Energy Reports 3 (2017) 119–123

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Efficiency improvement of flat plate solar collector using reflector

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ARTICLE INFO

Article history:
Received 20 December 2016
Received in revised form 17 July 2017
Accepted 16 August 2017

Keywords:
Solar energy
Solar water heating system
Flat plate collector
Reflector

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.

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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http://dx.doi.org/10.1016/j.egyr.2017.08.002

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, °C
T_{ow}	Outlet water temperature, °C
Q_w	Heat absorbed by water, W
ΔT	Temperature Different, $(T_{ow} - T_{iw})$, K

Greek symbols

η	Efficiency
ρ	Density of water, 1000 kg/m^3
λ	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 flows 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 flows 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° in 1 h, that means the solar ray deviates around 2.5° 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°00′N 90°26′E/24.00°N 90.43°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° S to the collector, the tilt angle of the left reflector was set at an angle 60°, and the right reflector was set at an angle 30°, so that the incident and reflection of sunlight was at 30°, 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° 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 litters. 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 °C. The ambient temperature was recorded as 23 °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 0.9×0.7 (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

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