Waste Heat Energy Recovery from Reciprocating Engine Using Thermoelectric Generator

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Abstract. This paper is covered waste heat energy recovery at SH1900 gasoline portable electric generator by using a thermoelectric generator (TEG). Thermoelectric is universally known as a device that can directly convert heat to the electricity. Voltage and current will be generated by the thermoelectric when temperature difference existing between the two surfaces of TEG. The exhaust system of the gasoline portable engine generator was used as the waste heat source. A single TEG1-199-1.4-0.5 Thermoelectric generator with the dimension of 40mm X 40mm was placed at the exhaust surface to harvest the waste heat from engine generator surface. Four tests were conducted to see the effect of the voltage and current generated on the temperature difference between cold source and hot source of TEG. The electric current generated through the temperature difference is then can be used to power an auxiliary device or to be stored.

1. Introduction
Increasing the concern of environmental issues of emission, limited availability of primary energy resources and rising worldwide demand toward preserving energy was encourage the researcher to search for new technologies in generating electrical power. Generally, this study covered about waste heat recovery using the thermoelectric generator (TEG) from a portable electric generator exhaust system. The amount of the energy used is transferred as heat to the exhaust gases over a standard driving cycle is 40% [1] which is expelled to the atmosphere and wasted as exhaust gases. Due to TEG potential to convert heat directly to electrical power with no pollution, it can be considered as an alternative green technology device. Several experiment conducted on TEG such as the placement of thermoelectric modules on water tube walls inside a boiler can effectively recover the waste heat at coal-fired power plants [2]. Also, the waste heat recovery by thermoelectric modules in automobile engine systems is a hot issue and has been widely investigated [3]. The TEG has the nature of heat engine governed by the laws of thermodynamics and the efficiency of energy conversion is limited by Carnot efficiency [4]. The TEG has many advantages over other conventional energy harvesting technologies, including simplicity, cleanliness, small size, long life span, high energy density, and quietness. TEG is currently widely used in applications ranging from power generators in space missions, common thermocouple sensors, small energy harvesters for self-powered sensors and to automobile exhaust energy harvesting.
2. Background
This paper presents the design and analysis if waste heat recovery energy using thermoelectric generator on exhausts surface of the portable generator. In the proposed solution, we make use of the thermoelectric compartment which is compact, small, able to withstand the vibration of the exhaust system. A single TEG is clamped on the exhaust system using compartment designed.

3. Research scope
The primary scope for this project is to design and analyses the TEG performance by utilizing waste heat recovery from the exhaust system in an internal combustion engine (ICE) which the engine that is used in this study was a portable generator. To achieve the scope, 4 tests carried out to determine the performance of TEG and the portable generator.
The temperature on aluminum heat sink and exhaust surface is determined using EXTECH VIR50 Infrared Thermometer. Voltage and current generated are determined by using a simple multimeter.

4. Working principle of TEG
Thermoelectric is universally known as a device that can directly convert heat to electricity. When there is temperature difference existing between the two surfaces of this device, voltage will be generated by the thermoelectric module. Conversely, the temperature difference is created when the voltage is transfer to it. The existing temperature different cause the charge carriers moving from the hot side to the cold side. This existing temperature gradient can be utilized to generate electricity. Due to the direction of the heating or cooling is regulated by the polarity of the voltage thermoelectric module can operate as a temperature controller device. Thermoelectric effect is referred to the three effects which are Seebeck effect, Peltier effect and Thomson effect. This classification was derived by Baltic German physicist Thomas Johann Seebeck and French physicist Jean Charles Athanase Peltier. Whenever an electric current passing through the resistive material Joule heating will generate, however, it is not same as the thermoelectric effect. The Thomson effects and Peltier–Seebeck are thermodynamically reversible, whereas Joule heating is not.

5. Prepare and assemble the Thermoelectric building block

![Sub part of the TEG module assembly](image)
Thermoelectric building block is built using 68mm × 76mm CPU heat sink, Heat Sink Compound ZP - 360 and TEGs 10 watt 5.6 volt with 44*40mm Thermoelectric Power Generation Peltier Module, as shown in Figure 1 and Figure 2. The temperature of the exhaust surface is measured around 180°C and the maximum temperature that able to stand by these TEGs is not provided by the seller. Commercial TEGs module usually able to operate below 220°C. Even though the exhaust surface temperature is low, but as a precaution aluminum plate is added to reduce contact temperature while preserving the TEGs from malfunction. The 68mm × 76mm aluminum plate is used as the heat conduction plate and clamped between TEGs and exhaust surface. The TEGs is clamped between the aluminum plate (hot surface) and heat sink (cold surface). 24-fins aluminum is used as a heat exchanger for this experiment and is mounted onto the compartment.

Figure 3 shows the final compartment that used in experiments. Special compartment needs to be designed to hold the TEG module tightly at the surface of the exhaust silencer. The surface of the silencer is larger than the TEG module and the main problem to place and hold the TEG is the exhaust surface vibration. The best design of jig can hold the TEG module without of any gap existing between the surface and the aluminum plate surface during the generator engine is running. In order to improve the heat conduction and heat removal from the aluminium heat sink a 3 mm inner diameter copper tube is installed onto the compartment. The copper tube is bent and fixed on the aluminum sink to ensure the copper tube has the maximum coverage on the heat sink in order to remove and conduct heat away in a faster rate. The copper tube consists inlets which allow coolant to flow in and outlets which allow the coolant to flow out. A mini aquarium pump is connected to the inlet with aquarium tube to push the coolant to pass through the copper tube.
6. Complete experiment setup

Figure 4 Complete experiment setup

Figure 4 shows the complete setup for experiments. The final compartment is mounted on the exhaust system. The complete setup consist of a generator, experiment compartment, multimeter, water pump and infrared thermometer. Each of the experiment instrument will be explained in the following section.

6.1. Portable generator
SH1900 gasoline portable generator is used to carry out the experiments. Rated output of 1.0kW, rated voltage output of 230V and rated frequency of 50Hz.

6.2. Booster converter
The main function of a booster converter is to step up the voltage from input to output. The input voltage is 0.9V-5V DC, the output voltage is 5V and the output current is 450mA to 500mA.

6.3. Mini water pump
The main function of mini water pump is to pump coolant such as water and ice water into the copper tube that mounted on the aluminum heat sink. Type of mini water pump used is submersible, power rated of 8W and maximum flow rate of water is 600L/H.

7. Type of experiment

7.1. Control test
A control experiment is set up to test the hypothesis by looking for changes bought by alterations to a variable. The experiment is conducted with no coolant flow through the copper tube mounted on the aluminum heat sink and as a datum for wind test, water test and ice water test. The experiment is conducted to study the effect of natural convection on the temperature difference between the aluminum heat sink and exhaust surface. TEG and booster converter is connected to multimeter respectively to record the voltage and current generated. An infrared thermometer is used to measure the temperature on the aluminum heat sink and exhaust surface. Duration for the experiment is 30 minutes. Data is collected and recorded every minute. The data is then tabulated into graph for further analysis.
7.2. Wind test
Wind test is conducted by using a standing fan to generate air blow and air movement toward the aluminum heat sink. A standing fan is put at a distance of 1.5m away from the generator. This experiment is conducted with no coolant flow through the copper tube that mounted on the aluminum heat sink. The experiment is conducted to determine the effect of forced convection on the temperature difference between the aluminum sink and exhaust surface. TEG and booster converter is connected to multimeter respectively to record the voltage and current generated. The infrared thermometer is used to measure the temperature on the aluminum heat sink and exhaust surface. Duration for the experiment is 30 minutes. Data is collected and recorded every minute. The data is then tabulated into graph for further analysis.

7.3. Water test
The water test is conducted by using water as coolant the water coolant is pump into 4 mm outer diameter and 3 mm inner diameter copper tube that mounted on the aluminum heat sink using a 8 W mini water pump. 25 liter of 30oC water is pumped and circulate inside the copper tube throughout the experiment. The experiment is carried out to determine the effect of water cooling on the temperature difference between the aluminum heat sink and exhaust surface. TEG and booster converter is connected to multimeter respectively to record the voltage and current generated. An infrared thermometer is used to measure the temperature on the aluminum heat sink and exhaust surface. Duration for the experiment is 30 minutes. Data is collected and recorded every minute. The data is then tabulated into graph for further analysis.

7.4. Ice test
Ice test is conducted by using a mixture of ice water as a coolant. The ice water coolant is pump into 4 mm outer diameter and 3 mm inner diameter copper tube that mounted on the aluminum sink using a 8 W mini water pump. A mixture of 7oC ice water is pumped and circulate inside the copper tube throughout the experiment. The experiment is carried out to determine the effect of ice water cooling on the temperature difference between the aluminum heat sink and exhaust surface. TEG and booster converter is connected to multimeter respectively to record the voltage and current generated. An infrared thermometer is used to measure the temperature on the aluminum heat sink and exhaust surface. Duration for the experiment is 30 minutes. Data is collected and recorded every minute. The data is then tabulated into graph for further analysis.

8. Calculation for power generated
Electrical power production can be determined by using the equation below

\[ P = IV \]

Where,
I – Current generated in Ampere
V- Voltage generated in Volts
P- Power generated in watt

9. Result and discussion
4 test was carried out which was control test, wind test, water test and ice test. The result and data collected are then tabulated into graph and bar chart for further analysis.
Figure 5 show graph of temperature difference between exhaust surface and aluminum heat sink of tests against time. The maximum temperature for exhaust surface achieved is around 180°C. Ice test has the highest ΔT compare to control test, wind test and water test due to 7°C of ice water mixture is run as coolant on the aluminum heat sink. The mixture of ice water is able to maintain the temperature of aluminum heat sink due to the heat absorbed is used to melt the ice. 25 liter of 30°C water is used in water test experiment as coolant on aluminum heat sink. The trend for ΔT value of water test is slightly decreased after 15 minutes due to the heat is absorbed and increase the temperature of the coolant. Therefore, the temperature on aluminum heat sink is increase and temperature different between aluminum heat sink and exhaust surface, ΔT is decreased. The overall trend for wind test is slightly higher than the control test. The fluctuation is caused by the air flow produced by standing fan blow toward aluminum heat sink and also exhaust surface. Control test has the lowest overall trend for ΔT value compare to wind test, water test and ice test. The fluctuation is caused by the irregular heat radiation from the aluminum heat sink which only guided by natural convection from the surrounding.

Figure 6 shown the graph of voltage generated for control test, wind test, water test and ice test against time. The yellow line indicated the voltage generated for ice test, the grey line indicated the voltage generated for water test, the orange line indicated the voltage generated for wind test and the blue line indicated the voltage generated for control test. The highest trend for voltage generated is ice test compare to water test, wind test and control test due to ice test have the greatest ΔT trend caused ice
water mixture as a coolant. The maximum voltage generated for ice test is around 1.92V and remain stable according to ΔT. The second highest trend for voltage generated is water test due to it has the second highest ΔT trend. The maximum voltage generated for water test is 1.35V and decreasing slowly as the trend for ΔT decrease. The control test has the lowest voltage generated trend compare to wind test, water test and ice test. The maximum voltage generated is 0.98V and decreasing as the ΔT for control test decreasing.

![Current generated of tests against time](image)

**Figure 7 Graph of current generated of tests against time**

Figure 7 shown the graph of current generated for control test, wind test, water test and ice test against time. The yellow line indicated the current generated for ice test, grey line indicated the current generated for water test, orange line indicated the current generated for wind test and blue line indicated the current generated for control test. The highest trend for current generated is ice test compare to water test, wind test and control test due to ice test has the greatest ΔT trend caused ice water mixture as coolant. The maximum current generated for ice test is around 0.32A and remain stable according to ΔT. The second highest trend for current generated is water test due to it has the second highest ΔT trend. The maximum current generated for water test is 0.22A and decreasing slowly as the trend for ΔT decrease. The control test has the lowest current generated trend compare to wind test, water test and ice test. The maximum current generated is 0.14A and decreasing as the ΔT for control test decreasing.

![Power generated of tests against time](image)

**Figure 8 Graph of power generated of test against time**
Figure 8 shown the graph of power generated for control test, wind test, water test and ice test against time. The yellow line indicated the power generated for ice test, grey line indicated the power generated for water test, orange line indicated the power generated for wind test and blue line indicated the power generated for control test. The highest trend for power generated is ice test compare to water test, wind test and control test due to ice test has the greatest $\Delta T$ trend caused ice water mixture can maintain low temperature on aluminium heat sink. The maximum power generated for ice test is around 0.62W and remain stable according to $\Delta T$. The second highest trend for power generated is water test due to it has the second highest $\Delta T$ trend. The maximum power generated for water test is 0.3W and decreasing slowly as the trend for $\Delta T$ decrease. Wind test has maximum power generated of 0.16W. The control test has the lowest power generated trend compare to wind test, water test and ice test. The maximum voltage generated is 0.13W and decreasing as the $\Delta T$ for control test decreasing.

![Maximum voltage, current and power generated](image)

**Figure 9** Bar chart for maximum voltage, current and power generated for 4 type of test

Figure 9 shown the bar chart for maximum voltage, current and power generated for control test, wind test, water test and ice test. The blue bar indicated voltage, orange bar indicated current and grey bar indicated power. For control test, the maximum voltage generated is 0.98V, maximum current generated is 0.14A and maximum power generated is 0.13W. The control test has the lowest value for maximum voltage, current and power generated amongst these 4 type of experiment due to it has the lowest temperature difference between exhaust surface and aluminum heat sink. For wind test, the maximum voltage generated is 1.05V, maximum current generated is 0.15A and maximum wind test is slightly higher than control test due to forced convection stimulate by standing fan in wind test conduct the heat from aluminium heat sink to surrounding and maintain a greater temperature different between exhaust surface and aluminium heat sink for wind test. For water test, the maximum voltage is 1.35V, maximum current generated is 0.22A and maximum power generated is 0.3W. The value for maximum voltage, current and power generated for water test is higher than control test and wind test due to coolant of water has higher and better heat conductivity. The ice test has the highest value for maximum voltage, current and power generated which is 1.92V, 0.32A and 0.61W. The highest maximum value is achieved by ice test due to ice water can maintain the temperature of aluminium heat sink for lowest (10°C) amongst 3 other test and achieved greatest temperature different between exhaust surface and aluminium heat sink.
Figure 10 Bar chart for maximum voltage, current and power generated using DC booster

Figure 10 shown the bar chart for maximum voltage, current and power generated using DC booster. Due to the voltage, current and power generated are low for any application utilization, a 1V input and 5V output DC booster is used to step up and boost up voltage, current and power for each experiment. For control test, the voltage generated is below 1V (0.98V) thus the dc booster is unable to boost up the voltage, current and power. For wind test, water test and ice test voltage generated is greater than 1V thus the dc booster is able to boost up the voltage, current and power. The maximum voltage, current and power boost up by using dc booster is 5V, 0.45A and 2.25W.

10. Conclusion
In this project, we have been successfully developed waste heat recovery power generator by using the thermoelectric building block. Waste heat from the exhaust surface of the portable generator has been utilized to convert to electrical power by using the single thermoelectric generator module. The amounts of waste heat carried out from the exhaust surface of the generator toward the environment were analyzed through the experiment that was conducted. Four experiments that were conducted showed the positive effect of the temperature gradient toward the voltage harvesting from the waste heat. The ice test has the highest voltage, current and power generated without using booster converter is 1.92V, 0.32A and 0.61W. The maximum voltage, current and power generated by using booster converter is 5V, 0.45A and 2.25 for wind test, water test and ice test. Even though the amount of voltage harvested directly from the exhaust surface of temperature is too small, but this voltage has been stepped up using a commercial booster converter. Sufficient amount of voltage is achieved and able to directly powered any auxiliary device or it can be stored in the battery. The whole objective of the project to utilize waste heat using the thermoelectric is achieved.

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