Experimental Analysis of Evacuated Tubular Collectors with Plain & Concave Reflectors

Paul Thomas[1], Praveen Ajith[1], Arjun Palayakkodan[1], M. Natarajan[2]
[1] Mtech Energy & Environmental Engineering,
[4] Faculty, Energy Division, School of Mechanical & Building Sciences,
VIT University, Vellore-632014, Tamil Nadu, India

Abstract—**This paper presents about the comparative tests between three different types of solar thermal collectors. A standard evacuated tubular collector, two evacuated tube collector with external plain and concave reflector attached below the tubes. The tests are carried out under same experimental conditions in order to compare the performance analysis.**

Efficiencies of the three experimental setups are determined at different mass flow rates and solar flux. The test is conducted at the VIT University, Vellore in the last week of October 2013 after optimizing the position of setup with respect to the latitude and longitude of the place.

The purpose of this work is to find out which one is experimentally efficient, and to determine the amount by which the performance has been increased. The experimental analysis shows that the efficiency is higher for evacuated tubular collector with concave reflector. The plain reflector reflects the incident radiation depending upon the incident angle whereas concave reflector concentrates the same on to the focal line. This paper discusses about how the analysis is done and made the conclusions.

Keywords: **Efficiency, Evacuated tube collector, Reflector**

I. INTRODUCTION

In this era, the demand for the energy is increasing day by day. Majority of the energy production is from conventional energy sources like fossil fuels. As these sources are not sufficient in quantity to meet the growing demand, the stepping to the renewable sources of energy is very essential. The renewable sources can be utilized for many applications. One of them is the utilization of solar energy to heat the water. The solar thermal collectors absorb the incident solar energy to heat up the running water through the tubes. Different types of solar thermal collectors are available based on the requirements, amount of heating required etc. and researches are going on to find out the ways to increase the efficiency further.

In the case of solar thermal collectors, the two main types are flat plate collector and evacuated tube collectors. In both types, water is used as the transferring medium for heat. The evacuated tubular collector consists of glass vacuum sealed tubes. The presence of vacuum medium reduces the conductive and convective losses when compared to flat plate collector.

The evacuated tube collectors may be subdivided in two types. In the direct flow heat transfer liquid is pumped through the tubes. The second type consists of heat pipes inside vacuum sealed glass tubes.

II. EXPERIMENTAL APPARATUS

The experimental work was done after fabricating a sample test setup (Figure: 1.0) with single glass evacuated copper tube in each set. A plain and concave mirror made of high reflective material was attached below the evacuated tubes to divert the incoming radiation into the tubes. The aperture of the concave reflector is adjusted so that the radiation concentrates on the evacuated tube. These are protected by a wooden box and are insulated to reduce the losses. The copper tubes carry the water medium for heat transfer. Two header pipes made of copper having a slightly larger diameter are attached to the both ends of the evacuated tubes for making the inlet and outlet.

Fig: 1.0 Experimental apparatus

For all the setups inlet and outlet connections are made. The inlet is connected to an external water tank of 20L whose mass flow rate can be adjusted with the help of a rotameter which was calibrated initially. Thermocouples are attached to the inlet and outlet valves. A Pyranometer and Pyreheliometer were used to measure the global radiation and beam radiation respectively.

Table 1.0: Specifications of the Experimental Setup

No.	Components	Dimensions
1	Copper tube Diameter	12.5mm
2	Copper tube thickness	0.5mm
3	Effective length of Copper tube	978mm
4	Header pipe diameter	19.05mm
5	Header pipe length	200mm
6	Separation between Cu tube & glass tube	25mm
7	Length of plane reflector	1000mm
8	Width of plane reflector	200mm
9	Thickness of plane reflector	2mm
10	Length of concave reflector	1000mm
11	Width of plane reflector	200mm
12	Thickness of plane reflector	2mm
13	Distance to the focal line from reflector	125mm

The experimental apparatus is located at the VIT University, Vellore, India. Based on the location coordinates, the apparatus is placed focusing towards the south. The experiment is carried out in the last week of October 2013 which was partially cloudy.

Table 2.0. Installation condition of the Experimental Setup

Location	VIT University/ Vellore/ Tamil Nadu/India
Latitude	12.9692° N
Longitude	79.1559° E
Tilt angle	20°
Direction	South

III. Efficiency in Steady State Conditions

The useful output power of a solar collector for near normal incidence angle of the solar radiation during steady state conditions is given by Duffie and Beckman as

$$Q = F'.\ A_a\ .\ [(\tau\alpha)_{en}.\ I_g - U_L\ .\ (t_m\text{-}t_a)] \qquad (1)$$

where Q is the useful output power transmitted to the liquid, F' the collector efficiency factor, A_a the aperture area of collector, $(\tau\alpha)_{en}$ the effective transmittance–absorptance product at normal incidence, I_g the global solar irradiance, U_L the overall heat loss coefficient and $(t_m\text{-}t_a)$, the difference between the average fluid temperature in the collector t_m and the ambient air t_a..

The efficiency is given as to

$$\eta = F'.\ [(\tau\alpha)_{en}. - U_L\ .\ T_m^*] \qquad (2)$$

where T_m* is the reduced temperature difference.

IV. Efficiency in Normal Conditions

The performance of three apparatus is compared on the basis of the efficiency obtained under the identical experimental conditions. The experiment was performed with two different mass flow rates and different solar radiations. For a particular mass flow rate, the inlet temperature, outlet temperature, ambient temperature, global radiation and beam radiation are measured. The same is repeated at regular intervals for obtaining different values. The rotameter used for controlling the mass flow rate is calibrated initially. The losses occurred in the determination of efficiency is not taken into account since all the three apparatus have the same design. The analysis involves the study of increased efficiency due to the increase in the outlet temperature of the evacuated tubes with reflector.

The efficiency is given by

$$\text{Efficiency},\ \eta = m_w\ .\ C_p\ .\ (\ T_o - T_i\ )\ /\ I_s\ .\ A \qquad (3)$$

Where, A the absorber area of collector, I_s the global solar irradiance, $(t_o\text{-}t_i)$ the difference between the outlet temperature and inlet temperature. The global solar irradiation can be measured by the pyranometer which is having a sensitivity of $12.56*10^{-3}$ mV.

V. Results & Discussions

The experiments were carried out on that particular day and the observations were analyzed. The highest global radiation occurred at 11:40am comes to 931.53 W/m^2 and the lowest is at 11:15am which comes to 660.82 W/m^2.

The Figure 2.0 shows the relation between efficiency and solar flux. It is observed that the efficiency of the evacuated tube collectors varies with the variation in solar flux. The figure below shows the variation of efficiency with respect to solar flux for a mass flow rate of 24 LPH. Out of the three, the efficiency is higher for concave reflector. The maximum efficiency obtained for concave reflector is 28.29 %, whereas for plain reflector is 23.94% and the lowest value 19.58% which is for tube without reflector.

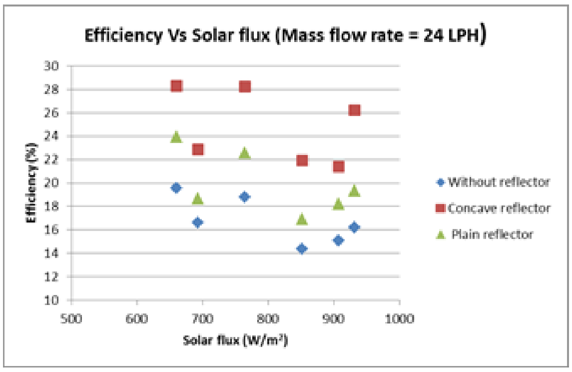

Fig 2.0: Graph between Efficiency & Solar flux at a mass flow rate of 24LPH

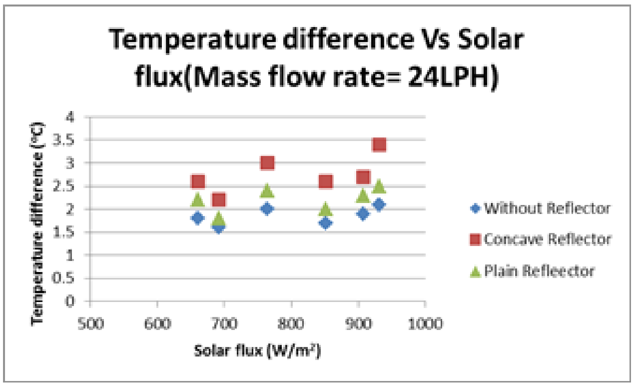

Fig 4.0: Graph between Temperature Difference & Solar flux at a mass flow rate of 24LPH

For the mass flow rate of 36 LPH, the efficiency curve gradually increases with increase in the solar flux. The fluctuation in efficiency is lower when compared to the previous one. It is observed that the maximum efficiency for concave reflector is 27.13%, for plain reflector is 26.18% and 20.05% for without any reflector. As in the below Figure 3.0, the efficiency variation is less than 2% for a change in the flux of 50W/m^2. The efficiency obtained for concave reflector varies between 25.34% and 27.13%, for plain reflector the variation is between 19.36% and 25.17%. In the case of tube without any reflector efficiency varies from 16.47% to 20.05%.

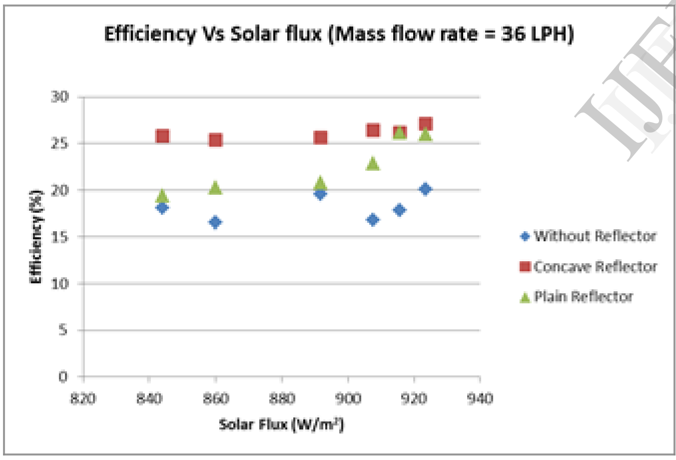

Fig 3.0: Graph between Efficiency & Solar flux at a mass flow rate of 36LPH

Relating the temperature difference between outlet and inlet to the solar flux, it is observed that the rise in temperature is higher at higher values of solar flux. Figure.4.0 shows the variation between the temperature difference of outlet and inlet with respect to Solar flux. The graph follows the same trend as the efficiency curve. A maximum rise of 3.4°C is observed for concave reflector type. All the three types follow the same trend in this observation. Considering the lowest points, for tube without reflector, at least 1.6 °C rise is there at the outlet. In the case of Plain reflector and Concave reflector, 1.8 °C and 2.2 °C is noted.

When compared to the 24LPH, again the temperature rise observed is lower according to the solar flux. The temperature difference varies from 2.0°C to 2.3°C for concave reflector and is from 1.5°C to 2.2°C for tube with Plain reflector. For a mass flow rate of 36LPH, the rise in temperature reduces to 1.4 °C, the lowest value observed.

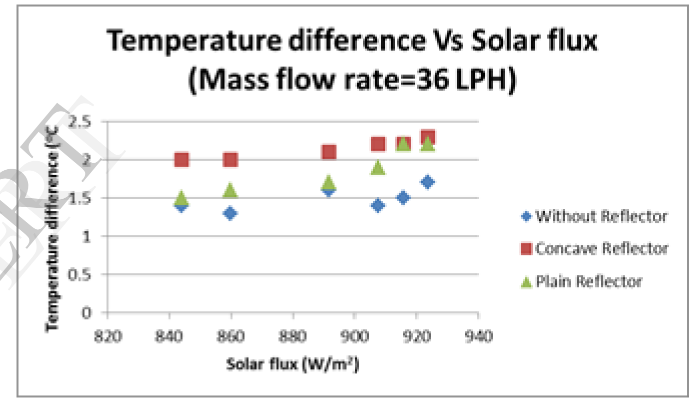

Fig 5.0: Graph between Temperature Difference & Solar flux at a mass flow rate of 36LPH

As seen from the above figures, the temperature difference decreases with increasing the mass flow rate and increases with increasing radiation amount.

VI. CONCLUSIONS

Experimental measurements taken on evacuated tube collectors with and without reflector are presented here. The efficiency curves at different mass flow rates have been obtained with respect to solar flux for the three configurations. It is observed that the efficiency of the tubular collectors depends on the mass flow rate, incident solar radiation, temperature difference between the inlet and outlet. Out of the three experimental setups here, the evacuated tube with concave reflector is more efficient. The use of the concave reflector diverts the incoming radiation to the focal line where the copper tube is located. That is, more incident energy is concentrating on it and the water in the tube will gets heated up easily. In case of evacuated tube with plain reflector, the reflector cannot concentrate the radiation, as it just reflects it. so the increase in the water temperature is found to be less than that of concave type. For the evacuated tube without any reflector, only the incident radiation causes the rise in temperature. Hence the efficiency is much lower. For the radiations obtained on the day of experiment, for a mass flow rate of 36LPH the evacuated tube without reflector shown a variation from 16.47% to 20.05%, while the evacuated tubes with plain and concave reflector shown 19.36% to 26.17% and 25.34% to 27.13% respectively. The experiment is conducted for two different mass flow rates, out of this lower mass flow rate gives higher temperature difference as the water will remain in the tube for more time. So it can be concluded that the efficiency can be further raised if the incident radiation can be more concentrated on the tube.

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