Performance of A New Model of Air Heating System: Experimental Investigation

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ABSTRACT: In the current paper, a new design for an air solar heater is tested and its results are compared with the corresponding results of a conventional air solar heater (two-pass black flat plate). Experimental measurements have been performed under Najaf city/Iraq (latitude and longitude are 32° 03 N and 44° 19 E) prevailing weather conditions. The new design is a longitudinal aluminum radiator placed inside a fully isolated bed. The radiator is covered with black paint to increase the heat absorption of the solar radiation and then distribute it regularly to the passing air. In addition to test the activity of the new system, the current experiments shed a light on influence of the air mass flow rate on the air outlet temperature, thermal efficiency and pressure drop. Three air mass flow rates are selected: 0.0046, 0.0092 and 0.0138 kg/s. The results show that increasing in the air mass flow rate leads to decrease in the air outlet temperature and increase of the pressure drop and thermal efficiency for both current solar collectors. Moreover, the radiator air solar heater is 18.62% more efficient at the maximum point compared to the conventional one with 0.0138 kg/s leading to obtain 32.66% as the maximum enhancement in the thermal efficiency.

KEYWORDS: Solar heater, Black air radiator, Solar radiation, Thermal performance, Thermal efficiency

INTRODUCTION

Fossil fuels are the main source of the thermal energy. Expensive prices and increased pollution rates of these fuels motivate us to find other sources of energy, as the solar energy.

More than 2000 years ago, the solar energy used to power a simple water pump. Archimedes employed solar concentrations mirrors to run Roman ships [1]. In 1960 and after, scientists showed a clear interest in the solar energy especially after the oil crisis that caused the correction of energy policies in the world [2]. Depending on the U.S. Energy Agency, development of solar heating systems started in 1990s with the growth rate for this field being around 20%. The solar heating systems are low cost and low greenhouse gases comparing with burned fossil fuels making these systems ideal for cold areas with solar intensity [3].

Despite all solar energy advantages, it is worth pointing out to know that the productivity of solar heaters is low leading to pay more efforts to test various designs for increase the heat transfer rate inside the solar heater. Thus, many methods have been presented in experimental and theoretical studies to improve the performance of the solar heaters.

Ozgen et al. [4] conducted an experiment to reveal the effect of inserting an absorbing surface (made from aluminum cans arranged on a plate) into a double pass channel within a flat plate solar air heater. The solar collector was covered with 4-mm single glass plate. Three case studies were applied: absorber plate (without cans) and two arrangements of cans on absorber plate (zigzag and in order). Thermal efficiency of the solar air heater with the zigzag arrangement of cans was the highest due to the highest heat transfer coefficient between the absorber plate and the air.

Conventional single-pass solar collector was improved theoretically and experimentally by Sopin et al. [5]. The new solar system was constructed from double-pass with using of a porous media in the lower channel. The improved design provided higher outlet temperature leading to higher thermal efficiency compared to the conventional collector. This was because the influence of the porous media that increased the total heat transfer rate. In this study, it was also
investigated the effect of the depth change of upper and lower channel, mass flow rate, solar radiation and temperature rises on the thermal efficiency of the double-pass solar collector. In general, it was concluded that the presence of the porous media in the lower channel had the significant role to increase the thermal efficiency of the solar collector.

Numerical simulations were carried out in Al-Khaffajy and Mossad [6] to minimize the total heat losses in a solar water heater with double glass cover. Three CFD models were implemented to predict the best air gap between the absorber and the lower glass cover and between the two glass covers. For both cases, the air gap spacing was changed within a range of 15-50 mm. It was concluded that the optimal distances between the absorber and the lower glass cover and between the two glass covers were 40 and 25 mm respectively, where the lowest heat loss was 213.18 W. It was also presented that the conduction was the responsible of the heat loss within the small gap size while increasing in the gap size led to increase in air velocity that increased contribution of the convection of the heat loss.

Model of a solar air heater was constructed by El Sebaii et al. [7 and 8] to compare between theoretical and experimental results. The model was based on double pass-finned plate. Theoretical predictions were in good agreement with measured results. So, the authors extended their study to experimentally investigate the difference between performances of two sola air heaters: the double pass-finned and double pass v-corrugated plate. Based on collected data of output power and temperatures of outlet flowing air and absorber plate, El Sebaii et al. [7] showed that the efficiency of the double pass v-corrugated plate was more than the other solar air heater by 9.3-11.9%. In addition, it was presented that to obtain the maximum efficiencies of the double pass-finned and v-corrugated plate solar air heaters, the air mass flow rates were 0.0125 and 0.0225 kg/s respectively.

Nowzari et al. [9] replaced absorber plate of a double pass solar air heater with fourteen layers of steel wire mesh (0.2 × 0.2 cm in cross section opening). In this experiment, steel wire meshes were painted with black and arranged in parallel to the glass cover with 0.5 cm as a distance between each of them. The results illustrated that with the increasing of the air mass flow rate (which was within the range of 0.011-0.037 kg/s), the efficiency of the solar collector increased and temperature rise through the system decreased. The obtained maximum temperature difference was 53°C for 0.011 kg/s and the average efficiency was 53.7% for 0.037 kg/s.

Srivastava et al. [10] experimentally investigated the time between energy supply and energy demand in a solar dryer using lauric acid as a phase change material (PCM), which was employed to enhance internal heat storage capability. The experiment focused on the characteristics of the heat transfer of the PCM through the intervals of charge and discharge. The results illustrated that using of lauric acid increases the storage efficiency of the solar dryer.

Standalone hot air space heating system was designed and tested in the work of Tyfour et al. [11]. Multi panel installation, which was the main part of this design, was proper to serve requirements of any space heating system. Different shapes of the system were implemented and the results showed that the multi-plate structure in the form of vertical expansion gave higher efficiency.

Kabeel [12] carried out an experiment to identify the effect of paraffin wax as a phase change material (PCM) on energy absorption of flat and v-corrugated plates inside solar air heaters. The main act of PCM is thermal energy storage. In this study, thermal performance, which includes several parameters, of the solar air heaters was tested with and without PCM. Three experimental air mass flow rates were selected: 0.062, 0.028 and 0.009 kg/s. Change of thickness of PCM was also investigated. Experimental results showed that at the mass flow rate of 0.062 kg/s, using the PCM led the outlet temperature of the v-corrugated plate and flat plate solar air heaters to be higher than the ambient temperature after sunset by 1.5-7.2°C and 1-5.5°C respectively. It was also presented that the daily efficiency of v-corrugated solar heater with PCM exceeded by 12% compared to the similar case without PCM and it also increased by 15% and 21.3% in a comparison with the flat plate with and without PCM respectively.

Chaichan et al. [13] increased the ambient air temperature by about 101% using an aluminum flat plate that inserted in 1 m² transparent collector solar air heater. The air passed from the top of the flat plate and left from the bottom. The authors showed that the aluminum plate was a heating source taking its heat from the solar radiation. So, its presence was necessary to enhance the thermal performance of the solar air heater.

Aluminum cans were also experimentally employed by Abdullah et al. [14] as flow turbulutors in a double pass solar air heater. Aluminum cans were joined to the both sides of the absorber plate. Nusselt number and pressure drop were

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studied with and without cans. Results for each case were compared with results of a single pass solar air heater with 0.02 kg/s-0.05 kg/s as a range of the air mass flow rate. In this study, three absorber flat plates were chosen depending on the cans arrangements: without cans, cans in aligned configuration and cans in staggered configuration. It was reported that the increasing in the turbulence intensity due to using aluminum cans provided 68% as the maximum daily efficiency at 0.05 kg/s for the staggered configuration.

Thermal performance of a solar air heater associated with helical flow path was experimentally analysed and numerically modelled in Heydaria and Mesgarpour [15]. The flow channel was designed as a triangular cross-section shape to ensure helical air flow in order to exchange heat with the bottom and top surfaces of the absorber plate through the heater. The results indicated a fairly good agreement between experimental and numerical calculations. At the air mass flow rate of 0.026 kg/s, the average thermal efficiency of the system was higher than that in a conventional solar air heater by 14.7%. The overall heat transfer coefficient and average thermal efficiency of the presented case were recorded as 65.14 W/m² K and 55.4% respectively.

In the practical study of Darici and Kilic [16], two different absorber plates were used with two solar air collectors: trapezoidal corrugated and flat plates. The point of view of the authors was to investigate the effect of the absorber shape and air mass flow rate on the thermal performance of the solar collector. Three different air mass flow rates were used: 0.022, 0.033 and 0.044 kg/s. It was showed that the solar air collector outlet temperature increased with decreasing in the air mass flow rate. The maximum temperature difference in the solar air collector with trapezoidal corrugated plate was more than that in the corresponding ones with flat plate by 9 °C for the air mass flow rate of 0.022 kg/s. It was also noted that the thermal performance of the solar air collectors increased as the air mass flow rate increased where at 0.044 kg/s, 63% was recorded as average daily thermal efficiency for using the trapezoidal absorber plate.

Saeed et al. [17] argued that Iraq is considered as one of the sunny countries with long sunny day and high solar intensity. Average solar radiation ranges in Iraq are from 245 W/m² in winter to 980 W/m² in summer. Therefore, Iraq is one of the best places to use various solar energy applications to reduce the dependency on the electrical energy.

Aim of the present study is to design and test a unique type of solar air heater. This type is constructed with available and cheap materials. Characteristics of the current model, which are easy installation and ability to obtain better efficiency, encourage believing that this study will effectively contribute to reduce pollution by reducing fuel consumption to generate electricity.

DESCRIPTION OF THE AIR HEATING SYSTEM

In the current experiments, two models of solar air heater are used. The first model A is designed to flow air over an absorber made from 1.5 mm galvanized iron sheet with black chrome selective coating, as shown in Figure 1-a. The plate absorber area is 1.25 m (length) x 0.8 m (width) and the absorbance coefficient α is 0.9. In the second model B, air passes inside absorber part of an absorber made from an air aluminum (single raw of pipes) radiator coated with a matte black thermal dye, as illustrated in Figure 1-b. The black aluminum radiator area is 1.25 m x 0.8 cm and its thickness is 0.04 m. This radiator is placed inside MDF bed that is insulated from the bottom and all its sides by a thermal insulation (white cork layer) with thickness of 2 cm. Thermal conductivity of the thermal insulation is 0.035 W/m.k. The bed top is covered by 4 mm glass panel in thickness with absorption coefficient of 0.05. The bed has two holes (each one with 0.07 m diameter); the first one is located at the bottom to connect the radiator with a D.C. electric fan that delivers ambient air to inside the radiator. The other hole is placed at the bed top to allow the passage of a PVC tube to transfer hot air from the black radiator. MDF frame is at tilt angle of 32.1° with the horizon toward south. The pictorial view of these experimental models is shown in Figure 2.

For both models, two K-type thermocouples with efficient insulation employed to measure the temperatures of inlet and outlet air in the heating unit. One of these thermocouples is inside the air inlet hose and the other one is at exit of PVC tube. Hourly temperatures are recorded using a digital thermometer display DM6802B with accuracy of ± 1 °C. Solar radiation is measured each hour along the time of experiment at direction of the solar still tilt angle by a solar power meter, that shown in Figure 3, type TENMARS (TM-207) model with range from 0 to 1400 W/m² and accuracy of (± 5%, ± 10 W/m²). Air mass flow rates from the test rig and wind speed measurements are taken hourly by
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An anemometer device, that shown in Figure 4, type (AM-4206M) with range of (0.4 – 30 m/s) and accuracy of (±1.8% N+2d). Pressure drop across the solar air heater is obtained by using U-tube manometer with water as working fluid, whereas the both ends of the manometer are joined to inlet and outlet tubes of the solar heater.

All current experimental tests were carried out in April 2020 at the communication department building roof top in the Engineering Technical College, Najaf, Iraq. The location latitude and longitude are 32° 03’ N and 44° 19’ E. The systems data were measured at each hour within an interval between 9.00 and 16.00.

Figure 1-a. Schematic diagram of the experimental model A.

Figure 1-b. Schematic diagram of the experimental model B.
Figure 2. Pictorial view of the experimental rigs for model A and model B.

Figure 3. Solar radiation measurement (Pyrometer) device.

Figure 4. Air flow meter (anemometer) device.
GOVERNING EQUATIONS

Related to the solar heater thermal efficiency and according to [18], the gained heat that obtained from absorbed solar radiation for a known absorption area during a time period is:

\[
\eta = \frac{\text{Solar Energy Collected}}{\text{Total Solar Striking Collector Surface}} = \frac{Q}{(I_0 \times A_c)} = \frac{\dot{m}c_p\Delta T}{(I_0 \times A_c)}
\]  

(1)

Where:

\(I_0\) is irradiation (W/m\(^2\))

\(A_c\) is the area of the collector (m\(^2\))

From main factors that affect the efficiency of the air heating system are the air mass flow rate and the outlet temperature, which they describe the output (useful) energy. Thus, the output energy is calculated from the following formula:

\[Q = \dot{m}c_p\Delta T\]  

(2)

Where:

\(Q\) is power (W).

\(\dot{m}\) is mass flow rate of air (kg/s).

\(c_p\) is specific heat capacity of air (J/kg.\(^°\)C).

\(\Delta T\) is outlet and inlet temperature difference of heating system (\(^°\)C).

From the empirical study of Klein [19], the lower thermal efficiency of the solar air heater is due to the small heat transfer coefficient between the absorber plate and the airstream. Increasing in the heat transfer coefficient between the absorbent surface and the airstream requires increasing in the absorption area.

The calculated thermal efficiencies of both current models are detailed in Table 1.

The enhancement in thermal efficiency due to the using of model B comparing to model A can be obtained as:

\[\text{Enhancement}\% = \frac{\eta_{\text{model B}} - \eta_{\text{model A}}}{\eta_{\text{model A}}}\]  

(3)

\(\eta_{\text{model A}}\) and \(\eta_{\text{model B}}\) are the thermal efficiencies of models A and B, respectively.

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Thermal Efficiency for 0.0138 kg/s (%)</th>
<th>Thermal Efficiency for 0.0092 kg/s (%)</th>
<th>Thermal Efficiency for 0.0046 kg/s (%)</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td>Model B</td>
<td>Model A</td>
</tr>
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<td>52.75</td>
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<tr>
<td>16</td>
<td>44.68</td>
<td>52.00</td>
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</table>
RESULTS AND DISCUSSION

According to the measured ambient conditions and temperatures of the flowing air through both models in the present experiments that shown in Table 2. The following relationships are illustrated.

Variation of the solar radiation with the measuring time that illustrated in Figure 5 clearly states an increase in the solar radiation up to its peak value of 827 W/m² at 1 PM, after that there is a dramatic decrease in its value reaching to 360 W/m² at the end of the experiment. It can be also seen in this figure behavior of the ambient temperature and wind speed along the time. There are a slight rise in the wind speed and 7 °C as a difference between magnitudes of the ambient temperature at the start and end of the experiment.

Figures 6 and 7 present the change in the inlet and outlet temperatures with different air mass flow rates along the time of the experiment for the models A and B respectively. For the model A and with each selected air mass flow rate, manner of temperatures distribution at the outlet port seems to be similar. It can be shown that the maximum temperature is recorded at 1 PM as shown in Figure 6. This can be explant due to nature of the solar radiation with the time, which reaches its maximum value at noon time. It is always possible to get the highest temperature outside when the amount of the solar radiation is the highest. Similar behavior of the outlet temperatures distribution in the model B can be noted in Figure 7. Regarding the effect of the air mass flow rates, the reduction in the amount of the passing air leads to higher outlet temperatures at all times of the experiment due to increasing of the exchanging time of the heat transfer. This can be illustrated for both models A and B. The highest exit temperature of the model A is 70 °C, 65 °C and 61 °C at the air mass flow rate of 0.0046, 0.0092 and 0.0138 kg/s respectively. For the similar air mass flow rates, the highest exit temperature in the model B is recorded as 81 °C, 76.1 °C and 72.1 °C respectively. So, it is clearly seen that the radiator air solar heater enhances the magnitude of the outlet air temperatures compared to that in the conventional solar heater at all experimental air mass flow rates.

Variation of the pressure drop with the air mass flow rate for both present models is plotted in Figure 8. For the air mass flow rate of 0.0138 kg/s, the pressure drop in the model A is 166.6 Pa, while its value increases to 313.6 Pa in the model B. Reason for the difference in the pressure drop between both models is because using tubes as passages in the radiator in the model B leading to higher pressure drop. In general, the direct relationship between the pressure drop and the air velocity, which related to the mass flow rate, gives the meaning of going up of the pressure drop with increase in the mass flow rate in both models.

By investigating the thermal performance of the conventional air solar heater and the new suggested one (model B), the surface heat exchange in the model B is enhanced leading to enhance the outlet air temperature and the thermal efficiency of the system. This is clearly shown in Figures 9 and 10 that present magnitudes of the thermal efficiency represented to the time for the models A and B respectively. For both models, the thermal efficiency increases with the increasing of the air mass flow rate. The maximum thermal efficiency of the model A, as shown in Figure 9, is 24.03, 42.48 and 57.01% for air mass flow rates of 0.0046, 0.0092 and 0.0138 kg/s, respectively. While for the model B, its value is 30.18, 54.89 and 75.63% for the same selected air mass flow rates as illustrated in Figure 10.

The comparison that is carried out in Figure 11 between the thermal efficiencies in the model A and model B refers that the thermal efficiency in the model B is higher than that in the other model at each mass flow rate for all experimental hours. It is clearly seen that the maximum difference in the thermal efficiency is 18.62% at 1 PM and 0.0138 kg/s. This can be explant depending on the enhancement in the heat exchanging surface area of the model B.

Enhancement in the thermal efficiency along the time of the experiments that achieved due to using the model B is presented in Figure 12. It can be indicated that employing the black radiator in the model B rather than the double pass solar air heater in the model A improves the performance of the system by increasing in the maximum enhancement of the thermal efficiency. On the other words, the maximum enhancement in the thermal efficiency that obtained from using the radiator air solar heater is 32.66%, 29.21% and 25.59% at 0.0138, 0.0092 and 0.0046 kg/s respectively.
Table 2. The measured parameters.

<table>
<thead>
<tr>
<th>time (hr)</th>
<th>solar radiation (W/m²)</th>
<th>wind speed (m/sec)</th>
<th>ambient temp. (°C)</th>
<th>inlet temp. (°C)</th>
<th>outlet temp. at 0.0138 kg/s (°C)</th>
<th>outlet temp. at 0.0092 kg/s (°C)</th>
<th>outlet temp. at 0.0046 kg/s (°C)</th>
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CONCLUSION

This study presents a design review and thermal analysis to identify the thermal efficiency of a solar air heater. Practical results of the absorbent surface model are compared with the black exchanger (radiator) model. It is concluded that the efficiency of the models is directly affected by the amount of available solar radiation, the rate of air mass flow and the engineering design of the absorbent body. When the solar radiation reaches the maximum value, the outlet air temperature also reaches the maximum value, where it is recorded in the current experiment as 70 °C for the double pass solar air heater model and 81 °C for the radiator solar air heater model with the air mass flow rate of 0.0046 kg/s. As well as, the thermal efficiency increases with the solar radiation increase, and it is 57.01% for the double pass solar air heater and 75.63% for the radiator solar air heater with the air mass flow rate of 0.0138 kg/s. The maximum enhancement can be obtained, at the maximum solar radiation, may reaches up 32.64% at the air mass flow rate of 0.0138 kg/s. Finally, the thermal efficiency is noted to be directly proportional to the air mass flow rate for both current models.

The current work can be extended by examining the effect of coting the outer surfaces of both models with nanoparticles (Al₂O₃). In addition, the phase change material (PCM) that is inserted between the air passages can be considered as a parameter influences on the heat exchanging efficiency.

![Figure 5. Variation of the solar radiation, ambient temperature and wind speed with the time.](image-url)
Figure 6. Variation of the inlet and outlet temperatures along the time with different air mass flow rates for the model A.

Figure 7. Variation of the inlet and outlet temperatures along the time with different air mass flow rates for the model B.
Figure 8. Variation of the pressure drop with air mass flow rate for both models A and B.

Figure 9. Variation of the thermal efficiency along the time with different air mass flow rates for model A.
Figure 10. Variation of the thermal efficiency along the time with different air mass flow rates for model B.

Figure 11. Variation of the thermal efficiency along the time with different air mass flow rates for both models A and B.
Figure 12. Enhancement in the thermal efficiency along the time with different air mass flow rates for the model B with respect to the model A.

REFERENCES


