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Technical Note

ELECTRIC POWER GENERATION USING A THERMOELECTRIC GENERATOR FROM COOLANT FLUID OF INTERNAL COMBUSTION ENGINE OF CARS

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ABSTRACT

A large part of the heat generated in the engine is removed from it by a cooling system consisted of coolant fluid and a radiator. In this paper, the use of Thermoelectric Generators (TEGs) and utilization of the difference between "engine coolant fluid temperature" and "ambient temperature" to generate electrical current, are studied. According to the observed results, from the engine start moment to about 10 minutes later, the TEG does not produce an electric current due to the low temperature of the coolant fluid. After a few minutes, when the engine's working condition and the temperature of the coolant fluid become stable, the electric current generated by the TEG becomes fixed, too. In this study, the air flow was applied in both forced and natural ways on the cold surface of TEG. Due to the continuous on/off of the radiator cooling fan, the temperature of coolant fluid comes out of the engine had a fluctuation about 7°C, which consequently caused continuous changes in the electrical energy level produced by the TEG. In the case of natural air displacement and forced air displacement on the surface of TEG, the average output voltage of the TEG in a stable state was about 357mV and 890mV, respectively.
Keywords: Thermoelectric generator, TEG, I.C. engine, coolant fluid, radiator.

1. INTRODUCTION

The cars with an internal combustion engine have many fans. The highest thermal efficiency of an internal combustion engine is about 35%, and the extra heat generated by the engine is eliminated, that calls for finding some ways to use the removed heat to increase thermal efficiency [1]. One of how thermal energy is used that can be done using simple equipment is to use TEGs to generate electrical energy. The operation of the TEGs is based on the Seebeck effect, which produces electrical current by creating a temperature difference between the two sides of a TEG module [2]. By increasing the heat transferred from the hot side of the thermoelectric module to the cold side of it, the amount of electrical energy produced will also increase. Using TEGs, it is possible to generate electrical energy from different sources of thermal energy such as solar energy or waste heat from furnaces [3, 4].

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Högblom and Andersson [5] simulated and tested a TEG. They used a three-dimensional model to simulate the TEG and were able to validate the simulation results with high precision. They suggested that by eliminating contact resistance, the "generated electrical power" and the "heat transferred from the TEG generator" increased about 200% and 50%, respectively. Therefore, during the simulation of the TEGs, the contact resistance must be taken into accounts, too.

One of the properties of TEGs is their high sensitivity to the changes in the temperature of the cold and hot sources. Atouei et al. [6] showed that if a two-stage TEG is used, the sensitivity of the upper TEG to changes in temperature sources would be lower. As a result, if a two-stage TEG is used, the output electrical power of the set compared with a single-stage TEG is more stable [6].

After a brief empirical examination of the TEG, Mahmoudinezhad et al. [7] showed that by making changes in the temperature of the cold or hot side of the TEG, the rate of changes in its output voltage would be much more severe. For example, under certain conditions, the temperature of the hot side of the TEG decreases from 69°C to 66.5°C within 500 seconds, but the voltage fluctuation is much more intense so that it reduces from about 3.4V to 1.9V within a few seconds.

Liu and Li [8] transformed a part of the heat energy of combustion gases into electrical energy by using a thermoelectric device mounted on the exhaust path of an internal combustion engine. They considered the hot surface temperature to be 200°C. To keep the other thermoelectric surface at a low temperature, a water flow of 1.38 L/s was used. Using 48 TEG modules, they generated 202 watts of electrical energy from thermal energy, which yields a thermal efficiency of 4.04%. Then, applying a new design, they used a two-stage TEG. As a result, under the same operating conditions as that was applied for the single-stage TEG, the electrical energy produced by it and its efficiency increased to 250 watts and 5.37%, respectively [9]. The number of TEGs used in their new test was 96 modules, which is twice the previous test. In this case, the temperature difference between the two sides of the thermoelectric set, varied from 75°C to 172°C.

Using a TEG, In and Lee [1] generated electric energy from the waste heat of the exhaust gas of a diesel engine. The water flow was used as a coolant fluid to remove the heat and to keep the TEG cool surface at a constant temperature. The temperatures are considered 150°C and 200°C for the hot source, and 80°C and 120°C for cold source of the thermoelectric. The source of thermal energy for their TEGs was a hot stream of combustion gases; by keeping the engine speed constant and increasing its torque, the flow rate of the combustion gases also increases, and consequently, the output electrical power of the TEG also increases.

One of the most important mechanisms that waste the energy in the engine is the heat transfer through the cooling system of the car. The flow rate (discharge) of coolant fluid in the engine of the car depends on various parameters, including engine type, engine volume and the number of cylinders [10]. Because of the various devices mounted on an engine, which control its temperature to achieve the best performance of the engine, the temperature at different points of it varies continuously. According to researches, when coolant temperature of an engine exceeds a certain limit, cooling fans start to operate and cause the temperature of the coolant fluid to decrease [10]. When the temperature of the coolant fluid falls below a certain limit, the fans are turned off and cause the coolant temperature to rise again, and this cycle continues until the operating condition of engine changes to optimum conditions.

The use of mechanical equipment attached to an automobile engine that is used to generate electric energy causes some of the power of the engine, whose main task is to move the car, to be wasted. Furthermore, the use of a turbine in the path of the flow of the coolant fluid or the flow of the exhaust gas from the engine also reduces the efficiency of the engine.

In this study, the intention is to provide and review a novel method to produce electrical energy from the thermal energy which is wasted by the engine coolant fluid. The use of TEGs will not have any adverse effect on the engine performance because there are not any mechanical components, and also it will not cause a pressure loss in the flow path of the coolant fluid.

2. EXPERIMENTAL SETUP

Figure 1 shows the overview of an automobile engine, and a TEG connected to the hose which goes from engine to radiator. To carry out the heat transfer from the coolant fluid to the hot surface of TEG, one compact aluminum device which is shown in Figure 2 is used; it has an inlet and an outlet for fluid, and you can connect TEG parts to 4 sides of it. The dimensions of each TEG used in this research are 4×4 cm, which is why the dimensions of the TEG seat on the aluminum block are 4.2×4.2 cm.

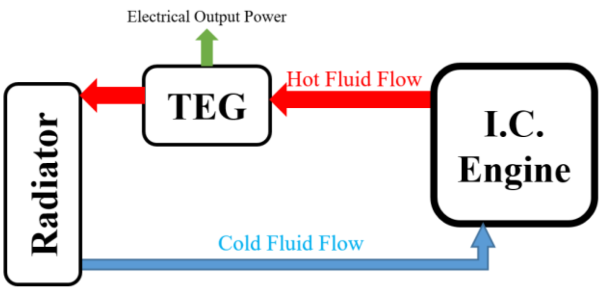

Figure 1. General schematics of an engine cooling system and a TEG

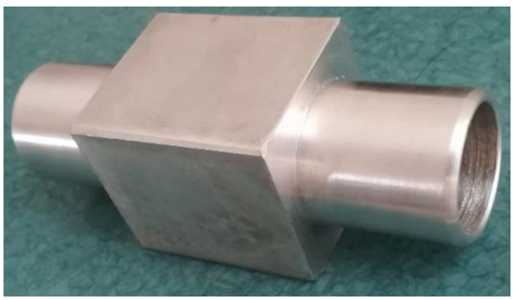

Figure 2. The aluminum device for connecting the TEG

To make TEG and the aluminum device better connected to each other, silicone thermal paste has been used. The air flow is applied in both natural and forced ways on the cold surface of TEG. 6×6 cm fans were used to create the forced airflow. As shown in Figure 3, a 320 Ω electrical resistor is used as a load for the electric energy produced by TEG. The digital thermocouples connected to a data logger are used to measure ambient temperature, the temperature of the output coolant of the engine, the temperature of the outer surface of the aluminum device, and the temperature of the cold surface of the thermoelectric. Also, using the data logger, the voltage across the resistor is measured.

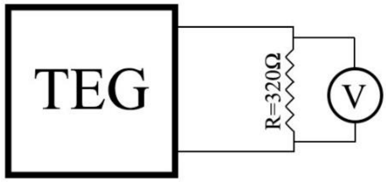

Figure 3. The scheme used to measure the power generated by TEG

To make the experimental results independent of environmental factors, the experiments were repeated three times. The experiments were performed for three consecutive days to ensure that the ambient temperature for the tests was approximately the same. After each test, the engine is placed subject to ambient air to ensure that the temperatures of the engine and the coolant fluid are identical with the ambient temperature at the beginning of the next test. After each engine start, the temperature of the coolant fluid increases from ambient air to the maximum temperature specified by the ECU of the car, which causes the operating conditions of the system to be very transient in the first few minutes of the test.

Table 1 lists the main accuracy values of equipment.

Table 1. The accuracy of the experimental equipment

Equipment	Measuring Range	Resolution	Accuracy
Waterproof DS18B20 Thermometer	-55°C to +100°C	0.5°C to 1°C	±0.5%
Voltmeter	1mV to 5V	1mV	±0.5%

3. RESULTS

To carry out the test, the car was placed subject to ambient air and underneath the shadow. Experiments started early in the morning. Figure 4 shows the ambient temperature during the test, which is the same for all consecutive days. All experiments were carried out in 50 minutes, which was sufficient to stabilize the working conditions of the system.

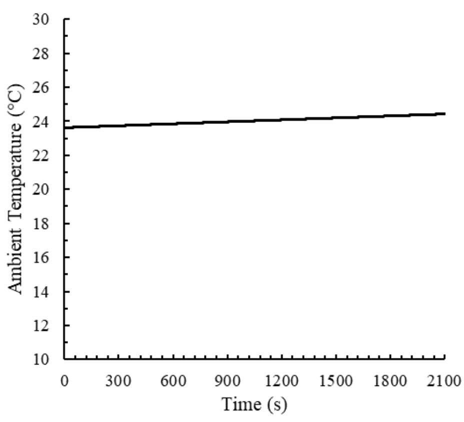

Figure 4. The ambient Temperature during the test

Since the measurement error of the measuring equipment is relatively low, the error value in the diagrams is ignored.

In Figure 5, the temperature of the output coolant fluid of the engine is shown. By comparing Figure 5 with Figure 4, it can be seen that the temperature of the coolant fluid at the beginning of the experiment was the same as the ambient temperature. Indeed, as it was mentioned before because the car was idle before the engine start, the engine's temperature was initially equal to the ambient air temperature. 5 minutes After the engine start, the temperature of the coolant fluid suddenly encounters a sharp change; the reason is the flowing of coolant fluid due to the engine's heating, and consequently, the opening of the flow path of the fluid by the thermostat.

About 5 minutes after flowing of coolant fluid, the temperature of the coolant fluid reaches a specified range, which maximum temperature will be determined by activating the fans for cooling the engine. When the coolant fluid temperature reaches around 88°C (the maximum temperature specified for the engine coolant fluid), the radiator cooling fans will be switched on, and the coolant fluid temperature will be reduced to 81°C. Due to the test requirement for placing the car in a fixed position and turning it on, the cooling fans were continuously switched on and off.

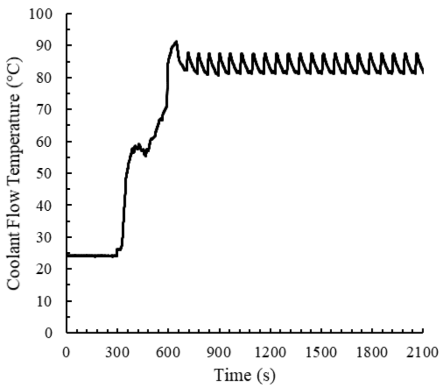

Figure 5. The temperature of output coolant fluid from the engine to the radiator

Figure 6 shows the temperature of the aluminum device surface in the vicinity of ambient air. By comparing Figure 5 with Figure 4, it can be seen that within the first 10 minutes after the engine start, the temperature of the coolant fluid and that of the aluminum device surface have sharp fluctuations. When the working condition is stable, the coolant fluid temperature is in the range of 81°C to 88°C, but the temperature of the aluminum device surface is in the range of 76°C to 83°C, which is due to the vicinity of the surface with the cold air flow of the ambient. The fluctuation in the temperature of the coolant fluid and that of the aluminum device surface is about 7°C; the reason is high conductivity and low thermal capacity of the aluminum, which causes the temperature of all points of the aluminum device to change uniformly in a few seconds.

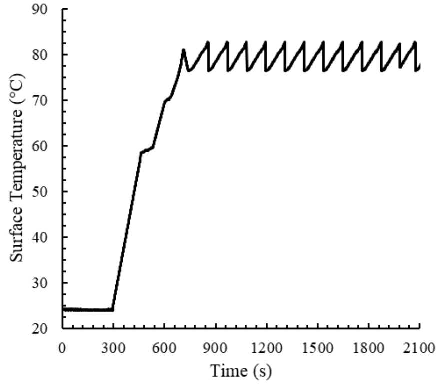

Figure 6. The temperature of the aluminum device surface in the vicinity of ambient air (natural displacement of ambient air)

Figure 7 shows the variations in the voltage generated by the TEG across the electrical load. By comparing Figures 5 to 7, it can be concluded that the potential difference, applied by the TEG, across the load is very dependent on the variations in the temperature of the engine coolant fluid. Within the first 10 minutes after the engine start that the difference between the coolant fluid temperature and the ambient temperature is less than 35°C, the TEG cannot produce electrical energy, so the potential across the load is zero. After the temperature of the coolant fluid stays in the range of 81°C to 88°C, the potential difference produced by the TEG across the load will also stay in the range of 200 mV to 700 mV. The average potential across the load, when the engine operates in a stable condition, is about 357 mV.

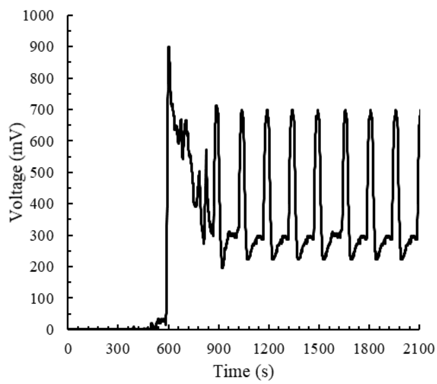

Figure 7. Variations in Voltage produced by the TEG across the load (natural displacement of ambient air)

By comparing Figures 6 and 7, it can be seen that the TEG generates an electric current only when the temperature variations of the two sides of the TEG are sufficiently increased, which causes the changes of the voltage generated by the TEG to be quite sudden. This issue is also was demonstrated by Mahmoudinezhad et al. [7].

Figure 8 shows the temperature of the aluminum device surface is in the vicinity of ambient air. It should be noted that in this section, the ambient air is under the forced displacement condition by a fan, which flows the ambient air over the device surface. The temperature of the aluminum device surface is around 75°C, which unlike the results shown in Figure 6, it has an almost fixed value when the engine is stable because the forced air flow on the surface of the unit causes the surface temperature to become even more uniform.

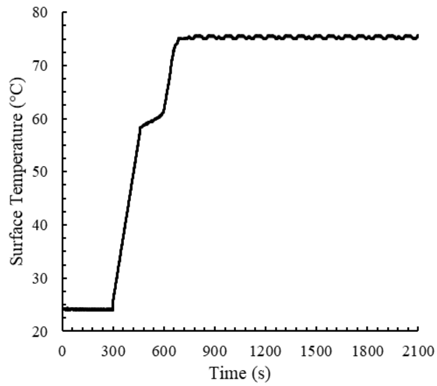

Figure 8. The temperature of the aluminum device surface in the vicinity of ambient air (forced displacement of ambient air)

Figure 9 shows the variation of the voltage, generated by the TEG, across the electrical load when the forced air of the ambient air, which is produced by using a fan, flows on the cold surface of the TEG. In Figure 9, too, as in Figure 7, within the first 10 minutes after engine start, where the temperature of the coolant fluid is low, the potential generated by the TEG is zero. After the temperature of the coolant fluid stabilizes, the potential, generated by the TEG, across the load also stays in the range of 845 to 960 mV. Also, the average potential across the load is 890 mV, which is approximately 2.5 times the potential generated by the TEG in the natural displacement of air on the cold surface of TEG; while the variation of the potential versus time is much less.

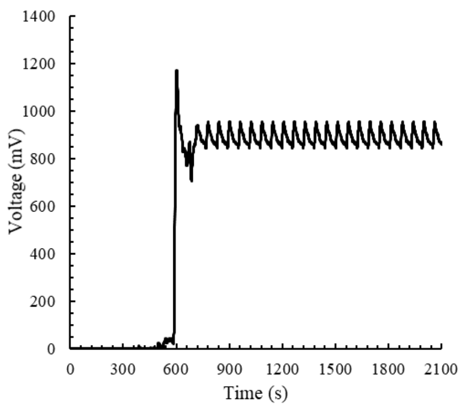

Figure 9. Variations in Voltage produced by the TEG across the load (forced displacement of ambient air)

4. CONCLUSION

It is essential to increase the thermal efficiency of the combustion engine; so, in this paper, a new method was proposed to improve it. According to experimental results, the heat of engine coolant fluid can be used as the thermal source of TEG. Since the electrical power generated by the TEG is susceptible to working conditions of the hot and cold sources, the output voltage of the TEG will change as the temperature and flow (discharge) of the engine coolant fluid changes. The temperature of the hot surface of the TEG varies within the range of 80°C to 90°C, which causes the voltage generated by the TEG under study to be very low. Due to the low voltage output of the TEG, it is anticipated that, economically, the use of TEGs is not a proper way to benefit by the waste heat of the coolant of the internal combustion engines; the most important solution for this problem is to increase the efficiency of TEGs in the future.

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