Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 44, No. 7, pp. 151-158
Published Year 2021

Recover Waste Heat Energy to Improve the Efficiency of the Automobile Internal Combustion Engines Using Thermoelectric Generators

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ABSTRACT

More than 70% of the energy is obtained through the fuel consumption of a vehicle engine released into the atmosphere as waste heat energy. We can exploit waste heat energy in 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 convert temperature differences to electrical energy. In order for the thermoelectric generator to produce electrical energy, it needs a temperature difference on both sides, so that a capability to produce electrical power by thermoelectric generation using the missing thermal energy from the vehicles exhaust system and relatively cool surrounding air temperature has been experimentally evaluated at various air velocity at different speeds. The objective of this paper is to examine the possibility of a thermoelectric generator to convert waste heat from a vehicle's exhaust system into available electrical energy. As a result, a laboratory apparatus was created in this paper to simulate the car's exhaust system. The exhaust pipe's surface temperature varies with a shift inspeed, the vehicle's load, and the surrounding environmental conditions. On the other hand, air will pass over the fins to cool down the other side of the thermoelectric generation device. Those factors will lead to a difference in temperature on both sides of the thermoelectric generator and this temperature difference directly affects the electrical power that the thermoelectric generator device can produce. In this paper, after experimental work, after the thermoelectric generator has undergone different operating conditions by changing the velocity of the air passing on one side to cool it down, the temperature of the other side is going rise when exposed to the heat flux that represents the exhaust surface temperature at those operating conditions. The maximum temperature difference between both sides of the thermoelectric generator was 52°C, and finally, the highest electrical power output was 0.38 watts at thehighest temperature difference.

KEYWORDS

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

INTRODUCTION

Larger and heavier alternators are attached to engines to fulfill the increasing electrical demands of automobiles. Larger and heavier alternators that operate at 50 to 62 percent efficiency approximately 1 to 5 percent of the engine's rated output is used by accessories, as well as the passenger compartment grows larger and the vehicle's aerodynamics improve, the space available for the generator in the engine room shrinks. About 30 percent of the energy provided to an internal combustion engine is lost as waste heat in the exhaust. If around percent of the heat from an automobile's exhaust can be recovered, the vehicle's electrical requirements can be met, and fuel consumption can be reduced by nearly 1 percent [1]. When compared to the ambient temperature, heat emit through exhaust gases at a high temperature. Thermoelectric generator is similar to a heat engine in that It transforms thermal energy into electricity via the Seebeck effect. Thermoelectric generations are also extremely dependable, operate silently, and are typically ecologically benign [2]. Semiconducting materials were discovered to provide the best combination of Seebeck coefficient, electrical resistivity, and thermal conductivity. Another advantage of semiconducting materials is the capacity to conduct current using electrons [3].

A thermoelectric module has two sides, one cold and one heated. On the hot side, heat is absorbed as electrons go from a higher energy level in the n-type semiconductor element to a lower energy level in the p-type semiconductor element [4]. Thermoelectric modules made of bismuth telluride are typically utilized for cooling or mixed cooling and heating applications in which a temperature differential exists between the thermoelectric modules. Using the modules in reverse, when a temperature differential is applied across the faces of the module, it is feasible to generate electrical power [5]. Although power production and generation efficiency are currently modest, if a source of heat is available, useful power can typically be generated. Where the advantages of thermoelectric materials in energy conversion are that they are easy to use, the units have been improved by the efforts of a group of researchers around the world[6 and 7]. Consequently, thermal applications have evolved beyond the realm of medical applications, armed forces applications, remote applications, and geographical utilization to include vehicle applications[8–11].

Severalstudies have been conducted on the thermal efficiency of thermoelectric generators, articles below will show address the idea. Hussain et al, in this paper, the output of a thermos electric generator in a 2.5 L gas-electric hybrid vehicle was investigated, and the results showed that this device could produce around 300W to 400W of electrical energy under US Environmental Protection Agency highway drive cycle conditions [12]. Ibrahim et al, by Using a rectangular exhaust gas tube, the characteristics of thermoelectric modules for automotive exhaust heat recovery were investigated. They discovered that packing a porous material into the exhaust gas channel increases thermoelectric energy conversion efficiency by increasing the heat transferred from the hot-side duct's gas stream to the thermoelectric modules' surfaces [13]. The main problem is The lack of efficiency of the car engines to take advantage of the largest possible amount of the thermal energy inherent in the fuel and the loss of precious thermal energy in the form of heat.

Aim of this study is to Take advantage of the wasted thermal energy in the car's exhaust system and convert it into available electrical energy using the thermoelectric generator device and check the capacity of the thermoelectric device to produce electrical power. The maximum amount of helpful heat available in the exhaust gas is about 6 kJ/sec [14]. This paper aims to increase the efficiency of the vehicle by utilizing the thermal energy of the exhaust gas. For this purpose, an experimental and numerical study has been performed by using thermoelectric generators in a test rig similar to the car's exhaust pipe. Experiments have been conducted under different operating conditions to exploit the waste thermal energy, and the experimental was examine with the ANSYS FLUENT model.

AUTOMOBILE EXHAUST SYSTEM TEMPERATURE DISTRIBUTION.

A 2015 Toyota Corolla with a 4-cylinder engine was selected. Temperature changes along the exhaust pipe were measured using K-type thermocouples at five locations on the exhaust pipe surface in which the thermocouple was installed as shown in Fig. 1. The exhaust pipe was tested under different engine speeds ranging from 0 to 100 km/h, the result shown in Fig. 2. She indicated that the temperature distribution and the exhaust pipe increase when the engine speed increases and ranges from 250 to 50 ° C at 100 km / h.

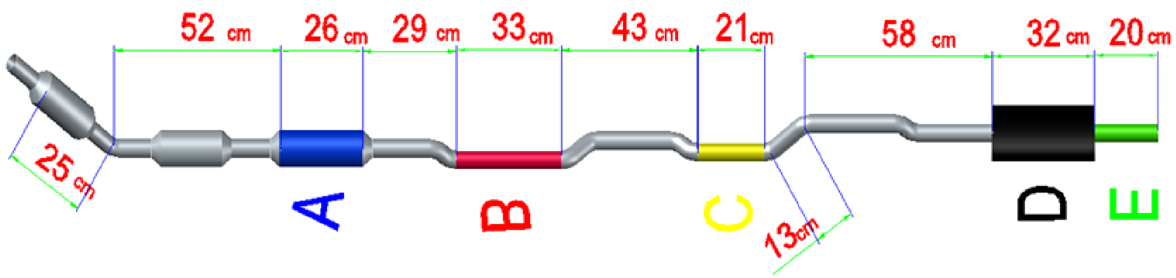

Figure 1. Showing the location of thermoelectric generations and thermocouples along exhaust pipe.

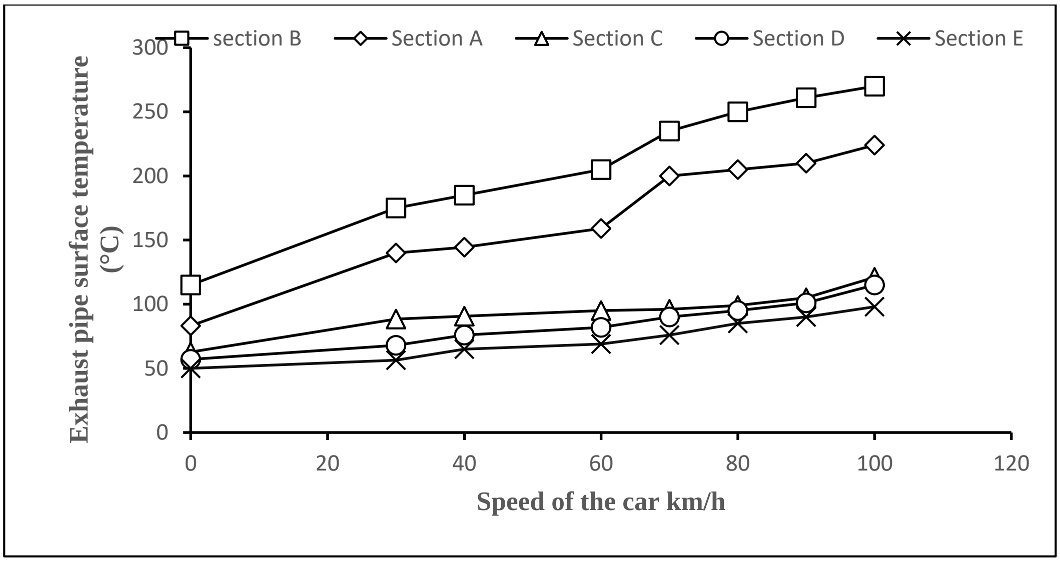

Figure 2. Exhaust duct surface temperature at different vehicle speeds.

ANALYTIC MODEL

To exploit the thermal energy in the car's exhaust system that is wasted, a geometric model has been developed. A rectangular duct with aluminum fins on the cold side and the other side of the thermoelectric generator in contact with a galvanized plate that is supposed to be a heat-controlled source are used in this model. Thermoelectric generators (thermoelectric generations) are located between the hotand cold sides in this design, increasing the heat transfer rate through the thermoelectric generations. The important parameter for the see-beck effect is the temperature difference across the thermoelectric generations and more power the device generates. The rectangularduct in this configuration is for moving exhaust gases from an automobile exhaust system. As shown in figure 3 and figure 4, the geometric model of the solid-work device is created based on anexperimental setting that is explained in the next part of this paper.

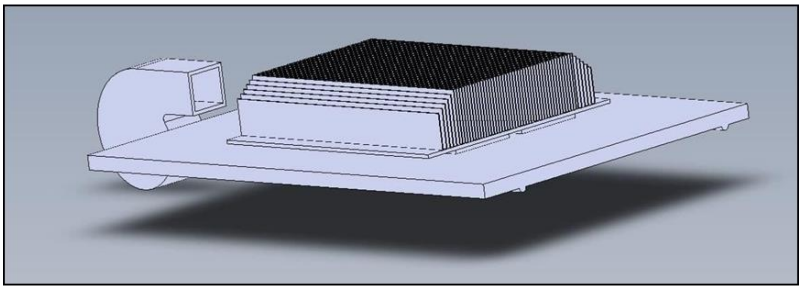

Figure 3. SOLIDWORK software model (front view)

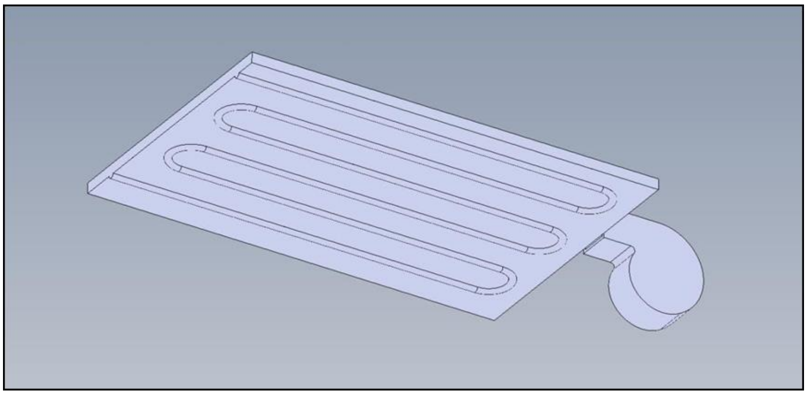

Figure 4. SOLIDWORK software model (view from the bottom)

A thermal model was simulated using the ANSYS FLUENT software. Figure 5 shows the geometry of the ANSYS FLUENT software model after meshing.

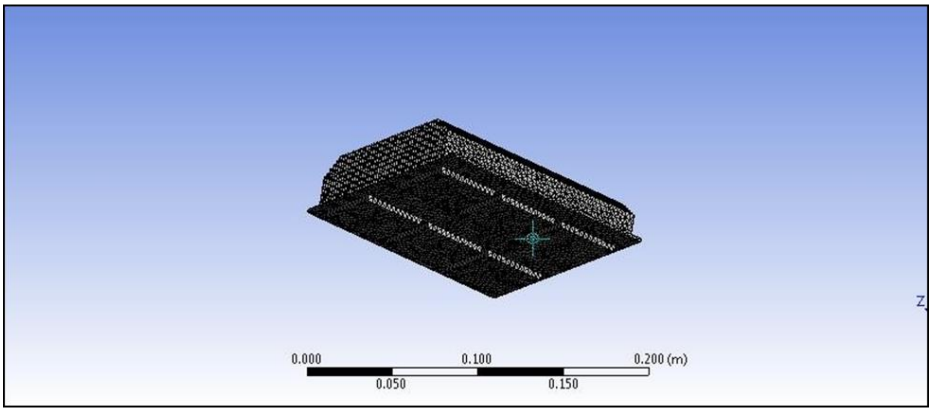

Figure 5. ANSYS FLUENT software geometry.

THERMOELECTRIC GENERATION AND EXPERIMENTAL INVESTIGATION

The experimental setup was prepared to simulate the car exhaust system. In this setting, six elements of the thermoelectric generator were used to verify the electrical power output under certain operating conditions; a thermoelectric generator is a device that converts temperature changes into electrical energy via the Seebeck effect. In comparison to other designs, the thermoelectric generator is useful forwaste-heat energy recovery and low-pressure reduction. Figure 6 depicts the thermoelectric generation.

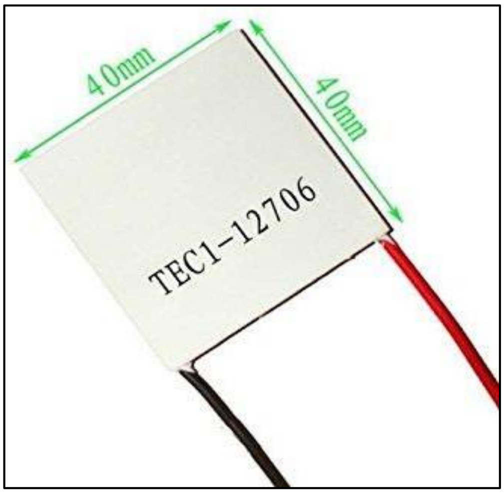

Figure 6. Thermoelectric generation.

Table 1. The thermoelectric generator's specifications.

Property	Value
Material	Bismuth telluride (Bi2Te3)
Ceramic material	Alumina (AL_2O_3)
Operating temperature limit	138°C
Voltage in an open circuit	12.1 volts
Dimensions	40 × 40 × 3.8 mm
Thermal conductivity	2 W/Mk
Density	7,790 kg/m3
Specific heat	250 J/kg K
Life expectancy	200,000 hours

The thermoelectric generators were placed in contact with a heated plate that heated by a heat source (flexible electric heater) and the top. The thermoelectric generators were covered by an aluminum fin sothat the air passes over the fin through a centrifugal fan and cools down the upper side of the thermoelectric generators, and the fan's speed controls the velocity of the air passing over the fin and controls the temperature of the billet surface touching the bottom of the thermoelectric generator. Then we can conclude the electrical power from these six elements of thermoelectric generators. Figure.7 shows the laboratory simulation system, and Figure 8 shows the circuit that supplies electricityto the system and controls it.

Figure 7. Experimental test rig

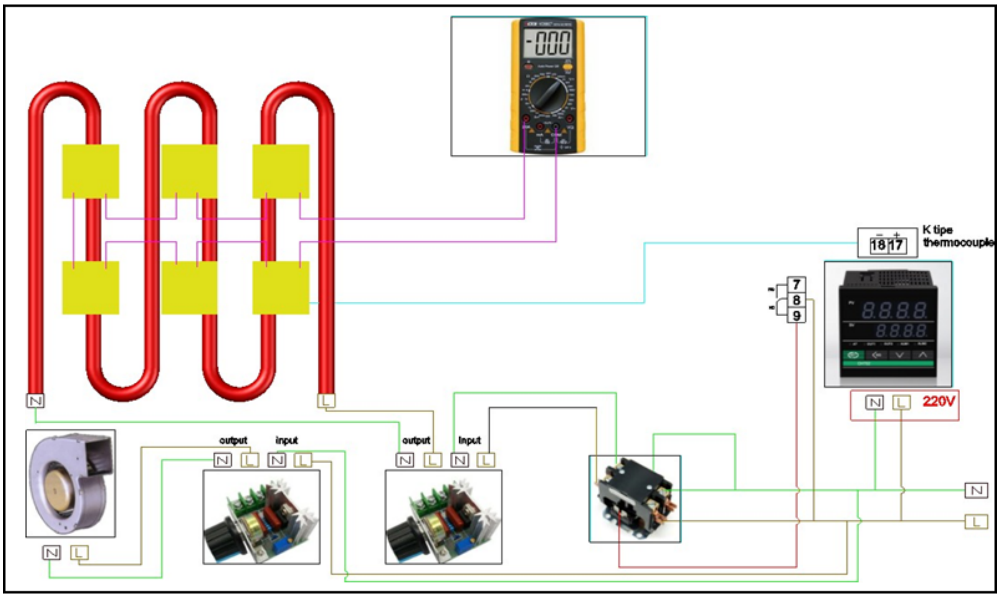

Fig. 8: Controller and electrical feed circuit.

RESULTS AND DISCUSSION

After taking the readings from the experimental device, we deduced temperature differences on both sidesof the thermoelectric generator device, which is the most important factor for the production of electrical energy. Figure 9 shows the temperature difference at the shift of speed and in varying surface temperatures.

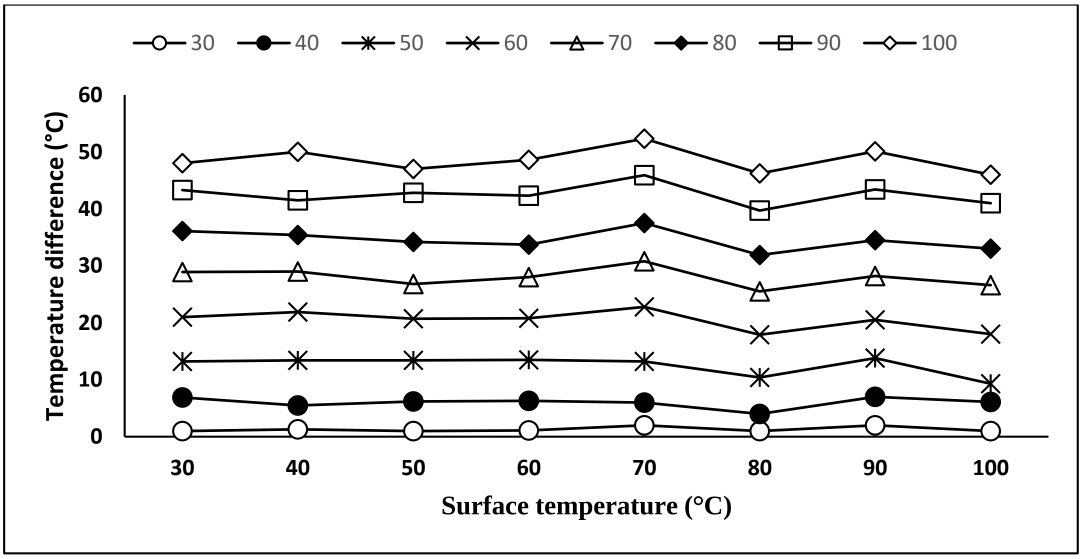

Figure 9. The temperature difference in a shift of vehicle speeds.

As a result of practical experience according to the difference in temperature on two sides of thethermoelectric generator device, we deduced the energy output from the thermoelectric generator device atevery temperature difference. The electrical output observations between each temperature difference were obtained under various conditions, as demonstrated in Figure 10.

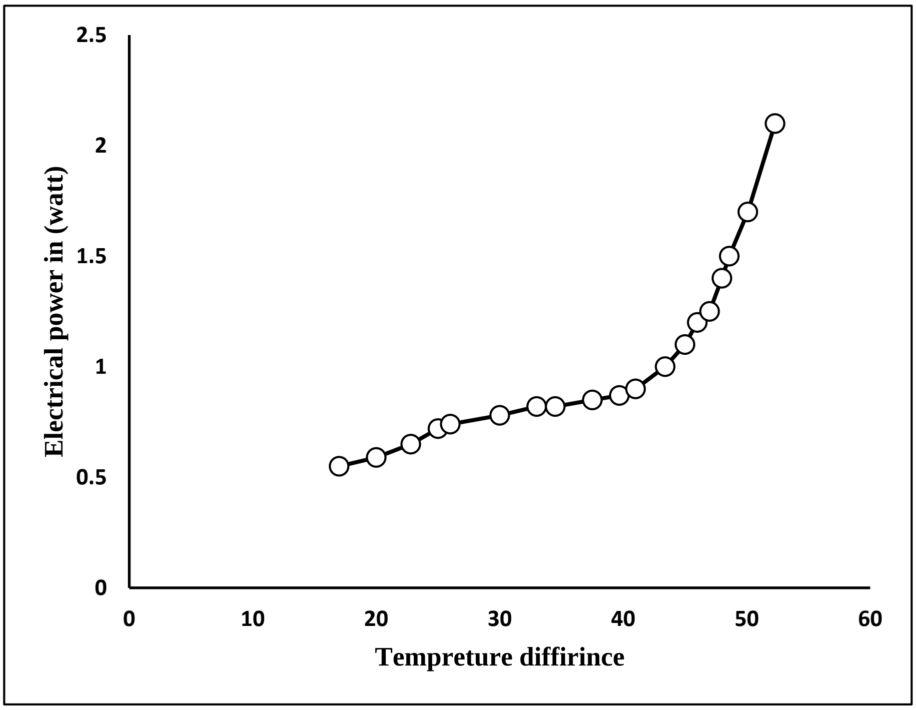

Figure 10. The electrical power output at various temperature differences.

The results reveal that for each of the thermoelectric engine units, the electrical energy in the best case is 0.38 watts, so it can be located on the exhaust pipe and used according to need and applications. From ANSYS FLUENT software, we can conclude the temperature distribution on thermoelectricgeneration geometry in the chosen condition of the sample. 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 with the shift of the car's engine load to accelerate the carat different speeds. From the result of the ANSYS FLUENT software analysis, the maximum temperature difference was 60°C. Figure 10 shows the temperature difference at the shift of speed and in various surfacetemperatures analyzed by the ANSYS FLUENT software.

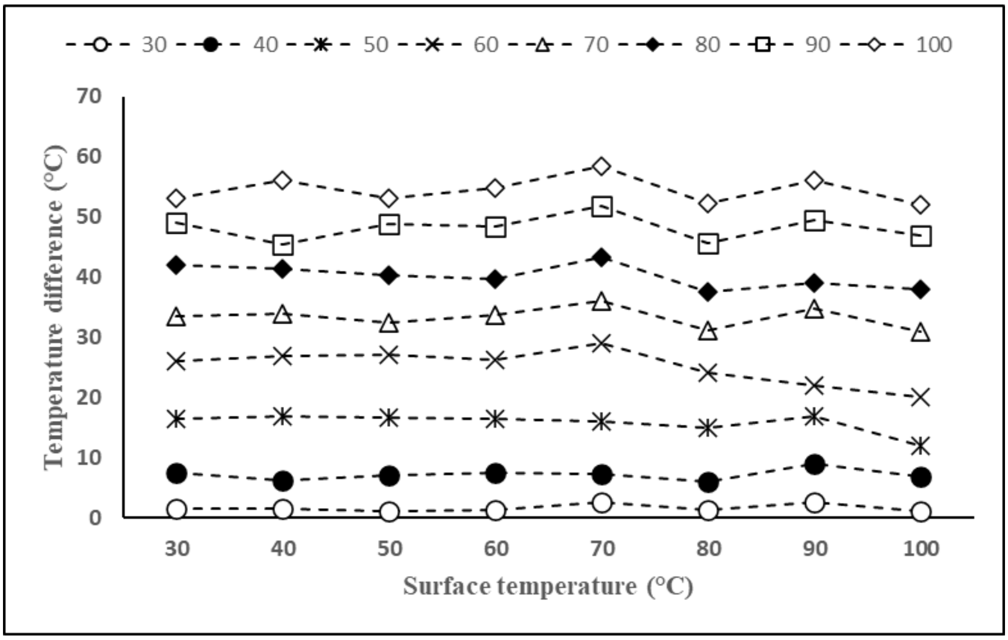

Figure 11. The temperature difference in ANSYS with a shift of vehicle speeds.

With the help of the simulation software, we were able to analyze the structure of the laboratory apparatus, analyze the temperature distribution, and deduce a temperature difference on both surfaces of the thermoelectric generator device to deduce the difference in temperature that corresponds to the temperature differences in the experimental device according to the readings of the measuring devices. The agreement between the experimental and simulation results was approximately around 94 percent, while the ANSYS FLUENT software simulation result showed a greater temperature difference.

CONCLUSION

We can install a group of the thermoelectric generator device and connect them in series along the exhaust pipe since the length of the exhaust pipe of the selected car is 340 cm while each element extract electrical energy of 0.37 watts, generally along the exhaust pipe section we can extract 129.2 watts of electrical power in the extreme case. An increase in the speed of a vehicle can cause more gas flow through the exhaust stream, which can raise the outside surface temperature of the gas stream in contact with the one side of a thermoelectric generator; it also increases the airspeed moving on the fins to cool down the other side of the thermoelectric generation, and this leads to a rise in the temperature difference between both sides of thermoelectric generator devise, where this temperature difference is a most important factor to generate the electrical power by the thermoelectric generators. The 129.2 watts of energy produced can help to reduce the strain on the engine by activating various auto accessories or supporting the car's generator, and thus we gained from the waste heat energy in the exhaust system.

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