The performance of thermoelectric exhaust heat recovery system considering different heat source’s fin arrangements

Sarwo Edhy Sofyan 1*, Muhajir, Khairil, Jalaluddin, Samsul Bahri

Department of Mechanical and Industrial Engineering, Syiah Kuala University
Jl. Tgk. Syech Abdurrauf No. 7 Darussalam – Banda Aceh 23111, Indonesia

E-mail: sarwo.edhy@unsyiah.ac.id

Abstract. The IC engine converts the chemical energy of the fuels into the mechanic energy with the efficiency is around 35-40% depends on the type and operation condition of the engines. It means around 60-65% of the energy is wasted mostly in the form of heat (dissipated through the cooling process and exhaust gas) and friction. A thermoelectric exhaust heat recovery system can be used to harvest the waste heat which potentially could increase the efficiency of the IC engine indirectly. In this experimental study, the heat recovery system consists of a rectangular duct in which sixteen thermoelectric modules are attached to its sides (each side consist of four thermoelectric modules). The aluminium fins are mounted at the cold sides of thermoelectric modules (at the outer sides of the rectangular duct) and cooled by air supplied by computer fan coolers. To harvest the exhaust heat of the IC engine, the heat recovery system is connected to the exhaust pipe. The effect of aluminium fin arrangements, mounted on the inner surfaces of the rectangular duct of the heat recovery device, is investigated. The arrangements include mounting of the fins at the lateral sides, top and down sides, and the whole sides of the heat recovery device. Besides, the effect of the absence of the fins at the exhaust gas passage of the heat recovery device is examined. The performance of the heat recovery system is studied when the engine operates under the no-load condition at rotational speeds of 1300, 1600, 1900 and 2200 RPM. The experimental result reveals that the voltage and current generated by the thermoelectric exhaust gas recovery system increase in line with the increase of engine speed. In addition, it is found that the highest voltage and current are generated by the whole side fin arrangement, namely 12.52V and 122 mA respectively, at an engine speed of 2200 RPM. It is observed that the finless arrangement generates the lowest voltage and current among others, namely 5.36 V and 20.43 mA.

1. Introduction

Energy is an essential aspect needed by the human being for conducting the activities. It is undeniable that the current source of energy still relies on fossil fuel, in which its reserves deplete over time. Therefore, a more energy-efficient system is required to be developed to reduce fuel consumption and benefit economically.

One of the biggest energy consumptions is IC engines. IC engines are widely used as prime movers for transportation, pumps, compressors and other mechanical equipment. Currently, the efficiency of the IC engines is still relatively low. It is only 35-40% used as the useful energy [1], while the rest is...
wasted in the form of friction and dissipated through the cooling and exhaust gas. Therefore, a heat recovery system can be introduced to improve their efficiency.

A thermoelectric exhaust heat recovery system has been used by a number of researchers to increase the efficiency of the IC engines indirectly [2-5]. However, its performance under different heat source’s fin arrangements has yet to be discussed. This study aims to investigate the effect of the heat source’s fin arrangements on the performance of the thermoelectric exhaust heat recovery system. The performance of the recovery system is investigated at four different engine speed namely 1300, 1600, 1900, and 2200 RPM.

2. Experimental setup
The thermoelectric exhaust heat recovery system is made up of the following components:

a. Thermoelectric generator
There are sixteen thermoelectric generators are mounted around the outer sides of the rectangular exhaust gas channel. In which each side consists of four thermoelectric generators. Table 1 shows the specification of the thermoelectric generator.

| Characteristics         | Details              |
|-------------------------|----------------------|
| Model                   | SP1848-27145         |
| Maximum temperature     | -60 – 125 °C         |
| Maximum power           | 2.5 ~ 3 x 10⁻³ W/°C  |
| Lead length             | 30 cm                |
| Dimensions              | 4 cm x 4 cm x 0.34 cm|

b. Aluminium Fins
Aluminium fins are attached to both sides of the thermoelectric generator to increase the heat transfer area. At the heat source, the fins are attached to the hot side of the thermoelectric generators to enhance the heat transfer rate between exhaust gas and thermoelectric generators. As a result, more heat can be extracted and converted to electricity. Fins are also attached on the cold sides of the thermoelectric generators in order to enhance the heat dissipation. Each fin has a dimension of 7 cm wide, 7 cm long, and 2 cm high. Figure 1 shows the schematic of the fins.

Figure 1. The schematic of fins

c. Rectangular Duct
A rectangular duct serves as the exhaust gas channel where the thermoelectric generators and fins are mounted. Figure 2 illustrates the schematic of the rectangular duct.

![Figure 2. The schematic of the rectangular duct](image)

d. Fans
Fans are mounted on the cold side fins and used to speed up cooling or dissipate more heat to the atmosphere. Figure 3 shows the photograph of the thermoelectric exhaust heat recovery system used in the experiment.

![Figure 3. The photograph of the thermoelectric exhaust heat recovery system](image)
e. Diesel Engine

A diesel engine was used to supply the exhaust gas to the recovery system. The specification of the diesel engine is presented in Table 2.

| Characteristics    | Details                                      |
|--------------------|----------------------------------------------|
| Model              | TF 65 R-di                                   |
| Type               | Horizontal, air cooling engine diesel, 4-stroke cooling system |
| Rated output       | 5.5 PK/2200 R.P.M                            |
| Max output         | 6.5 PK/2200 R.P.M                            |
| Ignition system    | Direct Injection                             |
| No. of cylinder    | 1 Cylinder                                   |
| Bore x Stroke      | 78 x 80 mm                                   |
| Volume             | 382 cc                                       |
| Cooling system     | Radiator                                     |
| Starting system    | Manual                                       |
| Air filter system  | Air filter dry element                       |
| Dimension (L x W x H) | 608 x 312 x 469 mm                       |
| Weight             | 103 kg                                       |

In this study, the performance of the thermoelectric exhaust gas recovery system considering different heat source’s fin arrangements is investigated. The arrangements include mounting of the fins at the lateral sides, top and down sides, and the whole sides of the heat recovery device. Besides, the effect of the absence of the fins at the exhaust gas passage of the heat recovery device is examined. The performance of the heat recovery system is studied when the engine operates under the no-load condition at rotational speeds of 1300, 1600, 1900, dan 2200 RPM. There are four measuring devices are used in this experiment. A stopwatch is used to measure the duration of the experiment. In which, each experiment was conducted for ten minutes. Thermocouples were also used to measure the exhaust gas temperature at both the inlet and the outlet of the exhaust gas recovery system. In addition, a multi-meter measurement device was used to measure the voltage and current generated by the thermoelectric generators. A tachometer was also utilized to measure the engine speed.

3. Result and Discussion

Figure 4 illustrated the effect of the heat source’s fin arrangements on the voltage generated by the thermoelectric exhaust gas recovery system at four different engine speeds. It is observed that the voltage increases in line with the increasing of the engine speed. It is found the lowest voltage is yielded by the finless arrangement. Adding the fins on the lateral or top and down sides of the exhaust gas passage have significantly increased the voltage by 39-40 %. From the figure, it can be seen that the voltage generated by these arrangements is almost identical. The exception is only at the lowest engine speed (1300 RPM), in which the voltage generated by the top and down fin arrangements is 27 % less than that yielded by the lateral side arrangement. This tendency could be affected by the non-homogenous flow pattern of the exhaust gas inside the passage at relatively lower engine speed. However, further study requires to be conducted to verify the aforementioned presumption. As illustrated in the figure that the highest voltage is generated by the whole side fin arrangement. From the experimental results, it can be seen that increasing the heat transfer area by introducing the fins on the inner sides of the
exhaust gas passage has significantly improved the performance of the thermoelectric heat recovery system.

Figure 4. The effect of fin arrangements on the generated voltage at four different engine speed

Figure 5 presents the effect of heat source fin’s arrangements on the electric current generated by the recovery system. It can be seen that the highest current is yielded by the system with the whole side fin arrangement. In addition, it is found that mounting fins at the lateral side of the exhaust gas passage of the heat recovery device allows better performance of the recovery system than that generated by the top and down fin arrangement even though not significant. It is observed that the lowest current is generated by the system with the finless arrangement. It is observed that the engine speed also significantly affects the electric current generated by the exhaust heat recovery device. This tendency is due to the heat contained in the flue gas increases in line with the engine speed. The higher the engine speed is, the higher of a mass flow rate of the exhaust gas produced. As illustrated in the figure that the current generated by the finless recovery system insignificantly increases over the engine speed. This phenomenon can be induced by the absence of the fin at the exhaust gas passage contributing to the heat transfer rate occurred at the recovery device. At the lowest engine speed (1300 RPM), it is noticed that the recovery system with a lateral side fin arrangement generated a slightly higher electric current. The current increases in line with the increasing of the engine speed. A nearly same pattern is illustrated by the electric current generated by the top and down side fin arrangement. However, this arrangement generates 15-57% relatively lower current compared to that generated by the system with the lateral side fin arrangement.
Figure 5: The effect of fin arrangements on the generated current at four different engine speed

4. Conclusions
The present results found that heat source’s fin arrangements significantly affect the performance of the thermoelectric exhaust heat recovery system. Besides, it is found that the voltage and the current generated by the recovery system increase in line with the increasing of the engine speed. It is obtained that the best performance of the recovery system is yielded by whole side fin arrangements. At the maximum engine speed, it is found that voltage and current are 12.53V and 122 mA, respectively. While the finless arrangement generates the lowest voltage and current among others, namely 5.36 V and 20.43 mA, respectively.

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