Vol. 5 No. 2 October 2017 ISSN: 2321-788X UGC Approval No: 43960 Impact Factor: 2.114

THERMAL EVALUATION OF SOLAR FLAT PLATE COLLECTOR WITH SHADOW EFFECTS

Article Particulars

Received: 28.8.2017 Accepted: 12.10.2017 Published: 30.10.2017

J. ABDUL AZIZ
M.Phil. Research Scholar
Post Graduate & Research
Department of Physics
The American College, Madurai, India

S. PAUL MARY DEBORRAH
Associate Professor
Post Graduate & Research
Department of Physics
The American College, Madurai, India

Introduction

Sun is the ultimate source of energy and the energy that comes from the sun directly reaches the earth through the atmosphere is known as solar energy. Most of the solar thermal systems are technically matured and they have attained the user friendly status. These solar thermal energy conversion systems are classified into the following categories of applications in the order of complexity and rising cost. Low temperature applications (below 100oC) for most common applications such as water heating, air heating, drying and desalination.

Medium temperature (100 to 300oC) for the applications like cooking, steam generation for industrial use, refrigeration, water pumping and power generation. High temperature applications (above 300oC) are for power generation. It is worth, mentioning here that the solar thermal systems pertaining to low temperature applications are commercially available and they are used by millions of people at various parts of the world. Solar water heating is one of the most attractive and technically matured solar thermal applications from an economic standpoint. In many countries of the world, it is already competing on equal terms with systems using other energy sources. Heating water using solar thermal route is one of the most efficient renewable energy technologies in terms of Energy, Environment and Economic perspectives and so this process can be adopted in domestic, commercial, agricultural and industrial sectors to match the demand and supply of hot water. So, it is imperative to study the thermal characteristics of solar water heaters extensively. This study results will provide the thermal efficiency of the solar collector, which is required for installing solar water heaters in various sectors as per temperature requirements. The factors that affect the thermal performances of the solar water heating systems in urban as well as rural areas are deposition of dust and falling of shadows. Of course, the dust can be cleaned periodically. But in some unavoidable conditions, the shadow effects cannot be avoided. So it is essential to evaluate the thermal performances of the solar collectors under shadow conditions.

Shadow may be caused by the sidewalls that are made by high reflectance materials. It may also be caused by supports that retain the solar water heating systems. By finding out the thermal efficiencies under the shadow effect, the reduction in the actual thermal efficiency of the solar collector may be found. As the thermal efficiencies of the solar water heaters are influenced by the shadow effects, it is essential to the study the effect of shadow on the thermal performances of the solar water heaters. So, this study will also provide the thermal efficiency of the solar collector under shadow effects. Considering these actualities, the following objectives are formed. (i) To evaluate the instantaneous thermal efficiency of the solar flat plate collector for various inlet temperatures. (ii) To evaluate the instantaneous thermal efficiency of the solar flat plate collector under shadow effects for various inlet water temperatures. (iii) To assess the reduction in thermal efficiency due to shadow effects.

The present investigation are not only to quantify the instantaneous thermal efficiency of the solar flat plate collector for various inlet water temperature but also to estimate the thermal efficiency of solar flat plate collector under shadow effects.

Experimental details

One commercially available solar flat plate collector was chosen and the experimental investigations were carried out. The standard procedures were adopted for finding out these thermal performances as well as thermal losses from the solar flat plate collectors.

Initially, the dimensions of the components such as channel section, bottom sheet, insulation material, and riser and header tubes were measured using screw gauge and Vernier caliper. The measured dimensions are presented in Table 1. As the dimensions of the components are as per the standards prescribed by Ministry of New and Renewable Energy, Government of India, they can with stand at all meteorological conditions. In fact, their durability and hence the life period will also be high.

Table: 1 Dimension of components

Sl.No.	Components	Dimensions (in mm)
1.	Channel section thickness	1.60
2.	Bottom sheet thickness	0.70
3.	Insulation side thickness	25.00
4.	Insulation bottom thickness	50.00
5.	Riser Diameter	12.70
6.	Header Diameter	25.40

Next, the transmittance of the glass cover was calculated by taking the radio of the integrated values of the global solar radiation through the glass cover and that received without glass cover that are found experimentally. The measured transmittance values are presented in Table 2. As the transmittance of glass cover is as per the standards prescribed by Ministry of New and Renewable Energy, Government of India, It can transmit substantial solar radiation. This is necessary for having better thermal performance in solar water heaters.

Table: 2 Transmittance of glass cover

S.No.	Solar Radiation Without glass cover	Solar Radiation with glass cover (in W/m2)	Transmittance (in %)
1	800	672	84
2	848	710	84
3	894	751	84

The thermal performances of the solar water heater were found experimentally with and without shadow effects. The collector mounting frame angle, orientation and location influence the results of thermal performance tests. So, the appropriate considerations were taken into account in respect of the collector mounting frame, orientation and tilt angle and choice of location in the present investigation. The experimental setup for solar water heater is as shown in Fig. (1)

Fig. (1) Experimental setup for solar water heater

As open mounting structure was used in the present investigation and so this set up allowed air to circulate freely around the collector. The solar water heater was mounted such that their lower edges were higher than 500mm above the local ground surface. Warm currents of air, such as those, which could rise up from the walls of a building was not allowed to pass over the solar water heater. The collector-mounting frame was in no way obstructed the aperture of the collector, and did not significantly affect the back or side insulation. The solar water heater was mounted outdoors at an angle of 30o from horizontal so as to have a normal incidence of solar radiation. It was mounted in fixed position facing equator. The solar water heater was located in such way that shadows would not be cost on the air heater at any time during the test period and there would be no significant solar radiation reflected on to it by surrounding buildings or surfaces during the tests. Surfaces, such as, large expanse of glass, metal or water, or having high temperature namely chimneys cooling towers, hot exhausts, were avoided from field view of the collector. Instantaneous efficiency measures how effectively the incident energy on the solar collector is transferred to the air flowing through the collector.

The following test conditions were observed for conducting the instantaneous efficiency test in the present investigation.

a) The total solar irradiance at the plane of collector aperture was not less than. 700 W/m^2.
b) The average value of the surrounding air speed lied between 0m/s and 5m/s.

Solar radiation was measured with a Sun meter (Manufactured by EDEN, Madurai). The range of this instrument is 0 – 1300 W/m2 and its precision is 1 W/m2. In fact, the sun meter is calibrated against the standard pyranometer. And the instruments used for the measurements are as shown in the Fig. (2).

Fig. (2) Instruments used for the measurements

A dry and wet thermometer was used for measuring ambient temperature. The range of these instruments is 0 – 100oC and its precision is 1oC. Alhocal thermometers were used for measuring inlet and outlet temperatures. Their ranges of measurements are 0 – 360^{o}C with precision of 1^{o}C. An anemometer in the range of 1m/s - 20 m/s with the precision of 0.1 m/s was used for measuring wind speed. The gross and aperture areas of the collectors were measured using measuring tapes. The instantaneous efficiency (η) was calculated using the standard formula. The steady state conditions that were mentioned during the tenure for experiments and the experiments were repeated with shadow effects.

Result and Discussion

The objectives of the present investigation are to study the instantaneous thermal efficiency of the solar flat plate collector for various inlet water temperatures and also to estimate the thermal efficiency of solar flat plate collector was chosen and the experimental investigations were carried out. The standard procedures were adopted for finding out these thermal performances as well as thermal losses from the solar flat plate collectors.

Finally, the thermal performance of the solar water heater was found experimentally with and without shadow effects. In this connection, the following measurements were noted during the experiments.

a) Gross area and aperture area
b) Solar radiation
c) Surrounding air speed
d) Temperature of air the collector inlet
e) Temperature of air the collector outlet
f) Mass flow rate of the water

It is worth mentioning that the mass flow rate of the water was fixed and it was set s 0.02 Kg/s square meter based on collector gross area. The collector area was measured and it was found to be 2.097 square meter.

During the period of study, the variables such as solar radiation, ambient temperature, inlet temperature and outlet temperature were recorded periodically. The recorded parameters are presented from Table 3 to Table 6.

Table: 3 Recorded parameters during thermal efficiency test Inlet temperature 30°C

S.No	Time	Solar Radiation (W/m2)	Inlet Temperature (oC)	Outlet Temperature (oC)	Ambient Temperature (oC)	Wind Speed (m/s)
1	11.00 am	724	30.0	36.4	32.2	2.6
2	11.30 am	768	30.0	36.6	32.8	1.5
3	12.30 Pm	831	30.0	37.0	33.1	1.5
4	13.00 Pm	812	30.0	37.2	33.6	2.2

Table : 4. Recorded parameters during thermal efficiency test Inlet temperature 40°C

S.No.	Time	Solar Radiation (W/m2)	Inlet Temperature (oC)	Outlet Temperature (oC)	Ambient Temperature (oC)	Wind Speed (m/s)
1	11.00 am	826	40.0	47.0	33.1	1.5
2	11.30 am	840	40.0	47.2	33.3	1.6
3	12.30 Pm	873	40.0	47.6	33.7	1.8
4	13.00 Pm	899	40.0	47.6	34.0	3.5

Table : 5. Recorded parameters during thermal efficiency test Inlet temperature 50°C

S.No	Time	Solar Radiation (W/m²)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1	11.00 am	714	50.0	55.8	33.5	1.8
2	11.30 am	738	50.0	55.9	33.8	2.2
3	12.30 Pm	780	50.0	56.2	34.0	2.6
4	13.00 Pm	830	50.0	56.6	34.1	2.9

Table: 6 Recorded parameters during thermal efficiency test Inlet temperature 60oC

S. No.	Time	Solar Radiation (W/m2)	Inlet Temperature (oC)	Outlet Temperature (oC)	Ambient Temperature (oC)	Wind Speed (m/s)
1	11.00 am	816	60.0	66.1	32.8	2.3
2	11.30 am	832	60.0	66.3	33.5	2.2
3	12.30 Pm	847	60.0	66.4	33.9	2.9
4	13.00	871	60.0	66.3	34.2	3.5

The instantaneous efficiencies of solar water heater without shadow effect for various inlet temperatures were calculated experimentally and they are shown in Table

The same procedures were followed for the same collector with shadow effects

Table: 7. Calculated instantaneous efficiency

Sl.No.	Inlet temperature (oC)	Instantaneous efficiency (%)
1	30.3	69.0
2.	40.0	68.1
3.	50.0	64.2
4.	60.0	60.0

It is obvious from the result that the instantaneous efficiency of the collectors of present investigation without shadow effect varies from 60% to 69%. The variation in the instantaneous efficiency may be correlated with the variation in inlet temperatures of water, heat transfer with respect to inlet temperatures of water, surrounding temperatures and wind speeds. It is studied earlier that the heat transfer from the conductor to the fluid decreases with respect to increase in water inlet temperatures. As it is known, wind flow shall vary the heat losses from the glass cover of the solar flat plate collector. In the experimental period, it was found that the wind speed varied from 1.5 m/s to 3.5 m/s. This range was found to be at higher sides of wind speeds that are generally recorded in the urban areas. As it is also known, ambient temperature shall affect the temperature of the solar flat plate collector. In the experimental period, it was found that the ambient temperature was greater than 30oC mostly.

The recorded and the calculated values for the Flat plate collector such as thermal efficiency test, (with 1/3 shading) for various inlet temperatures such as 30°C, 40°C, 50°C are presented form Table: 8 to 11.

Table 8: Recorded parameters during thermal efficiency test (with 1/3 shading) Inlet temperature 30oC

S. No.	Time	Solar Radiation (W/m2)	Inlet Temperature (oC)	Outlet Temperature (oC)	Ambient Temperature (oC)	Wind Speed (m/s)
1.	11.00 am	860	30.0	34.2	33.5	1.8
2	11.30 am	884	30.0	34.4	34.2	2.2
3.	12.30 Pm	861	30.0	34.4	35.2	2.9
4.	13.00 Pm	886	30.0	34.6	35.7	2.6

Table: 9 Recorded parameters during thermal efficiency test (with 1/3 shading) Inlet temperature 40°C

S. No.	Time	Solar Radiation (W/m^2)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	849	40.0	44.3	34.2	2.3
2.	11.30 am	882	40.0	44.4	34.8	2.2
3.	12.30 Pm	864	40.0	44.4	35.1	2.4
4.	13.00 Pm	898	40.0	44.7	35.9	2.6

Table: 10. Recorded parameters during thermal efficiency test (with 1/3 shading) Inlet temperature 50°C

S.No	Time	Solar Radiation (W/m^2)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	743	50.0	53.5	33.4	1.8
2.	11.30 am	712	50.0	53.4	33.7	1.6
3.	12.30 Pm	760	50.0	53.6	34.1	1.5
4.	13.00 Pm	772	50.0	53.8	34.6	2.5

Table: 11 Recorded parameters during thermal efficiency test (with 1/3 shading) Inlet temperature 60°C

S. No.	Time	Solar Radiation (W/m^2)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	860	60.0	63.8	33.8	2.2
2.	11.30 am	884	60.0	63.9	34.1	1.8
3.	12.30 Pm	861	60.0	64.1	34.6	1.6
4.	13.00 Pm	886	60.0	64.0	35.3	1.5

The calculated value for the instantaneous efficiency (with 1/3 shading) for the various temperatures are shown in Table:12.

Table: 12 Calculated instantaneous efficiency (with 1/3 shading)

Sl.No.	Inlet temperature (°C)	Instantaneous efficiency (%)
1	30.0	40.1
2	40.0	40.0
3	50.0	37.8
4	60.0	37.6

It is also obvious from the result that the instantaneous efficiency of the collectors of present investigation without shadow effect due to the coverage 1/3 of the total area of the glass cover varies from 37.6 to 40.1%. In the experimental period, it was found that the wind speed varied from 1.5 m/s to 2.9 m/s. This is also found to be higher that are generally recorded in the urban areas. In the experimental period, the ambient temperature was in the range of 33.5 to 35.9°C. The recorded and the calculated values for the other collectors such as thermal efficiency test, (with 1/4 shading) for various inlet temperatures such as 30°C, 40°C, 50°C are presented form Table:13 to 16.

Table: 13 Recorded parameters during thermal efficiency test (with 1/4 shading)Inlet temperature 30°C

S. No.	Time	Solar Radiation (W/m^2)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	850	30.0	35.4	29.5	1.8
2.	11.30 am	872	30.0	35.2	29.8	1.5
3.	12.30 Pm	867	30.0	34.9	30.4	1.7
4.	13.00 Pm	890	30.0	34.6	30.9	1.8

Table 14: Recorded parameters during thermal efficiency test (with 1/4 shading) Inlet temperature 40°C

S. No.	Time	Solar Radiation (W/m^2)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	862	40.0	44.5	30.1	1.6
2.	11.30 am	878	40.0	44.7	30.3	2.6
3.	12.30 Pm	886	40.0	44.5	30.8	1.5
4.	13.00 Pm	896	40.0	44.7	31.5	1.9

Table 15: Recorded parameters during thermal efficiency test (with 1/4 shading) Inlet temperature 50°C

S. No.	Time	Solar Radiation (W/m²)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	821	50.0	53.4	30.8	1.5
2.	11.30 am	836	50.0	53.3	31.3	1.9
3.	12.30 Pm	832	50.0	53.1	32.6	2.3
4.	13.00 Pm	859	50.0	53.0	32.8	2.9

Table 16: Recorded parameters during thermal efficiency test (with 1/4 shading) Inlet temperature 60°C

S. No.	Time	Solar Radiation (W/m²)	Inlet Temperature (°C)	Outlet Temperature (°C)	Ambient Temperature (°C)	Wind Speed (m/s)
1.	11.00 am	786	60.0	63.8	29.8	2.2
2.	11.30 am	780	60.0	63.9	30.4	2.3
3.	12.30 Pm	792	60.0	63.6	31.4	2.3
4.	13.00 Pm	801	60.0	63.8	31.6	2.8

The instantaneous efficiencies of solar water heater without shadow effect for various inlet temperatures were calculated experimentally and they are shown in Table. 17.

Table: 17 Calculated instantaneous efficiency (with 1/4 shading)

Sl.No.	Inlet temperature (°C)	Instantaneous efficiency (%)
1	30.0	46.0
2	40.0	41.6
3	50.0	38.1
4	60.0	39.9

It is also obvious from the results that the instantaneous efficiency of the collectors of present investigation without shadow effect due to the coverage ¼ of the total area of the glass cover varies from 38.1% to 46.0%. In the experimental period it was found that the wind speed varied from 1.5 m/s to 2.9 m/s. In the experimental period, it was found that the ambient temperature was in the range of 29.5 to 32.8°C.

Thermal Evaluation of solar Collectors with shadow effects were successfully calculated. It is obvious from the results that instantaneous efficiency of the collectors of present investigation varies from 60% t 69% without shadow effect. From 37.6% to 40.1% with shadow effect due to the coverage 1/3 of the total area of the glass cover and from 38.1 to 46.0% with shadow effect due to the coverage 1/4 of the total area of the glass cover. The variation in the instantaneous efficiency may be correlated with the variation in inlet temperatures of water, heat transfer with respect to inlet temperatures of water, surrounding temperatures and wind speeds. In the experimental period, it was found that the ambient temperature was in the range of 33.5 to 35.9°C. As the inlet temperature increases, the instantaneous efficiency of (1/3), and the efficiency of (1/4) decreases. From this results, the temperatures, wind speeds and heat transfers are found to be the major factors that can affect the thermal efficiency of the solar flat plate collectors with shadow effects. The performances of the solar flat plate collector of present investigation without shadow effect are satisfactory, as they exceed 65% that is fixed by American Standards for Water Heating It is studied that the shadow effects vary the thermal performance of the solar water heater.

Conclusion

On the basis of the testing results of the present investigation, it is concluded that the solar flat plate water heaters can be used for low temperature applications in domestic, commercial, agricultural and industrial sectors of our country effectively but also that at most care should be taken during installation, as the coverage of shadow and thermal performances are inversely proportional to each other.

References

1. Bannerot, R.B, Yi- Weq Tu, Hoton , 1992, A Simple Device for Monitoring Flow Rates in Solar Water Heaters, Solar Energy Engineering 114 (1) : 47 – 52
2. Bansal, N.K., Buddhi, D., 1992, Performance Equations of a Glass Plate Collector cum Storage System using Phase Change Materials, Solar Energy 48 (3) : 185-194.
3. Daniel Behraman, 1979, Solar Energy – The Awakening Science , Rout ledge and Kegan Paul Ltd., London , U.K.
4. Avidson, J.H., Walka, H.A., 1992, Design, Optimisation of a two phase Solar Water Heater , Solar Energy Engineering 114 (1) : 53 –61
5. Eggers-Lura, A., 1979, Solar Energy in Developing Countries, Pergamon Press, New York, U.S.A.
6. Frank Kreith and Jan F.Kreider, 1978, Principles of Solar Engineering, Hemisphere Publishing Company, London.U.K.
7. Garg, H.P., Prakash , J., 1997, Advances in Solar Energy Technology, Reidel Publishing company , Andhra Pradesh, India.
8. Horiqome,T., Kimura, K., Takura,T., 1990, Clean And Safe Energy Forever, Pergamon Press , New York, U.S.A.
9. John A.Duffe and William A.Beckman, 1980, Solar Engineering of thermal processes, A Wiley Interscience Publications, New York , U.S.A.
10. Kari W.Boer, Barbara H.Glenn, 1979, Sun, Pergamon Press , New York, U.S.A.

11. Nahar, N.M., Tsena, H., 1990, Design, Development and Testing of an Improved Solar Water Heaters, National Solar Energy Conversion Proceedings, Calcutta, India. Page No. 36 – 39.
12. Nayak, J.K., Saha, H., 1990, Energy Pay- Back Period of a Solar Collector, National Solar Energy Convention Proceedings, Calcutta- India. . Page No. 19 – 21.
13. Nejat Veqiroglu, T., 1982, Alternative Energy Sources, Elsevier Science Publishing Company, INC , New York , U.S.A.
14. Nejat Veqiroglu,T., 1976, Solar Cooling and Heating , Hemisphere Publishing Corporation, Washington, U.S.A.
15. Nicosia, 1992, An Investigation into the Performance and cost effectiveness of Solar Water Heaters , Renewable Energy 2 (3) : 76-79.
16. Rai, G.D., 1995 , Solar Energy Utilization , Khanna Publishers, Delhi, India.
17. Rai, G.D., 1996, Non-Conventional Energy Sources, Khanna Publishers, Delhi, India.
18. Richard Neville, 1986, Solar Energy Conversion, Pergamon Press, New York, U.S.A.
19. Spirkl, W., Muschaweek, J., 1992, General Model for Testing Solar Domestic Hot water systems, Solar Energy Materials and Solar Cells 28 (1) : 93 -102.
20. Sukhatme, S. P., 1996, Solar Energy, Tata McGraw – Hill Publishing company Limited, Delhi, India.
21. Suohrcke,H. Mc Cormick , P. Town Sville, 1992, A Performance Prediction Method For Solar Energy Systems, Solar Energy 48 (3): 169-175 .
22. Tiwari, G.N., Singh, A.K., 1993, Thermal Efficiency of Collection cum Storage Solar Water Heater, Energy Conversion & Management 34 (2) : PP.147-52.
23. Tiwari, G.N., Usha Singh, Nayak, J.K., 1985, Applied Solar Thermal Energy Devices, Andhra Pradesh , India.
24. Wenxian, L., Enreng, L., Yunnan, 1990 , A model for solar water heaters assisted by Auxiliary electric heaters, Energy 15 (9): 767 – 872.
25. Yeh , H.M. ,Tsena, 1990, A Water Heater with a Parallel Flat-Plates Radiator, Energy 15 (12): 1129 - 1141.