

Experimental Investigation of the Thermal Performance of a Solar Air Heater

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Abstract: Solar air heaters are widely used in many low temperature applications such as space heating, crops drying, desalination..etc. It collects solar radiant energy and transforms it into heat through a fluid (air) flowing inside the system. The outside cold air is heated through the system and delivered to the required application. It is simple, economic and clean. In this study, an experimental investigation is carried out using a test-rig installed at the laboratories facility for Center of Solar Energy Research and Studies (CSERS) in Tajoura-Libya equipped with all necessary measuring instruments and devices. The aim of this study is to investigate the effect of process air mass flow rate on the thermal performance of a solar air heater working at different operating conditions under the prevailing conditions of Tajoura-Libya. Experiments were conducted on specified days in August 2019, October 2019 and January, 2020.

Results show that there is a noticeable increase in the air temperatures of the solar air heater as incident solar radiation values increase during the day time, especially at afternoon. The maximum average outlet air temperature measured reaches 60 °C which is suitable for space heating and crops drying applications. Useful heat energy collected is directly proportional to the incident solar radiation. Increasing air mass flow rates leads to a corresponding decrease in the temperature at different locations in the solar air heater. Furthermore, the average thermal efficiency values of the solar air heater range from 35% to 65%. Average overall heat loss coefficient values tend to decrease with the day time. Finally, the present study results coincide with literature and show a good agreement.

التحقق عمليا من الأداء الحراري لسخان هواء شمسي

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ملخص: تستخدم سخانات الهواء الشمسية على نطاق واسع في العديد من التطبيقات ذات درجات الحرارة المنخفضة مثل التدفئة وتجفيف المحاصيل الزراعية والتجفيف وما إلى ذلك، فهي تجمع الطاقة الإشعاعية الشمسية وتحولها إلى حرارة من خلال تدفق مائع (هواء) داخل النظام. يتم تسخين الهواء البارد الخارجي من خلال النظام ودفعه إلى التطبيق المطلوب. وهي بسيطة واقتصادية ونظيفة. في هذه الدراسة، تم إجراء تحقيق تجريبي باستخدام جهاز اختبار تم تركيبه في معامل مركز أبحاث ودراسات الطاقة الشمسية في تاجوراء - ليبيا، مجهز بجميع أجهزة القياس والمعدات اللازمة. تهدف هذه الدراسة إلى دراسة تأثير العوامل التصميمية المختلفة على الأداء الحراري لسخان الهواء الشمسي تحت ظروف تشغيلية مختلفة وفي ظل الظروف المناخية السائدة في تاجوراء - ليبيا. أجريت التجارب في أيام محددة من شهر أغسطس 2019، أكتوبر 2019 و يناير 2020.

أظهرت النتائج أن هناك زيادة ملحوظة في درجات حرارة الهواء لسخان الهواء الشمسي مع زيادة قيم الإشعاع الشمسي أثناء النهار، خاصة في فترة ما بعد الظهر. بلغ الحد الأقصى لمتوسط درجة حرارة الهواء الخارج المقاسة من السخان الشمسي 60 درجة مئوية وهي مناسبة لتطبيقات التدفئة وتجفيف المحاصيل الزراعية. الطاقة الحرارية المفيدة المجمعة تتناسب تناسباً طردياً مع قيم الإشعاع الشمسي الساقط. تؤدي زيادة معدلات سريان كتلة الهواء إلى انخفاض مناظر في درجة الحرارة في أماكن مختلفة في سخان الهواء الشمسي. علاوة على ذلك، فإن متوسط قيم الكفاءة الحرارية لسخان الهواء الشمسي تتراوح بين 35% إلى 65%. تميل قيم متوسط معامل الفقد الحراري الإجمالي إلى الانخفاض في وقت النهار أخيراً، نتائج الدراسة الحالية تتوافق بشكل جيد مع الدراسات السابقة.

Keywords: Solar Air Heater, space heating, crops drying, thermal efficiency, heat transfer coefficient.

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1. INTRODUCTION

Solar energy is the origin of all forms of energy. The essence of energy to our society is growing to ensure the quality of life and to smoothly run the other elements of our economy. Several renewable energy technologies are in practice in the twenty first century, but many of these are still under development. In solar energy applications, the solar air heaters (SAHs) were commonly used as heat exchanger. Air heating is one of the major solar thermal applications, used for space heating and process heating like laundry, desalination, crop drying and other drying processes. Utilizing of conventional energy for this process will increase the process cost as well as pollute the environment. Using solar energy for air heating will reduce the operational cost of the system and the consumption of conventional energy [1].

The amount of solar energy reaching the surface of the planet is so vast that in one year, it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined [2]. This is a huge source of energy and many applications that use solar energy, which is an abundant, clean and safe source, have been investigated. Solar technologies can be classified into two groups; passive and active heating. Passive solar techniques include designing spaces according to natural circulation, locating buildings with reference to the sun or selecting high thermal conductive materials. On the other hand, active solar techniques include using solar panels, pumps or fans to convert solar energy into useful outputs [2]. Solar air collector is a type of system which collects solar energy and transforms it into heat. The general idea is that the air is flowing through solar collector and heat from sun naturally raises the temperature of the air. In other words, cold outside air is heated and delivered to the room. The collector has an outer layer of glazing/polycarbonate which is exposed to sun. Circulation of the air in the building can be initiated by natural driving forces (buoyancy effect) or forced by a fan which is more certain. Optionally the fan can be powered by a solar cell [3]. Preheating of air supplied to buildings has gained much interest during recent years. The advantage of this technology is that it is cheap and simple. It is especially efficient for

summer houses as it can work without anyone's attendance. It can help to get rid of mould and bad smells and increasing the temperature inside the building without any need for additional heating. In this way the indoor environment in such houses is maintained on a good level after winter [3].

Drying agricultural products is another application for the solar air collector. Drying is a method of dehydration of food products which means reducing the moisture content of the food to improve its shelf life by preventing bacterial growth. It is still used in domestic and small commercial size drying of crops, agricultural products and food such as fruits, vegetables, aromatic herbs, wood etc. contributing significantly to the economy of small agricultural communities and farms. Solar drying can help improving the quality of products [4].

S. Krishnananth and K. Murugavel fabricated a double pass solar air heater and integrated it with thermal storage system. Paraffin wax is used as a thermal storage medium. The performance of this heater was studied for different configurations. The solar heater integrated with thermal storage delivered comparatively high temperature. The efficiency of the air heater integrated with thermal storage was also higher than the air heater without thermal storage system. The study concluded that the presence of the thermal storage medium at the absorber plate is the best configuration [5].

L. S. Paraschiv et al investigated a solar air collector for space heating in order to develop more efficient and cost effective energy process. Various configurations of absorber and different air flows through the collector were tested. The influence of the air mass flow on the air outlet temperature and thermal efficiency has been studied. The thermal efficiency, fluid outlet temperature, heat increase and heat losses of the collector are calculated depending on the collector geometry, fluid properties, fluid inlet temperature, air flow rate, solar insulation and ambient temperature [6].

F. Bayrak and H. Oztop performed an experimental study to investigate the energy analysis of flat-plate solar air collectors (SACs) with porous obstacles at two different thicknesses and without obstacles (flat plate). As a porous material aluminum foams are used. They are placed sequentially and in a staggered manner onto the cover of the SACs. The measurements are performed at two different values of air mass flow rate as 0.016 kg/s and 0.025 kg/s and with thickness of 6 mm and 10 mm. Energy efficiencies of SACs are calculated based on first law of thermodynamics. In the experiments, five types of solar air collectors are tested and a comparison is made among them from the point of energy efficiency. The obtained results showed that the highest collector efficiency and air temperature rise are achieved by SACs at 6 mm thickness and 0.025 kg/s air mass flow rate [7].

T. Lam and L. Nhut presented the results of a solar air collector with internal crimped fins. It consists of a flat plate collectors with seven internal crimped fins and has the total collection surface area of 2m². The investigation results indicate that the introduction of internal crimped fins can strengthen the convective heat transfer process and lessen the radiation heat loss, which contributes to efficiency improvement. The result of the air mass flow rate should be controlled in a range of 0.025 - 0.027kg/s. The operating parameters such as the surrounding temperature, solar radiation intensity have significant influence on the temperature rise but have little influence on collector efficiency [8].

In the present study, it is aimed to focus on using solar energy to produce hot air for space heating and drying of crops. This will result in reducing cost, fossil fuel consumption and harmful environmental effects. The main objective of this experimental work is to study the effect of process air mass flow rate on the thermal performance of a solar air collector under different operating conditions and prevailing conditions at Tajoura, Libya. For this purpose, a single flow double pass flat plate solar air heater test rig is utilized.

2. EXPERIMENTAL WORK

2.1. Description of the test-rig

An experimental set-up was designed and constructed at different private mechanical workshops at Alkhums-Libya. It was assembled and started up at laboratories of Center for Solar Energy Research and Studies (CSERS) located at Tajoura-Libya as shown in Figure (1).

The main components of the experimental set-up are as follows;

- Double-pass flat plate solar air heater
- Variable Speed Air blower
- Measurements and data acquisition system

2.1.1. Double-pass flat plate solar air heater

The main dimensions of the solar air heater are (LxWxD) (1550 mm x 980 mm x 220 mm). It consists of one glass cover having a thickness of 4 mm. The galvanized steel absorber plate was placed at the middle of the solar air heater. It is black painted to increase the absorptivity of the plate. The insulation thickness is 50 mm and thermal conductivity of the insulation material is 0.04 W/m.k. The walls of the solar air heater were made of Aluminum of 4 mm thickness and constructed by welding and finally black painted and insulated. The galvanized steel absorber plate (1200 mm x 960 mm) with 2 mm thickness was placed horizontally on the central point of the container. The absorptivity and thermal conductivity of the absorber plate are, 95% and 350 W/m.k respectively. In order to minimize inlet and outlet friction losses, inlet and outlet channels have also been installed with an inlet length (500 mm) for inlet channel and a length (800 mm) for the outlet channel with a progressive cross-sectional area on the main container of the solar air heater as shown in Figure 1.

2.1.2. Variable Speed Air blower

A variable speed air blower (90W) is installed at the outlet of the solar collector. In order to control the air flow rate, blower speed controller is provided. A flexible circular air duct of 150 mm diameter was used to connect various components, see Figure (2). This blower is operated by the solar PV cell as shown in Figure 3.



Figure (1). General view of the test-rig.



Figure (2). Variable Speed Air blower.



Figure (3). Solar PV cell for operating Air blower.

2.1.3. Measurements and data acquisition system

The main function of the measurement system is to measure the following parameters;

- Site Prevailing weather conditions, include; (Ambient air temperature, wind speed, relative humidity and solar radiation).
- Air temperatures and air mass flow rate measurements.

2.1.3.1. Site prevailing weather conditions

Prevailing weather conditions; ambient air temperature, wind speed, relative humidity and global solar radiation, Tilted, were measured by the prevailing weather station, located near the laboratories of the Center for Solar Energy Research and Studies, CSERS, in Tajoura. Figure 4 shows a photo of the weather station on site.

2.1.3.2. Temperature measurements

Figure 5 shows the location of the different measurement and testing points in the entire system. The

measurement and testing parameters are described in the nomenclature. For the purpose of data recording, a data acquisition system was used. It consists of a digital data recorder; type (PC-Logger 3100), equipped with (24 measuring channels), fixed copper thermocouples (type T), and a computer program.



Figure (4). A photo of the site prevailing weather station at CSERS.

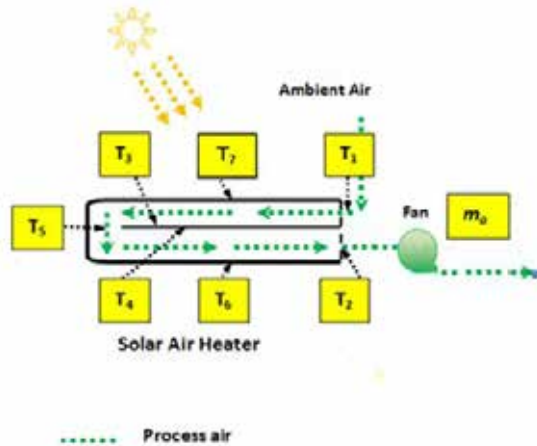


Figure (5). The location of the measuring and testing points on the system.

The accuracy of the readings is (± 0.1 °C). The data logging program was used to read the output of the data recorder in a specific time period, which was chosen to be ten minutes and stored in the personal computer hard drive. Figure 6 shows a photo of the data acquisition system.



Figure (6). The data acquisition system.

2.1.3.3. Mass flow rate measurements

Air mass flow rate measurements were performed by measuring the velocity of the outward air by an analog anemometer. Then, the measured air velocity is multiplied by the cross-sectional area of the air blower and air density. Figure 7 shows photo of the analog speedometer. It consists of an axial turbine and a representative circular scale. The axial turbine rotor is rotating by the forced air influence at the outlet process, which in turn exercises the circular scale indicator for rotation in cycles, each cycle reading (100 m/min) with accuracy of (± 0.1).



Figure (7). A photo of the analog anemometer.

2.2. Experimental Procedure

Experiments were conducted to investigate the effect of process mass flow rate on the thermal performance of solar air heater. Measured parameters include air temperature, air mass flow rate, air velocity, and other related parameters such as prevailing weather conditions. According to the experimental work plan, three experiments were proposed and conducted for different air mass flow rates at specified months of the year namely; August 2019, October 2019 and January 2020. Minimum, medium and maximum values of air flow rates were also specified; 0.03, 0.05 and 0.08 kg/s respectively.

Prior to experimentation, the whole setup connections, fittings...etc, were checked against leakage. All air passages in the solar air heater facility were also checked for any obstacles that may affect its working conditions. In addition, special attention should be taken into account for electric wiring, connections, grounding, and all safety measures to avoid undesirable electricity source accidents. The experiments were started by switching on the power to the air blower at the adjusted air flow rate value. Data acquisition system was also put in operation and configured to start data recording process. Air temperatures at different locations on the solar air heater were measured every 10 minutes interval by data logger, starting from 9.00 O'Clock AM until 17.00 O'Clock PM under the prevailing conditions of Tajoura-Libya. Site weather data were also recorded automatically by the weather station facility. In order to record the experimental data, a recording sheet was designed and used. Finally, the recorded data were analyzed, interpreted and graphically represented.

3. RESULTS AND DISCUSSION

3.1. Site Weather Conditions

The measured weather data for specified days in August-2019, October-2019, and January-2020 at Tajoura-Libya, are considered for this study. These data are measured and recorded every ten minutes by the site's weather station installed on site. Figure 8 illustrates the measured weather data for global solar radiation, Tilted, ambient air temperature, relative humidity and wind speed respectively.

3.2. The effect of process air mass flow rate

In this section, the effect of the process air mass flow rate on the thermal performance of the system is discussed. Experiments were carried out for the period from (9:00 AM) to (17:00 PM) at (4, 5 and 6 August-2019), (14, 15 and 16 October- 2019) and (28, 29 and 30 January- 2020). Different air mass flow rates were tried, namely; [$m_a = 0.03$ kg/s, $m_a = 0.05$ kg/s and $m_a = 0.08$ kg/s].

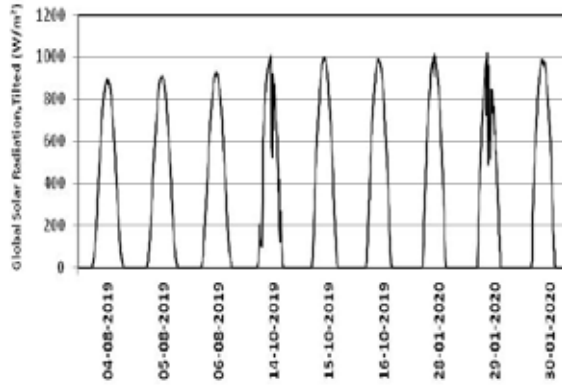


Figure 8-a. Measured meteorological data for Tajoura-Libya; global Solar Radiation, Tilted.

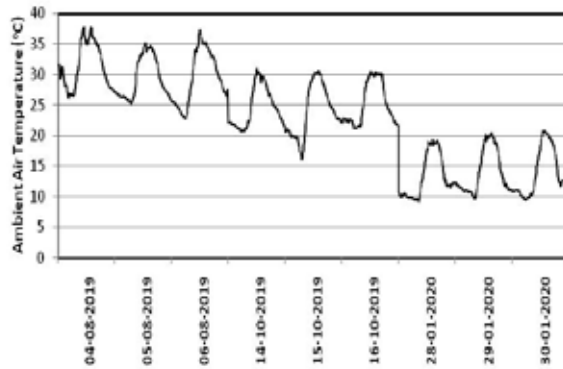


Figure 8-b. Measured meteorological data for Tajoura-Libya; Ambient Air Temperature.

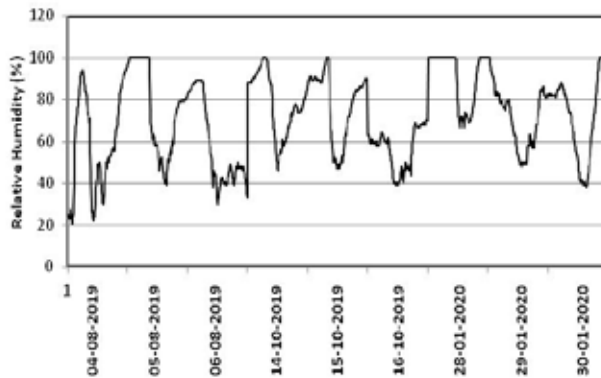


Figure 8-c. Measured meteorological data for Tajoura-Libya; Relative Humidity.

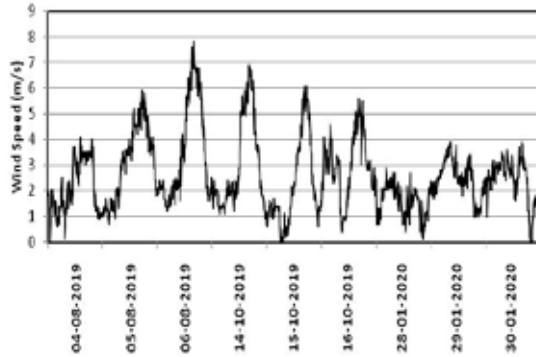


Figure 8-d. Measured meteorological data for Tajoura-Libya; Wind Speed.

Figure 9 shows the variation of temperature with time at different measurement points in the solar air collector for different air mass flow rates for August-2019. In general, it can be observed that as the intensity of solar radiation during the day time increases, temperatures at various measurement locations in the system increase to their maximum values, especially in the period, between 12:00 PM to 15:00 PM. The maximum recorded temperature reaches 90 °C corresponding to air mass flow rate of ($m_a=0.03$ kg/s), at the bottom surface of the absorption plate. While, the maximum measured air outlet temperature approaches 63 °C at 12:00 PM for the same air mass flow rate. In contrary, the temperature at different locations in the collector are decreasing as air mass flow rate increases.

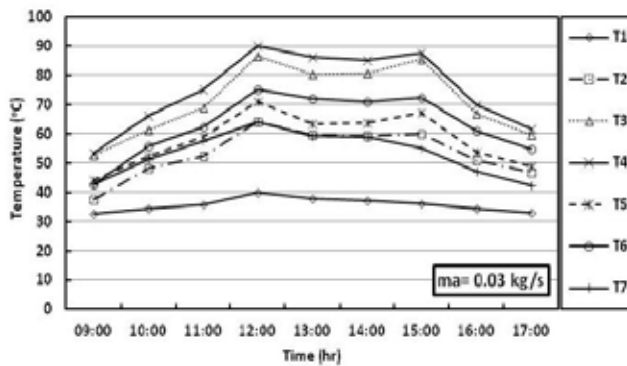


Figure 9-a. Variation of temperature with time at different measurement points, [$m_a = 0.03$ kg/s, August 6, 2019].

Figure 10 shows the variation of temperature with time at different measurement points in the solar air collector for different air mass flow rates for October-2019. As expected, when solar radiation values increase during the middle of day time, a corresponding increase in the air temperatures at various measurement locations in the system was remarked. The maximum temperature recorded is 100 °C corresponding to air mass flow rate of ($m_a=0.03$ kg/s), at the bottom surface of the absorption plate. While, the maximum measured air outlet temperature approaches 60 °C at 12:00 PM for the same air mass flow rate. However, system temperatures decrease as air mass flow rate increases.

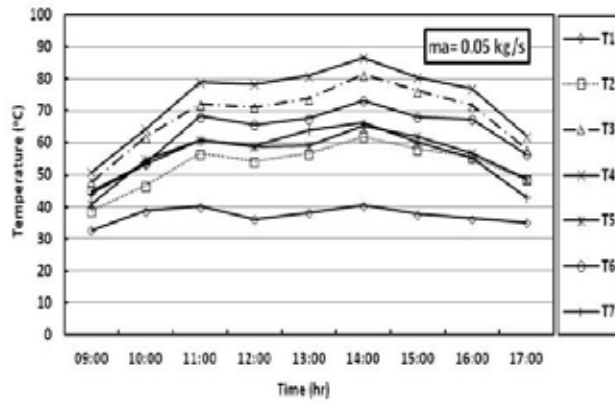


Figure 9-b. Variation of temperature with time at different measurement points, [$m_a = 0.05 \text{ kg/s}$, August 4, 2019]

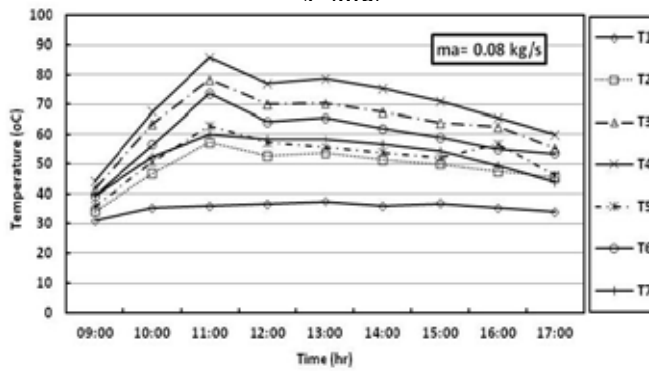


Figure 9-c. Variation of temperature with time at different measurement points, [$m_a = 0.08 \text{ kg/s}$, August 5, 2019].

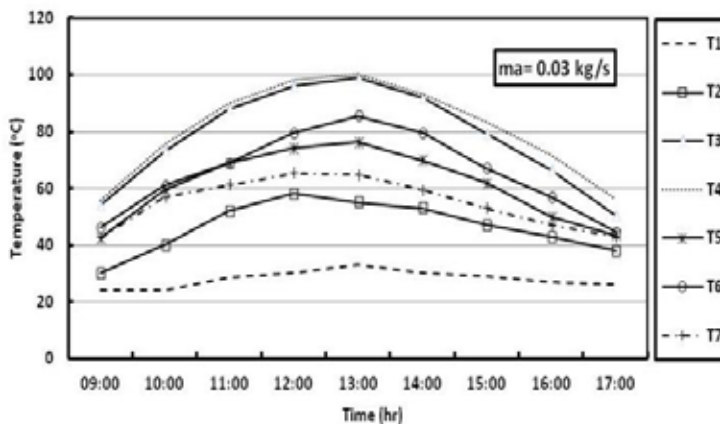


Figure (10-a). Variation of temperature with time at different measurement points, [$m_a = 0.03 \text{ kg/s}$, October 16, 2019].

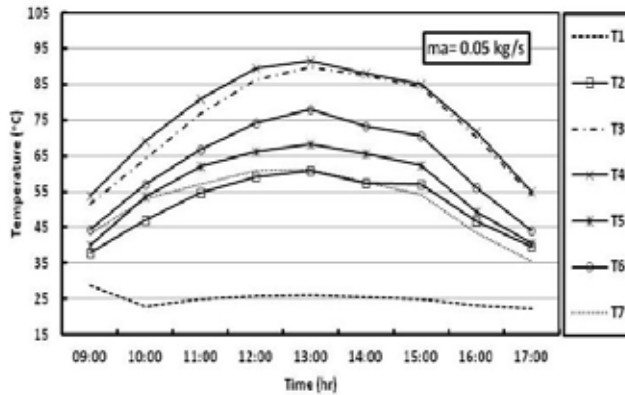


Figure (10-b). Variation of temperature with time at different measurement points, [$m_a = 0.05$ kg/s, October 15, 2019].

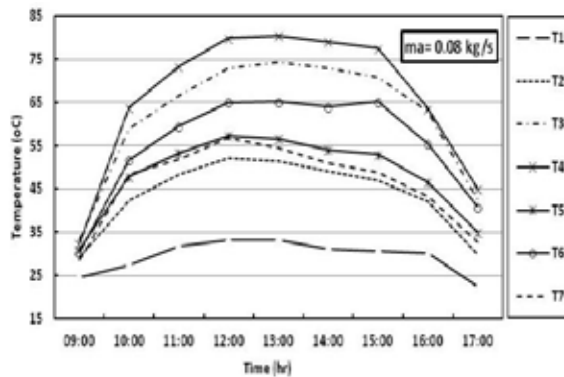


Figure 10-c. Variation of temperature with time at different measurement points, [$m_a = 0.08$ kg/s, October 14, 2019].

Figure 11 shows the variation of temperature with time at different measurement points in the solar air collector for different air mass flow rates in January, 2020. Again, for the same reasons discussed above, an identical trend is noticed as for the other results; August-2019 and

October-2019. The maximum temperature reached 88 °C, at air mass flow rate of ($m_a=0.03$ kg/s) recorded at the bottom surface of the absorption plate in the solar air heater. Moreover, the maximum outlet air temperature is 59 °C recorded at 14:00 PM at the same mass flow rate.

It should be noted that the variation of air outlet temperature for different results; (August-2019, October-2019 and January-2020), is very small and in average, the outlet air temperature is 60 °C. This temperature is very suitable for some applications such as space heating and crops drying.

3.3 Overall Heat Loss Coefficient

Another and very important parameter that affects the thermal performance of the solar air collector is the overall heat loss coefficient. It is calculated according to the procedure mentioned in reference [10]. It can be summarized as follows;

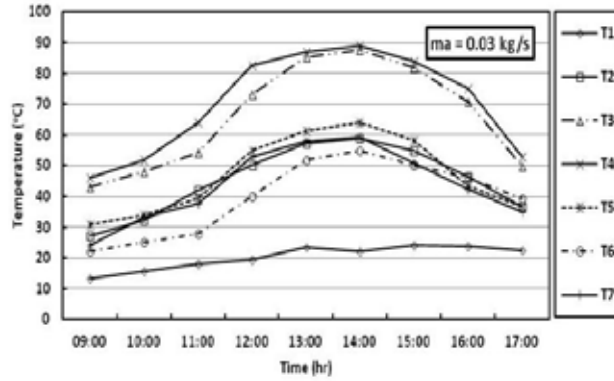


Figure (11-a). Variation of temperature with time at different measurement points, [$m_a = 0.03$ kg/s, 28 January 2020].

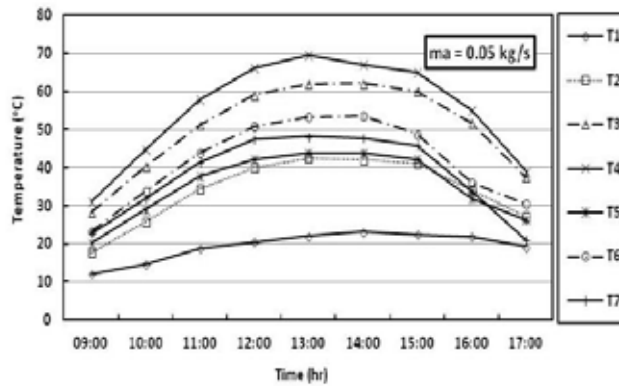


Figure (11-b). Variation of temperature with time at different measurement points, [$m_a = 0.05$ kg/s, 30 January 2020].

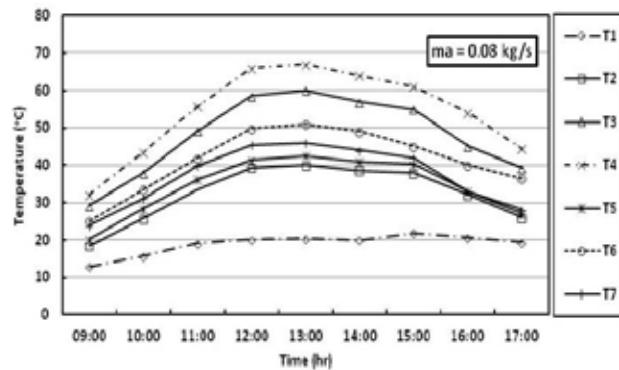


Figure (11-c). Variation of temperature with time at different measurement points, [$m_a = 0.08$ kg/s, 29 January 2020].

Assuming one-dimensional heat transfer through the solar flat plate collector, the radiant energy absorbed by the collector (Q_i), considering transmissivity of the glass cover (τ) and the absorptivity of the absorber plate (α), is:

$$Q_i = I_t \alpha \tau A_c \dots\dots\dots (W) \dots\dots\dots (1)$$

Where;

I_t : is the incident solar radiation on the tilted surface, in (W/m^2).

A_c : is the collector area, (m^2).

Rate of heat loss through the collector

$$Q_0 = U_L A_c (T_c - T_a) \dots\dots\dots (W) \dots\dots\dots (2)$$

Where; U_L : is the overall heat loss coefficient ($W/m^2 \cdot ^\circ C$) based on the top surface of the collector.

T_c and T_a : are top glass surface temperature of the collector and ambient air temperature respectively in ($^\circ C$).

Useful heat gained by the collector

$$Q_u = \dot{m}_a C_{pa} (T_{out} - T_{in}) \dots\dots\dots (W) \dots\dots\dots (3)$$

Where C_{pa} : is the specific heat of air, ($1005 J/kg \cdot ^\circ C$).

T_{out} and T_{in} : are the outlet and the inlet process air temperatures, T_2 and T_1 , for the air passes through the collector respectively in ($^\circ C$).

Energy balance through the collector is;

$$Q_i = Q_0 + Q_u \dots\dots\dots (W) \dots\dots\dots (4)$$

By applying the above equations, useful heat gained by the collector is calculated as follows;

$$Q_u = Q_i + Q_0 = I_t \alpha \tau A_c - U_L A_c (T_c - T_a) \dots\dots\dots (5)$$

Then, the overall heat loss coefficient (U_L) is;

$$U_L = \frac{Q_i - Q_u}{A_c (T_c - T_a)} = \frac{Q_0}{A_c (T_c - T_a)} \dots\dots\dots (6)$$

Invoking the experimental data of this study, the overall heat loss coefficient can be estimated as depicted in Figure 12.

Figure 12 shows the variation of the overall heat loss coefficient with time for the studied period at air mass flow rate of ($\dot{m}_a = 0.03 \text{ kg/s}$). The reason behind choosing the results for air mass flow rate of 0.03 kg/s is that the maximum outlet air temperature recorded is obtained at this value of air flow rate. In general, average overall heat loss coefficient values tend to decrease with time. The overall heat loss coefficient values for August, 2019 are greater than the ones for October, 2019 and January, 2020 respectively. It ranges from 5.5 to 10 ($W/m^2 \cdot ^\circ C$) for August, 2019 to its lowest values in January, 2020, to be ranged from 1.8 to 5 ($W/m^2 \cdot ^\circ C$). This could be interpreted in view of weather data and other study results. The measured solar radiation values are almost the same for Oct-2019 and Jan-2020, whereas lower values were recorded in Aug-2019 for the specified days. In addition, ambient air temperature and wind speed values for Jan-2020 are lower than those

for Aug-2019 and Oct-2019. It should be noted that the period of the daily measurements is kept constant (9.00 AM to 17.00 PM) for all the months of study; August 2019, October 2019 and January 2020.

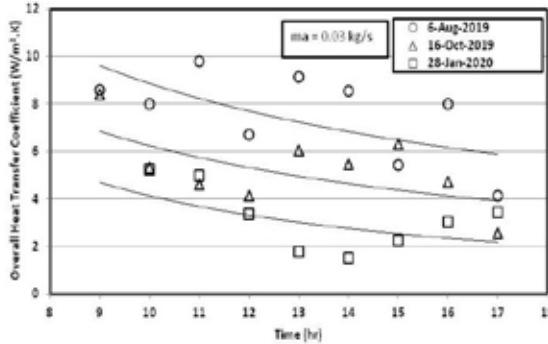


Figure (12). The variation of overall heat loss coefficient with time for the studied period, ($m_a=0.03$ kg/s).

3.4 Efficiency of the collector

The efficiency of a solar collector is defined as the ratio of the amount of useful heat collected to the total amount of solar radiation striking the collector surface during any period of time.

$$\eta = \frac{Q_u}{I_t A_c} \dots\dots\dots (7)$$

3.4.1 Useful Heat Collected

In view of equations 3 and 5 and the measured air temperatures, useful heat gained could be calculated and quantified. Figure 13 shows the amount of useful heat gained for different study periods at air mass flow rate of ($m_a = 0.03$ kg/s). As depicted, useful heat collected values increase as solar radiation intensity increases with time. At the period between 12:00 PM to 15:00 PM, the useful heat energy reaches its maximum values for all study period.

The maximum values are ranging from 700 W at 15:00 PM for Aug-2019 to 1100 W at 14:00 PM for Jan-2020. So, the useful heat gain values for Jan-2020 are higher than those for the other months; Aug 2019 and October -2019.

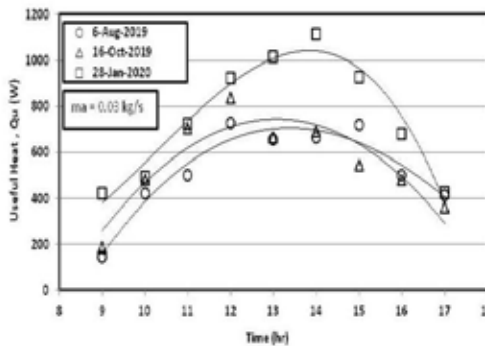


Figure (13). Useful heat collected for different study periods, [$m_a = 0.03$ kg/s].

3.4.2 Solar Air Collector Efficiency

The solar air collector efficiency could be evaluated by using equation 7 and according to the experimental data. The average values for the efficiency of the solar air collector are varied with time between a value of 35% at 16, Oct-2019 to 65% at 28, Jan-2020. This is depicted in Figure 14 below.

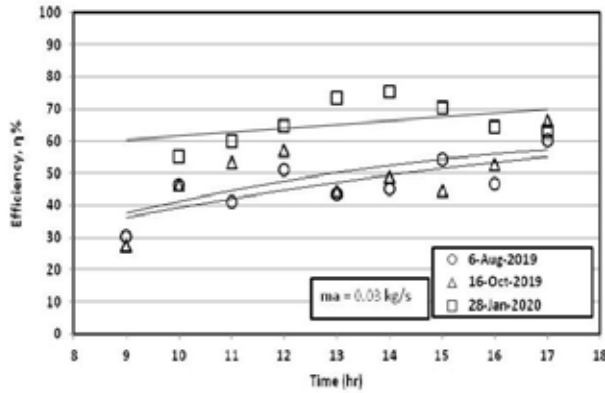


Figure (14). Variation of the collector efficiency with time, [$m_a = 0.03 \text{ kg / s}$].

3.5 Validation of Results

In this section, the present study results are compared by those published in reference [13]. In the study mentioned in reference [13], authors conduct a set of experiments on single- and double pass solar air heaters in the city of Famagusta in the north of Cyprus. The length and width of the collector were 150 and 100 cm, respectively. This is similar to the present study test-rig configuration and dimensions. In addition to the same air mass flow rate considered, ($m_a = 0.03 \text{ kg/s}$).

Figures 15 and 16 show a comparison of results for the present study results and the one mentioned in reference [13] in terms of process air temperature difference and efficiency. The comparison reveals that there is a good agreement. The general trend of results is similar. Some discrepancies and deviations in the results may be attributed to the slight differences in the prevailing weather conditions; solar radiation, ambient air temperature, relative humidity and wind speed.

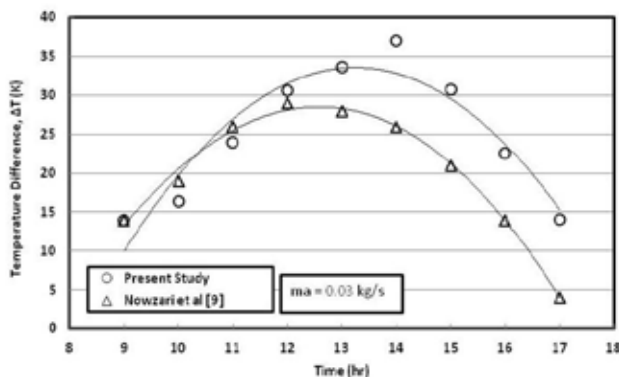


Figure (15). Variation of temperature difference with time for the present study and the one in reference [9], ($m_a = 0.03 \text{ kg/s}$).

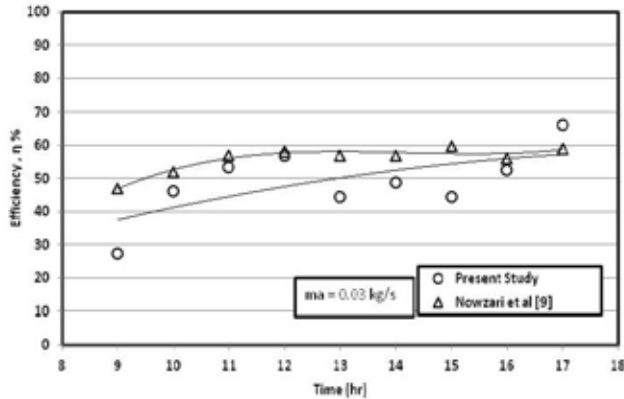


Figure (16). Instantaneous efficiency for the present study and the one in reference [9], ($m_a = 0.03 \text{ kg/s}$).

4. CONCLUSIONS

In this study, a series of experiments has been carried out on the solar air collector test-rig installed at the laboratories of the Center of Solar Energy Research and Studies (CSERS) in Tajoura-Libya. The main objective is to investigate the effect of process air mass flow rate on the thermal performance of a solar air heater under different operating conditions and prevailing conditions of Tajoura-Libya. These experiments were conducted on August 2019, October 2019 and January 2020 during day hours; (9.00 am to 17.00 pm). Results show that as incident solar radiation values increase during the day time, a remarkable increase in the air temperatures of solar air heater is noticed. It reaches its maximum value at afternoon. The maximum average outlet air temperature recorded is 60 oC. This temperature is suitable for space heating and crops drying. Furthermore, useful heat energy collected is proportionally related to incident solar radiation. Increasing air mass flow rates leads to a corresponding decrease in the temperature at different locations in the solar air heater. The average efficiency values of the solar air heater range from 35% to 65%. In addition, average overall heat loss coefficient values tend to decrease with day time. Finally, comparison of the present study results with literature shows a good agreement.

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6. NOMENCLATURE

Parameter	Description	units
T_1	Temperature of the process air at the inlet of the solar air heater	°C
T_2	Temperature of the process air at the outlet of the solar air heater	°C

T_3	Temperature of the upper surface of the absorber plate	°C
T_4	Temperature of the lower surface of the absorber plate	°C
T_5	Temperature at the end of the first pass of the process air	°C
T_6	Temperature of the base plate	°C
T_7	Temperature of the glass surface at the top of the solar air heater	°C
m_a	Mass flow rate of the process air	kg/s

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