

Investigation of a Combined ORC-TEG Waste Heat Recovery System for a Hybrid Electric Vehicle with a Lean-Burn SI Engine

Masaki Naruke¹⁾ Takaaki Kitamura²⁾

¹⁾ Japan Automobile Research Institute
2530 Karima, Tsukuba, Ibaraki, 305-0822, Japan (E-mail: mnaruke@jari.or.jp)

²⁾ Japan Automobile Research Institute
2530 Karima, Tsukuba, Ibaraki, 305-0822, Japan

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Recovering waste heat is essential for improving the fuel efficiency of hybrid electric vehicles. In this study, a waste heat recovery (WHR) system combining an organic Rankine cycle (ORC), including engine cooling, and a thermoelectric generator (TEG) was applied to a hybrid electric vehicle equipped with a lean-burn spark-ignition engine capable of operating at an excess air ratio of 2.0 or higher. The performance of the combined ORC-TEG system was evaluated using one-dimensional numerical simulations.

Four WHR system configurations were investigated, as shown in Fig. 1: (a) ORC with refrigerant engine cooling (ORC), (b) Recuperative ORC with TEG-equipped heat exchangers (Recuperative ORC with TEG-HX), (c) ORC for cooling losses combined with TEG for exhaust losses (ORC-TEG), and (d) Configuration (c) with an additional TEG-equipped heat exchanger (Recuperative ORC-TEG with TEG-HX). The ORC expander efficiency was varied from 10% to 70%, while the pump efficiency was fixed at 70%. BiTe-based thermoelectric modules were adopted for the TEG system. The boundary conditions for the WHR simulations were obtained from a series-parallel hybrid vehicle model equipped with a 1.5 L turbocharged three-cylinder lean-burn SI engine.

Fig. 2 shows the brake thermal efficiency improvement for the investigated WHR systems as a function of ORC efficiency. Recuperative ORC with TEG-HX provided a greater improvement in brake thermal efficiency than ORC. At an ORC efficiency of approximately 12%, the brake thermal efficiency improvement increased by 0.97%pt. Of this increase, 0.68%pt originated from recuperative heat recovery and 0.29%pt from the additional TEG. At an ORC efficiency of approximately 1%, the brake thermal efficiency improvement increased by 0.35%pt. Of this increase, 0.06%pt originated from recuperative heat recovery and 0.29%pt from the additional TEG. Recuperative ORC-TEG with TEG-HX outperformed ORC-TEG. At an ORC efficiency of approximately 12%, the brake thermal efficiency improvement increased by 0.50%pt. Of this increase, 0.48%pt originated from recuperative heat recovery and 0.02%pt from the additional TEG. At an ORC efficiency of approximately 1%, the brake thermal efficiency improvement increased by 0.05%pt. Of this increase, 0.03%pt originated from recuperative heat recovery and 0.02%pt from the additional TEG. A comparison of all configurations revealed a crossover point at an ORC efficiency of approximately 4.2%. Below this value, Recuperative ORC-TEG with TEG-HX achieved the highest thermal efficiency improvement. Above this value, Recuperative ORC with TEG-HX became the most effective solution.

The results showed that the optimal WHR system depends on the ORC efficiency, indicating the importance of appropriate system selection. Future work will consider the impacts on engine performance as well as system weight and volume.

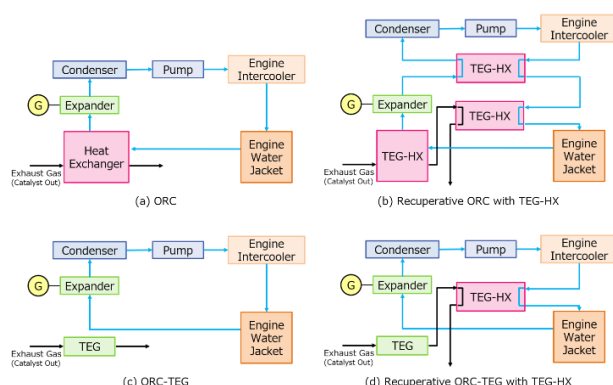


Fig.1 WHR system configurations

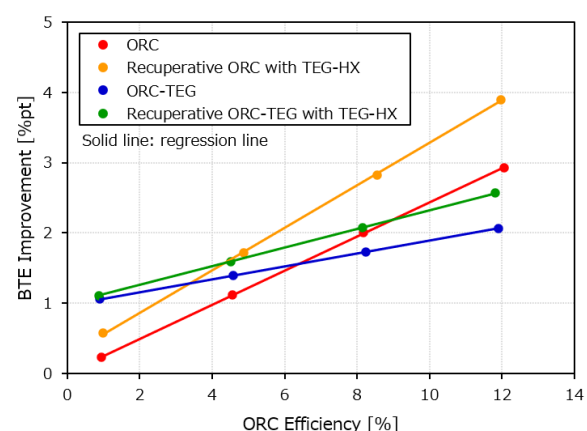


Fig.2 Brake thermal efficiency improvement using WHR system