International Journal of Thermophysics, Vol. 20, No. 1, 1999

Liquid Thermal Conductivity of Binary Mixtures of Pentafluoroethane (R125) and 1,1,1,2-Tetrafluoroethane (R134a)[1]

S. U. Jeong,[2] M. S. Kim,[2] and S. T. Ro[2,3]

Thermal conductivities of zeotropic mixtures of R125 (CF_3CHF_2) and R134a (CF_3CH_2F) in the liquid phase are reported. Thermal conductivities have been measured by a transient hot-wire method with one bare platinum wire. Measurements have been carried out in the temperature range of 233 to 323 K and in the pressure range of 2 to 20 MPa. The dependence of thermal conductivity on temperature, pressure, and composition of the binary mixture is presented. Measured thermal conductivity data are correlated as a function of temperature, pressure, and overall composition of the mixture. The uncertainty of our measurements was estimated to be better than 2%.

KEY WORDS: mixture; R125; R134a; R125 + R134a; refrigerant; thermal conductivity; transient hot-wire method.

1. INTRODUCTION

CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon) refrigerants have been recognized to have an influence on the depletion of the ozone layer and global warming. The production and use of CFC refrigerants have been strongly regulated, and the manufacture of HCFC refrigerants will be controlled in the near-future. HFC (hydrofluorocarbon) refrigerants such as R32, R125, R134a, and R143a have been considered as environmentally acceptable refrigerants. In many cases, their binary and ternary mixtures are considered as working fluids.

[1] Paper presented at the Thirteenth Symposium on Thermophysical Properties, June 22–27, 1997, Boulder, Colorado, U.S.A.

[2] Department of Mechanical Engineering, Seoul National University, Seoul 151-742, Korea.

[3] To whom correspondence should be addressed.

A number of measurements for the thermal conductivities of HFC refrigerants have been carried out by many researchers [1–6]. They have tried to establish property databases from measurements and predictions. However, the experimental data for the thermal conductivities of HFC refrigerants are not sufficient. Particularly, there are very few thermal conductivity data for binary or ternary HFC refrigerant mixtures, so it is meaningful to get HFC mixture thermal conductiviy data for development of databases and predictive models.

In previous papers, we have reported measured data for single-component HFC refrigerants (R32, R125, and R134a) and binary HFC refrigerant mixtures (R32 + R134a and R32 + R125) in the liquid phase [5, 6]. Following our previous studies, the thermal conductivity data for the HFC refrigerant mixture, R125 + R134a, are reported in this study for a wide range of temperature and pressure. Thermal conductivity in the liquid phase is presented for several compositions of the refrigerant mixture.

2. EXPERIMENTS

In this study, the transient hot-wire method has been used in the measurements. The fundamental governing equations to determine the thermal conductivity of the liquid phase and the details of the apparatus together with the test procedures were described in our previous work [4–6]. The main parts of the test apparatus consist of the hot-wire cell, pressure vessel and pressurizing device, electrical system with a Wheatstone bridge circuit, data processing system, and temperature control system. One bare platinum wire has been used to supply heat and to measure temperature change. The diameter and the length of the wire are 25 μm and 128.40 mm, respectively. The temperature of the bath in which the pressure vessel is submerged is kept at specified temperature levels, with a temperature variation of ± 0.02 K. The data were taken over a time interval of 100 to 300 ms after starting electric current supply to minimize possible errors due to natural convection in the hot-wire cell. The sampling frequency of our measurement is 2 kHz, and the temperature rise during the measurement is about 1.5 K. The uncertainties in temperature and pressure measurements are less than 0.05 K and 0.5 %, respectively. The purities of the sample refrigerants (R125 and R134a), supplied by Du Pont Company, are better than 99.8 %. Before charging the sample refrigerants into the system, the system was evacuated for a long period of time and purged with the refrigerant. The compositions of the refrigerant mixtures were analyzed by gas chromatography, and the uncertainty of composition determination is within a mass fraction of 0.005.

Major uncertainties of the experiment are attributed to several non-idealities [9–12]. However, we found that the measured temperature rise versus the logarithm of time was almost linear for the short time interval of measurement. Since the thermal conductivity data are analyzed for this period, it assures that the measurement is in accordance with its governing equation.

The thermal conductivity of toluene, which is regarded as one of the standard liquids, was measured before measuring the thermal conductivity of R125 + R134a to ensure the accuracy of our measurement. The data were found to agree within $\pm 1\%$ compared with other data [7, 8].

3. RESULTS

Measurements of the thermal conductivities of R125 + R134a mixtures in the liquid phase have been carried out over the temperature range from 233 to 323 K (−40 to 50°C) and the pressure range from 2 to 20 MPa. The mass fractions of R125 in the R125 + R134a mixture were selected to be 0.191, 0.374, 0.587, and 0.785 to investigate the composition dependence of the thermal conductivity.

The measured thermal conductivity data for R125 + R134a are listed in Table I. These values are the averages of five measurements under the same test conditions. The random error of the measurement is less than 0.5%. The thermal conductivities of R125 + R134a when the mass fraction of R125 in the mixture is 0.587 are plotted as a function of temperature in Fig. 1 and as a function of pressure in Fig. 2. As shown in Figs. 1 and 2, the thermal conductivity of R125 + R134a in the liquid phase decreases as the temperature increases, while the pressure has an opposite effect. Similar trends can be found for other compositions (see Table I). Figure 3 shows the composition dependence of the thermal conductivity along isotherms for $P = 10$ MPa, and Fig. 4 shows the composition dependence along isobars for $T = 0°\text{C}$. The curved lines in the figures represent fitted values calculated from Eq. (1). As shown in Figs. 3 and 4, the thermal conductivities for the R125 + R134a mixture are quite close to the mass fraction average of the pure R125 and R134a thermal conductivities.

The experimental data for the R125 + R134a mixtures were correlated by the following polynomial equation in terms of temperature, pressure, and mass fraction of R125;

$$\lambda = \lambda_0 \sum_{k=0}^{2} \sum_{j=0}^{2} \sum_{i=0}^{2} a_{ijk} T^i P^j w^k \tag{1}$$

Table I. Thermal Conductivity of R125 + R134a Mixtures

T (°C)	λ ($W \cdot m^{-1} \cdot K^{-1}$)	T (°C)	λ ($W \cdot m^{-1} \cdot K^{-1}$)	T (°C)	λ ($W \cdot m^{-1} \cdot K^{-1}$)	T (°C)	λ ($W \cdot m^{-1} \cdot K^{-1}$)	T (°C)	λ ($W \cdot m^{-1} \cdot K^{-1}$)
$P = 2.0$ MPa		$P = 5.0$ MPa		$P = 10.0$ MPa		$P = 15.0$ MPa		$P = 20.0$ MPa	
R125:R134a = 1.000:0.000 (by mass)									
−41.6	0.0898	−41.8	0.0915	−41.9	0.0939	−41.9	0.0963	−41.6	0.0984
−25.5	0.0812	−25.4	0.0830	−25.5	0.0858	−25.4	0.0882	−25.4	0.0910
−0.5	0.0706	−0.6	0.0726	−0.6	0.0761	−0.6	0.0793	−0.7	0.0821
26.9	0.0585	26.2	0.0621	26.5	0.0659	27.1	0.0696	26.5	0.0734
—	—	50.9	0.0524	50.8	0.0584	50.8	0.0624	50.8	0.0661
R125:R134a = 0.785:0.215									
−40.3	0.0941	−40.2	0.0956	−40.2	0.0978	−40.2	0.0999	−40.3	0.1019
−25.3	0.0869	−25.3	0.0881	−25.5	0.0906	−25.3	0.0931	−25.4	0.0953
−0.4	0.0761	−0.3	0.0779	−0.2	0.0814	−0.3	0.0841	−0.4	0.0866
24.5	0.0647	24.8	0.0679	24.7	0.0718	24.7	0.0750	24.7	0.0781
—	—	50.4	0.0597	50.0	0.0640	49.9	0.0679	49.9	0.0712
R125:R134a = 0.587:0.413									
−40.2	0.0974	−40.2	0.0988	−40.4	0.1007	−40.2	0.1034	−40.2	0.1055
−25.1	0.0907	−25.1	0.0922	−25.2	0.0945	−25.3	0.0974	−25.4	0.0998
−0.1	0.0796	−0.1	0.0814	0.0	0.0846	0.1	0.0878	0.1	0.0902
24.7	0.0684	24.9	0.0717	24.8	0.0750	24.9	0.0786	24.9	0.0818
—	—	49.8	0.0628	49.8	0.0668	49.8	0.0703	49.9	0.0740

R125:R134a = 0.374:0.626									
−40.4	0.1031	−40.3	0.1047	−40.2	0.1067	−40.2	0.1087	−40.2	0.1111
−25.5	0.0960	−25.2	0.0979	−25.3	0.1002	−25.4	0.1026	−25.5	0.1046
−0.2	0.0851	−0.3	0.0871	−0.3	0.0900	−0.2	0.0930	−0.2	0.0956
24.8	0.0748	24.7	0.0774	24.9	0.0806	24.9	0.0836	25.0	0.0867
49.9	0.0647	50.1	0.0674	49.9	0.0718	50.1	0.0752	50.1	0.0786
R125:R134a = 0.191:0.809									
−40.4	0.1071	−40.4	0.1085	−40.2	0.1105	−40.4	0.1125	−40.3	0.1143
−25.1	0.1000	−25.0	0.1012	−25.2	0.1036	−25.2	0.1059	−25.1	0.1081
−0.2	0.0891	−0.2	0.0911	−0.2	0.0938	−0.2	0.0966	−0.2	0.0991
24.6	0.0786	24.6	0.0805	24.8	0.0839	24.9	0.0878	25.0	0.0906
50.1	0.0687	50.1	0.0709	50.2	0.0747	50.2	0.0785	50.3	0.0816
R125:R134a = 0.000:1.000									
−40.4	0.1109	−40.4	0.1123	−40.4	0.1145	−40.2	0.1165	−40.4	0.1184
−25.5	0.1041	−25.5	0.1055	−25.1	0.1081	−25.4	0.1104	−25.3	0.1122
−0.3	0.0939	−0.2	0.0957	−0.4	0.0986	−0.4	0.1009	−0.1	0.1032
24.9	0.0830	25.1	0.0851	24.7	0.0885	24.7	0.0917	24.9	0.0944
49.7	0.0723	49.8	0.0751	49.8	0.0787	50.1	0.0824	50.1	0.0855

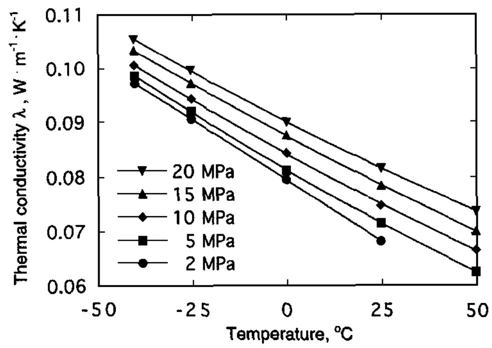

Fig. 1. Measured thermal conductivities of R125 + R134a mixtures; temperature dependence along isobars when the mass fraction of R125 is 0.587.

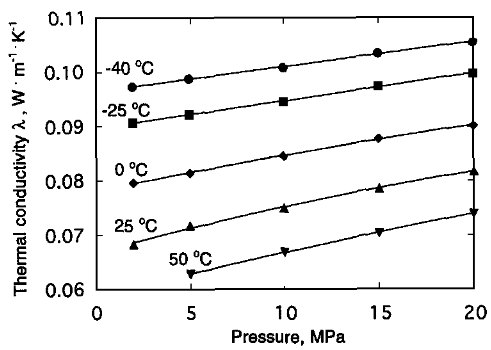

Fig. 2. Measured thermal conductivities of R125 + R134a mixtures; pressure dependence along isotherms when the mass fraction of R125 is 0.587.

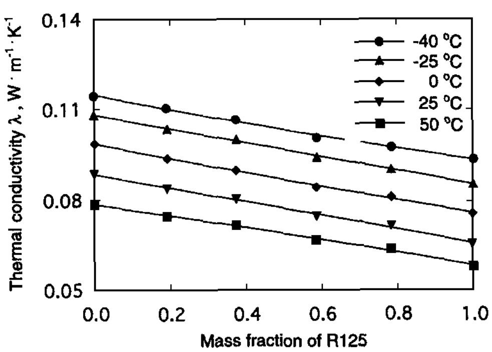

Fig. 3. Measured thermal conductivities of R125 + R134a mixtures; composition dependence along isotherms for $P = 10$ MPa.

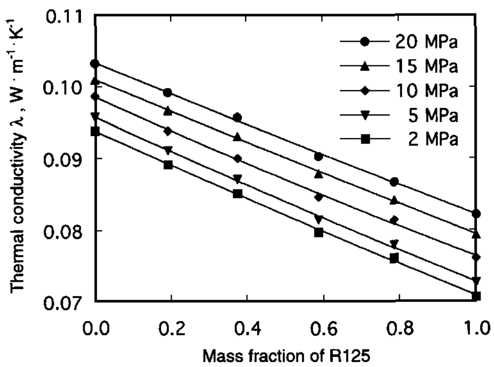

Fig. 4. Measured thermal conductivities of R125 + R134a mixtures; composition dependence along isobars for $T = 0°C$.

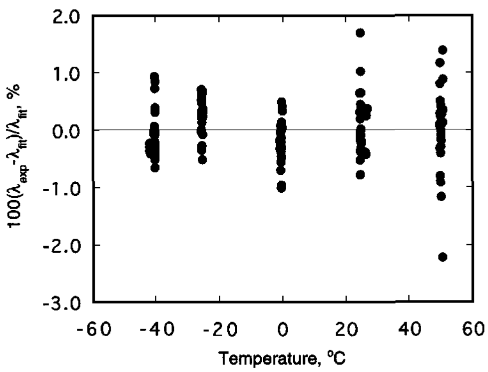

Fig. 5. Percentage deviations of the experimental thermal conductivities from Eq. (1) for R125 + R134a mixtures.

Table II. Coefficients in Eq. (1) for R125 + R134a Mixtures

	λ_0	2.103697×10^{-1}	
	$k=0$	$k=1$	$k=2$
a_{00k}	1.000000×10^{0}	7.209919×10^{-1}	-6.183520×10^{-1}
a_{01k}	4.849657×10^{-3}	-6.703170×10^{-2}	7.872269×10^{-2}
a_{02k}	-1.293985×10^{-4}	1.869815×10^{-3}	-2.360631×10^{-3}
a_{10k}	-2.043133×10^{-3}	-6.100480×10^{-3}	4.636145×10^{-3}
a_{11k}	-3.108052×10^{-5}	4.661615×10^{-4}	-5.715948×10^{-4}
a_{12k}	8.273776×10^{-7}	-1.243560×10^{-5}	1.680477×10^{-5}
a_{20k}	-4.109788×10^{-8}	1.113836×10^{-5}	-8.660620×10^{-6}
a_{21k}	8.901141×10^{-8}	-8.002610×10^{-7}	1.037339×10^{-6}
a_{22k}	-1.570988×10^{-9}	2.044185×10^{-8}	-2.990036×10^{-8}

where λ is the thermal conductivity in $W \cdot m^{-1} \cdot K^{-1}$, T is the temperature in K, P is the pressure in MPa, and w is the mass fraction of R125 in the R125 + R134a mixture. The numerical values of all coefficients in Eq. (1) are given in Table II. In Fig. 5, the percentage deviations of the measured thermal conductivity data from Eq. (1) are shown. The root-mean-square deviation of the experimental data from Eq. (1) is about 0.5%.

4. CONCLUSION

Measurements of the thermal conductivities of R125 + R134a mixtures in the liquid phase are reported. The experiments were performed with a transient hot-wire method over wide ranges of temperature, pressure, and composition. The measurements were carried out in the temperature range from 233 to 323 K (−40 to 50°C) and the pressure range from 2 to 20 MPa. The measured thermal conductivity data of R125 + R134a mixture are quite similar to the mass fraction average values of pure component thermal conductivity values. The experimental results for the thermal conductivity of R125 + R134a are correlated as a function of the temperature, pressure, and composition of the mixture. The average deviation of the measured thermal conductivity data from the values calculated by the fitting equation is about 0.5%. The overall uncertainty of our measurement is better than 2%.

ACKNOWLEDGMENTS

This work has been supported by the Korea Science and Engineering Foundation (Grand No. 965-1000-003-2) and by the Turbo and Power Machinery Research Center of Seoul National University.

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