iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 Issue: VIII Month of publication: August 2016

DOI:

www.ijraset.com
IC Value: 13.98
Volume 4 Issue VIII, August 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Performance Analysis of Flat Plate Solar Water Collector using Trapezoidal shape and Semi-circular Tubes

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Abstract - The flat plate collector forms the heart of any solar energy collection systems designed for operation in the low temperature range, from ambient to 60°c, or the medium temperature range, from ambient to 100°c. A well engineered flat plate collector delivers heat at a relatively low cost for a long duration. Generally flat plate collector consist of arrays of circular cross sectional tubes are bonded to the absorber plate to transfer of heat from absorber tube to working fluid. When using semi circular type tube blow to the absorber plate, the area of intimate contact is increases between fluid and absorber plate and also resistance due to adhesive is decreases. Also use of flat plate collector with trapezoidal shape with four sided mirror provision enhanced solar heat collection. The result shows that there is an improvement in the heat transfer rate. The heat transfer rate is increased by 45.79%. The maximum outlet temperature obtain was 56°c and maximum average absorber plate temperature obtain was 69.3°c with a 25kg/hr mass flow rate of water.
Keywords – solar flat plate collector, Trapezoidal shape, semi-circular tubes, absorber plate.

I. INTRODUCTION

In recent years solar energy has been strongly promoted as a viable energy source. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat. Hence way that the domestic sector can lessen its impact on the environment is by the installation of solar flat plate collectors for heating water. Although it should be said that some of these collectors have been in service for the last 40-50 years without any real significant changes in their design and Operational principles. A typical flat-plate collector consists of four components (i) absorber plate (ii) tubes fixed to the absorber plate (iii) the transparent cover (iv) the collector box. The collector plates absorb the maximum possible amount of solar irradiance and transfer this heat to the working fluid which is flowing in absorber tube. The fluid used for heat transfer generally flows through a metallic tube, which is connected to the absorber plate. The absorber is usually made of metallic materials such as copper, steel or
Aluminium and surface is generally black. The collector box can be made of plastic, metal or wood type insulator to prevent heat loss and the transparent front cover must be sealed so that Heat does not escape, and the collector itself is protected from dirt and humidity. The heat transfer fluid may be either water or water with antifreeze liquid. Still the heat losses due to the temperature difference between the absorber and ambient air result in convection and radiation losses. The main advantage of a flat plate collector is that it utilizes both beam and diffuse components of solar radiation. Efficiency of flat plate collector depends on the temperature of the plate, ambient temperature, solar insolation, top loss coefficient, emissivity of plate, transmittance of cover sheet, number of glass cover.

II. METHODOLOGY

A solar water flat plate collector performance influence by the number of parameters such as selective surfaces, numbers of covers, spacing between covers and absorber plate etc. In this study the shape of flat plate collector considered to be trapezoidal in shape with four sided reflective mirrors provision. Also shape of tube is considered to be semi circular in cross-sectional area attached to the absorber plate so that area of absorbing surface is more than that of a circular tubing system in solar flat plate collector.

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A. Conventional flat plate collector

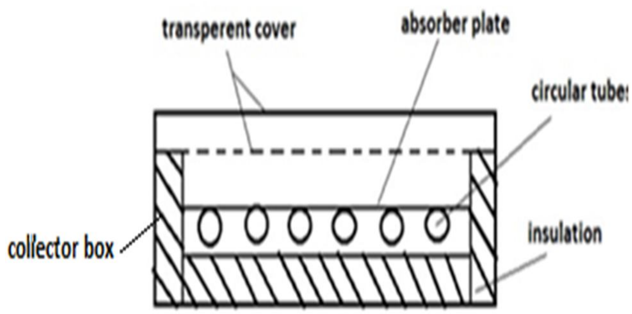

Fig-1: conventional flat plate collector

As from fig.1 shows conventional type flat plate collector with rectangular in shape with circular tubes attached to the absorber plate. in this type the resistance to heat flow to the tube from the plate may be consisted of three components;

1) The resistance due to the adhesive used for attaching the tubes to absorber plate = $\frac{1}{C_a}$

2) The resistance due to the wall thickness of the tube = $\frac{1}{C_w}$

3) The resistance due to the heat transfer coefficient at the inner surface of the tube = $\frac{1}{D_i h_{fi}}$

By considering this three resistence useful heat gain is given by,

$$Q_u = \frac{T_b - T_f}{\frac{1}{C_a} + \frac{1}{D_i h_{fi}} + \frac{1}{C_w}}$$

B. Trapezoidal shape flat plate collector with semi circular tubes

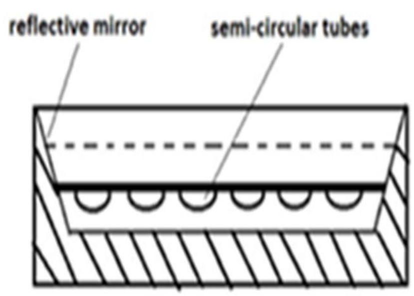

Fig-2: Trapezoidal flat plate collector with semi circular tubes

In this study flat plate collector with semi-circular tubes and collector box with trapezoidal in shape fig.2 is modified. By using this novel technique

1) The resistance due to the bonding material between the plate and the tube = $\frac{1}{C_a}$

2) The resistance due to the wall thickness of the tube = $\frac{1}{C_w}$

This two resistance are eliminated. Also use of flat plate collector with trapezoidal shape with four sided mirror provides enhanced solar heat collection. **Dci=1.414Di**, is the diameter of semi circular tube and useful heat gain (Qu) by tube is increase.By considering this useful heat gain is given by,

$$Q_u = \frac{T_b - T_f}{\frac{1}{D_{ci} h_{fi}}}$$

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III. DESCRIPTION OF EXPERIMENTAL SETUP

Fig-3: Experimental setup

The basic components of the experimental setup in this study are water flow, temperature measurement and flat plate solar collector in trapezoidal shape with four side reflective mirror. The water flows through absorber tubes and brings together the heat produced by the solar radiation that reaches to the absorber plates shown in Fig. owing to high thermal conductivity of absorber surface, the heat transfer from the back plate and water fluid inside tubes will increase.

The solar collectors have four essential static components: absorber plate on top, collector plate made from G.I sheet and semi-circular absorber tubes made from copper and welded to the absorber plate. The most important component of a solar collector is the absorber plate. In this study, the absorber plate has high conductivity and at constant high temperature. In order to improve the heat transfer from the absorber plate to the flowing water, the absorber surface needs to be enlarged to maximize contact surface of water tubes. In order to do this in this study, shape of tube is considered to be semi circular cross-sectional area. The tube attached to the absorber plate is semi circular, so that area of absorbing surface is more than that of a circular tubing system in solar flat plate collector. When considered tube is attached blow of tube, the resistance to heat flow to the tube from the plate may be consisted of three components;

A. The resistance due to the bonding material between the plate and the tube.
B. The resistance due to the temperature gradient in the fluid at the tube wall.
C. The resistance due to the wall thickness of the tube.

Now, calculating the useful heat gained by fluid per unit length. When the volume of fluid contains by circular tube and semi-circular tube assume to be same. Here the use of a flat plate collector with trapezoidal shape with four sided mirror provides enhanced solar collection, a better matching of solar collection to load requirements and acceptable efficiencies at higher operating temperatures.

IV. ANALYSIS OF SOLAR FLAT PLATE COLLECTOR

A. For proposed flat plate collector

Useful heat gain by water is given by,

$$Q_{u,p} = m_w \times C_{pw} \times (T_{out,p} - T_{inp})$$

Where,

T_{inp} - inlet temperature of water in °C
$T_{out,p}$ - outlet temperature of flat plate collector in °C

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m_w - mass flow rate of water in kg/hr
C_{pw} - specific heat of water, 4.18 kj/kg k

B. For conventional flat plate collector

Useful heat gain by water is given by,

$$Q_{u,c} = m_w \times C_{pw} \times (T_{out,c} - T_{inp})$$

Where,

T_{inp} - inlet temperature of water in °C
$T_{out,c}$ - outlet temperature of flat plate collector in °C
m_w - mass flow rate of water in kg/hr
C_{pw} - specific heat of water, 4.18 kj/kg k

V. RESULTS AND DISCUSSION

Experiment was conducted on 29th and 30th of the may 2016 between 10 am to 4 pm on sunny day. For the mass flow rate of water at 20 kg/hr and 25 kg/hr respectively. Rise in temperature of the water is recorded for both the plates.

A. Comparison of outlet water temperature for conventional and proposed flat plate collector

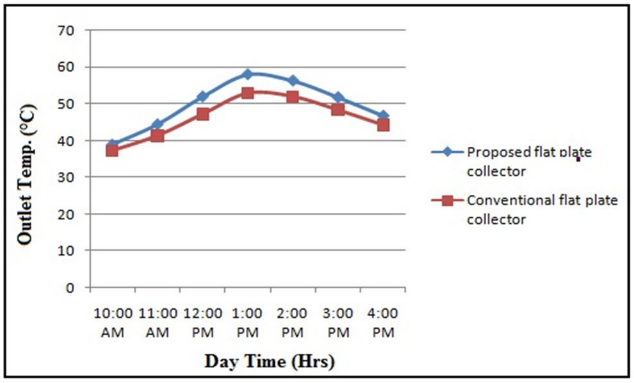

Fig-4: Comparison in Variation of outlet temperature with time for proposed and conventional collector on 29th may 2016

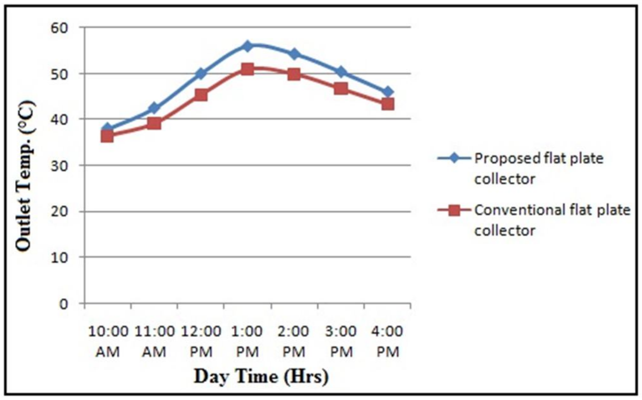

Fig-5: Comparison in Variation of outlet temperature with time for proposed and conventional collector on 30th may 2016

Fig.4 and 5 illustrates the variation of average temperatures of water at the outlet of conventional flat plate collector and proposed flat plate collector with respect to time on 29th and 30th may respectively.

It can be observed that the proposed flat plate collector provided the higher water temperature in the outlet.

As seen in Fig.4 and Fig.5 it is obvious that there is an increase in temperature of water at outlet of proposed collector as compared to conventional flat plate collector the maximum temperature in proposed collector on 29th may is 58°C at 1 PM at the same time conventional collector plate has maximum temperature 52.9°C. While on 2nd day it is 56°C and 51°C respectively.

In the graph we get the Resulting remarkable difference in temperature of 5.1°C and 5°C 1st and 2nd day respectively. That shows beneficial by using proposed modification in conventional flat plate collector.

B. Comparison of useful heat gain for conventional and proposed flat plate collector

Fig.6 and 7 illustrates the variation of useful heat gain to water of conventional flat plate collector and proposed flat plate collector with respect to time on 29th and 30th may respectively.

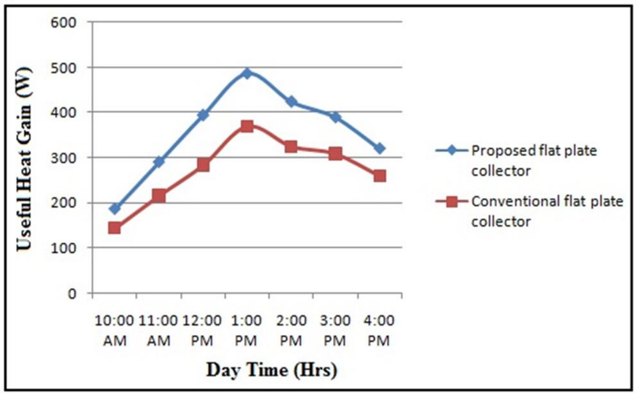

Fig-6: Comparison of useful heat gain for conventional and proposed flat plate on 29th may 2016

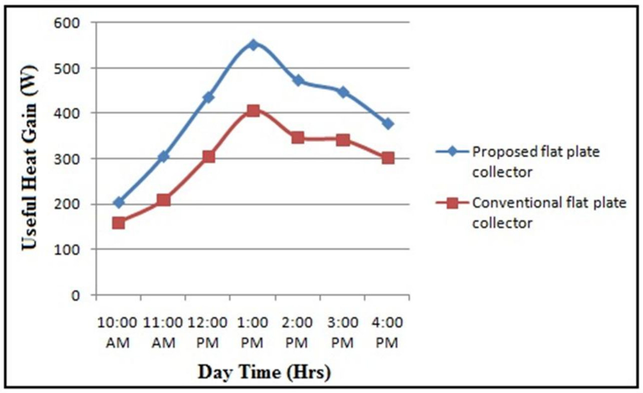

Fig-7: Comparison of useful heat gain for conventional and proposed flat plate on 30th may 2016

It shows the actual comparison between both graphs. It can be observed that the proposed flat plate collector provided the higher heat gain to water as compared to conventional flat plate collector.

The maximum heat gain is achieved in proposed flat plate collector on 29th may is 487.66w and 369.23w for conventional collector at 1PM while on 2nd day it is 551.42w and 406.38w respectively.

it is shows that there is beneficial over the conventional flat plate collector. In the graph we get the Resulting remarkable difference in useful heat gain is of 118.43w and 145.14w on 1st and 2nd day respectively.

It is observed that the heat transfer rate is increased by 39.34% on 29th may and 45.79% on 30th may.

C. Comparison of average Absorber plate temperature for conventional and proposed flat plate collector

Fig.8 and 9 illustrates the variation of average absorber plate temperatures of conventional flat plate collector and proposed flat plate collector with respect to time on 29th may and 30th may respectively.

The maximum absorber plate temperature recorded at study state, at top of absorber plate of proposed flat plate collector on 29th may is 69.6°C and 63°C over the conventional flat plate collector at 1:00 pm and it is 69°C and 62.6 on 2nd day.

it is shows that there is beneficial as compared to the conventional flat plate collector. In the graph we get the Resulting remarkable difference in temperature of 6.6°C on 1st day and 6.4°C on 2nd day. That shows beneficial by using proposed trapezoidal shape reflective mirror provisions as compared with conventional flat plate collector.

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ISSN: 2321-9653

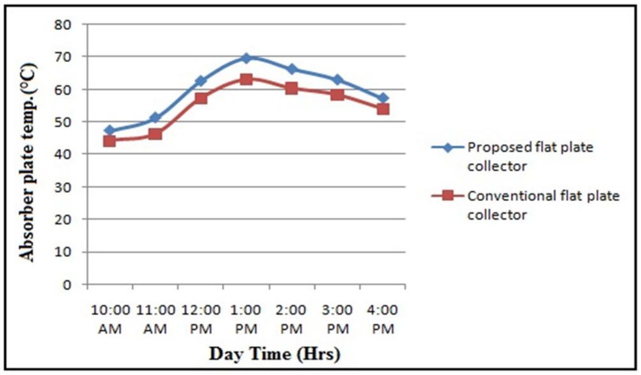

Fig-8: Comparison in Variation of absorber plate temperature for proposed and conventional collector on 29th may 2016

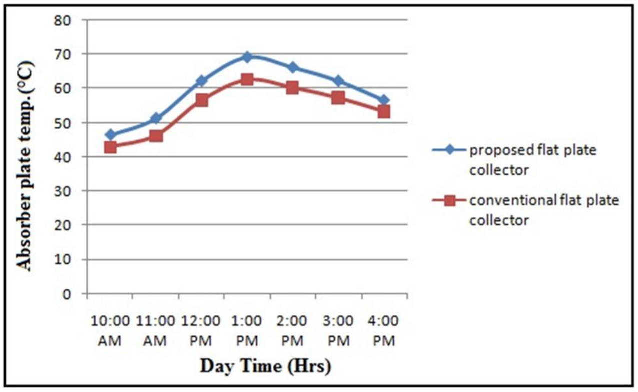

Fig-9: Comparison in Variation of absorber plate temperature for proposed and conventional collector on 30th may 2016

VI. CONCLUSION

The performance of a solar flat plate collector using trapezoidal shape and semi-circular tubes has been investigated. The experimental data are analysed and the correlations resulting are reported. Based on the experimental results reported herein, the following conclusion can be drawn. The experimental arrangement of solar flat plate collector is setup in Ayodhyanager, Nagpur, Maharashtra. Whatever the meterological conditions, it is possible to have hot water with very good temperature level using solar water heaters with semi circular tubes and reflective mirrors in trapezoidal shape. The experimental analysis has been done in ayodhyanager, Nagpur, Maharashtra. (21^{o}7'N latitude and 79^{o}6'E longitude).

The significant conclusions of experimentation study are as follow;

A. Experiment was carried out on 29th, May 2016

1) The maximum temperature gained by proposed flat plate collector is **58°C**. Whereas conventional flat plate collector is **52.9°C.**
2) The maximum change in temperature is found to be **5.1°C**
3) The maximum heat gained by proposed flat plate collector is **487.66 W.** whereas conventional flat plate collector is **369.23 W**.
4) The maximum change in heat gain is found to be **118.43 W**.
5) The percentage increase in heat gain is at maximum heat gain at **39.34 %.**
6) The maximum average absorber plate temperature of proposed collector is **69.6°C**. Whereas conventional flat plate collector is **63°C.**
7) The maximum change in average temperature of absorber plate is **6.6°C.**

B. Experiment was carried out on 30th, May 2016

1) The maximum temperature gained by proposed flat plate collector is **56°C**. Whereas conventional flat plate collector is **51°C.**
2) The maximum change in temperature is found to be **5°C**
3) The maximum heat gained by proposed flat plate collector is **551.52 W.** whereas conventional flat plate collector is **406.38W**.

4) The maximum change in heat gain is found to be **145.14 W**.
5) The percentage increase in heat gain is at maximum heat gain at **45.79 %.**
6) The maximum average absorber plate temperature of proposed collector is **69°C**. Whereas conventional flat plate collector is **62.6°C.**
7) The maximum change in average temperature of absorber plate is **6.4°C.**

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