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# Investigation of aluminum heat sink design with thermoelectric generator

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**Abstract.** This paper presents an investigation of aluminium heat sink designs with thermoelectric generator. Basically, for thermoelectric generator (Peltier module), the thermal conversion uses Peltier effect. Two heat sinks with different design, with thermoelectric module of Bismuth Telluride, $Bi_2Te_3$ were used in this investigation. The simulation and experimental studies were conducted with two different heat sinks attached with thermoelectric generator (TEG). System modelling was used to collect data and to predict the behaviour and performance of thermoelectric modules. Experiment was conducted in exhaust system at muffler section since the temperature at muffler section meets the requirement of thermoelectric generator.The result of the experiments shows that rectangular fin heat sink is more efficient in heat transfer compared to circular tube fin heat sink due to its geometry and properties.

## 1. Introduction

It has been quite some time that the researchers have developed means to generate power and generate voltage through temperature difference from thermal alternative energy. Recent development leads to generate energy by using thermoelectric generator. Basically, when there is a temperature difference at the module, energy will be converted to electricity. It is similar as the concept of pipeline system where potential energy is converted to kinetic energy. Thermoelectric generator produces power output due to its movement of electron in the semi-conductor material. When there is hot and cold side temperature, the electron will move from the hot side to the cold side, thus electricity will be produced.

There are many ways to get the renewable energy, such as wave energy, solar energy, wind energy, nuclear energy and many more. Therefore, in a creation and innovation, it must have boundaries and limitations. The main problem in dealing with the thermoelectric generator is the cold side also become hotter as the temperature at the hot side increases. So, the power output will be small as the temperature different small. In order to prevent this problem, the thermoelectric generator is attached with heat sink as a medium of heat dissipation. Recent research shows that heat sink plays the main role for optimizing the performance of thermoelectric generator as a coolant mechanism.

The main objective of this work is to determine the relationship between power output of the thermoelectric generator with the difference in temperature and the efficiency in heat transfer of various designs of heat sink used for test with thermoelectric generator. Heat sink is a cooling mechanism that has been used to cool the cold side of the TEG.

Zhang, Chau and Chan (2008) mentioned that, “Based on the Seebeck effect, the Thermoelectric Generator system has no part that is moving. It works in silent operation” [1]. According to Martins, Brito, Goncalves and Antunes (2011), the Seebeck effect is also used for the thermocouple operation. The electric voltage and electric current are produced by temperature difference between the junctions of two different materials when the electric circuit is closed [2]. The Seebeck effect is due to electromotive force generated in the contact of the closed circuit consisting of dissimilar conductors, when the temperature difference exists (Khripach, Papkin and Korotkov, 2014) [3].

Stobart and Weerasinghe (2006) carried out research on thermoelectric regeneration in vehicles. They had found that the output of the TEG has same potential as the alternator for a small vehicle [4]. Stobart et al. (2010) stated about the possibility of saving fuel by using thermoelectric devices for vehicles. These show that hybrid engine with the thermoelectric generator will increase the performance and also can reduce pollution [5].

## 2. Thermoelectric working principle

According to Shameer and Christopher (2013), thermoelectricity implies the immediate convert from heat into electricity, or the other way around. As indicated by Joule's law, a conductor conveying a current creates heat at a rate relative to the result of the resistance (R) of the conductor and the square of the current (I). A circuit of this type is called a thermocouple; a number of thermocouples connected in series are called a thermopile [6].

Thermoelectric devices are attached to the exhaust pipe to convert waste heat to electrical energy. This thermoelectric generator is placed at exhaust as shown in Fig.1. It is easy to implement and will cause less influence on the operation of engine. The thermoelectric device has two different semiconductors that are subjected to a heat source and heat sink. A voltage is created between the two conductors. The heat from cold side of thermoelectric devices is removed by liquid-cooling cold plate. Thermoelectric generator have several advantages such as, it is free of maintenance, silent in operation, system is independent on weather and has no moving and complex mechanical parts [6].

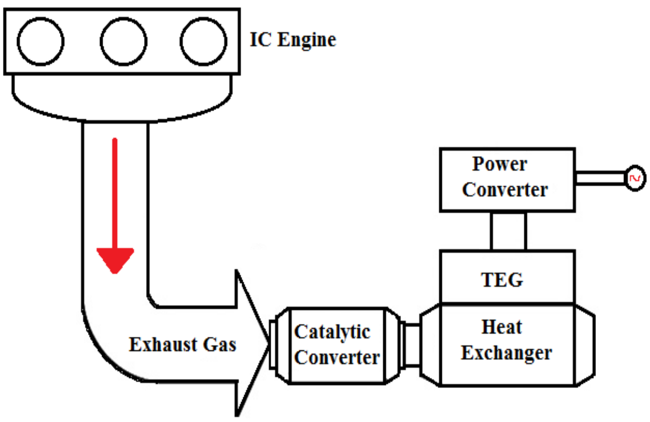


**Figure 1.** Position of the thermoelectric generator

### *2.1. Thermoelectric material*
Sharan and Felix (2014) explained that by using Bismuth telluride, thermoelectric will act as an efficient material that is good for power generation [7]. Bismuth telluride is a compound of tellurium and bismuth. It will become semiconductor when it is alloyed with antimony or selenium. Therefore, it will produce electricity through the direct conversion of heat when it is joined with other by metal conductor, and placed between two thermal conductive surfaces. According to Khripach, Papkin and Korotkov (2014), "However, a thermoelectric material intended for use in vehicles must satisfy additional requirements, such as environmental safety and accessibility, and low cost. Currently, few thermoelectric materials that meet all these requirements are in mass production. One such example is bismuth telluride (III) $Bi_2Te_3$ [3]." They claimed that bismuth telluride satisfies all the requirements needed as a part of thermoelectric generator material.

### *2.2. Basic idea of heat sink*
Heat sinks (Fig. 2) are devices that improve heat dissipation from a hot side, usually the case of a heat generating component, to a cooler ambient, usually air. For the following discussions, air is assumed to be the cooling fluid.

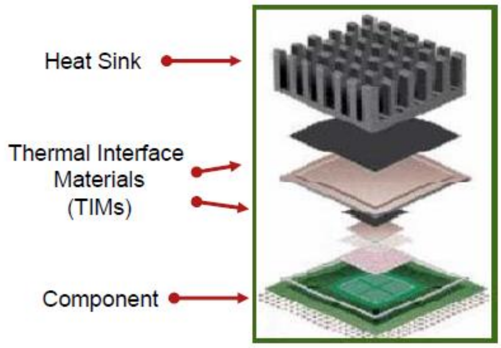


**Figure 2.** Heat sink

In order to have more prominent surface area for heat transfer, the heat sink is firmly packed (Fig. 3). However, it will give small coefficient of heat transfer due to the resistance. The extra fins restrict fluid to flow through the inter-fin passages. Consequently, heat sinks with sufficient space between fins will have a higher heat transfer coefficient; however they will have small surface area.

**Figure 3.** Designs of heat sink, flat plate, rectangular fin and circular tube fin.

To get a better surface area for heat transfer, the fins of heat sink must be closely packed. But it will have a low coefficient of heat transfer. This is a direct result of extra resistance of the supplementary fins that influences a fluid moving through the fins.

## 3. Modelling and experiment

### *3.1. Mathematical modelling of heat sink*

The design is based on orientation, size and number of Peltier module.
Size of Peltier module = $40 \times 40 \times 3\ mm$
Length (Peltier module), $L = w_{mod} \times N_{modseries} = 40 \times 2 = 80\ mm$
Width (Peltier module), $W = w_{mod} \times N_{modparallel} = 40 \times 1 = 40\ mm$
Surface area (Peltier module), $A_{mod} = L \times W = 80 \times 40 = 3200\ mm^2$
Ratio of the length (Peltier module), $\beta_{lw} = \frac{L}{W} = \frac{80}{40} = 2$
Surface area of zone, $A_{zone} = \beta_{lw} \times A_{mod} = 2 \times 3200 = 6400\ mm^2$
Insulation area, $A_{ins} = A_{zone} - A_{mod} = 6400 - 3200 = 3200\ sq.mm$
Heat sink's length = $\sqrt{\beta lw \times A_{zone}} = \sqrt{2 \times 6400} \approx 100\ mm$
Final dimension of heat sink = $100\ mm \times 100\ mm$.

### *3.2. Experiment of heat sink without and with thermoelectric generator*

The experiment was carried out to determine the best geometry of the heat sink. In the experiment the temperature at which heat dissipates from the heat sink was measured. The apparatus and device like thermocouples are connected to G.U.N.T. WL350 TEST UNIT. The heater is connected with the heat sink, and then placed it to the heater position at G.U.N.T. WL350 TEST UNIT (Fig. 4).

All results obtained were recorded. The experiments were carried out for both rectangular fin heat sink and circular tube fin heat sink.

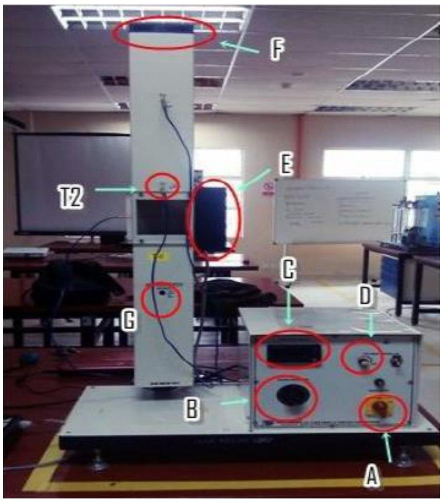


**Figure 4.** The Experiment setup

D = Speed of fan controller
E = Heat sink
F = position of fan
G = Anemometer port
T2 = Thermocouples

After analyzing the result, the best heat sink was chosen to proceed with the next experimentation with the Peltier modules.

Thermoelectric module TEC-12706 was used as shown in Figure 5. The dimension of the module is 40 mm × 40 $mm$ ×3.5 $mm$.

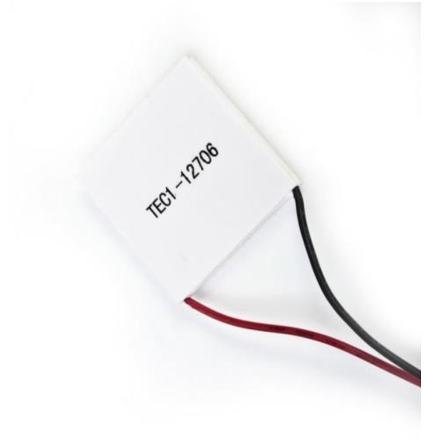


**Figure 5.** TEG Modules

In this experiment, four Peltier modules were used. All the modules were connected in series. The contact surfaces of the modules are enchanted by using thermal grease for efficient heat transfer.

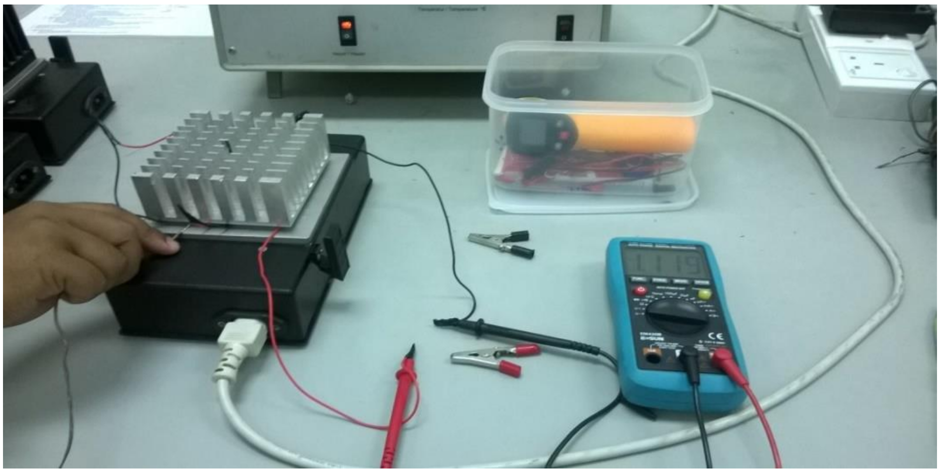

**Figure 6.** Experiment of heat sink with TEG

Figure 6 shows the heat sink attached with the TEG modules to conduct experiment. The hot section is maintained with a constant high temperature through heating and the cold section is supplied with the surrounding air at environmental temperature.

### *3.3. Application of thermoelectric generator ( TEG) at exhaust system*

The experiment continues with the application of the TEG at exhaust system. Surrounding air is used in cooling mechanism and heat supply is from the exhaust system. With the running engine data were recorded according to varying rpm. The temperature was recorded by using thermocouples and the current and voltage were measured by using a multimeter.

A 4G15 engine was used to complete this experiment. The waste heat from the exhaust was the heat source for the TEG. Basically, the heat source will transfer heat from the exhaust to aluminium plate and then to the TEG hot side.

## 4. Simulation and experimental results

The outcome of this project is based on the experiments which are the results of heat sink simulation, experiment of aluminum heat sink, experiment of Peltier modules with the heat sink and application of TEG at exhaust system.

### *4.1. Heat sink simulation*

The thermal analysis of the heat sink simulation was carried out by using ANSYS software (Figs. 7 and 8)

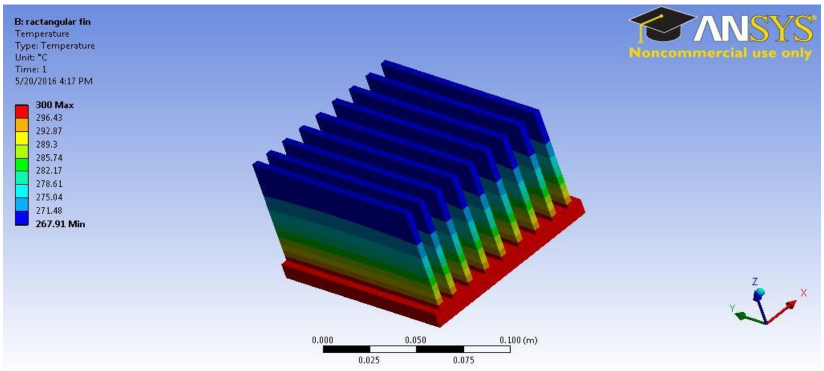


**Figure 7.** Heat sink (rectangular fin type)

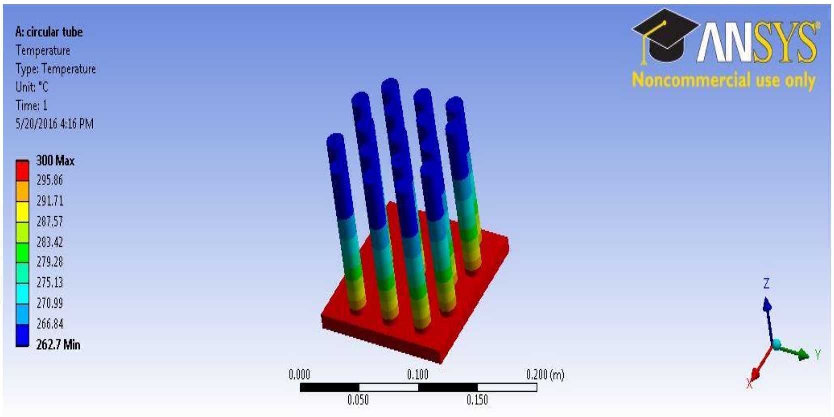


**Figure 8.** Heat sink (circular tube fin type)

Based on figures 7 and 8, the thermal analysis was carried out by using ANSYS software. From the figures it can be observed that the hot section is at the base plate and flow out through the fins. The top section of the fins has low temperature compared to lower section of the fins.

**Table 1.** Heat flux and temperature of heat sink (rectangular fin type)

| Results | | |
|---|---|---|
| **Minimum** | 484.23 W/m² | 267.91 °C |
| **Maximum** | 6.9874e+005 W/m² | 300. °C |

**Table 2.** Heat flux and temperature of heat sink (circular tube fin type)

| Results | | |
|---|---|---|
| **Minimum** | 3551.3 W/m² | 262.7. °C |
| **Maximum** | 2.1351e+005 W/m² | 300. °C |

From the results in Table 1 and Table 2, it can be seen that the heat sink with rectangular type of fin has higher rate of heat energy transferred compared to circular tube type of fin heat sink. The execution of rectangular fin heat sink is better compared to circular tube heat sink. Heat sink with rectangular fin design enhances the rate of heat transfer.

*4.2. Experiment of aluminum heat sink (Rectangular and circular tube fin)*

In this experiment, two types of heat sink were compared in terms of their temperature after dissipation of heat. This is to find out which one is more effective in heat transfer.

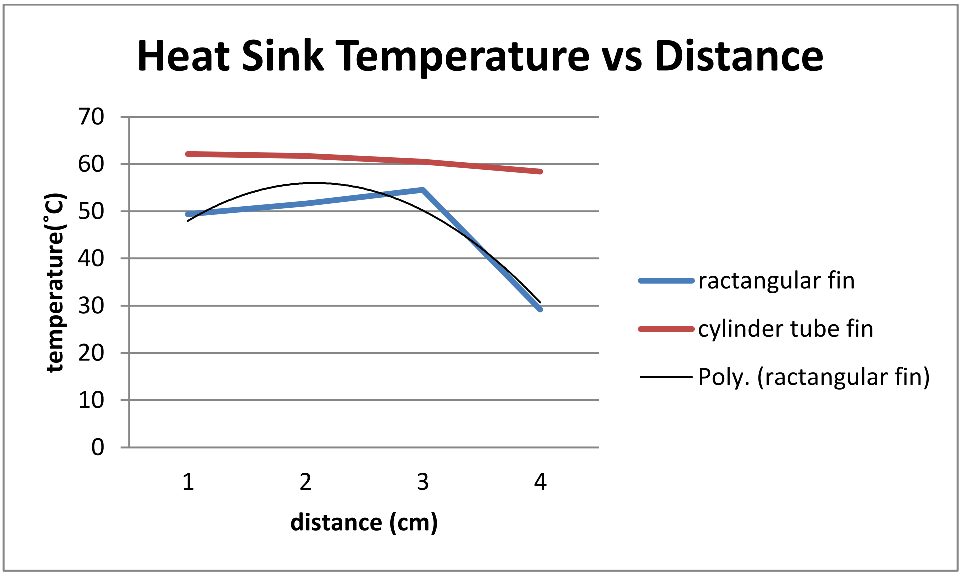


**Figure 9.** Heat sinks temperature

From the graph in Figure 9, it can be seen that rectangular fin heat sink has lower temperature compared to circular tube heat sink. Therefore, rectangular fin type has higher temperature difference compared to circular tube type. The differences in temperature near the heat exchanger (T2) with the temperature farthest away from the surface (T5) for free convection in this experiment is quite large which is 20.2 °C for rectangular fin compared to cylinder tube fin which is only 3.7 ˚C. This shows that rectangular fin type of heat exchanger transfers heat efficiently.

*4.3. Experiment of Peltier module with the heat sink*

The experiment results of performance for thermoelectric generator (TEG) are presented in Table 3.

**Table 3.** Experiment result

| $T_{hot}$ (˚C) | $T_{cold}$(˚C) | $T_{hot}$-$T_{cold}$(˚C) | Q (Watt) |
|---|---|---|---|
| 67.6 | 60 | 7.6 | 0.06 |
| 68 | 50 | 18 | 0.221 |
| 76 | 55 | 21 | 0.312 |
| 80 | 61 | 19 | 0.253 |
| 85 | 69 | 16 | 0.194 |
| 94.6 | 71 | 23.6 | 0.323 |
| 98 | 70 | 28 | 0.401 |
| 105.8 | 78 | 27.8 | 0.372 |
| 115.7 | 80 | 35.7 | 0.623 |
| 118.9 | 87 | 31.9 | 0.48 |

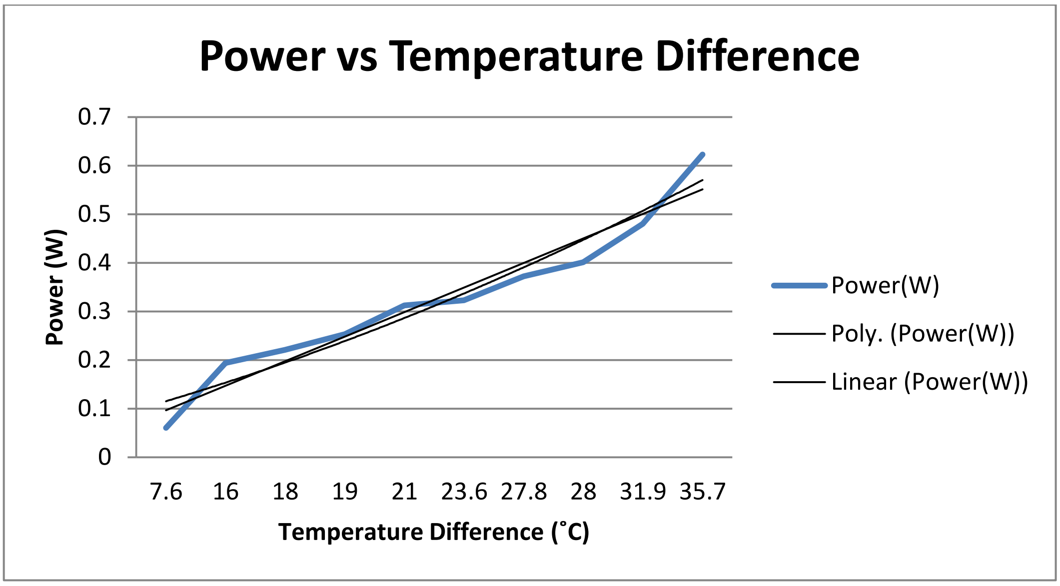


**Figure 10.** Power generated vs. Temperature Different

Figure 10 shows the power produced by TEG. It is clear from the figure that the power is steadily increased from 0-35.7°C temperature difference. When the temperature difference reached 35.7°C, the TEG produces 0.623 W of power.

*4.4. Application of TEG at exhaust system*

Table 4 shows the data collected at different rpm from the TEG attached with the heat sink at the exhaust system.

**Table 4.** Result (Application of TEG at Exhaust System)

| RPM | Voltage (V) | Current (A) | ΔT (˚C) | Q (Watt) |
|---|---|---|---|---|
| **1000** | 1.8 | 0.12 | 17 | 0.216 |
| **1500** | 2.9 | 0.18 | 32 | 0.522 |
| **2000** | 3.95 | 0.23 | 38 | 0.9085 |
| **2500** | 4.8 | 0.3 | 54 | 1.44 |
| **3000** | 5.1 | 0.38 | 63 | 1.938 |
| **3500** | 5.5 | 0.4 | 65 | 2.2 |
| **4000** | 5.8 | 0.43 | 67 | 2.494 |

Figure 11 illustrates the relationship between the temperature differences with the engine rotation (RPM). At 4000 rpm, the temperature difference is 67˚C. It can be seen that the temperature difference increases with the increase in rpm. So the power output of the TEG also increases.

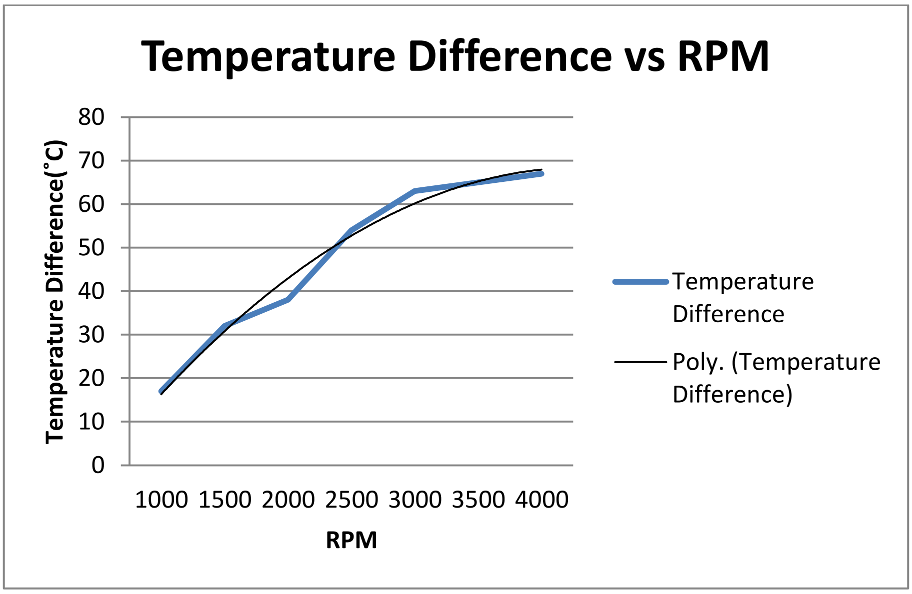


**Figure 11.** Temperature Difference vs. RPM

Figures 12 and 13 show that the maximum voltage obtained is 5.8V and maximum current produced is 0.43A respectively. This is due to the electrons of the material of semiconductor which will excite through the band gap when the temperature is sufficiently high enough. This will enhance the voltage and current.

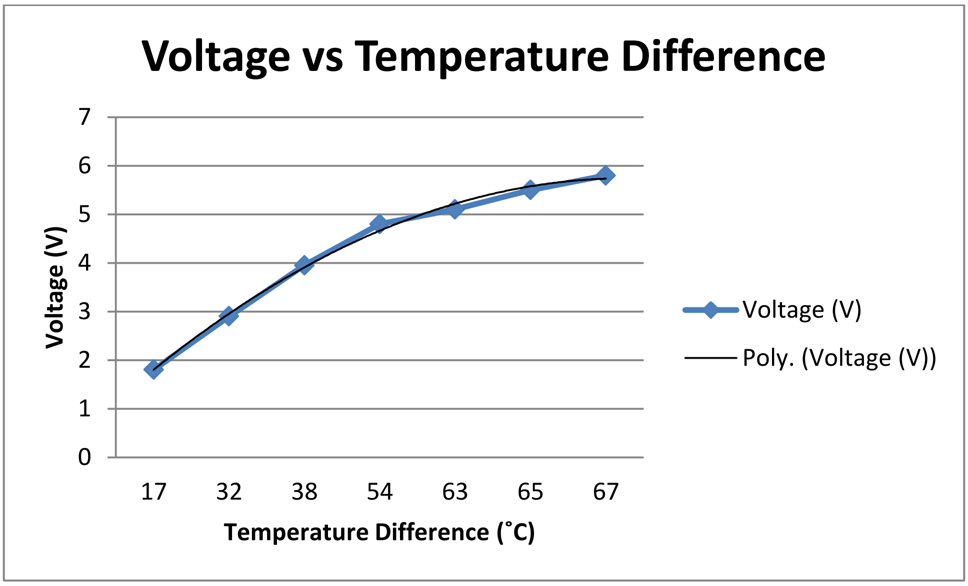


**Figure 12.** Voltage vs. Temperature Difference

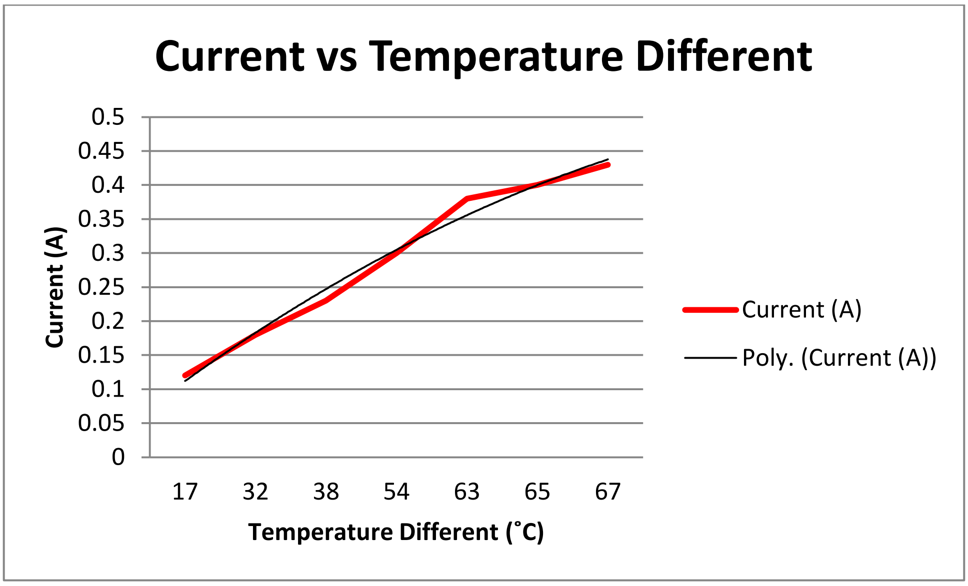


**Figure 13.** Current vs. temperature difference

Figure 14 shows the power produced by this TEG on the exhaust system. It can be seen that the same trend prevails as the other experiment. As the temperature difference increases, the power also increases. The maximum power output achieved is 2.494W at 4000 rpm.

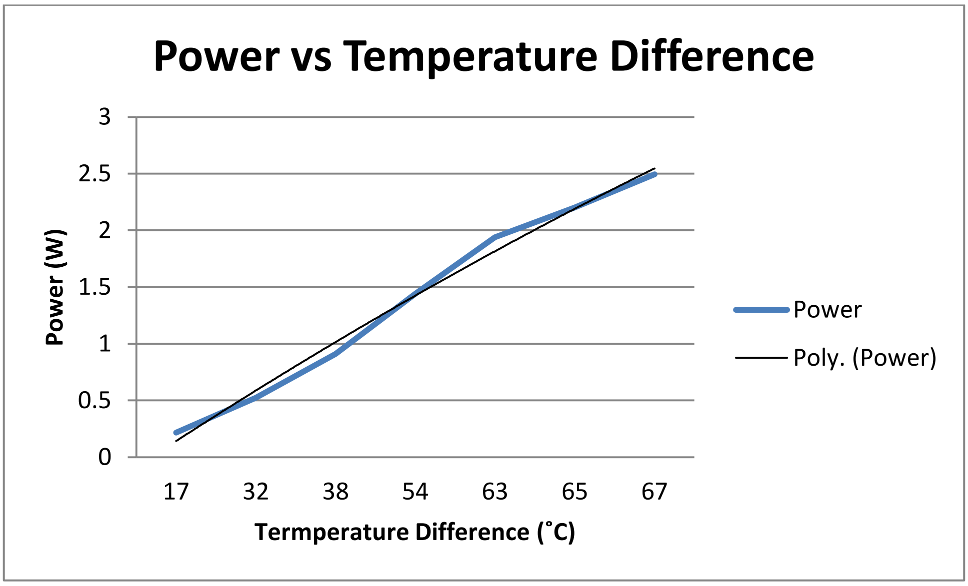


**Figure 14.** Power generated vs. Temperature Different

## 5. Conclusion

The following conclusion can be drawn from the present study:

1. The relationship between the power output of TEG and temperature different has been determined.
2. As the temperature difference increases, the power output also increases.
3. The result of the experiments shows that rectangular fin heat sink is more efficient in heat transfer compared to circular tube fin heat sink due to its geometry and properties.
4. For the application of thermoelectric generator in the exhaust system, the selection of material must be suitable as it will affect the performance of the thermoelectric generator.
5. The contact of surfaces of the module, the heat sink and the exhaust must be ensured. Smooth complete contact to each other is essential for boosting its performance.

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## References

[1] Xiaodong Zhang, Chau K T, and Chan C C 2008 *Journal of Asian Electric Vehicle,* Overview of Thermoelectric Generation for Hybrid Vehicles, **6**(2).

[2] Jorge Martins, Francisco P B, Goncalves L M, Joaquim Antunes 2011 Thermoelectric Exhaust Energy Recovery with Temperature Control through Heat Pipes, *MIT-Pt/EDAM-SMS/0030/2008*.

[3] Nikolay Khripach, Boris Papkin, Viktor Korotkov 2014 *Life Science Journal*, Thermoelectric Generators of motor vehicle powertrains, problems and prospects, 11(12) p.505.

[4] Stobart R K, Weerasinghe R 2006 Heat recovery and bottoming cycles for SI and CI engines—a perspective, SAE Paper no. 2006-01-0662, Presented at *SAE 2006 World Congress & Exhibition*, April 2006, Detroit, MI, USA, Session : Advanced Hybrid Vehicle Powertrains(Part 2 of 5).
[5] Stobart R K, Wijewardane A, Allen C 2010 The potential for thermo-electric devices in passenger vehicle applications, SAE Paper no.2010-01-0833, Presented at *SAE 2010 World Congress & Exhibition*, April 2010, Detroit, MI, USA, Session: Advanced Hybrid Vehicle Powertrains (Part 2 of 3).
[6] P Mohamed Shameer and Christopher D 2013 Design of Exhaust Heat Recovery Power Generation System Using Thermo-Electric Generator, *International Journal of Science and Research (IJSR)* ISSN (Online): 2319-7064 Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438, pp. 2.
[7] S Karthik Sharan and D Giftson Felix 2014 *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, Thermoelectric Materials in Hybrid Cars, e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume **11**, Issue 5 Ver. VI (Sep-Oct. 2014), pp.73-76.