Measurement of the Thermal Conductivities of 1,1,1-Trifluoroethane (R143a) and R404A in the Liquid Phase

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ABSTRACT

The thermal conductivities of 1,1,1-trifluoroethane (R143a) and R404A (containing R125, R134a, and R143a in the ratio of 44:4:52 by mass) in the liquid phase have been measured by the transient hot-wire method with one bare platinum wire. Measurements were carried out in the temperature range from 233 K to 323 K and the pressure range from 2 MPa to 20 MPa. Measured thermal conductivities of each refrigerant were correlated as a polynomial of reduced temperature and pressure, whose absolute average deviation from the experimental data was 0.20% for R143a and 0.24% for R404A. The uncertainty of the experiment was estimated to be within ±2% and the reproducibility of the data was better than 0.5%.

Key words: transient hot-wire method, HFC refrigerant, R143a, R404A

1. INTRODUCTION

As new alternatives, hydrofluorocarbon (HFC) refrigerants are promising 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, 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, R134a and R143a in the ratio of 44:4:52 by mass) as a promising alternative to R502 are not taken as test fluid until now. Because of the increased importance of environmentally benign refrigerants in refrigerators and heat pumps, the transport properties as well as thermodynamic properties are mostly required in the initial and advanced design stage.

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

2. EXPERIMENTS

A transient hot-wire with one 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 mm and the length of the wire is 130 mm. The temperature was measured by the resistance of the platinum wire in the 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 The ternary mixture of R404A was manufactured by DuPont, the liquid phase from the cylinder was withdrawn and put into the test cell and the composition of the refrigerant mixtures was checked by gas chromatograph. 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 under the same conditions. The reproducibility in our measurements is within 0.5%.

3. RESULTS

Measurement of the thermal conductivities of R143a and R404A has been performed in the temperature range of 233-323 K at intervals of approximately 25 K and in the pressure range of 2-20 MPa. The thermal conductivities of R143a and R404A for various temperatures and pressures are listed in Table 1. and Table 2., respectively.

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

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

$$l = l_0 \sum_{i=0}^{2} \sum_{j=0}^{2} a_{ij} \left(\frac{T}{T_c} \right)^i \left(\frac{P}{P_c} \right)^j \qquad (1)$$

where l is thermal conductivity in W·m^{-1}·K^{-1}, T is temperature in K, T_c is critical temperature in K, P is pressure in MPa and P_c is critical pressure in MPa, respectively. For R404A, the pseudo-critical values which are obtained as a mass-based average of pure components critical information are used. The values of the coefficients a_{ij} of R143a and R404A as well as l_0, T_c, and P_c are given in Table 3. and Table 4., respectively. The absolute average deviation of our experimental data from Eq. (1) is 0.20% for R143a and 0.24% for R404A.

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 R134a. The deviation of the experimental data by Yata et al.(1996) from Eq. (1) is about 2%.

4. 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 of 233-323 K, and in the pressure range of 2-20 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 0.20% for R143a and 0.24% for R404A. The uncertainty of the measurement is about 2%.

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LIST OF FIGURES

LIST OF TABLES

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

T/^{o}C	P/MPa	λ/(W·m^{-1}·K^{-1})
-39.5	2.0	0.0994
-39.8	5.0	0.1023
-39.8	10.0	0.1070
-39.3	15.0	0.1098
-40.0	20.0	0.1121
-25.7	2.0	0.0917
-26.1	5.0	0.0941
-25.5	10.0	0.0979
-25.3	15.0	0.1011
-24.8	20.0	0.1038
-0.7	2.0	0.0788
-0.2	5.0	0.0811
-0.3	10.0	0.0849
-0.1	15.0	0.0882
0.1	20.0	0.0913
25.7	2.0	0.0663
25.7	5.0	0.0689
25.6	10.0	0.0731
25.7	15.0	0.0768
25.6	20.0	0.0802
50.3	5.0	0.0576
50.2	10.0	0.0627
50.3	15.0	0.0670
50.3	20.0	0.0706

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

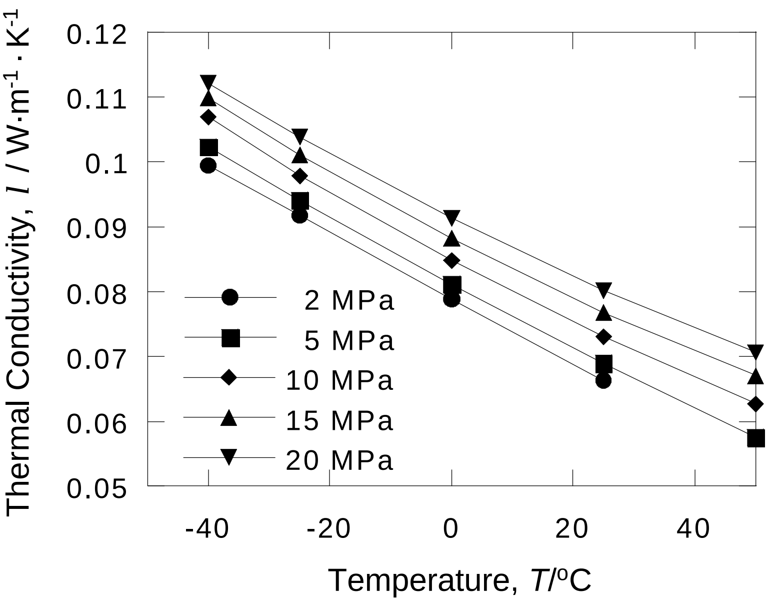
T/°C	P/MPa	λ/(W·m^{-1}·K^{-1})
-39.5	2.0	0.0951
-39.4	5.0	0.0973
-39.6	10.0	0.1006
-39.6	15.0	0.1034
-39.3	20.0	0.1056
-26.2	2.0	0.0870
-26.2	5.0	0.0891
-26.6	10.0	0.0924
-25.9	15.0	0.0952
-25.2	20.0	0.0979
0.6	2.0	0.0753
0.4	5.0	0.0774
0.1	10.0	0.0810
0.34	15.0	0.0844
0.7	20.0	0.0872
25.0	2.0	0.0631
25.1	5.0	0.0661
24.9	10.0	0.0701
25.2	15.0	0.0737
25.4	20.0	0.0773
49.7	5.0	0.0563
49.8	10.0	0.0613
49.6	15.0	0.0655
49.7	20.0	0.0692

Table 3. Coefficients in Eq. (1) for R143a

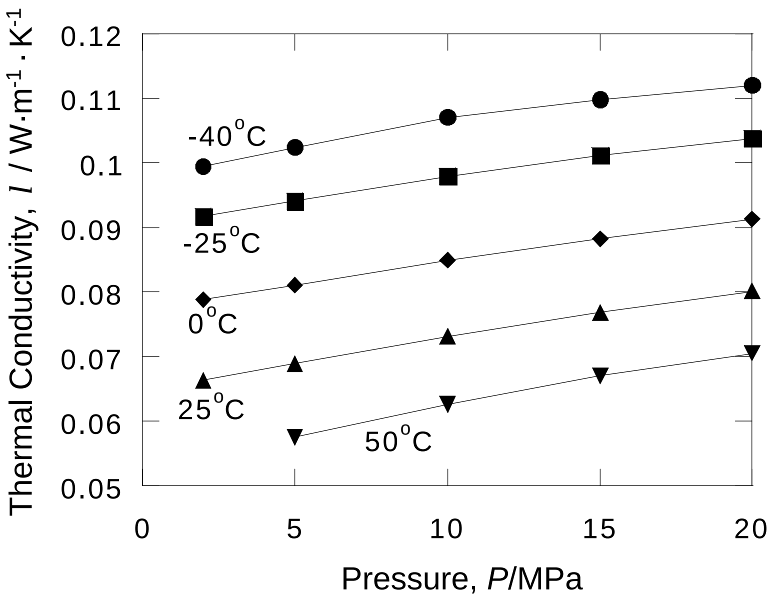
λ_o /(W·m^{-1}·K^{-1})	0.224467		
T_c /K	346.04	P_c /MPa	3.776
a_{ij}	j=0	j=1	j=2
i=0	1.000000	0.226310	-0.027333
i=1	-0.897963	-0.527214	0.064682
i=2	0.082932	0.327459	-0.038799

Table 4. Coefficients in Eq. (1) for R404A

λ_o /(W·m^{-1}·K^{-1})	0.239692		
T_c /K	345.24	P_c /MPa	3.731
a_{ij}	j=0	j=1	j=2
i=0	1.000000	0.122977	-0.016504
i=1	-1.057833	-0.302511	0.041933
i=2	0.228796	0.204503	-0.026913

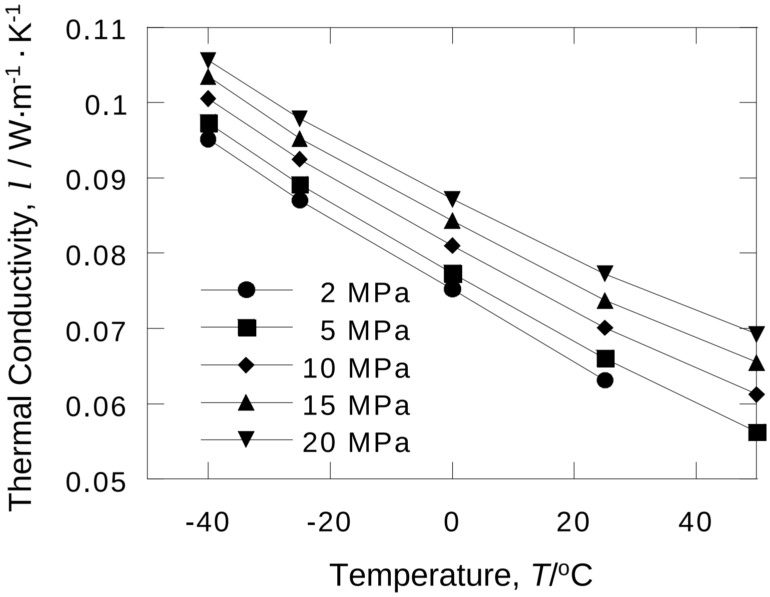


(a) Temperature dependence

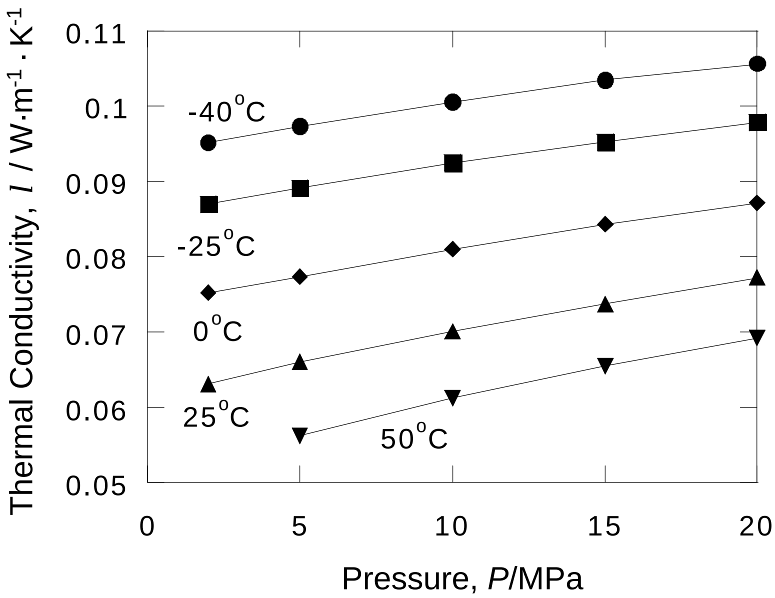


(b) Pressure dependence

Figure 1. Measured thermal conductivity of R143a.



(a) Temperature dependence



(b) Pressure dependence

Figure 2. Measured thermal conductivity of R404A.

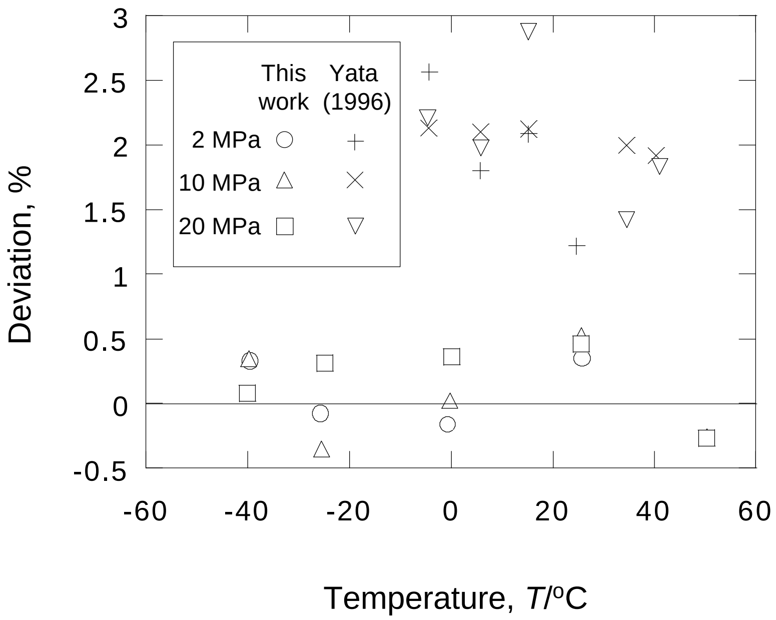


Figure 3. Comparison of measured thermal conductivity with the values by Yata *et al.*(1996) based on the correlation in this study.