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Thermal Conductivity of R32 and Its Mixture with R134a [1]

S. T. Ro,[2,3] J. Y. Kim,[2] and D. S. Kim[2]

The liquid thermal conductivity of R32 (CH_2F_2) and R134a (CF_3CH_2F) was measured in the range from 223 to 323 K and from 2 to 20 MPa by the transient hot-wire method. The thermal conductivity of the R32 + R134a mixture was also measured in the same range by varying the mass fraction of R32. The measured data are analyzed to obtain a correlation in terms of temperature, pressure and composition of the mixture. The uncertainty of our measurements is estimated to be within $\pm 2\%$.

KEY WORDS: R134a, R32; R32 + R134a mixture; thermal conductivity; transient hot-wire method.

1. INTRODUCTION

When designing and analyzing thermal systems, it is necessary to know the transport properties of the working fluid as well as its thermodynamic properties. Especially, the analysis of heat transfer process requires well-established data for thermal conductivity. As is well-known, CFCs are being replaced by the new environmentally acceptable fluorocarbons. R32 and R134a are among such alternative refrigerants. Many experimental data for the thermal conductivity of R134a have been provided so far. Unfortunately, few data for R32 are available in spite of the fact that it is one of the potential replacements for the refrigerant R22 currently in use. In addition, thermal conductivity data for binary and ternary mixtures of alternative refrigerants are very scarce [1, 2].

The main purpose of this study is to perform experiments and to provide precise thermal-conductivity data for the two possible alternative

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

[3] To whom correspondence should be addressed.

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refrigerants, R32 and R134a, and their mixtures. Following our previous works on the thermal conductivity of refrigerant mixtures [1, 2], this paper would also help to get an insight into the general characteristics of fluorocarbon mixtures.

2. EXPERIMENTS

In this study, the transient hot-wire method was used in the measurements. The basic equation to determine thermal conductivity and the details of the experimental setup and the apparatus were previously described in our recent works [1, 2]. The apparatus is mainly composed of a hot-wire cell, a pressure vessel, a Wheatstone-bridge circuit, a data-processing system, and a temperature-control and pressuring system.

The hot-wire cell described elsewhere [1, 2] was used in this study. A single bare platinum wire was used in the experiments. The diameter and the length of the platinum wire are 25 μm and 135.26 mm, respectively. The data were acquired over the time interval of 100 to 300 ms after the onset of current supply. The purities of the sample refrigerants R32 and R134a are better than 99.9 and 99.8%, respectively, according to the analysis of the manufacturers.

3. RESULTS

3.1. Thermal Conductivity of R32 and R134a in the Liquid Phase

Thermal conductivities of R32 and R134a were measured over a temperature range of 223.15 to 323.15 K (−50 to 50°C). All the measurements have been conducted by varying the pressure from 2 to 20 MPa. The measured values of thermal conductivity are compiled in Table I. Though the liquid thermal conductivity of R134a was measured in our recent work [2], it was measured again (prior to the measurements for R32 and its mixture with R134a) to confirm the reproducibility of the measurements. The difference between the previous values and those obtained here was found to be within 1%. The following equation in terms of reduced temperature and pressure has been fitted to the experimental data for the thermal conductivity of pure refrigerants in the liquid state:

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

where λ is in $mW \cdot m^{-1} \cdot K^{-1}$, T is in K, and P is in MPa.

Table I. Measured Thermal Conductivity of R32 + R134a Mixtures in the Liquid State

T_{nom} (K)	P (MPa)	Thermal conductivity λ ($mW \cdot m^{-1} \cdot K^{-1}$) at a mass fraction of R32 of 0.0000	0.3057	0.5107	0.7496	1.0000
223.15	20.0	122.68	139.49	151.69	173.78	198.40
	25.0	120.87	137.63	149.57	171.80	195.87
	10.0	119.17	135.72	147.35	169.36	193.22
	5.0	116.87	133.65	145.04	167.15	190.23
	2.0	115.84	132.03	143.63	165.44	188.54
248.15	20.0	112.51	127.33	137.96	158.43	183.55
	15.0	110.52	124.94	135.44	155.84	180.72
	10.0	108.22	122.44	132.88	152.90	177.35
	5.0	105.88	119.85	130.23	149.43	173.96
	2.0	104.35	118.23	128.58	147.77	171.43
273.15	20.0	102.43	115.55	125.43	143.16	166.86
	15.0	100.06	112.83	122.45	139.83	163.54
	10.0	97.64	110.07	119.47	136.52	159.68
	5.0	94.62	106.63	116.26	133.10	155.57
	2.0	92.99	104.67	113.98	130.52	152.71
298.15	20.0	93.42	104.23	112.90	128.46	150.57
	15.0	90.65	101.13	109.76	124.87	146.06
	10.0	87.67	97.91	105.79	120.83	141.05
	5.0	84.32	94.04	102.01	116.00	135.72
	2.0	82.17	91.73	98.89	113.31	131.66
323.15	20.0	85.85	94.20	101.24	113.81	130.40
	15.0	82.28	90.33	97.18	109.33	124.86
	10.0	78.60	86.57	92.72	104.16	118.62
	5.0	74.48	81.65	87.32	97.53	110.35

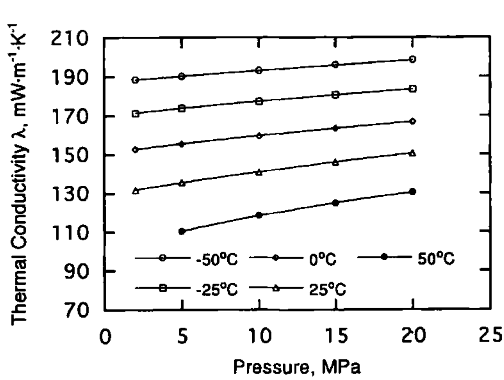

Fig. 1. Measured thermal conductivity of R32; pressure dependence along isotherms.

Table II. Coefficients in Eq. (1) for R32 and R134a in the Liquid State

	R32	R134a
T_c (K)	351.55	374.25
P_c (MPa)	5.830	4.067
λ^0	1.9808×10^2	2.3165×10^2
a_{00}	1.0000×10^0	1.0000×10^0
a_{01}	1.0360×10^{-1}	3.2951×10^{-2}
a_{02}	-1.6572×10^{-3}	-9.6170×10^{-4}
a_{10}	8.7262×10^{-1}	-9.2181×10^{-1}
a_{11}	-3.0038×10^{-1}	-9.4384×10^{-2}
a_{12}	7.9228×10^{-3}	3.3511×10^{-3}
a_{20}	-1.5169×10^0	1.2954×10^{-1}
a_{21}	2.6424×10^{-1}	8.8077×10^{-2}
a_{22}	-1.0129×10^{-2}	-3.4119×10^{-3}
δ (%)	0.26	0.14
δ_M (%)	0.83	0.34

Table II lists the coefficients and critical properties (T_c, P_c) used in Eq. (1) for each refrigerant. In the table, δ represents an average deviation of the experimental data from Eq. (1) and δ_M a maximum deviation. Figure 1 represents the pressure dependence of the thermal conductivity of R32 along isotherms and Fig. 2 the temperature dependence along isobars.

The measured thermal conductivities have been extrapolated from Eq. (1) to the saturation pressure of each refrigerant at a given temperature. For convenience, the extrapolated thermal conductivities of R134a and R32

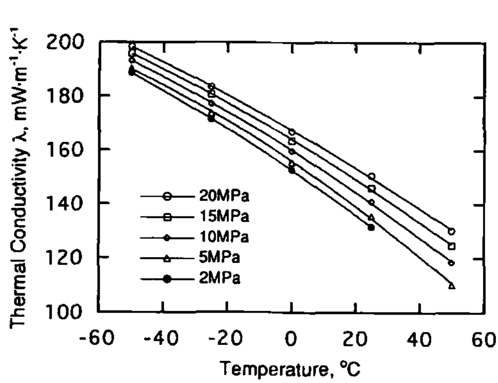

Fig. 2. Measured thermal conductivity of R32; pressure dependence along isobars.

in the saturated-liquid state can be correlated in terms of temperature as below:

for R32,

$$\lambda_{sl} = 2.4082 \times 10^2 + 0.1360T - 1.6914 \times 10^{-3}\, T^2 \tag{2}$$

for R134a,

$$\lambda_{sl} = 2.4159 \times 10^2 - 0.6539T + 3.8857 \times 10^{-4}\, T^2 \tag{3}$$

where λ_{sl} is in $mW \cdot m^{-1} \cdot K^{-1}$ and T is in K.

There are relatively many data available for thermal conductivity of R134a in the literature. However, it has been known that many of the reported values of the thermal conductivity of refrigerants are somewhat scattered. For thermal conductivity of R32, there have been only a few measurements. The present data are compared with the results of other measurements. Figures 3 and 4 compare the present data for R32 and R134a, respectively, with some available data [3–11] in the saturated-liquid state. The deviation values in the figures are based on Eq. (1).

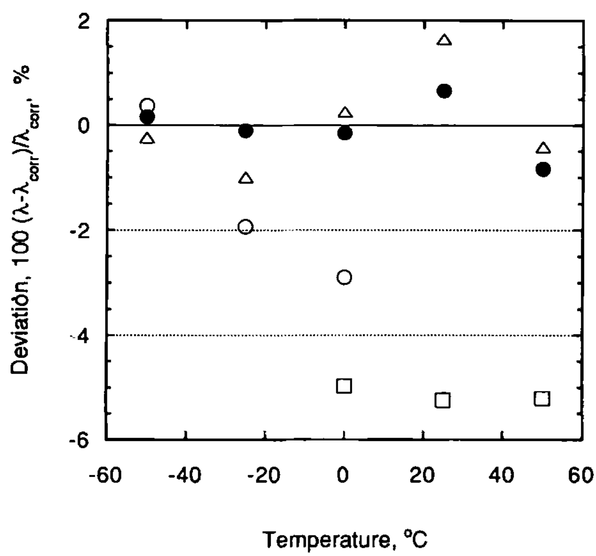

Fig. 3. Comparison of the thermal conductivity of R32 at saturated-liquid state. (●) Present measurements at 5 MPa; (○) Tauscher [3]; (□) Yata [4]; (△) Papadaki [5]. The baseline represents Eq. (1).

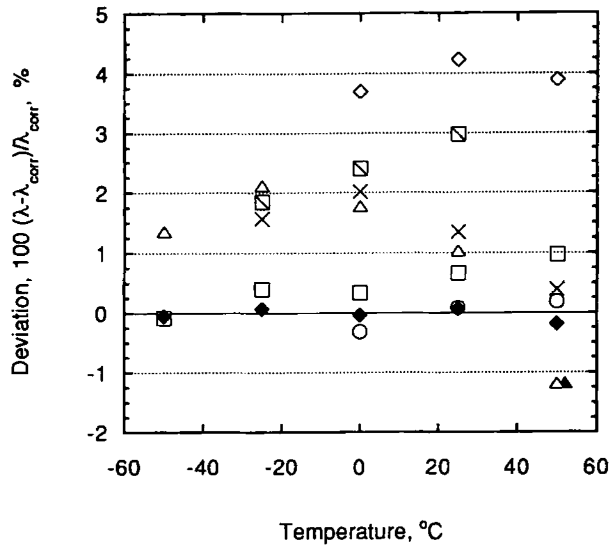

Fig. 4. Comparison of the thermal conductivity of R134a at saturated-liquid state. (◆) Present measurements at 2 MPa; (□) Kim [2]; (▲) Fellows [6]; (△) Laesecke [7]; (◇) Gross [8]; (○) Assael [9]; (⊠) Papadaki [10]; (×) Krauss [11]. The baseline represents Eq. (1).

3.2. Thermal Conductivity of R32 + R134a Mixtures in the Liquid Phase

The thermal conductivities of R32 + R134a mixtures were measured in a temperature range of 223.15 to 323.15 K (−50 to 50°C) and a pressure range of 2 to 20 MPa. The mass fractions of R32 were chosen as 0.3, 0.5 and 0.75, approximately. The results are shown in Table I. The experimental data for R32 + R134a mixtures can be correlated in terms of temperature, pressure, and mass fraction by an equation of the following form:

$$\lambda = \lambda^0 \sum_{k=0}^{2} \sum_{j=0}^{2} \sum_{i=0}^{2} a_{ijk} T^i P^j w^k \tag{4}$$

where λ is in $\mathrm{mW \cdot m^{-1} \cdot K^{-1}}$, T is in K, P is in MPa, and w is the mass fraction of R32. Table III gives the numerical values of the coefficients used in Eq. (4). The average and maximum deviations of the experimental data from Eq. (4) are 0.46 and 1.21 %, respectively.

Table III. Coefficients in Eq. (4)

	$\lambda^0 = 2.3026 \times 10^2$		
	$k=0$	$k=1$	$k=2$
a_{00k}	1.0000×10^{0}	9.8428×10^{-1}	-1.0490×10^{0}
a_{01k}	2.4888×10^{-3}	1.7110×10^{-2}	-5.4456×10^{-3}
a_{02k}	9.2080×10^{-5}	-1.2400×10^{-3}	1.1086×10^{-3}
a_{10k}	-2.4431×10^{-3}	-5.3408×10^{-3}	9.3795×10^{-3}
a_{11k}	-1.8135×10^{-5}	-1.3968×10^{-4}	3.9875×10^{-5}
a_{12k}	-6.7062×10^{-7}	9.8358×10^{-6}	-8.6215×10^{-6}
a_{20k}	9.0005×10^{-7}	7.6894×10^{-6}	-1.8194×10^{-5}
a_{21k}	7.0442×10^{-8}	2.8292×10^{-7}	-5.3062×10^{-8}
a_{22k}	9.2447×10^{-10}	-1.9074×10^{-8}	1.6158×10^{-8}

A preliminary investigation has been carried out to obtain the composition dependence of the thermal conductivity of R32 + R134a mixtures and the results show that the thermal conductivity of the mixtures is smaller than the mass-fraction average and varies monotonically with composition. Figure 5 exhibits the isothermal composition dependence of the thermal conductivity of R32 + R134a mixtures for an isobar of 10 MPa, and Fig. 6 the isobaric composition dependence for an isotherm of 273.15 K (0°C). The solid lines in the figures represent values calculated with Eq. (1).

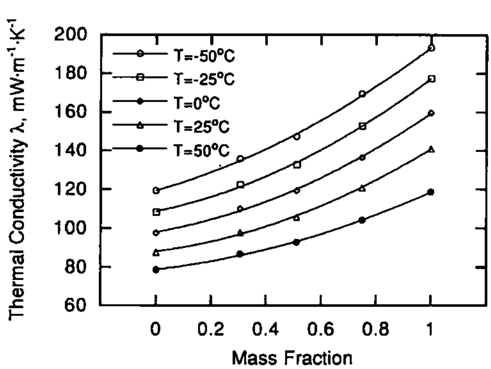

Fig. 5. Measured thermal conductivity of R32 + R134a mixtures; composition dependence along isotherms for an isobar $P = 10.0$ MPa.

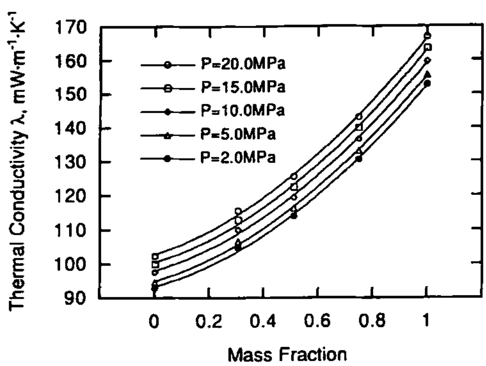

Fig. 6. Measured thermal conductivity of R32 + R134a mixtures; composition dependence along isobars for an isotherm $T = 0°C$.

4. CONCLUSION

Using the transient hot-wire method, the thermal conductivities of two pure refrigerants R32 and R134a and their mixtures R32 + R134a have been measured by varying temperature, pressure and mass fraction in the liquid state. Correlation equations for the prediction of the thermal conductivity of the two pure refrigerants and their mixtures were presented from the measurements.

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