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# Thermal characteristics of a flat-plate solar collector of hybrid solar water heater

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**Abstract.** In the present work, thermal characteristics of a flat-plate type solar collector that is used in a hybrid solar water heater is explored. 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  $1.196 \text{ m} \times 0.541 \text{ m}$  and the capacity of the Tank is 80 L. The results show that, the maximum temperature of the absorber plate can reach  $90^\circ\text{C}$  and the minimum one is  $57.3^\circ\text{C}$ . The average temperature of the absorber plate is  $72.93^\circ\text{C}$ . On the other hand, the average temperature of the ambient air is  $38.45^\circ\text{C}$ . Thus, the average temperature of the plat absorber is  $34.43^\circ\text{C}$  higher than the ambient temperature. In the solar water tank, minimum temperature of the water is  $28.33^\circ\text{C}$  and it is heated up to  $58.23^\circ\text{C}$ .

## 1. Introduction

Energy consumption of the world is increasing due to population and living standard. In the present time, the world energy consumption is mainly supported by energy from fossil. At the same time, the burning of fossil fuel increases the Green House Gases (GHGs) emission to the atmosphere. The increasing amount of GHGs in the atmosphere cause the global warming. In order to avoid global warming and decreasing the fossil fuel dependent, utilization of renewable energy resources must be enhanced. One of the most promising renewable energy resources is solar energy [1]. Solar energy can be harvested in two different ways, 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], adsorption refrigeration [7 – 10], solar drying process [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 investigated by Ambarita et al. [15]. Budihardjo and





Morrison [23] studied 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] investigated the thermal performance of integrated collector solar water heater with corrugated absorber surface. In their 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] reported the evaluation of 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.

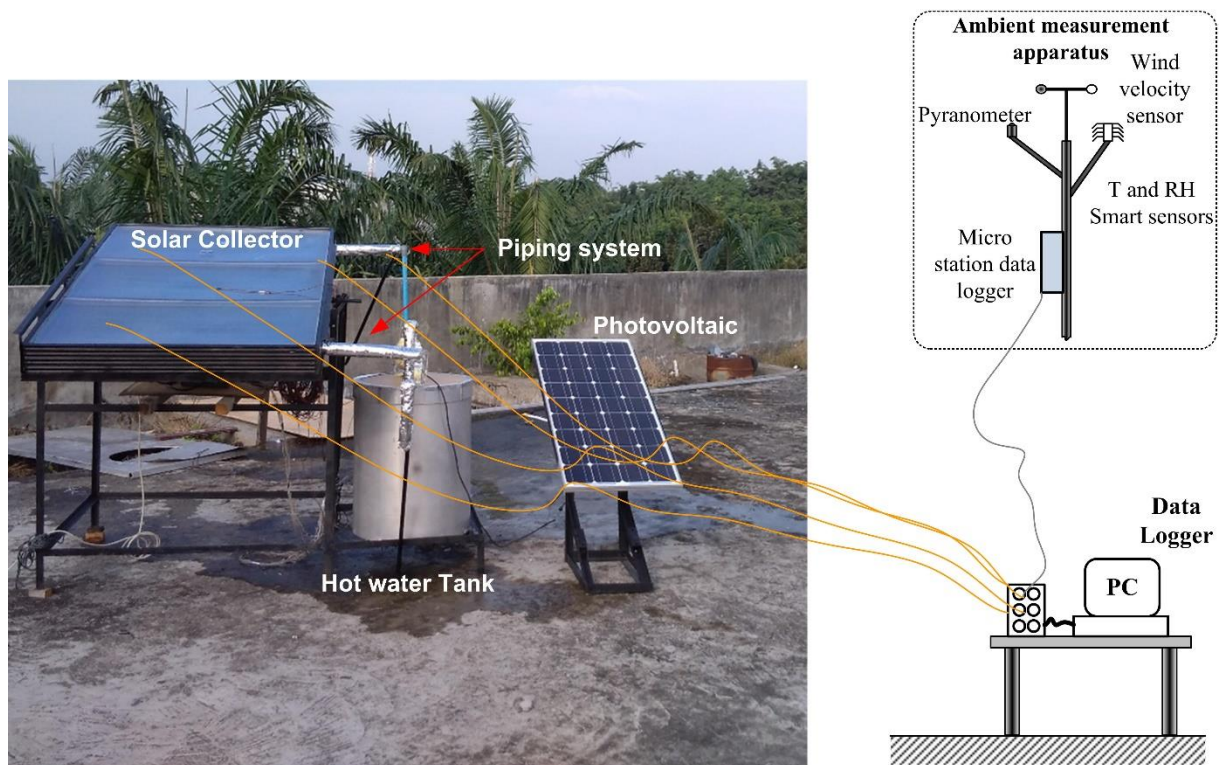
The above reviewed studies showed that there are many types of solar water heater have been found in literature such as evacuated tube, passive flat plate collector and solar collector with PCM. To the best knowledge of the author, there is no study on hybrid type solar water heater reported in literature. In this work a hybrid solar collector is tested. The objective is to explore thermal characteristics of the solar water heater. The thermal characteristics consists of temperatures on the solar collector and temperature of the water inside the tank. The thermal characteristics include the temperatures of the solar collector. The results are expected to supply the necessary information in designing high performance solar water heater.

## 2. Method

In the present work a hybrid solar water heater has been designed and fabricated. The solar water heater is depicted Figure 1. It comprises 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  $1.6 \text{ m} \times 1.1 \text{ m} \times 0.15 \text{ m}$ . The total area of the plate absorber is  $1.5 \text{ m}^2$ . 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  $30^\circ$ .

In order to power the pump, a solar panel is also installed to the system. The dimension of the solar panel is  $1.196 \text{ m} \times 0.541 \text{ m} \times 0.03 \text{ m}$ . 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  $0 - 60^\circ\text{C}$ . The dimension and mass of the pump are  $135 \text{ mm} \times 110 \text{ mm} \times 85 \text{ mm}$  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 uncertainty of  $0.1^\circ\text{C}$ . 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  $0.2^\circ\text{C}$  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  $G$  [Watt/ $\text{m}^2$ ]. Thus, the total energy  $Q_r$  [Joule] received by the solar collector is given by the below equation.

$$Q_r = R_b A \int_{t_0}^t G dt \quad (1)$$

where,  $A$  [ $\text{m}^2$ ] and  $t$  [second] are absorber area 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.

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

Where,  $\delta$  is the inclination angle which depends on the day of experiment. The total clear sky radiation is the sum of beam radiation ( $G_{beam}$ ) and diffuse radiation ( $G_{diffuse}$ ) which can be estimated by using the below equation.

$$G_{total} = G_{beam} + G_{diffuse} \quad (3)$$

In addition, the beam and diffuse radiations are calculated using equation (4) and equation (5), respectively.

$$G_{beam} = G_{on} \tau_b \cos \theta_z \quad (4)$$

$$G_{diffuse} = G_{on} \cos \theta_z [0,271 - 0,294\tau_b] \quad (5)$$

The parameter  $\tau_b$  is the atmospheric transmittance for beam radiation. It is given by the below equation.

$$\tau_b = a_0 + a_1 \exp\left(\frac{-k}{\cos \theta_z}\right) \quad (6)$$

The constants in the above equation can be estimated as follows.

$$a_0 = r_0 (0,4237 - 0,00821(6 - A)^2) \quad (7)$$

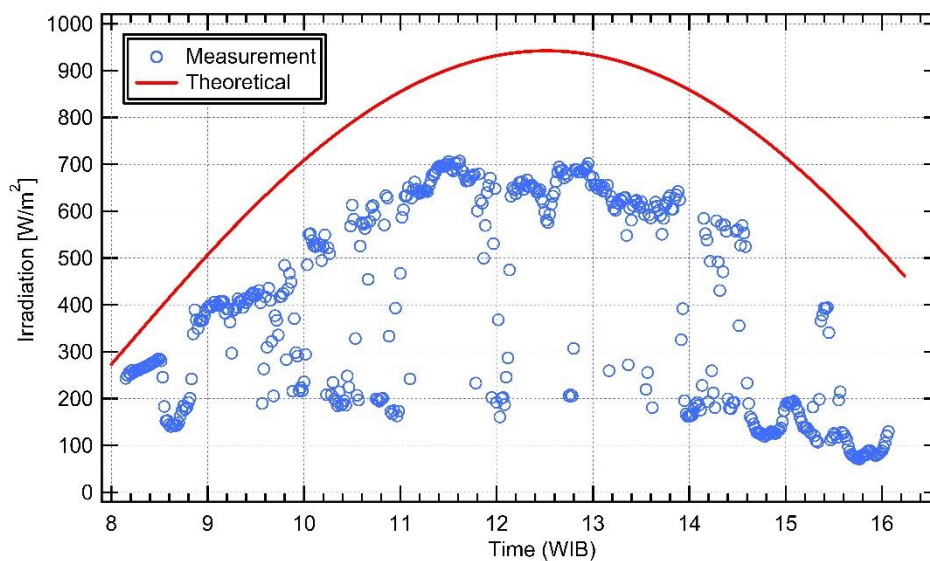
$$a_1 = r_1 (0,5055 + 0,00595(6,5 - A)^2) \quad (8)$$

$$k = r_k (0,2711 + 0,01858(2,5 - A)^2) \quad (9)$$

Here, for Medan city the parameters in the above equations are  $r_0 = 0,95$ ,  $r_1 = 0,98$ , and  $r_k = 1,02$ . The altitude of the present experimental apparatus is  $A = 0,02$  km.

### 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.



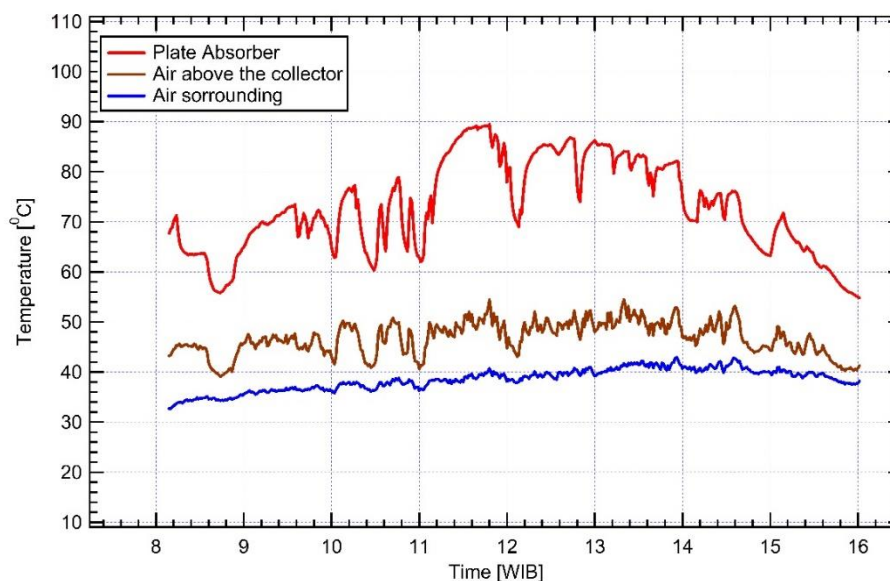
**Figure 2.** Theoretical and measured solar irradiation during experiment



It can be seen in the Figure 2, 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  $950 \text{ W/m}^2$ . In the measurement, however, the maximum solar irradiation is only  $710 \text{ W/m}^2$ . 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  $397.9 \text{ W/m}^2$  and the total energy was  $11.36 \text{ MJ/m}^2$ .

### 3.1. Temperature of solar collector

Figure 3 shows temperature history on the solar collector during the experiment. In the figure, temperature on the absorber plate, ambient air above the collector and ambient air surrounding the collector are shown by red solid line, brown solid line and blue solid line, respectively. It can be seen that in general, temperature of the absorber plate increases as time increases until reaching the maximum value. After reaching the maximum value temperature of the absorber plate decreases as time increases. This fact suggest that temperature of the absorber plates strongly affected by solar irradiation. The maximum temperature of the absorber plate can reach  $90^\circ\text{C}$ . In addition, temperature of the air above the collector is relatively higher than temperature of the surrounding air. This is because the heat from the top cover of the solar collector is high. During the experiment, temperature minimum of the plate absorber is  $57.3^\circ\text{C}$ . The average temperature of the absorber plate is  $72.93^\circ\text{C}$ . On the other hand, the average temperature of the ambient air is  $38.45^\circ\text{C}$ . This fact suggests that the present solar collector results in high temperature of absorber plate. In average, temperature of the absorber plate is  $34.43^\circ\text{C}$  higher than the ambient temperature.

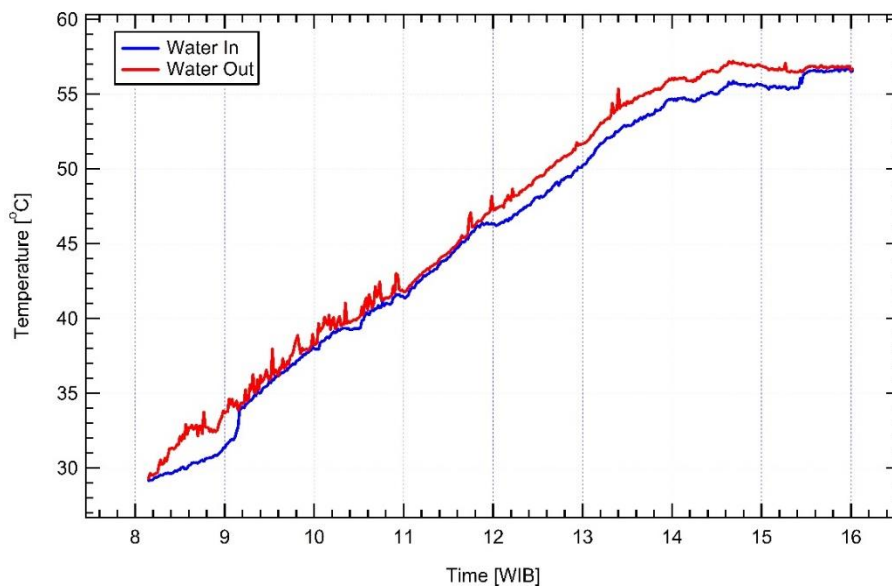


**Figure 3.** Temperature history of the solar collector

### 3.2. Temperature of the water in the solar collector

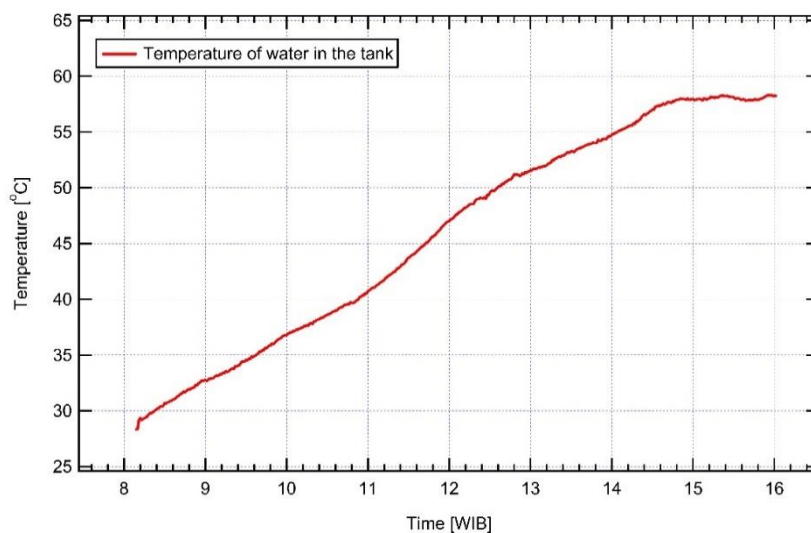
As a note, the working principle of the present solar water heater can be explained as follows. The water from the tank is flowed inside the pipe and entering the solar collector. In the solar collector, the water received the heat from the solar irradiation and it is used to increase the temperature of the water. In order to increase the heat transfer rate from the solar collector into the water, the configuration of the tube is serpentine. The water will be flowed out from the solar collector and collected in the tank. Temperature of the water entering and leaving the solar collector are shown in Figure 4. Temperature

of the water entering the solar collector is shown by solid blue line. On the other hand, temperature of the water leaving the solar collector is shown by solid red line. In general, the temperature history shows the same trend. It increases gradually as time increases. Temperature of the water leaving the solar collector is relatively higher than temperature entering the solar collector. This is because the solar collector receives the heat from solar irradiation and use it to heat the water. It can be seen in the figure that after 15.00 WIB, temperature of the water entering and leaving the solar collector are almost constant. This is because the solar irradiation is already low. At the same time, heat losses to the surrounding is high due to high temperature of the water. The low solar irradiation and high heat losses make the temperatures are almost constant.



**Figure 4.** Temperature of the water in the solar collector

### 3.3. Temperature of the water inside the Tank



**Figure 5.** Temperature of the water inside the tank

Figure 5 shows temperature of the water in the tank. As a note, solar water heater is loaded with 80 liters of water. The figure shows that the trend of temperature of water in the tank is similar to the temperature of water entering the solar collector. This is because, the water to the solar collector comes from the water in the tank. In the beginning of the experiment, temperature of the water is 28.33°C. It increases gradually as the time increases. The maximum temperature of the water in the tank is 58.23°C. This fact reveals that the present water heater can be used to heat the water with maximum hot water temperature can be up to 58.23°C.

#### 4. Conclusions

A hybrid type solar water heater has been designed, fabricated and tested. The solar water heater has been tested by exposing it to the solar irradiation in Medan city of Indonesia. The conclusions of the present study are as follows. On the solar collector, the maximum temperature of the absorber plate can reach 90°C and the minimum one is 57.3°C. The average temperature of the absorber plate is 72.93°C. On the other hand, the average temperature of the ambient air is 38.45°C. Thus, the average temperature of the plat absorber is 34.43°C higher than the ambient temperature. In the solar water tank, minimum temperature of the water is 28.33°C and it is heated up to 58.23°C.

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