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A preliminary test of a flat-plate solar collector of hybrid solar water heater

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A preliminary test of a flat-plate solar collector of hybrid solar water heater

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Abstract. A flat-plate type solar collector for hybrid solar water heater is preliminary tested by exposing to solar irradiation at Medan city of Indonesia. The flat plate collector is used to heat the water which is circulated by a pump. The pump is powered by electric power resulted from the photovoltaic. The collector area of the solar collector is 1.196 m × 0.541 m and the capacity of the Tank is 80 L. The results show that the total energy received by the solar collector during the experiment is 17.916 MJ and the total energy loss from the solar collector is 5.015 MJ. The useful energy is 12.396 MJ. Thus, the thermal efficiency of the system 69.1%.

1. Introduction

In the present time, the world is fighting to reduce Green House Gases (GHGs) emission to the atmosphere. This is to avoid the human being from a catastrophe. Many countries have released the target on reducing GHGs emission. In energy sector, enhancement the using of renewable energy resources is the solution to mitigate GHGs emission. Solar energy is one of the potential solution to mitigate the GHGs emission [1]. Solar energy can be harvested in two different forms, they are solar thermal and photovoltaic. There are many applications of the solar energy thermal have been found in literature such as solar desalination [2 – 6], solar cooling [7 – 10], solar drier [11 – 13] and solar water heater [14 – 22]. This fact suggests that research on solar energy thermal has come under scrutiny in the last decades. Typically, solar energy thermal technologies based on the natural mechanism. For instance, the heat transfer mode is mainly dominated by natural convection. As a result, the efficiency is relatively low. In order to increase the efficiency, the natural mechanism can be coupled with forced mechanism. The forced mechanism can be provided by employing hybrid solar collector. Here, the thermal solar collector is coupled with photovoltaic. In this work, the authors focus on hybrid solar water heater.

Studies on solar water heater include the characteristics of the solar collector have been found in literatures. Ambarita et al. [14] explored the characteristics of double glass cover of a flat-plate solar collector. The effect of the inclination is also explored [15]. Budihardjo and Morrison [23] reported their study on the performance of water-in-glass evacuated tube solar water heaters. The performance of water-in-glass evacuated tube solar collector systems have been compared with flat plate solar collectors in several locations. The results showed that the performance of a typical 30 tube array was found to be lower than two panel flat plate array type. Kumar and Rosen [24] reported a study on the thermal performance on integrated collector solar water heater with corrugated absorber surface. In the study, the surface of the absorber was considered to be corrugated, with small indentation depth, instead of plane. The results show that the corrugated surface based solar water heater has a higher operating temperature for longer time than the plane surface. Soo Too et al. [25] evaluated the performance of narrow-gap vertical mantle heat exchangers with a two-pass arrangement for use in pumped-circulation solar water heaters. The tests were carried out for Australia case. Jaisankar et al. [26] performed a comprehensive review on solar water heaters. The results showed that that thermal efficiency can be up to 70% which is way higher than direct energy conversion (solar electrical direct conversion) system typically only 17%. Various techniques to improve overall thermal performance were reviewed. The conclusions are as follows. More researches may be initiated in thermosyphon solar water heaters to improve the performance, research work in parallel flow will improve will give a new insight into the thermal performance, variation in flow velocity of the working fluid in the riser tubes can be made uniform using variable headers and the convective heat loss from the glass cover may be reduced using a suitable aero profile design that will prevent the movement of air over the glass surface. Recently, Tambunan et al. [16] reported numerical study on the effect of absorptivity on performance of flat plate solar collector of a water heater. Effects of several type of coating to the performance have been tested. Sitepu et al. [18] reported experimental study on a prototype of heat pipe solar water heater using refrigerant R134a as a transfer fluid.

The above reviewed studies showed that there are many types of solar water heater have been found in literature such as evacuated tube, passive flat plate collector and solar collector with PCM. To the best knowledge of the author, there is no study on hybrid type solar water heater reported in literature. In this work a preliminary test of a hybrid solar water heater is carried out. The objective is to explore the performance characteristics of the designed solar water heater. The results are expected to support the necessary information in developing high-performance solar water heater.

2. Method

In order to perform the study a hybrid solar water heater has been designed and fabricated. Figure 1 shows the solar water heater system. As shown in the figure, it consists of flat plate solar collector, hot water tank and piping system. The flat plate solar collector consists of a plat absorber, insulation wall, double glass cover and serpentine heating coil. Here, the working fluid is the water that flows inside the heating coil. The hot water is circulated into the hot water tank by using a pump. The pump is powered by electricity from photovoltaic. The gross dimension of the solar collector is 1.6 m $\times$ 1.1 m $\times$ 0.15 m. The total area of the plate absorber is 1.5 m^2. The solar collector is employed to heat water which circulates the heating coil. The heating coil made of serpentine pipes with length of 80 cm. The distance between pipes is 0.08 m and it consists of 16 passes. The diameter of the pipe is 1 inch. The distance of between the glasses of the double cover and the distance between lower glass to the absorber plate are 0.02 m and 0.08 m, respectively. The inclination of the solar collector is 30^o.

In order to power the pump, a solar panel is also installed to the system. The dimension of the solar panel is 1.196 m $\times$ 0.541 m $\times$ 0.03 m. The solar panel collect the solar irradiation and converts it into electricity directly. The maximum capacity and voltage of the solar panel are 100 WP and 18 Volt, respectively. In this study, the used pump is a DC pump with commercial name of DC RF-B12. The specification are as follows. The maximum power, electric current and flow rate are 12 W, 5.4 A and 70 L/min, respectively. The working temperature ranges from 0 – 60^{o}C. The dimension and mass of the pump are 135 mm $\times$ 110 mm $\times$ 85 mm and 1.3 kg, respectively. The water will be collected in a tank. Here the load of tank is 80 liters of water.

During the experiment all the needed parameters are measured by using data acquisition system. Temperatures are measured by using *J*-type thermocouples with uncertainly of 0.1^{o}C. In order to record the temperature measurement an Agilent 34972, multi channels data logger is used. The measurement interval is 1 minute. The solar radiation is measured using HOBO pyranometer smart sensor. The ambient temperature and relative humidity (RH) is measured using HOBO temperature RH smart sensor with an accuracy of 0.2^{o}C and $\pm$ 2.5% RH, respectively. The wind speed around the experimental apparatus is measured with HOBO wind speed smart sensor with accuracy $\pm$ 1.1 m/s. The schematic diagram of the data acquisition system is also shown in Figure 1. The flowrate of the water is measured using flowmeter and the flow rate of the water is fixed at 3 liters per minute.

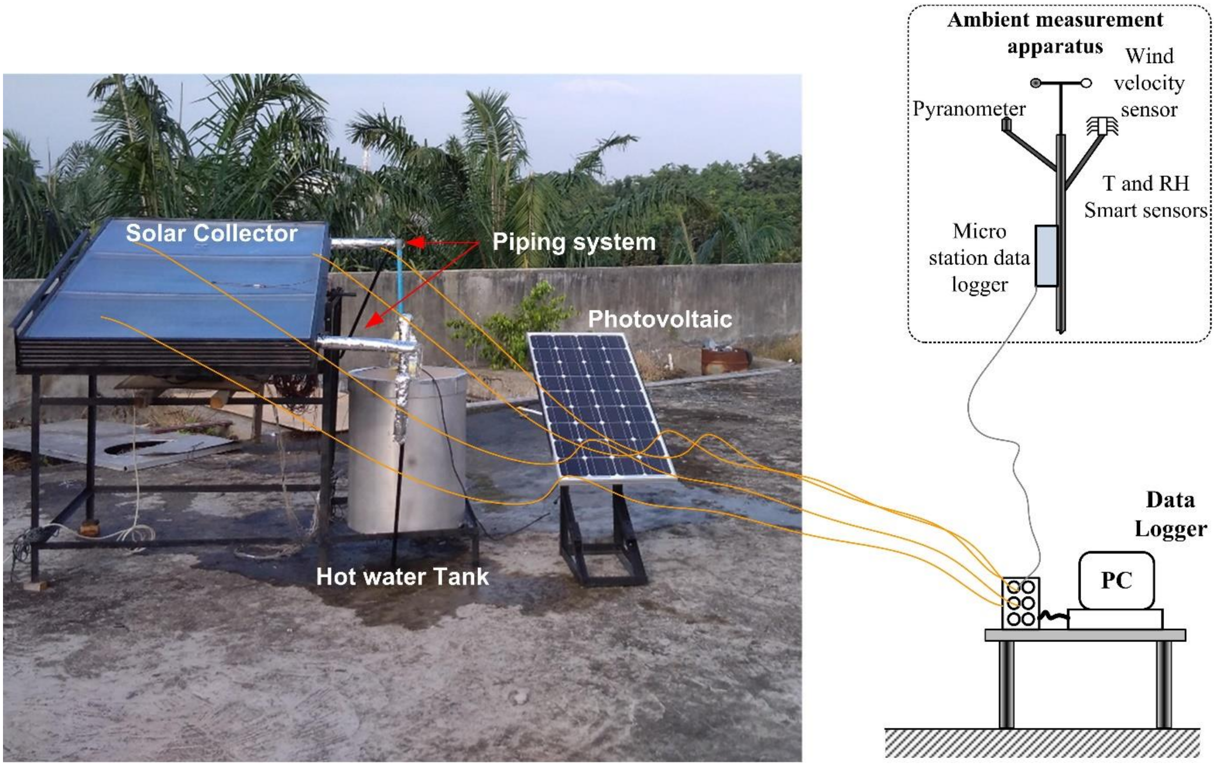

Figure 1. Experimental setup and data acquisition system

2.1 Theoretical analysis

The present work focuses on the performance of the flat plate solar collector of the system. The flat plate collector receives solar irradiation I [Watt/m^2]. Thus, the total energy Q_r [Joule] received by the solar collector is given by the below equation.

$$Q_r = R_b A \int_{t_0}^{t} I dt \tag{1}$$

where, A [m^2] and t [second] are absorber are and time of experiments. In the above equation, R_b is a factor to correct the measured irradiation on an inclined surface. The below equation is used to calculate the factor.

$$R_b = \frac{\cos(\phi - \beta)\cos\delta\cos\omega + \sin(\phi - \beta)\sin\delta}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta} \tag{2}$$

Where, δ is the inclination angle which depends on the day of experiment.

The heat loss from the flat plate collector consists of heat loss from the collector wall (include bottom) and from the top cover. The heat loss from the wall is given by

$$Q_{lw} = \sum U_w A_w \left(T_p - T_\infty\right) \tag{3}$$

Where, U_w [W/m^2 K] and A_w [m^2] are overall heat transfer coefficient and area of the wall, respectively. The parameter T_∞ [^{o}C] and T_p [^{o}C] are temperature of the ambient and temperature of the absorber plate, respectively. The total heat loss from the top cover is calculated by the below equation.

$$Q_{lt} = U_t A_t \left(T_p - T_\infty\right) \tag{4}$$

Where, U_t [W/m^2 K] and A_t [m^2] are overall heat transfer coefficient and area of the double glass cover, respectively.

The useful solar energy is defined as the net of solar energy used that is used to heat the water in the pipe. The below equation is used to calculate the useful solar energy.

$$Q_{use} = F_{R,ave}\left(Q_r - \sum Q_{loss}\right) \quad (5)$$

Where, $F_{R,ave}$ is the average collector heat removal factor. The thermal efficiency of the solar collector is defined as

$$\eta = \frac{Q_{use}}{Q_r} \quad (6)$$

The measured parameters will be used to calculate all of performance parameters that shown in the above equations.

3. Results and Discussions

The experiments are carried out in Mechanical Engineering building, Universitas Sumatera Utara, at Medan city of Indonesia. The location of the experiment is at coordinate 3°34' North and 98°40' East. The experiments have done during June 2017. In this paper only experiment of day June 9, 2017 is presented. The solar irradiation during the experiment is shown in Figure 2. In the figure, theoretical solar irradiation is also shown. It can be seen that the theoretical solar irradiation is way higher than measurements. This is because during the experiment some clouds were present and blocs the solar irradiation hit the solar collector. Theoretically, the maximum solar irradiation is up to 950 W/m^2. In the measurement, however, the maximum solar irradiation is only 710 W/m^2. Even though the maximum values are different, however the trend is similar. The solar irradiation increases with time before 13.00 WIB. After this time, solar irradiation decreases with increasing time. The average solar irradiation during the experiment was 397.9 W/m^2 and the total energy was 11.36 MJ/m^2.

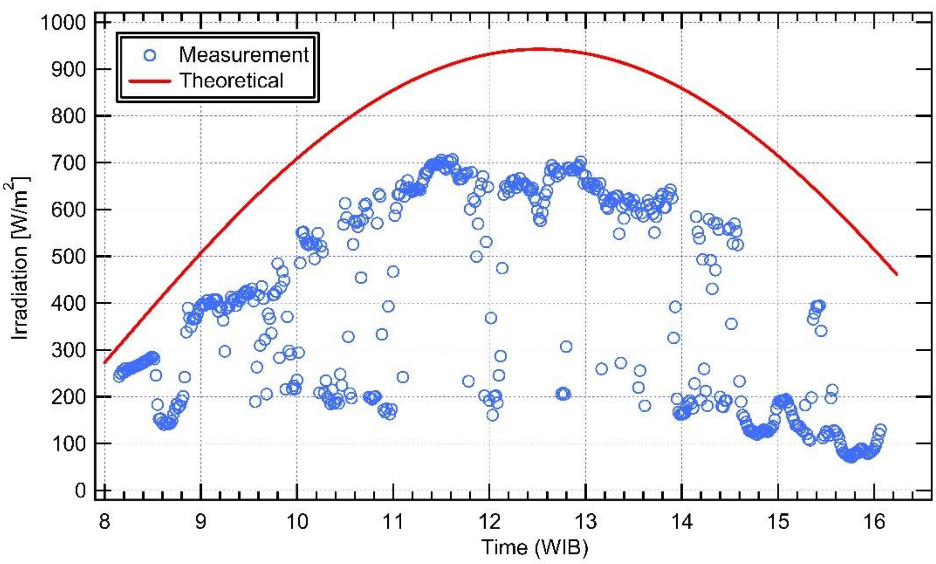

Figure 2. Theoretical and measured solar irradiation during experiment

3.1. *Heat loss from the collector*

The heat loss from the collector has been estimated using equation (3) and equation (4) and the result is shown in Figure 3. It can be seen that the heat loss follows the trend of the solar irradiation. It increases as solar irradiation increase and it decrease as solar radiation decreases. The maximum heat loss was 18 kW and occurs at 11.45 WIB. This is because at this time the temperature at the solar collector also hits the maximum value.

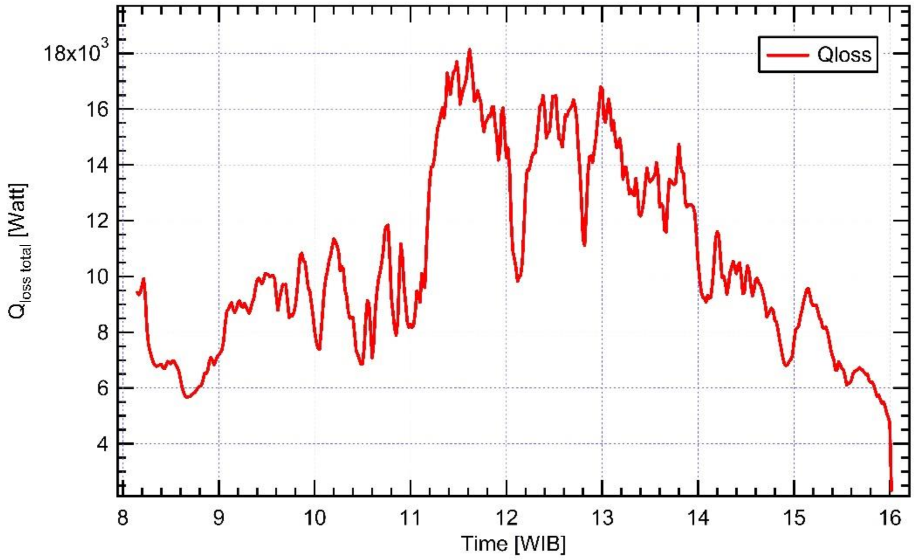

Figure 3. Heat loss from the collector

3.2. *Useful Energy*

The useful heat resulted by the solar collector is shown in Figure 4. It is estimated using equation (5). As a note, the useful heat strongly affected by solar irradiation and heat loss from the solar collector. It can be seen that useful energy shows the similar trend with the solar irradiation. This useful heat is used to heat the water that flows in the heating coil.

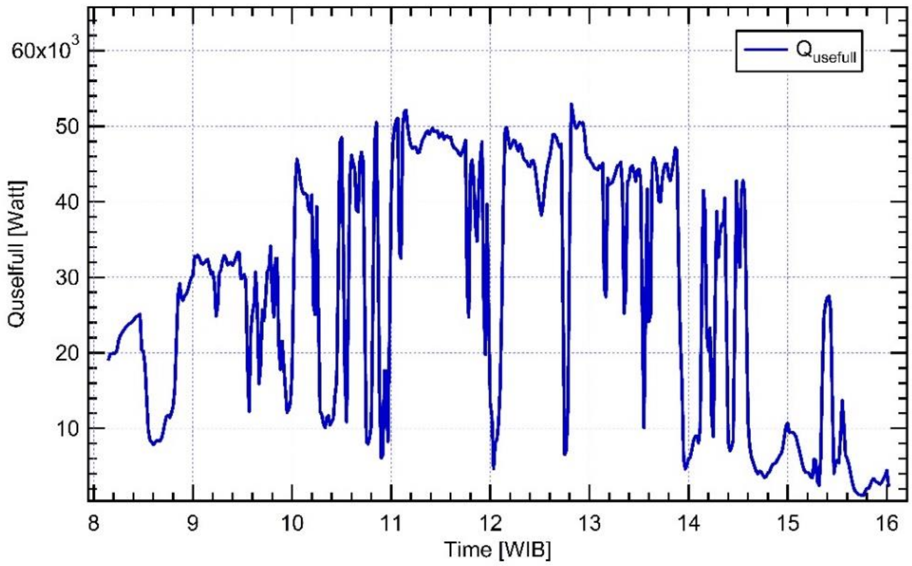

Figure 4. Useful energy

3.3. *Thermal Efficiency*

The performance of the solar collector is examined using thermal energy efficiency. The thermal efficiency is estimated using equation (6) and the result is shown in Figure 5. During the experiment, the lowest thermal efficiency is 18% occurs at 15.50 WIB and the highest is 82% at 10.50 WIB. The thermal efficiency varies from 18% and 82%. The average thermal efficiency is 66.76%. This fact suggest that the thermal efficiency of the present solar collector is categorized high.

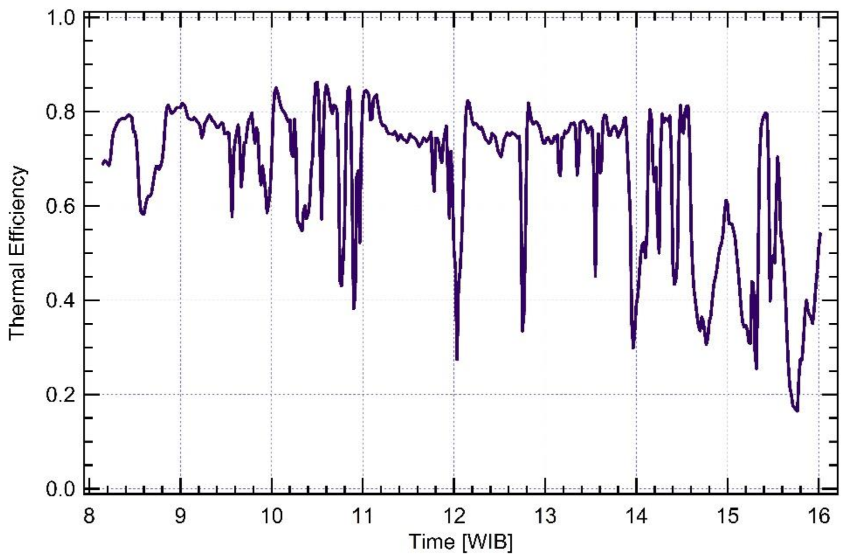

Figure 5. Thermal efficiency of the solar collector

4. Conclusions

A hybrid solar water heater with flat plate solar collector has been designed and tested. The dimension of the collector area is 1.196 m $\times$ 0.541 m and the capacity of the Tank is 80 L. A preliminary test was carried out by exposing the system under solar irradiation at Medan city of Indonesia. Based on the experiment and the analysis the conclusions are as follows. The total energy received by the solar collector during the experiment is 17.916 MJ and the total energy loss from the solar collector is 5.015 MJ. The useful energy is 12.396 MJ. Thus, the thermal efficiency of the system 69.1%.

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