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Research Paper

An Experimental Study of the TEG Performance using Cooling Systems of Waterblock and Heatsink-Fan

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Abstract

Two third of the total energy in the internal combustion engine (ICE) system is lost and turns as waste heat through the exhaust system and coolant circulations. Therefore, it is necessary to have a technology that is able to convert waste heat from ICE into electrical energy using thermal electric generator (TEG). To have the best thermoelectric generator (TEG) performance in terms of higher electricity generation, the temperature on the hot surface should be higher, and the temperature on the cold surface should be as low as feasible. The goal of the study was to study how differences in TEG cooling systems affected the overall performance. Water block and heatsink-fan are two different types of cooling systems that have been used in this experiment. The water flow rate in water block cooling systems varies between 200, 300, 400, 500, and 600 *l*/h. The TEG module was heated with gas-fired lighters. Arduino-based data loggers were used to record hot and cold temperatures on the TEG surface. A USB multimeter is used to measure TEG performance as electrical voltage. The results showed that 300 *l*/h was the best water flow rate for TEG cooling. When using a water block cooling system instead of a heat sink, the electrical voltage generated by the TEG module is 12 percent higher. This study found that a cooling system with water blocks is superior to heatsink-fan.

Keywords: Thermoelectric generator; Water flow rate; Cooling system; Heatsink-fan; Water block

1. Introduction

Automotive vehicle are the most widely used transportation currently that utilizes the combustor of fossil fuel as the major of power source, and this is predicted to increase until the year 2040 [1]. According to statistic, two third of the total energy in the internal combustion engine (ICE) system is lost and turns as waste heat through the exhaust system and coolant circulations [2], [3]. Therefore, it is necessary to have a technology that is able to convert waste heat from ICE into more useful energy. Among various energy conversion technology from waste heat, thermal electric generator (TEG) has attracted the notice of many researchers [4], [5]. TEG has a working system by directly converting heat energy to electrical energy based on a "Seebeck" effect practice principle [6], where electrical energy will come out from the end of the semiconductor material arrangement that makes up the module if both sides of the TEG surface have a temperature difference [7]. There are several advantages of the TEG module when compared with other energy conversion technologies in this world. The TEG technology includes no need for regular maintenance (maintenance-free), no moving parts, working in silent conditions (noiseless operation), being compact, easy to use and apply [8], [9]. Many studies have been conducted for the waste heat recovery of ICE by using TEG. Weng and Huang [10], found that the installation of a large number of TEGs does not necessarily produce more generate electric output, but the correct positioning of the TEG on the heat exchanger is important.

The thermoelectric module contributes an attractive energy conversion technology solution, but there are many challenges for researchers to improve performance and efficiency because the performance and efficiency of the module are still low, ranging from ~5% [11]. It should be noted that in order to produce a higher electric output from the TEG, the temperature on the hot surface must be higher, and the temperature on the cold surface should be as low as possible [12]. Research that focuses on improving TEG performance by optimizing the cooling system on the cold surface of the TEG is still rare. Currently, there are four cooling system methods to dissipate heat on the cold surface of the TEG module: natural air cooling system, forced air cooling system, natural water cooling system, and forced water cooling system [7], [13].

Natural air cooling systems (natural draft convection cooling) [14], [15] and forced air cooling systems (forced draft air cooling) [16], [17] have been adopted by researchers to remove heat from the cold surface of TEG. Cooling utilizing force air cooling systems has attracted attention among researchers given the drawbacks of the natural air cooling system, that is, a relatively large volume and mass weight [18]. The cooling system on the cold surface of the TEG has been considered by Robel K. et al [19], who discussed the experiment of a cooling system based on a self-cooling system. This paper investigated the effect of the self-cooling system on the value of heat dissipated efficiency when compared with a heatsink (natural air cooling system). The self-cooling system in this research paper adds a DC-fan to heatsink materials, where the electric source is obtained from the electric output of TEG. The purpose of this experiment was to maintain the temperature of the TEG and heat sink at their optimal values. It was shown that the heat from cold surface TEG can be decreased by 20–40% when related to a heatsink (natural air cooling system).

Based on that background, the researchers tried to formulate the best performance of TEG to produce electric output by optimizing the cooling system on the cold surface of TEG. The objective of this research work was to investigate the effect of the cooling method on the performance of TEG in producing an electrical output, especially the water flow rate in the water block as a cooling medium for the cold surface of the TEG module.

2. Method

Gas-fired lighters (torches) are used as a heat source of energy for the TEG module. According to the specifications of the torch product, the mass flow rate of fire is in the range of 50-140 g/h. In this research the mass flow rate of gas is 100 g/h by adjusting the valve torches. The amount of heat source from torches is 1258 J/s which is calculated using the formulation Eq. 1. [15].

$$Q_f = \dot{m}_{gas} \cdot LHV \quad (1)$$

where Q_f is the heat generated by the torches (J/s), ṁgass is mass flow rate of the gas (kg/h) and LHV is low heat value based on fuel type (KJ/kg).

On a cold TEG surface, two types of cooling systems are used, namely a forced air-cooling system (heatsink-fan) and a forced water-cooling system (water block). The type of thermoelectric used in this study is TEG type SP1848-27145 SA with specifications shown in **Table 1**.

The schematic of the research can be seen in **Figure 1**. The experiment was carried out in two steps. The first step is to vary the water flow rate at the water block as a cooling system for the TEG's cold side surface. The water flow rates in this research were 200, 300, 400, 500, and 600 l/h by adjusting the electric power supply used to start the pump. Variations in the value of power used to start the pump are presented in **Table 2**. To measure the water flow rate, a water flow sensor was combined with an Arduino. The purpose of the variation of the water flow rate is to determine the optimal value of water flow rate when used as a cooling media at the cold surface TEG. The schematic of the research experiment by variation of the water flow rate in the water block can be seen in **Figure 1a**. The second step is to vary the type of cooling system, specifically a forced air cooling system (heatsink combined with a fan) and a forced water cooling system (water block). The volume water in a water tank is 5 liters. Temperature measurements were made at the hot surface (T.H) and cold surface (T.C) of TEG using Arduino-based data logger, and the performance of the voltage generated by the TEG module was measured using a USB multimeter according to

Table 1. Spesification of TEG SP1848-27145 SA Module [20]

No	Parameters	Spesification
1	Dimension:	
	- Width of TEG (mm)	40
	- Length of TEG (mm)	40
	- Total area of TEG (mm²)	160
	- Thickness of TEG (mm)	3.8
	- Mass of TEG (gr)	25
	- Ceramic wafer thickness (mm)	1
2	Materials:	
	a. TEG surface materials	Ceramic
	b. Positive leg of TEG materials	Bi2Te3
	c. Negative leg of TEG materials	Bi2Te3
3	Physical:	
	a. Seebeck coefficient (V/K)	0.054 [21]
	b. Max temperatur working of TEG	~300 °C
	c. Thermal conductance (W/K)	1/0.85 [15]
	d. Electric conductivity (W/m K)	0.6
	e. Semicondutors pairs number	12
4	Manufacturing by	SRT (Shenzhen Ruised Technology Co., Ltd)

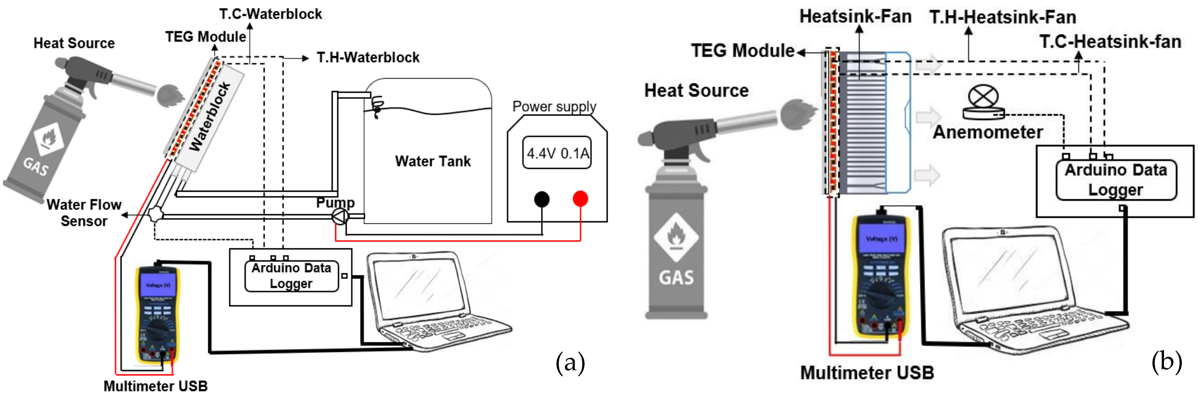

Figure 1. Schematic research of TEG system with the different cooling system; (a) Forced water cooling (water block), (b) Forced air cooling (heatsink-fan)

the research scheme in **Figure 1b**. The specifications and accuracy of the data measurement instrument can be seen in **Table 3**.

Table 2. The value of electric power for supply DC pump

Water flow rate (l/h)	Voltage (V)	Current (I)	Power (W)
200	3.2	0.1	0.32
300	4.4	0.1	0.44
400	5.8	0.1	0.58
500	7.8	0.2	1.56
600	9.6	0.2	1.92

3. Result and Discussion

3.1. Electrical Output of TEG with Various Water Flow Rate

The results of the TEG performance measurement are shown in **Figure 2**. The performance measurement is carried out on the electrical output voltage generated by the TEG with variation in water flow rate is 200, 300, 400, 500, and 600 l/h. The purpose of this experiment was to determine the optimal water flow rate for cooling media in the cold surface of TEG. The measurement result provides some information that all variations in water flow rate will produce a TEG performance curve in the form of the output voltage, which shows an increase during the experiment. However, the curve in **Figure 2** shows that the highest electrical voltage when the water flow is used is 300 *l*/h, while the lowest electric voltage when the water flow is used is 200 *l*/h. The reason is that mass flow rate water 200 *l*/h the water circulation in the water block is to slow which causes the water temperature to approach the temperature of the cold surface TEG so that the heat rejected from the cold surface TEG is not

Table 3. Specification of the measurement instrument

No	Object	Instrument	Type	Range
1	Water flow meter	Microcontroller arduino + Water flow sensor	Uno R3 + YF S401	0.3-6 *l*/min (accuracy ±10%)
2	Temperature	Microcontroller arduino + Temperature sensor + Thermocouple	Mega 2560 + Max 6675 + K Type	-200 to 1260 °C
3	Air wind speed	Anemometer	GM816	0-30 m/s (accuracy ±0.5%)
4	Voltage	Multimeter USB	WH5000	60 mV-600 mV(accuracy ±0.5%)

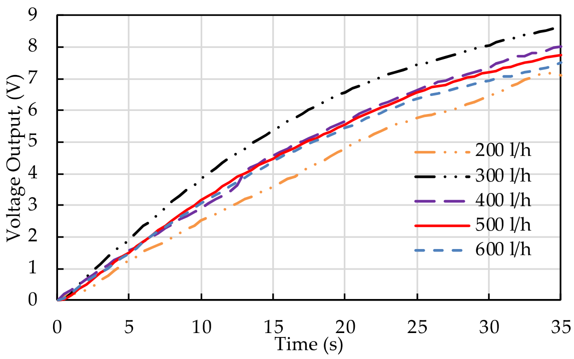

Figure 2. Electric Output Voltage From TEG With Various Water Flow Rates

optimal. It should be noted that the electric output is highly dependent on the temperature difference between the hot and cold sides of TEG [12]. Furthermore, the mass flow rate of 300 l/h produces a higher output voltage than the mass flow rate of 200 *l*/h. This indicates that the absorption of heat by water on the cold side of TEG is more optimal.

In other hand, when the mass flow rate is increased by 400, 500 and 600 *l*/h there is a decrease in the TEG output voltage, it can be happen because the water flow inside water block is too fast so the water has not yet had time to carry heat from the cold surface TEG. This indicates that the water flow rate is most optimally used as a cooling medium for the cold surface of TEG at 300 *l*/h.

To make it easy to analyze, from **Figure 2**, measurement data is converted to a bar graph as shown in **Figure 3**. In **Figure 3** can be seen that the differences in water flow rate can be affected the electric output is in the form of the maximum voltage generated by TEG module. When the variation of the water flow rate is 200 *l*/h, the resulting voltage value is still quite low, i.e. 7.18 V, this is because the flow of water flowing inside water block is too slow to cooling the TEG surface so that the water is not effective because the water in the water block too hot. While, the most optimal water flow rate is to produce a maximum voltage when the water flow rate is 300 *l*/h, which produces a voltage of 8.65 V. However when the water flow rate is 400-600 *l*/h, the average voltage value decreased by 7.75 V, it can happen because the flow of water flowing inside water block is too fast to the inside water block so that the water has not yet had time to carry heat from the cold surface TEG.

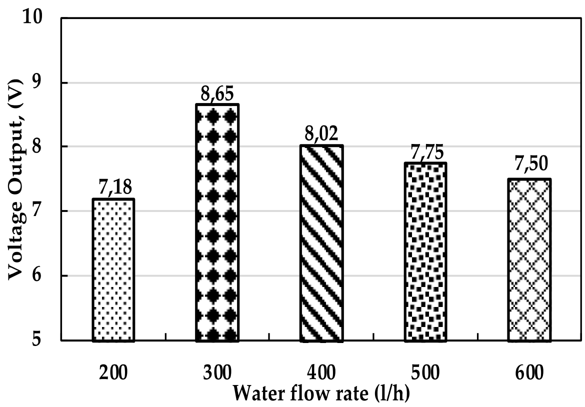

Figure 3. Effect of Water Flow Rates on the Average Electric Output Voltage TEG

3.2. *Temperature Measurement of TEG Surface Based on Air Cooling and Water Cooling System*

Figure 4 shows the temperature profile observed on the hot surface (T.H) and the cold surface (T.C) of the TEG with the different cooling systems, which are heatsink-fan and water block. The purpose of this experiment is to determine the effect of different cooling systems on performance in the form of output current from the TEG module during 120 s. While the water flow rate of the TEG cold surface cooling system is 300 l/h, the water flow rate is used based on considerations as a result of the optimal water flow rate from the previous data.

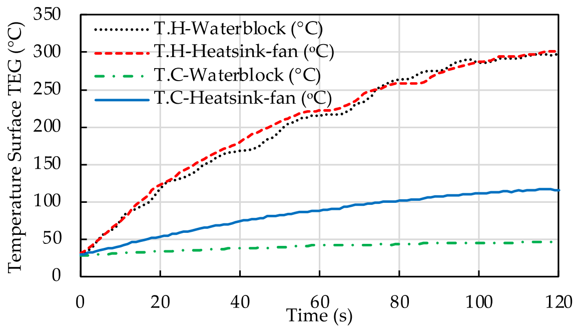

Figure 4. Temperature Measurement on the Surface of TEG

The calculation results of the temperature difference between the hot and cold TEG surfaces are shown in **Figure 5**. The results show that the water block cooling system can produce a higher difference in temperature on the TEG surface than the heatsink-fan cooling system. The differences in TEG surface temperature are related to the amount of heat energy absorbed by the cooling system on the cold side of the TEG. On the other hand, the force water cooling system can absorb more heat on the cold's surface of the TEG.

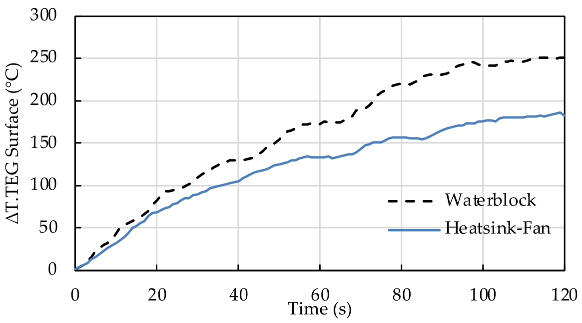

Figure 5. Different Temperature on the Hot With Cold Surface of TEG

3.3. *Open Circuit TEG Measurement*

The heat absorption of the TEG cold surface by the cooling system will affect the temperature difference in the module. It will have a direct impact on the voltage output generated by the TEG module. The formulation used to determine the performance of the voltage output generated by the TEG module is as follows Eq. 2 [15].

$$V_{oc} = a(T_H - T_c)TEG \qquad (2)$$

Where, V_{oc} is the voltage output generated by TEG (Volt), is the Seeback coefficient (V/K), while $T_H$and T_c is the cold side surface temperature and the hot side surface temperature of TEG (°C), respectively.

Figure 6 shows the effect of surface cooling system variations on performance in the form of voltage generated by the TEG module. From the measurement results, it is evident that for variations in the heatsink-fan cooling system, the curve shows a rapid increase in the first 40 seconds, then the curve forms a slope, so that in this condition, the performance of the voltage generated by the module is in a stable condition (steady state). When the TEG cold surface cooling system uses a water block, the curve that is formed tends to be the same as the heatsink-fan cooling system, which increases rapidly at the beginning of the experiment, but after that, the curve will continue to increase until the end of the experiment. When the cooling system uses a heatsink-fan, the electrical output voltage produced by TEG is 6.215 V, but the electrical output will increase if the cooling system uses a water block at 8.232 V. This indicates that the use of a water block cooling system will be more effectively used as a TEG cold surface cooling system because it produces higher voltage performance. This finding is in line with the research conducted by Pfeiffelmann et al. [22], the results of the study found that active water-cooling should be the method of choice to achieve high electric output generated by TEG.

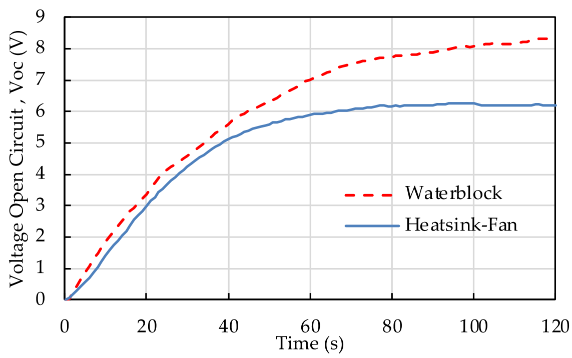

Figure 6. Effect of Different Cooling Systems on the Voltage Open Circuit TEG

4. Conclusion

Variations in the water flow rate as a cooling medium for the TEG cold surface and the cooling system, according to the study, will affect the performance of the TEG module in terms of the voltage generated. The water flow rate 300 *l*/h is the most ideal since, when compared to other water flow rates, it produces the highest voltage performance. When compared to the heatsink-fan cooling system, the cooling system using water block (force water cooling system) will result in improved performance in the form of a higher voltage generated by the TEG module. If a water block is used to absorb heat from the TEG's cold surface, a water flow rate of 300 *l*/h is strongly recommended as one of the parameters.

Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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