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PERFORMANCE ENHANCEMENT OF SOLAR FLAT PLATE COLLECTOR WITH ALUMINIUM FOIL REFLECTORS AND TRAPEZOIDAL GLASS COVER

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ABSTRACT

Solar energy is believed to be future source of energy for preventing environmental degradation. Solar collectors are the most important components in a solar thermal heating system. Flat plate collectors are simple in design and construction, quite economical and popular compared to other type of solar collectors. In the present paper, a solar flat plate collector is modified by (i) replacing flat glass cover by trapezoidal glass cover and (ii) placing aluminium foil reflectors on both sides with trapezoidal cover. Experimental analysis has shown significant increment in efficiency as high as 12% for trapezoidal glass cover. Moreover, trapezoidal cover with aluminium foil reflectors have delivered the efficiency increment up to 29% compared to flat cover collector. The maximum outlet and inlet water temperature difference is as high as 14.3 ^{0}C compared to 11.4 ^{0}C in case of flat cover collector. The maximum top loss co-efficient is reduced by a factor 2.43 times in case of trapezoidal glass cover. Other parameters have also shown significant improvement in the performance of collector.

Keywords: solar flat plate collector, trapezoidal glass cover, solar energy, aluminium foil reflector.

A_p= collector plate Area (m^2)
C_p= specific Heat Capacity (Jkg^{-1}k^{-1})
I = incident Radiation of Collector (Wm^{-2})
L = length of Collector (m)
m = mass flow rate (Kgs^{-1})
T = temperature (K)
U_T = Top loss co-efficient
h = heat transfer co-efficient

Greek
η = Efficiency
$\boldsymbol{\sigma}$ = Stefan-Boltzmann constant

Subscripts
a = ambient
c = glass cover
p = collector plate
f = fluid
i = inlet
o = outlet
w = water

1. INTRODUCTION

In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them. The commercially available energy sources are electricity, coal, oil, gas and lignite. However, all of these sources are expected to be exhausted in a matter of few decades, due to their ever increasing demand and relatively slow formation. Also, with their decreasing levels and increasing demand the cost of these resources are likely to increase in the future. In view of this scenario, it becomes necessary for any country to invest in the research of renewable energy sources and make it more commercially viable.

One of the major renewable energy resources is solar energy. The main advantage of it is that it is available everywhere and in abundance especially in India, and its running cost is almost negligible. Solar energy can be converted into three main types, i.e. thermal energy, chemical energy (solar fuel) and electricity. Direct conversion of solar radiation into electricity is made possible by the development of Photo-voltaic Cell Technology. However, its efficiency is still low and storage of sufficient amount of electricity remains one of the major challenges of this industry. Solar fuels eliminate the problem of storage and are seen as an alternative to fossil fuels. However, it faces similar problems (as that of fossil fuels) like carbon emission and low efficiency obtained in conventional thermal power plants. Many of the day-to-day applications involve the use of heating, such as space heating and water heating for domestic (mainly) and industrial purposes. Such requirements can be met by using active or passive solar heating systems. Since they directly convert radiation into heat energy, a very high efficiency is obtained with very less cost as well as carbon footprint. One of the major challenges in this technology is that on a cloudy day, when amount of direct radiation is very less, the heat available may not be enough to serve the purpose. Thus, research is being conducted to improve the efficiency of these systems in order to make it usable in all the weather conditions.

A solar collector is a device for collecting solar radiation and transfers the energy to a fluid passing in contact with it. Utilization of solar energy requires solar collector. Solar energy collector, with its associated absorber, is the essential component of any system for the conversion of solar radiation energy into more usable form. Soteris A. Kalogiroue *et al* [1] 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 uses of solar energy is attempted followed by a description of the various types of collectors including flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, 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 combinations of incident radiation, ambient temperature, and inlet fluid temperature. Wang *et al* [2] investigated with several collectors connected in parallel to interpret a single collector.

Duffie and Beckman [3] observed the thermal performance of a direct solar domestic hot water system operated under several controlled strategies. Rasmussen and Svendsen [4] calculated the efficiency of soar flat plate collector using the simulation program SOLEFF. Weitbrecht V *et al.* [5] performed an experimental study in a water solar flat plate collector with laminar flow conditions and observed the distribution of flow through the collector. The higher collector efficiency factor was observed at a higher rate of water flow.

Jianhua Fan *et al* [6] theoretically and experimentally investigated the flow and temperature distribution in a solar collector panel with an absorber consisting of horizontally inclined strips. The measured temperatures are compared to the temperatures determined by the CFD model and there is a good similarity between the measured and calculated results. Tabaei and Ameri, [7] investigated in summer to obtain the highest solar intensity on the collector, the inclination angle of the reflector was maintained at 45°with respect to the horizontal axis.

Sivakumar *et al* [8] changed the design parameters for solar flat plate collectors. They changed number of riser tubes and their arrangements. Zigzag arrangement in the riser tube provided higher efficiency compared to straight arrangement. Shekhar *et al.* [9] conducted theoretical and experimental analysis on the solar flat collector with single glass cover and showed the significance of emissivity of absorber plate on the performance of collector. They systematically calculated loss co-efficient and effect of emissivity on top loss co-efficient.

Bhowmik *et al* [10] used glass mirrors on both the sides of flat plate collector. They achieved approximately 10 % improvement in the efficiency of collector. Manual tracking was provided during the testing of collector.

2. EXPERIMENTAL SET-UP AND PROCEDURE

2.1 Experimental set-up

In order to carryout comparative study of flat plate collector with proposed modifications, a commercially available collector with following standard dimensions/specifications has been purchased. The photograph is shown in Table-1.

Table-1. Specifications of Solar flat plate collector under consideration.

Specification/Dimensional Parameter	Value
Absorber plate area	1900 x 950mm
Diameter of copper pipe (risers)	12.4mm
Diameter of header and footer pipe	25.66mm
Thickness of cover glass	4.5mm
Number of glass cover	1
Thickness of copper absorber plate	0.7mm
Insulation	Glass wool
Thermal conductivity of glass wool	0.04 W/m K
Back Insulation Thickness	1.5 cm
Absorber Plate Material	Copper
Thermal Conductivity of Plate Material	350 W/m-K
Vertical Tube pitch	10.5 cm
Size of Collector after reflector sheets	204.5 cm ×176.5 cm
Projected area of collector after reflector sheets	3.6 m^2

Initially experimental analysis was conducted on collector with flat glass cover. Collector is connected with a water tank with capacity of 20 litre. Water was allowed to enter from the bottom of the collector through piping provided and allowed to flow from collector under thermosyphon effect. Mass flow rate of water was measured carefully by using conventional stopwatch method and fixed volume flask at the outlet. Radiation intensity readings were recorded by standard pyranometer (LP PYRA 03) and also compared with the standard

available radiation data for Ahmedabad (23°12' N, 72°54' E). Three thermocouples were mounted at different locations each on absorber plate and glass cover to measure the temperature. RTD sensors have been used to measure the inlet and outlet water temperature.

Experiments were conducted in three stages to evaluate and compare the performance of collector. Initially, experiment was conducted with flat glass cover on 23rd April 2018. Afterward, collector was modified with replacing flat glass cover with trapezoidal glass cover and evaluated on 1st May, 2018. As the size of collector is large, water is allowed to flow under the effect of natural circulation.

Figure-1. Photograph of Flat Plate collector with flat glass cover.

Figure-2. Photograph of Flat Plate collector with flat Collector with trapezoidal cover.

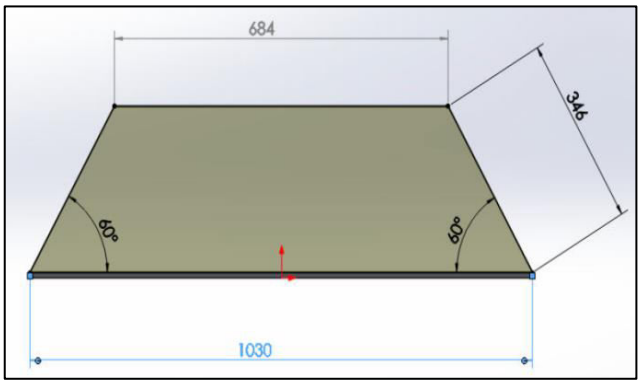
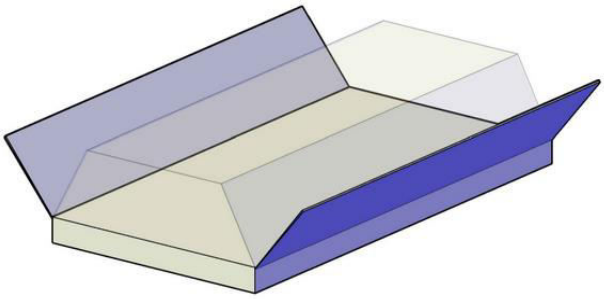
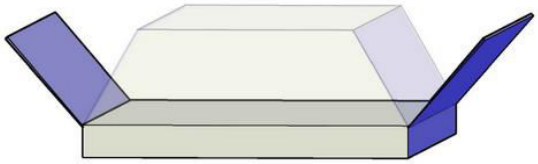


Figure-3. Physical dimensions of Trapezoidal Glass cover.

Finally two fixed aluminium foil reflectors were placed at an angle of 45° to the plane of collector and experimented on 10th May 2018. 45°angle was selected to reflect maximum amount of radiation throughout the day irrespective of the position of the sun. In all three cases, the collector tilt angle has been kept constant equals to 35°. The modified collector with trapezoidal glass cover and trapezoidal cover with reflector is shown in figures below.



(a)



(b)

Figure-4. CAD models of collector with trapezoidal glass cover and aluminium foil reflectors.

2.2 Experimental procedure

Experiments were conducted at Institute of Technology, Nirma University, Ahmedabad, India (23.0225° N, 72.5714° E) on 23rd April 2018, 1st May 2018 and 10th may 2018. The daily average solar radiation intensity values from 9:00 a.m. to 4:00 p.m. for these days were 760 W/m^2, 805 W/m^2 and 720 W/m^{2}respectively for global radiation.

Collector was placed at a fixed position at an angle of 35° tilted with the horizontal, facing due south.

No manual tracking was provided. Experiments were conducted for three different cases to compare the results and performance.

2.3 Experimental calculations

Efficiency of the collector is calculated for different modifications by the method suggested by Sivakumar *et al* [8] and Sukhatme and Nayak [11]. The collector area is considered 1.8 m^2 for flat plate and trapezoidal case and 3.6 m^2 is taken for collector with reflectors on both sides. Reflectivity of aluminium foil is taken 0.88 and 70 % radiations are assumed to incident on collector. So intensity factor comes out 0.616. Top loss co-efficient is calculated for flat plate collector and collector with trapezoidal glass cover by the method suggested by Sukhatme and Nayak (2008).

Efficiency of Solar Collector $\eta = \frac{\dot{m}C_p(T_{ow}-T_{iw})}{\sum A_c \times I}$

Calculation of top loss co-efficient [11]

$$\frac{q_t}{A_p} = h_{p-c}(T_{pm} - T_c) + \frac{\sigma\,(T_{pm}^4 - T_c^4)}{\left(\frac{1}{\epsilon_p} - \frac{1}{\varepsilon_c} - 1\right)}$$

$$\frac{q_t}{A_p} = h_w(T_c - T_a) + \sigma\,\varepsilon_c\,(T_c^4 - T_{sky}^4)$$

$$h_w = 8.55 + 2.56\,V_\alpha$$

$$T_{sky} = T_a - 6$$

$$U_t = \frac{q_t/A_p}{T_{pm} - T_a}$$

2.4 Uncertainty

RTD Temperature sensors have accuracy of ± 0.1 ^{0}C. Accuracy in flow rate measurement is 1 ml/s. Second class pyranometer (LP PYRA 03) with accuracy of ± 5 W/m^2 has been used in the measurement of radiation intensity. Total uncertainty in the calculation of efficiency lies below 5 %. Also change in thermo physical properties are not taken into account. Uncertainty is not of much significant as in the present article, comparative experimental analysis has been carried out by using same instrumentations.

3. RESULTS AND DISCUSSIONS

Commercially available solar flat plate collector is used for experimentations. Experiment is conducted on 23rd April for the flat glass cover. Average value of solar intensity on the day from 9:00 am to 4:00 pm was 760 W/m^2. Temperature, intensity and mass flow rate readings were taken carefully between 9:00 am to 4:00 pm. The same collector then modified by replacing flat glass cover with trapezoidal glass cover.

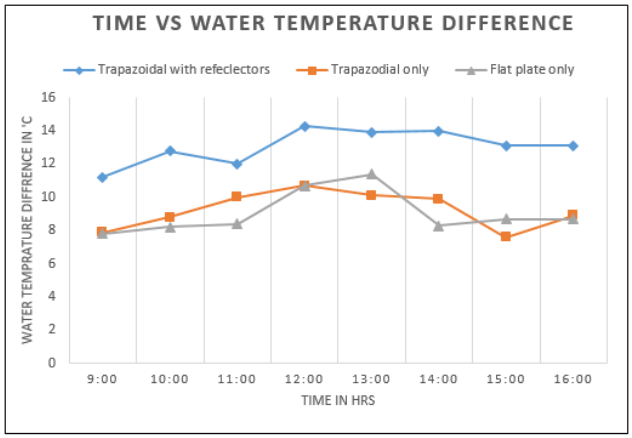


Figure-5. Time vs. Water Temperature Difference for flat plate, trapezoidal and trapezoidal with aluminium reflector.

Experiment was conducted on 1st May with trapezoidal glass cover. Radiation intensity on 1st May was 805 W/m^2. Finally, aluminium foil reflectors were attached at an angle of 45^0 on both sides. No tracking is provided during the experiments. Reading were taken on 10th May and average intensity was 720 W/m^2.

Figure-5 shows the graph between water temperature differences against time in hours for all three modifications. It should be noted that the outlet temperature is not useful parameter for evaluating performance of collector as it is dependent on radiation intensity. From the graph, it is clear that the collector with trapezoidal glass cover and reflectors delivers as high as 14.3 ^{0}C water temperature difference at 12:00 pm which is in good agreement with Sivakumar *et al.* [8]

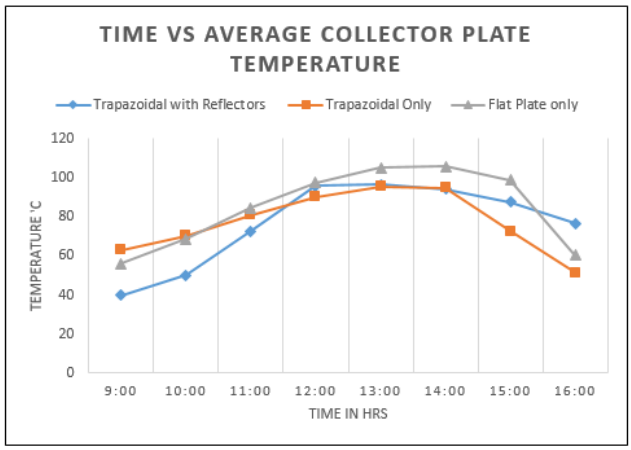


Figure-6. Time vs. Collector plate temperature for flat plate, trapezoidal and trapezoidal with aluminium reflector.

Three temperature sensors have been mounted on the surface of absorber plate to measure average collector plate temperature. Figure-6 shows the time against avg. collector plate temperature for different modifications. During the time of interest between 9:00 am to 4:00 pm the average collector plate temperature for flat glass cover

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is highest. Irrespective of radiation intensity, higher collector plate temperature indicates poor heat transfer or larger heat loss from the collector. Collector plate temperature inspired authors to calculate top loss co-efficient for different modifications as the other losses are necessarily same for all.

Three sensors have been mounted on the glass cover to obtain average temperature in each case. Figure-7 shows the average glass cover temperature against time for all three cases. From the graph it is clear that the average glass cover temperature in case of flat glass cover is highest throughout. Higher glass cover temperature is the indication of larger heat loss from the top by re-reflection of radiation.

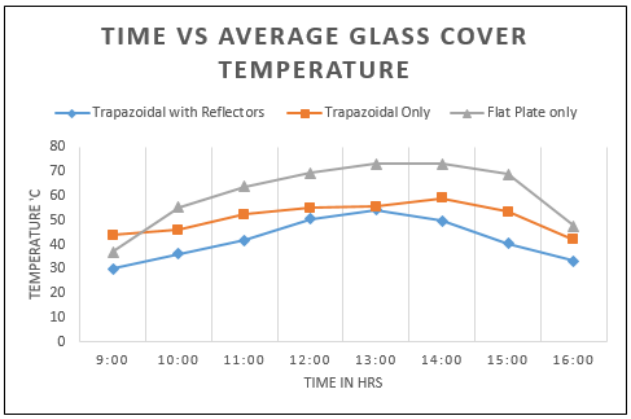

Figure-7. Time vs. Average glass cover temperature for flat plate, trapezoidal and trapezoidal with aluminium reflector.

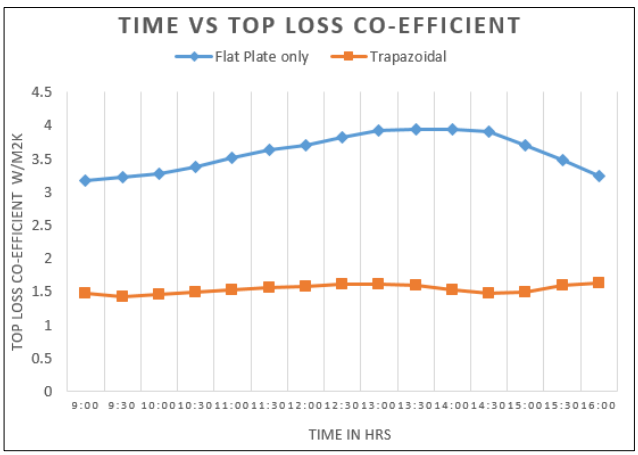

Figure-8. Time vs. Top loss co-efficient for flat cover and trapezoidal glass cover.

As indicated in Figure-8, the maximum top loss co-efficient in case of flat glass cover is 3.94 W/m^2 K and in case of trapezoidal glass cover is 1.62 W/m^2 K. The reduction in maximum top loss co-efficient is lesser by a factor 2.43 times in case of trapezoidal glass cover.

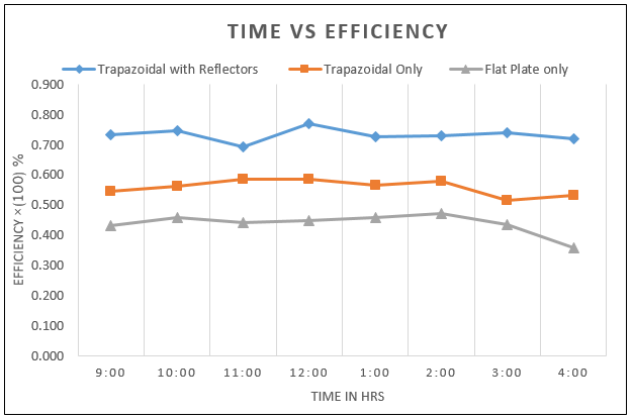

Figure-9. Time vs. Efficiency for flat plate, trapezoidal and trapezoidal with aluminium reflector.

Figure-9 shows time against efficiency curve for all three cases. Maximum efficiency is 77% for collector with trapezoidal cover and reflector at 12:00 pm. Compared to flat cover collector, increment in collector efficiency is 12% for collector with trapezoidal cover and 29 % in case of trapezoidal cover with aluminium foil reflector sheets. Figure-10 shows comparison of efficiencies obtained by various researchers in different literature for solar flat plate collector.

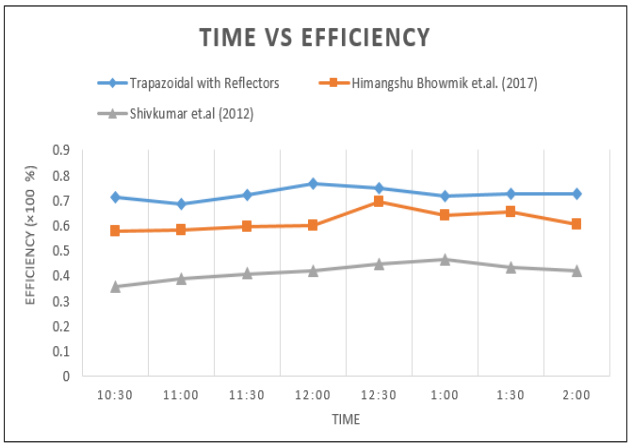

Figure-10. Time vs. Efficiency comparison by various researchers.

CONCLUSIONS

A commercially available solar flat plate collector is taken into consideration for experimental analysis and modified by replacing trapezoidal glass cover and reflector foil. Systematic experiments for all three cases showed significant improvement in efficiency from 48% to 77%. Top loss co-efficient has been calculated for flat glass cover and trapezoidal glass cover and showed significant reduction in the same which is actually the cause in efficiency improvement. Trapezoidal glass cover can be visualized as a greenhouse for collector absorber plate. Hot air present in the trapezoidal glass cover provides insulating characteristics between collector absorber plate

and atmosphere which in turn minimises the heat loss from top.

ACKNOWLEDGEMENTS

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