Exhaust temperature and peltier element optimization of thermoelectric generator output

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Abstract. The purpose of this study are to obtain (1) the optimum exhaust temperature for the highest voltage output, (2) the optimum number of peltier elements for the highest voltage output, (3) the optimum peltier circuit type for the highest voltage output. The analysis were done to obtain the optimum Seebeck coefficient as a representation of the thermoelectric generator performance. The design of this study is an L20 orthogonal matrix with three replications using a factorial design. The independent variables varied were exhaust temperature and number of peltier elements, while data analysis using ANOVA Two Way. Based on the results of the research data it can be concluded that the furnace wall temperature affects the TEG current output. The optimal wall temperature was 480 ºC that produces a TEG current output of 168 mA. This indicates an increase in the temperature of the used metal smelting furnace walls cause the increase in the TEG current output. Meanwhile, the number of peltier elements influenced the TEG current output. The optimum values combination of exhaust temperature and peltier’s number which cause the highest TEG output voltage are 480 ºC and 6 (six) peltier element in series circuit, respectively.

1. Introduction
The development of advanced technology requires a lot of equipment in everyday life using ferro and non-ferrous metals. This cause metal waste is spread throughout the archipelago. The problem becomes an opportunity for small and medium industries to process ferro and non-ferro waste. The metal smelting industry requires high temperature to melt used metal and requires long melting time depending on the type of scrap metal, for example, the melting point of aluminum is 660 ºC or 1220 ºF. High temperature and old metal smelting processes cause a lot of heat energy to be wasted during the metal smelting process. At present, the rapid grow of metal smelting industry causes a lot of heat energy wasted, whereas at this time energy must be processed efficiently to overcome the electricity needs.

Thermoelectric generator (TEG) is a technology that can directly change the temperature difference into electrical voltage. The use of waste heat from the melting furnace can add a list of alternative energy that can be used to overcome the energy crisis at this time. Some of the advantages of this TEG include, it is very reliable (usually over 100,000 hours of operating conditions), without sound when operated because it has no moving mechanical parts, does not require more maintenance, is simple, compact and safe, has a very small size and very light, capable of operating at high temperatures, capable of operating for small scale and remote locations, environmentally friendly, and a flexible energy source. In addition to the advantages, this TEG has disadvantages, namely at low efficiency, but if TEG is used to convert waste heat into electrical energy, low efficiency in TEG can be ignored [1].
The low efficiency of TEG will only produce a small TEG output while the electrical energy requirements for daily life are quite large. The value of the TEG current output is influenced by several factors including the number of peltier elements used and the hot side temperature of the peltier. Assume increasing the number of peltier elements and providing a high temperature on the peltier heat side to affect the TEG current output [2]. The purpose of this study are to obtain (1) the optimum exhaust temperature for the highest voltage output, (2) the optimum number of peltier elements for the highest voltage output, (3) the optimum peltier circuit type for the highest voltage output, and (4) optimum point of the Seebeck coefficient on the performance chart. The advantages of the research that is expected to be able to utilize thermal energy from the exhaust channel into a form of energy that can be more utilized so that thermal energy is able to have a better use value. Previous research on the effectiveness of the Tec-12706 peltier module as a generator utilizing heat energy from the Peltier Tec-12706 module [3]. Based on the studies it can be concluded that the amount of peltier current is influenced by several factors including the type of peltier, number of elements, type of electrical circuit, and temperature difference. The more the number of peltier elements the greater the TEG current output, the greater the temperature difference the greater the TEG current output and the type of electrical circuit that can increase the acquisition of TEG current output is a parallel circuit. Therefore, further research is done on how exhaust temperature optimization, the number of peltier elements to produce optimum voltage in a metal melting furnace, so that the lost heat energy can be reused in the form of electrical energy.

2. Material and methods

2.1. Experimental procedure
The flow diagram of this thermoelectric generator research is shown in figure 1.

![Figure 1. Research flow chart.](image)

2.2. Research instrument
- Peltier module used is TEG type SP 1848 27145 SA are shown in figure 2.
Figure 2. Peltier module *Thermometer Infrared.*

- Cable for compiling parallel electrical circuits are shown in figure 3.

Figure 3. Parallel sequence.

- Digital multitester.
- Heatsink.
- Nuts and bolts.
- Thermal paste.
- Expenses.

2.3. *Data collection procedures*

Data retrieval is done repeatedly 3 times. The steps of data collection in this study are shown in figure 4-7.

- Measuring the temperature of the metal melting furnace wall with a predetermined temperature variation.

Figure 4. Measurement of furnace wall temperature.

- Measuring the temperature of the heat heatsink attached to the wall of the furnace insulator.

Figure 5. Heat heatsink temperature measurement.
• Measuring the temperature of the cold heatsink.

Figure 6. Cold heatsink temperature measurement.

• Measuring the TEG current output using a digital multimeter connected with an assembled peltier element electrical cable.

Figure 7. Record the results of the research data in the design data table of the research results.

2.4. Data analysis
Analysis of this research data is quantitative analysis, therefore the data analysis uses statistical analysis of variance (ANOVA) method with a significant level of 5%.

3. Results
Retrieval of research data that has been done with replication 3 times the data obtained as shown in table 1.

| Total of Peltier | Exhaust’s Temperature (°C) | Current (ma) |
|------------------|----------------------------|--------------|
|                  |                            | 1  | 2   | 3   |
|                  | 4                          | 400| 135.5| 144.5| 141.5|
|                  |                            | 420| 139.5| 148.5| 146.8|
|                  |                            | 440| 145.3| 153.5| 150  |
|                  |                            | 460| 148.5| 154.4| 157  |
|                  |                            | 480| 150  | 156  | 161  |
|                  | 6                          | 400| 132  | 141.4| 140  |
|                  |                            | 420| 147.3| 146  | 146  |
|                  |                            | 440| 152.6| 149  | 148.2|
|                  |                            | 460| 156  | 160  | 149  |
|                  |                            | 480| 160.3| 168  | 153.6|

Based on table 1, it can be seen that the largest current that can be produced is 168 mA which is located at a temperature of 480 °C and the number of elements 6. The results of the test data analyzed by Two Way ANOVA obtained P-value and F count, which were then used as guidelines to test the hypothesis with the following results:
3.1. Comparison of P-value with α
The second hypothesis testing is to compare the value of P-Value of each independent variable with a significant level, namely α = 0.05 with the provision that if the value of P-Value <α then there is the effect of independent variables on the TEG current output and if the value of P-Value> α then there is no effect of independent variables on TEG current output as shown in table 2.

Table 2. P-value comparison.

| No. | Research Factors   | P-Value | α      |
|-----|-------------------|---------|--------|
| 1   | T.Exhaust         | 0.000   | < 0.05 |
| 2   | Total of Peltier  | 0.491   | > 0.05 |

3.2. Comparison of $F_{0.05}$ with $F_{value}$
After being analyzed with ANOVA, it was obtained that $F_{value}$ of each independent variable was compared with $F_{0.05}$ with the provision that if the value of $F_{value} < F_{0.05}$ then $H_0$ is accepted and if the value of $F_{value} > F_{0.05}$ then $H_0$ is rejected as shown in table 3.

Table 3. F-value comparison.

| No. | Research Factors   | $F_{value}$ | $F_{0.05}$ |
|-----|-------------------|-------------|------------|
| 1   | T.Exhaust         | 15.85       | > 2.76     |
| 2   | Total of Peltier  | 0.49        | < 4.20     |

3.3. Test the hypothesis
Based on the second hypothesis testing, it can be seen in table 4.

Table 4. Test hypothesis.

| No. | Research Factors | Conclusion  |
|-----|------------------|-------------|
| 1   | T.Exhaust        | accepted    |
| 2   | Total of Peltier | rejected    |

3.4. Main effect plot
Data analysis with the main effect plot was used to support the research conclusions, can be seen in figure 8.

Figure 8. Main effect plot.
The Main Effect Plot image shows that:

- Furnace wall temperature has a significant effect on TEG current output.
- The number of peltier elements has an influence on the TEG current output but is not too significant even though the hypothesis test shows no influence on TEG current output.

4. Discussion

Based on the experiment’s results, the optimum furnace temperature is 480°C that produce 166 mA of current. The higher the temperature of the furnace wall the greater the current. This due to the increase in the heatsink temperature (while the cold heatsink is kept constant <100°C) causes a large temperature difference between the two heatsinks. When the heat increase, the electric ion mobility will rise in thermoelement, which eventually enlarge the current. The most optimum difference in temperature to obtain a large current output is the highest temperature difference in the independent variable of the researcher and the largest arrangement [4,5].

The second independent variable is the number of peltier elements that have 2 levels, among them 4 peltier elements and 6 peltier elements. Based on the results of hypothesis testing there is no effect of the number of peltier elements on the TEG current but in showing a large increase in the current as the number of elements increases but does not have a large effect because the unbalanced voltage has a direct effect on the current, because the unbalanced voltage has an angle not the same and can be broken down into 3 sequences namely positive, negative and zero [6]. At balanced voltages have the same angle and only produce a symmetrical sequence without zero and negative, this applies the same as the current. When arranged in parallel, the voltage will be divided equally and the voltage is not balanced because the negative and zero prices appear causing the outgoing voltage to be disturbed and the value is small, this affects the current produced. The peltier voltage inequality of parallel circuits, peltier which has a smaller voltage will be a burden but not fully and causes the current produced by peltier with the highest voltage to pass through another peltier which has a lower voltage. Based on research on the value of Vp (parallel voltage) the current TEG can be positive or negative [7]. A positive value current means an open circuit that is no external load applied, whereas if the current is negative it means that the element module absorbs the current during the heating process.

5. Conclusion

Based on the study, it can be concluded that the variations of wall temperature effect TEG output voltage. The optimum value of wall temperature is 480°C resulting in TEG current output of 168 mA. The greater the temperature the greater the TEG current output. From hypothesis test statistical analysis, the increase in the number of peltier elements does not significant affect TEG current output. The optimum values combination of exhaust temperature and peltier’s number which cause the highest TEG output voltage are 480 °C and 6 (six) peltier element in series circuit, respectively.

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