Thermal Conductivity of 1,1,1-Trifluoroethane (R143a) and R404A in the Liquid Phase†

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The thermal conductivities of 1,1,1-trifluoroethane (R143a) and R404A (mixture of pentafluoroethane (R125), 1,1,1-trifluoroethane (R143a), and 1,1,1,2-tetrafluoroethane (R134a) in the ratio of 44:52:4 by mass) in the liquid phase have been measured by the transient hot-wire method with a bare platinum wire. Measurements were carried out in the temperature range from 233 to 323 K and the pressure range from 2 to 20 MPa. Measured thermal conductivities were correlated as a polynomial of reduced temperature and pressure, whose absolute average deviation from the experimental data was 0.22% for R143a and 0.28% for R404A. The uncertainty of the experiment was estimated to be within ±2%, and the reproducibility of the data was better than 0.5%.

Introduction

Hydrofluorocarbon (HFC) refrigerants are promising as new alternatives due to their zero ozone depletion effect and reduced global warming potential. So far, thermal conductivities of pure HFC refrigerants and their mixtures of R32, R125, and R134a have been intensively investigated.[1−14]

However, liquid thermal conductivities of R143a have not been widely investigated, and R404A (ternary refrigerant mixtures of R125, R143a, and R134a in the ratio of 44:52:4 by mass), which is a promising alternative to R502, has not been studied in detail. Because of the increased use of these environmentally benign refrigerants in refrigerators and heat pumps, their transport properties, as well as thermodynamic properties, are required in the initial and advanced design stages.

This paper presents experimental data of the thermal conductivity of R143a and the ternary refrigerant mixture, R404A, in the liquid phase.

Experiments

The transient hot-wire method with a bare platinum wire has been used. The basic principle, the apparatus, and the procedures of our experiment have been described in detail in our previous work.[15] The diameter of the platinum wire is 25 μm, and the length of the wire is 130 mm. The temperature was measured by the resistance of the platinum wire in the test cell with an accuracy of 0.01 K. The pressure was measured by an absolute pressure transducer (Druck, PMP4070) with an accuracy better than 0.04%. The ternary mixture, R404A, was supplied by DuPont, and R143a was supplied by Atochem. The purities of both refrigerants are 99.9% on the basis of the manufacturers' data. For R404A, the liquid phase from the cylinder was withdrawn and put into the test cell to minimize composition change, and the composition of the refrigerant mixture was checked by gas chromatography. The uncertainty in the composition measurement was less than 0.7%. The overall uncertainty in the thermal conductivity measurement is estimated to be ±2%. The measured thermal conductivity data are taken as an average of five measurements at the same test conditions. The reproducibility in our measurements is within 0.5%.

Table 1. Measured Thermal Conductivity of R143a in the Liquid Phase

T/K	P/MPa	λ/(W·m^{-1}·K^{-1})	T/K	P/MPa	λ/(W·m^{-1}·K^{-1})
233.65	2.0	0.0994	272.85	10.0	0.0849
233.35	5.0		273.05	15.0	0.0882
233.35	10.0	0.1070	273.25	20.0	0.0913
233.85	15.0	0.1098	298.85	2.0	0.0663
233.15	20.0	0.1121	298.85	5.0	0.0689
247.45	2.0	0.0917	298.75	10.0	0.0731
247.05	5.0	0.0941	298.85	15.0	0.0768
247.65	10.0	0.0979	298.75	20.0	0.0802
247.85	15.0	0.1011	323.45	5.0	0.0576
248.35	20.0	0.1038	323.35	10.0	0.0627
272.45	2.0	0.0788	323.45	15.0	0.0670
272.95	5.0	0.0811	323.45	20.0	0.0706

Table 2. Measured Thermal Conductivity of R404A in the Liquid Phase

T/K	P/MPa	λ/(W·m^{-1}·K^{-1})	T/K	P/MPa	λ/(W·m^{-1}·K^{-1})
233.65	2.0	0.0951	273.25	10.0	0.0810
233.75	5.0	0.0973	273.45	15.0	0.0844
233.55	10.0	0.1006	273.85	20.0	0.0872
233.55	15.0	0.1034	298.15	2.0	0.0631
233.85	20.0	0.1056	298.25	5.0	0.0661
246.95	2.0	0.0870	298.05	10.0	0.0701
246.95	5.0	0.0891	298.35	15.0	0.0737
246.55	10.0	0.0924	298.55	20.0	0.0773
247.25	15.0	0.0952	322.85	5.0	0.0563
247.95	20.0	0.0979	322.95	10.0	0.0613
273.75	2.0	0.0753	322.75	15.0	0.0655
273.55	5.0	0.0774	322.85	20.0	0.0692

Results

Measurement of the thermal conductivities of R143a and R404A has been performed in the temperature range (233

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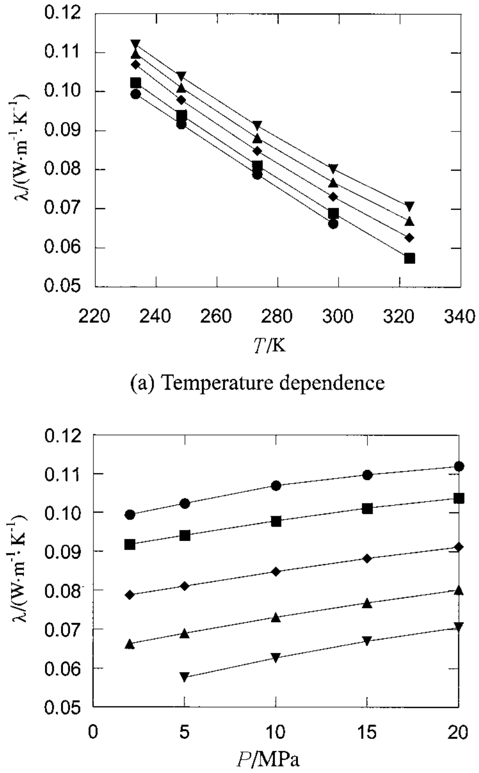

Figure 1. Measured thermal conductivity of R143a: (a) ●, 2 MPa; ■, 5 MPa; ◆, 10 MPa; ▲, 15 MPa; ▼, 20 MPa; (b) ●, 233.15 K; ■, 248.15 K; ◆, 273.15 K; ▲, 298.15 K; ▼, 323.15 K. (a) Temperature dependence. (b) Pressure dependence.

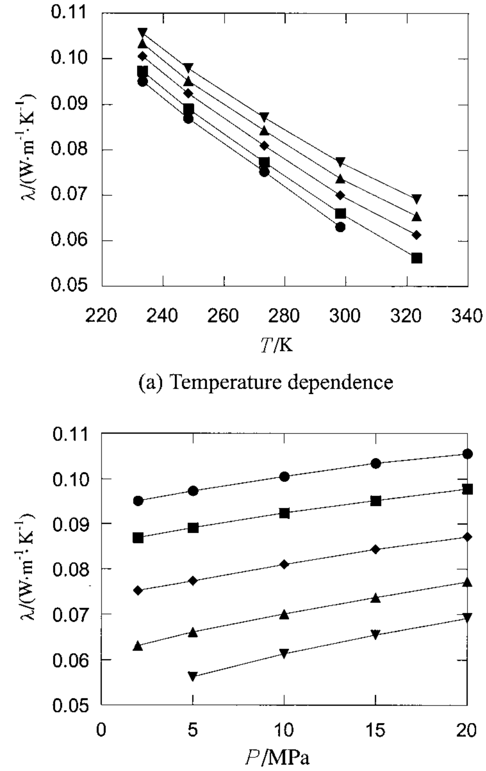

Figure 2. Measured thermal conductivity of R404A: (a) ●, 2 MPa; ■, 5 MPa; ◆, 10 MPa; ▲, 15 MPa; ▼, 20 MPa; (b) ●, 233.15 K; ■, 248.15 K; ◆, 273.15 K; ▲, 298.15 K; ▼, 323.15 K. (a) Temperature dependence. (b) Pressure dependence.

Table 3. Coefficients in Eq 1 for R143a

λ_o/W·m^{-1}·K^{-1} = 0.226 886 T_c/K = 346.04 P_c/MPa = 3.776

	a_{ij}/W·m^{-1}·K^{-1}		
	$j = 0$	$j = 1$	$j = 2$
$i = 0$	1.000 000	0.222 730	−0.029 354
$i = 1$	−0.915 671	−0.519 684	0.070 270
$i = 2$	0.099 321	0.323 260	−0.042 484

to 323) K at intervals of approximately 25 K and in the pressure range (2 to 20) MPa. The thermal conductivities of R143a and R404A for various temperatures and pressures are listed in Tables 1 and 2, respectively.

The pressure dependence of the thermal conductivity of R143a along isotherms is plotted in Figure 1a, and the temperature dependence along isobars is shown in Figure 1b. The pressure dependence of the thermal conductivity of R404A along isotherms is plotted in Figure 2a, and the temperature dependence along isobars is shown in Figure 2b. Like other HFC refrigerants and their mixtures, the liquid thermal conductivities of R143a and R404A decrease almost linearly with temperature increase. On the other hand, as the pressure increases, the thermal conductivities for both fluids increase monotonically.

The measured thermal conductivities have been correlated by a least-squares regression method with the following polynomial equation.

$$\lambda = \lambda_0 \sum_{i=0}^{2}\sum_{j=0}^{2} a_{ij}\left(\frac{T}{T_c}\right)^i\left(\frac{P}{P_c}\right)^j \qquad (1)$$

where λ represents thermal conductivity, T is absolute temperature, T_c is critical temperature, P is pressure, and P_c is critical pressure of the refrigerant. For R404A, the pseudocritical values that are obtained from a mass-based average of pure components' critical information are used. The values of the coefficients a_{ij} for R143a and R404A as well as λ_0, T_c, and P_c are given in Tables 3 and 4, respectively. The absolute average deviation of the experimental data from eq 1 is 0.22% for R143a and 0.28% for R404A.

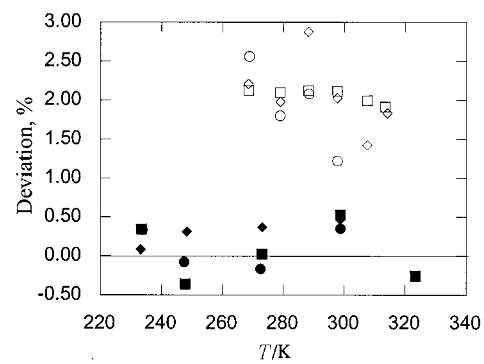

Figure 3. Comparison of measured thermal conductivity with the values by Yata et al.[10] based on the correlation in this study: (●, ○) 2 MPa; (■, □) 10 MPa; (◆, ◇) 20 MPa; full symbols, this work; open symbols, Yata et al.[10].

Table 4. Coefficients in Eq 1 for R404A

λ_o/W·m^{-1}·K^{-1} = 0.238 858 T_c/K = 345.24 P_c/MPa = 3.731

	a_{ij}/W·m^{-1}·K^{-1}		
	$j = 0$	$j = 1$	$j = 2$
$i = 0$	1.000 000	0.126 321	−0.016 996
$i = 1$	−1.052 885	−0.311 214	0.054 540
$i = 2$	0.224 602	0.210 012	−0.027 744

Figure 3 shows deviations of measured thermal conductivity data of this study and the measured data by Yata et al. (1996) from the values calculated from eq 1 for R143a. The deviation of the experimental data by Yata et al. (1996) from eq 1 is about 2%.

Conclusion

Measured thermal conductivity data of R143a and R404A in the liquid phase are reported. The experiments have been performed with a transient hot-wire method in the temperature range (233 to 323) K and in the pressure range (2 to 20) MPa. The experimental data of thermal conductivities have been correlated by a polynomial equation, and the absolute average deviation between experimental data and the correlation is 0.22% for R143a and 0.28% for R404A. The uncertainty of the measurement is about 2%.

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