Experimental of collector box solar water heaters using finned pipes as water flow

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Abstract. Solar energy is a renewable energy where heat obtained from the sun can be utilized without damaging the environment. The most common use of solar energy is to heat water both the active system and the thermosifon system. Using photovoltaic cells as an energy source to pump water is a promising breakthrough. This study aims to improve the efficiency of flat plate collectors with a size of 1.62m x 1.14m x 0.08m to heat water with a capacity of 120 L by adding finned pipes as continuous water circulation. After the collector finishes in the design, it is being tested and analyzed in order to obtain the efficiency and total value of calorific waste of collector.

1. Introduction
Renewable energy sources, namely solar energy produced by the process of nuclear melting by hydrogen into helium and producing an emptying mass rate of 4.7x106 tons / s [1]. Nowadays solar heat has been applied as an energy source for generating engines, cooling machines, heat exchangers, and hot water systems in cities. Based on data from the Directorate General of Electricity and Energy Development, the installed capacity of solar electricity in Indonesia has only reached 0.88 MW of the available potential of 1.1 x 109 MW [2]. Utilization of solar thermal energy is applied with solar water heating technology that uses a heating medium in the form of water fluid [3]. Solar water heaters can be classified into 2 types namely passive heating and active heating. Pure passive heaters rely on solar heat and do not use electricity. While active heaters utilize pumps and electric power control systems and are equipped with emergency back-ups. Passive solar water heaters have 2 parts, namely the collector panel and the water storage tank connected to each other by two pipes. In the collector panel that is covered by glass, inside there is a series of copper pipes for running water with fins as heat absorbers [4].

Storage tanks are used to store water after it has been heated so that the heat lasts long. There are three types of collector panels that are most widely applied, namely flat type collectors, collectors with integrated storage systems and pipe-shaped collectors [5]. Flat type collectors can use materials with light and simple mass with a black coated heat absorber so that it can produce solar energy absorption efficiency of 60%. Solar Panel Water Heater is a profit application utilizing solar panels. A simple heat transfer system with flat plate-shaped or pipe-mounted collectors mounted horizontally and horizontally on the roof of a building can produce a heating temperature of 100 °C - 160 °C while concentration collectors (Fresnel, satellite dish, tower and oven) can reach heating temperatures up to 250°C [6].

Research on the use of flat plate solar collectors has been widely carried out. Chen, Z, et al. [7] Conducted a study of two flat plate solar collectors by varying the flow rate to increase its efficiency. The result is that if the flow rate is increased, the efficiency of the solar collector will increase. Flat plate studies using double glazing and between glazing filled with argon have been carried out and the results have improved the thermal efficiency of the collector [8]. The maximum temperature and temperature of the collector that can be achieved by solar water heaters with a flat type collector with the use of fins on a water flow pipe is 49.84 °C. The purpose of this study is to design and test a Flat Type Solar Water Heater with a finned pipe that can be used as a heat source for the production of
renewable energy, for example biodiesel and bioethanol. Solar water heaters are made using lightweight materials and are more economical. Besides that, the water heater is designed simple so that it is easier to operate. The indicators tested were water storage tank temperature and solar light intensity.

The application of this technology is expected to increase the independence of the community in meeting energy needs, especially in rural areas and borders that often experience fuel crises and have not been electrified. In addition, the use of this technology can reduce people's dependence on fossil fuel needs. In the collector of water heater can not be separated from the word solar radiation emitted by the sun toward the earth, and the radiation emitted against the heating surface is radiation with long waves. Acrylic and glass have opaque properties with hot light in long wave radiation so that heat can enter. Solar radiation enters the collector through transparent acrylic and glass covers and then reaches the absorber where the radiation is converted into a form of heat energy. A material with good heat conductivity is needed to transfer the collected heat to the pipe to be delivered to water. Aluminum absorbers function to reduce radiation energy loss. Black coating on the absorber surface can reduce radiation energy loss by 4% to 7% [9]. Higher water temperatures can be generated by increasing the concentration of light radiation to the absorber surface [10]. Therefore in this research the collector to be tested to improve the efficiency of water heaters is the addition of finned pipes in the flow of water, where the fins on the pipe are useful to accelerate the rate of heat transfer to heat water.

2. Solution method

2.1. Experimental set-up

In this research a solar water heater collector will be tested with a capacity of 120 liters of water. The collector design to be discussed includes the body of the collector, absorber plate, transparent cover (glass) and insulation on the collector. Considerations that need to be considered in designing a collector are: economical, strong, high productivity, easy to manufacture and easy to operate. Making this collector includes several stages. The first stage is the installation of the collector's frame. The framework used is aluminum extrusion profile C with a length of 1.62 m x width 1.14 m x thickness 0.08 m. The second stage is the installation of polyurethane. After the polyurethane is installed, proceed with the installation of the absorber plate on top of the polyurethane. After installing the absorber plate, the next step is the installation of copper pipes to circulate the water in the collector. The next step is the installation of acrylic with a certain distance from the absorber plate and the installation of glass with a certain distance from the acrylic.

In the experiment, solar radiation were recorded every five minute. The temperature of the solar collector was measured by An Agilent. A HOBO-micro station was used to record the solar radiation.

![Figure 1. Experimental setup of water heater process](image-url)
2.2. Collector efficiency

The heating’s value needed by the collector to increase the temperature of 120 liters of water from 27 °C to 50 °C is calculated by the equation:

\[ Q_{kolektor} = \dot{m} \cdot C_p \Delta T \]  \hspace{1cm} (1)

By assuming a collector's efficiency value of 55%, a collector's Q value can be obtained. By knowing the average value of radiation obtained in the city of Medan for one day that is equal to 12 MJ, the collector’s cross-sectional area can be determined. The area of the collector is obtained by the equation:

\[ A = \frac{Q_{in}}{Q_{kolektor}} \]  \hspace{1cm} (2)

To obtain the average heat gain per unit time (Watt), for one study day (8 hours), then the equation is used:

\[ q = \frac{Q_{kolektor}}{3600 \times 8} \]  \hspace{1cm} (3)

The speed of water flowing in the collector is 2.5 liters / minute. The minimum copper pipe length is obtained by the method \( \Delta T_{lm} \), where the equation used is as follows:

\[ q = U_o \cdot A \cdot \Delta T_{lm} \]  \hspace{1cm} (4)

\( U_o \) value is obtained by the following equation:

\[ U_o = \frac{1}{R_i \cdot \frac{A_o}{A_i} + R_s} \]  \hspace{1cm} (5)

\[ R_s = \frac{\ln(r_0/r_1)}{2 \pi k} \]  \hspace{1cm} (6)

\[ R_i = \frac{1}{h_i A_i} \]  \hspace{1cm} (7)

During the work collectors heat water, heat loss occurs in collector by convection and conduction. Convection occurs at the top of the collector, while conduction occurs at the bottom and sides. This loss of heat value will greatly affect the efficiency of the collector. Here is a scheme of heat loss from the solar collector:

*Figure 2. Schematic heat loss in the collector*

The heating’s value wasted from the side of the collector every one minute during the test is obtained by the equation:

\[ q_{out,s} = U \cdot A \cdot (T_p - T_u) \]  \hspace{1cm} (9)
The value of heat energy wasted from the side of the collector every one minute during the test is obtained by the equation:

\[ q_{\text{out},d} = U \cdot A \cdot (T_p - T_u) \]  

(11)

The value of heat energy wasted from the top side of the collector every one minute during the test is obtained by the equation:

\[ q_{\text{out},t} = U_1 \cdot A \cdot (t_{p1} - t_{u1}) \]  

(13)

The value of heat energy wasted from the underside of the collector is obtained every one minute during testing with the equation:

\[ q_{\text{out},b} = U \cdot A \cdot (T_p - T_u) \]  

(15)

Total heat wasted from the whole side of the collector was obtained by the equation:

\[ \Sigma Q_{\text{out}} = \Sigma Q_{\text{out},s} + \Sigma Q_{\text{out},d} + \Sigma Q_{\text{out},t} + \Sigma Q_{\text{out},b} \]  

(17)

The energy used to heat water is the amount of energy available in the collector multiplied by the heat transfer factor in the collector. The following is the equation used:

\[ q_{\text{use}} = F_{R,\text{ave}} \times (\Sigma q_{\text{in}} - \Sigma q_{\text{out}}) \]  

(18)

Collector thermal efficiency is the value of the comparison between quse and qin. To obtain the value of the efficiency of the collector then use the following equation:

\[ \eta_{\text{thermal}} = \frac{q_{\text{use}}}{q_{\text{in}}} \]  

(19)

3. Result and discussion

Experiment of Solar water heater have been done on August, 22 at Medan city, Indonesia with geographic coordinate 3°34’ North and 98°40’ East. Duration of the daytime solar water heater is 8 hours from 8 am to 6 pm.

3.1 Heat received (Qin), wasted heat (Qout), and heat used (Quse)

Here is a graph of the Heat received (Qin), waste heat (Qout), and the heat used (Quse).
In Figure 3 is shown a graph of heat received ($Q_{in}$), wasted heat ($Q_{out}$), and heat used ($Q_{use}$). In the heat received ($Q_{in}$) obtained 16378168.5 Joules, the wasted heat ($Q_{out}$) obtained 4066980.054 Joules, and the heat used to heat water obtained for 11908462 Joules.

3.2. Collector efficiency

In this section, the chart shows the efficiency of a solar water heater collector.

In Figure 4 is shown that the highest collector efficiency occurred at 10:54 pm obtained by 86.28% collector efficiency.
3.3. Tank temperature

In this section will be indicated temperature at the absorber plate and water vs. time during the test date August 22, 2019.

![Graph showing temperature vs. time](image)

**Figure 5.** The absorber plate and the water temperature vs time.

In figure 5 is shown a graph of temperature and water absorber plate vs. time and temperature chart obtained from the absorber plate of 73.14 °C and water temperature obtained at 49.84 °C.

4. Conclusion

The result of the test on water heating collectors by using fins in the water circulation pipe channel at 49.84 °C with the highest plate temperature obtained at 73.14 °C. And in the collector efficiency was obtained at 86.28% with the heat received \((Q_{in})\) obtained at 16378168.5 Joules, the wasted heat \((Q_{out})\) was obtained at 4066980.054 Joules, and at the heat used to heat water obtained at 11908462 Joules.

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