.2 kJ/s, the thermal efficiency is said to be varied from 5 to 14% and the drying chamber efficiency is said to be range from 9.70 to 77.52% with an average of 57.48% for the entire duration of the experiment. A comprehensive evaluation yielded that the double slope solar dryer was best suited for drying the samples.

Keywords Drying tomato slices · Solar energy · Activation energy · Exergy · Energy · Performance dryer

1 Introduction

Tomato plant ("*Solanum lycopersicum*") has an edible berry that is commonly called as tomato and is consumed raw and cooked all around the world. Tomatoes are a major source of lycopene which is an antioxidant and is linked with various health benefits like reducing heart disease and cancer. Global exports for tomato cumulatively had a quantity of 7.3 million tonnes with an estimated value of $9.7 Billion in 2018. The

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K. Govindan et al. (eds.), *Advances in Mechanical and Materials Technology*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-2794-1_16

largest exporter of tomato is Mexico at 1.8 million tonnes followed by the Netherlands and Spain at 1.1 million and 797 thousand tonnes, respectively. Tomatoes grown in India are primarily consumed by the domestic market due to the large demand in the country. Arepally et al. [1] investigated the mixed-mode solar drying of tomato samples at 30°–60° air temperature. The moisture content of drying tomato samples decreased from 93.67–8% on a wet basis within 20, 23, and 30 h for three different load conditions. The experimental results were better in agreement with two-term drying model for 2, 4 kg m^{-2} for load condition and having a Logarithmic drying model for 6 kgm^{-2} load condition. They reported that energy utilization ratio of the dryer was varied from 24.2–58% and exergy efficiency varied from 50–59%. Pankaew et al. [2] used a equipped rice husk burning system on parabolic greenhouse dryer for producing dried banana. The highest efficiency of the burning was 87.7%. It was concluded that the drying efficiency increased by 12.6%. Murugavelh et al. [3] developed a mixed-mode solar tunnel dryer to dry tomato waste at 44–68 °C. The content of moisture of drying tomato paste reduced from 71.1–0.3% on a wet basis within 7 h in the tunnel dryer and 15 h in sun drying. It was concluded that the experimental results were better in agreement with Midilli et al. drying model and the exergetic efficiency of the tunnel dryer was varied from 38.5 to 67.5%. Ligayat et al. [4] conducted the experiment in an indirect solar dryer, which reduces the usage of fossil fuel. The mean thermal efficiency in the collector was 31.50% whereas the drying chamber efficiency was reported as 22.38%. They concluded that drying time was reduced in indirect solar drying method and more efficient than open drying process. Hamdi and Kooli [5] used mixed-mode greenhouse and solar dryer to dry tomato samples at 25–54 °C drying temperature. The moisture content of drying tomato decreased from 20.27 to 0.36 g water/g dry matter within 31 h under the greenhouse dryer and 48 h under open drying. experimental results were better in agreement with Midilli et al. drying model. They concluded that the exergetic efficiency of a dryer varied from 16.4–70.4% and average efficiency of energy of the system was 42%.

Johnson et al. [6] used a hot air dryer to determine the moisture diffusivity and shrinkage within the cylindrical piece of plantain were the thickness and the temperature will vary. They reported that the activation energy of the sample was estimated at 38.81 kJ, and Fick's diffusion equation identified the distribution of moisture. Kumar and Elavarasan [7] reviewed the application of computational fluid dynamics in natural and forced convection greenhouse dryer in different samples. Berinyuy et al. [8] developed a solar tunnel dryer to dry the vegetables containing very high moisture content. The dryer contains four trays and can dry 17 kg of cabbage moisture content reduced from 95 to 9% in five days. The mean efficiency of dryer was 17.86%, with airflow of 9.86 m^3/h. It was reported that there was a reduction in dehydrating period by 30 and 50% based on the crop used and the dried product was acceptable visually. Hossain and Bala [9] studied mixed-mode type forced convection solar tunnel dryer to dry green and red chilies. The final moisture content of red chili 0.05% in 20 h in dryer and it took 32 h in open drying. In the case of green chili, 0.06% final moisture was obtained from 7.6% in 22 h in tunnel dryer and 35 h in sun drying. They concluded that the use of a solar tunnel leads to decrease the dehydrating period. Vijayan et al. [10] studied the thermodynamic characteristics of the bitter gourd by using indirect solar drying. They concluded that the mean value of moisture diffusivity was 12.95×10^{-10} m^2/s, the mean value of pickup efficiency was 54.29%, and the mean value of exergy efficiency was 40.68%.

Midilli and Kucuk [11] studied indirect type of solar cabinet dryer to dry shelled and unshelled pistachios at 40–60 °C drying air temperature. The equilibrium moisture content of dried pistachios was observed within 6 h. They reported that exergy loss of solar cabinet dryer was varied from 0.5–3 kJ $(kg)^{-1}$. Kesaven et al. [12] made an indirect-type triple-pass forced convection dryer to analysis the exergy, thermal and pickup efficiency of drying potato slices. The flow rate was 0.062 kg s^{-1}, and the exit air temperature was 62 °C. The final moisture content of sample of potato was 13% after the drying process in 4.5 h. The thermal efficiency was 45%, the pickup efficiency was 29.9%, and the exergy efficiency was 53.57%. The Midili and Kucuk model were best suited drying models for potato slices. Abbaspour-Gilandeh et al. [13] used a hot air dryer for drying quince sample at 50–70 °C drying air temperature with three different wind velocities used. The effective moisture diffusivity of drying quince sample was varied from $4.1–1.18 \times 10^{-9}$ m^2 s^{-1} and Midilli et al. drying model gave good agreement with experimental results. The energy utilization ratio, exergy efficiency and loss of hot air dryer were 0.882, 87.9% and 0.04 kJ s^{-1}. Nazghelichi et al. [14] analyzed exergy and energy of fluidized bed drying of carrot. Three inlet temperatures of 50, 60, 70 °C and 30, 60, 90 mm were used for the experiment. The size of the carrot cube was 4, 7 and 10 mm, respectively. The energy utilization range between 0.105 and 1.949 kJ/s and the energy utilization ratio (EUR) varied from 0.103 to 0.707. They concluded that the high air inlet temperatures, small particles and deep beds increased the energy utilization ratio (EUR). Tan et al. [15] conducted drying of cassava chips at temperatures of 30, 50 and 70 °C with different airflow rates. They concluded that the modified page model gave the best fit with the drying air temperature and rate of flow across the dryer. Based on the above-cited literature review, very few papers reported the drying parameters of tomato. Hence, in this paper, experimental studies were carried out to determine the pickup, dryer, thermal, drying chamber, exergy and energy efficiency of drying tomato slice of developed low-cost double slope solar dryer.

2 Experimental Setup

The experiment was conducted on February 11, 2020, in Karaikal District, Puducherry, India, to evaluate the drying characteristics of the tomato slices. The setup consists of a double slope dryer of a double trapezoid shape with a total length of 2.49 m, a breadth 0f 0.8 m and a height of 0.3 and 0.25 m on the longer and shorter sides of the dryer. The trapezoid shape of the dryer enabled the movement of moisture from a higher pressure to lower pressure region inside the dryer thus enabling faster drying of the samples. The inclination of the dryer was given at 10.2°on each sides matching the latitude of the experimental area which was covered with a pane glass

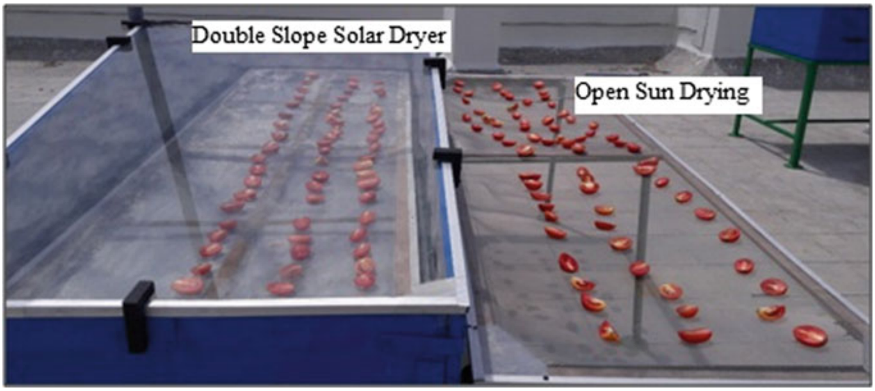


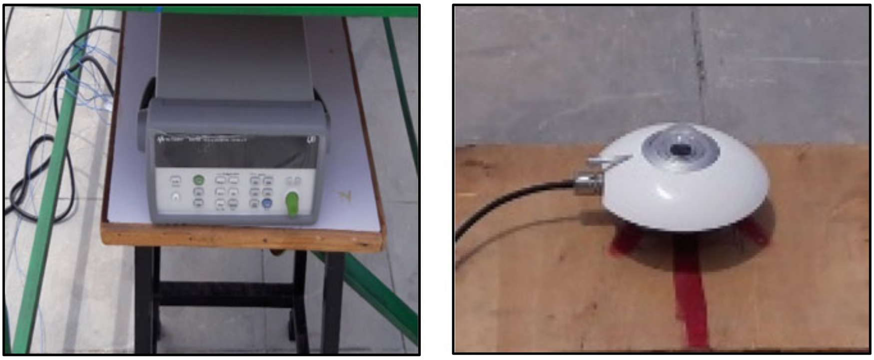
Fig. 1 Picture of double slope solar dryer and open sun drying for drying tomato

of thickness 0.04 m, the dryer was made out of galvanized Iron along with plywood of thickness 0.025 m to restrict heat transfer to and from the dryer. The samples were placed in an Aluminum mesh of 2.41 m × 0.74 m inside the dryer to study wetness of the samples. One kg of samples was taken inside the dryer and open drying to compare and evaluate their drying capabilities. The entire drying setup was placed in the East–West direction for entire drying process [16, 17]. The highest temperature developed inside the dryer was recorded to be 70 °C, with a maximum RH value of 45%. Vents were employed to facilitate dehydration of the samples. The pictorial representation of the solar dryer was given in Fig. 1.

The acquired data via a data acquisition system (Agilent 34972A), which has a ± 0.25% error correction. Eight K-type thermocouples were utilized to measure the various parameters within the system, within where five of them were used to measure the absorber plate temperature and three of them measured the drying air temperature at different locations. The ambient temperature was measured using a J-type thermocouple throughout the experiment. The average solar radiation was obtained using a Hukseflux Pyranometer with a sensitivity of 14.77×10^{-6} V/(W/m^2). The photographs of the data acquisition system and Pyranometer used were shown in Fig. 2(a, b).

3 Analysis

The model presented by Midilli and Kucuk [11] for exergy and energy techniques of thin layer dehydrating operation is connected to this investigation. In the techniques of thermodynamics, a thin layer dehydrating operation is considered a constant steady flow method.



(i) Agilent Data Acquisition Unit (ii) Hukseflux Pyranometer

Fig. 2 Picture of **a** Agilent data acquisition unit and **b** Hukseflux Pyranometer

3.1 Energy Technique

In extent of the first law of thermodynamics, the energy techniques of thin layer dehydrating operation of tomato was done to determine energy characteristic and dehydrating characteristic of drying air all through convective kind of chamber dryer. The air operation is modeled as a constant steady flow operation investigated by utilizing steady flow protection of mass and preservation of the energy standards [11].

The energy analysis of tray and dehydrating chamber can be calculated by following equations

$$\eta t = \frac{\dot{m}_w h_f}{\dot{m}_d C_p (T_{ti} - T_h)} \tag{1}$$

$$\eta_d = \frac{\dot{m}_w h_f}{\dot{m}_d C_p (T_{di} - T_h)} \tag{2}$$

$\dot{m}_w$ is denoted by the mass flow rate of removed moisture from tomato.

The required energy to transfer the wetness content during dehydrating operation was calculated by

$$Q_s = m_{ao}(h_i - h_o)$$

where Q_s = Mass flow rate of outlet, h_i = Enthalpy of the intake air, h$_o$ = Enthalpy of exhaust air.

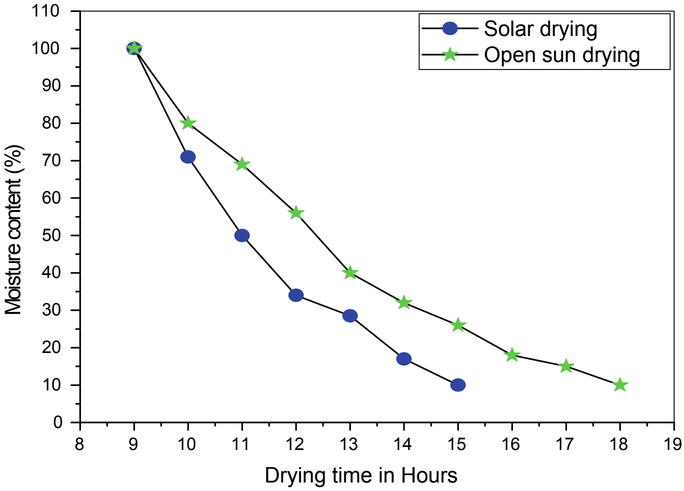


Fig. 3 Variation of moisture content reduction of tomato respective to drying time for solar dryer with double slope and open drying method

3.2 Exergy Analysis

In the extent of second law of thermodynamics, overall outflow of exergy, losses and inflow tray, and dehydrating chamber were evaluated. The essential technique for the exergy investigation of dehydrating chamber was to calculate the values of exergy at a constant steady flow and the exergy deviation for dehydrating operation [11].

The term exergetic efficiency was characterized as inflow to outflow ratio for dehydrating chamber. The generalized form of exergy efficiency was derived as

$$\text{Exergy Efficiency} = \frac{\text{Exergy (inflow}-\text{outflow)}}{\text{Exergy Inflow}} \tag{3}$$

$$\eta_{\text{exergetic}} = 1 - \frac{E_L}{E_i} \tag{4}$$

To calculate the exergy losses by the following equation.

$$\sum EX_{\text{LOSS}} = \sum EX_i - \sum EX_o \tag{5}$$

4 Results and Discussion

Figure 3 observes variation in content of moisture in tomato samples in a solar dryer with double slope and open drying process. The content of moisture in the samples decreased from an initial moisture from 94.42% to 10% (wb) in 7 h under solar dryer and 10 h under open drying process, respectively. The samples in the double slope solar dryer had faster drying rate than samples under open drying due to enclosed chamber and restricted inlet of air inside the drying chamber. The highest amount of moisture removal happened between 12:00 and 13:00 when peak solar radiation was recorded. The open sun drying required a second day of drying to achieve similar results to that of the double slope solar dryer.

The global solar radiation for the entire experiment peaked at 1031.82 W/m^2, having average value of 739.50 W/m^2. On observing Fig. 4, it was noted that there was a direct relation between the absorber plate temperature and the drying air temperature inside the dryer. The temperature of the absorber plate had a peak temperature of 59.25 °C at 13:00 with average of 42 °C, respectively. The temperature of drying air also followed the same pattern by obtaining a peak temperature of 54 °C and having a temperature of 42 °C on average, respectively. The inlet air had a maximum temperature of 44.67 and 38.23 °C on average. The ambient temperature hovered at 25.7 °C to 27.67 °C, with average of 26.86 °C, respectively. The drying pattern has been observed and has followed the usual path of drying.

On analyzing Fig. 5, the exergy loss varied from 1196.82 to 11,758.18 kJ/kg, having average value of 6302.47 kJ/kg. The exergy loss peaked during 13:00–14:00 when the incident solar radiation was also maximum. The exergy loss remains low if the exergy was properly utilized inside the dryer. Figure 6 shows the exergetic efficiency of the samples that was reported to peak around 12:00 noon due to the

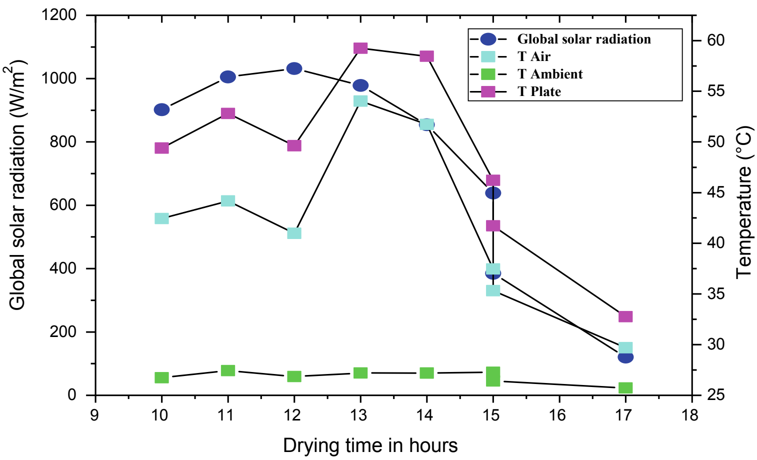


Fig. 4 Variance in global solar radiation, surface plate temperature, ambient temperature, and average air temperatures in double slope solar dryer

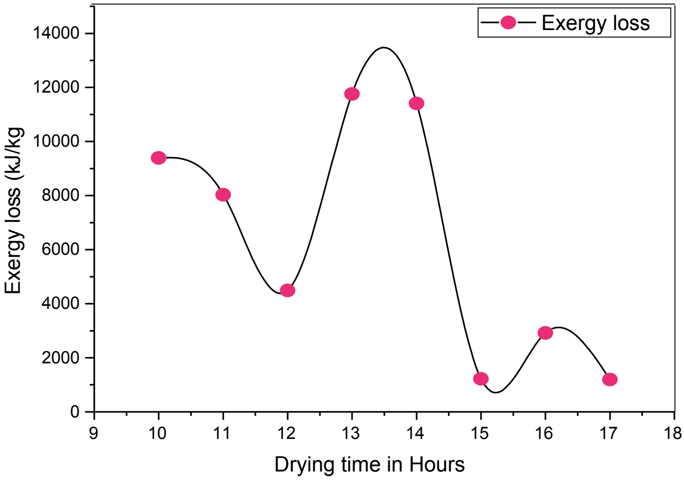


Fig. 5 Variance of exergy loss with a time of drying of the samples

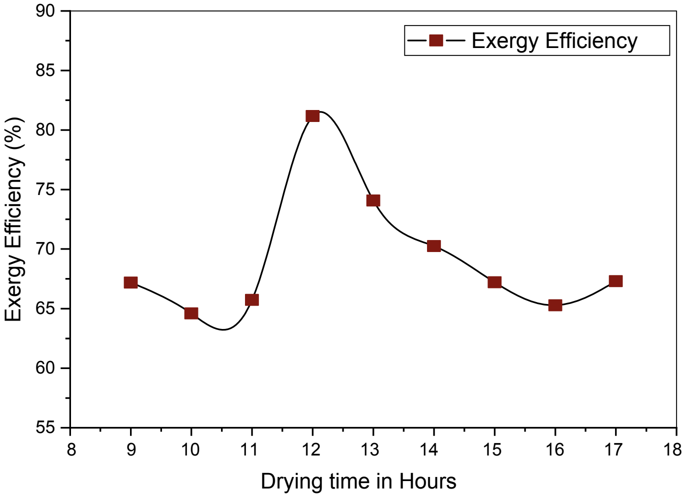


Fig. 6 Variance of exergy efficiency with the time of drying of the samples

maximum utilization of available exergy inside the drying chamber. The exergetic efficiency varied from 67.19 to 81.17% with an average value of 70.20% and it can also be observed that the exergetic efficiency kept decreasing after the peak value until the supply of exergy became low after 16:00 h after which a small increase was observed.

Figure 7 demonstrates the efficiency of pickup of solar drying. The value varies from 10.89 to 14.33%, with an average value of 12.22% for the entire duration of the

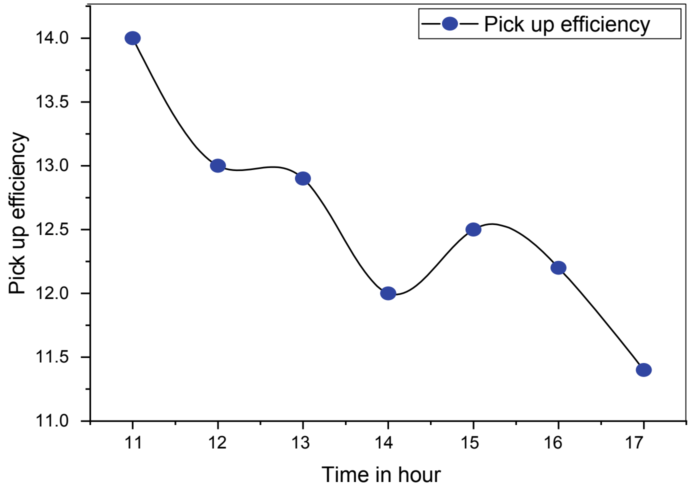


Fig. 7 Variance of efficiency of pickup with the time of drying of the samples

experiment. The pickup efficiency peaked at 11:00 and then proceeded to decrease till 14:00, after which it showed an increase till 15:00 before falling again for the remaining duration of the experiment. Figure 8 shows variance of dryer efficiency with the time of drying of the samples. The effectiveness of the dryer was varied from 11.58 to 44.76%, with an average value of 25.76%. The lower effectiveness of the dryer at 10.00 am due to the beginning of the experiment and that the arrangement had not yet been balanced out. At the point when insolation drops, the put-away heat was

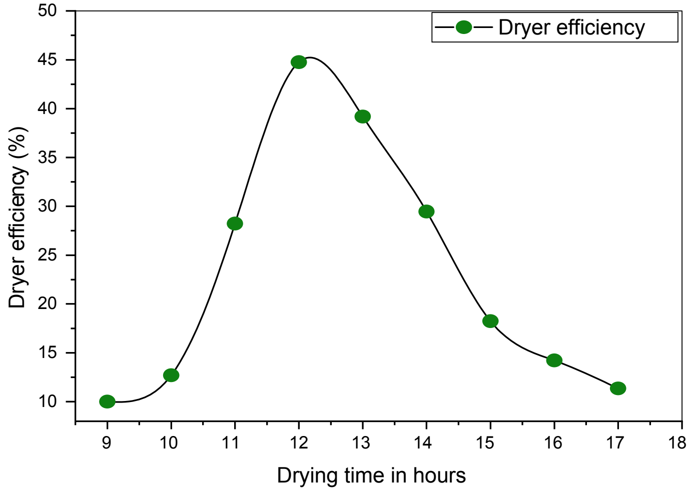


Fig. 8 Variance of efficiency of dryer with the time of drying of the samples

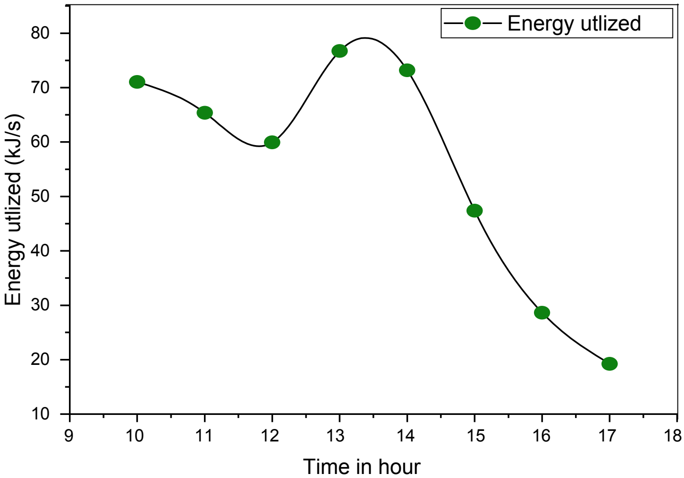


Fig. 9 Variation of Energy used with a drying time of samples

recovered while consequently keeping up greater air warmth and subsequently greater effectiveness. The effectiveness of the dryer was least during the peak incident solar radiation at 12:00 noon due to the rapid increase in surface temperature in the early afternoon with high incident solar radiation whereas the effectiveness of heat of air doesn't meet the extra load because of fixed speed causing it to lose its effectiveness.

Figure 9 shows variance of energy used with the time of drying of the samples. The values for energy utilized ranged from 19.23 to 76.73 kJ/s, with an average value of 55.2 kJ/s, respectively. The values peaked at 13:00–14:00 due to the high availability of energy caused by the peak in incident solar radiation where the energy used has been determined by utilizing the data of wetness expelled during analysis, as concluded by Emulue et al. [18]. The values of thermal efficiency were said to be varied from 5 to 14% peaking at 11:00–13:00 due to the high amount of solar radiation incident on the dryer. The drying chamber efficiency was said to be varying from 9.70% to 77.52%, having an average value of 57.48% increasing with the increase in chamber inlet temperature that facilitates the drying of the samples, respectively.

5 Conclusion

- Performances of a solar drying have been evaluated for tomato in double slope solar dryer.
- The drying was conducted from 9:30 to 16:30 on day 1 and 9:30 to 12:30 on day 2 to evaluate the drying properties of the samples. It is observed that the drying from 94.42 to 10% wet basis moisture took 7 h under solar drying and 10 h under open drying. The average solar radiation had a value of 739.5 W/m^2 and the airflow rate

had a value of 1.052 kg/s, the drying system, thermal, drying chamber and pickup efficiencies were found about 34.76%, 13%, 63% and 14.33%, respectively.

- The efficiency of exergy of the dryer is varied from 17.4 to 81.17%. The overall efficiency of energy of the dryer is reported as 77%.
- Thermal diffusivity of dried tomato sample minimum value of 1.891×10^{-4} m^2/s and maximum value of 4.823×10^{-4} m^2/s.
- The rehydration ratio, density and porosity of dehydrated tomato slices is 10.26%, 1.57 g/cm^2 and 42%.
- The dried tomato samples also possessed excellent sensory characteristics while being hygienic and of a high quality due to shielding from pollutants and other quality hampering agents.
- It is concluded that double slope solar dryer is better and most suited for drying the samples than the open sun drying process.

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