Low Grade Heat Power Generation using Thermoelectric Generator

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Abstract. Over years, researches on power generation from low grade heat energy sources have been increasing rapidly as it will be beneficial towards environment, human lives and also for long term sustainability. Due to its biggest potential and advantages, thermoelectric generator has been reliably used to generate electricity. In this project, an experiment on power generation using thermoelectric generator by employing low grade heat (<150 °C) energy source was carried out. The main purpose of this project was to generate useful electricity using thermoelectric generator and to investigate the quality of heat exchanger in enhancing the performance of thermoelectric generator. A prototype heat exchanger was used to carry out this experiment. The heat exchanger was tested with varied hot and cold water supply to study the effect of temperature difference on the thermoelectric generators. For this project, the highest output power obtained was 0.98 W and the maximum efficiency was 1.91%.

Keywords: Low Grade Heat; Power Generation; Thermoelectric Generator

1. Introduction
World consciousness of the presence of waste heat in their life has increased day by day. Hundreds of studies on how to recover this wasted thermal energy into a good use were carried all over the countries. In Europe, heat recycling is quite common where Denmark gets half of its electricity from recycled heat, followed by Finland 39%, Russia 31% while US only 12% [1].

Waste heat practically classified into three range of heat which high, intermediate and low [2]. High and intermediate waste heat can be directly recycled into electric power using turbine system while conventional methods such as Organic Rankine Cycle and Kalina Cycle were the typical technologies used for low grade heat conversion. However, due to its complexity and big size installation, the application of these methods are often limited only in transportation and mobile sector [3]. Thus, thermoelectric seems to appear as the most reliable and preferable system choice of all for utilizing low grade heat. Thermoelectric presents a good potential for the conversion of low temperature thermal energy considering its solid state conversion mode. Additional advantages include no moving parts which contributes to less vibration and noiseless, ability to operate over an extended period of time with minimal maintenance and its capability of operating at elevated temperature [4].

According to Seebeck, thermoelectric will deliver voltage when there is temperature difference applied on the hot and cold ends of the device [5]. In Seebeck effect, the resulting voltage (V) is proportional to the temperature difference (ΔT) via seebeck coefficient, α (V=αΔT) [5]. Thus, the higher the temperature difference across the device, the higher the electrical power output. Yet, creating temperature difference from low grade heat is rather difficult when the hot temperature itself is already low.

Research on thermoelectric application have been started long ago. Not only applied on natural sources of thermal energy, the research has been varied from all sources of wasted heat. One of the most popular research on the application of TEG was recovering heat from exhaust system. About 40% to 70% of thermal energy from exhaust system lost to ambient and it contributes to more fuel
usage and low efficiency of the vehicles [6]. In order to solve this problem, TEGs were installed to the surface of exhaust system to utilize the heat. Hsu. C [7], in his study successfully produced 12.4 W maximum power from the utilization of low temperature heat of car exhaust. The average temperature difference was about 30°C and the experiment was carried when the engine reach 3500 RPM.

In another research, by constructing a plate heat exchanger based TEG where metal foams were used to fill the flow channel of the heat exchanger, this experimental setup obtained 108.1 mV maximum open voltage circuit [4].

Since low grade heat also exists in term of natural resources, researches on the use of TEG on converting the energy were also carried. Kossyvakis et al. [8] performed his analytical study on thermoelectric based solar conversion unit. This study was carried by using ANSYS software and the results of the study was 33.7 W of power output generated from the system under various operating conditions.

Other than experiment, analysis and simulation also performed. X. Gou et al. [9] conducted both theoretical and experimental analysis in order investigate further performance of thermoelectric generator. Both theoretical model and experiment showed almost equivalent result where the theoretical obtained 31 V while experimental obtained 35 V.

For this study, a concept of power generation using thermoelectric generator (TEG) double pipe heat exchanger was used for low grade heat conversion. Since heat exchanger is widely used in commercial, industrial and other type of sectors, generating electricity from low grade heat within heat exchanger provides a great advantage as this electricity can be used to power up any low loads such as sensors or other electronic devices. Moreover, the double pipe heat exchanger was used in this study due to its simplicity and wide range of usage. This experiment investigated the viability and the performance of the TEG to recover heat in any low grade temperature area. By conducting this experiment, this paper studies the influence of temperature difference on the TEG performance in generating power. Previous literatures as mentioned above did not carry out a thorough study on comparison between different type of TEG array configurations. Thus, in this study, we investigated the effect of having different type of TEG array configuration as well as the different flow inside the heat exchanger.

As TEG consist of hot and cold side, the hot side was attached to the aluminum hollow for this experiment while the cold side was exposed to the cold fluid in the heat exchanger in order to create temperature difference which produce voltage.

2. Methodology

Figure 1 shows an experimental setup of double pipe heat exchanger used for this experiment and Figure 2 is the schematic diagram for the whole experiment. In this setup, 10 TEGs were used as a bench top to produce electric power output and attached to the surface of the aluminum hollow pipe of the heat exchanger as shown in the schematic diagram below. Concentric tube heat exchanger was used to supply hot water to the double pipe heat exchanger. The hot water flows inside the hollow pipe and the cold water was circulated on the outside of the pipe. The inlet and outlet water temperatures of both streams were recorded for each case study. The temperature of the hot water was varied from 40°C to 70°C. The cold water inlet was assumed to be constant and same as the temperature of the tap water supply located in the laboratory.
In this experiment setup, Hioki data logger was used to record the temperature of the hot water out, cold water in and also ambient temperature. The open circuit voltage output was obtained from the electronic load in order to electric power output of the system which varied from 900 Ohm until 0.2 Ohm. Once all the required parameters were obtained, to evaluate the performance of thermoelectric generator (TEG), power output and the conversion efficiency of the TEG must be calculated. To calculate power, the following formula can be used,

\[ \dot{W} = IV \]  
\[ \text{or;} \]  
\[ W = \frac{V}{R^2} \]

Where \( I \) is the current, \( V \) is the output voltage and \( R \) is the load resistance.

While to find the conversion efficiency,

\[ \eta = \frac{W}{Q} \]
3. Results and Discussion

For any given thermoelectric generator construction design, the hot and cold condition of fluid in the heat exchanger is very much affecting the power output and efficiency produced by the TEG. This was explained in the literature reviews as TEG will only works when there is temperature difference. Therefore, the main objective for this experiment was set to determine the current and the output voltage required to evaluate the performance of the TEG heat exchanger. During the experiment, the temperature for the hot fluid flowing through the heat exchanger was from 40°C to 70°C while the temperature of the cold fluid was measured during the experiment. Each temperature was tested on different types of flow; counter and parallel flow, and also different types of TEGs connection; parallel and series connection. Results of the experiment are shown below.

Figure 3. Combination of I-V and P-V graphs of all temperature for counter flow in: (a) parallel connection, (b) series connection.
Figure 3 illustrates the combination of I-V and P-V graph for counter flow which connected in series and parallel respectively. Analyzing each of the I-V and P-V graph for both connections, it can be seen that the current and power increases when the temperature increases. When connected in parallel, the highest power produced by the TEGs was 630 mW and 980 mW was obtained from series connection both occurred at the highest temperature 70 °C.

![graphs](image)

(a)

(b)

**Figure 4.** Combination of I-V and P-V graphs of all temperature for parallel flow in: (a) parallel connection, (b) series connection.

Next, when the experiment was carried by changing the counter flow to parallel flow, the same pattern of graphs as in counter flow experiment was obtained (as shown in the Figure 4 above) where the current and power both increases with the temperature. Comparing both graphs, the highest power
generated was 720 mW yielded by series connection whereas parallel connection gave 640 mW. Both values were obtained at the 70°C.

![Bar chart of maximum power output of the TEGs.](image)

**Figure 5.** Bar chart of maximum power output of the TEGs.

For a clearer view, a bar chart of maximum power output was plotted as shown in the Figure 5. From this chart, counter flow seems to give higher output power in both connections compared with parallel flow. The highest maximum output acquired was 980 mW given by the counter flow heat exchanger when the thermoelectric generators connected in series at temperature of 70°C while the highest power generated by parallel flow was 720 mW which 260 mW lower than the output of counter flow. This performance might be caused by the temperature difference created by each flow. Counter flow is known to give more uniform temperature difference between the cold and hot fluid over the length of the fluid path while temperature gradient in parallel flow decreases gradually along the fluid flow. Therefore, counter flow has better heat transfer rate in the system compared with parallel flow.

During this experiment, both connections were tested in order to find out which connection gives a better result. As expected, from all experiments involving both counter and parallel flow, series connection generated more power compared with parallel. This can be seen in the bar chart below where for both flows, series connection gave better performance than parallel. There was only slight difference of the reading between series and parallel connection in counter flow at 50°C and 60°C. However, for a long term operation of TEG, parallel connection is preferable due to its higher reliability. Comparing with series connection which only having one pathway for electric to flow, parallel connection allows current to flow at more than one path where the other TEGs will not be affected if one of it fails to work. Parallel connection also requires low resistance to operate. However, according to the principle of electric connection, there is no better connection between both series and parallel as both have their own advantages and disadvantages.
Figure 6 shows the graph of efficiency of TEGs.

4. Conclusion and Recommendations

In this study, a TEG double pipe heat exchanger has been used and tested in order to convert waste heat into electric power. As a conclusion, it has been demonstrated that electric power can be generated from waste heat. The results obtained from the experiment are reported for different flow of heat exchanger and different connection of TEGs. As expected, the results show that higher temperature difference gives higher power generated by the thermoelectric generator. By using 10 TEGs, this experiment obtained maximum power output of 980 mW with highest efficiency of 1.91%. Based on this result, we can generally say that one set of counter flow heat exchanger with 10 TEGs connected in series, we could produce about 1 W. In one factory, there are more than one heat exchangers used, and these heat exchangers are much larger than the one used in this study. Thus, more TEGs can be accommodated in these heat exchangers. As a result, a significant amount of electricity can be produced by TEGs and this can power up any low load equipment such as light bulbs, fans, and others. In addition, the results also show that counter flow improves heat transfer rate which then helps in the performance of power generation of the TEG. Though the analysis of the data presented better reading in series connection, parallel connection of TEGs is a good choice in the operation of the system.

The significant availability of waste heat in our daily life can make this TEG system as a good preference compared with conventional methods. For recommendation, it is better to take heat losses into consideration by insulating not just the internal but also the external of the heat exchanger in order to prevent more heat loss to the ambient. Besides, increasing the number of TEG used in the heat exchanger might also help to improve the power performance.
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