Waste Heat Energy Recovering to Increase The Efficiency of Automotive Internal Combustion Engines Using Thermoelectric Generators

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Abstract The waste heat energy discharged into the atmosphere by a car engine's fuel consumption provides more than 70% of the energy. We can use waste heat energy in a car's exhaust system if a thermoelectric generator is used to convert the lost thermal energy into electricity. A thermoelectric generator is a device that uses the Seebeck effect to turn temperature differences into electricity. A thermoelectric generator is a device that uses the Seebeck effect to transform temperature differences into electrical energy. In this study we examined the feasibility of installing thermoelectric generation in cars exhaust system and test it's ability to use the thermal waste energy to produce electrical power. As a result, Changes in speed, vehicle load, and surrounding environmental variables affect the thermoelectric generators performance to product electrical usuful power also We predict that at 20°C, the output power for each thermoelectric generator device is 1.18 watts in the best environmental conditions.

Keywords: Thermoelectric generation; Exploitation of waste heat; Thermoelectric generation; Exhaust system; Seebeck effect; Availability; Internal combustion engines.

1-Introduction

Larger and heavier alternators are installed to engines to fulfill the increasing electrical demands of automobiles. The area available for the generator diminishes as the passenger compartment grows larger and the vehicle's aerodynamics improve. Accessories employ larger and heavier alternators that function at 50 to 62 percent efficiency, and they consume about 1 to 5 percent of the engine's rated output. Exhaust gases emit heat at a high degree when compared to the ambient temperature. The Seebeck effect is used by thermoelectric generators and heat engines to transform thermal energy into electricity. Thermoelectric generators are also extremely dependable, quiet, and ecologically friendly [2].

Another advantage of semiconducting materials is their capacity to conduct electricity utilizing electrons [3]. A thermoelectric module has one cold side and one hot side. Heat is absorbed when electrons in an n-type semiconductor element move from a higher energy level to a lower energy level in a p-type semiconductor element [4]. When there is a temperature differential between the thermoelectric modules, bismuth telluride thermoelectric modules are often utilized for cooling or mixed cooling and heating applications. When a temperature differential is placed across the faces of the module, it is feasible to generate electrical power by employing the modules in reverse [5]. Although current power generation and efficiency are low, provided a source of heat is available, usable power may typically be generated. As a result, thermal applications have extended to include vehicle applications, in addition to medical, armed forces, distant, and geographical functions. Several research on the thermal efficiency of thermoelectric generators have been undertaken, and the articles below will discuss the topic. [8–11] The output of a thermos electric generator in a 2.5 L gas-electric hybrid vehicle was investigated in this paper by Hussain et al, and the results showed that under US Environmental Protection Agency highway drive cycle conditions, this device could produce around 300W to 400W of electrical energy [12]. They discovered that adding a porous substance to the exhaust gas channel improves thermoelectric energy conversion efficiency by transferring more heat from the hot-side duct's gas stream to the surfaces of the thermoelectric modules. [13] The purpose of this study is to employ a thermoelectric generator device to convert lost thermal energy in a car's exhaust system into useable electrical energy, as well as to determine the thermoelectric device's capacity to create electrical power. In the exhaust gas, the highest amount of usable heat is roughly 6 kJ/sec [14]. The purpose of this research is to use the thermal energy in exhaust gas to increase vehicle economy. For this purpose, thermoelectric generators in a test configuration that resembled a car's exhaust pipe were used in an experimental and numerical examination. Experiments were carried out under various operating settings in order to exploit waste thermal energy, and the results were analyzed using the ANSYS FLUENT model.

2- Thermoelectric Generators Model:

2.1 Fundamentals of thermoelectric generators:

TEG's working principles include the Seebeck effect, conduction effect, and Joule effect. The Seebeck effect describes how a temperature difference in an electrical conductor causes current to flow. The basic goal of the TEG is encapsulated in this phrase. Commercial TEGs commonly include ceramic substrates, electrical insulators, electrical conductors, and N-type/P-type semiconductor blocks. The thermoelectric generation employed in this paper is depicted in Figure 1.

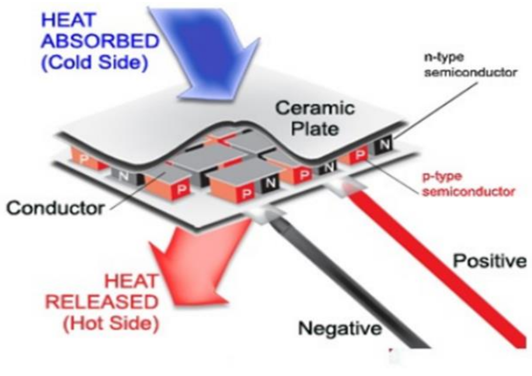

Figure 1: construction of thermoelectric generation. [9]

2.2. model:

Electric current is generated by altering the temperature on both sides of it due to the thermoelectric effect. The concept of a working model geometry to test the TEG is shown in Figure 2 and Figure 3 produced with solid-work software.

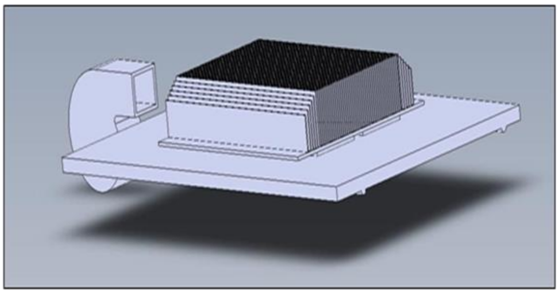

Figure 2: shows a working thermoelectric generator in schematic form.

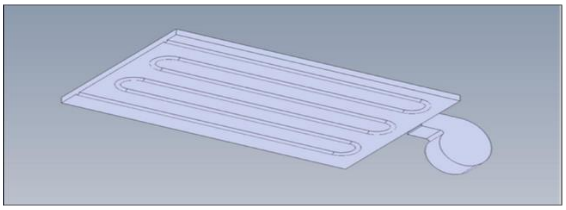

Figure 3: shows a working thermoelectric generator in schematic form.

2. *Temperature distribution in automobile exhaust systems.*

The vehicle chosen was a 2015 Toyota Corolla with a 4-cylinder engine. The capacity to mount thermoelectric generators, which have limited conditions of usage, was determined by measuring temperature variations along the exhaust pipe using K-type thermocouples in various positions on the surface of the exhaust pipe. The exhaust pipe of the chosen car measures 340 cm in length. Figure 4 depicts the thermocouple's location on the exhaust system, as well as the temperatures in each portion at various speeds for the car's exhaust.

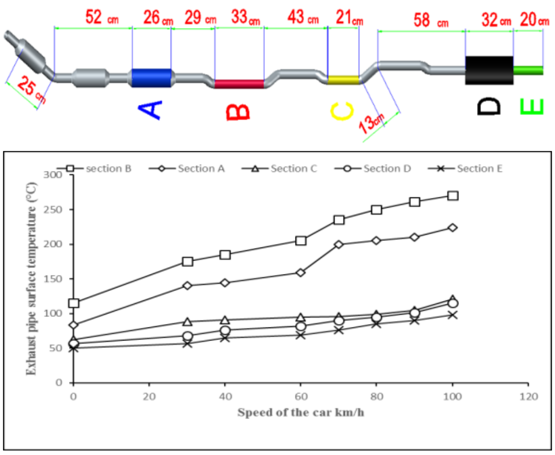

Figure 4: Surface temperature of the exhaust duct at various vehicle speeds.

3. Testimonial:

The thermoelectric generators were in contact with a heated plate and the top, which were both heated by a heat source (flexible electric heater). The thermoelectric generators were covered by an aluminum fin, which allows air to pass through a centrifugal fan and cool the upper side of the thermoelectric generators. The fan's speed controls the velocity of the air passing over the fin, as well as the temperature of the billet surface touching the thermoelectric generator's bottom. The electrical power generated by these six thermoelectric generator elements may then be concluded. Figure 5 depicts the laboratory simulation system, whereas Figure 6 depicts the circuit that powers and operates the device.

Figure 5: A test rig for experiments.

The ANSYS FLUENT software was used to simulate a thermal model. The geometry of the ANSYS FLUENT software model after meshing is shown in Figure 7.

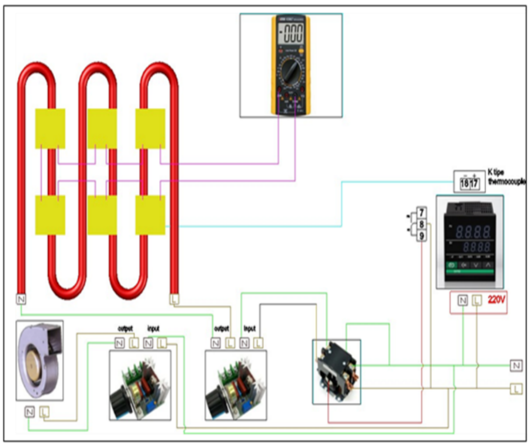

Figure 6: The electrical feed circuit and the controller.

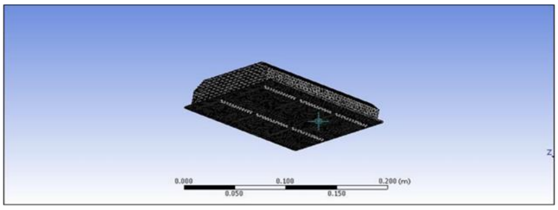

Figure 7: Shows the geometry of the ANSYS FLUENT software.

4. Results and Discussion:

We monitored the measurements of the electrical power production at each temperature difference after the practical research on the laboratory apparatus. Then, using the ANSYS FLUENT program, we alter the air temperature surrounding the car's exhaust system in order to track the ideal weather conditions and the amount of maximum electrical energy that TEG can generate under various scenarios. The temperature differential at various ambient temperatures is depicted in Figures 8,9,10, and 11.

A-At 20°C ambient temperature

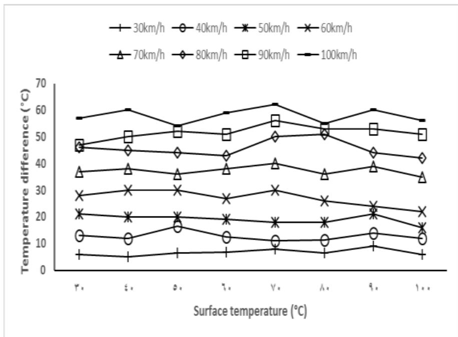

Figure 8: shows the temperature difference at 20°C ambient temperature.

B- At 25°C ambient temperature

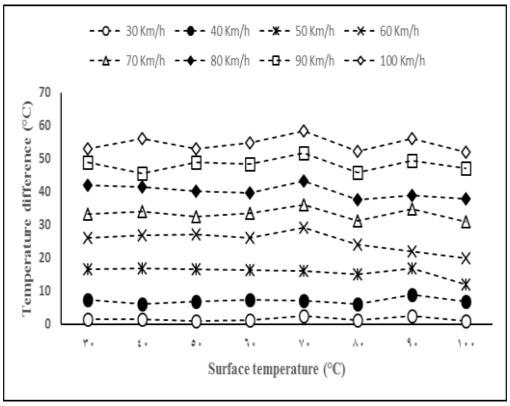

Figure 9: shows the temperature difference at 25°C ambient temperature.

C- At room temperature 30 ℃

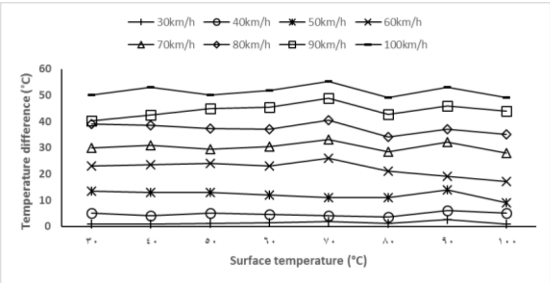

Figure 10: shows the temperature difference at 30°C ambient temperature.

D- At 40°C ambient temperature

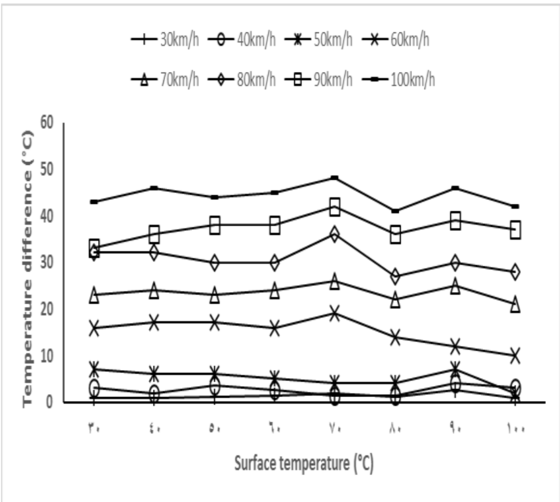

Figure 11: shows the temperature difference at 40°C ambient temperature.

We will provide the results of the practical test that show the electrical energy coming out of the thermoelectric generator devices at each temperature difference after deducing a temperature difference in all distinct environmental situations. The relationship between the electrical energy output in watts and the temperature differential is seen in Figure 12.

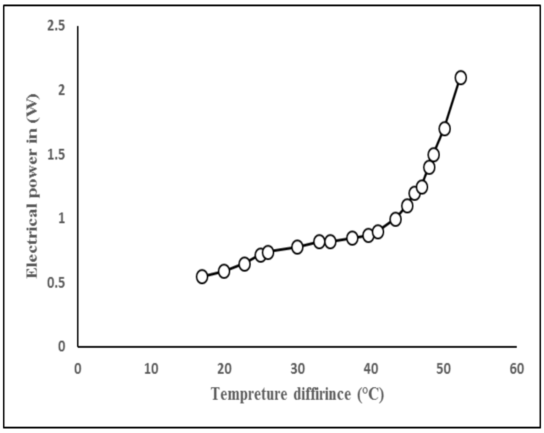

Figure 12: shows the output of electrical power as a function of temperature.

We can see that in the high-temperature range of 45°C and above, a 3°C rise in temperature results in a 0.2 watt increase in output electrical energy. The following are the results in perfect weather circumstances (ambient temperature 25°C) The results show that the electrical energy in the best scenario for each of the thermoelectric engine units is 0.38 watts, allowing it to be mounted on the exhaust pipe and used as needed. We can calculate the temperature distribution on thermoelectric generating geometry in the specified sample condition using the ANSYS FLUENT program. With the change of the automobile's engine load to accelerate the car at different speeds, one side of the thermos electric generation is subjected to a temperature that shifts from 30 to 100 and a speed of air that varies from 30km/h to 100km/h. The largest temperature differential, according to the ANSYS FLUENT software analysis, was 60°C. The temperature difference at the speed shift and in various surface temperatures as analyzed by the ANSYS FLUENT program are shown in Figure 10. At 20°C, we project that the output power for each thermoelectric generator device will be 1.18 watts in the best climatic circumstances that cause the greatest temperature differential.

5-Conclusion:

1. An increase in the temperature difference of 3°C improves the electrical output energy from the thermoelectric generator devices by 0.2 watts at a high-temperature difference of 45 and above, according to ANSYS FLUENT SOFTWARE.
2. As a vehicle's speed increases, more gas flows through the exhaust stream, boosting the gas stream's outer surface temperature in contact with one side of a thermoelectric generator. It also creates a rise in the temperature difference between the two sides of the thermoelectric generator device, which is a vital factor in the thermoelectric generators' ability to generate electrical power. It also increases the airspeed traveling over the fins, cooling the other side.

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