

Heat Transfer Characteristics of Oscillating Heat Pipe using Low-GWP Refrigerant as Working Fluid

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With the rapid increase in heat dissipation density in modern electronic components due to higher power outputs and dense integration, an oscillating heat pipe (OHP) has attracted significant attention as a highly efficient passive thermal management device. An OHP consists of a meandering capillary tube filled with a working fluid and contains no mechanical moving parts, offering structural advantages such as compactness, low weight, flexible routing, and a thin profile. Selecting an appropriate working fluid is essential for maximizing heat transfer efficiency and thermal transport capability. Refrigerants are promising working fluids because their steep saturation-pressure slopes and low liquid viscosities enhance the self-excited vapor-liquid driving forces between the heating and cooling sections. However, stricter global environmental regulations and the increasing demand to reduce global warming impacts require a transition from conventional hydrofluorocarbons (HFCs) to environmentally friendly refrigerants with low global warming potential (GWP). In this study, five refrigerants with different GWP values and thermal properties—conventional HFCs (R134a and R32) and low-GWP alternatives (R1234yf, R454C, and R474B)—were experimentally investigated to clarify their heat transport capabilities and internal fluid-flow behavior. Figure 1 shows the schematic configuration of the experimental OHP apparatus used in this study. The experimental setup was fabricated using a 30-turn SUS304 capillary tube with an inner diameter of 1.0 mm and an outer diameter of 3.0 mm. Thermocouples were installed along the centerline on the outer surface to measure temperature distributions. All tests were conducted in a bottom-heating orientation at a constant cooling temperature of 10°C and a fluid filling ratio of 50 wt%. Heat input to the heating section was increased stepwise from 30 W to 90 W. Thermal transport performance was evaluated using thermal conductance, defined by Eq. (1) based on the temperature difference.

$$G = \frac{Q}{\Delta T} = \frac{Q}{(\bar{T}_5 - \bar{T}_1)} \quad (1)$$

Across all heat inputs, all refrigerants operated successfully and reached stable operating regimes. As shown in Fig. 2, R32 exhibited the highest overall heat transport performance, maintaining a thermal conductance above 10 W/K. The low-GWP refrigerant R1234yf showed a monotonic increase in conductance with increasing heat input, following a trend almost identical to that of conventional R134a. In contrast, R454C and R474B reached high conductance values at 60 W, nearly equal to those at 90 W. Overall, the low-GWP refrigerants R1234yf, R454C, and R474B provided thermal transport capabilities comparable to those of the conventional R134a. However, the measured heat transfer performance did not directly align with intrinsic thermophysical property trends, such as the potential superiority suggested by property values for R454C. This discrepancy occurred because the present experimental setup used specifications based on R134a as the reference, with a uniform filling ratio of 50 wt%, resulting in different internal flow characteristics among the refrigerants. Therefore, future work must focus on clarifying the relationship between thermophysical properties and dynamic heat transfer characteristics, as well as optimizing operating parameters, particularly the filling ratio, for each specific refrigerant.

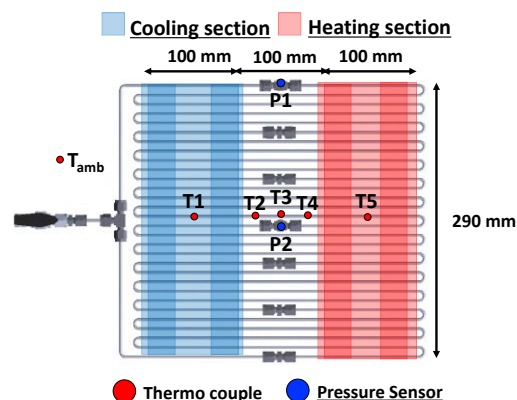


Fig.1 Schematic of the OHP

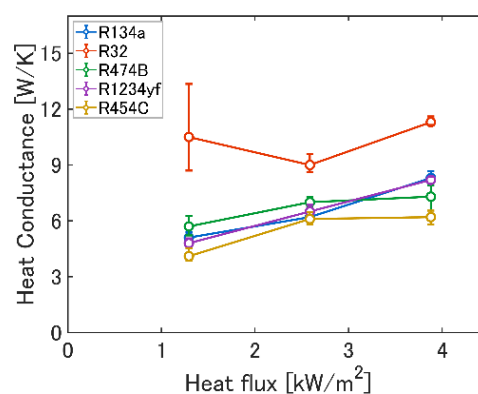


Fig.2 Thermal Conductance