International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 1234-1238 www.ijaem.net ISSN: 2395-5252

The Influence of the Tilt Angle of a Flat Plate Solar Collector with Granite Stone Absorber on Its Performance

Made Wirawan, Mirmanto Mirmanto*, Imam Fahrurrozi
Mechanical Department, Faculty of Engineering, the University of Mataram, Jl. Majapahit, no. 62, Mataram, 83125, NTB, Indonesia.

Date of Submission: 15-04-2023 Date of Acceptance: 25-04-2023

ABSTRACT: An experiment to investigate the effect of the inclination angle of a solar collector has been conducted. The experiments used a flat plate collector with granite stone as the absorber material. The collector size was 100 cm x 80 cm x 10 cm with parallel channels made of seven copper pipes. The inclination angles of the collector varied were 15°, 30° and 45°, and the water flow rates used were 300 cc/minute, 400 cc/minute, and 500 cc/minute. The total duration of the experiment was 7 hours, from 10:00 am to 5:00 pm local time. The results show that the highest temperature difference between the inflow and outflow water is dominated by the collector with a 30° inclination angle, which is about 17.64°C at a flow rate of 300 cc/minute. Meanwhile, for the 15° and 45° angles, the obtained temperature differences were 16.11°C and 15.91°C, respectively. However, the highest average efficiency of 64.44% was obtained at the inclination angle of 30°C, but at the flow rate of 400 cc/minute.

KEYWORDS: Collector angle, Flow rate, Inlet-outlet temperature difference, Efficiency

I. INTRODUCTION

Petroleum is the main choice for meeting the world's energy needs, especially in Indonesia. If this energy is used continuously, it will run out because its availability is very limited and cannot be renewed [1-5]. In addition, this energy harms the surrounding environment because it can cause air pollution and, further, accelerate global warming [6-8]. Therefore, efforts to use or utilize alternative energy sources need to be sought. One alternative energy source is solar energy. This alternative energy is considered appropriate for the current condition because, in addition to being cheap, it is also renewable and abundantly available in tropical regions, especially in Indonesia which is crossed by the equator line [9-11].

The solar energy that reaches the earth can be collected and converted into useful heat energy through a device called a solar collector. A solar collector is a system that collects solar radiation and converts it into heat through an absorber. The wavelength of solar radiation that can be absorbed ranges from 0.29 to 2.5 μm, according to Rosa [12]. A solar collector is composed of an absorber plate with good thermal conductivity. Its surface can be either corrugated or flat. In addition to the absorber plate, a solar collector also consists of an insulator and a light-transmitting cover on top, such as glass.

One way to increase the useful energy output of a solar collector is by varying the angle of the collector. The angle of the collector can be adjusted to find the best intensity. The effect of the collector's angle on a water heater has been studied by previous researchers, such as Wilis and Santosa [13]. They used angles of 0°, 15°, and 20° and found that the highest efficiency was obtained with a 15° angle. However, the general angle of a house roof is around 30°, so the collector to be studied is placed at a 30° angle and varied with other angles. Therefore, this study examines the effect of the angle of the collector on the performance of a flat plate collector with a granite absorber.

II. MATERIALS AND METHOD

The research equipment diagram presented in Figure 1 consists of a pump, a plastic tank to hold the water source, a water source hose, a copper pipe, an overflow pipe, a water tank, a hose, a solar collector, a stop valve, a measuring glass, a stopwatch, a pyranometer, and an anemometer. The copper pipes attached to the

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 1234-1238 www.ijaem.net ISSN: 2395-5252

absorber are parallel and consist of seven 1/2-inch diameter copper pipes. The parallel pipe arrangement was chosen because previous research showed that a heat exchanger with parallel pipes is better than a serpentine shape, as stated by Wirawan et al. [6-8] and Mirmanto et al. [14-16]. Meanwhile, the research equipment photo is presented in Figure 2. The fluid used in this research is clean water. The water flows by gravity through a pipe from the upper tank. Then, the water flows towards the flat plate collector and gains heat inside the collector. The flow rate or volume is controlled using the stop valve and measured using the measuring glass and stopwatch.

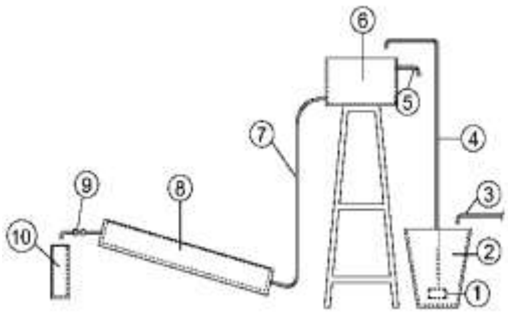

Figure 1. Research apparatus scheme. 1. Pump, 2. Plastic tank for storing water source, 3. Water source hose, 4. Pipe, 5. Overflow pipe, 6. Water storage tank, 7. Hose, 8. Solar collector, 9. Stop valve, 10. Measuring cup.

All inlet and outlet water temperatures, ambient temperature, and collector temperature are measured using calibrated K-type thermocouples with an uncertainty of ±0.5°C. The collector temperatures measured include the temperature of the cover, walls, absorber, and copper pipes. All thermocouples are directly connected to the NIDAQ9714 data logger so that all temperatures can be recorded simultaneously. The pump used is an aquarium pump, which is only used to raise water from the bottom tank to the top tank. There is an overflow pipe in the top tank to maintain the water level.

Before starting the test, the research equipment and measuring instruments are prepared, and the condition of the measuring instruments is checked and calibrated. The testing is carried out from 10.00 am - 5.00 pm with the following procedure:

1. Place the solar collector under direct sunlight and position it at 15°, 30°, and 45° angles.
2. Adjust the water flow rate to a flow rate of 300 cc/minute for each collector.
3. Run the data logger program on the computer.
4. Run the solar intensity recorder and place it near the solar collector.
5. Record all temperatures with a data logger for approximately 7 hours and save them directly into the computer.
6. Repeat steps 2-5 for different flow rates.

Figure 2. Photo of three solar collectors with inclinations of 15°, 30°, and 45°.

The energy that enters the collector can be defined as the magnitude of the solar radiation intensity multiplied by the perpendicular area that is exposed to the solar radiation intensity. Therefore, in a flat plate collector, the incoming heat energy can be expressed by equation (1), which can be obtained from Duffie and Beckman [14].

$$Q_{in} = Ib_T A_c \quad (1)$$

Q_{in} is the rate of heat flow entering the collector (W), Ib_T is the solar radiation intensity (W/m²), and A_c is the area of the collector (m²) perpendicular to the incoming solar radiation. This equation has also been used by several previous researchers, as done by Wirawan et al. [6-8]. In addition to heat entering, there is also heat gain and heat loss in the collector [15-17].

The heat absorbed by the water, Q_{use}, is known as heat gain. This heat is a function of the fluid mass flow rate used to transfer heat from the absorber, the heat capacity of the fluid at constant pressure, and the inlet and outlet fluid temperatures, Ti and To, respectively. Q_{use} can be estimated as follows, according to Wirawan et al. [6-8] and [15-17]:

$$Q_{use} = \dot{m} c_p \left(T_o - T_i\right) \quad (2)$$

$\dot{m}$ is the mass flow rate (kg/s), c_p is the specific heat of the fluid (J/kgK). The solar radiation that hits the collector surface is mostly absorbed and conducted into the fluid, which is utilized as useful energy or heat. Equation (2) is

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 1234-1238 www.ijaem.net ISSN: 2395-5252

also used by Wirawan et al. [6-8] and [15-17]. In addition to useful heat, heat loss from the collector is also a very important variable. This heat loss, Q_{loss}, in a solar collector is the difference between the heat that enters the collector, Q_{in}, and the heat absorbed by the fluid, Q_{use}, and can be written as:

$$Q_{loss} = Q_{in} - Q_{use} \quad (3)$$

Apart from the use of heat, the performance of a flat plate collector can be seen from the efficiency parameter. Collector efficiency, η, can be defined as the ratio between useful heat and solar radiation that enters, as described by Wirawan et al. [6-8] and [15-17], Syamsu et al. [18], and expressed by the equation:

$$\eta = \frac{Q_{use}}{Q_{in}} \quad (4)$$

III. RESULTS AND DISCUSSION

After conducting the experiment and obtaining the necessary data, the next step is to perform calculations on the obtained data from the research. The calculations are done to determine the amount of radiation intensity entering the Ib_T collector, the temperature difference between the inlet and outlet water of the collector (ΔT), the amount of heat entering the collector (Q_{in}), the amount of heat used (Q_{use}), the amount of heat lost (Q_{loss}), and the collector efficiency (η).

The results of the Q_{in} calculation using equation (1) are shown in Figure 3. Q_{in} received by the collector at 15°, 30°, and 45° angles is almost the same as the graphs overlap with each other. However, the highest Q_{in} is dominated by the solar collector with a 30° tilt angle. This is due to the direction of sunlight on the collector, which is more perpendicular at a 30° tilt angle compared to other tilt angles. Figure 3 appears to be inconsistent as Q_{in} obtained at certain times drastically drops or is very low. This is due to the sky condition, which is sometimes cloudy or the sun is covered by clouds. Similar results were also found by Wirawan et al. [6-8] and [15-17]. Clear and cloudy sky conditions cannot be avoided as they are dependent variables that cannot be controlled.

The variable of the temperature difference between the inlet and outlet water is presented in Figure 4. This variable is later used to determine the useful heat Quse. The temperature difference is expressed by the equation:

$$\Delta T = T_o - T_i \quad (5)$$

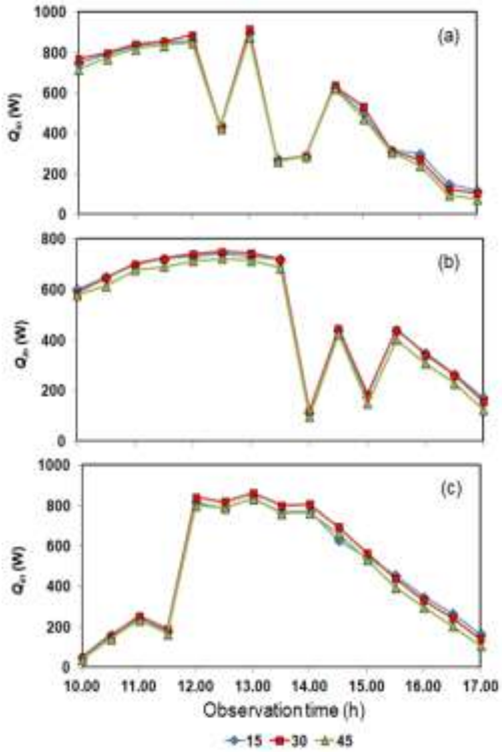

Figure 3. The Relationship of Q_{in} with the Time of Research, (a) April 1st, 2023 at a flow rate of 300 cc/minute, (b) April 3rd, 2023 at a flow rate of 400 cc/minute, (c) April 5th, 2023 at a flow rate of 500 cc/minute. The numbers 15, 30, and 45 indicate the slope of the collector at 15°, 30°, and 45°.

The results of using equation (5) are presented in Figure 4. As with Q_{in}, ΔT also fluctuates greatly due to changing weather. In the early hours of the study until 1:00 p.m., the average ΔT increased. After that time, ΔT generally decreased because the sun was tilting towards the west and was no longer visible. However, Figure 4 indicates that a collector tilt angle of 30° produces a higher ΔT.

With a high ΔT, Q_{use} will also be high. Q_{use} is calculated using equation (2), which is also used by Wirawan et al. [6-8] and [15-17]. The results of the calculation using equation (2) are presented in Figure 5. Figure 5 also shows fluctuations due to the fluctuation of Q_{in} received by the collector. Because ΔT is higher for a collector tilt angle of 30°, Q_{use} is generally higher than Q_{use} generated by collectors with tilt angles of 15° and 45°.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 4 April 2023, pp: 1234-1238 www.ijaem.net ISSN: 2395-5252

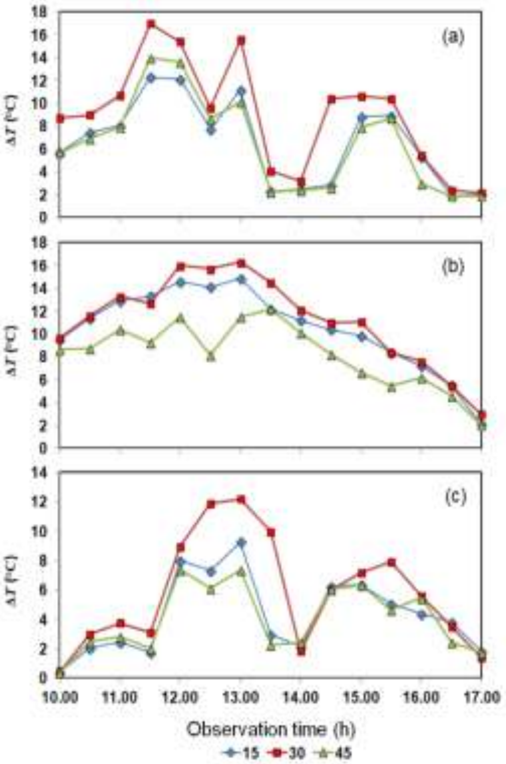

Figure 4. The Relationship between ΔT and observation time: (a) April 1st, 2023 at 300 cc/minute, (b) April 3rd, 2023 at 400 cc/minute, and (c) April 5th, 2023 at 500 cc/minute.

To determine the effect of flow rate, a Q_{use} graph must be created for the same tilt angle but with different flow rates. However, in this experiment, different flow rates were tested at different times, so Q_{use} for different flow rates cannot be compared. Therefore, further research is needed for various flow rates but at the same date and time.

The performance of the collector can also be expressed in terms of collector efficiency [6-8], [14-17]. This parameter is calculated using equation (4), and the results are shown in Figure 6. Figure 6 shows that the highest daily average efficiency is achieved by the solar collector with a tilt angle of 30°, followed by the collector with a tilt angle of 15°. The lowest daily average efficiency is obtained with a collector tilt angle of 45°.

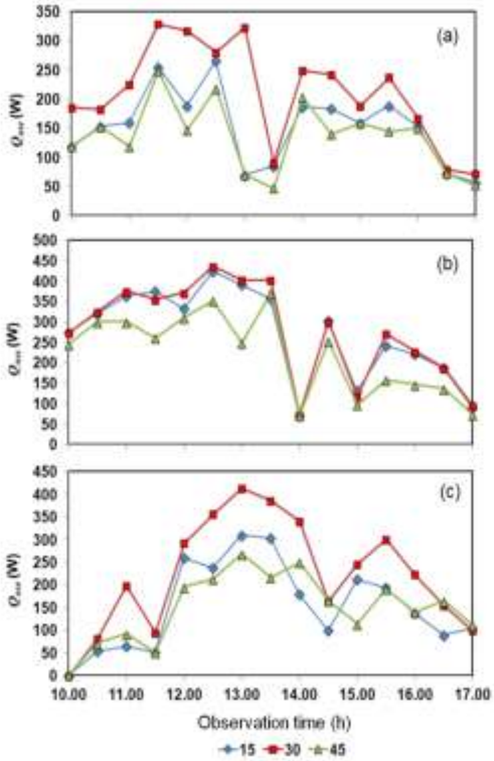

Figure 5. The Relationship between Q_{use} and observation time: (a) April 1st, 2023 at 300 cc/minute, (b) April 3rd, 2023 at 400 cc/minute, and (c) April 5th, 2023 at 500 cc/minute.

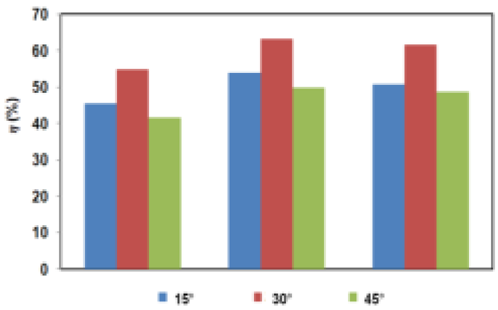

Figure 6. Relationship between daily average efficiency and collector tilt angle.

IV. CONCLUSION

A study to investigate the effect of collector tilt angle on the performance of a solar collector with a granite rock absorber has been conducted. Based on the experimental results and data analysis, several statements can be made as follows:

1. The heat input into the solar collector, represented by Q_{in}, is highly fluctuating depending on the weather (sunny or cloudy).
2. As a result of the fluctuating heat input, ΔT also fluctuates.

3. Q_{use}, which depends on ΔT, also fluctuates.
4. The highest ΔT and Q_{use} were obtained with the solar collector with a tilt angle of 30°.
5. The highest daily average efficiency was also dominated by the solar collector with a tilt angle of 30°.

REFERENCES

[1] "Indonesia's Energy Mix: Moving Away from Oil Dependency" by the Embassy of Indonesia in Washington DC. Accessed on April 18, 2023. Link: https://www.indonesianembassy.org/indonesia-s-energy-mix-moving-away-from-oil-dependency.

[2] "Petroleum: The World's Primary Energy Source" by the Energy Information Administration (EIA). Last updated on January 20, 2022. Link: https://www.eia.gov/energyexplained/petroleum/use-of-petroleum.php

[3] "The Limited Availability of Fossil Fuels" by the Union of Concerned Scientists. Accessed on April 18, 2023. Link: https://www.ucsusa.org/resources/limited-availability-fossil-fuels

[4] "Oil will run out in 53 years: BP" by CNN Business. Published on June 17, 2021. Link: https://www.cnn.com/2021/06/16/business/bp-oil-report/index.html

[5] "Indonesia's Energy Outlook 2021" by the Ministry of Energy and Mineral Resources of the Republic of Indonesia. Accessed on April 18, 2023. Link: https://www.esdm.go.id/assets/media/content/content-outlook-energy-2021-indonesia.pdf

[6] Wirawan, M.; Mirmanto; Susana, I.G.B.; and Sutanto, R., 2015, "Pengaruh Susunan Pipa Laluan Terhadap Pemanfaatan Kalor pada Kolektor Surya Pelat Datar Absorber Granite," Dinamika Teknik Mesin, vol. 5, no. 1, 50-55.

[7] Wirawan, M.; Kurniawan, R.; and Mirmanto, 2016, "Pengaruh Jumlah Haluan Pipa Paralel pada Kolektor Surya Pelat Datar Absorber Batu Kerikil Terhadap Laju Perpindahan Panas," Dinamika Teknik Mesin, vol. 6, no. 2, 127-133.

[8] Hoel, M.; and Kvemdokk S., 1996, "Depletion of Fossil Fuels and The Impacts of Global Warming," Resource and Energy Economics, vol. 18, 115-136.

[9] Setyadi, U.D.; and Dwiyantoro, B.A.; 2015, "Pengaruh Sudut Kemiringan Kolektor Surya Pelat Datar terhadap Efisiensi Termal dengan Penambahan Eksternal Annular Fin pada Pipa," Jurnal Teknik ITS, vol. 4, no. 1, 31-36.

[10] Mirmanto, M.; Wirawan, M; Sayoga, I.M.A; Abdullah, A; and Faisal, M., 2020, "Unjuk Kerja Distiller Tenaga Surya Sistem Kontinue dengan Berbagai Jumlah Kaca Penutup," Jurnal Teknik Mesin Mercu Buana, vol. 9, no. 1, 24-32.

[11] Mirmanto, M.; Wirawan, M.; Sayoga, I.M.A.; Wijayanta, A.T.; Pranowo, P.; Faisal, M.; and Abdullah, A., 2020, "Performances of three solar distillers with different absorbers," AIP Conference Proceedings, vol. 2187, no. 1, 020022.

[12] Rosa, Y., 2007, "Rancang Bangun Kolektor Pelat Datar Energi Surya untuk Sistem Pengering Pasca Panen," Jurnal Teknik Mesin, vol. 4, no. 2, 68-82.

[13] Wilis, G.R.; and Santosa, I., 2014, "Variasi Sudut Kemiringan Kolektor Surya Solar Water Heater," Prosiding Seminar Nasional Aplikasi Sains & Teknologi (SNAST), Yogyakarta.

[14] Duffie, J.A., and Beckman W.A., 1980, Solar Engineering of Thermal Process 2nd Edition," John Wiley & Sons Inc., New York.

[15] Saputra, B.H., 2015, "Pengaruh Jumlah Pipa Pada Kolektor Surya Absorber Batu Granit Terhadap Laju Perpindahan Panas," Skripsi, Jurusan Teknik Mesin, Fakultas Teknik, Universitas Mataram.

[16] Hamzanwadi, 2015, "Pengaruh Jumlah Pipa Terhadap Laju Pelepasan Kalor pada Kolektor Surya Absorber Batu Granit," Skripsi, Jurusan Teknik Mesin, Fakultas Teknik, Universitas Mataram.

[17] Fahrurrozi, I., 2017, "Pengaruh Variasi Sudut Kemiringan Kolektor Surya Plat Datar Absorber Batu Granit Terhadap Unjuk Kerja Kolektor," Skripsi, Jurusan Teknik Mesin, Fakultas Teknik, Universitas Mataram.

[18] Syamsu, W.D.; Selleng, K.; and Mustofa, 2012, "Efektifitas Kolektor Energi Surya pada Konfigurasi Paralel-Serpentine," Majalah Ilmiah MEKTEK, no. 1, 12-16.