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Experimental Analysis of Double Glazed Flat Plate Solar Water Heater with Various Absorber Plate Geometries

J. Manikandan*[1] and B. Sivaraman*

Abstract – A study was undergone to assess the performance of double glazed solar flat plate water heater subjected with different geometries of absorber plates namely flat plate, v-grooved and square pulse, were experimentally investigated. Mild steel plate of 1.42 x 0.7 m^2 size was employed as absorber plates. Two glass plates of similar size were used to protect the absorber plate from heat loss to atmosphere. Performance of double glazed solar water heater for various geometries and at different mass flow rate (0.0041, 0.0083, 0.0125 kg/s) were investigated and reported. Thermal efficiency is found to be higher for double glazed flat absorber plate when compared to v-grooved and square pulse plates.

Keywords – Double glazed solar water heater, flat plate, mild steel plate, square pulse, v-grooved.

1. INTRODUCTION

A flat plate solar collector is a special kind of heat exchanger that transforms solar radiant energy to internal energy of the transport medium in the tubes to be carried out as usable energy. It is widely used for supplying thermal energy at moderate temperatures. The common application of the flat plate collectors are mostly found in domestic hot water and space heating, industrial processes, vapour absorption refrigeration and air conditioning system. Therefore, due to their various applications, there is continuing endeavor of a designer to determine thermal performance of flat plate solar collectors.

Farahat and Sarhaddi [1] determined the optimal performance and design parameters of solar flat plate collector. A detailed energy exergy analysis is carried out for evaluating the thermal performance and optical performance, exergy flows and losses as well as exergetic efficiency for a typical flat plate solar collector under given operating conditions. In this analysis ,the following geometric and operating parameters are considered as variables: the absorber plate area, dimensions of solar collector, pipe's diameter, mass flow rate, fluid inlet and outlet temperature, the overall loss coefficient *etc*. and also a simulation program is developed for the thermal and exergetic calculations.

Zehib and Chaker [2] performed the modeling of a domestic solar water heating installation. The results of simulations performed on daily basis for a solar water heater. The installation consists of a solar flat plate collector, a water storage tank, a source of auxiliary energy and radiators. Author analysed more accurately the thermosyphon flow rate and consequently the stratification degree of the tank on the water heater system performances. The interest of this study resides in the approach used to model the tank and in the analysis of the number of nodes used in the gained energy.

Many authors [3], [4] have concentrated on the development of effective design methods for solar collectors. For their analysis the cross sectional area of the absorber plate has been constant. However, the collector receives energy from the sun that is absorbed by the plate and is then transferred to the fluid. On this basis, energy transferred increases in the direction of flow energy in a plate. It is well known fact that for effective design, the profile shape of the absorber plate increases the collector performance.

Abdul Majeed and Sulaiman [5] have determined to increase the output temperature of the water flowing inside an absorber of flat plate solar water heater, here concentrating material had been used. With this study influenced the improvement in thermal efficiency of the flat plate solar water heater by increasing the water temperature along the absorber pipe length.

Kalogirou [6] performed an analysis of the environmental problems related to the use of conventional sources of energy and the benefits offered by renewable energy systems. The various types collectors including flat plate, compound parabolic, evacuated tube, Fresnel lens, parabolic trough, parabolic dish and heliostat field collectors were followed by an optical, thermal and thermodynamic analysis of the collectors and a description of the methods used to evaluate their performance. The thermal performance of the solar collector was determined by obtaining values of instantaneous efficiency for different combination of incident radiation ambient temperature and inlet fluid temperature

Kundu [7] have determined the performance and optimization of several profile shapes namely, rectangular, trapezoidal and rectangular profile with a step change in local thickness (RPSLT). The result indicates that there is optimum fin efficiency of trapezoidal profile for constant plate volume

Chong [8] performed study of solar water heater using stationary V-trough collector. The result shown was cost effective cum easy fabricated v-trough solar collector can improve the overall performance of the solar water heater.

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Ihaddadene and Ihaddadene [9] performed the effect of distance between double glazings on the performance of a solar thermal collector. Experiments were carried out on an active solar energy demonstration system. The results show that the efficiency of double glazing solar collector decreases with increasing the distance separating the two glasses.

Duffie and Beckman [10] performed annual simulation to monitor the thermal performance of a direct solar domestic water heating system operated under several controlled strategies. According to the authors higher flow rate leads to higher collector efficiency factor. However, it also leads to higher mixing tank and therefore, a reduction in the overall solar water heating system efficiency.

Jaisankar and Radhakrishnan [11] have performed experimental investigation of heat transfer, friction factor and theoretical performance of thermosyphon solar water heater system with helical twisted tape of various twist ratios has been performed and presented. The overall thermal performance of twisted tape collector is found to increase with increase in solar intensity.

Kajavali and Sivaraman [12] have performed an analysis of single tube and a newly designed modified absorber in a parabolic trough collector. The solar energy recovery efficiency of the modified absorber was found to be higher than the single tube in the form of increased water temperature.

Sae-jung and Krittayanawach [13] have determined the mathematical model and the experimental study for prediction of the temperature of hot water produced from thermosyphon solar water heater. Results are presented of storage temperature, collector temperature and thermal efficiency of the solar water heater.

Visa and Duta [14] investigated a new flat plate solar thermal collector with isosceles trapeze shape was developed and stepwise optimised focussing on the insulation the bonding between the tubes and the absorber plate. The results show that the improved contact between the tubes and the absorber plate has a significant effect on the experimental conversion efficiency, as also the tubes with larger diameters have. A self-cleaning coating applied on the outer side of the glazing and multi-coloured absorber plate is formulated and tested. Eight types of solar thermal collectors were tested and optimized.

Beikircher and Möckl [15] investigated advanced insulation methods for flat plate collectors. The collector front losses have been reduced by transparent insulation materials, the rear losses by an integrated vacuum super insulation (VSI). Four front side insulations have been developed and investigated.

Facão [16] determined the thermal performance of flat-plate solar collectors with riser and header arrangements. A more uniform flow distribution leads to a homogenous temperature distribution which gives higher collector efficiency. The *Z* distribution usually has better performance when compared to Π distribution. The design of the manifold influences the observed flow distribution. To optimize the manifold design, a correlation model was developed, based on correlations for minor pressure losses. Furthermore, the flow in this optimized geometry was simulated in 3D using the computational fluid dynamics (CFD) software code in order to confirm the results of the correlation based model. A new experimental low-intrusive technique was used to measure the flow distribution in an existing solar collector, validating the simulation results. The flow inside the absorber tubes is laminar; the major pressure loss inside riser tubes was measured using a high accuracy differential pressure transmitter, which then permits the indirect estimation of the mean velocity inside the tubes. It was the first time that this experimental methodology has been applied to analyse the flow distribution in solar collectors. The influence of the total water flow rate was analysed. For a good flow distribution it was concluded that the outlet header manifold should have a higher diameter compared to the inlet header diameter. Usually commercialised solar collectors have the headers with same diameter.

Various studies reviewed above shows the importance of performance improvement of the collector in solar water heating system. In this study the different geometries of absorber plate namely flat plate, v-grooved and square pulse are designed and constructed with the aim of the cost and to bring out better efficiency.

2. OBJECTIVE

To investigate the performance of double glazed flat plate solar water heater subjected to various absorber plate geometries (flat type, v-grooved and square pulse) at different mass flow rate.

3. EXPERIMENTAL SETUP

The experimental setup made up of mild steel box and different shape of absorber plates. The line diagram of the experimental setup and the different geometries of absorber plates are shown in Figures 1 and 2, respectively. Mild steel flat plate of 1.4 x 0.7 m^2 was employed as absorber plate. Two glass plates of similar size were used to protect the absorber plate from heat loss to atmosphere. A gap of 2 cm was maintained in between top glass cover and the bottom glass cover. The bottom of the collector was covered with heat resisting material to minimize the heat loss to the surroundings.

Flat absorber plate: The flat absorber plate made of mild steel, width of the absorber plate is 0.69m, length of the plate is 1.38m and the thickness is 22 gauge.

V-grooved absorber plate: The v-grooved absorber plate is made of mild steel, width of the absorber plate is 0.69m, length of the plate is 1.39m and the thickness is 22 gauge.

Square pulse absorber plate: The square pulse absorber plate made of mild steel, width of the absorber plate is 0.69m, length of the absorber plate is 1.39m and the thickness is 22 gauge.

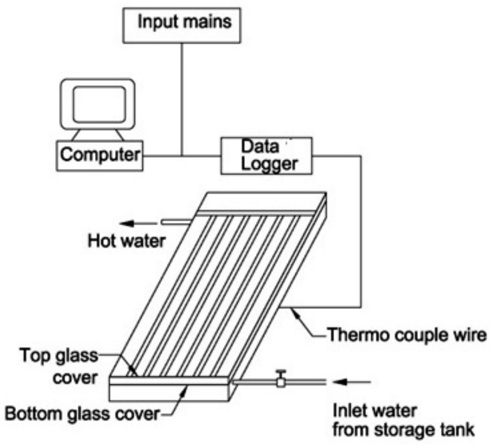

Fig. 1. Double glazed solar water heater.

Fig. 2. Three different types of absorber plates (flat plate, square pulse andv-grooved).

Fig. 3. Double glazed solar water heater.

Fig. 4. Agilent data logger.

Table 1. Specification of the experimental setup (double glazed solar water heater).

Length of the collector	1.42m
Width of the collector	0.7m
Area of the collector	$1m^2$
Diameter of the tube	0.0127m
Tube centre to centre distance	0.1m
Length of the absorber plate	0.69m
Material of the absorber plate	M.S
Absorber plate thickness	22 gauge
Glass cover emissivity	0.85
Refractive index	1.5
Diameter of the header pipe	0.019m
Insulating material	glass wool
Density of the insulating material	$200kg/m^3$

4. MEASURING EQUIPMENT

An Agilent data logger (34970A) shown in Figure 4 has been used to acquire all the data. T-type copper constantan thermocouples have been used to measure the inlet, outlet, absorber plate, glass plate, and ambient temperatures.

5. EXPERIMENTAL PROCEDURE

As an initial preparation, the data logger is switched on 10 minutes before the commencement of the experiment. This is to ensure the proper connections. Readings are recorded at a uniform interval of 1 min from 10.00 am to 3.30 pm. Experiments were conducted on flat plate, v-grooved and square pulse with uniform mass flow rate and the datas were collected in the data logger. The thermal efficiency and heat gained by the water were calculated and the results are discussed.

The thermal performance of double glazed solar water heater was done. T-type thermocouple with an accuracy of $\pm$ 0.1^{0}C have been used to measure the inlet, outlet, absorber plate, glass plate and tube temperatures global pyranometer (Model PSP serial No. 35031F30) mounted on a surface parallel to the collector surface has been used to measure the global solar irradiance. A temperature sensor with an accuracy of $\pm$ 0.1^{0}C was used to measure ambient temperature. All the data have been collected using data logger at an interval of 1 minute.

Based on the measured parameters, the effective heat gained by the double glazed flat plate solar water heater can be calculated as:

$$Q_{U}= \dot{m} * C_p * \Delta T \quad (1)$$

The thermal efficiency of the double glazed solar water heater can be calculated as:

$$\eta = QU \ / A_{C} * G \quad (2)$$

Where Q_U is the effective heat gain, W; $\dot{m}$ is mass flow rate of water kg/s; C_p is the specific heat of water , J/Kg. K ; ΔT is the change in water temperature, ^oC; η is the thermal efficiency, % ; A_C is the aperture area, m^2; G is the solar irradiance, W/m^2.

6. RESULTS AND DISCUSSION

The performance of the double glazed solar water heater with different absorber plates for various mass flow rate (0.0041, 0.0083 and 0.0125 kg/s) have been investigated and presented in this work.

Figure 5 presents the heat gained by the water for three different absorber plates namely flat-grooved and square pulse at a mass flow rate of 0.0041kg/s. It is evident from the plot that all the three absorbers have been behaving similar and the flat absorber performs better than other two.

Similarly, Figures 6 and 7 show that the flat absorber is performing relatively better at 0.0083kg/s and 0.0125kg/s flow rate.

Figures 5 to 7 show that the heat gained by the flat absorber plate is more than other two plates (v-grooved and square pulse) because flat absorber covers the full aperture area of the double glazed solar water heater, Absorb the maximum amount of solar irradiance and conduct the heat to the working fluid more effectively with minimum loss.

Figure 8 presents different absorber plate temperature at a mass flow rate of 0.0125 kg/s out of the three plates, flat absorber gains maximum temperature of 107 ^{0}C around 1.00 pm. So, the flat absorber covers the full aperture area of the collector and absorb maximum possible amount of solar irradiance, compare to other absorber plate geometries.

Figure 9 presents the global solar irradiance in the aperture plane for the three continuous days measured at 1 minute interval. During the testing time (10.00 am to 3.30 pm), the solar irradiance gradually increases and then decreases, reaching maximum during midday, the solar irradiance ranges for the three days have been 650 W/m^2 to 950 W/m^2, 750 W/m^2 to 1050W/m^2 and 725 W/m^2 to 950 W/m^2.

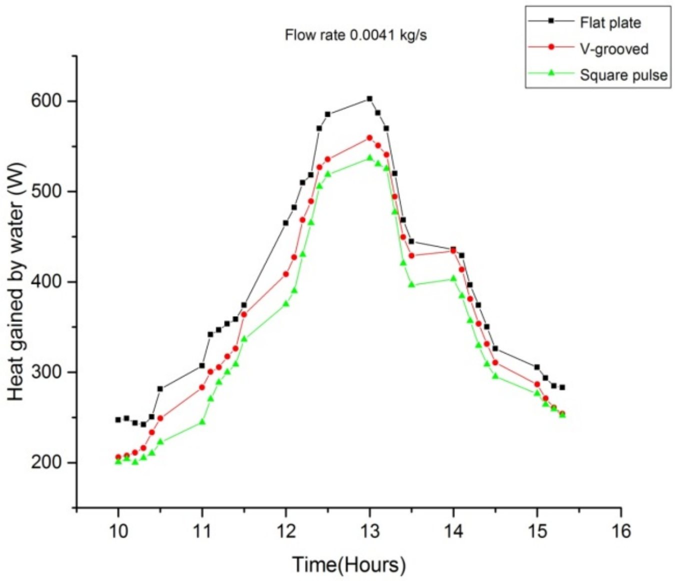

Fig. 5. Heat gained by water versus time (flow rate at 0.0041 kg/s).

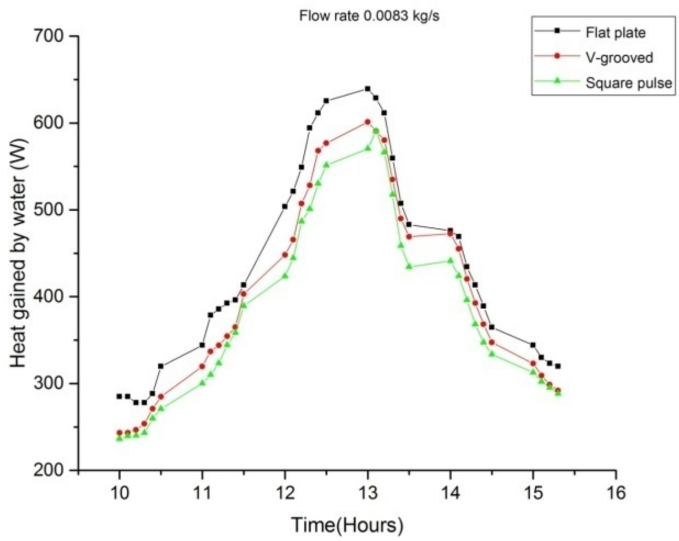

Fig. 6. Heat gained by water versus time (flow rate at0.0083 kg/s).

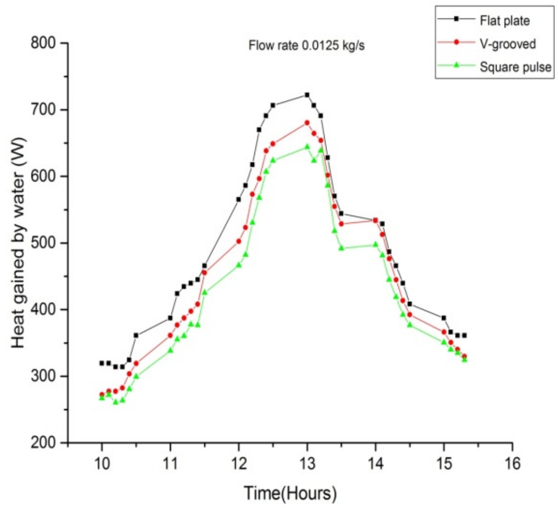

Fig. 7. Heat gained by water versus time (flow rate at 0.0125 kg/s).

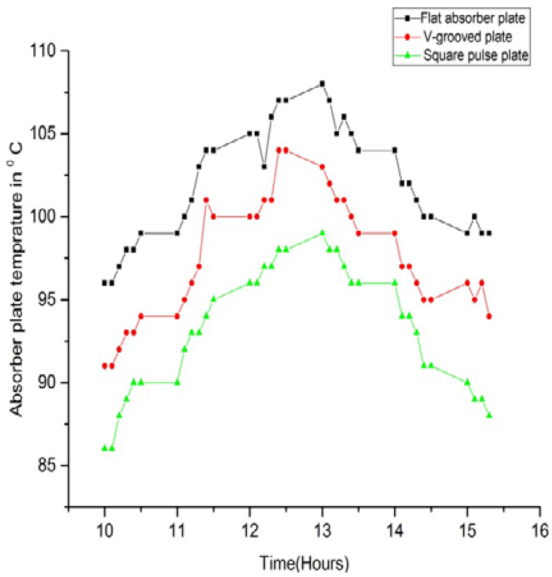

Fig. 8. Absorber plate temperature versus time (flow rate 0.0125 kg/s).

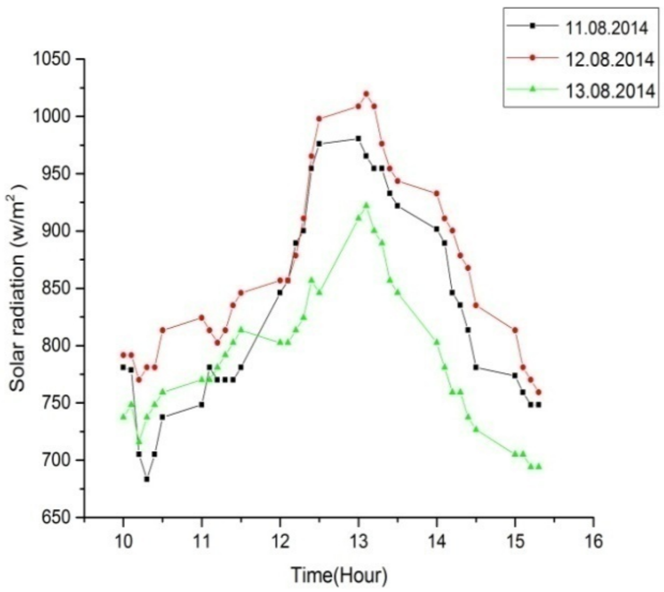

Fig. 9. Solar intensity versus time.

From the above figures it has been found that the flat type absorber plate is performing satisfactorily than v-grooved and square pulse absorber geometries with respect to heat gained by the water and the thermal efficiency of the solar water heater.

7. CONCLUSION

Experiments were conducted with double glazed solar water heater for the different geometric absorber plates subjected to uniform mass flow rate to find the performance of the set-up. The following conclusions were obtained from this study.

1. The flat absorber geometry temperature is higher than the other geometries during experimentation.
2. Thermal efficiency is higher for flat absorber geometries.
3. Heat gained by the water in flat absorber geometry is comparatively higher than other geometries.
4. Thermal efficiency and heat gained by the water increases with increase in mass flow rate.

REFERENCES

[1] Farahat S. and F. Sarhaddi. 2009. Exergetic optimization of flat plate solar collectors. *Renewable Energy* 34:1169-1174.

[2] Zeghiba I. and A. Chaker. 2011. Simulation of solar water heating system. *Energy Procedia* 6: 292-301.

[3] Duffie J.A. and W.A. Beckman. 1980. *Solar Engineering of Thermal Processes*, 3rd edition. John Wiley & Sons, New York: pp 238-321.

[4] Hsieh J.S., 1986. *Solar Energy Engineering*, revised edition. Prentice-Hall, New Jersey: 110-138.

[5] Abdul Majeed A.M., Sulaiman M.Y. and Sopian K., 2012. Thermal analysis of concentrating flat plate solar water heater absorber using 'ANSYS' simulation. In *Proceedings of the International Conference on Engineering and Built Environment (ICEBE)*, Malaysia, 6-7 November: pp. 1-7.

[6] Kalogirou S.A., 2004. Solar thermal collectors and applications progress. *Energy and Combustion sciences* 30: 231-295.

[7] Kundu B., 2002. Performance analysis and optimization of absorber plates of different geometry for flat plate solar collector: a comparative study. *Applied Thermal Engineering* 22: 999-1012.

[8] Chong K.K., 2012. Study of a solar water heater using stationary v-trough collector. *Renewable Energy* 39: 207-215.

[9] Ihaddane N., Ihaddadene R. and Mahdi A., 2014. Effect of distance between double glazing on the performance of a solar thermal collector. In *International Conference on Renewable Energies and Power Quality (ICREPQ14)*, Cordoba, Spain, 8-10 April.

[10] Duffie J.A and W.A. Beckman. 1991. Solar Engineering of Thermal Processes, 2nd edition. John Wiley and Sons, New York, USA. pp. 488.

[11] Jaisankar S. and T.K. Radhakrishnan. 2009. Studies on heat transfer and friction factor characteristics of thermosyphon solar water heating system with helical twisted tapes. *Energy*: 1054-1064

[12] Kajavali A. and B. Sivaraman. 2014. Investigation of heat transfer enhancement in a parabolic trough collector with a modified absorber. *International Energy Journal* 14(2014): 177-188.

[13] Sae-jung P. and T. Krittayanawach. 2015. An experimental study of thermo siphon solar water heater in Thailand. *Energy Procedia* 79: 445-447.

[14] Visa I. and A. Duta. 2015. Design and experimental optimization of a novel plate solar thermal collector with trapezoidal shape for facades integration. *Applied Thermal Engineering* 90: 432-443.

[15] Beikircher T. and M. Möckl. 2015. Advanced solar flat plate collectors with full area absorber, front side film and rear side vacuum super insulation. *Solar Energy Materials and Solar Cells* 141: 398-406.

[16] Facão J., 2015. Optimization of flow distribution in flat plate solar thermal collectors with riser and header arrangements. *Solar Energy* 120: 104-112.