Abstract: - Internal combustion engines rejects 30-40% of the energy supplied by fuel to the environment through exhaust gas. Thus, there is a possibility for further significant improvement of efficiency with the utilization of exhaust gas energy and its conversion to mechanical energy or electrical energy. The Thermoelectric Generator (TEG) will be located in the exhaust system and will make use of an energy flow between the warmer exhaust gas and the external environment. Predict to the optimum position of temperature distribution and the performance of TEG through numerical analysis. The experimental results obtained show that the power output significantly increases with the temperature difference between cold and hot sides of thermoelectric generator.

Key-Words: - Thermoelectric generator, Numerical analysis, Seebeck coefficient, Figure of merit

1 Introduction
The worldwide trend intends to tighten even vehicle fuel consumption with regulations to reduce CO2 gas which is a main factor of global warming. In case of internal combustion engines, only 30-40% of fuel energy can be converted into useable power and the others are wasted as cooling loss from coolant and exhaust gas. Therefore vehicle engine efficiency could be improved with minimizing the loss of coolant and exhaust gas. In present day, technologies to use the wasted energies of the vehicle have been attracting.¹

Hi-Z Technology Inc. developed an 1kW-thermoelectric generation system using a wasted thermal energy of a heavy duty diesel engine instead of using mechanical electric generator and as a result, they finally improved fuel consumption.²

Douglas et al. studied a combination technology of a generator and TEG using a passenger car.³ Richard drew a result of increasing in 6% of fuel consumption with numerical analysis using a thermo-electric regenerator of a passenger car.³

Thermoelectric generator to improve fuel economy is an energy converting device which can directly convert thermal energy into electric energy and so it could be one of the environmental friendly technologies generating electric power without using any other extra energy source and mechanical equipment.

The principle of thermoelectric generating is an electric flow from heat absorption and generation phenomena of thermoelectric module using Seebeck effect which electromotive force is occurred by temperature difference between both ends of two different thermoelectric devices.

In this study, we could expect the efficiency of thermoelectric generator using a simulation modeling before taking an experiment with real thermoelectric generator.

2 Numerical analysis and method

2.1 Modeling of numerical analysis
In this study, WAVE simulation modeling of Ricardo was used to expect the performance of the thermoelectric generator with 2 liter common rail type diesel engine shown in Figure 1. The engine bore and stroke were set as 83mm and 92mm, the compression ratio was set as 18.4 appeared in Table 1. The temperature of the air-fuel mixture was set as 350K. The injector nozzle size and spray angle were 0.1mm and 40°.
The performance equations of thermoelectric generating appear as following equations. 5)–7) The Seebeck coefficient \( (\alpha) \) and electric resistance \( (R) \) could be calculated experimentally from equations(1). 8) The Seebeck coefficient was calculated with the temperature difference between both ends of thermoelectric device and the voltage \( (V) \) at non-load condition \( (I=0) \). The electric resistance of the thermoelectric device module was calculated from the average value of the electric resistance appeared.

\[
P = VI = (\alpha \Delta T - IR)I \tag{1}
\]

\[
Z = \frac{\alpha^2 \theta}{R} \tag{2}
\]

\[
Q_h = \alpha T_h + \frac{\Delta T}{\theta} - \frac{1}{2} f^2 R \tag{3}
\]

### 3 Result and discussion

Figure 2 shows the variation of exhaust gas temperature according to various thermal conditions. As shown in Figure 2, Duct 777 has a little temperature variation but other conditions have big temperature variation. Therefore when the thermoelectric module was applied; it was possible to predict a high consistent temperature could be used at the duct 777. So the performance result of the thermoelectric module was anticipated using the temperature of duct 777. Accordingly, when the thermoelectric module was applied to a commercial vehicle, advantages of efficiency and performance could be expected from the duct 777 position.

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**TABLE I**

<table>
<thead>
<tr>
<th>Contents</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>2000 cc</td>
</tr>
<tr>
<td>Bore</td>
<td>83 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>92 mm</td>
</tr>
<tr>
<td>Injection duration (msec)</td>
<td>18.4</td>
</tr>
</tbody>
</table>

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**2.2 Method of numerical analysis**

We organized several test conditions to carry out a simulation modeling as follows. At first, the target engine speed was increased from 1000rpm to 4000rpm and the data was acquired every 500rpm increased while the exhaust gas temperature was varied at 4 different positions of the exhaust pipe line. The first setting position was for the pure combustion gas condition and the others were set at further positions of ducts from the exhaust port.

For the second, we drew results from the exhaust gas obtained under the estimation, which the thermoelectric module was belonging to the same chain as Bi₂Te₃, to explain the principle of thermoelectric generating, which an electric flow occur from heat absorption and generation phenomena of thermoelectric module. The temperature of the lower temperature part of the module was selected as 120 °C.
Figure 3 and 4 show the Seebeck coefficient and Electrical resistance of thermoelectric module, and Figure 5 shows the figure of merit to thermoelectric module. Seebeck coefficient was decreased according to RPM increased, thereafter the values of Seebeck coefficient were almost same over 3000 rpm. Also Electrical resistance and Figure of merit was kept similar after decreasing. Accordingly, Figure of merit with Seebeck coefficient and Electrical resistance of thermoelectric module was excellent at lower RPMs.

![Fig. 3 Seebeck coefficient of TEM](image1)

![Fig. 4 Electrical resistance of TEM](image2)

![Fig. 5 Figure of merit](image3)

Figure 6 shows the performance curve of thermoelectric generator according to the temperature difference of thermoelectric module. Output voltage was linearly decreased according to current value increased; the value of output power was decreased after increasing and also maximum power was indicated in process of output power. Because temperature of high heat source is constant, maximum value by each condition hardly has variation. In the thermoelectric generation, thermal condition of both ends temperature differential is important factor to result of generation (electric power) performance.

![Output voltage](image4)

(a) Engine speed: 1000 rpm

![Output voltage](image5)

(b) Engine speed: 1500 rpm

![Output voltage](image6)

(c) Engine speed: 2000 rpm
generator) enhance the development of material and efficiency, Thermoelectric generator (it) can be used as a part of heat recovery system.

![Fig. 6 Performance curves according to RPM](image)

(d) Engine speed: 2500 rpm

![Fig. 7 Diagram of simulation modeling](image)

Fig. 7 shows the maximum value and minimum value of voltage and power of thermoelectric generator according to conditions. As shown in the figure the difference between the maximum and the minimum value is few. Because of high temperature is steady that values of thermoelectric generator are little difference. In the thermoelectric generation, thermal condition of both ends temperature differential is important factor to result of generation (electric power) performance.

4 Conclusion
From this research, exhaust gas temperature was anticipated by simulation modeling and thus performance of thermoelectric module was understood. Constant temperature position of exhaust line was found and thus Seebeck coefficient and Electrical resistance of thermoelectric module was understood and Figure of merit for thermoelectric module was understood with electric power and voltage.

(g) Engine speed: 4000 rpm

Fig. 6 Performance curves according to RPM

Prediction result value is very difficult to (the application of) reality but if it(Thermoelectric

(c) Engine speed: 3000 rpm

(f) Engine speed: 3500 rpm

(e) Engine speed: 3000 rpm
Exhaust gas temperature was surveyed from various parts of exhaust line. From exhaust line, duct 777 was maintained low variation temperature and constant temperature. Therefore thermoelectric module will get constant performance and efficiency at duct 777.

- Figure of merit and Electrical resistance and Seebeck coefficient of thermoelectric module was kept after decrease according to RPM increase. In case of low RPM, Electrical resistance and Seebeck coefficient and figure of merit had large value.

- Output voltage was linearly decreased according to current increase and output power was decreased after increase also maximum power was indicated in process of output power. Because temperature of high heat source is constant, maximum value by each condition hardly have variation. In the thermoelectric generation, thermal condition of both ends temperature differential is important factor to result of generation(electric power) performance. therefore thermoelectric module need to material development and efficiency increase for the prediction result value apply to reality.

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References:


