



The Hybrid (PVT) Double-Pass System with a Mixed-Mode Solar Dryer for Drying Banana

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ABSTRACT

This paper proposes a developed numerical and experimental design of a hybrid Photovoltaic-Thermal (PVT) double-pass counter-flow system connected with the mixed-mode solar dryer system. The mixed-mode solar dryer considers the most efficient mode because it has two heat sources, from solar radiation and the hot airflow which is supplied by the PVT system. The PVT system is often unused for drying applications; therefore, the whole proposed PVT solar system in this work is utilized for drying applications. This system is not only massive fuel savings, but also crucial to improve the quality of the dried product in terms of color, aroma, and taste. To verify the effectiveness and robustness of the proposed system, the system is utilized to dry 300g of slices of banana, where the obtained range of air temperature is from 43.2 to 60.2°C. The slices of banana are distributed identically between upper and lower trays. The initial moisture rate of banana was about 78%, and the most dropped in moisture content was from 78% to 28.12% in the lower tray at 0.031 kg/s after 8 hours of the drying process. It was noticed that the most and least decreasing in weight of banana samples was from 150 to 48g and from 150 to 55g in lower and upper tray, respectively, at 0.031 and 0.017 kg/s mass flow rate. This gives an indication that the highest reduction was 68% of banana weight at a high mass flow rate of airflow. The critical parameter such as temperature distribution of the PVT with dryer room, useful heat gain, and thermal efficiency are computed by using the MATLAB 2015b program which is built for this purpose. The highest heat gain and thermal efficiencies were 423.7 W and 52.98%, respectively, at 1:00 PM when the mass flow rate 0.031 kg/s.

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1. Introduction

The contemporary hybrid PVT system is considered the ingenious technology that converts the radiation energy of the sun into both electrical and thermal energies simultaneously. The design comprises the photovoltaic (PV) module, which is solar cells connect in series or parallel and produce electrical power, and the PV system is integrated with the thermal collector as a PVT solar system and this system is connected with solar dryer. By blowing air by the fan which is generated by the PV module, into the PVT system, the temperature of the solar cells will decrease to develop the electrical efficiency of the PV module. The hot air output as heat gain from the PVT system is supplied to the dryer system. The main purpose of the drying crop is to reduce the moisture of products to a safe limit to be able to store the products for a long time and prevent deterioration. The solar dryer system not only decreases fossil fuel consumption for drying purposes, but also supply the best quality and taste of the dried crops [1]. Various studies of researchers have been to design and develop solar dryer performance. Vineet et al. discussed the performance of various types of PVT solar system technologies, which is integrated with the solar dryer system. The mathematical model and energy analysis have been carried out for various kinds of partly covered PV technologies (namely, c-Si, p-Si, a-Si, CdTe, and CIGS) with a thermal collector. The CIGS type was found to be the most suitable PV technology for large systems in terms of minimum embodied energy and payback duration [2]. Mohamed et al. developed a hybrid PVT solar system as a portable tunnel dryer for drying mint. The solar dryer system can be worked as a direct and indirect mode with forced convection. The PV system is used to operate a fan (forced mode). Results showed that the drying peppermint period was changed from 210 to 360 min for the developed dryer, while changing from 270 to 420 min for the open sun drying [3]. Sumit et al. discussed the combination of PVT air-based systems with solar drying systems and the thermal model of all systems has been analyzed. It was found that one drying system can be utilized for different products by changing the airflow rate and packing factor of the PV panel. Average thermal, electrical, and overall efficiencies were found to be 26.68%, 11.26%, and 56.30% respectively at 0.01kg/s [4]. Hadi et al. designed and fabricated a PV-assisted solar dryer system to investigate the drying tomato slices at different air velocities and the thickness of the product. The sun tracking system was evaluated on the drying behavior of tomato slices and it was found that the drying time dropped around (16.6% to 36.6%). The drying time also decreased with rising airflow velocity. While increasing the thickness of the slices, the drying time was decreased, and the effect of slice thickness on drying was more significant [5]. Fterich et al. experimented and examined the performance of a hybrid PVT system with a solar dryer under forced mode for drying tomatoes. It was observed that the dried tomatoes can be conserved for longer periods and reduce the loss of crops. Also, It was indicated that the moisture content decreased from 91.94 (%) to 22.32 (%) for tray 1 and to 28.9 (%) for tray 2 by using the realized prototype, conversely, it decreased to 30.15 (%) by using the open sun dryer. [6]. Mohamed et al. studied the hybrid PVT solar system with a solar tunnel dryer under forced mode for drying potato. In addition, it was investigated the effect of the different mass flow rates of air on the solar dryer. It was found that the highest drying efficiency of 28.49 and 34.29% was recorded at 0.0786 kg/s in case of without and with using thermal curtain, respectively. [7]. Abhay et al. (2017) designed and developed an indirect solar dryer type for drying banana slices. The dryer consists of a V-corrugated collector, drying room, and chimney. A banana was chosen to study the drying behavior. The results were shown that the banana moisture content was reduced from 356% (db) to 16.3292%, 19.4736%, 21.1592%, 31.1582%, and 42.3748% (db) for Tray1, Tray2, Tray3, Tray4, and open sun drying, respectively, which means the indirect dryer is more efficient than open sun dryer [8]. Ehsan et al. analyzed and constructed a solar dryer under forced convection for drying apricot samples on two parallel trays. A PV module and battery are integrated with the solar dryer to generate the electrical power required. The phase change material effect was analyzed. It was found that the collector performance is enhanced and the process of drying is effectively continued when solar energy is not available. [9]. Essalhi et al. designed and improved an indirect solar dryer system for drying pear products with natural convection mode. It was obtained that the weight of the crop was decreased from 997.3g to 135.13g after 24 hours of drying process [10]. Vinay et al. designed an indirect, active type of solar dryer to dry banana slices. The experiment was tested to study the characteristics of drying banana. It was found that the drying at 1 m/s of airflow was of the best quality in taste, color, and shape when compared with drying at 0.5 and 2 m/s airflow. After around 16 h of drying time, the difference in moisture rate was 3.1%, which is occurring between the top and bottom configurations [11]. The hybrid PVT system at present work faces the south direction and tilts at 33° to gather more solar radiation intensity. This degree of the tilt angle is most convenient and depends on the latitude of Baghdad-Iraq, which is 33°L approximately [12]. According to previous works, a few studies addressed the

incorporation of the hybrid PVT system with solar dryer and without exploiting the output warm air from the hybrid PVT system as the drying process. Subsequently, most studies considered the solar collectors as solar dryers working at force mode, where the fan is generated by using a traditional power that depends on fossil fuel. In the present work, the PVT system is connected with the solar dryer system to dry crops. The traditional power is not needed in the case of the PVT system as a solar dryer because the PV module is the main source of the required power in drying applications.

2. System description

The main components of the PVT system with a solar dryer are consist of the PV module, thermal collector, dryer room, DC fan (Type: ZONGSHEN LIFAN), and duct as shown in Figure 1. The monocrystalline silicon PV module is covered by two glasses from the top and below of solar cells. The thermal collector made of pure aluminum and contains fins from the upper and lower surface. The PV module is integrated with a double pass thermal collector as a PVT solar system. The forced convection mode is used to pass the air from the fan to PVT solar system and then into the drying room. The solar dryer room was fabricated with dimensions (52cm*42cm*60cm) from the wooden frame and covered from four sides by glasses with 4 mm thickness, also, the drying room was equipped with a wooden door with dimensions (42cm* 60cm) to supply the dryer room by crops easily. Further, the dryer chamber contains two parallel trays to carry the crop products for drying as a square shape. Furthermore, the chimney was applied for exhausting air output. The DC fan was provided for blowing air into the PVT system and generated by the PV module, and produce an output hot air by extracting heat from the back surface of PV cells and thermal collector, and this hot air was applied to the dryer chamber by a duct which connects the PVT system and solar dryer. The schematic diagram shows the composition of the the PVT system with the dryer room and the airflow by a counter-flow method is illustrated in Figure 2.



Figure 1: Component of the PVT system to dryer solar system.

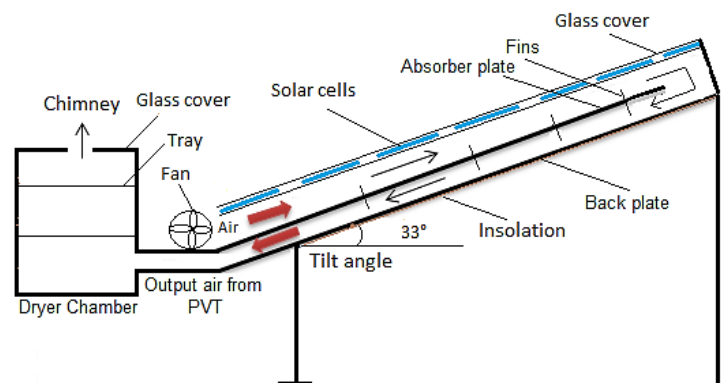


Figure 2: Schematic diagram of airflow current through the PVT system with solar dryer.

3. Methodology

The hybrid PVT double-pass solar system with a dryer room was modeled and designed. In order to maximize the solar radiation, the PVT solar system with dryer was faced to the south direction with a tilt angle of 33° which is approximately equal to the latitude of Baghdad. The experimental readings were taken on the third of August in 2019 in Baghdad, Iraq. The mathematical model of this system has been proven by applying the energy balance equations. The input mass flow rate for the PVT system is measured experimentally by hot-wire anemometer device and these values of mass flow rates are the same input values of the MATLAB program. After investigation of the model, the theoretical analysis has been completed to estimate the temperatures of the PV cell, absorber plate, back plate, output fluid, dryer chamber, heat gain, the thermal efficiency of the PVT system, and thermal efficiency of dryer respectively by using MATLAB program 2015b. The dryer performance has been studied by observing the decrease of moisture rate, which was measured the dried banana weight every hour by the device (Type: Pocket Scale). The slices of banana have been distributed uniformly on two trays and each tray contains about 150g of banana slices.

I. Electrical model

The electrical model of the PV panel can be done by analyzing the equations based on a single diode of an equivalent circuit that presented in [13]. The designed parameters of the hybrid PVT solar system are illustrated in Table 1.

Table 1: Specifications of the designed PVT solar system.

Parameter	Value	Parameter	Value
V_{oc}	21.55 V	β_c	0.74
I_{sc}	5.33 A	τ_g	0.95
A_m	0.66 m ²	α_c	0.88
P_{mp}	84.3 W	t_g	0.0035 m
V_{mp}	16.99 V	α_p	0.8
I_{mp}	4.962 A	k_p	200 w/m.k
F. F.	0.734	k_g	0.8 w/m.k
L_f	1 m	t_f	0.0009 m
L_p	1.1 m	t_p	0.001 m
L_b	1.2 m	t_b	0.001 m
H_f	0.03 m	t_f	0.0009 m
W_b	0.54 m	No. of fins	20
W_p	0.54 m	No. of cells	32

The electrical efficiency can be calculated as:

$$\eta_E = \frac{P_E}{G_t A_m} = \frac{I V}{G_t A_m} \quad (1)$$

II. Thermal model

The main objective of analyzing the thermal model is to predict the mean temperature of the dryer room. Therefore, the energy balance of thermal model in each segment of the PVT solar system with dryer was done by imposing many assumptions, such as the quasi-steady-state case, the convective heat coefficients from thermal collector and backplate to fluid are equal, and the temperature in tray1 and tray2 in the dryer room are the same. The convection and radiation heat coefficients, top and bottom losses in the PVT solar system with a dryer chamber are illustrated in Figure 3.

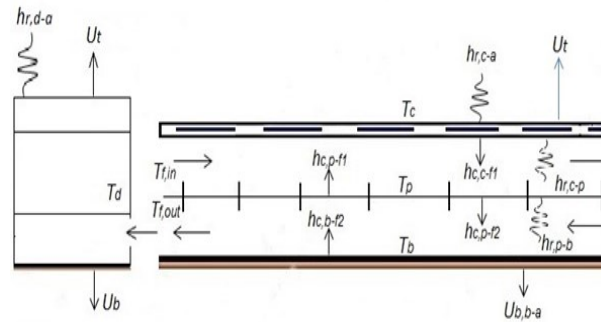


Figure 3: Convection and radiation heat transfer coefficient distribution

The representation of energy balance equations for each segment of the PVT system with dryer in watt unit is illustrated in the block diagram as shown in Figure 4.

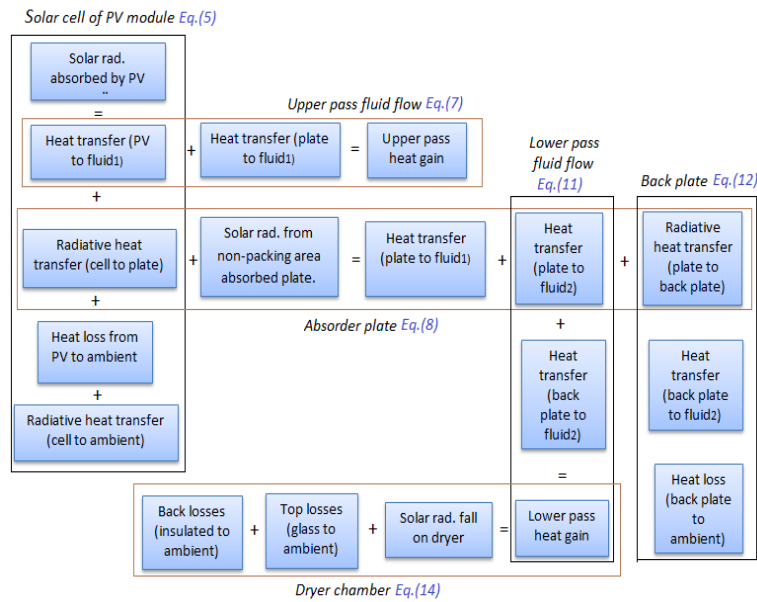


Figure 4: The block diagram of energy balance equations.

The energy balance equations of the double-pass technique are demonstrated as [14].

1- Solar cells of the PV module

$$G_t \alpha_c \tau_g = h_{r,c-p} (T_c - T_p) + U_{t,c-a} (T_c - T_a) + h_{r,c-sky} (T_c - T_{sky}) + h_{c,c-f1} (T_c - T_{f1}) + h_{r,c-a} (T_c - T_a) + G_t \beta_c \tau_g \eta_e \quad (2)$$

From Eq. (2), the cell temperature equation can be written as [14]:

$$T_c = \frac{G_t \tau_g (\alpha_c - \eta_e \beta_c) + (\frac{1}{h_w} + \frac{t_g}{k_g})^{-1} T_a + h_{r,c-sky} T_{sky} + h_{r,c-p} T_p + 0.5 h_{c,c-f1} (T_{f1} + T_{f2})}{(\frac{1}{h_w} + \frac{t_g}{k_g})^{-1} + h_{r,c-p} + h_{c,c-f1} + h_{r,c-sky}} \quad (3)$$

$$G_{eff1} = G_t \tau_g (\alpha_c - \eta_e \beta_c) \quad (4)$$

$$U_t = (\frac{1}{h_w} + \frac{t_g}{k_g})^{-1} \quad (5)$$

2- Fluid flow in the upper channel:

$$\dot{m}_a c_{pa} (T_{f2} - T_{f1}) = h_{c,p-f1} (T_p - T_{f1}) A_{pf} + h_{c,c-f1} (T_c - T_{f1}) \quad (6)$$

3- Absorber plate

$$G_t (1 - \beta_c) \alpha_p \tau_g^2 A_p + h_{r,c-p} (T_c - T_p) A_p = h_{c,p-f1} (T_p - T_{f1}) A_{pf} + h_{c,p-f2} (T_p - T_{f2}) A_{pf} + h_{r,p-b} (T_p - T_b) A_b \quad (7)$$

The plate temperature is expressed as:

$$T_p = \frac{G_t A_p + 0.5 A_t (h_{c,p-f1} (T_{f1} + T_{f2}) + h_{c,p-f2} (T_{f2} + T_{f3}))}{A_p (h_{r,p-b} + h_{r,c-p}) + 0.5 A_t (h_{c,p-f1} + h_{c,p-f2})} \quad (8)$$

Where:

$$A_t = A_p + A_f \quad (9)$$

4- Fluid flow in the lower channel

$$\dot{m}_a c_{pa} (T_{f3} - T_{f2}) = h_{c,p-f2} (T_p - T_{f2}) A_{pf} + h_{c,f2-b} (T_b - T_{f2}) A_b \quad (10)$$

5- Back plate:

$$h_{r,p-b} (T_p - T_b) = U_b (T_b - T_a) + h_{c,f2-b} (T_{f2} - T_b) \quad (11)$$

By arranging the equation Eq. (11), the backplate temperature is formulated as:

$$T_b = \frac{h_{r,p-b} T_p A_p + U_b T_a A_b + 0.5 h_{c,b-f2} A_b (T_{f2} + T_{f3})}{U_b A_b + h_{r,p-b} A_p + h_{c,b-f2} A_b} \quad (12)$$

$$U_b = \left(\frac{1}{h_w} + \frac{t_b}{k_b} \right)^{-1} \quad (13)$$

5- Dryer room

$$\dot{m}_a c_{pa} (T_{f3} - T_d) + \tau_g G_{dryer} = U_{td} A_g (T_d - T_a) + U_{bd} A_b (T_d - T_a) \quad (14)$$

The dryer temperature is presented as:

$$T_d = \frac{\dot{m}_a c_{pa} T_{f3} + G \tau_g A_g + U_t T_a A_g + U_{bd} T_a A_{bd}}{\dot{m}_a c_{pa} + U_t A_g + U_{bd} A_{bd}} \quad (15)$$

$$U_{bd} = \left(\frac{1}{h_w} + \frac{t_{bd}}{k_{bd}} \right)^{-1} \quad (16)$$

Where (G_E , G_W , G_N , G_T) are total solar radiations from east, west, north, and top of the dryer room respectively [16]. To calculate the moisture content of banana M_i (kg/kg) can be using the equations below [17]:

$$MR(\%) = \frac{M_i - M_f}{M_i} * 100\% \quad (17)$$

$$M_{dry,b} = \frac{w_{wet} - w_{dry}}{w_{dry}} \quad (18)$$

$$M_{wet,b} = \frac{w_{wet} - w_{dry}}{w_{wet}} \quad (19)$$

The initial mass content of banana (w_{wet}) and final mass content of dried banana (w_{dry}) were measured every hour by weighing the banana samples. The moisture rate of the banana is about 78% approximately. The rate of thermal heat gain, which carried away from the hybrid PVT solar system by the airflow in watt unit, thermal efficiency, the overall efficiency of the PVT solar system and dryer efficiency have been modeled as [14]:

$$Q_u = \dot{m}_a c_{pa} (T_{fo} - T_{fi}) \quad (20)$$

$$\eta_{th} = \frac{Q_u}{G_t A_m} = \frac{\dot{m}_a c_{pa}}{G_t A_m} (T_{fo} - T_{fi}) \quad (21)$$

$$\eta_{overall} = \eta_{th} + \frac{\eta_E}{0.36} = \frac{1}{G_t A_m} \left[\dot{m}_a c_{pa} (T_{fo} - T_{fi}) + \frac{IV}{0.36} \right] \quad (22)$$

The physical properties of air such as mean fluid temperature, density, viscosity, heat capacity, Prandtl number, and thermal conductivity, also, the coefficients of heat transfer under forced mode are shown in [18]. The root means square of percentage deviation (e) and linear coefficient of correlation (r) are analyzed to investigate from the agreement between the practical and theoretical results by depending on the equations of [19].

III. Computer Simulation

The heat transfer coefficients by convection and radiation were calculated, and the initial trials of temperatures and electrical efficiency are necessary to evaluate the energy balance equations. Besides, the properties of air are evaluated at mean air temperature. By analyzing the energy balance equations, the temperatures of each part of the PVT system with the dryer chamber have been resolved by reinforced MATLAB program. The input parameters to the program include the airflow rate, the dimensions of the PVT system with a dryer chamber, the solar radiation, wind velocity, ambient temperature, and inlet air temperature in each hour. Finally, it has been conducted the temperatures of the PVT system and dryer room, useful heat gain, the thermal efficiency of the PVT system, and dryer system.

4. Results and Discussion

The root means square of percentage deviation (e) and linear coefficient of correlation (r) are illustrated in Table 2 to investigate the agreement between the practical and theoretical results. Figure 5 shows the variation of solar intensity in each hour during the process of drying banana in August and the maximum solar radiation is 1160 at 1:00 PM. Figure 6 illustrates the comparisons between the temperatures in tray1 (upper tray) and tray2 (lower tray) experimentally, with the predicted readings of average dryer temperature at 0.017kg/s. The temperature in tray2 is higher than that in tray1 because the tray2 is exposed directly to the sun. The maximum temperature in tray1 and tray2 are 56.5°C and 57.5°C respectively at 1160W/m². Figure 7 displays the comparisons between the experimental and theoretical results of temperatures in tray1, tray2, and average dryer at 0.031kg/s. The greatest temperatures in tray1 and tray2 are 58.5°C and 60.3°C respectively at 1:00 PM and the ambient air ranges from 36 to 43°C.

Figure 8 shows the reduction in banana weight, which varies with time in the tray1. The reduction of weight occurs due to the decrease in the moisture content of bananas. The weight of banana decreases from 150 to 53 and 48g at 0.017 kg/s and 0.031kg/s respectively. It can notice that the airflow has a large effect on the moisture content, and it is obvious that the most decrease in weight obtains in the highest flow rate of air. When the mass flow rate of air increases from 0.017 to 0.031 kg/s, the weight reduction improved by 9.4%. Figure 9 demonstrates the hourly reduction in the weight of the banana in the tray2. The weight of banana drops from 150 to 55 and 50g at 0.017 and 0.031kg/s, respectively. It can observe that the reducing moisture in the lower tray is higher than in the upper tray because the hot air flow passes directly over banana slices. When the airflow rate increases from 0.017 to 0.031kg/s, the drop in weight improved by 9.09%. The loss in the moisture content of the crop in the tray1 at diverse flow rates is demonstrated in Figure 10. It can notice that the crop moisture drops from 78% to 34.90% at 0.017kg/s, while the highest reduction value is 28.12% at 0.031kg/s. The drying performance evidently becomes soundly established by 19.42% when increasing the airflow rate from 0.017kg/s to 0.031kg/s, respectively.

Figure 11 illustrates the hourly reduction of moisture rate in the tray2. The results elucidate that the drying rate increases with increasing the airflow rate. It is indicated that the moisture drops from 78% to 37.27% and to 31.00% at an airflow rate of 0.017 and 0.031 kg/s respectively. The drying process is enhanced by 16.82% when raising the airflow rate from 0.017kg/s to 0.031kg/s, respectively. The variation of useful heat gain of the PVT system time is illustrated in Figure 12. It is obvious that the useful heat gains directly rely on the airflow rate. The maximum useful heat gain is 423.7 W at 0.031 kg/s at 1:00 PM. Figure 13 demonstrates the change of thermal efficiency of the hybrid PVT solar system in each hour and indicates that the maximum thermal efficiency was 52.98.73% at 0.031 kg/s. The comparison between this work and approached work has been presented in Figure 14 to show the difference in performance results trend in the same conditions as much as possible. It can observe that the reduction of moisture content in the present work is more than previous work at the same airflow rate and drying time. This means that the performance of the dryer is improved and the drying period is reduced by utilizing the mixed-mode dryer system.

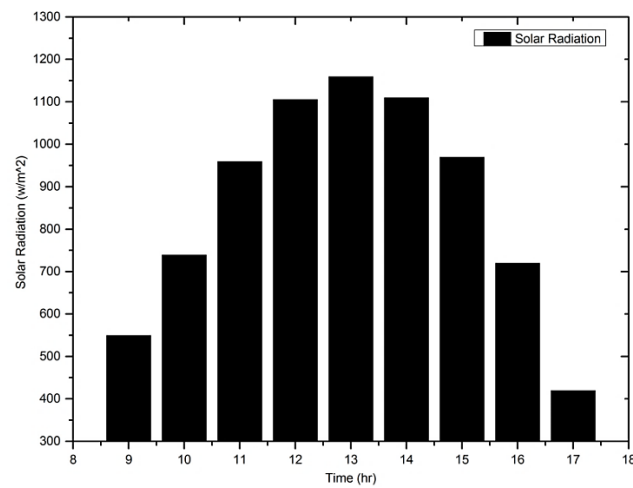


Figure 5: The hourly variation of solar radiation in August (04/08/2019).

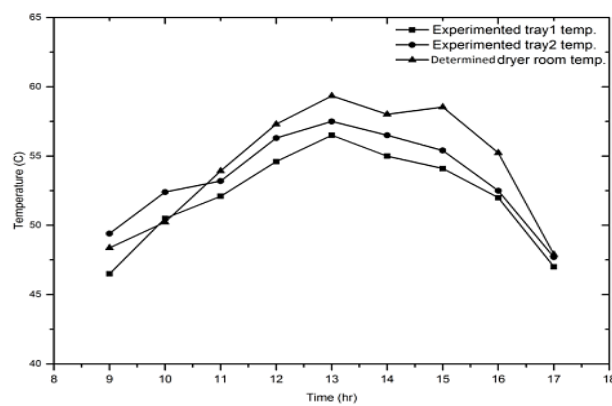


Figure 6: The experimented and predicted results at 0.017 kg/s.

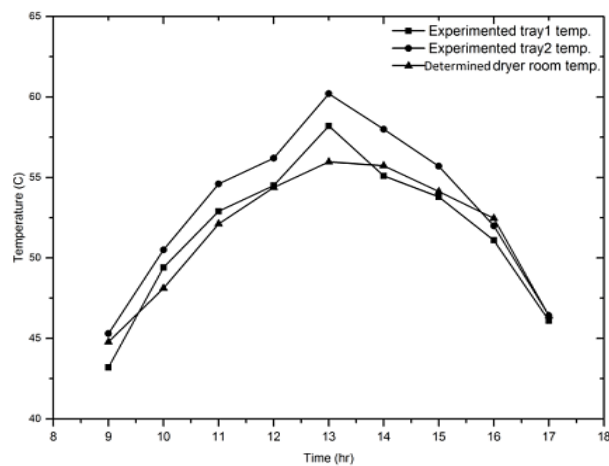


Figure 7: The experimented and predicted results at 0.031kg/s.

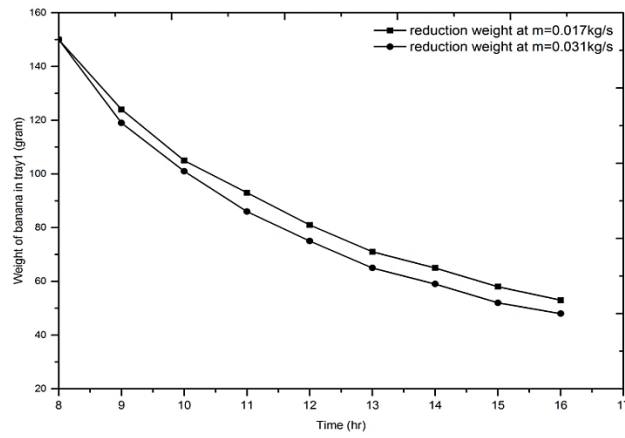


Figure 8: The reduction in weight of banana in tray1

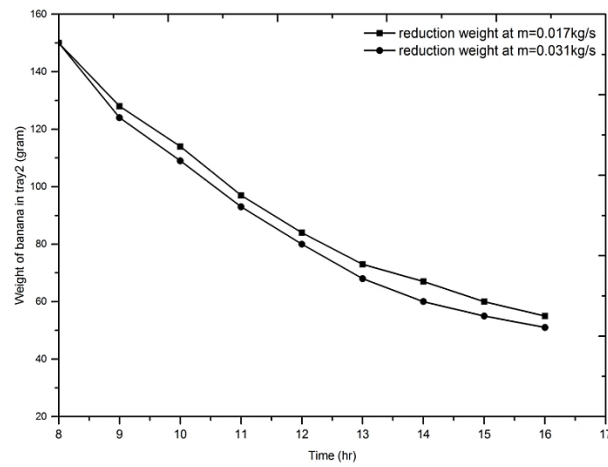


Figure 9: The reduction in weight of banana in tray2.

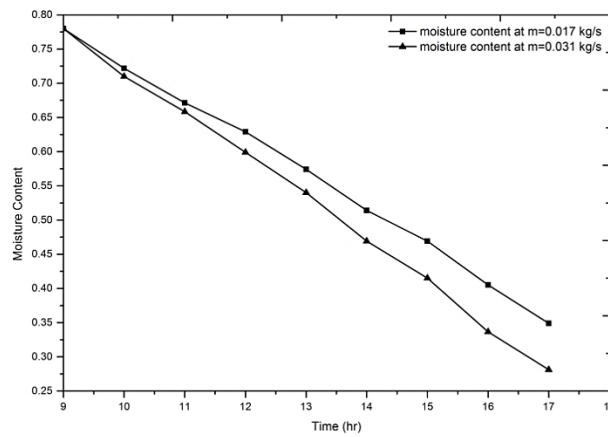


Figure 10: The reduction in the moisture content of banana in tray1.

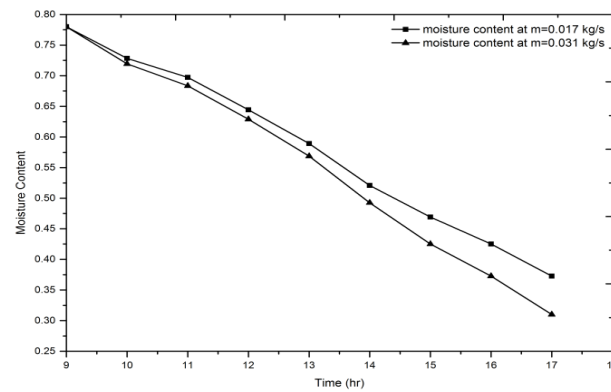


Figure 11: The reduction in the moisture content of banana in tray2.

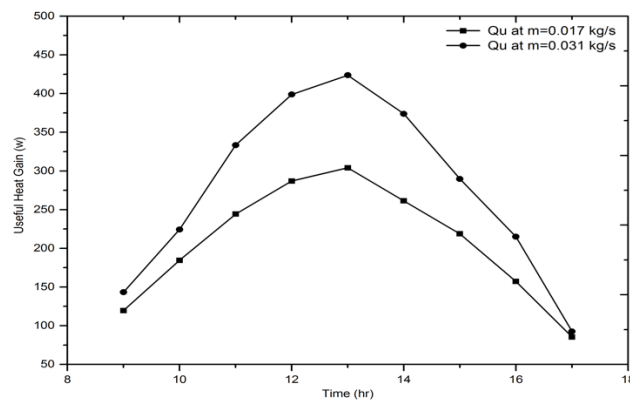


Figure 12: Useful heat gain of the PVT solar system.

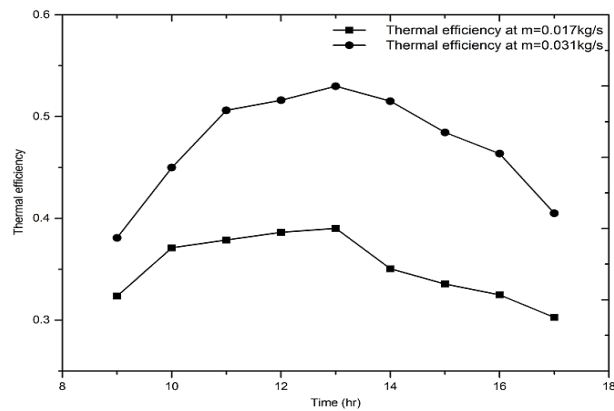


Figure 13: The thermal efficiency of the PVT solar system.

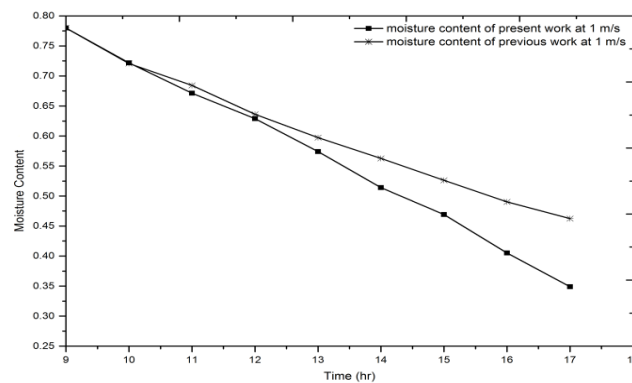


Figure 14: The comparison between present works and [11].

5. Conclusions

The hybrid PVT double-pass counter-flow system with the mixed-mode solar dryer system was designed and fabricated to dry crops under forced convection mode. The thermal model of the hybrid PVT solar system with a dryer room was analyzed. Besides, the predicting of theoretical results was carried out. The comparison between the predicted with experimented results has been checked out. The maximum and minimum drying rates were 31 gram/hour and 4gram/hour, respectively. The highest temperature of the dryer was obtained in the upper tray was about 60.2°C at 1:00 PM and the maximum heat gain and thermal efficiency were 423.7 W and 52.98%, respectively at 0.031 kg/s. The drying process was continued 8 hours without stopping. It was observed that the most reduction in weight and moisture content of banana slices was from 150 to 48g and from 78% to 28.12% in the lower tray at a higher mass flow rate of air.

Nomenclature:

A_m : PV module area (m^2)
 A_p : Absorber plate area (m^2)
 A_f : Fin area (m^2)
 A_b : Backplate area (m^2)
 A_{gd} : Area of dryer glasses (m^2)
 A_c : Cross-section of channel (m^2)
 c_{pa} : Specific heat of the air (kJ/kg.k)
 G_t : Total solar radiation (W/m^2)
 h_r : Radiative heat coefficient ($W/m^2.k$)
 h_c : Convective heat coefficient ($W/m^2.k$)
 h_w : Convective heat by wind ($W/m^2.k$)
 H_f : High of fin (m)
 k_a : Air thermal conductivity (W/m.k)
 k_b : Back thermal conductivity (W/m.k)
 k_p : Plate thermal conductivity (W/m.k)
 k_g : Glass thermal conductivity (W/m.k)
 L_p : Plate length (m)
 L_f : Fin length (m)
 t_p : Plate thickness (m)
 T_c : Cell temperature (°C)
 T_p : Absorber plate temperature (°C)
 T_b : Back plate temperature (°C)
 T_f : Fluid temperature (°C)
 T_d : Dryer chamber temperature (°C)
 T_a : Ambient temperature (°C)
 t_{bd} : Dryer insulated thickness (m)
 U_t : Top losses heat coefficient ($W/m^2.k$)
 U_b : Back losses heat coefficient ($W/m^2.k$)
 W_p : Plate width (m)
 W_b : Backplate width (m)
 μ_a : Viscosity of air
 ρ_a : Density of air
 β_c : Packing factor

References

- [1] S. Pushpendra, V. Shrivastava, and A. Kumar, "Recent developments in greenhouse solar drying: a review," *Renewable and Sustainable Energy Reviews* 82: 3250-3262, 2018.
- [2] V. Saini, S. Tiwari, V. Gain, and G. Tiwari "Performance evaluation of different types PV materials for PVTAC with solar drying system," *Materials Today Proceedings*, 2019.
- [3] E. Mohamed, M.M. Azam, and A. O. Alghannam, "Energy analysis of hybrid solar tunnel dryer with PV system and solar collector for drying mint (*Mentha Viridis*)," *Journal of Cleaner Production* 181: 352-364, 2018.
- [4] T. Sumit, S. Agrawal, and G. N. Tiwari, "PVT air collector integrated greenhouse dryers," *Renewable and Sustainable Energy Reviews* 90: 142-159., 2018.
- [5] S.A. Hadi, and A. Arabhosseini, "Accelerating drying process of tomato slices in a PV-assisted solar dryer using a sun tracking system," *Renewable Energy* 123: 428-438, 2018.
- [6] M. Fterich, M.H. Chouikhi, H. Bentaher, and A. Maalej, "Experimental parametric study of a mixed-mode forced convection solar dryer equipped with a PV/T air collector," *Solar Energy* 171: 751-760, 2018.
- [7] E. Mohamed, M. M. Azam, and A.O. Alghannam, "Solar PV powered mixed-mode tunnel dryer for drying potato chips," *Renewable Energy* 116: 594-605, 2018.
- [8] L. Abhay, V.P. Chandramohan, and V. R. K. Raju, "Design, development and performance of indirect type solar dryer for banana drying," *Energy Procedia* 109: 409-416, 2017.
- [9] B. Ehsan, S. Ranjbar, and O. Boostanipour, "Experimental investigation of the performance of a mixed-mode solar dryer with thermal energy storage," *Renewable Energy* 112: 143-150, 2017.
- [10] H. Essalhi, T. Rachid, and B. M. Najib, "Conception of a solar air collector for an indirect solar dryer, pear drying test," *Energy Procedia*, 141: 29-33, 2017.
- [11] V.N. Hegde, V.S. Hosur, S.K. Rathod, and P.A. Harsoon, "Design, fabrication and performance evaluation of solar dryer for banana," *Energy, Sustainability and Society* 5.1: 23, 2015.
- [12] https://www.mapsofworld.com/lat_long/iraq-lat-long.html
- [13] B. Sangram, and R. P. Saini, "A mathematical modeling framework to evaluate the performance of single diode and double diode based SPV systems," *Energy Reports* 2: 171-187, 2016.
- [14] R. R. Kant, and R. P. Saini "A review on different techniques used for performance enhancement of double pass solar air heaters," *Renewable and Sustainable Energy Reviews* 56: 941-952, 2016.
- [15] W. Chang, Y. Wang, M. Li, X. Lou, Y. Runa, Y. Hong, and S. Zhang, "The theoretical and experimental research on thermal performance of solar air collector with finned absorber," *Energy Procedia* 70 : 13-22, 2015.
- [16] T. Sumit, and G. N. Tiwari, "Thermal analysis of photovoltaic-thermal (PVT) single slope roof integrated greenhouse solar dryer," *Solar Energy* 138: 128-136, 2016.
- [17] E. Mohamed, M. M. Azam, and A. O. Alghannam, "Solar PV powered mixed-mode tunnel dryer for drying potato chips," *Renewable Energy* 116: 594-605, 2018.
- [18] A. Fudholi, K. Sopian, M.Y. Othman, M.H. Ruslan, and B. Bakhtyar, "Energy analysis and improvement potential of finned double-pass solar collector," *Energy Conversion and Management* 75: 234-240, 2013.
- [19] A. Karima, and H. M. T. Al-Najjar, "Analysis of thermal and electrical performance of a hybrid (PV/T) air based solar collector for Iraq," *Applied Energy* 98: 384-395, 2012.