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Research Article

Thermal Performance of Recycle Pass Solar Air Heater with V-Corrugated Absorber Plate

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Abstract

The performance of recycle pass solar air heater with V-corrugated absorber plate was examined experimentally. The results were compared with single pass solar air heater with V-corrugated absorber plate. The measured parameters were temperature difference, useful energy, pressure drop, and collector efficiency. It's founded that, the recycle pass has an increase in these parameters as they compared with single pass. The air flow rate range between 0.01 – 0.03 m^3/s was tested in winter 2016 in Iraq. Experimental data show that, the useful energy and thermal efficiency were increased with increases of air flow rate. The useful energy generated by recycle pass was 18.8 % more energy per day than the single pass solar air heater. Maximum temperature difference between outlet air temperature and ambient temperature for recycle pass and single pass were 31 ^oC and 25 ^oC, respectively. The maximum value of the performance curve of the recycle and single pass were 68 % and 61 %, respectively.

Keywords: *Thermal performance, Recycle pass, Solar air heater, V-corrugated*

1. Introduction

Solar air heaters represent the main type of the solar energy exploitation system. They attract solar radiation at the absorbing plate to convert it into thermal energy. The working fluid across the collector will pick up this energy to use it into another application. Such as greenhouse heating, industrial process heating in textile and paper industries, space heating and drying agricultural products (Joudi and Dhaidan, 2001).

The assumption of a solar air heater is the same as that of the water flat-plate collector. Air is flowed in contact with a black absorber plate which is usually overlaid by one or more transparent covers for heat loss reduction. A variety of designs has been made for solar air heaters according to the type of absorbing surface. Solar air heaters can be classified into two broad categories. The first is commonly known as non-porous absorbers in which the air does not flow through the absorber plate. Air may flow above and/or below the absorber plate. The second is known as porous bed absorbers, in which the air pass through the absorbing material (Garg and Parhash, 2008). Fins, ribs or corrugated surfaces are used to improve collector efficiency (Bashria *et al*, 2007; Mittala *et al*, 2007).

A performance study on a V-corrugated solar collector was evaluated analytically and experimentally by Karim and Hawlader (Karim and Hawlader, 2004). Experiments were carried out, data were documented for different operating variables to obtain the performance of the solar air heater. The results revealed an improvement in the efficiency by 12 % as compared to a flat plate collector of a similar design. Bashria *et al*. were performed and developed a mathematical simulation to calculate the performance of different shapes of solar collectors with V-corrugated absorbers using double and single glass covers, with and without using porous media. Single and double flow types were tested, and as expected, the mode of double flow was 4 – 5 % higher than the mode of single flow. In contrast, the use of porous media increases the collector efficiency in double flow by 7 % more than that a single mode. Also, it is 2 - 3 % more efficient in double flow type without using porous media (Bashria *et al*, 2004).

Mahmood *et al*. studies the influence of expanding the way of the air in the passage of a single and double pass solar collector with using porous media in the second passage without an absorber surface (Mahmood *et al*, 2015). They found that the proposed design has a thermal efficiency and an average efficiency of the double pass are more than that of the single pass solar air heater at constant air mass flow rate, and will enhance by increasing the air mass flow rate. Analytical models of thermal performance of solar air heaters of double parallel flow and double pass counter flow was presented by Hernandez and Quinonez (Hernandez and Quinonez, 2013).

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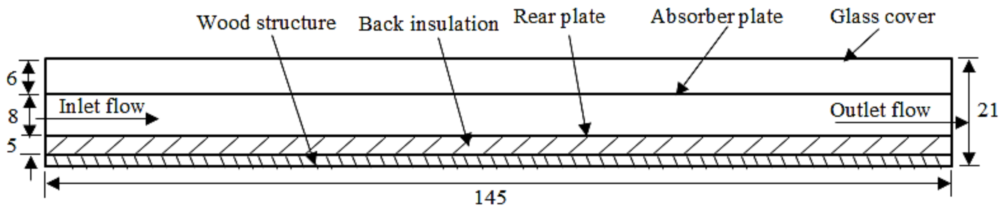
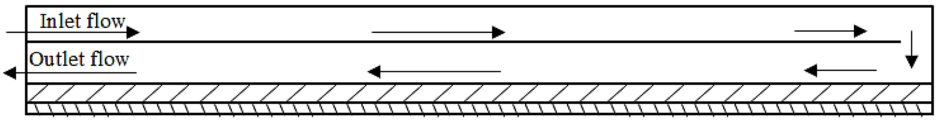
Fig. 1 Photograph of two solar air heaters



a. Single pass solar air heater.



b. Recycle pass solar air heater.

Fig. 2 Schematic of solar air heaters (All dimensions in centimeters)

They found that the increasing in air flow correspondingly increases the temperature ratio ascent in the inlet channel while, the outlet temperature was less than that current in the central portion of the bottom channel of the collector. For more details, review papers on different techniques used to improve the thermal performance of double pass solar air heaters were accomplished by Chamoli *et al*. and Ravi and Saini (Chamoli *et al*, 2012; Ravi and Saini, 2016).

The aim of this study is to provide systematic experimental findings that affect the thermal performance of solar air heater. Data were recorded to compare the results between two solar air heater of recycle pass and single pass with a single glass cover, V-corrugated absorber plate type solar air heater a V-angle of 60^o.

2. Experimental setup

Two solar air heaters were shown in Fig. 1. They were composed of the glass cover, the absorber plate, the insulation on the side and rear. A supporting frame to hold together these components was made from wood. They measure 145 cm (length) × 97 cm (width) × 21 cm (height) for each. The absorber plate was measured 120 cm × 112 cm. corrugations were made with an angle of opening of 60^o with equal sides of corrugation, each side being 8 cm long. The corrugated plate was fixed directly on a flat rear plate to form triangular passages. The absorber plate surface was coated with mat black paint. Fig. 2 shows a schematic of solar air heater with recycle and single pass. The tilt angle solar air heater was 40^o from horizontal. The latitude of Baghdad is equal to 33.3 ^{o}N. The solar air heaters were fixed to face south. The transparent cover of the collector was 4 mm glass. It is held in a wood frame.

Hourly solar radiation and ambient temperature data were taken from Iraqi meteorological organization and seismology. Absorber plate, air inlet and outlet temperatures of solar air heater were recorded every 900 s intervals using fifteen integrated circuit sensors LM35, which has an accuracy of ±0.8 ^{o}C over a range of 0 to 100 ^{o}C. These integrated circuit sensors were coupled to a USB DAQ model U3 LV device with 16 flexible input / output channels, manufactured by Lab-Jack Company of Lakewood, Colorado, USA. Five sensors were distributed on the absorber plate for each solar air heater. Four sensors were used to measure the inlet and outlet air temperatures. One sensor was used to measure the air temperature of the return air inside the recycle pass solar air heater. Measurement of air flow rate was accomplished by means of a multi-function measurement instrument for air-conditioning, ventilation and indoor air quality manufactured by testo company, Lenzkrich, Germany, model 435. A handheld Extech HD350 Pitot Tube Anemometer and Differential Manometer manufactured by Extech company, Nashua, USA, was used to compute the pressure drop through the solar air heater.

Experimental tests were carried out to evaluate the thermal performance of recycle pass solar air heater with V-corrugated absorber plate. Experimental data was recorded from 9 a.m. to 4 p.m. with each experiment in winter 2016. Five values of air flow rate were used through the solar air heaters ranging between 0.01 – 0.03 m^3/s. A constant air flow rate was used during the day for any test. A mean value of air flow rate uses from six measurements across the solar air heater outlet. The density variation was treared by ideal gas law to compute the mass flow rate from solar air heater.

3. Results and Discussion

The solar radiation values between 7 a.m. and 6 p.m. are illustrated in Fig. 3. The highest value of solar radiation was 969 W/m^2 at 1 p.m. Also, it shows variations of the ambient temperatures were similar to inlet temperature and which range between 14 to 27 °C.

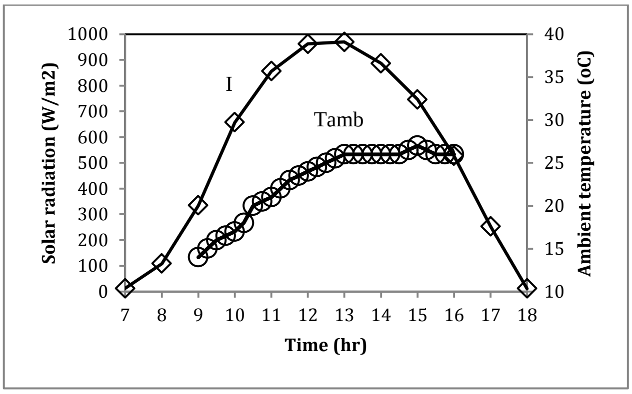


Fig. 3 Variation of solar radiation and ambient temperature with time of day 17/2/2016

The variation of temperature difference across the recycle and single pass solar air heater for different air flow rates are presented with time of day in Figs. 4 and 5, respectively. The temperature difference is increased with time from 9 a.m. to solar noon due to the increase in solar insolation. After solar noon, it began to fall due to the reduction in solar insolation. Clearly, from these results shown for test day that the value of the temperature difference depends strongly on the air flow rate utilized and ambient temperature. The finding is consistent with findings of published studies. Higher temperature difference was found with lower air flow rate and vice versa i.e. temperature difference is inversely depending on the air flow rate. Maximum temperature difference between outlet air temperature and ambient temperature for recycle and single pass were 31 °C and 25 °C, respectively as shown in Fig. 6. It is observed that, higher temperature difference is found for the recycle pass for the same air flow rate 0.01 m^3/s.

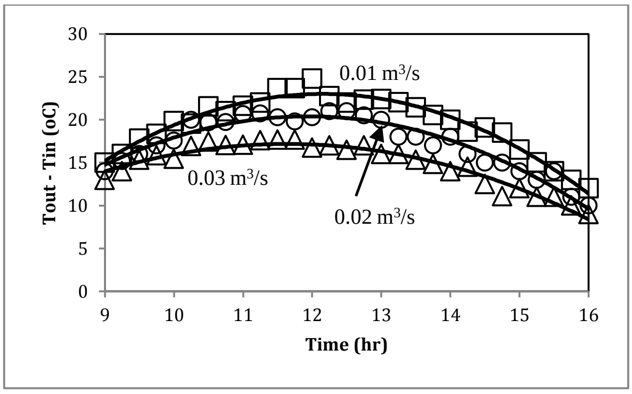


Fig. 4 Variation of temperature difference across the single pass solar air heater with time of day

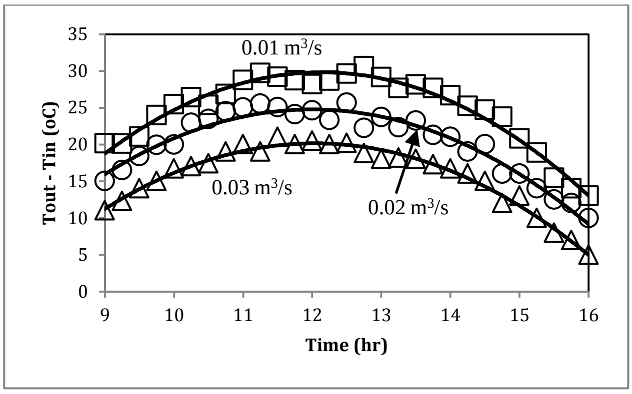


Fig. 5 Variation of temperature difference across the recycle pass solar air heater with time of day

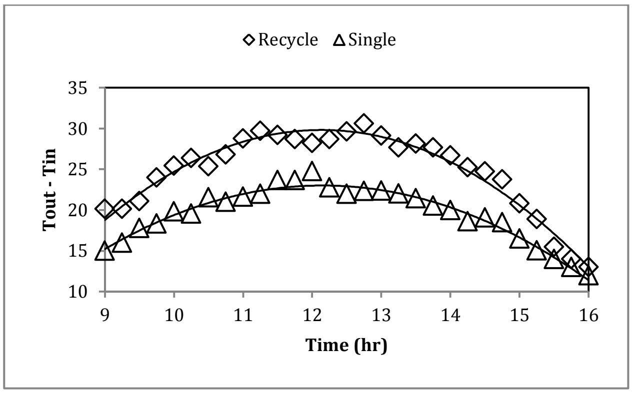


Fig. 6 Comparison of temperature difference across the solar air heaters with time for same air flow rate 0.01 m^3/s

The useful energy can be determined experimentally as;

$$Q_u = \dot{m} c_p (T_{out} - T_{in}) \quad (1)$$

Figs. 7 and 8 show the variation of useful energy across the solar air heater for single and recycle pass, respectively. It can be seen that the useful energy is directly proportional with the air flow rate. It is clear that, high useful energy is obtained for the recycle pass. The maximum value of useful energy for recycle and single pass were 760 and 640 W, respectively for the same air flow rate 0.03 m^3/s. The useful energy values generated during 7 hr. of testing are 5.32 kJ for recycle pass and 4.48 kJ for single pass. Therefore, the useful energy generated by recycle pass was 18.8 % above energy per day for the single pass solar air heater.

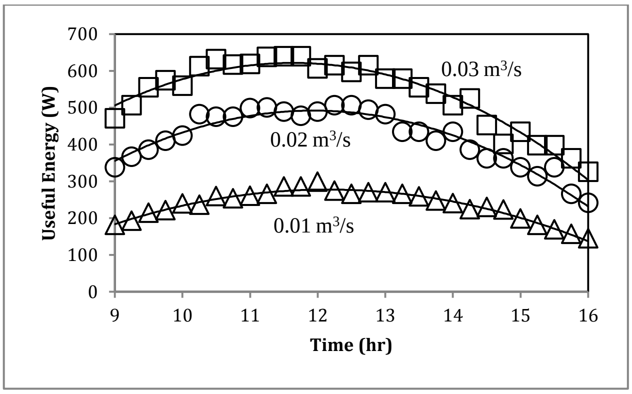


Fig. 7 Variation of useful energy for single pass solar air heater with time of day

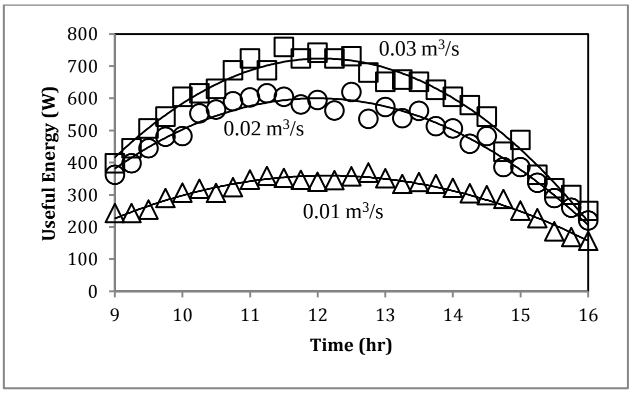


Fig. 8 Variation of useful energy for recycle pass solar air heater with time of day.

A measure of collector performance is the collection efficiency which is defined as the ratio of the useful gain over some specified time period to the incident solar energy over the same time period (Duffie and Beckman, 2006).

$$\eta = \frac{Q_u}{A_c\, I} \tag{2}$$

An operational curve for Winter month is plotted in Fig. 9. This curve was gotten from experimental data for clear sky days in the test time. The scatter in experimental result points because of the changing in operating conditions. Furthermore, varies in wind speed through the test. The value of intersection point of efficiency curve with vertical axes is 68 % and 61 % for recycle and single pass solar air heaters, respectively. The curves corresponding to the values plotted in Fig. 9 are:

$$\text{Recycle pass: } \eta = 0.68 - 10.74\,\frac{T_{out} - T_{amb}}{I} \tag{3}$$

$$\text{Single pass: } \eta = 0.61 - 12.38\,\frac{T_{out} - T_{amb}}{I} \tag{4}$$

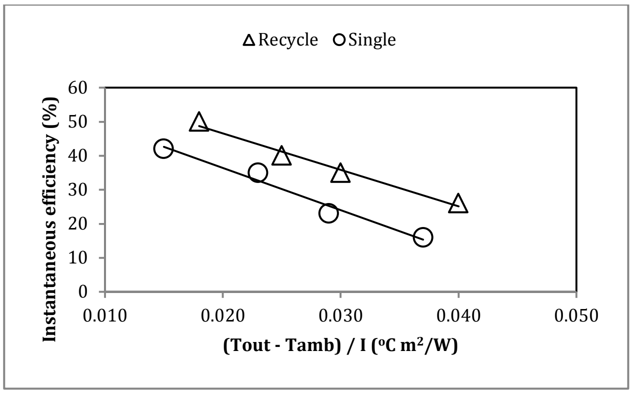


Fig. 9 Operational efficiency curve for recycle and single pass solar air heater

The influence of air flow rate variation on the pressure drop for recycle and single pass solar air heater is shown in Fig. 10. Clearly, the pressure drop was increased with increases of the air flow rate because of the increased velocity of the flowing air with increasing the air flow rate; consequently, the pressure drop increases. In addition, the pressure drop past the recycle pass is higher than that for the single pass as a result of increases in the friction when using long path for air flow rate across the solar air heater. These findings are in good agreement with that reported in literature.

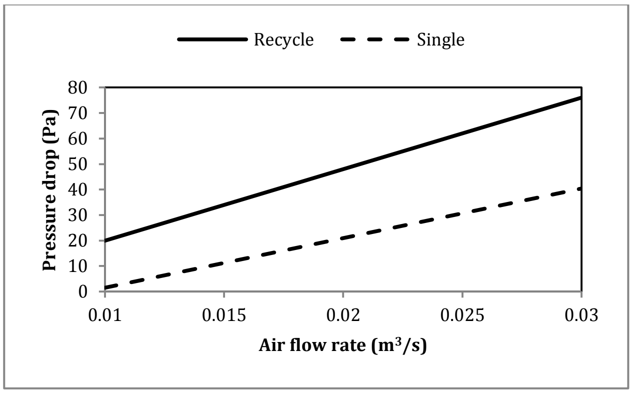


Fig. 10 Variation of pressure drop with air flow rate for recycle and single pass solar air heater

The comparison between the present experimental work and the analytical models obtained by Hernandez and Quinonez is presented in Fig. 11. The dimensional air temperatures across the recycle pass with the length of solar collector for air flow rate of 0.01 m^3/s. Both results are in agreement, the slight difference between the two curves due to the flat and V-corrugated absorber plate were used by Hernandez and Quinonez and present work, respectively. The figure shows that, 77% of the inlet and outlet temperature difference take place in the enter passage of the solar air heater. This value has been influenced by the air flow rate selected for each purpose.

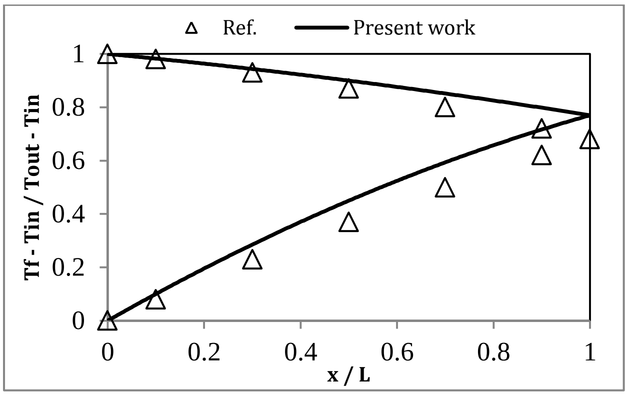


Fig. 11 Variation of dimensional air temperature along the length of solar air heater

Conclusions

The recycle and single pass solar air heaters with V-corrugated absorber plate were fabricated and experimented for various air flow rates in winter 2016 in Iraq. The experimental results shows that the temperature differences across the solar air heater are associated with low air flow rate and vice versa. While, useful energy gained is increased with increasing air flow rate and vice versa. The temperature difference for recycle pass is increased by 24 % than that single pass at the same air flow rate. Useful energy generated by recycle pass was 18.8 % more energy per day than the single pass solar air heater. A maximum value of the performance curve of the recycle and single pass were 68 % and 61 %, respectively. The pressure drop through the recycle pass is more than the single pass at constant air flow rate.

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Nomenclature

A_c Cross section of the solar air heater in m^2
c_p Specific heat at constant pressure of air in J/kg K
I Solar radiation intensity in W/m^2
$\dot{m}$ Air mass flow rate in kg/s
Q_u Useful energy in W
T_{amb} Ambient temperature in ^oC
T_f Air temperature inside the solar air heater in ^oC
T_{in} Inlet air temperature in ^oC
T_{out} Outlet air temperature in ^oC
η Instantaneous efficiency of the solar air heater in %