

Study on Thermal Management System Utilizing Next-generation Refrigerant for Future xEVs.

Ryo Michikawauchi¹⁾ Hiroyuki Sugihara¹⁾ Atsuharu Ota¹⁾ Yuichi Kami²⁾

1) TOYOTA MOTOR CORPORATION

1 Toyota-cho, Toyota, Aichi, 471-8571, Japan (E-mail: ryo_michikawauchi@mail.toyota.co.jp)

2) DENSO CORPORATION.

1-1 Showa-cho, Kariya, Aichi, 448-8661, Japan

KEY WORDS: Heat • fluid, Refrigerant, Temperature control, Thermal management, Propane(R290) [D1]

The rapid adoption of electrified vehicles has increased the importance of thermal management systems for improving driving range, charging convenience, cabin comfort, and battery temperature control. Meanwhile, current automotive refrigerants such as R1234yf are being discussed as potential targets of future PFAS regulations in Europe, driving the need for alternative refrigerants. Propane refrigerant (R290) has attracted attention as a non-PFAS natural refrigerant with superior thermodynamic characteristics and the potential to improve thermal performance and energy efficiency. However, its high flammability requires additional safety measures for vehicle applications.

To address this challenge, this study investigated a secondary-loop heat pump (SLHP) architecture that restricts refrigerant circulation outside the cabin and transfers cooling energy through a coolant loop. Although this configuration improves safety, concerns remain regarding increased system complexity and potential performance degradation. Therefore, both the performance benefits of R290 and practical thermal circuit configurations were evaluated.

Thermodynamic analysis showed that R290 possesses significantly higher latent heat and volumetric heat transport capability than R1234yf, indicating strong potential for improving heat pump performance. Comparative evaluations were conducted using simulation and bench testing under both cabin heating and cooling conditions. Results showed that the R290-SLHP system achieved superior heating and cooling performance compared with a production R1234yf thermal management heat pump system. Experimental results agreed well with simulation predictions, confirming the validity of the analytical model and the performance advantages of R290.

Detailed cooling analysis revealed that secondary-loop implementation did not necessarily result in performance loss. Relocating the chiller closer to the compressor reduced suction-line pressure losses, partially offsetting additional heat exchange losses associated with the coolant loop. Combined with the favorable refrigerant properties of R290, the proposed system demonstrated overall cooling performance improvements.

To further improve practicality, a simplified single-chiller thermal circuit was investigated. Compared with a dual-chiller configuration, the proposed architecture reduces component count, refrigerant charge, packaging volume, and system complexity while improving safety. To resolve thermal distribution challenges between cabin cooling and battery cooling, a Flow Assist Loop Circuit was introduced. The proposed control concept enables flexible thermal distribution while maintaining sufficient coolant flow through the battery cooling circuit. Analytical validation confirmed that thermal capacity allocation can be adjusted according to changing vehicle operating conditions.

The results demonstrate that an R290-based secondary-loop thermal management system can simultaneously achieve improved thermal performance, enhanced safety, and reduced system complexity. The proposed single-chiller architecture provides a promising approach for realizing compact, cost-effective, and low-refrigerant-charge thermal management systems for future electrified vehicles.

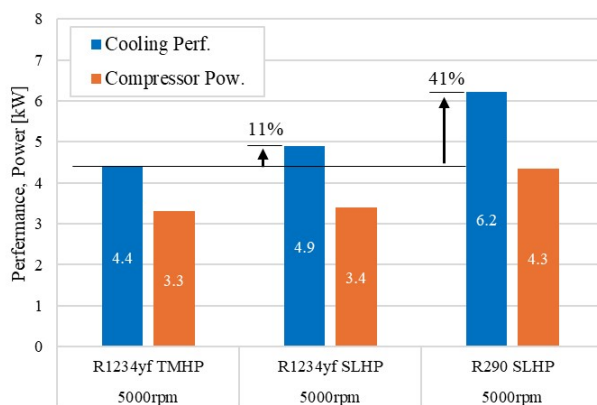


Fig.1 Cooling Performance Simulation Results

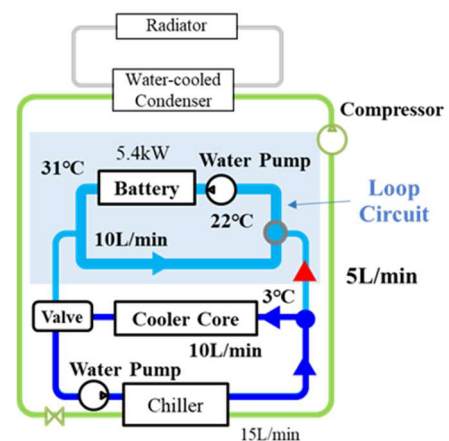


Fig.2 Proposed New Thermal Circuit Configuration