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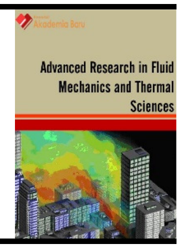

A Study on the Potential of Peltier in Generating Electricity Using Heat Loss at Engine and Exhaust Vehicle

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ABSTRACT

In the era of globalization, the electrical energy supply is the main priority in order to do our jobs and daily activities. Unfortunately, limited power supply for the electrical energy usage makes it hard to continuously provide electrical energy for 24 hours. By using Peltier device, it is possible to develop a portable generating system using heat loss in machines and vehicles. The generating system theoretically can harness the heat loss to produce additional electricity for other usage. The objective of the generating system is to study on the potential of Peltier device to generate useful electricity for additional power supply using heat loss. This generating system can be applied on many types of machines and other type of mechanism such as vehicle that release heat loss. In this project, the generating system is evaluated based on the magnitude of voltage output, and it is found that the system shows higher efficiency at 12.59% by using the proposed heat sink.

1. Introduction

Peltier device is a special device that can operate for cooling system by supplying voltage to the device to eject hot and cold air. The cold air will be used for cooling system. Reversely, the device can generate electricity by absorbing heat without supplying any voltage to power up the Peltier device based on W. Thomson in 1851 rewrite Thomas Johann Seebeck foundation on "Seebeck effect" in 1821. In Seebeck effect theory, the electrons in the semiconductor act as transferring agent to transfer the heat from one medium to another medium according to the law of thermodynamics. In this case, the application where the energy conversion system applied is on vehicle engines and exhaust system. Based on Electrical Energy Conversion (E2C) past research at the KTH School of Electrical Engineering 2011, all machines are not working 100% effectively, most appears to work only 70% to 80% effectively as shown in Figure 1 [1].

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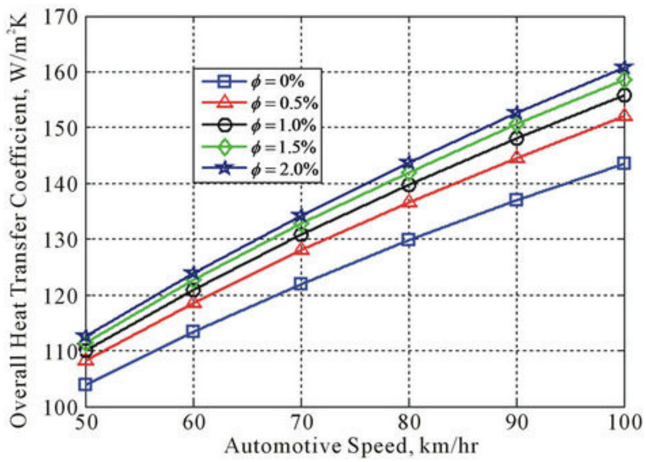

Fig. 1. Heat loss in Car Engine

Meanwhile, the other 30% to 20% are released into energy loss in term of heat. In order to recover the heat loss, this project will design a portable generating system using Peltier device to produce electricity by absorbing heat loss.

There are many applications can be applied using Peltier device and Seebeck effect. Siti Halma Johari *et al.*, [2] generate voltage by using the TEG Peltier module by heating process using Bunsen burner. The voltage produced by the thermal energy reaction is enough to generate small electricity with value in the range of 1V – 3.75V. Another application and study by Harun *et al.*, using Peltier device for producing hot and cold air. From the result, the system can produce 14°C (cold temperature) and up to 56°C (hot temperature) [3].

There are a lot of criteria need to be considered in developing this system. Heat sink designs also a part of the criteria need to be considered in order to get optimize heat transfer area. According to Rosli *et al.*, [4], Khalil Azha Mohd Annuar and Fatimah Sham [5], various pin fin arrangement will give different thermal performance distribution. From the result it shows the staggered pin fin heat sing will give better performance compare to conventional type [6-7].

2. Methodology

The basic operations for the device have been discovered for many years by Thomas Seebeck in 1821 where the temperature difference is established between hot and cold npn junction type semiconductors. Heat loss will be absorbed on the hot side and leaving to the cold side of the Peltier device as shown in Figure 2. During the process, the electrons in the npn semiconductor will active and vibrate due to heat then collides with each other in order to release the heat to the cold side. This activity results in the voltage to be generated at the cool side due to Seebeck effect.

The hot side absorbs heat loss at rate of TH high temperature ejected by the system and transfer the heat to the cold side to be released at a rate of TL low temperature. By referring to Seebeck effect, the heat loss absorbed at the hot junction causes electrons to be active and electric current then flow in the npn semiconductor and electrical energy is generated. Using the thermodynamics first law energy conservation principle, the difference between TH and TL will generate the electrical energy output power, We. The heat released then enter cooling agent which is to maximize the efficiency or the output voltage generated by the device in order to achieve higher temperature gradient between both hot and cold side. The increasing temperature difference between two junctions will increase voltage generation. The generated voltage will flow to the control circuit to provide 12V output voltage to charge battery for other usage [8]. Two types of experimental are considered to determine the efficiency for this Peltier. Both experiments is conducted using four peltier TEC1-12706, staggered fin heat sink, high efficient series PWM controller charging complete with 12V 1.2 Ah battery as a main supply. Peltier TEC1-12706 selected to compare with the previous research done by Harun *et al.,* [3] which is used conventional heat sink.

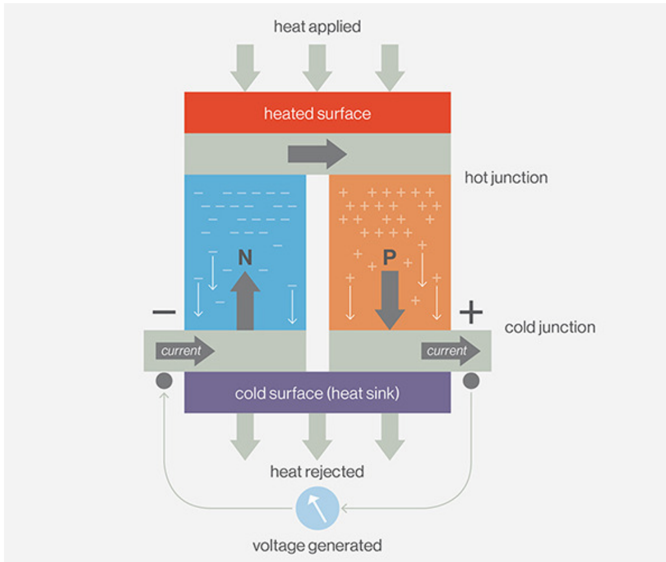

Fig. 2. Heat transfer from hot to cold side

2.1 Heat Loss at Engine System

The experimental data are tested at the engine system in order to determine the maximum efficiency for Seebeck Effect. Figure 3 shows the experimental conducted at the engine system. Two system of generating electricity using Peltier are placed at the engine system as shown in Figure 3. The placement of the Peltier system is based on the hottest part at the engine system. The experiment is conducted about 30 minutes in order for the system able to generate voltage around 12V. Every 5 minutes voltage and temperature difference data are collected as shown in Table I. Temperature difference obtained from the engine system is recoded to determine the efficiency of the system.

Fig. 3. Generating system on car engine system

2.2 Heat Loss at Exhaust System

For the second experiment, the Peltier generating system is tested at exhaust system that has higher heat loss other than engine system. This experiment is conducted to determine the efficiency of the Peltier generating system at the exhaust part. Figure 4 shows the experimental is conducted at the exhaust system.

All the data obtained from this experimental are recoded based on voltage generated and temperature difference. Recorded data used to determine the efficiency for both experimental in order to achieve higher efficiency as shown in Table II. At the heart of the thermoelectric effect is the fact that a temperature gradient in a conducting material results in heat flow; this results in the diffusion of charge carriers. The flow of charge carriers between the hot and cold regions in turn creates a voltage difference.

Fig. 4. Generating system on car exhaust system

Thermoelectric materials are determined by their figure of merit to represents their standard of performance, or efficiency defined:

$$Z = \frac{\alpha}{kR} \quad (1)$$

Where, α is Seebeck coefficient, k is thermal conductivity constant and R is electrical resistivity. The efficiency of a Peltier material can be measured by calculating the Seebeck coefficient. Seebeck coefficient is directly proportional to the voltage generated by the Peltier. In order to achieve high figure of merit, the specification of Peltier must have low electrical resistivity and thermal conductivity. The figure of merit can be calculated based to the electrical conductivity as Equation 2 and Equation 3:

$$\boldsymbol{Z\overline{T}} = \frac{\alpha^2 \boldsymbol{\overline{T}}}{kR} \quad (2)$$

$$\boldsymbol{\overline{T}} = \frac{\boldsymbol{T_H + T_L}}{\boldsymbol{2}} \quad (3)$$

Where T_H is temperature high and T_L is temperature low. The maximum efficiency, η of a Peltier device can be defined using the figure of merit, temperatures of the hot side and cold side [3]. For this system the heat loss assume zero.

$$N = n_{carnot}\left[\frac{\sqrt{1+Z\bar{T}}-1}{\sqrt{1+Z\bar{T}}+\frac{T_L}{T_H}}\right] \tag{4}$$

The value of Carnot efficiency can be calculated by,

$$n_{carnot} = 1- \frac{T_H}{T_L} \tag{5}$$

By referring to Peltier electric generating calculation, the potential electricity generated by the Peltier device can be calculated by,

$$V = \alpha(T_H - T_L) \tag{6}$$

Where V is thermoelectric material figure of merit, α is Seebeck coefficient, TH is temperature at hot side and TL temperature at cold side. The Seebeck coefficient can be calculated by,

$$\alpha = \frac{\bar{x}V}{\bar{x}T} \tag{7}$$

Where $\bar{x}V$, average voltage generated through this system and $\bar{x}T$ is average temperature difference. The magnitudes of voltage generated are affected by the temperature difference 1 ºC across the Peltier device, as stated the Seebeck effect. Material with high Seebeck effect is the main factor to increase the efficiency of the Peltier device.

3. Results and Discussion

3.1 Results at Engine System

The reading was taken at every 5 minutes with total of 30 minutes by considering temperature difference between hot side and cold side is being considered as shown in Table 1. The data was taken when the car idle for every 5 minutes. The car speed is limited to approximately 50 km/h and the ambient temperature is around 32-34 ºC. Table I shows the data collected at the engine system.

Table 1
Voltage generated by four Peltier modules at engine system with temperature difference

Time (min)	Voltage (V)	$T_{Difference}$ (ºC)
0	0	0
5	2.16	16
10	5.34	33
15	7.82	49
20	9.63	67
25	12.58	86
30	12.76	98

Based on the data collected, the generating system with four number of TEC1-12706 modules able to generate voltage up to 12.76 V maximum. As the car engine system become hotter, the temperature difference between hot and cold side of the generating system increases. The value of voltage generated and temperature difference are increasing over time then voltage generated reach its maximum value 12.76V due to the maximum operating for four Peltier device. By using the average voltage and temperature difference values, can be calculated using Seebeck coefficient shown in (7) for four Peltier modules TEC1-12706.

$$Seebeck\ coefficient, \alpha = \frac{7.18}{49.86} = 144.00mV/°C$$

3.2 Results at Exhaust System

The reading was taken at every 5 minutes with total of 30 minutes by considering temperature difference between hot side and cold side is being considered as shown in Table 2. The data was taken when the car stop for every 5 minutes. The car speed was limited to approximately 50 kmh. Temperature of the surrounding are 32-34 ºC which is unstable. Table II shows the data collected at the exhaust system.

Table 2
Voltage generated by four Peltier modules at exhaust system with temperature difference

Time (min)	Voltage (V)	$T_{Difference}$ (ºC)
0	0	0
5	2.43	18
10	5.82	37
15	8.99	54
20	12.54	71
25	12.76	93
30	12.76	112

Based on the data collected, the generating system with four number of TEC1-12706 modules able to generate voltage up to 12.76 V maximum starting from 25 minutes. As the car exhaust system become hotter, the temperature difference between hot and cold side of the generating system increases. The value of voltage generated and temperature difference are increasing over time then voltage generated reach its maximum value 12.76V due to the maximum operating for four Peltier device. The data recorded for generating electricity in terms of relationship between temperature differences against time.

By using the average voltage and temperature difference values, can be calculated using Seebeck coefficient in (7) for four Peltier modules TEC1-12706.

$$Seebeck\ coefficient, \alpha = \frac{7.9}{55} = 143.64mV/°C$$

3.3 Analysis Data for Both Systems

All the data recorded in both experiments being plotted into graph as shown in Figure 5 and Figure 6. Based on the results occur, there’s a big difference in minutes 20 which voltage generated by both system differs by 2.91 V. This is because the heat release by the exhaust system higher compared to engine system. All the energy that is released by burning up fuel in the car is eventually converted into heat - either directly via heat of the motor and heated exhaust gasses. The more voltage is generated the higher temperature difference occur in the system.

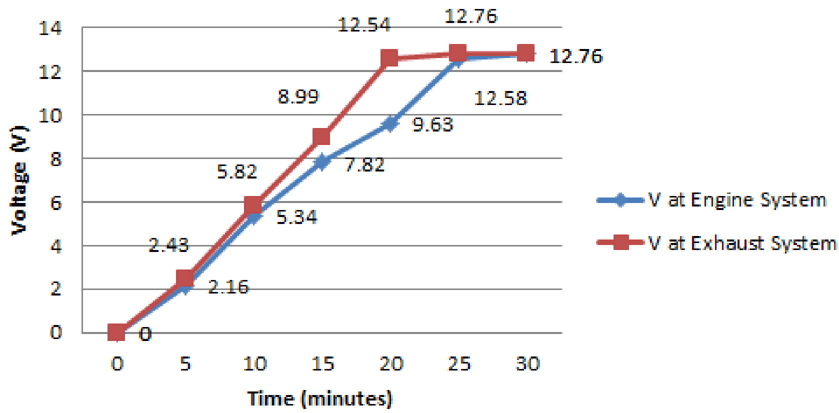

Fig. 5. Voltage Generated for Engine and Exhaust System

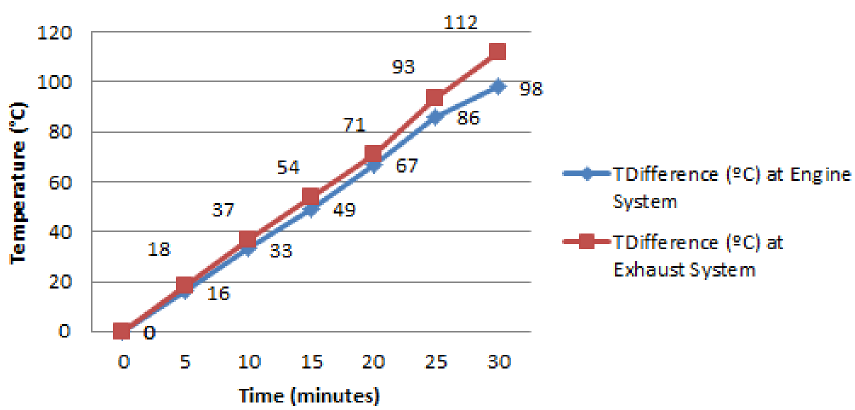

Fig. 6. Temperature Difference for Engine and Exhaust System

The value of thermal resistivity is according to [9] states that thermal conductivity for TEC1-12706 is k = 1.5 $Wm^{-1}K^{-1}$. The value of thermal resistivity according to data sheets of TEC-12706 is 1.98 Ω. Temperature high, T_H is 131°C and temperature low, T_L is 33°C which create temperature difference 98°C. From the efficiency of Carnot, the maximum efficiency of the Peltier TEC1-12706 using (1) calculated as shown below.

$$N = 0.7481 \left[\frac{\sqrt{1 + 0.5711} - 1}{\sqrt{1 + 0.5711} + \frac{33}{131}} \right] = 12.59\%$$

By comparing the maximum efficiency of this generating system to past research by researcher [9], this generating system has higher efficiency which 12.59% compared to 6% using staggered heat sink with the same module TEC1-12706.

4. Conclusion

In conclusion, Peltier modules TEC1-12706 are able to generate voltage from the heat loss at engine system and exhaust system of the car. The efficiency of this system achieved about 12.59% that twice compare to previous research [3] that achieved around 6% using same four TEC-12706 Peltier module. The Carnot efficiency reflects on the ability of the system to generate electricity using the heat loss released at engine and exhaust system.

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