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Liquid Thermal Conductivity of Binary Mixtures of Difluoromethane (R32) and Pentafluoroethane (R125)[1]

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The thermal conductivities of refrigerant mixtures of difluoromethane (R32) and pentafluoroethane (R125) in the liquid phase are presented. The thermal conductivities were measured with the transient hot-wire method with one bare platinum wire. The experiments were conducted in the temperature range of 233–323 K and in the pressure range of 2–20 MPa. An empirical equation to describe the thermal conductivity of a near-azeotropic mixture, R32 + R125, is provided based on the measured 168 thermal conductivity data as a function of temperature and pressure. The dependence of thermal conductivity on the composition at different temperatures and pressures is also presented. The uncertainty of our measurements is estimated to be ±2%.

KEY WORDS: mixture; R125; R32; refrigerant; thermal conductivity; transient hot-wire method.

1. INTRODUCTION

The ozone layer depletion and global warming caused by CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon) refrigerants have become a worldwide issue, and great efforts are being made to protect the environment. Since regulations on the production and use of these refrigerants have already been established, new environmentally acceptable alternatives and related techniques should be developed. HFC (hydrofluorocarbon) refrigerants have been considered as adequate alternatives,

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and their mixtures are also widely investigated as temporary and long-term replacements.

Both thermodynamic and transport properties of new refrigerants are essential for designing, manufacturing, and analyzing thermal systems such as heat pumps, air-conditioners, and refrigerators. However, the available experimental data are often limited and different sets of data are sometimes inconsistent. Especially, well-established thermal-conductivity data are very important in analyzing heat transfer processes in evaporators and condensers of the thermal systems because heat transfer is directly dependent on this property.

The new environmentally acceptable HFC refrigerants (R32, R125, R134a, etc.) and their mixtures are promising candidates as alternative refrigerants. Some of the refrigerant mixtures, such as R32 + R134a, R32 + R125 + R134a, and R32 + R125, have already been proposed as alternatives, and many manufacturers have tested the feasibility of using these refrigerants. Among others, mixtures of R32 and R125 show near-azeotropic (azeotrope-like) behavior. Therefore, temperature changes during evaporation and condensation are negligible, and there is no significant composition shift during charging and recharging processes of the refrigerant mixture into the system. The fractionation during leak, if any, also becomes insignificant. Another reason that R32 + R125 mixtures draw attention as future replacements for R22, which is widely used for air-conditioning applications, is that the system size can be smaller for the same heat capacity because of the higher vapor pressure of the mixture. However, advanced technology in the manufacturing processes is required, with some machinery design changes, in order to overcome the higher pressure of R32 + R125 mixtures in condensing processes.

Up to now, many researchers have tried to establish a property database from measurements and predictions. So far, several data sets for the thermal conductivity of R32 and R125 are available [1–15], and data for the mixtures of these refrigerants are seldom found in the open literature. The main objective of this study is to provide thermal-conductivity data for HFC refrigerant mixtures of R32 + R125 at several compositions obtained with the transient hot-wire method over wide ranges of temperature and pressure. Following our previous studies of the thermal conductivity of several refrigerants [1, 16–18], this paper provides reliable thermal conductivity data. This paper supersedes the authors' previous report [18], where the compositions of the mixtures were evaluated improperly. The data in Ref. 18 are no longer recommended.

2. THERMAL-CONDUCTIVITY MEASUREMENTS

In this study, the transient hot-wire method was used to measure the thermal conductivities of refrigerant mixtures of R32 and R125. This technique requires the measurement of a timewise temperature change of the hot wire in a test cell. The details of the transient hot-wire method are well described by de Groot et al. [19]. The basic equation to determine thermal conductivity is

$$\lambda = \frac{q}{4\pi} \Big/ \frac{d(\Delta T)}{d \ln T} \tag{1}$$

where q is the heat generated per unit length of the wire, ΔT represents the temperature rise of the hot wire, and t denotes time. The thermal conductivity is obtained from Eq. (1) by measuring the temperature rise as a function of time. As is evident from Eq. (1), the temperature rise is linear in $\ln t$ as long as only heat conduction dominates the heat dissipation from the wire during the initial stage. After a certain period of time, natural convection becomes dominant [20] and the transient hot-wire method cannot be used to determine the thermal conductivity. In this study, the measurement was done before natural convection occurred. Details of the experimental setup and the apparatus are given in our previous work [16]. The main pressure vessel is made of SUS 304 stainless steel, of which the inner space has a height of 315 mm and a diameter of 28 mm. The diameter and length of the platinum wire are 25 μm and 125.01 mm, respectively. The temperature of the liquid refrigerant is measured with a 100-Ω Pt resistance thermometer. A spring made of copper wire is attached at the top of the hot wire to give the minimum tension required to make the wire vertical. A liquid pump was used to pressurize the fluid and the pressure was measured with a Bourdon-type pressure gauge with an accuracy of 0.4%. The temperature of the bath is controlled with a maximum variation of 0.02°C. The purities of the sample refrigerants R32 and R125 are better than 99.9 and 99.8%, respectively, according to the information provided by the manufacturers.

The thermal conductivity was measured during a very short period of time (100 to 300 ms after the onset of current supply) in order to reduce possible errors due to the onset of natural convection in the hot-wire cell. The electric conductivity of the refrigerant is not considered in this study. The sampling frequency of our measurement is 2 kHz and the temperature rise during the measurement is about 1.5°C.

3. RESULTS AND DISCUSSION

The thermal conductivities of R32 + R125 mixtures were measured in the temperature range from 233.15 to 323.15 K (−40 to 50°C) and the pressure range from 2 to 20 MPa. In addition, the weight fractions of R32 in R32 + R125 mixtures were chosen to be 0.2522, 0.4131, 0.4956, 0.5939, and 0.7595 to investigate the composition dependence of the thermal conductivity. For every combination of temperature and pressure at a certain composition, the thermal conductivity was measured five times, and the average value was taken. The standard deviation of these measurements was found to be within ±0.5%. The measured thermal-conductivity data for these mixtures are presented in Table I. The liquid thermal conductivities of R32 and R125 have been presented in our recent work [1]. However, the data measured again for these refrigerants are shown in Table I, with average deviations of 0.5% for R32 and 0.4% for R125 from the previous measurements. It is noteworthy that the thermal conductivity of R125 is almost half the value of R32 for the entire range of experiments. It is evident that the thermal conductivity of the liquid phase of R32 + R125 decreases as the temperature increases, while the pressure has the opposite effect. Measured thermal conductivities of R32 + R125 mixtures are shown in Fig. 1 to demonstrate composition dependence along isotherms for $P = 10$ MPa. A minor discrepancy among the measured temperatures at a given pressure and composition is corrected by adjusting the measured conductivity data with the fitting equation in order to plot the

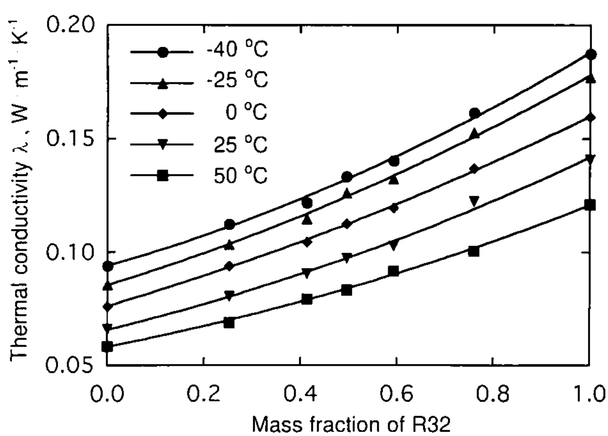

Fig. 1. Measured thermal conductivities of R32 + R125 mixtures: composition dependence along isotherms for $P = 10$ MPa.

thermal-conductivity data along isotherms. Figure 2 represents the composition dependence of the thermal conductivity along isobars for $T = 0°C$. The solid lines in the figures represent fitted values calculated from Eq. (2). In our previous study, an investigation was carried out to obtain the composition dependence of the thermal conductivity for R32 + R134a mixtures and the results showed that the thermal conductivity of the mixtures is lower than the weight fraction-averaged thermal conductivity and varies monotonously with composition [1]. In this study, a similar trend is found for R32 + R125 mixtures with slight deviations from linearity.

The experimental data for R32 + R125 mixtures were fitted to the following equation in terms of temperature, pressure, and weight fraction of R32:

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

In Eq. (2), the thermal conductivity, λ, is expressed in $W \cdot m^{-1} \cdot K^{-1}$, the temperature, T, in K, and the pressure, P, in MPa. In this equation, w represents the weight fraction of R32 in the R32 + R125 mixtures. Table II gives the numerical values of the coefficients in Eq. (2). In Fig. 3, the percentage deviations of the measured thermal-conductivity data from Eq. (2) are shown. The root-mean-square deviation of the experimental data from Eq. (2) is 1.2% for the 168 thermal conductivity data obtained in this study.

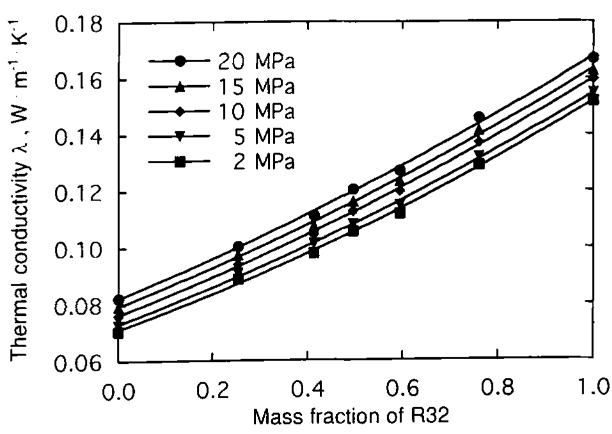

Fig. 2. Measured thermal conductivities of R32 + R125 mixtures: composition dependence along isotherms for $T = 0°C$.

Table I. Thermal Conductivity of R32 + R125 Mixtures

$P = 2.0$ MPa		$P = 5.0$ MPa		$P = 10.0$ MPa		$P = 15.0$ MPa		$P = 20.0$ MPa	
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 ($W \cdot m^{-1} \cdot K^{-1}$)
				R32:R125 = 0.0000:1.0000 (by weight)					
−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
				R32:R125 = 0.2522:0.7478					
−39.8	0.1085	−39.9	0.1101	−39.8	0.1126	−39.8	0.1147	−39.8	0.1176
−25.1	0.0992	−25.0	0.1009	−24.8	0.1037	−25.0	0.1064	−25.1	0.1094
−0.2	0.0889	−0.1	0.0910	−0.1	0.0941	0.0	0.0975	−0.1	0.1006
25.2	0.0724	25.1	0.0757	25.2	0.0805	25.2	0.0843	25.8	0.0875
	—	50.3	0.0639	50.7	0.0689	50.7	0.0736	50.8	0.0780
				R32:R125 = 0.4131:0.5869					
−40.4	0.1179	−40.3	0.1194	−40.5	0.1220	−40.1	0.1246	−40.2	0.1273
−25.4	0.1114	−25.0	0.1131	−25.0	0.1150	−24.9	0.1174	−25.0	0.1202
−0.6	0.0981	−0.4	0.1013	−0.5	0.1047	−0.3	0.1075	−0.5	0.1113
24.9	0.0828	24.9	0.0860	25.0	0.0905	25.1	0.0941	25.2	0.0974
	—	50.1	0.0731	50.1	0.0795	50.1	0.0841	50.2	0.0887
				R32:R125 = 0.4956:0.5044					
−40.0	0.1291	−40.2	0.1309	−40.1	0.1337	−39.9	0.1358	−39.9	0.1378
−25.3	0.1215	−25.1	0.1239	−25.2	0.1263	−25.0	0.1292	−25.2	0.1316
−0.3	0.1058	−0.4	0.1083	−0.3	0.1129	−0.3	0.1164	−0.2	0.1206
24.6	0.0901	24.4	0.0936	24.9	0.0976	24.8	0.1021	24.7	0.1052
	—	50.1	0.0769	50.0	0.0835	49.8	0.0898	50.0	0.0945

				R32:R125 = 0.5939:0.4061					
−40.0	0.1357	−40.1	0.1381	−40.1	0.1406	−40.3	0.1431	−40.2	0.1456
−25.3	0.1282	−25.4	0.1304	−25.2	0.1328	−25.2	0.1366	−25.3	0.1399
−0.4	0.1120	−0.4	0.1150	−0.3	0.1199	−0.3	0.1235	−0.3	0.1272
24.5	0.0950	24.4	0.0978	24.7	0.1029	24.7	0.1072	24.6	0.1121
		50.0	0.0858	49.9	0.0918	50.1	0.0964	50.3	0.1003
				R32:R125 = 0.7595:0.2405					
−39.5	0.1568	−39.8	0.1585	−39.8	0.1615	−39.7	0.1646	−39.4	0.1667
−25.3	0.1488	−25.4	0.1506	−25.1	0.1529	−25.2	0.1556	−25.2	0.1586
−0.2	0.1293	−0.3	0.1320	−0.2	0.1371	−0.1	0.1415	−0.6	0.1458
24.8	0.1106	24.6	0.1151	24.7	0.1226	24.7	0.1250	24.8	0.1293
		50.3	0.0938	50.4	0.1008	50.0	0.1067	50.1	0.1132
				R32:R125 = 1.0000:0.0000					
−40.6	0.1827	−40.5	0.1846	−40.5	0.1874	−40.5	0.1897	−40.6	0.1927
−25.6	0.1719	−25.4	0.1735	−25.7	0.1773	−25.7	0.1810	−25.7	0.1837
−0.5	0.1520	−0.6	0.1547	−0.5	0.1596	−0.4	0.1627	−0.6	0.1670
24.9	0.1312	24.9	0.1356	24.8	0.1407	24.8	0.1456	24.7	0.1504
	—	49.7	0.1141	49.8	0.1211	49.5	0.1270	49.8	0.1324

Table II. Coefficients in Eq. (2) for R32 + R125 Mixtures

	λ_0	2.185366×10^{-1}	
	$k = 0$	$k = 1$	$k = 2$
a_{00k}	1.000000×10^{0}	-6.600279×10^{-1}	1.125011×10^{0}
a_{01k}	2.220416×10^{-2}	2.352145×10^{-2}	-6.877394×10^{-2}
a_{02k}	-7.422716×10^{-4}	-1.317644×10^{-3}	2.976829×10^{-3}
a_{10k}	-2.916130×10^{-3}	8.272182×10^{-3}	-7.253132×10^{-3}
a_{11k}	-1.770383×10^{-4}	-2.055364×10^{-4}	5.368597×10^{-4}
a_{12k}	6.070319×10^{-6}	1.027912×10^{-5}	-2.273215×10^{-5}
a_{20k}	1.495256×10^{-6}	-1.786627×10^{-5}	1.287940×10^{-5}
a_{21k}	3.933418×10^{-7}	4.602183×10^{-7}	-1.043006×10^{-6}
a_{22k}	-1.245789×10^{-8}	-2.040378×10^{-8}	4.332244×10^{-8}

4. CONCLUDING REMARKS

The thermal conductivities of near-azeotropic refrigerant mixtures of R32 and R125 in the liquid phase have been measured with the transient hot-wire method by varying the temperature, pressure, and weight fraction of R32 in the mixture. The thermal conductivities were measured over a temperature range from −40 to 50°C at several pressures from 2 to 20 MPa. Composition dependence along isotherms and isobars has been

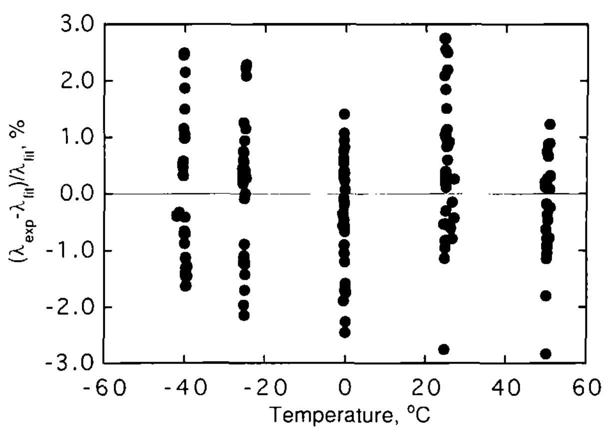

Fig. 3. Percentage deviations of the experimental thermal-conductivity data from Eq. (2) for R32 + R125 mixtures.

presented for R32 + R125 mixtures. An empirical equation for the prediction of the thermal conductivity of the R32 + R125 mixtures has been presented from the measured thermal-conductivity data.

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