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**Article**

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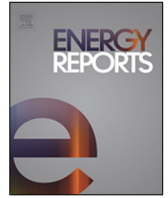
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# Efficiency improvement of flat plate solar collector using reflector

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## ABSTRACT

Solar collectors are the main components of a solar heating system. The collectors collect the sun's energy, transform this radiation into heat, and then transfer this heat into a fluid, water or air, which has many household or industrial applications. This paper introduces a new technology to improve the performance of the solar thermal collectors. The solar reflector used here with the solar collector to increase the reflectivity of the collector. Thus, the reflector concentrates both direct and diffuse radiation of the sun toward the collector. To maximize the intensity of incident radiation, the reflector was allowed to change its angle with daytime. The radiations coming from the sun's energy were converted into heat, and then this heat was transferred to the collector fluid, water. A prototype of a solar water heating system was constructed and obtained the improvement of the collector efficiency around 10% by using the reflector. Thus, the present solar water heating systems having the best thermal performance compared to the available systems.

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## 1. Introduction

In order to develop a poverty free world, energy security for all sectors must be ensured. As the conventional sources of energy are limited and cannot meet the increasing need of the common people, wide dissemination of renewable energy technologies is the only way out. The solar energy which is coming from the sun in the form of solar radiation can be an alternative source of energy. When this radiation falls on an absorbing surface, the surface absorbs heat and this heat is used as a source of heating water. This heated water is used for many purposes; sometimes for producing steam that used in domestic and industrial applications. Again, this water can be used in water pipelines or tanks to protect them from freezing in winter. Due to increasing demand for energy and rising cost of fossil type fuels (i.e., gas or oil) solar energy is becoming an important source of renewable energy. Solar water heating systems are the cheapest and consume about 20% of the total energy consumption of a family (Shelke et al. 2015).

Considering the heating requirements and environmental conditions three types of solar thermal collectors are employed, such as flat plate collector, evacuated tube solar collector and concentrated solar collector. Due to the simplicity of design, the flat plate collectors are extensively used for water heating. It requires very

little maintenance and can collect both direct and diffuse radiation. Sivakumar et al. (2012) and Vijay et al. (2013) were reviewed various types of flat plate solar collectors with various applications. They also discussed the design parameters, construction, arrangement, and sizing of various solar collectors and their performances.

Prasad et al. (2010) classified solar collectors into two types: water-type (hydronic), used water as the heat transfer fluid, and air-type used air as the heat transfer fluid. It was noted that air-type having the low heat transfer coefficient and low thermal efficiency was employed water-type collector for high thermal performance.

A combined system of solar water heater with circulating water through the aluminum tube was designed and tested by Mongre and Gupta (2013). The efficiency was increased by 55% by increasing the glazing area. Weitbrecht et al. (2002) 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. Duffie and Beckman (1991) observed the thermal performance of a direct solar domestic hot water system operated under several controlled strategies. Wang and Wu (1990) investigated with several collectors connected in parallel to interpret a single collector. The efficiency was calculated using the simulation program SOLEFF, for flat plate solar collectors (Rasmussen and Svendsen, 1996). To obtain the highest solar intensity on the collector, in summer, the inclination angle of the reflector was maintained at 45° with respect to the horizontal axis (Tabaei and Ameri, 2015).

It is observed from the literature review that various studies were available for the improvement of the performance of solar

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### Nomenclature

$A_c$	Collector Area, $m^2$
$c_p$	Specific heat capacity, $kJ/kg\ K$
$I$	Radiation intensity of collector, $W/m^2$
$m$	Mass flow rate, $kg/s$
$T_{iw}$	Inlet water temperature, $^{\circ}C$
$T_{ow}$	Outlet water temperature, $^{\circ}C$
$Q_w$	Heat absorbed by water, $W$
$\Delta T$	Temperature Different, $(T_{ow} - T_{iw})$ , $K$

### Greek symbols

$\eta$	Efficiency
$\rho$	Density of water, $1000\ kg/m^3$
$\lambda$	Wavelength

### Subscripts

iw	Inlet water
ow	Outlet water
w	Water

collectors. No studies were found based on the improvement of collector efficiency by using the rectangular solar reflector. In fact, this type of thermal collector suffers from the heat losses due to conduction, convection, and radiation, and these losses increase with the temperature of the working fluid (Vishal et al., 2015). Again, the efficiency of the collector is directly proportional to the temperature difference between the inlet and outlet of the collector. However, realizing the potentiality of this issue, to improve the performance of the flat plate collector, a prototype solar heating system (collector) is designed and constructed to improve the performance of the system. The reflector is introduced here to concentrate both the direct and diffuse radiation of the sun on the collector, which will increase the temperature difference between the inlet and outlet water flow through the collector. To observe the improvement of performance, the collector efficiency for two conditions, with or without using reflector is obtained in this analysis. The results are also compared with the results available in the literature.

## 2. Experimental set-up and procedures

### 2.1. Experimental set-up

To carry out the experimental analysis, the flat plate solar thermal collector was made of an iron plate, as shown in Fig. 1(a). The collector was designed in such a way that fluid can flow from inlet to outlet at constant flow rate, and with a parallel flow pattern. The collector was designed in such a way that fluid can flow from inlet to outlet at constant flow rate, and with a parallel flow pattern, shown in Fig. 1(a). The absorber plate of the collector was painted black and was covered with a transparent glass of thickness 4 mm to absorb the maximum amount of incident radiation. To decrease the heat loss by conduction through the absorber plate, glass wool of thickness 5 cm was used to insulate the underneath of the collector. The rectangular flat plate solar reflector generally consists of two pieces of mirror or mercury glass that were mounted on both sides of the collector, as shown in Fig. 1(a). The reflector was mounted in such a way that it can change its position with the position of the sun. In fact, the earth moves one revolution about its axis in every 24 h, gives a rotation of about  $15^{\circ}$  in 1 h, that means the solar ray deviates around 2.

$5^{\circ}$  in 10 min. To supply water to the collector, a water reservoir of 25 l capacity was placed 5 ft above the collector. The photography of the combined system is shown in Fig. 1(b). The experiments were performed, with or without using reflectors to analyze the change of efficiency for the two conditions.

### 2.2. Experimental procedure

The experiments were conducted at Dhaka University of Engineering and Technology, Gazipur, Bangladesh campus (Coordinates:  $24^{\circ}00'N\ 90^{\circ}26'E/24.00^{\circ}N\ 90.43^{\circ}E$ ) on January 2015. The collector was faced toward the sun and changed its position with time or the position of sun. However, the system was tested in several times in a day and the collector was changed its position with the position of the sun in a day. It was assumed that the heat transfers and fluid flow rates were in steady-state condition and the uniform solar heat gains throughout the collector. The experiments were conducted to study the performance of the solar thermal collector with the reflector and without the reflector. A solar energy collector is used to collect direct radiant energy having parallel paths and diffused radiant energy from the sun. The maximum concentration of solar energy collector collects diffuse and direct solar radiation. A reflector focuses direct radiation onto a first or movable collector, as in Fig. 1(a) and reflects a substantial portion of the diffused radiation onto the flat plate collector positioned near the focus of the reflector.

The flat plate collector was oriented in such a way that it received both direct and diffuse radiation during the daytime. When the sun was at angle  $30^{\circ}$  S to the collector, the tilt angle of the left reflector was set at an angle  $60^{\circ}$ , and the right reflector was set at an angle  $30^{\circ}$ , so that the incident and reflection of sunlight was at  $30^{\circ}$ , shown in Fig. 1(a). The author does not want to claim that this angle is the best choice for the whole year, but results show that at this incline angle maximum reflected light can fall on the collector that leads to increasing the transfer of heat to the water that flows through the collector. In fact, the inclination angles affect strongly on the heat transfer rate of flat plate solar collectors (Sarkar, 2013), and Tabaei and Ameri (2015) also noted the maximum collector efficiency at an inclination angle of  $45^{\circ}$  from the horizontal surface. The water flows due to gravity from the reservoir; the volume flow rate of water was measured by rotometer, and was selected as 0.1 l/min and 0.2 l/min, with the accuracy of 0.005 liters. The mass flow rate of water was calculated by multiplying the volume flow rate and the density of water. The collector inlet and outlet water temperatures were measured by a thermometer with a precision of  $0.5\ ^{\circ}C$ . The ambient temperature was recorded as  $23\ ^{\circ}C$ . The collector and reflector surface area were selected as  $1.05\ m^2$  and  $1.85\ m^2$ , respectively. The solar intensity was taken as  $430\ W/m^2$  (Bhuiyan, 2013), for global solar radiation for Gazipur, Bangladesh. The reflectivity of mirror glass was taken as 0.9 and assumes that the incident radiation on the collector surface was around 70%, and the total intensity factor for the reflector surface was calculated as 0.63 or  $0.9 \times 0.7$  (Bhuiyan, 2013). The total heat absorbed by collector and the collector efficiency were calculated by, Eqs. (2) and (3), respectively.

### 2.3. Handling of experimental data

The heat absorbed by water in the collector, and the efficiency of the collector can be calculated from the equations suggested by Sivakumar et al. (2012), Rai (2005) and Sukhatme and Nayak (2008).

The heat energy from sun is converted into thermal energy of water in the collector as

$$Q_w = mc_p(\Delta T) = mc_p(T_{ow} - T_{iw}) \quad (1)$$

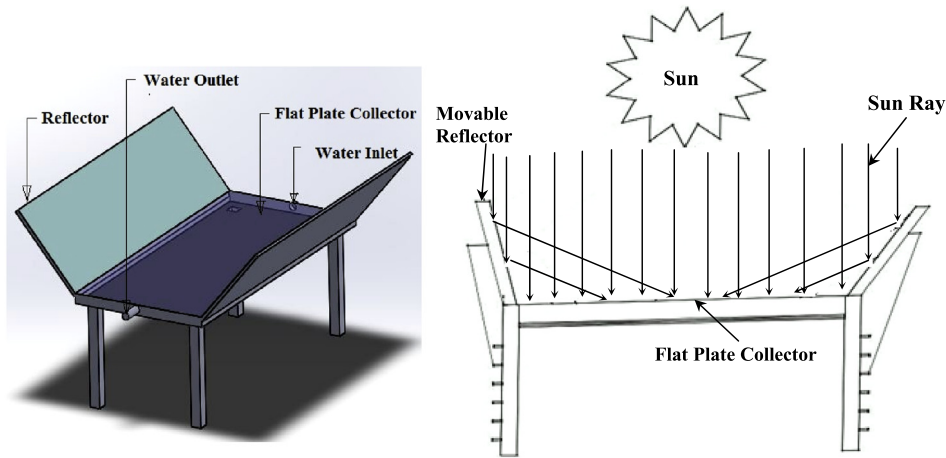


Fig. 1(a). Schematic view of the flat plate collector with reflector.



Fig. 1(b). Photography of the combined system.

in a day. As the solar rays always strike it perpendicularly, the solar radiation losses or the reflection of energy from the collector surface will be decreased, and the efficiency of a solar system will be maximized. The collector was covered by a transparent, smooth glass, which has a higher solar radiation transmissivity. However, the radiation emitted by the absorber plate of the collector cannot escape through the glass, thus increasing its temperature. The reflector on the other hand made of a planar mirror/solar mirror, used here to achieve a concentrated solar heat on the collector surface. All these issues help to get highest solar heat on the collector surface. This heat was absorbed by the water when flows steadily over the collector surface. The maximum water temperature was recorded at around 12:30 p.m. Fig. 2 shows the half-hourly temperature variation in a sunny day of 16th January 2015. The figure shows the variation of collector water temperature, with or without the reflector. It is observed in Fig. 2, the maximum water temperature at 12:00 p.m. and the steady variation of temperature during the morning time from 10:30 to 11:30 a.m. In fact, at around 12:30 p.m. when there was a high solar intensity of around  $430 \text{ W/m}^2$ , the maximum temperature of the outlet water of the collector with reflector and without reflector was achieved as  $50^\circ\text{C}$ , and  $47^\circ\text{C}$ , respectively. The results obtained by Sivakumar et al. (2012) at Tiruchirappalli (longitude  $78^\circ 43'$ , latitude  $10^\circ 46'$ ) are also plotted with the present data, in the same Fig. 2, showing favorable agreement with similar slopes. The higher temperature value of around  $10^\circ\text{C}$  was achieved during 12:30–1400 p.m. The difference between the reference graph and the present experimental graph occur because of the different solar intensity and also for the different collector surface area. Sivakumar et al. (2012) also recorded the solar intensity,  $950 \text{ W/m}^2$  at 11:00 a.m. Thus, it is ensured that the present experimental setup is good enough for further analyses.

Fig. 3 also shows the half-hourly temperature variation of the collector on 18th January 2015. The similar variation as of Fig. 2, is observed, but a slight variation of outlet water temperatures is noticed, as  $52^\circ\text{C}$  for the collector with reflector and  $48^\circ\text{C}$  for collector without the reflector. However, it is observed that collector with reflector always produces a higher water temperature than that of collector without the reflector.

To analyze the effect of flow rate, the experiments were conducted at different flow rates of 0.1 lpm and 0.2 lpm and the variation of outlet temperature at different flow rates is shown in Fig. 4. It is observed that at 0.1 lpm and at 0.2 lpm the maximum temperatures of about  $49^\circ\text{C}$  and  $38^\circ\text{C}$ , respectively. It is also seen in Fig. 4 that the outlet temperature decreases with increasing the volume flow rate of water. However, the recorded data can be used for the calculation of collector efficiency according to Eq. (3).

$$\text{Total heat absorbed by the collector} = \sum A_c \times I. \quad (2)$$

The collector efficiency as

$$\eta = Q_w / \sum A_c \times I. \quad (3)$$

#### 2.4. Experimental uncertainty analyses

The uncertainty associated with temperature and water flow rate measurement technique was measured with the policy of uncertainty (Jong et al., 1993). Heat loss through the absorber plate was minimized by the design of the equipment and assumed to be unaffected by the conduction and radiation. The uncertainty of the temperature measurements was calculated and found to be less than 1% that provides the uncertainties of  $Q_w$ ,  $\eta$  were about 2.0%, and 3.5%, respectively. These values were based on the assumption of negligible uncertainty in the relevant thermophysical properties.

### 3. Results and analyses

The system was tested in several times in a day and the position of the collector was changed with the position of the sun



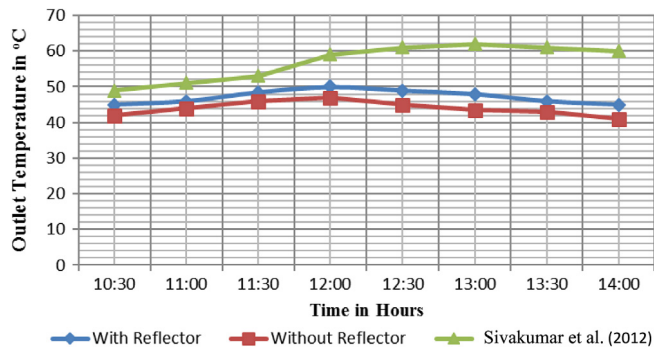


Fig. 2. The variation of outlet temperature with solar time on 16th January 2015.

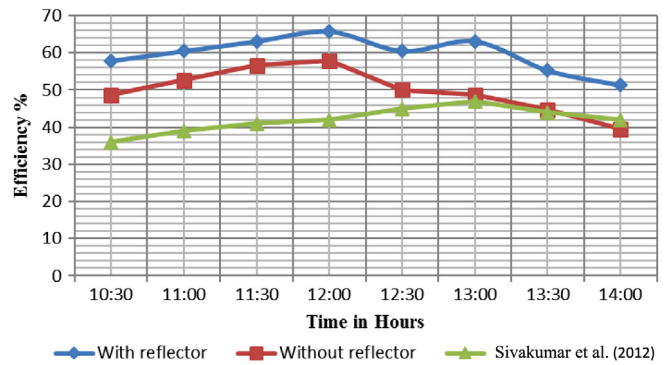


Fig. 5. The variation of collector efficiency with solar time on 16th January 2015.

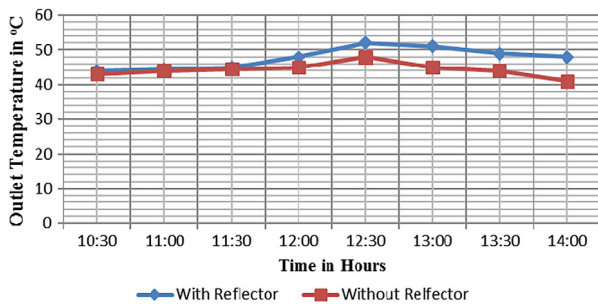


Fig. 3. The variation of outlet temperature with solar time on 18th January 2015.

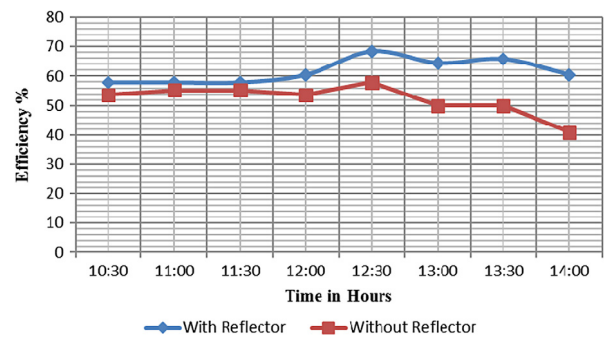


Fig. 6. The variation of collector efficiency with solar time on 18th January 2015.

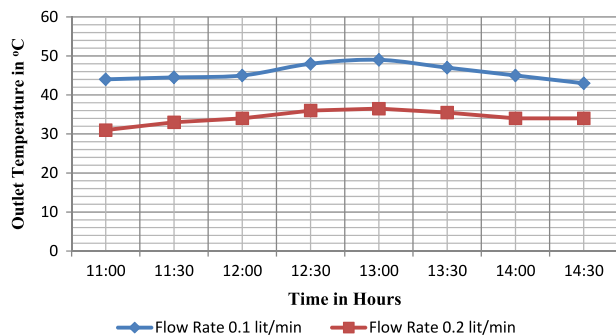


Fig. 4. The variation of outlet temperature with solar time on 18th January 2015.

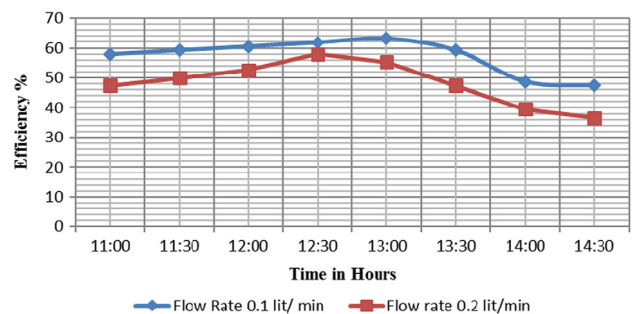


Fig. 7. The variation of collector efficiency at different flow rates on 18th January 2015.

Figs. 5 and 6, show the variation of collector efficiency with hourly time, and Fig. 7 shows the variation of collector efficiency at different flow rates of water. It is seen, the collector efficiency on 16th and 18th January is maximum at around 12:00 p.m. to 13:00 p.m. Due to the similar reason, at this time the intensity of the light was maximum and the collector absorbed more heat. The variation of efficiency of Sivakumar et al. (2012) is also presented in the same Fig. 5, showing favorable agreement with 15% discrepancy with that of the present results. The maximum collector efficiency without reflector is obtained around 51% and with reflector is around 61%. Thus, the presence of reflector increases the collector efficiency of around 10%. The solar collector efficiency of around 55% to 60%, was also obtained by Hematian et al. (2012), Sarkar (2013) and Sivakumar et al. (2012) by using different methods of improving the collector efficiency. Finally, it can be concluded that the present solar collector with the reflector is performed better than that of solar collector without the reflector. From Fig. 7, it is also noted that the collector efficiency decreases with increasing

flow rate, because at a high flow rate; the water does not get enough time to absorb heat from the collector.

#### 4. Practical significance

This analysis introduces a technique to use the solar energy technology effectively that can reduce the consumption of electrical energy for water heating purpose. This system can be used as a renewable energy source in regions where abundant sunlight is available. However, the uses of renewable energy sources (solar energy) have a large potential to mitigate the climate change impacts by reducing the emissions of greenhouse gases (GHG) from the combustion of fossil fuels.

#### 5. Conclusions

A prototype of a flat plate collector with or without reflector was constructed and tested at Gazipur, Bangladesh (Coordinates:

24°00'N 90°26'E/24.00°N 90.43°E) on January 2015. The reflector was introduced here to improve the performance of the solar collector. It is obtained from the observation that the heat transfer rate and the collector efficiency are strongly depending on solar radiation. In fact, the radiation emitted by the absorber plate of the collector cannot escape through the glass, and the reflector on the other hand used to concentrate the solar heat on the collector surface, thus maximize the collector efficiency. The collector efficiency is obtained here, without reflector as 51%, and with reflector as 61%. Thus, the overall efficiency of the flat plate solar collector is increased approximately 10% by using the reflector with the collector.

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