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COMPARATIVE STUDY OF THERMOELECTRIC GENERATOR MODULE PERFORMANCE WITH VARIOUS TYPES OF PLATE MATERIALS

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Abstracts

Advanced materials are used in thermoelectric generator (TEG) technology to turn heat into electricity using the Seebeck effect, which helps make better use of heat sources. The Seebeck effect is a result of the temperature disparity that exists between the two surfaces of the TEG. The configuration utilized in this investigation comprises several primary components, including the water block, thermoelectric, heat exchanger plate, and heater plate. The water block is positioned on the cold surface side of the thermoelectric to optimize the cooling process, while the heater plate is positioned on the surface side to facilitate the heating process. Initially, we position the heater plate to avoid direct contact between the heated surface side and the material plate. The plates consist of both copper and aluminum elements. This is done to facilitate the identification of the configuration systems, specifically TEG A (copper) and TEG B (aluminum). The research findings indicate that the TEG B configuration system, when subjected to a heating rate, yields superior voltage, current, and power outputs.

Keyword: *TEG, Heating rate, Power output*

INTRODUCTION

The utilization of fossil fuels in industry has considerable environmental consequences, such as air pollution and climate change, necessitating the advancement of renewable energy technologies and energy efficiency to enhance environmental performance (Yan, Fazilati, *et al.*, 2020)(Tian *et al.*, 2020). A recent study has investigated the feasibility of harnessing waste heat from industrial operations, thereby diminishing the energy produced by fossil fuels (Bobean and Pavel, 2013)(Jouhara *et al.*, 2021).

The utilization of waste heat through thermoelectric power generation technology has garnered widespread attention as an effective approach to optimizing energy efficiency. The thermoelectric materials used in this technology can convert heat into electricity through the Seebeck effect, thereby offering new opportunities to generate electrical energy from unused heat sources (Demir and Dincer, 2017)(Sladek *et al.*, 2020). The Peltier effect converts electric energy into thermal energy; thermoelectric becomes a cooler (Shittu *et al.*, 2019)(Wu, Zhang and Liao, 2017).

In thermoelectric technology, p-type and n-type semiconductor materials are lined up together to change heat energy into electricity, with a conversion efficiency of about 5% to 8% (Chen and Lee, 2015)(Deasy *et al.*, 2018). This process facilitates the advancement of more efficient and eco-friendly energy systems, positioning thermoelectric technology as a possible answer to future energy concerns world (Yan, Gholami, *et al.*, 2020). Thermoelectric (TE) technology has demonstrated efficacy in energy conversion, with many applications spanning cooling to power generation that harness waste heat to generate electrical energy, hence enhancing total energy efficiency (Mirhosseini *et al.*, 2017)(Kim, Kwak and Kim, 2019).

Thermoelectric technology provides notable benefits, such as the direct transformation of thermal energy into electrical energy without mechanical intervention, along with static module configurations that eliminate the need for working fluids, facilitating the creation of more efficient, dependable, and eco-friendly systems (Najjar and Kseibi, 2017)(Børset *et al.*, 2017). Thermoelectric technology provides significant flexibility and reliability across diverse applications, such as microgeneration in limited locations and silent operation suitable for embedded systems (Jaziri *et al.*, 2020)(Catalan *et al.*, 2020). Consequently, thermoelectric systems necessitate low maintenance and are straightforward to regulate, rendering them superior to alternative conversion methods (Aranguren, Astrain and Pérez, 2014).

Thermoelectric technology has numerous advantages; nonetheless, its limitation in enduring elevated temperatures on the hot side poses a significant obstacle. This study aimed to evaluate the efficacy of thermoelectric materials and identify methods to augment the generated electrical output.

EXPERIMENT METHODS

This study examines the impact of various heat exchanger plate materials on the efficacy of thermoelectric generator (TEG) modules. The performance metrics assessed encompass voltage, electric current, electric power, and temperature distribution at six distinct measurement points to guarantee excellent data precision. We employ a data logger to capture this parameter data in real time. Two varieties of heat exchanger plate materials are utilized: copper and aluminum, both with consistent dimensions of 40 x 40 x 3 mm. The selection of these varied materials facilitates a more thorough examination of the impact of their thermal properties on the performance of the TEG module. The TEG module used is the SP 1848 27145 SA type, which is commonly used in the industry, as shown in Fig. 1, with its details listed in Table 1. We used a bulb with specifications of 4.8 VDC and 0.5 A to simulate real-world operating conditions for the voltage measurement under load.

This study's configuration and experiment setup has several primary components: the water block, thermoelectric device, heat exchanger plate, and heater plate, as seen in Figure 2. We position the water block on the cold side of the TEG surface to optimize the cooling process, thereby enhancing the energy conversion efficiency. Conversely, on the heated side, heat exchanger plates composed of diverse materials function as efficient thermal conductors. We position the heater plate after the heat exchanger plate, acting as a heat source to start the energy conversion process. This study employs two versions of plates composed of distinct materials: copper and aluminum. Each plate material possesses distinct thermal properties, facilitating a comprehensive examination of the material's impact on TEG performance. Each variant is assigned a distinct label for identification and analysis: TEG A for the variation utilizing copper plates and TEG B for the variation utilizing aluminum plates. The study method consists of two phases: a 45-second heating phase using a heating system, followed by a 500-second cooling phase employing a cooling system.

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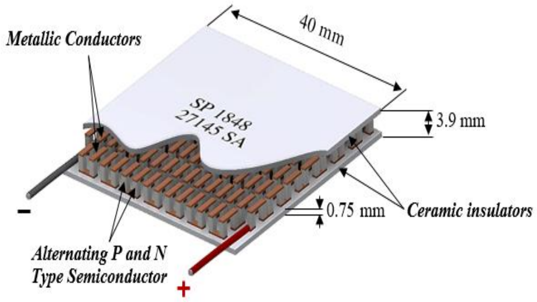
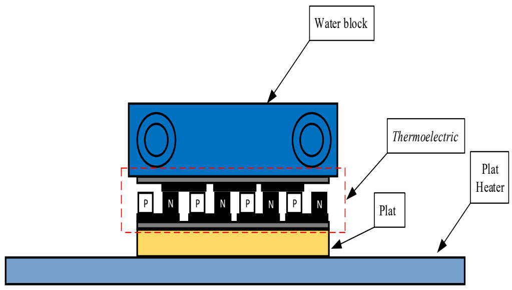


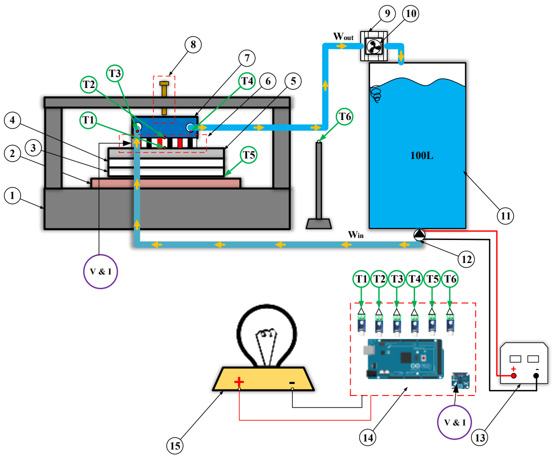
Figure 1 Module Thermoelectric Generator (Merienne *et al.*, 2019)

Tabel 1. Specifications of the thermoelectric generator type SP 1848 27145 SA (Atmoko, Veza and Riyadi, 2021)

Parameters	Specif.
Length [mm]	40
Width [mm]	40
Thickness [mm]	3.9
Mass [g]	3.6
Number of semiconductor P-leg	110
Number of semiconductor N-leg	110
Operating Temperature [°C]	0-150
Maximum operating temperature [°C]	300
Thermal conductivity [W/m °K]	1.6
Electrical conductivity [W/m.K]	0.6
Seebeck coefficient [V/K]	0.054



(a)



(b)

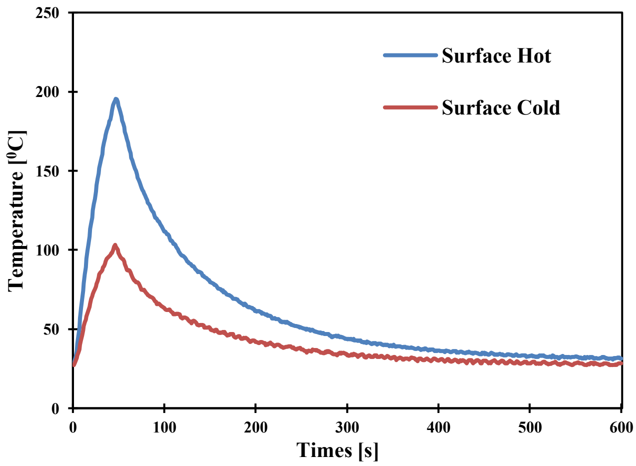
Figure 2. (a) Configuration Experiment (b) Experiment Setup

RESULT AND DISCUSION

The data acquisition process revealed distinct heating rates for the two configurations under investigation. Specifically, the TEG A configuration, utilizing a copper plate, exhibited a heating rate of 2.66 °C/s. In contrast, the TEG B configuration, which employed an aluminum plate, demonstrated a slightly lower heating rate of 2.46 °C/s.

Temperature

Figure 3(a) shows the temperature profile for the TEG A configuration, measured at both the hot and cold surface sides of the TEG, yielding a heating rate of 2.66 °C/s. A significant temperature increase was observed on the hot surface side of the TEG during heating, reaching a peak temperature of 195.5 °C at 45 seconds. Concurrently, cooling was applied to maintain the temperature on the cold surface side of the TEG, which reached a maximum temperature of 102.5 °C during the heating phase. Figure 3(b) shows the temperature profile for the TEG A configuration, measured at both the hot and cold surface sides of the thermoelectric generator, with a heating rate of 2.46 °C/s.



(a)

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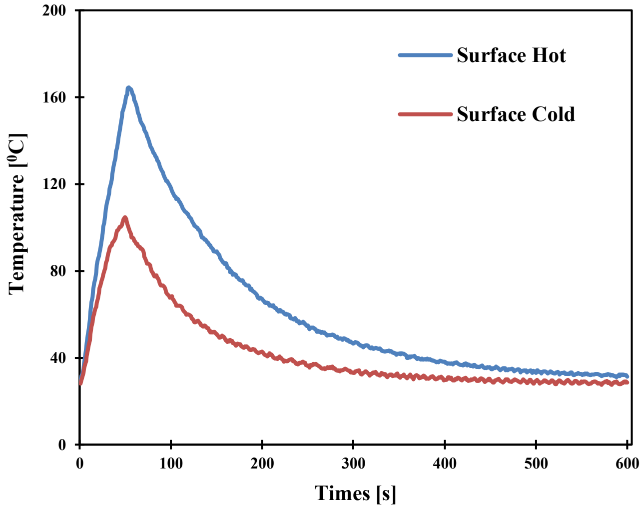
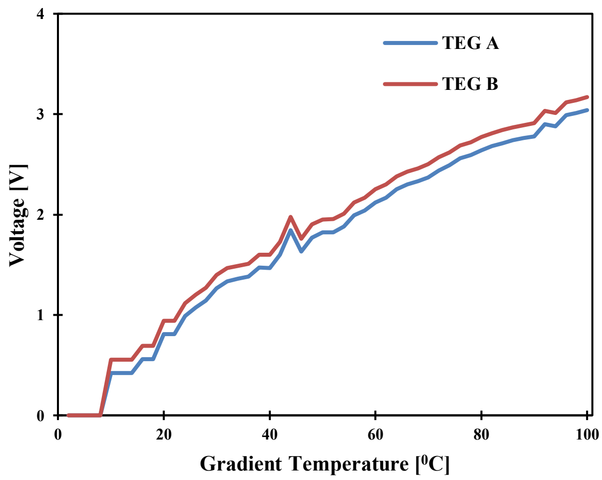


(b)

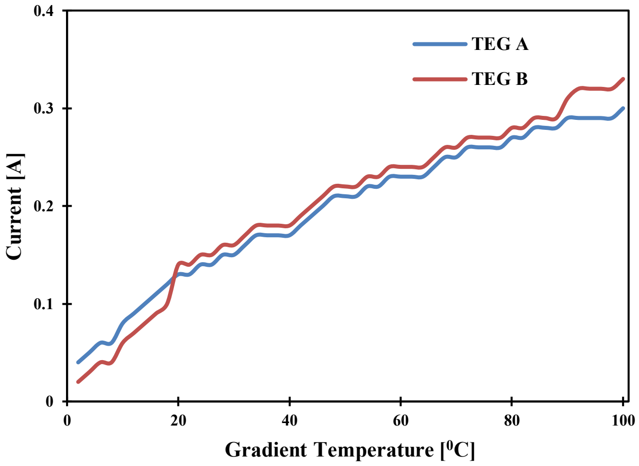
Figure 3. (a) TEG A (Copper), (b) TEG B (Aluminum)

A significant temperature increase was observed on the hot side of the thermoelectric generator during heating, reaching a peak temperature of 164.5 °C at 58 seconds. Concurrently, cooling was applied to maintain the temperature on the cold side of the thermoelectric generator, which reached a maximum temperature of 98 °C during the heating phase. These results are consistent with the significant temperature increase due to simultaneous heating and cooling, as well as the function of the plate placed on the hot side of the thermoelectric generator to achieve a slower heating rate. The low heating rate observed in this study is in agreement with the research conducted by Nurmuntaha et al (Nugraha *et al.*, 2024). A low heating rate, in conjunction with the Seebeck effect principle, enhances the performance of the thermoelectric generator by increasing the temperature difference between the two sides.

Voltage and Current



(a)



(b)

Figure 4. (a) Voltage Output, (b) Current Output

Figure 4(a) shows the output voltage profile generated by each configuration of TEG A and TEG B, with heating rates of 2.66 °C/s and 2.46 °C/s, respectively. A significant increase in output voltage is observed for both TEG A and TEG B configurations, corresponding to the increasing temperature difference between the two surfaces of the TEG. The output voltage generated by TEG A configuration reaches 3.04 V, while TEG B configuration yields an output voltage of 3.17 V, with both values obtained at the maximum temperature difference between the two TEG surfaces. These results indicate that the addition of a plate on the hot side surface, which affects the heating rate, also influences the output voltage of the TEG. The slower heat propagation to the hot side surface allows for more effective heat absorption by the TEG, resulting in a generated output voltage. Figure 4(b) shows the output current profiles for TEG A and TEG B configurations. The results indicate a substantial increase in output current for both configurations, commensurate with the growing temperature difference across the TEG surfaces. Notably, the output current values for TEG A and TEG B are relatively close, measuring 0.29 A and 0.33 A, respectively, which can be attributed to the load used in the experiment.

Power Output

Figure 5 shows the output power profiles of the TEG A and TEG B configuration systems. Both systems demonstrate a substantial increase in output power, commensurate with the increasing temperature difference between the hot and cold sides of the TEG. The TEG B system generates greater power than the TEG A system, likely due to its utilization of an aluminum plate that alters heat transfer and influences the rate of heating. The TEG B system exhibits a slower heating rate of 2.46 °C/s compared to the TEG A system. As previously discussed, the heating rate plays a crucial role in enhancing power output, as highlighted by Riyadi et al. (Riyadi *et al.*, 2022). The use of a plate to mitigate direct exposure on the hot side surface can lead to a reduced heating rate, thereby influencing the TEG's output power performance.

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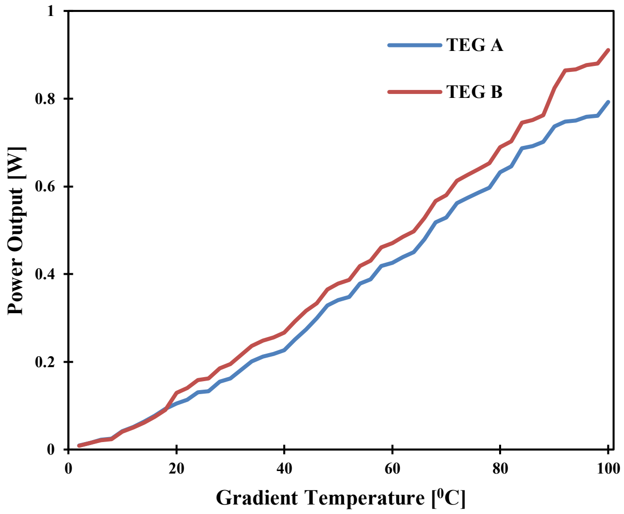

Figure 5. Power Output

Thermoelectric generator modules have significant potential to enhance energy efficiency and reduce dependence on conventional energy sources. With their ability to generate electricity from heat, these modules offer an innovative solution for renewable energy applications. Thermoelectric generator modules can be utilized in various applications, such as generating power from waste heat, charging batteries for electronic devices, and developing autonomous energy systems for remote areas. By leveraging ambient heat, thermoelectric generator modules can enhance energy efficiency and lower operational expenses. Therefore, these modules can be a suitable choice for the development of sustainable and environmentally friendly energy systems. We suggest using the findings of this study while paying close attention to the temperature difference between the hot and cold sides of thermoelectric generators to reach a heating rate that matches the TEG B configuration's shown rate of 2.46°C/s.

CONCLUSION

This research has looked into how a system works by adding a plate to the hot side of the TEG, using copper and aluminum, with heating rates of 2.66 °C/s for TEG A and 2.46 °C/s for TEG B. The temperature measurements in the TEG B configuration system reveal lower values due to the aluminum plate's ability to mitigate direct heat exposure, resulting in a reduced temperature and heating rate compared to the TEG A system. This study enhances our comprehension of heating rates in TEG materials and the advantages of employing an aluminum plate for indirect heat exposure on the hot side surface, resulting in a reduced heating rate and enhanced power output performance.

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