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Waste Heat Power Generation Using Low Thermal Resistance Thermoelectric Generators

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To improve the overall thermal efficiency of passenger vehicles, it is important to recover and utilize waste heat. Thermoelectric generators (TEGs) have attracted attention as devices that recover waste heat from automobile exhaust gases and convert it into electric power. Numerous studies have been conducted on the properties and potential of the material. However, there are not many published papers on practical performance of TEGs as a device and a system. In this study, an exhaust gas waste heat recovery system was constructed and evaluated in a practical condition. The objective of this study is to evaluate the practical performance of TEG and assess its effective power generation efficiency from exhaust heat. We assumed a series-hybrid PHEV with a lean-burn IC. Temperature of exhaust gas at the exit of catalyst is 291°C in maximum, the mass flow rate is 42.5g/s. A phase-changed-cooling system with R1336mzz(Z) refrigerant is applied in this PHEV and the lowest temperature in the system is about 20°C. It is important to minimise heat loss to the outside and retain thermal energy within the system. Although the power generation efficiency of a single TEG device is not necessarily high, the heat that passes through the device is returned to the system rather than being discarded, so it does not result in a loss. It is the amount of heat passing through the device—rather than the temperature difference itself—that leads to higher output. Therefore, in this study, we prepared multiple thermoelectric devices made of Bi_2Te_3 based material with low thermal resistance and conducted TEG evaluation tests designed for automotive applications, whilst comparing them with commercially available Peltier devices. Based on the assumed system temperature, experiments were conducted with the high-side temperature of the thermoelectric device ranging from several tens of degrees Celsius up to the exhaust gas temperature, and the low-side temperature set at approximately 15–35 °C. First, the basic performance of the thermoelectric device alone was evaluated under heat transfer conditions that allowed a sufficient heat flux to be delivered to the device. Furthermore, an exhaust heat recovery system for automotive applications was constructed, and the power generation performance of the thermoelectric power generation system was evaluated under simulated in-vehicle conditions.

In experiments using aluminium nitride devices, a maximum power of 11.6 W was achieved when the cooling water temperature was 20 °C and the surface temperature difference of the device was 162.6 °C. Table 1 shows the results of a comparison of power output under conditions where ΔT is approximately 150°C. At all cooling water temperatures, power output increased as the temperature difference applied to the device increased. Furthermore, as the cooling water temperature increased, power output decreased even under conditions of the same temperature difference. Systems using thin-walled alumina devices achieved a greater temperature difference than other systems, resulting in higher maximum power output. For similar ΔT values, the aluminium nitride-based system achieved the highest power output.

The net power generation efficiency was calculated as the ratio of power output to heat flux which passed through the system. The net power generation efficiency obtained from the experiments is summarised in Fig. 1. The net power generation efficiency increases with a larger surface temperature difference; when the cooling water temperature was 20 °C, a maximum value of η' = 2.2% was obtained for the thin-walled alumina system at a device surface temperature difference of 193 °C, whilst when the cooling water temperature was 35 °C, a maximum value of η' = 2.0% was obtained for the same thin-walled alumina system at a device surface temperature difference of 185.3 °C. In terms of efficiency calculated from the power output relative to the heat consumed, the aluminium nitride system performed best, achieving 17.8% (surface temperature difference of 162.6°C) and 11.3% (surface temperature difference of 156.7°C) at cooling water temperatures of 20°C and 30°C, respectively.

Approximately 80–90% of the heat flow is not utilised for power generation but simply passes through to the cooling water. In other words, it is clear that cooling the low-temperature side of TEG using LLC or air cooling, as has traditionally been done, merely dissipates almost all of the waste heat outside the system. To achieve more efficient heat recovery and thermal energy utilisation, it is necessary to consider system configurations that keeps thermal enery within the system, rather than releasing it outside.

Table.1 Max. generated power of TEG systems at ΔT=150℃

	40mm	30mm	Thin Al_2O_3	AlN
20℃	11.1W	7.1W	7.7W	10.4W
35℃	10.3W	6.6W	7.2W	9.9W

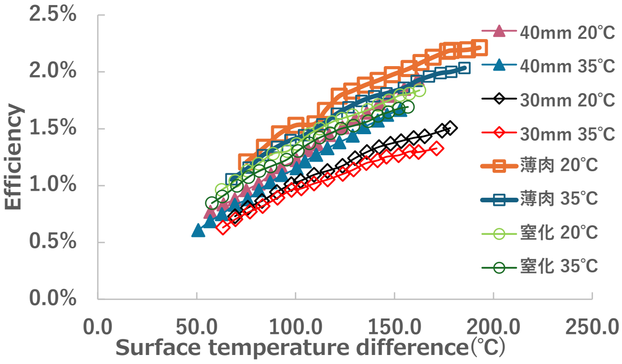

Fig.1 Efficiency of each system at on-board conditions