Enhancing Solar Power Harvest By Using Absorber Plates on Thermoelectric Generator Modules

Abdul Halim, Zuryati Djafar(✉), and Wahyu H. Piarah

Mechanical Engineering Department, Faculty of Engineering, Universitas Hasanuddin, Sungguminasa 92171, South Sulawesi, Indonesia
{zuryatidjafar,wahyupiarah}@unhas.ac.id

Asbtract. Research on thermoelectric as a power generator known as a thermoelectric generator (TEG) shows a positive trend. The current constraint is the relatively low efficiency, especially if it is used to absorb direct sunlight energy. To increase the output power of TEG, it is endeavored to increase the temperature of the hot side by placing the absorber plate on the hot side so that the temperature difference between the hot and cold side (ΔT) will also increase. This study was conducted to determine the magnitude of the increase in electrical energy generated from the TEG module using several variations of absorber plates such as aluminum, iron, and copper compared to without absorber plates. The results showed that the intensity of solar radiation greatly affects the temperature difference obtained from both sides of the TEG module so that it can produce an increase in the difference in output power voltage and efficiency. The power and efficiency of Copper, Iron, Aluminum and without plates were obtained: 0.0023 W and 1.831 %, 0.0019 W and 1.301 %, 0.0004 W and 0.628 %, and 7.14×10^{-5} W and 0.1014 %. It can be seen that there is an increase in output power using Al, Fe, and Cu plates by 5.6, 26.6, and 32.2 times, respectively, and an increase in efficiency by 6.2, 12.8, and 18.1 times.

Keywords: Absorber plate · Efficiency · Solar power · Thermoelectric generator · Voltage difference

1 Introduction

In everyday life, we cannot be detached from the use of energy, both on a small and large scale. The need for energy will continue to increase along with technological developments. Most of the energy sources currently used are non-renewable, such as oil and coal. They are classified as fossil energy and will run out due to their use in everyday life [1]. Therefore, it is necessary to find and utilize new renewable energy sources. Currently, the use of renewable energy is still in a relatively small percentage but is expected to be able to supply energy needs in the future. Alternative energy sources such as wind, sunlight, temperature differences in the sea, geothermal, river flows, and other sources, can be used to produce electrical energy [2].

Akhyar et al. (Eds.): ICECME 2021, LNME, pp. 53–59, 2023.
https://doi.org/10.1007/978-981-19-3629-6_6

The development of the use of new and renewable energy (EBT) has received support from the Government of Indonesia through the regulation of the minister of energy and mineral resources number 39 of 2017 concerning the implementation of physical activities using new and renewable energy and energy conservation. Through these official regulations, it is expected that the wider community will be willing and able to utilize EBT in order to ensure the availability of electrical energy [3].

In Indonesia, one of the renewable energy sources that can be utilized is sunlight. Based on solar radiation data collected from various locations in Indonesia, it shows that the potential in the western region of Indonesia is 4.5 kWh/m^2.day with a monthly variation of about 10%, and the eastern region of Indonesia is 5.1 kWh/m^2.day with a monthly variation. around 9% with an average Indonesian value of 4.8 kWh/m^2.day with a monthly variation of around 9%. This energy potential is equivalent to 112 thousand GWp. However, currently, only about 49MWp of solar energy has been utilized. This means that the potential for solar energy that has been utilized is still far from 1% [4].

As a form of support in the development of alternative energy sources, we offer the use of a thermoelectric generator (TEG). In this study, the source of heat energy is obtained from sunlight which is then absorbed by an absorbent plate that functions to increase the absorption of solar energy which is then converted into electrical energy

2 Literature Review

In 1821 a German researcher Thomas Johann Seebeck discovered a device that could convert heat energy into electrical energy [5–9]. Thermoelectric Generator (TEG) is a power generating device that uses the principle of the Seebeck effect [5–8]. The principle of the Seebeck effect itself is: when two metal rods or wires which are generally semiconductors are connected where one end is heated and the other end is kept cold, it will produce a voltage difference or electromotive force [10–13].

In Fig. 1, the structure of the thermoelectric generator (TEG) consists of an arrangement of elements of n-type (electron-excess material) and p-type (electron-deficient material). Heat enters on one side and is discharged on the other. The difference in temperature between the two sides causes diffusion of the material to receive the hot side which is actively moving and has a higher flow velocity to the cold side [11]. As a result of this diffusion creates an electric field. The number of electrons on the hot side of the

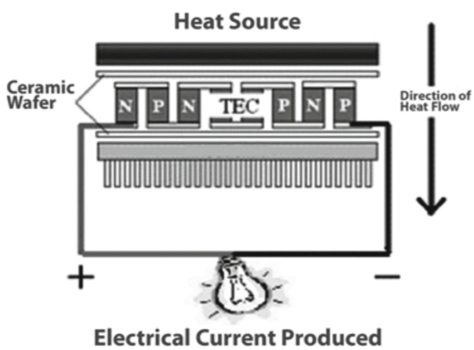

Fig. 1. Thermoelectric generator structure [13]

metal is more tenuous when compared to the cold side which is denser [12]. The amount of voltage generated is proportional to the temperature difference [13].

Thermoelectric technology is a solid-state technology that is unmoving and environmentally friendly [12, 14]. In addition, this technology is one of the alternative energy sources in overcoming the energy crisis from year to year [15]. The advantages of this thermoelectric technology are that it is safe for the environment, small in size, silent, does not require complicated and light maintenance [13, 16].

In addition to having advantages, thermoelectric generators also have disadvantages, namely, the efficiency value is still low. This is something that always gets attention to be improved, among others, by optimizing the performance of the components in the thermoelectric generator, or developing thermoelectric materials and improving the manufacturing quality of the thermoelectric generator itself [13].

The efficiency value of the thermoelectric module can be increased by lowering the temperature on the cold side by using a heatsink, fan, water jacket, or by providing a low ambient temperature above the cold side of the thermoelectric to keep the temperature difference high [17].

Another way to increase the efficiency offered here is to attach the absorber plate to the hot side surface of the thermoelectric.

In analyzing the performance of the thermoelectric module, the Seebeck coefficient which describes the voltage (electromotive force) arising due to temperature differences becomes very important. Seebeck coefficient can be expressed by the following equation [5, 12]:

$$\propto = \frac{\Delta V}{(T_h - T_c)} \tag{1}$$

where ΔV is Voltage difference (Volt), α is Seebeck Coefficient (V/°C), T_h is Hot side temperature (°C) and T_c is Cold side temperature (°C).

While the electric current generated is given by the following equation [5]:

$$I = \frac{\propto \Delta T}{R_i + R_L} = \frac{\propto (T_h - T_c)}{R_i + R_L} \tag{2}$$

In this equation, I is Current (Ampere), R_i is Internal Resistance (Ω), R_L is External resistance and ΔT is Temperature difference ($T_h - T_{c)}$.

The heat transfer rate (Q_h) from the heat source on the hot side surface to the cold side surface is as follows [12]:

$$Q_h = (\propto I\, T_h) + k(T_h - T_c) \tag{3}$$

where k is the thermal conductivity of the module. The output power (P) generated to resist external loads [R_L] and efficiency (η) thermoelectric generator is as follows [5] :

$$P = I^2 R_L \tag{4}$$

$$\boldsymbol{\eta} = \frac{\mathbf{P}}{\mathbf{Q_h}} \tag{5}$$

3 Research Method

The design of the equipment used in this study can be seen in Figure 2 below. The absorber plate has a thickness of 2 mm in a rectangular shape, placed on top of the thermoelectric. The thermoelectric bottom surface uses a heatsink-fan cooling system. Three variations of absorber materials are used, namely Aluminum (Al), Iron (Fe), and Copper (Cu) plates. Measurements were carried out simultaneously for the 3 variations of the absorber plate and without the absorber plate.

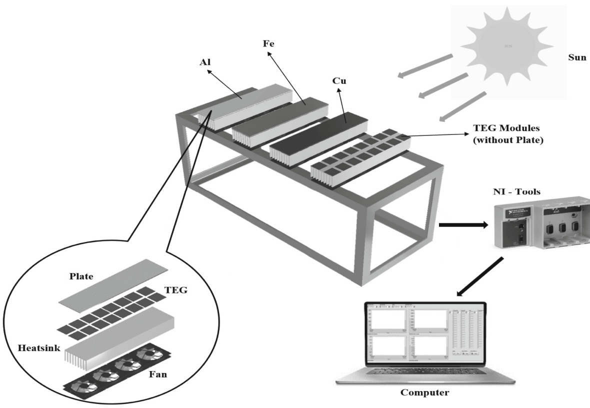

Fig. 2. Testing installation schematic

The measurements of the temperature of the hot side (Th), the cold side (Tc), and the voltage (ΔV) using the National Instrument and carried out with an interval of 15 min for 8 h, starting from 9.00 a.m to 17.00 p.m. Measurement data recording using LabVIEW software.

4 Results and Discussion

In this paper the testing parameters are focused on the temperature difference (ΔT), voltage difference (ΔV), heat absorbed (Q_h) output power (P) and efficiency (ɳ). The results of measurements and calculations are displayed in graphical form.

Figure 3 shows the characteristics of the temperature difference between the hot and cold sides of the thermoelectric T and the voltage V generated during data collection. It appears that the pattern of temperature differences is identical to the resulting stress pattern. This is in accordance with the principle of the Seebeck effect. At first, there was an increase in temperature and voltage differences along with the increasing intensity of sunlight and was at a high condition between 10.30 a.m and 13.00 p.m. After that, there was a decrease as the intensity of the sun decreased in the afternoon. The difference in temperature and the highest voltage for each absorber plate is as follows: for copper (Cu) plates, it produces T and V of 4.767 °C and 0.871 V; iron plate (Fe), T and V of 6.295 °C and 0.805 V; aluminum plate (Al), T and V of 2,996 °C and 0.369 V;

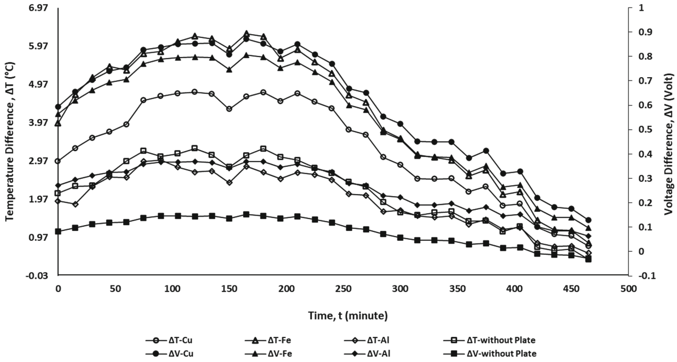

Fig. 3. Characteristics of temperature (ΔT) and voltage differences (V) to time (t)

Figure 4 shows the characteristics of the temperature difference with the heat absorbed by the thermoelectric module. The characteristic patterns that occur are very identical to each other where the increase and decrease in heat absorbed also depends on the intensity of sunlight. The measurement values obtained are: for copper (Cu) plates, T and Qh are 4.767 °C and 0.127 W; iron plate (Fe), T and Qh of 6.295 °C and 0.155 W; aluminum plate (Al), T and Qh of 2,996 °C and 0.0722 W and for non-plate produce T and Qh of 3.295 °C and 0.0744 W. It also appears that the heat absorbed is highly dependent on the absorber material used. For aluminum material, the rate of heat absorption is not too influential compared to iron and copper materials.

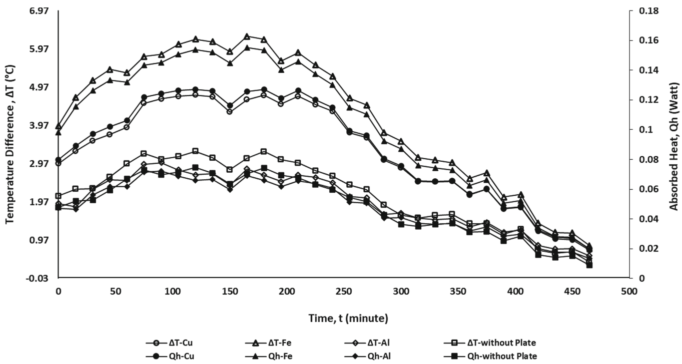

Fig. 4. Characteristics of temperature difference (ΔT) and absorbed heat (Q_h) to time (t)

Figure 5 shows the characteristics of the output power and the heat absorbed. The ability to convert the output power from the absorbed heat is relatively low for aluminum which is shown by the graph gap which is relatively large compared to iron and copper. In addition, the use of absorber plates shows an increase in the output power produced. The results are shown for copper (Cu), accounted for 0.0023 W for power and heat absorbed 0.1271 W; iron (Fe), produces a power of 0.0019 W and absorbed heat of 0.1550 W; aluminum (Al), produces a power of 0.0004 W and absorbed heat of 0.0722 W and for non-plate produces a power of 0.00007 W and absorbed heat of 0.0744 W. The intensity of the sun also shows a great influence on the output power produced.

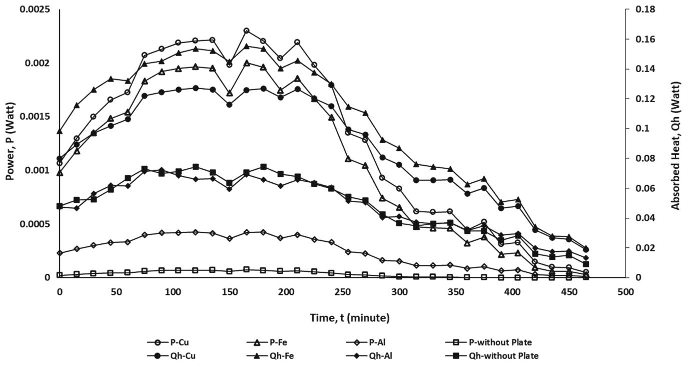

Fig. 5. Relationship between power (P) and absorbed heat (Q_h) to time

Figure 6 shows output power characteristics and thermoelectric efficiency which is resulted from measurements on the absorber plate. It can be seen that the output power and efficiency will increase with the use of absorber plates where the absorber plates that provide the best output power and efficiency are descending from copper, iron, and aluminum. The power and efficiency values produced are copper plate (Cu), producing P and η of 0.0023 W and 1.831 %; iron plate (Fe), producing P and η of 0.0019 W and 1.3014 %; aluminum plate (Al), producing P and η of 0.0004 W and 0.6287 %; as well as for without-plate produces P and η of 0.00007 W and 0.1014 %.

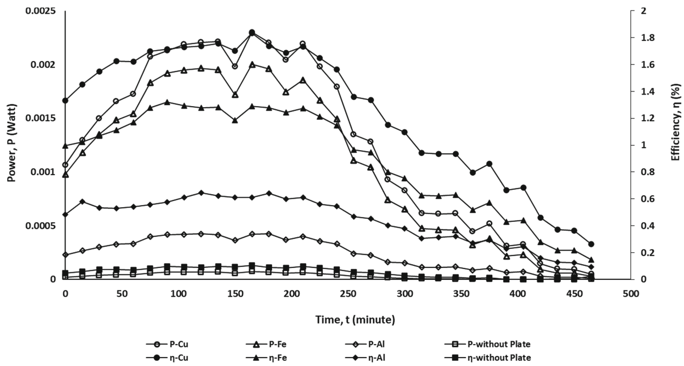

Fig. 6. Relationship of power (P) and efficiency (η) to time

5 Summary

The characteristics of the output power and thermoelectric efficiency indicate that the use of absorbent plates will have a positive impact on the thermoelectric performance.

The power and efficiency of Copper, Iron, Aluminum and without plates were obtained: 0.0023 W and 1.831%, 0.0019 W and 1.301%, 0.0004 W and 0.628%, and 7.14×10^{-5} W and 0.1014%. It can be seen that there is an increase in output power using Al, Fe, and Cu plates by 5.6, 26.6, and 32.2 times, respectively, and an increase in efficiency by 6.2, 12.8, and 18.1 times.

References

1. Kholiq, I.: Utilization of alternative energy as renewable energy to support fuel substitution. J. Sci. Technol. **19**(2) (2015)
2. Ramadhan, A.I., Diniardi, E., Mukti, S.H.: Analysis Design System Solar Power Generation Capacity 50 WP, Engineering (2016)
3. Budiman, A., Das, K., Mohammad, A., Tan, K.T., Tonby, O.: Ten ideas for reinvigorating Indonesia's energy sector. McKinsey & Company, Technical report (2014)
4. Directorate General of New, Renewable Energy and Energy Conversion, Strategic Plan of the Ministry of Energy and Mineral Resources 2015-2019, Ministry of Energy and Mineral Resources, Technical report (2015)
5. Djafar, Z., Putra, N., Koestoer, R.A.: The utilization of heat pipe on cold surface of thermoelectric with low-temperature waste heat. Appl. Mech. Mater. **302**, 410–415 (2013)
6. Mustofa, M., Djafar, Z., Syafaruddin, Piarah, W.H.: A new hybrid of photovolatic-thermoelectric generator with hot mirror as spectrum splitter. J. Phys. Sci. **29**, 63–75 (2018)
7. Usman, S., Djafar, Z., Tjandinegara, T., Djafar, Z., Piarah, W.H.: Heat utilization of incinerator chimneys as mini power generation based on thermoelectric. EPI Int. J. Eng. **1**(1), 1–2 (2018)
8. Cai, Y., Mei, S.J., Liu, D., Zhao, F.Y., Wang, H.Q.: Thermoelectric heat recovery units applied in the energy harvest built ventilation: parametric investigation and performance optimization. Energy Convers. Manag. **171**, 1163–1176 (2018)
9. Shittu, S., Li, G., Akhlagi, Y.G., Ma, X., Zhao, X., Ayodele, E.: Advancements in thermoelectric generator for enhanced hybrid photovolatic system performance. Renew. Sustain. Energy Rev. **109**, 24–54 (2019)
10. Min, G., Roe, D.M.: Peltier devices as generator. In: Handbook of Thermoelectrics, p. 479. CRC Press LLC, Florida (1994)
11. Willfahrt, A.: Screen printed thermoelectric devices. Linköping Studies in Science and Technology, no. 1663 (2014). 49
12. Goldsmid, H.J.: Introduction to Thermoelectricity, Springer Series in Material Science 121. Springer-Verlag, Heidelberg (2010). https://doi.org/10.1007/978-3-642-00716-3
13. Putra, N., Koestoer, R.A., Adhitrya, M., Roekettino, A., Trianto, B.: The potential of thermoelectric power generation for hybrid vehicles. J. Makara Teknologi **13**(2), 53–58 (2009). (in Bahasa)
14. Prasetyo, Y., et al.: Characteristic of thermoelectric TEC varies type with variation load resistor. J. Energi dan Teknol. Manufaktur **2**, 36–41 (2019). (in Bahasa)
15. Nugrah, S., Aziz, A., Mainil, R.I.: Testing a thermoelectric generator (TEG) with a 60 Volt electric heater using cooling water at environmental temperatures. Energy Conversion Laboratory, Department of Mechanical Engineering, Faculty of Engineering, University of Riau. J. TEKNIK **4**(2) (2017). (in Bahasa)
16. Riffat, S.B., Ma, X.: Thermoelectrics: a review of present and potential applications. Appl. Therm. Eng. **23**, 913–935 (2003)
17. Ismail, B.I., Ahmed, W.H.: Thermoelectric power generation using waste-heat energy as an alternative green technology. Recent Patents Electr. Eng. **2**, 27–39 (2009)