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The Effect of Collector Slope Angle on the Performance of Solar Water Heater

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Abstract. The purpose of this research is to know the effect of slope angle of the flat plate collector on the performance of solar water heater. The research was conducted in Makassar city of Indonesia. This research was conducted on solar water heater system by varying the angle of collector slope at 5\(^\circ\), 10\(^\circ\), 20\(^\circ\) and 30\(^\circ\). Measurement data are the temperature of the collector input, the temperature of the collector output, the temperature of water in the tank, and the intensity of solar radiation. The measurement data were processed to obtain the input energy of system, the output energy of system, and the efficiency of system. The result shows that the greater the collector’s slope angle, the greater the performance of the system. It is indicated by the largest maximum output energy produced by the angle of 30\(^\circ\) of 9858.32 kJ, and the largest maximum efficiency is also produced by the angle of 30\(^\circ\) of 30.78%.

INTRODUCTION

The community’s need for hot water continues to increase. It has a direct impact on the increasing demand for electrical energy or petroleum energy. One solution to solve the problem is by using solar energy as an alternative and renewable energy. Indonesia is an equatorial country that gets solar energy throughout the year.

Solar water heater (SWH) is one form of utilization of solar energy to heat water. SWH feasibility studies in terms of cost and benefits have been widely conducted [1–4]. The results demonstrate that SWH is very feasible to be developed as well as very safe for the environment [2]. Utilization of SWH is not only for household needs but also for industrial needs [3]. Nevertheless, there is a constraint in the performance of SWH is less optimal for thermo-siphon efficiency system of 18% [5], so it is necessary to do continuous research. Efforts to improve the performance of SWH have been carried out by combining the use of solar and electric energy [4], while adding a collector controls system so that it always follows the direction of sunlight [6]. Another research is to construct several solar collectors in series and parallel arrangements [7].

One interesting problem is the issue related to the effect of collector angle on the performance of SWH. In the equator, sunlight can be obtained perpendicular to the collector with a near-zero collector angle. The constraint that possibly occurs is a flat collector will cause the flow rate of water is hampered because the friction with the wall of the pipe is getting bigger. This research needs to be performed at another angle although the sunlight is not perpendicular to the collector.

This research is intended to find the best slope position of solar collector which can absorb the solar energy optimally. This position also makes the water flows with optimal movement resulting in optimum performance of SWH. The purpose of this research is to know the effect of slope angle of the flat plate collector on the performance of SWH.
FIGURE 1. The working system of solar water heater.

The water heating cycle of SWH can be seen in Figure 1. The process of heating water occurs in the solar collector. The reception of solar radiation energy in the solar collector causes the water in the tank to gradually become hot. The natural cycle of water will take place in SWH, where the hot water will lead into high ground, and cold water will be in a lower place. The natural cycle of cold water in the tank moves toward the collector and turns into hot water, then hot water will move towards the tank. This cycle will occur continuously until maximum temperature is obtained and water cannot be heated to any further extent.

The performance of SWH system can be calculated using the following equations:

- Input energy of collector system \( (Q_{in}) \)
  \[ Q_{in} = Q_{bt} \cdot A_a \cdot t \]  \hspace{1cm} (1)

- Temperature differences of tank \( (\Delta T) \)
  \[ \Delta T = (T_{final} - T_{initial}) \]  \hspace{1cm} (2)

- Fluid mass of system \( (m) \)
  \[ m = V_s \cdot \rho_w \]  \hspace{1cm} (3)

- Output energy of system \( (Q_{out}) \)
  \[ Q_{out} = m \cdot C_p \cdot \Delta T \]  \hspace{1cm} (4)

- Efficiency of system \( (\eta) \)
  \[ \eta_s = \frac{Q_{out}}{Q_{in}} \times 100\% \]  \hspace{1cm} (5)

where:
- \( Q_{bt} \) = Intensity of solar radiation (kJ)
- \( A_a \) = Collector cross section (m²)
- \( t \) = Duration of testing (s)
- \( T_{final} \) = the final temperature of tank (°C)
The testing was conducted in Makassar city, South Sulawesi Indonesia, precisely at -5.14 latitude and 119.42 longitude with elevation of 8 meters above sea level. SWH testing was commenced with SWH system creation for laboratory scale. Furthermore, the test was conducted at alternative energy laboratory of Mechanical Engineering Department of Politeknik Negeri Ujung Pandang. SWH system design is presented in Fig. 2.

**FIGURE 2.** Design of solar water heater.

Two units of SWH system were created for supporting the testing. The testing of SWH system was implemented every day. The steps of testing the SWH system with diverse collector angles are as follows:

1. On the first day, the position of unit 1 of the SWH system was set with the collector slope angle of 5°, and unit 2 with collector slope angle of 10°.
2. Fill the storage tank with water to the fullest.
3. Install a temperature measuring instrument of one unit at the collector input ($T_{fi}$), one unit at the collector output ($T_{fo}$) and three units in the tank ($T_r$) with different depths.
4. Testing was performed from 08.00 am to 04.00 pm.
5. Data observation was performed every 5 seconds using data acquisition system. The observed data included the temperature of the collector input ($T_{fi}$), the temperature of collector output ($T_{fo}$) and the temperature of water in the tank ($T_r$) and the intensity of solar radiation.
6. Test was performed on the second day, set the position of the system SWH unit 1 with 10º collector slope angle, and unit 2 with 5º collector slope angle.
7. Test was performed on the following days by testing unit 1 and 2 at collector angles of 10º and 20º, 20º and 30º, and 30º and 5º, respectively.

RESULTS AND DISCUSSION

Based on the performance of solar water heater (SWH) design, the solar water heater (SWH) system is presented in Figure 3.

![System of solar water heater.](image)


After testing the solar water heater (SWH) system, the results can be demonstrated in graphical form as shown in Fig. 4 and Fig. 5.

![Effect of diverse heating times on the system output energy.](image)

FIGURE 4. Effect of diverse heating times on the system output energy.
The test was done from 8:00 to 16:00 WITA as shown in Figure 4. Test results show that the longer the heating time, the greater the amount of the absorbed energy (energy output system). Figure 4 also shows the results of SWH system test with various collector slope angles. The collector angles of 30°, 20°, 10° and 5° obtained the system energy output of 9858.32 kJ, 9464.51 kJ, 8348.72 kJ and 9321.60 kJ, respectively.

Figure 5 shows the results of testing conducted from 8:00 to 16:00 WITA. The finding shows that the addition of heating time will make the system efficiency to form a parabolic chart. Initially, there will be an increase in system efficiency yet after reaching the peak, the system efficiency will decrease.

Figure 5 also shows the testing of SWH system with collector slope angle of 5° obtained the maximum system efficiency of 23.41% occurred at 11.00 WITA. Meanwhile, at the collector slope angle of 10°, the maximum system efficiency was 24.81% occurred at 11.30 WITA. Likewise, the result of the collector slope angle of 20° showed the maximum system efficiency of 29.89%, which occurred at 11.30 WITA. In testing SWH system with collector slope angle of 30°, the maximum system efficiency was 30.78% occurred at 10.30 WITA.

CONCLUSION

Based on the results of Solar Water Heater performance to determine the effect of collector slope angle, several points can be concluded as follows:

- The larger the slope angle of the collector, the greater the output energy. The slope angle of 30° produces the maximum output energy of 3,858.32 kJ.
- The larger the slope angle of the collector, the greater the efficiency of the system. The angle of 30° produces the maximum efficiency of 30.78%.

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