Thermoelectric as recovery and harvesting of waste heat from portable generator

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Abstract. Generation of waste heat was ineluctable especially during energy producing process. Waste heat falls into low temperature grade make it complicated to utilize. Thermoelectric generator (TEG) offers opportunity to harvest any temperature grade heat into useful electricity. This project is covered about recovery and utilizing waste heat from portable electric generator by using a TEG which placed at exhaust surface. Temperature difference at both surfaces of TEG was enhanced with supplying cold air from a wind blower. It is found that, even at low air speed, the TEG was successfully produced electricity with aid from DC-DC booster. Results shows possibility to harvest low temperature grade heat and still exist areas for continual improvement.

1. Introduction

Power production devices, regardless of conventional or renewable always face heat loss problems, which decrease the energy efficiency. The heat loss also includes of heat energy that is rejected to the environment with lower temperature, also known as waste heat. Recently, instead of dumping waste heat into the environment, many efforts being done to reuse the lower grade energy into useful energy [1],[2]. Internal combustion engine (ICE) as a power produce device also produce waste heat as by-products, and the fact is the contribution of waste heat from ICE are not negligible. Severe environment pollution, entropy rise and greenhouse effect are conveyed when almost 60 – 70% of energy from internal combustion is released as waste heat. Organic Rankine Cycle (ORC) and Thermo-Electric Generator (TEG) are therefore the examples of a system that is applied to vehicles to increase the power efficiency[3]. Due to TEGs potential to convert heat directly to electrical energy, thermoelectric is the amongst of technology that promising alternative green technology device. In this paper, authors will deal with the potential of converting waste heat from small ICE engine to generate useful energy. Broadly implementation of this alternative green technology will extensively save a large amount of heat energy to useful electrical power and increase the utilization of energy conversion system and reduce the fuel consumption by 6% depending on the waste heat recovery technology [4].
Heat energy trapped at the exhaust of portable generators was used to simulate waste heat, since the portable engine operates at steady condition with longer running time. The main purpose of this project is to study the feasibility of converting waste heat carried out from the small ICE into useful energy. Although it is reported that at the current state, the conversion efficiency is low, this energy recovery from waste heat has a promising future potential as it is low cost and emission free technology.

2. **Working Principle of Thermoelectric Generator (TEG)**

Thermoelectric generator which also known as a Seebeck generator is a device that can directly convert heat to the electricity. It works when there is temperature difference existing between the two opposite surfaces of TEG, electrons will move from hot side to the cold side and produce electricity. The higher the temperature difference, the higher electricity can be produced. Conversely, the temperature difference (hot and cold at opposite surface) is created when the voltage is transfer to TEG.

3. **Applying TEG to small internal combustion engine (ICE)**

Recently Malaysia government encourage industry level until consumer level to explore green technology. Nevertheless, at the current state, the dependency on small ICE as a power source still shows high demand, for e.g. small engine (below 100cc) motorcycle, portable electric generator, water pump for agriculture, etc. The usage of these small cc engine however have fewer thermal efficiency, therefore, a lot of heat energy being dumped as waste heat.

Such small ICE engine wastes lower temperature of heat, especially through the engine block and exhaust pipe. Lower temperature of heat energy unfortunately carries lower grade energy. As previously mentioned, the larger temperature difference, the higher efficiency of TEG. However, dealing with small ICE means the temperature difference between waste heat and environment temperature is not relatively high compared with temperature differences of TEG that applied in the industry. This paper tends to convert even lower grade waste heat into useful energy in term of electricity.

A portable electric generator that used 4-stroke gasoline engine was used as the waste energy source due to this type of ICE is often used especially at morning market or night market in Malaysia. The TEG module was attached to the exhaust pipe of the generator to extract direct waste heat from the engine. An external fan was used to supply cold wind to the other side of TEG to enhance greater temperature differently.

The modeling of thermoelectric is based on building block. The complete thermoelectric building block can be divided into three major parts which are a thermoelectric material as a medium of electric current flow, an aluminum plate to absorb waste heat from exhaust plate, a heat sink to increase cooling effect from external wind. The thermoelectric building block is build using 66mm × 76mm heat sink, heat sink Compound ZP - 360 and a 10 watt 5.6 volt with 44mm × 40mm thermoelectric power generation Peltier module, as shown in figure 1.

Preliminary experiment result shows that temperature of the exhaust surface was around 150°C and commercial TEGs module usually able to operate below 220°C. Even though the exhaust surface temperature was in the range operation of TEG, as a precaution step an aluminum plate is added to reduce direct contact temperature while preserving the TEGs from malfunction [5]. The 66mm × 76mm aluminum plate was sandwiched between TEG module and exhaust pipe surface. The TEG was inserted between the aluminum plate (hot surface) and heat sink (cold surface). To increase the efficiency of heat transfer, heat sink compound was applied between every contact surface.
4. Jig design
Due to simplified design, almost small ICE face higher vibration problems at the whole body when it operates, which leads to difficulties to ensure the TEG module always intact to the exhaust pipe even though the contact surface area is larger enough. Consequently, a custom TEG module mounting was designed to hold TEG building block tightly on the exhaust contact surface in this module. The jig was design so that able to hold the TEG module without existing of any gap between the TEG hot surface and the aluminum plate surface. The jig was fabricated using 0.25 inch steel plate which joined by welding process.

Figure 1. (Left) Actual part and (Right) sub part of the TEG module assembly and thermoelectric building block

Figure 2. (Top) Actual jig, (Bottom) Jig design that used in the experiment
5. Experimental setup – Effect of wind towards TEG

Effect on temperature difference to the harvested energy was investigated in this section. It is important to face the wind direction toward the heat sink fin of the thermoelectric module. Figure 3 shows experiment setup which consists of a portable engine, a small wind tunnel and a wind blower. Multimeters was placed near the engine. The wind tunnel is fabricated using the Galvanic plate which have 508 mm long and has a 635 mm in diameter. The wind tunnel is designed to wrap around the heat sink fins to ensure cooled air supplied from air blower reached the heat sink. The air blower that has three variable control speeds was used as a wind source with ambient temperature. The speed of air was measured using digital anemometer (MASTECH MS6252B). It is found that the air velocity range of wind that breeze the cold area of the heat sink is around 4.44 m/s to 4.69 m/s. For each experiment, the engine was run steadily and data was collected within 15 min. The surface heat temperature data was collected using an infrared thermometer (EXTECH VIR50) and the data of the voltage generated by TEGs and booster was recorded using digital multimeters. For each air velocity, the experiment was repeated three times and data presented in this paper were the average value from collected data. After one experiment had completed, the portable engine will be shut down to allow the temperature of exhaust surface cooled to ambient temperature.

Figure 3. Experiment setup for the effect of wind test

6. Result and Discussion

6.1 Exhaust Surface Temperature

The waste heat source in this study was origin from exhaust surface and for experiment purpose, exhaust surface temperature were set to be as the hot temperature ($T_h$). Exhaust temperature increases up to 153°C after 570 seconds. As mentioned earlier, the aluminum plate was placed in between exhaust surface and TEG module, therefore it was expected that the highest temperature for the aluminum surface is only at 75°C. This step was necessary to avoid over heat temperature that will cause permanent damage to TEG module. Therefore, for the temperature difference $\Delta T$, temperature of the aluminum plate will be used instead of the temperature of exhaust surface.

6.2 Effect of wind speed to the temperature different.

The air velocity was varied from 4.44 m/s to 4.69 m/s. This air was directed to cooling fin which attaches at cold side ($T_c$) of TEG module. Temperature ambient however not considered in this study. Figure 4 shows the development of surface temperature at the hot side of TEG module. At early of engine running, temperature of aluminium plate was increase at a different rate for each air speed, and reach maximum temperature between 500 s to 600 s. After that period, the temperature at aluminum plate was observed to be maintained throughout the experiment. From the Figure 4, effect of air speed were significant from air speed 1 and air speed 3. It was confirmed that although the difference of air speed 1 and air speed 3 was only about 0.25 m/s, however, the effect of the temperature successfully showed difference of maximum temperature about 20°C. Overall, even with air speed 1, the temperature different between $T_h$ and $T_c$ was successfully increase which will affect the increment of
electricity generated by TEG module. This experiment also shows same behaviour with experiment conducted by Alexander et al [6], which applying TEG on exhaust surface of a motorcycle.

![Figure 4](image1.png)

**Figure 4.** Effect of air velocity to the development of average surface temperature of aluminium plate

Figure 5 shows voltage, current and power that were harvested from experiment based on temperature differences between $T_h$ and $T_c$. It is obvious that harvested voltage, current and power from TEG module was minimal, therefore it need to boost up in order to get better electrical supply. A DC-DC converter was applied as a booster, and Figure 6 shows the voltage, current and power that being boost up. After the temperature difference increase more than 80°C, the DC-DC converter was able to boost up voltage to the maximum value, 5V. As for this study, it needs three minutes from engine start to achieve temperature different to be 60°C. The current and power generated for both TEG and booster is calculated using resistance value of 3.07 ohm. It was found that the maximum voltage, current and power generated by TEG is 1.19V, 0.39 amp and 0.46 watt, respectively. For the booster the maximum electric harvest is 5.01V, 1.63 amp and 8.18 watt, respectively.

![Figure 5](image2.png)

**Figure 5.** Voltage, current and power harvested from TEG module
Figure 6: Voltage, current and power output being boost up by a DC-DC converter

7. Conclusion
In this study, we have been successfully developed waste heat recovery power generator by using thermoelectric building block. Waste heat from the exhaust surface of the portable generator had been utilized and recovered and converted to electrical power by using the single thermoelectric generator (TEG) module. Objectives of this study achieved by looking at the highest voltage that harvest by TEGs was 1.19V, the maximum electric current is 0.39 amps and the maximum power output is 0.46 watt. Maximum voltage after boost up by a DC-DC converter was 5V, maximum current was 1.63 amp and maximum power output is 8.18 watt. An aluminum plate was placed between exhaust surface and TEG module which may contribute to the results of lower harvesting current. In next study, TEG may be applied directly to exhaust surface to increase temperature differently and increase possibility of harvesting waste heat. Vibration from small engine makes us difficult to keep TEG stay intact with exhaust surface, therefore need to be taken care in the next study. For future project, fuzzy logic was proposed to enhance DC-Dc converter as presented in paper [7].

8. References
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