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Study Characteristic Thermal Electric Generator (TEG) Type SP1848 27145 SA

Studi Karakteristik Thermal Electric Generator (TEG) Tipe SP1848 27145 SA

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Abstract

The TEG component, which operates on the Seebeck principle like a thermocouple, is widely used in the market, with TEG SP1848 27145 SA being one of the most common types. However, experiments must be conducted to determine its Seebeck coefficient, voltage, and power output when used with different heat and cold sources. This research aims to observe how the Seebeck coefficient, voltage, and power output of TEG SP1848 27145 SA change with variations in system temperature. To experiment, TEG SP1848 27145 SA is tested with a heater, and water flow rates are varied for cooling. Furthermore, the correlation between output voltage and ΔT has been determined through statistical analysis. The experiment results showed that the voltage output ranged from 0.54–1.03 V at a heater temperature of 86°C and an ΔT system value of 70.5-75°C. The Seebeck value was between 1,551.7-2,998.5 μV, and the power output was 43.5-67.7 mW. Additionally, the statistical analysis found a significant correlation between the temperature variable and output voltage variable, with an adjusted r square value of 89.2% for zero water flow rate and increasing to 95.8% for maximum water flow rate.

Keywords: thermal energy, TEG, seebeck effect, flow rate, correlation.

***SDGs*:**

7 AFFORDABLE AND CLEAN ENERGY

Abstrak

TEG adalah suatu komponen elektrik seperti termokopel yang dimana bekerja berdasarkan efek *Seebeck*. Salah satu TEG yang banyak dijual di pasaran dan mudah ditemukan yaitu TEG tipe SP1848 27145 SA. Namun, karakteristik tegangan keluaran, nilai koefisien *Seebeck,* dan daya keluaran TEG SP1848 27145 SA ini belum diketahui oleh pengguna ketika pengguna memiliki sebuah sumber panas dan dingin. Tujuan utama dari penelitian ini adalah untuk mengetahui karakter keluaran tegangan, daya, dan nilai koefisien *Seebeck* TEG SP1848 27145SA ketika terjadi perubahan temperatur pada sistem. Metode penelitian menguji TEG SP1848 27145 SA dengan pemanas dan pendinginan air mengalir dengan berbagai variasi. Selanjutnya, dilakukan analisis statistik untuk mengetahui hubungan antara tegangan dan ΔT pada sistem. Hasil experimen menunjukkan bahwa nilai keluaran tegangan sebesar 0,54-1,03 V dengan temperatur panas heater 86°C dan ΔT sistem yaitu 70,5-75°C. Nilai *Seebeck* sebesar 1.551,7 – 2.998,5 μV dan keluaran daya 43,5-67,7 mW. Selain itu, dari hasil analisis satistik diperoleh bahwa hubungan variabel temperatur sangat signifikan dengan variabel keluaran tegangan dengan nilai *adjusted r square* 89,2% untuk laju aliran air nol dan meningkat menjadi 95,8% untuk laju aliran air maksimum.

Kata Kunci: energi termal, TEG, efek *seebeck*, *flow rate*, korelasi.

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1. INTRODUCTION

The demand for electricity in Indonesia is on the rise. Currently, most of the electricity power plants in the country rely on fuel and coal as their primary sources (Saputra *et al.*, 2019). According to Figure 1, in 2016, around 54.7% of the electricity power plants in Indonesia still used coal, which is expected to increase to 67.2% (Rizaty and Bayu, 2023). However, it is essential to note that using non-renewable energy sources like coal contributes to global warming. Hence, countries worldwide have agreed that by 2050, all electricity power plants should have net-zero emissions (Rogelj *et al.*, 2021).

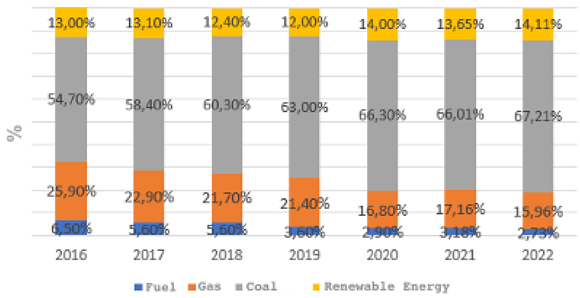

Figure 1. Energy electric power plant in Indonesia (Rizaty and Bayu, 2023).

One way to net zero emissions is by using renewable energy to produce electricity. Thermal energy is renewable energy obtained from geothermal or sunlight (Halkos and Gkampoura, 2020). Thermal Electric Generator (TEG) is an electric component that can convert thermal energy into electricity is called Thermal Electric Generator (TEG). TEG was made by a couple of thermocouple works by the Seebeck effect. TEG is already applied in many devices because TEG is free to maintain, efficient, and long lifetime (Jaziri *et al.*, 2020).

In a study conducted by Olabi et al. the potential application of thermoelectric generators (TEGs) in various waste heat recovery systems was explored (Olabi *et al.*, 2022). TEGs utilize waste heat sources from various applications to generate electricity, making it an environmentally friendly electricity source. The study found that TEGs can be applied to various waste heat recovery systems, including fuel cells, heat exchangers, photovoltaics, internal combustion engines, electric vehicles, and hybrid waste heat recovery systems. Combining waste heat recovery with thermoelectric generators (TEGs) in various thermal systems will likely result in high efficiencies.

There are many types of TEGs available in the market. The most affordable and easily accessible type is TEG type SP1848 27145 SA (Hudaya, 2021a). In recent years, various experiments have been conducted to test TEG SP1848 27145 SA, such as the research conducted by Hudaya et al. (Hudaya, 2021b). They tested eight TEG SP1848 27145 SA pieces in both series and parallel conditions, using waste heat from a motorcycle exhaust as the heat source. The results showed that TEG SP1848 27145 SA generated a power output of 9.0048 W in a ΔT system of 60°C (Hudaya, 2021b).

In TEG, there are two cooling methods: active and passive. Active cooling involves a cooling system, while passive cooling relies on natural cooling. Pfeiffelmann et al. found that active cooling can improve the net output power from TEG (Pfeiffelmann, Benim and Joos, 2021). To test this, Haripuddin et al. added water cooling as an active cooling method and obtained a 2.25 V output in TEG SP1848 27145 at ΔT 46°C, with a maximum generated power of 0.09 W (Haripuddin, Irfan and Suhardi, 2023).

A study conducted by Atmoko et al. examined the performance of TEG using water block and heatsink-fan cooling systems (Atmoko, Jamaldi and Riyadi, 2022). The objective was to compare the impact of different cooling systems on the overall performance of TEGs. The results showed that a water flow rate of 300 l/h is the optimal rate for TEG cooling. The study also found that the electrical voltage produced by the TEG module is 12% higher when using a water block cooling system rather than a heat sink. Thus, it was concluded that a cooling system with a water block is superior to a heatsink fan.

Nurdinawati, researched thermoelectric studies of a TEG SP1848 27145 SA type generator using a thermoelectric module. The research involved simulating the heating of aluminum attached to the hot side of the thermoelectric module while varying the temperature between 66.6°C and 103.9°C. The result was the output voltage of 4 TEG SP1848 27145 SA thermoelectric generator modules, connected in series, at a maximum of 8.4 volts. This was achieved with a maximum ΔT of 55.7°C, producing a power of 3.484 Watts (Nurdinawati, 2017).

Furthermore, Wijayanto et al. examined how variations in pump power in the TEG cooling system affect the voltage produced by the TEG. The heat used for this experiment was the cylinder wall of the furnace. The goal was to determine the efficiency and amount of power used to cool the hot side of the TEG by varying the pump size that supplies coolant to the water block. This produces high-temperature differences and generates significant amounts of electrical energy (Wijayanto *et al.*, 2022). However, research has not been carried out on the relationship between the variable temperature increase and the variable increase in TEG output voltage under zero flow rate, varying flow rate, and maximum flow rate.

Based on the previous explanation, this research aims to determine the characteristics of the TEG type SP1848 27145 SA with temperature difference parameters on the hot and cold parts on the TEG side of the measurement results of the system that has been created. Moreover, a statistical analysis is carried out to determine whether there is a significant influence of temperature differences on the voltage output produced on the TEG type SP1848 27145 SA and to determine the correlation between the increasing temperature variable and the TEG output increasing voltage variable with the conditions of zero flow rate and maximum flow rate using regression analysis. By obtaining a study of the characteristics of TEG type SP1848 27145 SA, the benefit of this research is to make it easier for users to determine the number of TEGs needed when they want to design a power generation system based on TEG type SP1848 27145 SA so that the required voltage and current can be achieved by cooling or specified heater.

2. METHODOLOGY

2.1. Research Flow Chart

The research began with a review of the literature on TEG and other relevant research areas. Following that, research tools and materials were prepared. A flow chart of the research process is presented in Figure 2 to aid in understanding the steps involved.

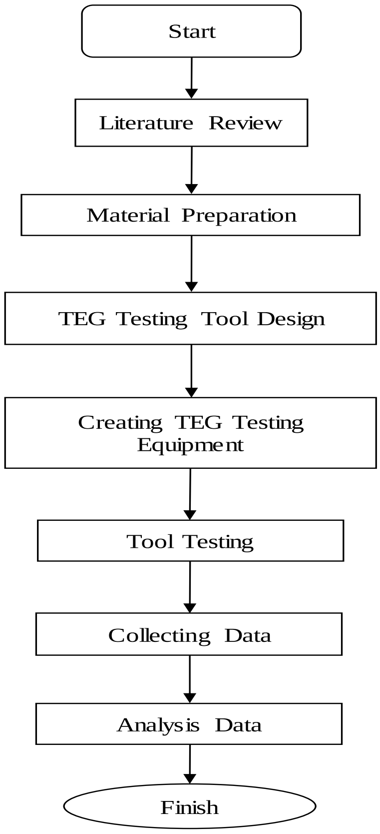

Figure 2. Research flow chart.

Initial testing of the tool is intended to test whether the system is working correctly or not. The system's parameters already working well include the heater functioning, the cooling system circulation, the temperature measurement record as a data logger, and the flow meter working correctly. Improvement in tools will be made if any element does not work properly.

Data research was collected based on the research parameters, temperature conditions, and output TEG. Data processing and analysis were carried out after data collection was completed. Accounting is used based on data and equations related to the research. Finally, conclude the results of the previous analysis.

2.2. Research Tools and Materials

This experiment requires various tools and materials. The following are the tools and materials needed in this research:

- Water tank (300x400x200 mm)
- Submersible water pump with specifications of 18 W ac h.max 1 m flow 1000 l/h
- Yf-s201 flow meter
- K-type thermocouple
- Max 6675 module
- Aluminum water block (40x40x12mm)
- Heater with 5 W (40x20x10mm)
- Led lamp
- Voltage sensor
- Current sensor
- Arduino uno
- Pipe 1/2"
- Water tap
- Water hose 3/8"
- Adaptor 1/2" to 3/8"
- Elbow 1/2"
- Clamp 1/2"
- Thermal paste
- Solder
- Male to female jumper wires
- Protoboard
- Teg sp1848 27145 sa with specifications as shown in Table 1.

Table 1. Specifications of TEG SP1848 27145 SA.

The Details	
Dimension	40x40x40 mm
Operating Temperature	30°C until 120°C
Voltage Max	2,4 V
Current Max	469 mA

2.3. TEG Testing Tool Design

2.3.1. Heating System

Figure 3 shows design electricity of heater. In order to indicate whether the heater is working, a heating lamp indicator is added and connected in parallel. This heater and lamp powered by 220 V AC same with housing electricity. Totally in this experiment using 2 heater 5 Watts and 2 heater lamps.

Figure 4 shows a assembly of heater system alreaday created. Thermal paste is applied to ensure that the heater cannot be separated from the TEG. The equation (1) provide the required calculation electric current of heater system.

$$I = \frac{5\ W}{220\ V} \times 2 = 45\ mA \quad (1)$$

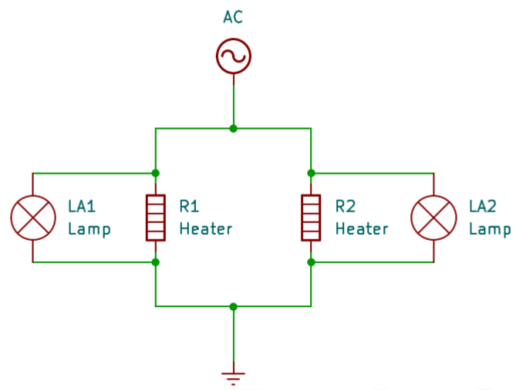

Figure 3. Wiring diagram heater.

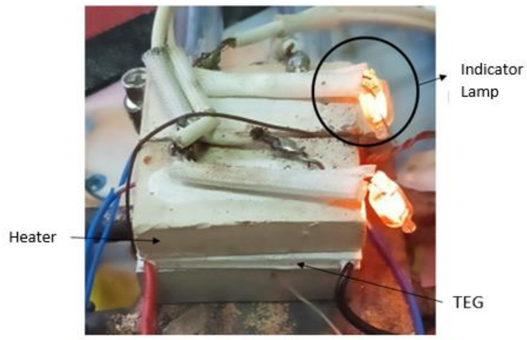

Figure 4. Heater system.

2.3.2. Cooling System

In Figure 5, the placement of the component materials is displayedshows each position of component material. The water pump is 10 cm below the water level, with a volume of 10 liters. The system includes two hoses: one from the adaptor input to the water block and the other from the water block, as shown in Figure 6. The water block includes a separator composed entirely of aluminum (Wijayanto *et al.*, 2022). To avoid TEG moving from the cooler system and make it stay, all system was tight with aluminum wire.

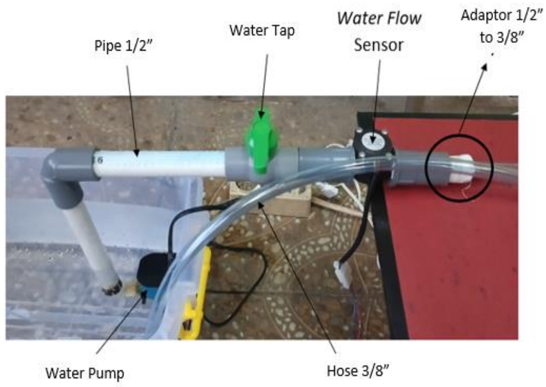

Figure 5. Structure cooler component

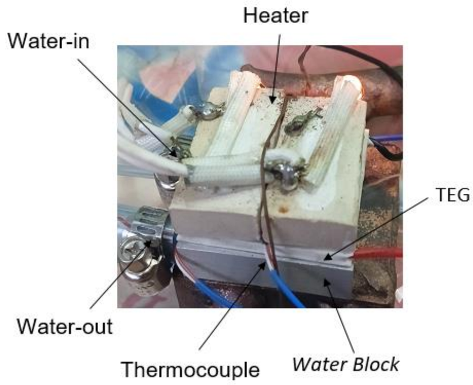

Figure 6. Water block position and the series

2.4. TEG Testing Equipment Concept

Based on Figure 7, a water pump will circulate the water from the tank to the water block. The water flow rate is measured using a flow meter. Then, the water block will be placed on the cold side of the TEG, while the heater will be placed on the hot side of the TEG. The TEG output will be measured for voltage and current. To determine the temperature of the heater, water block, water entering and water leaving the water block, a thermocouple is provided at that point. The experimental results read by the flow meter, thermocouple, voltage sensor, and current sensor are then sent to the Arduino Uno program and stored as a data logger (Banzi and Shiloh, 2015).

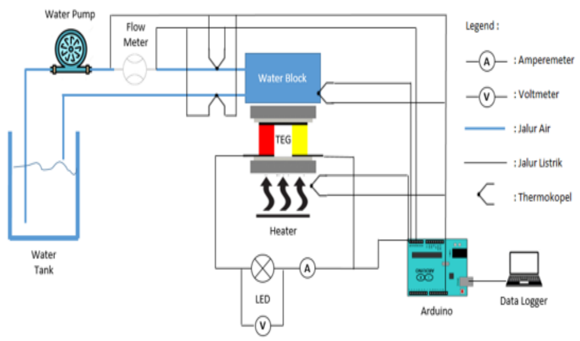

Figure 7. Design of TEG testing equipment.

Furthermore, the stages of data collection in the experimental experiment are carried out as follows:

a. Start by turning on the heater and measuring the voltage and current output of TEG until the heater reaches maximum temperature.
b. Then, turn on the water pump with the water tap fully open and measure TEG's voltage and current output until ΔT stabilizes.
c. Measure TEG's voltage and current output in water tap conditions of ¾, ½, and ¼. Each measurement should last for 5 minutes.

After collecting data from all steps, calculate the power output and efficiency and analyze the regression to determine the correlation between the voltage and ΔT variables.

2.5. Thermal Electric Generator (TEG)

TEG is one of the electric components that can change thermal energy into electricity based on the Seebeck principle (Qasim *et al.*, 2022). To find the value coefficient Seebeck in TEG, we can follow equation (2) (Jaziri *et al.*, 2020).

$$\propto = \frac{V}{\Delta T} \tag{2}$$

where:

α : Seebeck coefficient (mV/K, °C)
ΔV : Output voltage TEG (mV)
ΔT : Temperature differences (K, °C)

In equation (3) is the formula for finding ΔT in the system

$$\Delta T = T_{hot} - T_{cold} \tag{3}$$

A thermoelectric generator (TEG) usually consists of thermocouples arranged in series and supplied with thermal energy in parallel. Furthermore, Figure 8 shows the temperature system in the TEG where T_{hot} is the part of the TEG that gets the hot temperature from the heater, and T_{cold} is the part of the TEG that gets the cold temperature from the cooler.

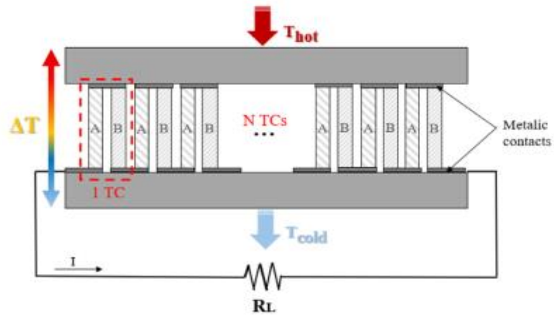

Figure 8. Temperature system TEG.

The calculation of the output power delivered by a TEG is obtained using Equation (4) and finding out how big the ratio or efficiency of heat energy to be converted into electrical energy can be obtained through the thermoelectric conversion Carnot efficiency formula, which is written in equation (5) below.

$$P = V \times I \quad (4)$$

where:

P : Power (W)
V : Voltage (V)
I : Current (A)

$$\eta = \frac{T_{hot} - T_{cold}}{T_{hot}} \quad (5)$$

where:

η : Carnot efficiency (%)

2.6. Heat Transfer

Heat transfer is a science that predicts thermal energy transfer due to temperature differences between materials. There are three heat transfer types: conduction, convection, and radiation (Holman, 1990). Conduction heat transfer is transferring heat from a high temperature to a low temperature through a medium (solid, liquid, or gas) or a different medium in contact with each other. Convection heat transfer transfers heat due to movement/flow/mixing from high to low temperatures. If the flow movement is caused by a difference in density by a difference in temperature, then this movement is called free convection movement. However, if the flow movement is caused by force (for example, being pumped), this heat transfer is called forced convection transfer (Holman, 1990).

Meanwhile, radiation transfers heat from a high to a low temperature when an object is separated in space, even in a vacuum. This movement releases energy, which is called radiation energy. When this energy strikes a material, the energy is either reflected, absorbed, or transmitted. In heat transfer, there is also the speed of heat transfer, also known as the heat transfer rate. Calculating how much heat energy in a heat transfer system can be obtained through the following equation (6) (Holman, 1990).

$$Q = m.C_p.\Delta T \quad (6)$$

where:

Q : Heat energy (kW)
m : Mass flow (kg/s)
C_p : Specific heat capacity (kJ/kg°C)
ΔT : Differences temperature (°C)

2.7. Statistics Analysis

Linear regression is a technique in statistics to look for logical relationship patterns between an independent and dependent variable. The linear regression model can be formulated through equation (7) (Pramana, 2016).

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad (7)$$

where:

Y : Dependent Variabel
X : Independent Variabel
β_0, β_1 : Parameter
ε : Random error

The dependent variable in this research is voltage output from TEG, while the independent variable is ΔT. The correlation coefficient formula (r) is displayed in equation (8) (Walpole *et al.*, 2017):

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - (\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{\sqrt{\{(n\sum_{i=1}^{n} x_i^2) - (\sum_{i=1}^{n} x_i)^2\}\{n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2\}}} \quad (8)$$

After obtaining the linear regression analysis equation, the two variables need to be tested to determine whether they have a strong relationship, as measured using the correlation value. Correlation numbers range from 0 to ± 1 (Agresti, Franklin and Klingenberg, 2016). Interpretation of correlation values is shown in Table 2.

Table 2. R coefficient and corellation (Puspa, Riyono and Puspitasari, 2021).

Interval Coefficient	Relation
0.800 - 1.000	Very strong
0.600 - 0.799	Strong
0.400 - 0.599	Normal
0.200 - 0.399	Weak
0.000 - 0.199	Very Weak

3. RESULTS AND DISCUSSION

3.1. Heating System Characteristics

From the heating system that has been created, the heating temperature is obtained from initially a room temperature of 30°C, then increasing expansionally to a temperature of 88°C for 208 seconds. The heating temperature remained stable at 88°C, and there was no increase/stable for about 52 seconds. After that, the heater was turned off, and the temperature dropped to room temperature again in 147 seconds (see Figure 9).

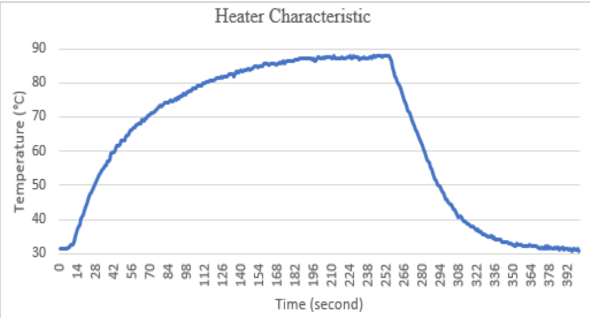

Figure 9. Heater characteristic.

3.2. Cooling System Characteristics

According to the data in Table 3, this experiment tested the performance of a cooler for 10 minutes. The results showed that the average temperature input to the water block was 30.75°C, while the temperature out from the water block was 33.87°C. This indicates a temperature difference of 3.12°C between the input and output of the water block. The water flow rate during the system's operation was 12.3 L/m. Based on these findings, it can be said that the heater and cooler were functioning normally during this experiment.

3.3. Output Characteristics Zero Flow Rate

In this condition, there is no circulation on water cooling. The measurement of water flow is 0 L/m. As seen in Figure 10 the voltage increased logarithmically from 0 V to 0.54 V over 758 seconds, remaining stable for 1,924 seconds. For the ΔT condition, the value started at 2.25°C and increased logarithmically to 75°C over 1524 seconds. There is a difference in the rate of increase between voltage and ΔT, with voltage increasing 766 seconds faster than ΔT.

Table 3. Results of the cooling system measurement.

Time (m)	In (°C)	Out (°C)	ΔT Water (°C)	Flow Rate (L/m)
1	30.5	34	3.5	12
2	31	34	3	12.1
3	30.75	33.75	3	12.1
4	31	33.75	2.75	12.2
5	30.25	34.5	4.25	12.2
6	30.75	33.75	3	12.3
7	31	33.75	2.75	12.6
8	30.5	33.75	3.25	12.5
9	31	33,5	2.5	12.5
10	30.75	34	3.25	12.5
Average	30.75	33.875	3.125	12.3

From the voltage and temperature data ΔT previously obtained, we can calculate the Seebeck coefficient value at zero flow rate. To calculate the Seebeck coefficient value, use the formula shown in equation (2).

$$\alpha = \frac{0.54\ \text{V}}{75\ ^\circ\text{C}} = \frac{540{,}000\ \mu\text{V}}{348\ \text{K}}$$

$$= 1{,}551.7\ \mu\text{V}$$

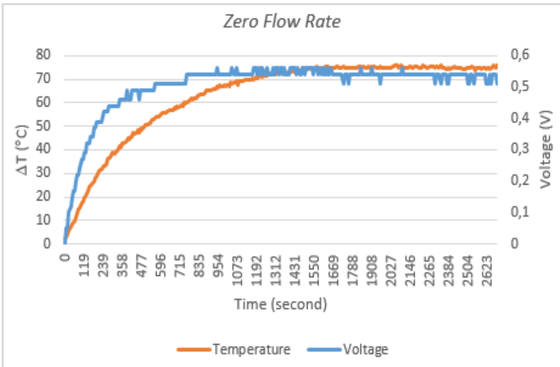

Figure 10. Voltage output TEG at zero flow rate.

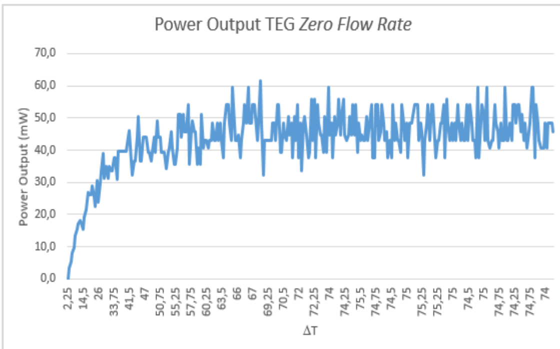

Figure 11. Power characteristics at zero flow rate.

Moreover, a visualization of the TEG power output results at zero flow rate is displayed with temperature changes ΔT in Figure 11. At zero flow rate conditions, there is a logarithmic increase from 2.25°C to 75°C in output power, and an average output power value obtained is 43.5 mW.

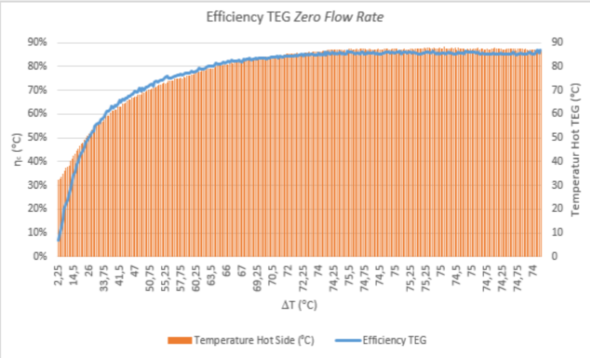

Figure 12. Efficiency of TEG at zero flow rate.

Then, the TEG efficiency is calculated at zero flow rate. The TEG efficiency value increases from 7% to 85% at ΔT 2.25°C to 73°C. The TEG efficiency value stabilized at ΔT 73°C to 75°C with an efficiency value of 85%, as shown in Figure 12.

3.4. Output Characteristics Maximum Flow Rate

Next, we will discuss the characteristics of the TEG with the Maximum Flow Rate Cooling system where the water tap is fully open in this condition. A flow rate value of 11.5 L/m is obtained when the water flows. So, the hot side of the TEG gets heat from heating, and the cold side of the TEG gets cooling from circulating water.

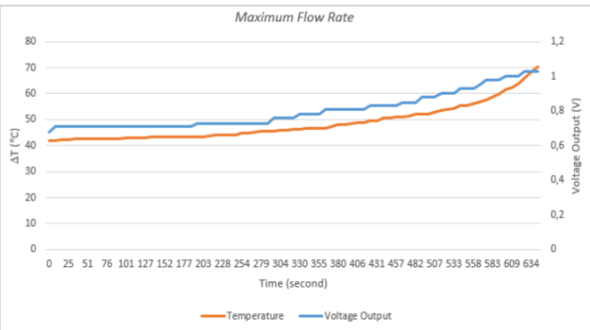

Figure 13. Voltage output at maximum flow rate.

Figure 13 indicates a rise in voltage and subsequent increase in ΔT with temperature. The output voltage rises from 0.68 V to 1.03 V in 643 seconds. Also, the system ΔT starting from 42°C increases to 70.5°C simultaneously. These results show that when compared to the zero flow rate condition, the maximum flow rate condition can quickly obtain a higher voltage value. Therefore, the value of the Seebeck coefficient when the maximum flow rate is written below.

$$\alpha = \frac{1.03\ \text{V}}{70.5\ {}^{\circ}\text{C}} = \frac{1{,}030{,}000\ \mu\text{V}}{343.5\ \text{K}}$$

$$= 2{,}998.5\ \mu\text{V}$$

In Figure 14 it is demonstrated that the power output of the system increases as there are changes in ΔT. At the maximum water flow rate, the TEG power output is 67.7 mW when the temperature changes from 42°C to 68.25°C. This is a significant improvement, as it is 24.2 mW higher than the power output at zero water flow rate. Therefore, by increasing the flow rate of cooling water, the TEG power output can be increased.

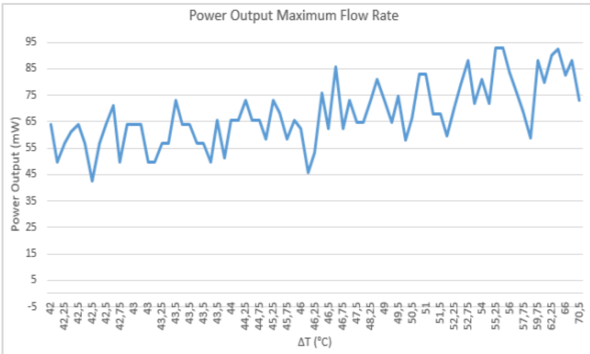

Figure 14. Power characteristics at maximum flow rate.

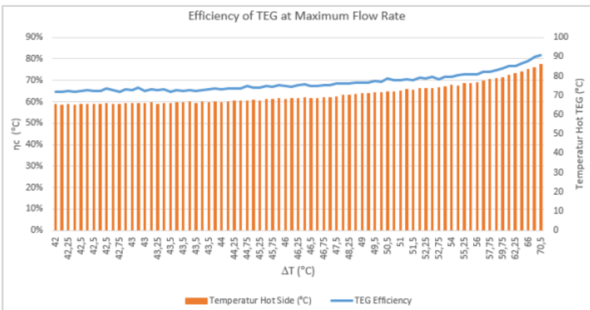

Figure 15. Efficiency of TEG at maximum flow rate.

The increase in efficiency value occurred at the maximum flow rate from 65% to 82%, accompanied by an increase in ΔT from 42°C to 86.25°C. Compared with efficiency data at zero water flow rate, this condition is 3% lower. This condition occurs because the ΔT value is lower at the maximum flow rate at the same heating temperature conditions (see Figure 15).

3.5. Output Characteristics with Variation Water Flow Rate

In this condition, the water tap closed in ¾, ½, and ¼. Each open condition lasts 5 minutes after the water tap opens in ¼, ½, and ¾ simultaneously. Figure 16 shows that voltage output is stable, although the water-cooling flow rate changes lower and higher. The voltage output is constant at 0.68 V.

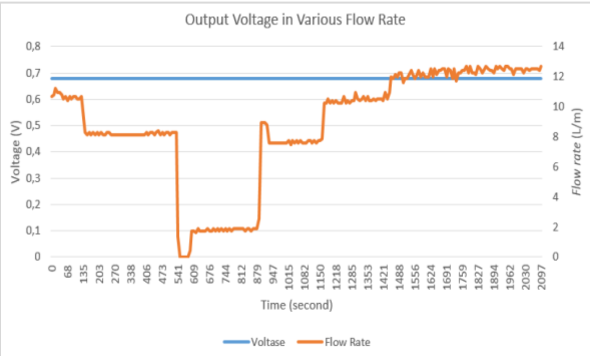

Figure 16. Output voltage in various flow rate.

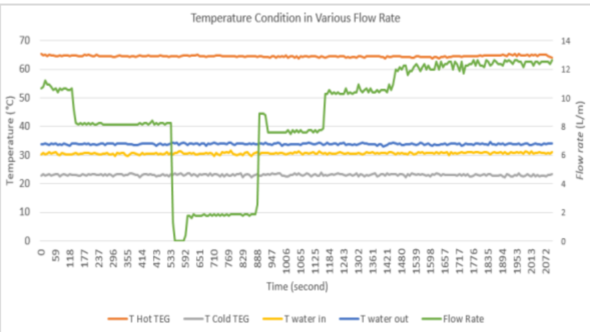

Figure 17. Temperature condition in various flow rate.

The output of TEG is stable and constant because there is no changing value temperature at the hot side, cold side, and water cooling when the water fooling flow rate changes. Based on Figure 17, it can be shown that the temperature hot side is stable at 65°C and the cold temperature side is stable at 23°C. Also, the water temperature is 31°C, and the temperature is 34°C. So, in this condition, ΔT stable at 42°C with heat temperature transfer to water is 3°C.

3.6. Statistics Analysis

After obtaining data on the voltage and temperature characteristics of the TEG SP1878 27145 SA, statistical analysis was then carried out to determine whether there was a significant relationship between temperature and the TEG voltage output. This analysis is assisted by the SPSS software, where temperature is the dependent variable (X), and the increase in voltage is the independent variable (Y). The hypothesis testing in this research is as follows:

H_0: There is no significant relationship between the increasing temperature variable and the TEG output increasing voltage variable.

H_1: There is a significant relationship between the increasing temperature variable and the TEG output increasing voltage variable.

By using the linear regression analysis method, it was found that the relationship between the increasing temperature and the TEG output increasing voltage variable at zero flow rate of cooling water had a correlation of 94.5%. This means that the relationship between two variables has a very strong correlation. Furthermore, based on the adjusted R squared value, 89.2% is obtained, where this value explains the ability of variations in the voltage variable to be explained by variations in the temperature variable under conditions of zero flow rate, while the remaining 10.8% is explained by other variables not explained in this research (see Table 4).

Table 4. Correlation results at zero flow rate.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.945[a]	.893	.892	.04832

Based on Table 5, the Sig. value is obtained or a p-value of 0.000, which means the p-value is lower than α (0.05), so H_0 is rejected. This means that there is a significant relationship between the increasing temperature variable and the TEG output increasing voltage variable at zero flow rate. The linear regression equation for zero flow rate is written in equation (9).

$$Y = 0.006\,X + 0.129 \qquad (9)$$

Table 5. Regression analysis for zero flow rate.

Model		Unstandardized Coefficients B	Std. Error	t	Sig.
1	(Constant)	.129	.009	14.165	.000
	Temp.	.006	.000	40.238	.000

Moreover, the correlation value of r will also be calculated with the maximum flow rate conditions of cooling water. Based on Table 6, the r-value is 97.9%, which means that increasing temperature strongly correlates with the variable increasing output voltage. Furthermore, from the adjusted r-squared results obtained at 95.8%, the variation in the output voltage variable can be explained by the temperature increase variable of 95.8% at maximum flow rate conditions. Meanwhile, the remaining 4.2% is explained by other variables not explained in this study.

Table 6. Correlation results at maximum flow rate.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.979[a]	.958	.958	.02119

Based on Table 7, Sig 0.00 is obtained, which means the value is lower than α (0.05), and H_0 is rejected. Hence, there is a significant relationship between the increasing temperature variable and the TEG output increasing voltage variable at maximum flow rate. Linear regression for maximum flow rate is shown through equation (10):

$$Y = 0.015\,X + 0.072 \qquad (10)$$

Table 7. Regression analysis for maximum flow rate.

Model		Unstandardized Coefficients B	Std. Error	t	Sig.
1	(Constant)	.072	.018	4.079	.000
	Temperature	.015	.000	41.581	.000

Furthermore, from equations (14) and (15), Figure 18 shows a graph of the output voltage with the ΔT system at zero flow rate and the maximum water flow rate. Based on Figure 18, it can be seen that the TEG output voltage at the maximum flow rate is more significant than when the flow rate is zero. At ΔT 120°C, the zero flow rate output voltage has a voltage of 0.8 V, while the maximum flow rate jumps to 1.8 V.

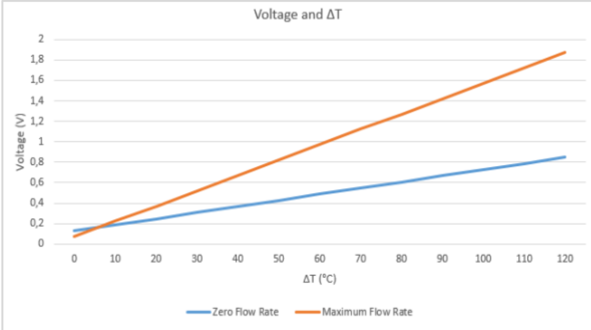

Figure 18. Output voltage TEG SP1848 27145 SA.

4. CONCLUSION

At zero flow rate conditions, The output power TEG shows a logarithmic increase from 2.25°C to 75°C, with an average output power of 43.5 mW. The TEG efficiency value increases from 7% to 85% with a temperature difference (ΔT) of 2.25°C to 73°C. At ΔT 73°C to 75°C, the TEG efficiency value stabilizes at 85%, and a Seeback coefficient value of 1,551.7 μV is obtained.

Under maximum flow rate conditions, we obtained a Seeback coefficient of 2,998.5 μV and the TEG power output increased significantly to 67.7 mW with a temperature change of 42°C to 68.25°C. This improvement in power output was 24.2 mW higher than that observed at zero water flow rate. The efficiency value was highest during the maximum flow rate, ranging from 65% to 82%, with an increase in ΔT from 42°C to 86.25°C. However, this condition was 3% less efficient when compared to efficiency data at zero water flow rate.

At zero flow rate, the linear regression analysis shows that the adjusted R-squared value is 89.2%, while the adjusted R-squared value obtained at maximum flow rate conditions is 95.8%. This value shows the ability of the temperature variable to explain most of the variation in the voltage variable, while the rest is explained by other variables that were not studied.

Obtained the p-value (0.000) < α (0.05) in zero flow rate and maximum flow rate, so H_0 is rejected. Thus, it is evident that there is a significant correlation between the TEG output increasing voltage variable and the increasing temperature variable at zero flow rate and maximum flow rate.

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