Iraqi Journal of Desert Studies
2020, 10 (2): 98-117

Original Article

Experimental Investigation of Double Pass Solar Air Collector for Using in Agricultural Applications

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ABSTRACT

In this research, an experimental study has been performed in order to enhance the thermal performance of a double-pass solar air collector by employing extended surfaces. In order to increase the heat transfer area, triangular-shaped fins were mounted on the longitudinal direction of the absorber plate. Four models of the solar air collectors were made of aluminum with different fin configurations. The experiments were carried out at the winter season in the climate of Iraq - Ramadi city with longitude 43.268 and latitude (33.43). The used range of mass flow rate in the experiments was from 0.027 kg/s to 0.037 kg/s. The comparison with previous studies in terms of thermal efficiency showed good agreement where the percentage of error does not exceed 1% between them. The results also provided that the existing of fins was a good technique for enhancing the thermal performance of double-pass solar air collector with a marginal increase in pressure drop. Consequently, it is possible to adopt this kind of solar air collectors for many agricultural applications such as solar dryer.

Keywords: solar air collectors, double-pass solar collectors, agricultural applications, extended surfaces.

دراسة تجريبية لمجمع الهواء الشمسي ذو مسار مزدوج لاستخدامه في التطبيقات الزراعية

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المستخلص

تم إجراء دراسة تجريبية من أجل تحسين الأداء الحراري لمجمع الهواء الشمسي مزدوج االمسار باستخدام أسطح ممتدة من أجل زيادة مساحة نقل الحرارة . تم تركيب زعانف مثلثة الشكل على الاتجاه الطولي للوح الماص . تم تصنيع أربعة نماذج من مجمعات الهواء الشمسية من الألومنيوم بترتيب الزعانف باوضاع مختلفة . أجريت التجارب في فصل الشتاء بمناخ العراق - مدينة الرمادي بخط طول 43.268 وخط عرض 33.43. كان المدى المستخدم لمعدل التدفق الكتلي في التجارب من 0.027 كغم/ثانية إلى 0.037 كغم/ثانية. أظهرت المقارنة مع الدراسات السابقة من حيث الكفاءة الحرارية توافقا جيدا حيث لا تزيد نسبة الخطأ بينهما عن 1٪. كما بينت النتائج على أن الزعانف الموجودة كانت تقنية جيدة لتحسين الأداء الحراري لمجمع الهواء الشمسي مزدوج المسار مع زيادة هامشية في انخفاض الضغط وبالتالي ، من الممكن اعتماد هذا النوع من مجمعات الهواء الشمسية للعديد من التطبيقات الزراعية مثل المجفف الشمسي.

الكلمات المفتاحية: مجمعات الهواء الشمسية، المجمعات الشمسية مزدوجة المسار، التطبيقات الزراعية، السطوح الممتدة.

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https://doi.org/10.36531/ijds/20100207
Received 16 September 2020; Accepted 10 October 2020

INTRODUCTION

Energy is an important source of economic development in the fields of agriculture and industry and many other fields. The increasing use of conventional energy led to increasing pollution and its effects on the environment. The increasing cost of the conventional fossil fuels all these reasons led the researchers to search for alternative resources of energy. Worldwide efforts are underway to develop renewable energy systems to reduce the environmental impact of fossil fuel use (Khalil, 2007; Salih *et al*., 2019). Solar air heater (SAH) represent one of the important applications that can be utilized for domestic purposes and other purposes. Solar energy collectors are a special type of heat exchanger that employs solar radiation and converts the energy absorbed by the absorber plate to the working fluid. The principal components of solar collectors are absorber plate, one or many channels for the airflow, insulation for the lateral sides and bottom of the solar air collector and one or many transparent covers. The solar air heater is used in many applications such as space heating, air conditioning, drying of agricultural products, water heating, and industrial process heating (Gizem, 2012). The heating system based on solar applications have vast majority both in domestic and agricultural sectors. So, great attention is going on to improve the performance of solar air heaters by using multiple-pass solar air heater number. In addition to using such air heater its necessary to enhance the heat transfer rate using extended surfaces. These augmentation techniques have a great effect on increasing heat transfer area and prompt a-local turbulence which led to a good mixing of air currents. The huge production of agricultural products needs a cheap preservation way. The oldest way and the most friendly of environment way is the using of indirect solar irradiation for drying purposes. The researchers pay a great attention to modify the solar heater collectors for use in reducing the moisture contents of the agricultural products (Kareem *et al*., 2014).

Due to the great importance of the drying process of agricultural products many researchers try to check the different techniques used in this field that improve the performance of such systems. (Azharul and Mohammad, 2004**)** conducted an experimental investigation to study different types of absorber plates namely (flat plate ,finned and corrugated plate) and examine their effect on the performance of the drying process. The results of this investigation showed that the v-corrugated absorber plate present the most efficient performance. Also the results showed that the double pass collector is better than that of single pass solar collector.

There are different ways used to improve the performance of double pass solar air heater collectors (DPSAC) and as a result improve the drying process. The researchers (Ruslan *et al.*,2010; Fudholi *et al.*,2011; Ramadan *et al.*,2011; Velmurugan and Kalaivanan, 2016; Sharma and Saha., 2017; Abdullah *et al.*, 2017; Sharma and Saha., 2017) achieved their studies, depending on the using of increasing heat transfer area and promotion local turbulence to increasing the heat transfer coefficients and as a result enhances the thermal performance. These techniques namely, (ribs, fins, corrugated plates, tabulators and roughened surfaces). All these techniques proved to be good for the improvement of the thermal performance.

Some researchers (Ozgen *et al.*, 2009; Hitesh *et al.*, 2011; Adil *et al.*, 2015) took advantage of the disposal of waste metal cans and used them as a means of creating disturbance of the flow inside the solar heaters. The turbulence in the flow in addition to the high thermal conductivity of these cans led to an improvement in the thermal performance of the solar collectors. Another way studied by researchers (Ramani *et al.*, 2010; Nowzari *et al.*, 2011; Ajay and Sharma, 2012; Ho *et al.*, 2014; Abdel, 2019) depending on introducing the porous media inside the channels of the double pass solar air heater collectors. These techniques showed the porous media enhances the performance of such collectors to a great extent with a higher pressure drop. The researcher (Hussein *et al.*, 2019) presented a review investigation to the most works in enhancement the efficiencies of solar air heater driers. The conclusions were shown that the multiple pass solar air heater was the best technique in solar harvesting. (Sudhakar and Cheralathan, 2019) performed an experimental study of the performance of double pass solar air heater collector. The absorber plate was of shape V-groove and equipped with pin-fin **as** enhancement additives for their performance**.** The results showed that the V-groove absorber plate with the existing of pin-fin on both sides of the absorber enhances the heat transfer area, and as a result improves the thermal efficiency and the drying process of the crops. Both an experimental and theoretical study was performed by (Nandan *et al.*, 2017).The study depends on the using of longitudinal fins at the bottom of the absorber for enhancing the thermal performance of the crop dryer. It is concluded from this study that the instantaneous efficiency and air outlet temperature increased both. Theoretical analysis has been made as well for the present set up. The difference between the theoretical and experimental values lies within 1.23-9.75%. (Budhi *et al.* ,2020) presented an extensive experimental study to examine the effect of (geometry and number) of extended surfaces on the thermal performance of the double pass solar air heater collector using in drying process. The result depicts that the increasing the length and the height of fins led to an increase of air outlet temperature by approximately 35 °C, also the thermal efficiency increased to a value of 51.5%.

Studying the previous literature shows that there have been many studies focusing on some specific aspects of the double pass solar air collectors (DPSAC), such as the effects of the number of passes, the shape of the fins and their effects on the performance. According to the best knowledge of the author of the open access literature, there are few comprehensive studies investigating the effects of the existence of both extended surfaces (fins) of different orientations. The aim of this work is a try to fill the gap in the knowledge related to DPSAC that used as a dryer of agricultural products especially in rural communities. The study will focus on the effect of existence extended surface (of triangles shapes) with different orientations. The main objectives of the study may be stated first, the transfer mechanism of solar radiation with double-pass solar air heater is experimentally evaluated. Second a comparison of the augmented absorber plate with the conventional one (without fins) will be made experimentally.

MATERIALS AND METHODS

Experimental Arrangements

Because of the development in the performance of solar collectors that work by using solar energy, many countries have begun to urge researchers to develop these systems to obtain the maximum benefit from them in providing heating without relying on traditional fuel. The solar collector system with fins fixed to the absorber surface at different configuration will be studied. Practical experiments will be conducted in the city of Ramadi, Anbar Governorate - Iraq, which is located at longitude 43.268 east, latitude 33.43 north and height above sea level 59.8 asl. Experiments will take place in winter months namely: February 2020 and early March 2020.The period of the experiment will extended from 09:00 am to17:00 pm. The collectors facing south with an angle of 45°.

Manufacturing of Experimental Set-up

These models are designed to indicate the thermal performance of the double pass solar air heater collectors and justify the optimal design of these systems. The following considerations were taken into account (Holman, 2010):

1. Choosing the plywood to construct the box of the collector for the following reasons:
   A. Minimize the weight of the system.
   B. Improve the insulation of the system.
   C. Easy in dealing with system in measuring requirement and moving.
   D. Minimize the edge losses.
2. Choosing the Aluminum as a material of the absorber plate, because it is lightweight with reasonable thermal conductivity.
3. Choosing 4mm thickness of perpex cover to decrease optical losses, thermal storage and to obtain high transmissivity.
4. Paint the absorber plate with Black Chrome of (α=0.95 and ε=0.1) to decrease optical losses and to obtain high transmissivity and low emissivity.

Four models were manufactured for the DPSAC with equal dimensions and with different absorber plate, plywood with a thickness (2cm) used to manufacture the bases and sides for collectors. Plywood was considered insulation to prevent heat leakage to surrounding, while the upper part of the collector was covered with transparent plastic (Perspex) to allow solar radiation to pass through it and to prevent heat leakage out of the collector. The commercial Perspex panel of 4 mm thickness. The Dimensions of DPSAC were: length 122 cm, width 60 cm and height 25 cm. The shape of the solar collector is rectangular of 100 cm length and 60 cm width and the end of the collector is a trapezoidal shape of length of 22cm with upper base and lower base of 60cm and14cm respectively. All parts of collector painted a black color to increase absorbitivity and reduce heat loss. The collector divided into two channel upper and lower by absorber plate. The channels formed are of the same height.These channels end of trapezoidal section to meet with a two pipes for input and output pipes.These pipes are of diameter of 48mm.

The solar collector was installed on the iron stand frame to allow move, rotate, and control the tilt angle. The air was provided to the system with the help of a blower fan. To get the best benefit from having the optimum performance from the solar system all of the time of the experiments. The tilt angle of the SAH is selected to be (45°). This angle of inclinations is chosen to get the optimum performance from the solar system all of the time of the experiments. All absorber plates used in this experiment were made from aluminum with a thickness of (1mm). The dimensions of the absorber plate were (85 cm x 56cm) and painted with black color to keep high absorbance. Absorber plate was placed at (12.5 cm) from collector base and lead to division inside the collector to upper and lower channel and made empty region with length (15cm) to force air to change its direction from the upper channel to lower channel and exit from the collector. It is thus considered a double pass solar air collector. Four models were designed and manufactured.

Figure (1): The different configurations of absorber (a: Flat Plate, b: With fins placed perpendicular on airflow , c: With fins placed inclined at an angle 45° , d: With double fins placed perpendicular on airflow)

depending on the shape of absorber plate. The Aluminum plate used forth absorber plate has a thermal conductivity of (K=217 w/m. k) at (Temperature=100 °C), absorptivity of (0.94) with transmissivity (0.09) (Holman, 2010).The first model is a flat plate and this model will be taken as a reference one. The second model is a flat plate contain six hollow longitudinal fins with length (55 cm). The fins are of triangular shape with a hydraulic diameter of (5 cm) and attached on the surface of the absorption plate. In the third model, the longitudinal triangular fins filled are placed symmetrically on a flat absorption plate at an angle of inclination (45°) with different lengths but the sum of fin length is equal length fins in second model and same hydraulic diameter. The last model, with six of the longitudinal triangular fins was placed upper the absorber plate and six under the absorber plate perpendicular with airflow. Figure (1) shows the different shape of configuration used in experiments. Figure (2) indicate the experimental set-up. Table (1), represent the designation letter that used for each type of absorber used in experiments.

Figure (2): Experimental Set-up with Measurement devices

Table 1. Types of absorber used in experiments.

Type A	Flat Plate
Type E	With fins placed perpendicular on airflow
Type F	With fins placed inclined at an angle 45°
Type G	With double fins placed perpendicular on airflow

Measurement Equipment's

The k-type thermocouple wire was used to measure temperature in the experimental procedure. The temperature range measure of this type is (<400 °C) with accuracy ± 2.5 °C. Good care was taken when fixing the thermocouple wires at the appropriate position on the absorber plates. Therefore, each thermocouple bead was placed in its proper groove and well insulated with a silicone rubber sealer. Twenty-five thermocouples were used in the experiment, and connected to the selector switch. These thermocouples were used to measure temperature of (inlet, outlet, and absorber plate). The measuring of air velocity is made by using Anemometer. The measurement of solar intensity is made by using a solar meter. This device model (SP-216) and has an absolute error of ±2%.

Energy analysis

The useful heat gain (Qu) is given by (Duffie and Beckman ,1991)

$$Q_u = \dot{m}\, C_P\, \Delta T \qquad (1)$$

where

$$\Delta T = (T_{out} - T_{in})$$

Cp = specific heat (J/kg. °C), which is calculated below (Ong, 1995):

$$C_p = 1.0057 + 0.000066(T_{ave} - 27) \qquad (2)$$

The air mass flow rate ($\dot{m}$) is given by (Holman, 2010):

$$\dot{m} = \rho\, A_C\, V \qquad (3)$$

Where

A_c = the across section area of the collector inlet pipe (m^2)

The thermal efficiency of the heater (η_{th}) is defined as the useful heat gain rate of the air across the heater to the solar energy incident on the heater surface which is given by (Khalil *et al.*,2019) :

$$\eta_{th} = \frac{Q_u}{I\, A_b} \qquad (4)$$

Where: A_b = the area of absorber plate (m^2).

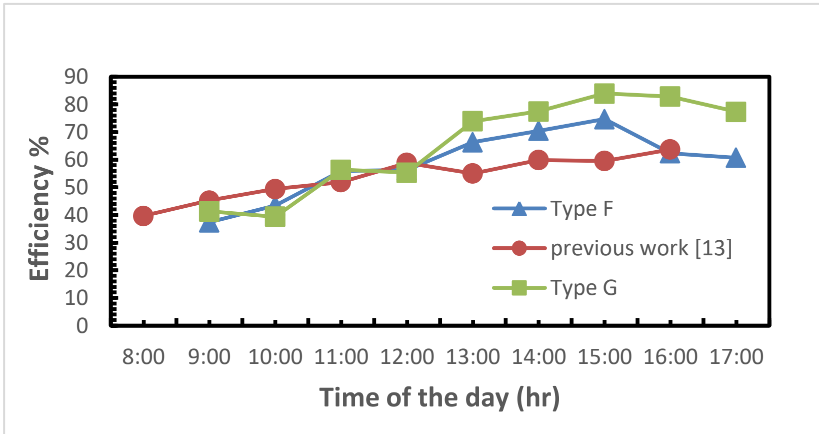
I = the total solar radiation incident on the heater (W/m^2).

RESULTS AND DISCUSSIONS

Experimental results are presented and discussed which; include the results of DPSAC of different absorber plates. The results of the current study were compared with that published in literature surrey. Also a comparison between the different types of collectors were achieved. The experiments were conducted for 11 days. Result were shown for only clear sky days. Several experiments were conducted to evaluate the thermal performance of solar heater collector with and without using thermal storage materials.

Figure (3) Shows the thermal efficiency comparison between the present DPSAC for both type F and G with previous work of (Nowzari *et al.*, 2011**)** at different two days for a mass flowrate of (0.037kg/s) .

(a)



(b)

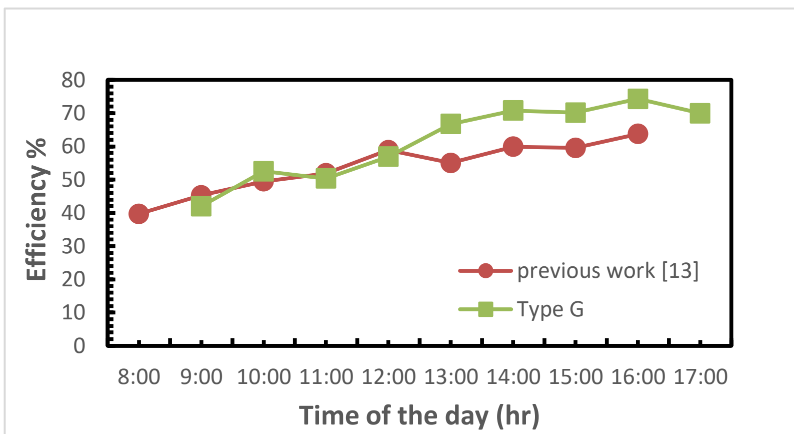


Figure. 3 Comparison thermal efficiency with previous works , (a) Type G, and F with (Nowzari *et al.*, 2011) at 3/2/2020, (b) Type G with (Nowzari *et al.*, 2011) at 8/3/2020 at mass flow 0.037 kg/s.

From these figures, it can be shown that the convergence with the previous work. until noon is acceptable and the difference is of 1%. After that time(i.e. noon time), the thermal efficiency of DPSAC, type F, and G in the present work is better than from previous work that using wire mesh as heat transfer enhancement technique to improve heat transfer between the absorber plate and air.

To study the behavior of the solar radiation with time .Figure (4) indicates solar radiation with time of three days as shown in figure. Clear days were chosen. It’s obvious from figure that the solar radiation intensity increase linearly from the starting reading to until it reaches peak values at noon or beyond little, then it starts to decrease until it faded at sunset. It was noted that the peak solar radiation was 1011.11 W/m^2 in 7/3/2020.Also the solar radiations for these three days approximately closed to each other's. The behavior of solar radiation during experiment times will strongly affect the thermal performance of the solar heater collector.

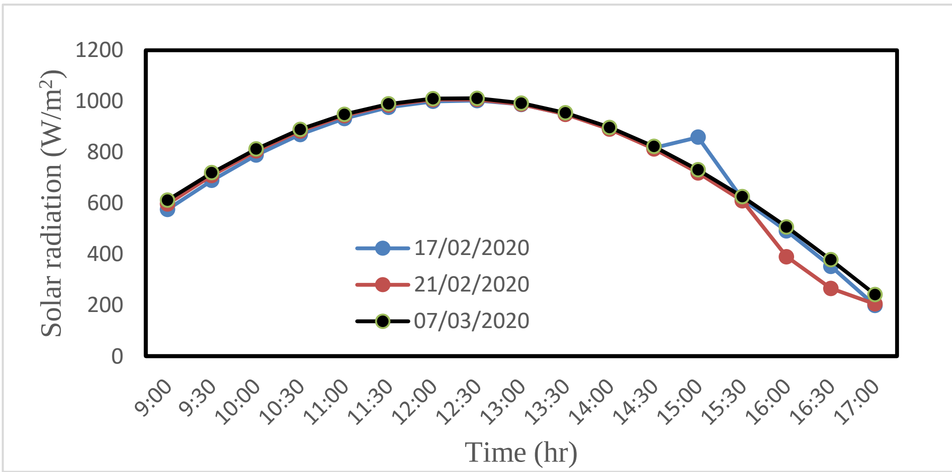


Figure 4. Hourly solar radiation, at 17/2/2020, 21/2/2020, 07/03/2020.

Figure (5) depicted the hourly temperature distribution for DPSAC for types A, E, F, and G respectively on a clear day on 17 February 2020. The experiment was achieved at mass flow rate of 0.034 kg/s.The temperatures were observed normal behaver of the inlet, outlet, and ambient. Which was recorded maximum temperature at midday and begun to decrease gradually. It's clear from this figure that there is a gradual increase in temperature from 09:00 a.m. to higher values at 01:30 p.m. After this higher value, it can be noticed a decrease in the temperature values until the outside temperature values (from the collector) close to that of incoming air at the end of the day. This behavior is normal due to the decrease in the value of incident energy due to the decrease in solar radiation after midday. The maximum outlet temperature from the collector has been obtained in this present work, at the day of 21/2/2020 which is (51.5 °C) in type (G), as shown in figure (6).

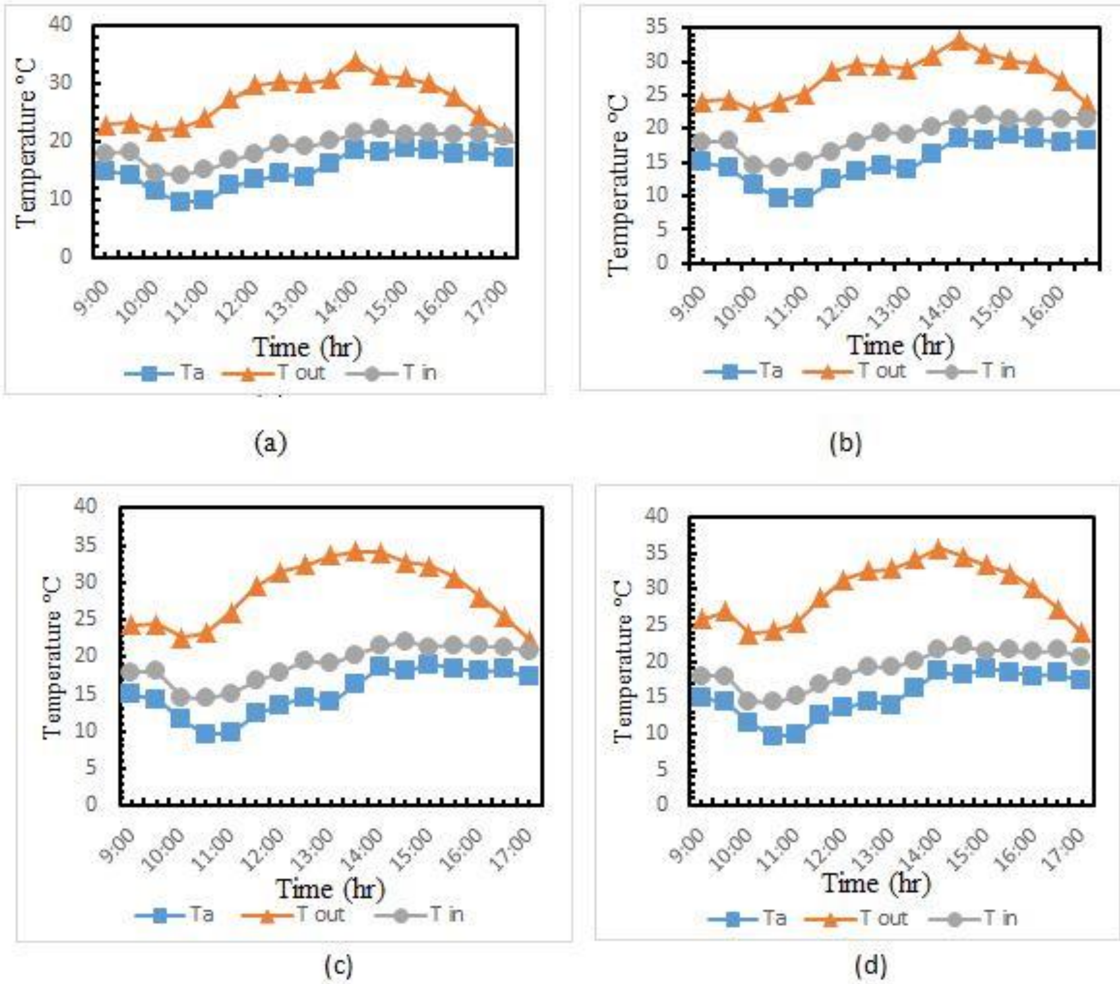


Figure (5) Hourly temperature variation of the ambient, inlet, and outlet for different types of collector versus time at 17/2/202020, (a) Type A , (b) Type E (c) Type F, (d) Type G at mass flow rate 0.034 kg/s.

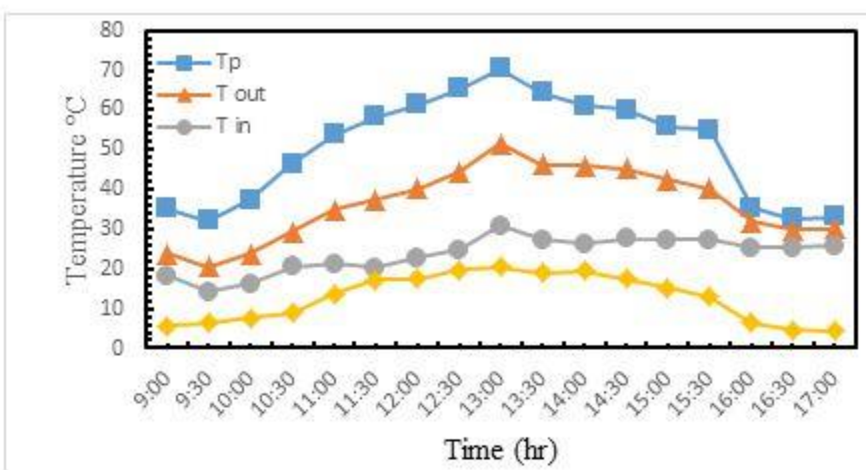
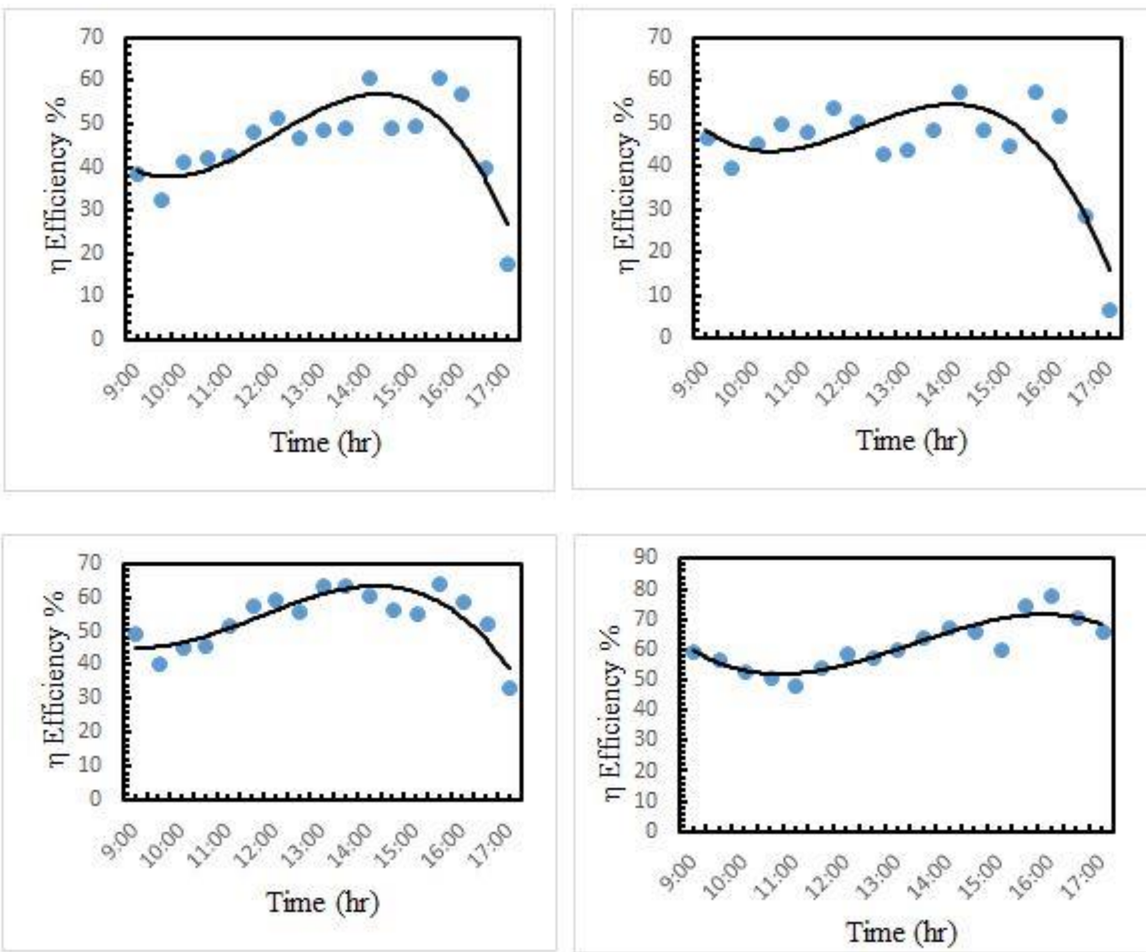


Figure 6. maximum outlet temperature from type (G) at mass flow 0.037 kg/s.

Figure (7) shown the thermal efficiency for DPSAC for types A, E, F, and G respectively on a clear day on 17 February 2020 from 09:00 a.m to 05:00 p.m. The experiment was performed at mass flow rate of 0.034 kg/s. From these figures it was noted the thermal efficiency was increased until midday and begin decreasing gradually. Figure (8) shows that the DPSAC type G gives the highest thermal efficiency from other types. Because type G gives the highest temperature difference and absorber plate contains double fins which are led to an increase in the area of absorber plate greater than other types. Type E and F give thermal efficiency highest from type A (flat plate).



(c) (d)

Figure (7) Thermal Efficiency versus Time at 17/2/202020. (a) Type A, (b) Type E, (c) Type F, (d) Type G at mass flow 0.034 kg/s.

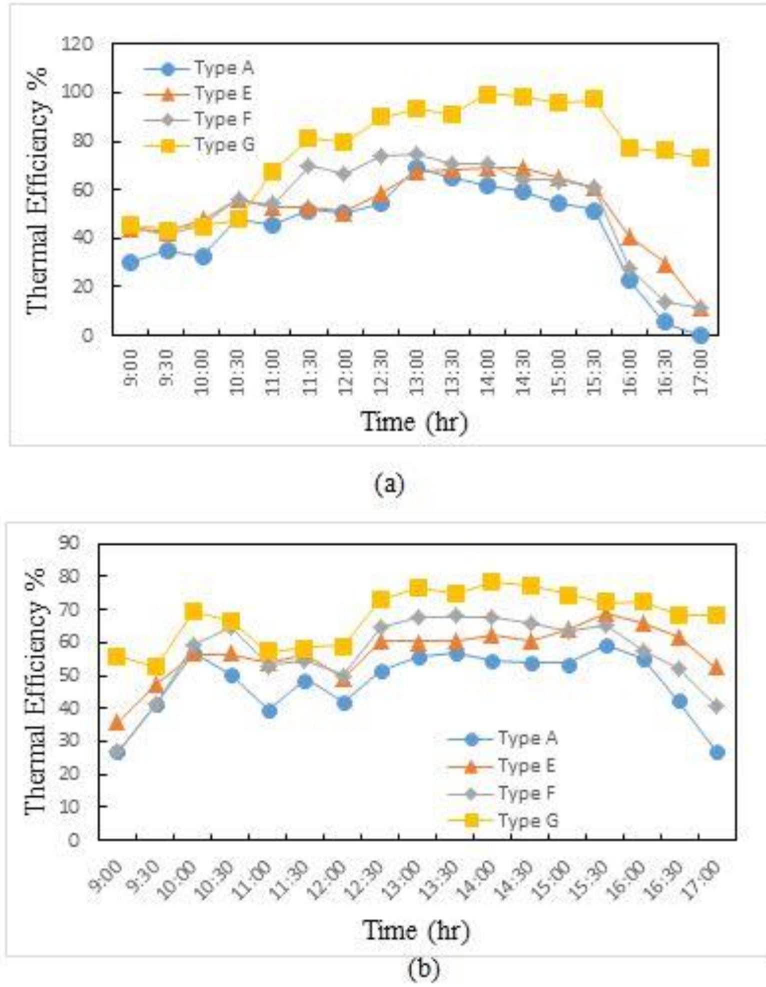


Figure 8. Comparison Thermal Efficiency between Different Types of DPSAC, (a) at 21/2/2020, (b) at 7/3/2020 at mass flow 0.037 kg/s.

Figure (9) depicted the thermal efficiency for DPSAC for all types on a clear day on 17 February 2020. The mass flowrate at this experiment was 0.034 kg/s. From these figures it was noted when the temperature difference between inlet and outlet increases, the thermal efficiency increased too, for all types of collector because of the increase in heat gain.

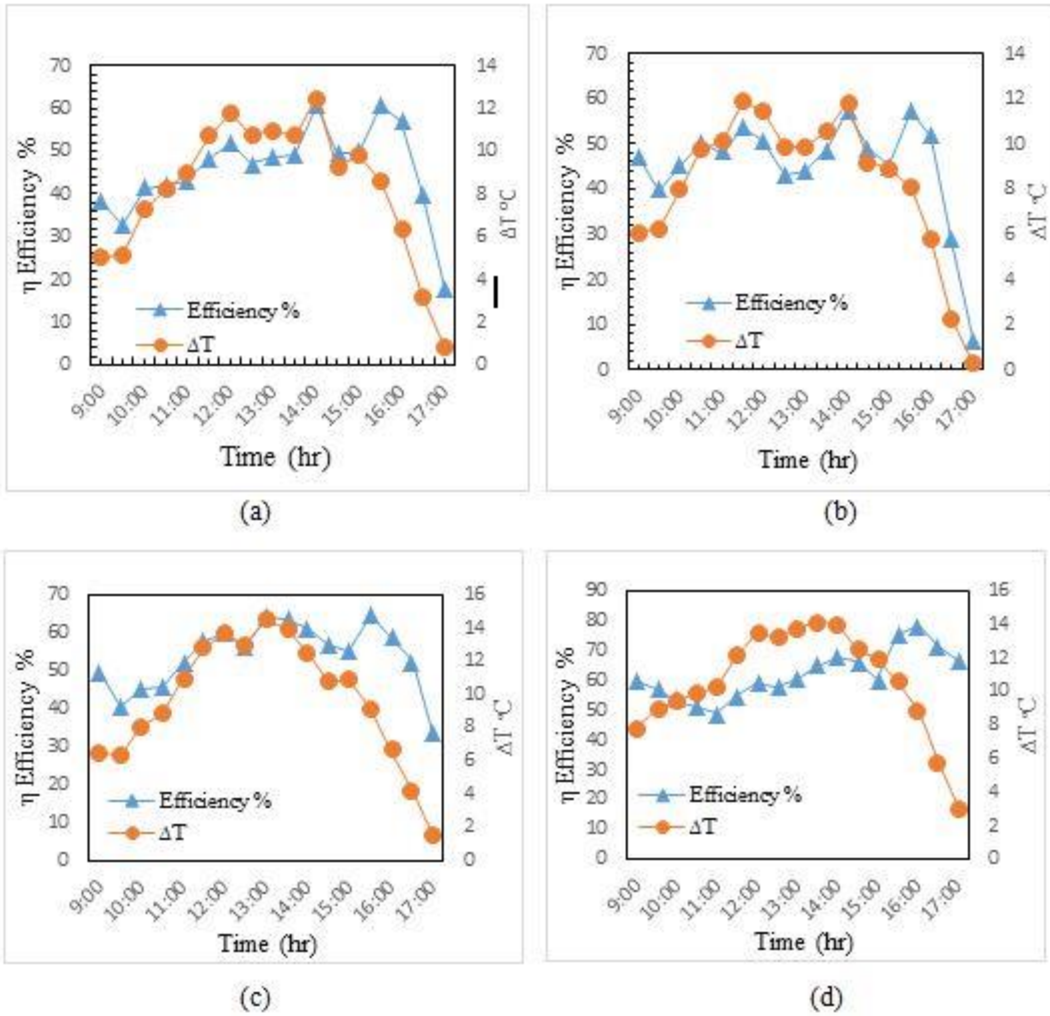
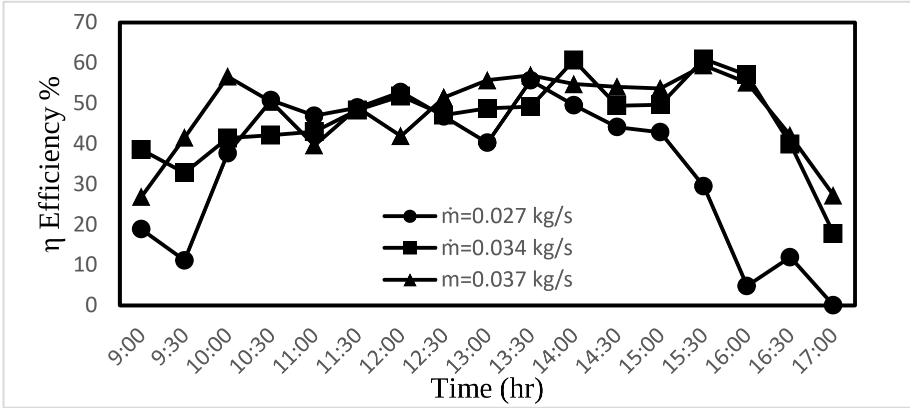


Figure 9. Thermal Efficiency and Temperature Difference versus Time for Different Types of DPSAC at 17/2/202020. (a) Type A, (b) Type E, (c) Type F, (d) Type G at mass flow rate 0.034 kg/s.

Figure (10) showed the effect of mass flow rate on the thermal efficiency with time for different types of DPSAC, at different mass flow rates .From these figures. It was noted thermal efficiency, increased with the mass flow rate increased because the thermal efficiency is proportional to the mass flow rate. This is because as the mass flowrate increase the velocity increases which prompt greater local turbulence which make a good mixing for the air currents.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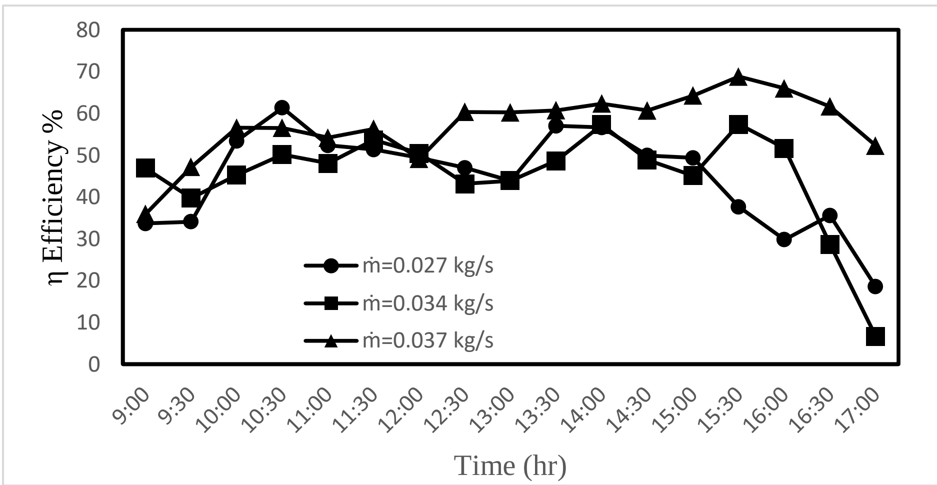
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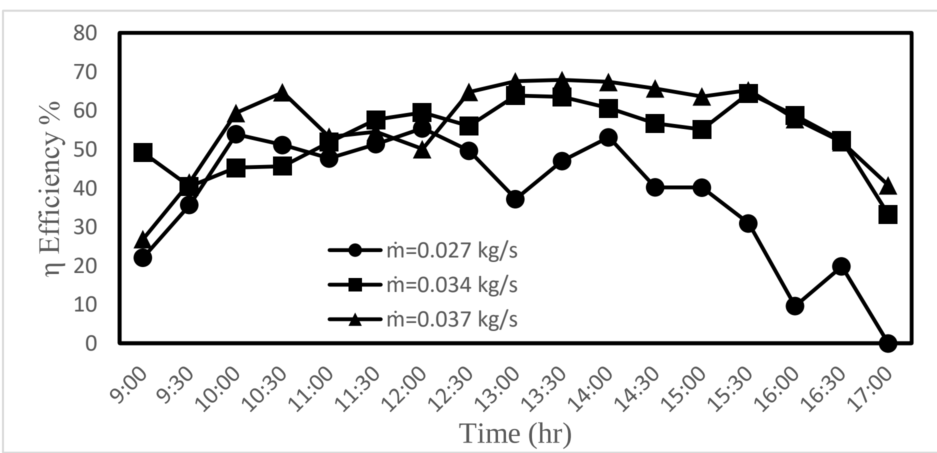
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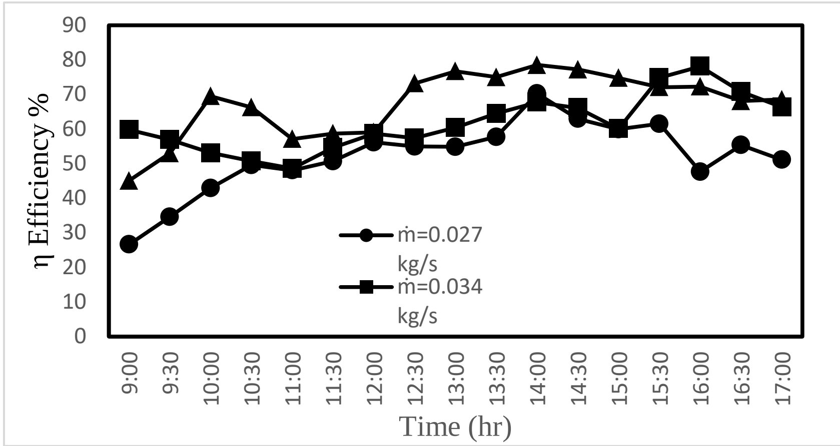
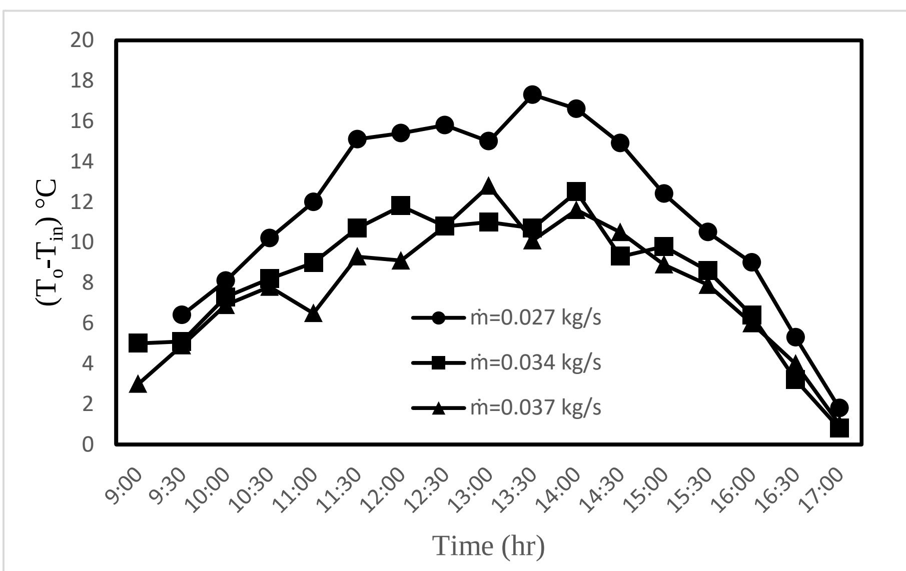


(d)

Figure 10. Effect of Mass Flow Rate on Thermal Efficiency, (a) Type A, (b) Type E, (c) Type F, (d) Type G (turbulent flow at Re= 4093 to 6052).

Figure (11) depicted the effect of mass flow rate on the temperatures different with time for different types of DPSAC, at different mass flow rate. From these figures. It was noted temperatures difference decreased with the mass flow rate increased. This behavior is normal which may be interpreted by the fact that the higher velocity the lower time for the air to be in contact with the absorber plate which leads to a lower exit temperature.



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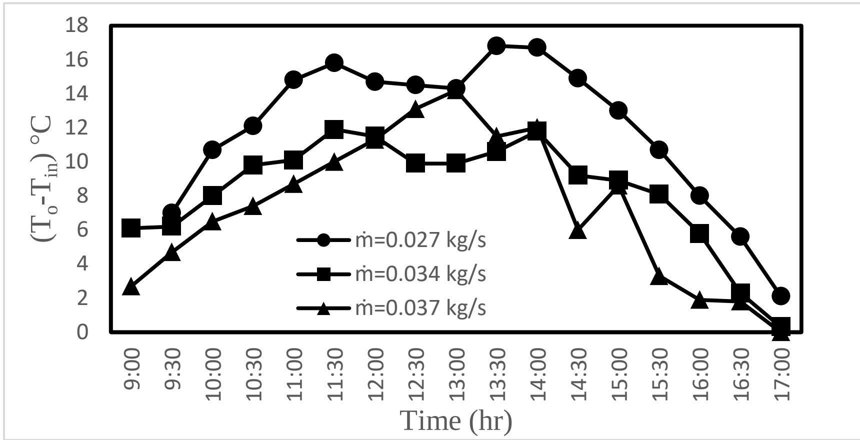

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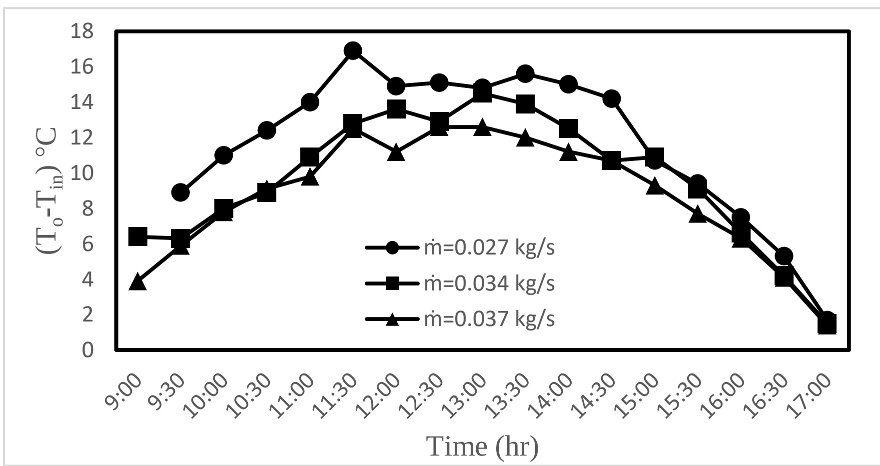

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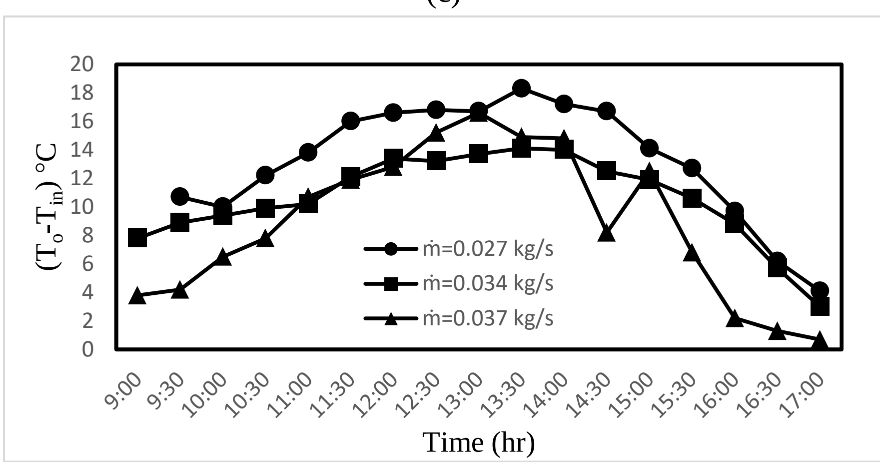
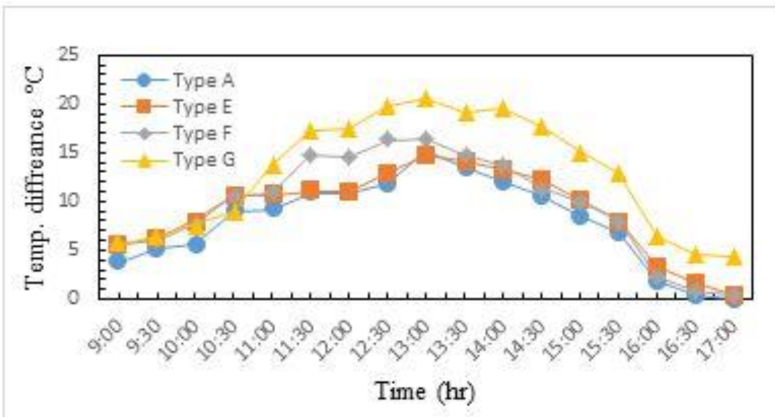


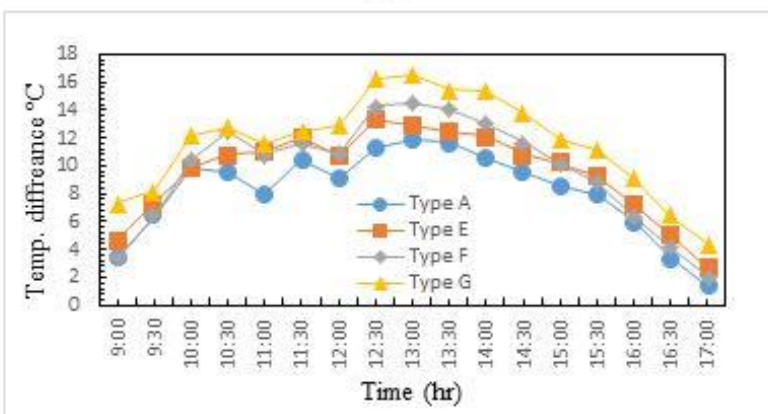
(d)

Figure 11. Effect of Mass Flow Rate on Temperatures Difference, (a) Type A, (b) Type E , (c) Type F, (d) Type G.

Figure (12) showed the temperature difference between types A, E, F, and G. on 21/2/2020 and 7/3/2020 respectively. From these figures. It has been observed that DPSAC of type G gives the highest temperature difference from other types during the day, due to the presence of longitudinal triangle fins above, and below the absorption plate. This leads to an increase in the area exposed to solar radiation, as well as, that the fins cause fracture of the boundary layer to the air, which increases the heat transfer process between the absorbent plate and the air passing over it. As for the type E, and F, it gave a difference of temperature lower than the type G, but higher than that of the flat plate types A also due to the presence of longitudinal triangular fins.



(a)



(b)

Figure 12. Comparison Temperature Difference between Deferent Types of DPSAC, (a) at 21/2/2020, (b) at 7/3/2020.

CONCLUSIONS

An experimental apparatus was designed and fabricated to study the effect of using different configuration of absorber plate on the performance of DPSAC. Many conclusions may be drawn from the results of this study. The main conclusion: highlight on the dual benefit of using fins. The use of fins increases the surface area of the absorbent plate, which in turn increases the amount of heat received by the absorber plate. Also, the presence of fins leads to a higher intensity of turbulence, which led to a good mixing of the cold and hot air. These two actions enhances the performance of the DPSAC. Also the results showed that the thermal efficiency depends entirely on the intensity of solar radiation and the mass air flow rate. As solar radiation and air mass flowrate increase efficiency will increase. The maximum temperature difference was being obtained 20.6 °C at collector type G. The improvement of the thermal performance of the double pass solar heater collector may be benefit for the using of such collectors as a drying process unit.

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