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Utilization Heat Energy from Cooling Water of Diesel Engine to Electrical Energy Using the Thermoelectric Generator

Muhammad Hasan Albana,[a,*] and Bella Rukmana[b]

[a)] *Department of Mechanical Engineering, Politeknik Negeri Batam, Batam 29461, Indonesia*
[b)] *Department of Mechanical Engineering, Politeknik Negeri Batam, Batam 29461, Indonesia*

*Corresponding author: hasan@polibatam.ac.id

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ABSTRACT

This research objective is to convert heat from radiator fluid of the diesel engine to electrical energy by using the thermoelectric generator (TEG). TEG consist of 20 semiconductors and be equipped with the heat sink. Research shows that the heat of radiator fluid can be used to generate electrical energy by using TEG although the electricity produced is still small. The maximum electrical voltage generated from the use of TEG is 9.8 volts when connected in series. When connected in parallel and series-parallel than the maximum voltage generated is only 2.096 volts and 2.465 volts respectively. The maximum electric current generated by TEG when connected in series-parallel is 128.4 mA. When connected in series and parallel, the maximum electrical current generated is 108,3 mA and 68,7 mA respectively. The series circuit is the best choice for TEG because it produces the highest electrical power. TEG efficiency in this study was 5% to 7.1%. The voltage and electric current generated by the TEG will be higher if the temperature difference between the hot side and the cold side of the semiconductor is higher. Use of this TEG does not reduce the performance of the engine cooling system or radiator system.

KEY WORDS: *diesel engine, radiator fluid, thermoelectric generator*

NOMENCLATURE

ZT	Factor of the Merit of the Materials
T_H	Temperature of the Hot Side of the TE
T_C	Temperature of the Cold Side of the TE
ΔT	Temperature Difference Hot and Cold
η_{TEMAX}	Efficiency of a TEG

1.0 INTRODUCTION

Vehicle production in Indonesia tendency increase every year. Motorcycle production in 2010 is 7,395,390, but in 2014 motorcycle production in Indonesia increase to 7,926,104 [1]. This high production correlates with the need of Indonesia society about the motor vehicle and automatically the need to energy increase. Indonesia energy consumption in 2014 in the transportation sector is 334.20 million BOE (barrel of oil equivalent) [2]. While Indonesia oil reserve only 7.37 billion barrels in 2014 [2]. If new oil reserve not found, it is about 23 years forward, oil reserve in Indonesia is out.

A motor vehicle like a car, motorcycle or ship usually use internal combustion engine as a power source. Internal combustion engine can be divided into two categories namely spark ignition engine (SIE) and compression ignition engine (CIE). Spark ignition engine (SIE) use gasoline as a fuel and compression ignition engine (CIE), use diesel oil as a fuel. On this machine (SIE and CIE) was only a fraction of the energy from the fuel that is converted into power to drive the vehicle while most of the fuel energy is wasted. Conklin and Szybist found that only 10.4% energy from fuel that convert to power, 27.7% energy from fuel wasted to exhaust manifold and 61.9% wasted because another factor like friction, cooling water and other [3]. He et al [4] found that only 1/3 chemical energy from fuel convert to effective power while the others discarded to exhaust manifold and absorb by cooling water. The energy used in gasoline combustion engines breaks down into 25% for mobility, 30% in coolant, 5% in other parasitic losses and 40% in exhaust gas [5]. For diesel light-duty trucks using 100 kW of fuel power, this represents 30 kW of heat loss in exhaust gases [5].

A solution to reduce of loss fuel energy and increase engine

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efficiency is used the thermoelectric generator. Thermoelectric generator (TEG) is a technology that directly convert heat to electrical energy and has some advantage like there isn't moving part so easy to maintain, compact and environmentally friendly [6]. No moving parts and no working fluids inside the TEG, hence no maintenance and no extra costs [5]. Other advantages of TEG is long lifespan, especially when working with constant heat sources, TEG can be used for micro generation in very limited spaces, noiseless operations and any working position is possible, making TEG well suited for embedded systems [5].

Thermoelectric generator (TEG) found by Thomas Johann Seebeck in 1821 and named Seebeck effect. TEG change thermal energy to electrical energy because different temperature hot and cold in a semiconductor as shown in Figure 1. Previous research relating to the use of TEG on vehicles focuses more on the exhaust gases. Liu [8] discovered that in order to increase the electrical energy generated by TEG the temperature on the hot side of the semiconductor should be raised. Sun et al [9] have conducted a study comparing the performance of single-stage and two-stage thermoelectric generators (TEG) used in internal combustion engines. The thermoelectric material they used is bismuth telluride. Bismuth telluride (Bi_2Te_3), in the last decades, are the only modules available for industrial applications (with the exception of space) at a reasonable price [5,10]. The results of Sun et al [9] research indicate that the temperature of the heat source plays an important role in the selection of TEG design when the heat transfer coefficient is more than 400 W / m2K. Performance of a TEG single stage is better than two-stage TEG if the heat source temperature is less than 600 K. If the heat source temperature is 800 K, the two-stage TEG usage in series produces greater maximum exergy efficiency than single-stage TEG. This research objective is to convert heat from radiator fluid of diesel engine to electrical energy by using thermoelectric generator (TEG).

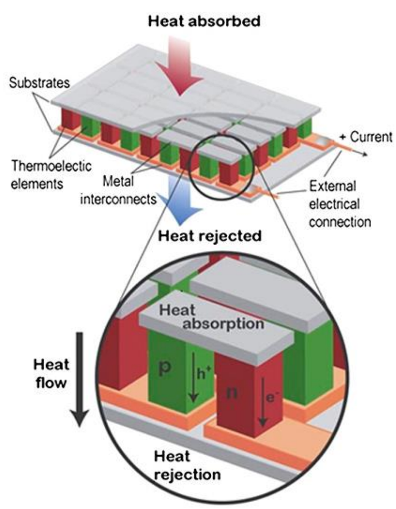

Figure 1 : Schematic of a typical thermoelectric device [7].

2.0 METHODS

This research was conducted experimentally by designing, manufacturing and assembling thermoelectric generator (TEG) and applied to diesel motor (compression ignition engine). The specifications of the test machine used in this study are shown in Table 1.

The TEG is placed in the upper tank radiator hose where it receives heat directly from the machine. The upper tank, radiator hose is cut and among these are placed heat collectors of TEG. Heat collector TEG has four sides were on each side are placed 5 semiconductors to convert heat into electrical energy. Semiconductors used for TEG are 20 pieces. The dimensions of the heat collector made are shown in Figure 1. The heat collector is made of aluminum material. The aluminum has a high ability to absorb heat.

Table 1. Specification of the test machine

Numbers of Cylinders	4
Engine Displacement	1372 cc
Bore	75 mm
Stroke	77,6 mm
Compression Ratio	22,8:1
Maximum Torque	84 Nm @ 2000 rpm
Minimum Idling Speed	900 rpm

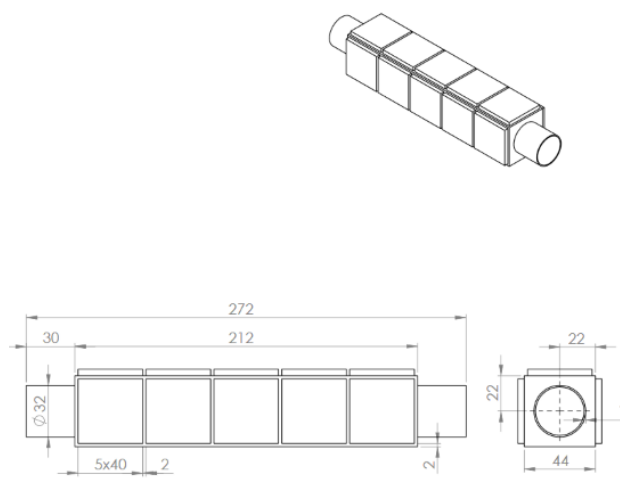

Figure 2 : Heat collector dimension.

The electric voltage generated by the TEG is measured using a digital multimeter and the temperature difference in TEG is measured using a thermocouple. Performed with many configurations of TEGs to produce the most optimal electrical output. One of the variations performed on TEGs is to use the different circuit. The circuits between semiconductors are done in series, parallel, and series-parallel. Parallel and series-parallel configurations are shown in figure 3 and figure 4. The construction of TEG with 20 semiconductors is shown in figure 5. The TEG made in this study are still prototypes.

Preliminary data about the amount of the heat transferred to TEG are shown in figure 6. As shown in Figure 6, the engine temperature will increase with the increasing time operation. The heat received by TEG also increases with the increase of engine operating time. The maximum temperature received by TEG is

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68.3° Celsius. After reaching the maximum temperature, the heat received by TEG is slightly reduced. This is probably due to wind flow from the radiator fan has started to work in lowering the temperature of TEG. Based on this data, it is unfortunate if the heat is not utilized into another useful energy.

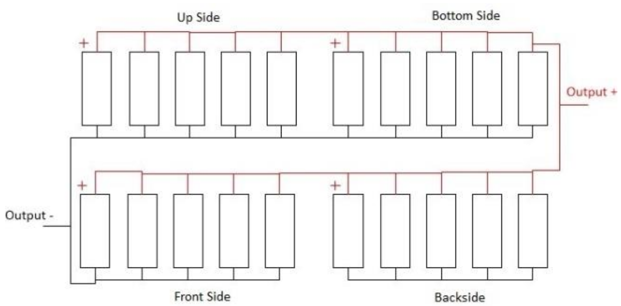

Figure 3: Parallel configuration on TEG.

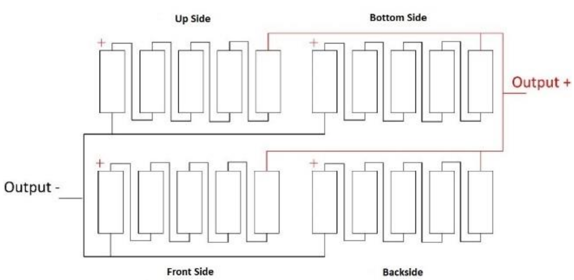

Figure 4 : Series-parallel configuration on TEG.


Figure 5 : TEG construction with 20 semiconductors.

Efficiency of a TEG can defined as the ratio of the electrical energy produced to the thermal energy entering the hot face [5]. Efficiency of TEG can be approximated by the following relationship:

$$\eta_{TEmax} = \frac{\Delta T}{T_H}\cdot\frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_c}{T_H}} \quad (1)$$

T_H is the temperature of the hot side of the TE modules, T_c is the temperature of the cold side of the modules and ΔT is the temperature difference of T_H and T_c. ZT is the factor of the merit of the materials. Efficiency of TEG is dependent on the temperature difference and figure of merit [11]. For bismuth telluride (in last decades, has been the only material which has been used for industrial thermoelectric modules), the average value of ZT is between 0,5 and 0,8 [5].

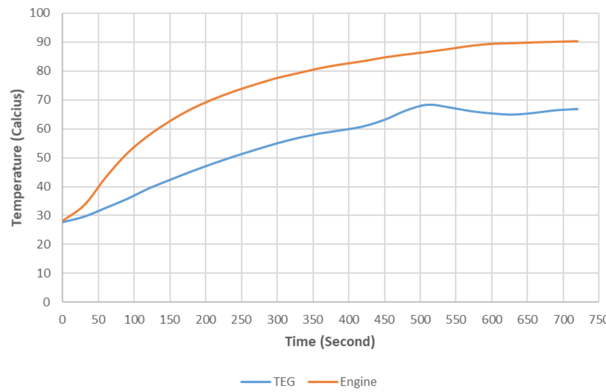

Figure 6 : Heat transfer to TEG

3.0 RESULTS AND DISCUSSION

To obtain the most optimal electrical output, then made a variety of modifications to the TEG. From the tests conducted it is known that the role of cooling fins (heat sink) is very significant in terms of increasing the voltage generated by the TEG. The construction of a TEG when using a heat sink and without using a heat sink is shown in Figure 7. A comparison of the voltage generated by TEG when using a heat sink and when not using a heat sink is shown in Figure 8.

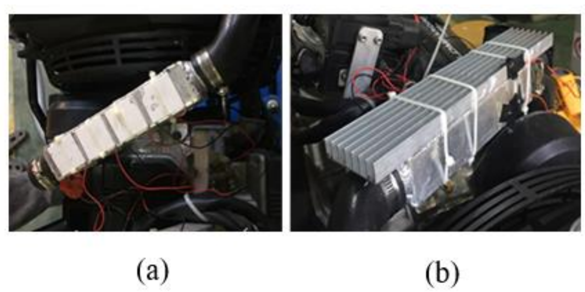

Figure 7 : TEG construction with four semiconductors (a) without heat sink (b) with heat sink

Figure 8 shows the voltage generated by the TEG in units of time. The maximum power voltage generated by TEG without using heat sink is 1.513 Volt. When TEG uses a heat sink, the maximum voltage generated is 3.5 Volt. Based on these data, the use of heat sinks on the TEG raises the resulting electricity voltage by 131%. Therefore, the TEG to be used to utilize radiator heat and convert it to electrical energy in this study is

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recommended for using heat sinks.

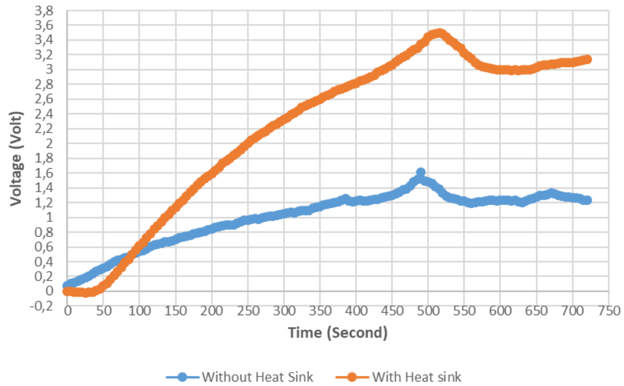

Figure 8 : The electrical voltage generated on TEG with heat sink and without a heat sink

The electric voltage generated by TEG with 20 semiconductors is shown in Figure 9. The voltage generated by the TEG tends to increase with increasing time. At some point, the voltage generated reaches the maximum point and then decreases. After that, the generated voltage tends to be stable or reach the average value. The electric voltage generated by TEG series is shown to be much higher than parallel or series-parallel. The maximum voltage generated by the TEG when connected in series is 9.8 volts with an average voltage generated at 8.5 volts. The maximum power voltage generated when TEG is connected in series-parallel is 2.465 volts with an average voltage generated at 2.1 volts. When connected in parallel, the maximum voltage generated by the TEG is 2.11 volts with an average voltage is 1.8 volts.

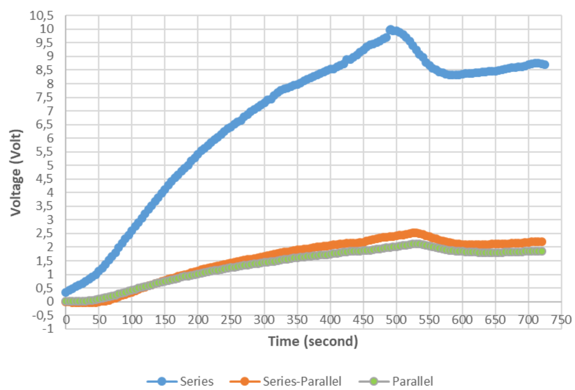

Figure 9 : The electrical voltage produced by TEG

Figure 10 shows the voltage generated by the TEG versus the temperature difference between the hot side and the cold side of semiconductors. Based on Figure 10, it is known that the electric voltage generated by TEG increases with the higher temperature difference. If the higher the temperature difference between the hot side and the cold side of the semiconductors, the electric voltage is also higher. The highest temperature difference (delta T) for TEG connected in series is at 25°C. When the temperature difference gets small, the electric voltage generated is also small. Based on the data it can be concluded that to increase the voltage generated by TEG one can be done by increasing the temperature difference (delta T) between the hot side and the cold side of the semiconductor.

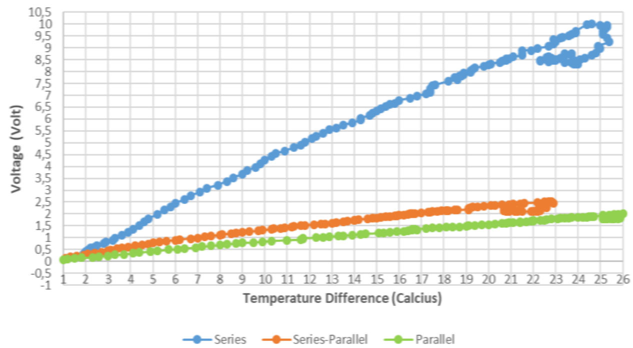

Figure 10 : The electrical voltage generated by TEG versus temperature difference on semiconductor surface

Figure 11 shows the electric current produced by TEG in units of time. The electric current generated by TEG tends to increase with increasing time. At some point, the electric current generated reaches the maximum point and then decreases. After that, the generated current tends to be stable or reach the average value. The maximum electric current generated by TEG when connected in series-parallel is shown to be higher than series or parallel. This result differs from the voltage generated by the TEG, in which series produce higher voltages than parallel or parallel series. The maximum electric current generated by the TEG when connected in series-parallel is 128,4 mA with an average current generated at 116.2 mA. The maximum electric current generated when TEG is connected in series is 108,3 mA with an average current generated at 93.3 mA. When connected in parallel, the maximum electric current generated by TEG is 68,7 mA with an average current is 64.2 mA.

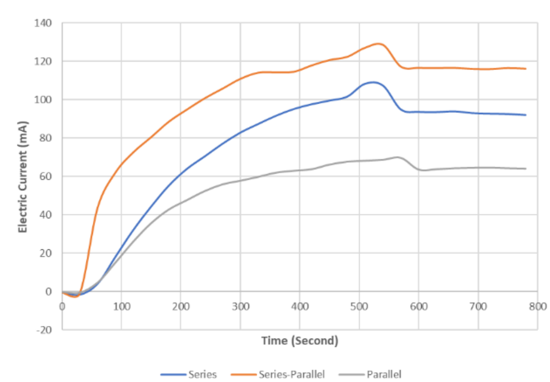

Figure 11 : The electric current produced by TEG

The electric current generated by TEG versus the temperature difference between the hot side and the cold side of semiconductors is shown in Figure 12. Based on Figure 12, it is known that the electric current generated by TEG increases with

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the higher temperature difference. If the higher the temperature difference between the hot side and the cold side of the semiconductors, the electric current is also higher. When the temperature difference gets small, the electric current generated is also small.

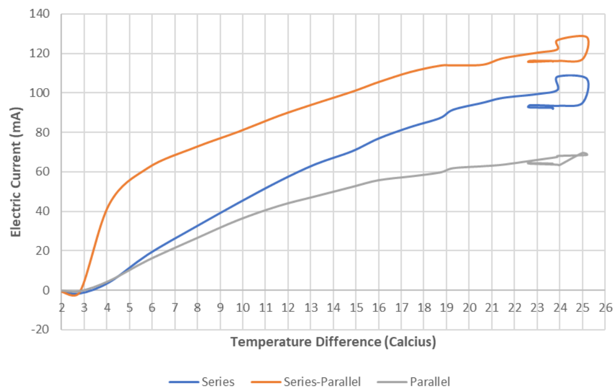

Figure 12 : The electric current generated by TEG versus temperature difference on semiconductor surface

Based on Figure 9 and Figure 10, it is known that the maximum voltage generated by the TEG is obtained when the TEG is arranged in series. But based on Figure 11 and Figure 12, it is known that the maximum electric current generated by TEG is obtained when the TEG is arranged in series-parallel. To determine the best type of circuit to be used for TEG (series or parallel or series-parallel), electrical power is used as a reference. Figure 13 shows the electrical power produced by TEG. Based on Figure 13, it is known that the maximum power is obtained when the semiconductor on the TEG is connected in series. The maximum electrical power generated by TEG when connected in series is 1061 mW. When connected in parallel and series-parallel, the maximum electrical power generated by TEG is only 144 mW and 317 mW respectively.

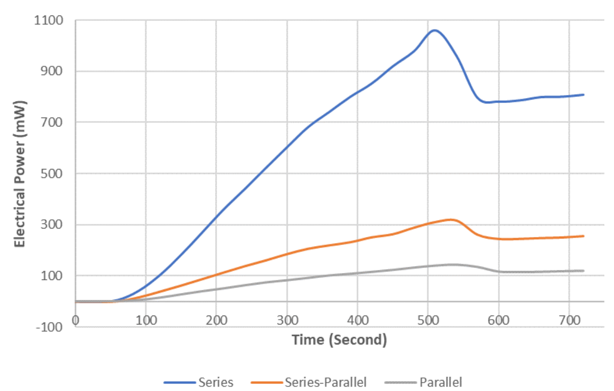

Figure 13 : The electrical power produced by TEG

Figure 14 shows typical values of TEG efficiency for different values of ZT in series configuration. As described previously, 0.5-0.8 is the ZT value of Bismuth Telluride materials. The efficiency of TEG will increase if the value of ZT is higher. Moreover, the efficiency of the TEG will increase if the temperature difference between the hot side (TH) and the cold side (TC) of the TE module is higher. As shown in Figure 14, the highest TEG efficiency was obtained at a temperature difference of 25^{o}C. When the temperature difference between the hot side and the cold side of semiconductors gets smaller, the efficiency of TEG will decrease. The maximum efficiency of TEG in this study was 7.1%, assuming the ZT value of the material was 0.8. When it is assumed that the ZT value is 0.5, the maximum efficiency value that can be obtained is 5%. The efficiency values of 5% to 7,1% can be said to be low, so next research needs to be done to raise the efficiency of this TEG.

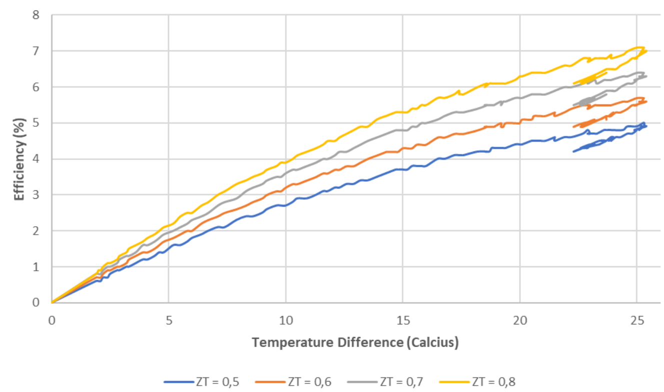

Figure 14 : Typical values of TEG efficiency for different values of ZT in series configuration

The Further development that can be done to improve TEG performance in generating electrical energy is by improving TEG construction and use semiconductors (TE module) with higher ZT values. For TEG construction, the cooling system needs to be redesigned to limit the rise in temperature of the cold side of TE module. In this study, the only reliable component to cool the cold side of the TE module is the heat sink. For TE module with higher ZT values, in the past few months, new modules have become commercially available or are close to commercialization: half heusler, skutterudites, oxides, magnesium silicides and tetrahedrites [5].

Figure 15 shows the machine's temperature vs the machine's operating time when TEG is installed. The engine temperature will increase along with the increase of engine operating time. The engine temperature reaches 90°C when the engine has been operated for 12 minutes and it is assumed that at 12 minutes the engine is operating normally. It can be concluded that the use of TEG on the engine cooling system in this test is not very influential on the performance of the engine cooling system or in other words the use of TEG does not cause the engine to overheat.

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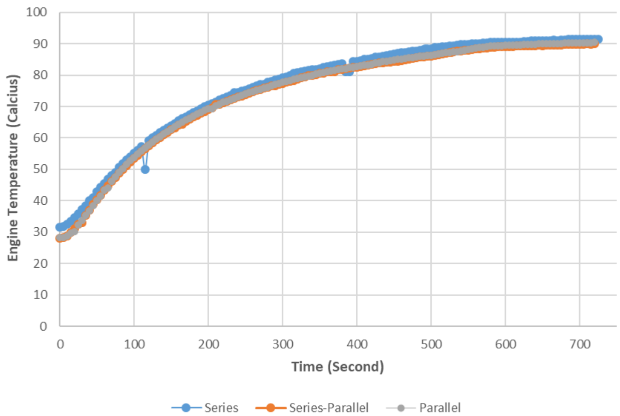

Figure 15 : Engine temperature vs engine operating time when TEG is installed

4.0 CONCLUSIONS

Research shows that radiator heat can be used to generate electrical energy by using TEG although the electricity produced is still small. The maximum electrical voltage generated from the use of TEG is 9.8 volts when connected in series. When connected in parallel and series-parallel, the maximum voltage generated is only 2.096 volts and 2.465 volts respectively. The maximum electric current generated by TEG when connected in series-parallel is 128.4 mA. When connected in series and parallel, the maximum electrical current generated is 108,3 mA and 68,7 mA respectively. The series circuit is the best choice for TEG because it produces the highest electrical power. The maximum electrical power generated by TEG when connected in series is 1061 mW. When connected in parallel and series-parallel, the maximum electrical power generated by TEG is only 144 mW and 317 mW respectively. TEG efficiency in this study was 5% to 7.1%. The voltage and electric current generated by the TEG will be higher if the temperature difference between the hot side and the cold side of the semiconductor is higher. Use of this TEG does not reduce the performance of the engine cooling system or radiator system.

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REFERENCES

1. Asosiasi Industri Sepeda Motor Indonesia, Statistic Motorcycle Production, 2016. http://www.aisi.or.id/statistic
2. Ministry of Energy and Mineral Resources, Handbook of Energy and Economic Statistics of Indonesia, Center for Data and Information on Energy and Mineral Resources, Jakarta, 2015.
3. Conklin JC & Szybist JP, A highly efficient six-stroke internal combustion engine cycle with water injection for in-cylinder exhaust heat recovery, Energy vol. 35, 2010, p.1658.
4. He MG, Zhang Xinxin, Zeng K, Gao KA, Combined thermodynamic cycle used for waste heat recovery of internal combustion engine, Energy vol. 36, 2011, p.6821.
5. Daniel Champier, Thermoelectric generators: A review of applications, Energy Conversion and Management, vol. 140, 2017, p.167.
6. Wang Y, Dai C, Wang S, Theorical analysis of a thermoelectric generator using exhaust gas of vehicles as heat source, Applied Energy vol. 112, 2013, p.1171.
7. Saidur R, Rezaei M, Muzammil WK, Hassan MH, Paria S, Hasanuzzaman M., Technologies to recover exhaust heat from internal combustion engines, Renewable and Sustainable Energy Reviews, vol. 16, 2012, p.5649.
8. Liu X, Zeng YD, Li Z, Su CQ, Performance analysis of a waste heat recovery thermoelectric generation system for automotive aplication, Energy conversion and management, vol. 90, 2015, p.121.
9. Sun X, Liang X, Shu G, Tian H, Wei H, Wang X, Comparison of two-stage and traditional single-stage thermoelectric generator in recovering the waste heat of the high temperature exhaust gas of internal combustion enginge, Energy, 2014, p.1-10.
10. Chengjian Ju, Guansuo Dui, Helen Hao Zheng, Libiao Xin, Revisiting the temperature dependence in material properties and performance of thermoelectric materials, Energy, 2017.
11. Muhammad Sajid, Ibrahim Hassan, Aziz Rahman, An overview of cooling of thermoelectric devices, Renewable and Sustainable Energy Reviews, vol. 78, 2017, p.15-22.

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