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Thermal Conductivity of Alternative Refrigerants in the Liquid Phase[1]

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Measurements of the thermal conductivity of five alternative refrigerants, namely, difluoromethane (HFC-32), pentafluoroethane (HFC-125), 1,1,1-trifluoroethane (HFC-143a), and dichloropentafluoropropanes (HCFC-225ca and HCFC-225cb), are carried out in the liquid phase. The range of temperature is 253–324 K for HFC-32, 257–305 K for HFC-125, 268–314 K for HFC-134a, 267–325 K for HCFC-225ca, and 286–345 K for HCFC-225cb. The pressure range is from saturation to 30 MPa. The reproducibility of the data is better than 0.5%, and the accuracy of the data is estimated to be of the order of 1%. The experimental results for the thermal conductivity of each substance are correlated by an equation which is a function of temperature and pressure. A short discussion is given to the comparison of the present results with literature values for HFC-125. The saturated liquid thermal conductivity values of HFC-32, HFC-125, and HFC-143a are compared with those of chlorodifluoromethane (HCFC-22) and tetrafluoroethane (HFC-134a) and it is shown that the value of HFC-32 is highest, while that of HFC-125 is lowest, among these substances. The dependence of thermal conductivity on number of fluorine atoms among the refrigerants with the same number of carbon and hydrogen atoms is discussed.

KEY WORDS: alternative refrigerants; difluoromethane (HFC-32); pentafluoroethane (HFC-125); 1,1,1-trifluoroethane (HFC-143a); dichloropentafluoropropanes (HCFC-225ca, HCFC-225cb); liquid phase; thermal conductivity.

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1. INTRODUCTION

The thermophysical properties of many alternative refrigerants have been investigated recently. However, the experimental results of the thermal conductivity of CFC alternatives are not enough at present. In the previous papers the present authors have reported the results for HCFC-123, HCFC-124, HFC-134a, HCFC-141b, HCFC-142b, and HFC-152a [1, 2]. In this paper the experimental results of liquid thermal conductivity for HFC-32, HFC-125, HFC-143a, HCFC-225ca, and HCFC-225cb are reported.

2. EXPERIMENTS

The transient hot-wire method is used in this study. The experimental apparatus is almost the same as those used previously [1, 2]. Two hot wires with different lengths have been used to compensate for end effects. The diameter of the wires is 20 μm and the effective length of the wires is around 60 mm. The thermal conductivity cell which contains the hot wires is installed in a high-pressure vessel, and the vessel is placed in a thermostated aluminum block whose temperature is kept at prescribed temperatures within ±0.02 K. The purity of refrigerants supplied is better than 99.5%.

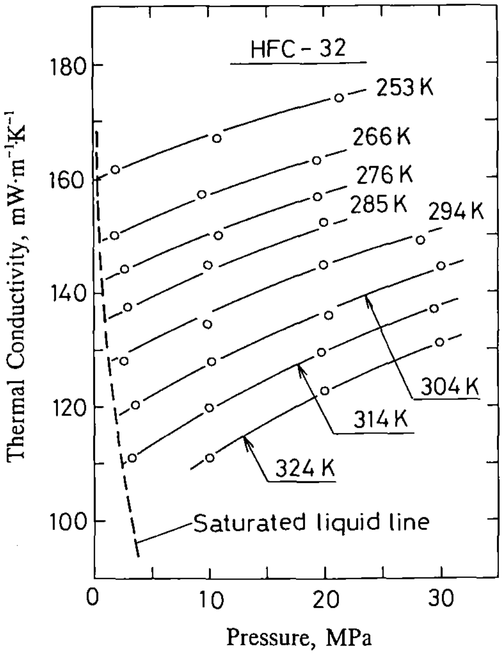

Fig. 1. Thermal conductivity of HFC-32 as a function of pressure.

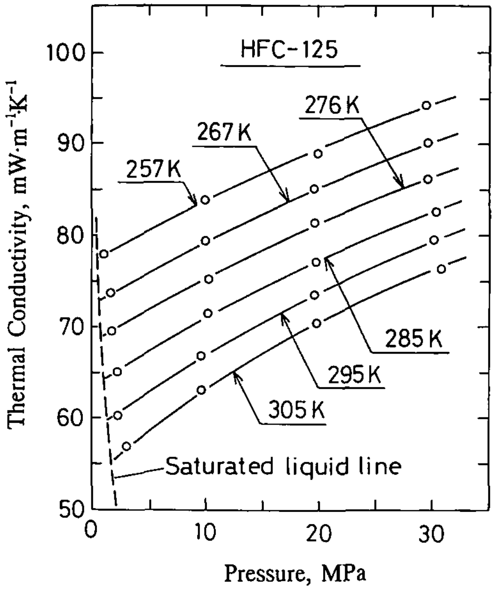

Fig. 2. Thermal conductivity of HFC-125 as a function of pressure.

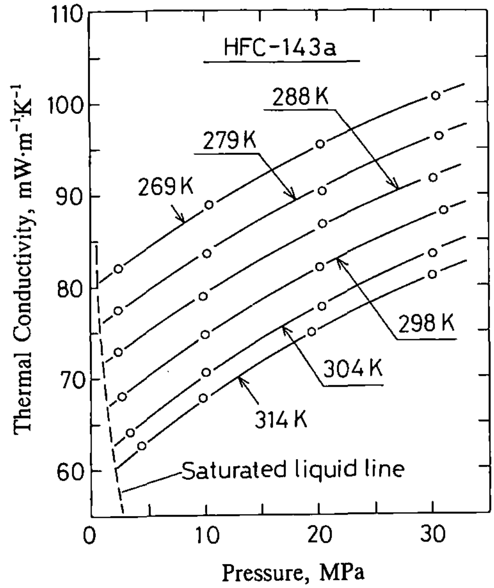

Fig. 3. Thermal conductivity of HFC-143a as a function of pressure.

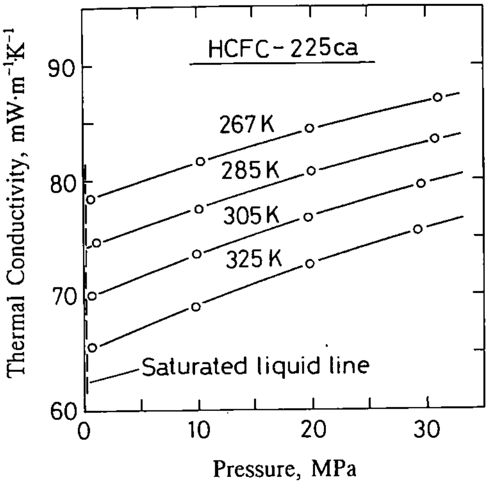

Fig. 4. Thermal conductivity of HCFC-225ca as a function of pressure.

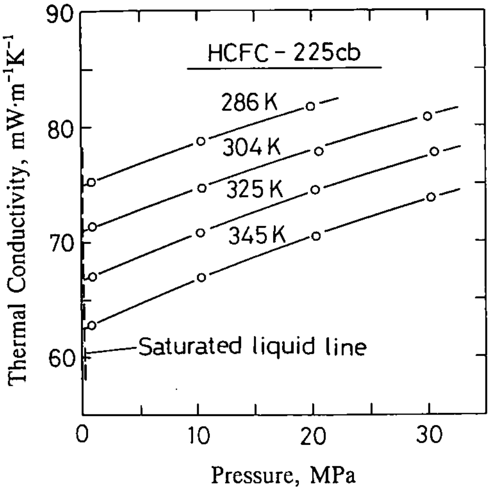

Fig. 5. Thermal conductivity of HCFC-225cb as a function of pressure.

3. RESULTS

Measurements of the thermal conductivity have been carried out in the liquid phase, over the temperature range 253–324 K for HFC-32, 257–305 K for HFC-125, 268–314 K for HFC-143a, 267–325 K for HCFC-225ca, and 286–345 K for HCFC-225cb, and over the pressure range from saturation to 30 MPa. The reproducibility of the data is better than 0.5%, and the accuracy of the presents results is estimated to be of the order of 1%. The experimental results for HFC-32, HFC-125, HFC-143a, HCFC-225ca, and HCFC-225cb are shown in Figs. 1, 2, 3, 4, and 5, respectively. The experimental results for thermal conductivity are also tabulated in Tables I, II, III, IV, and V.

Table I. Experimental Results for the Thermal Conductivity of HFC-32

Temperature (K)	Pressure (MPa)	Thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
253.43	2.0	161.6
253.16	10.8	167.1
253.57	21.3	174.1
266.28	1.9	150.2
266.17	9.4	157.6
266.03	19.4	163.6
275.88	2.7	144.4
275.81	10.8	150.1
275.59	19.4	156.6
285.11	3.1	137.4
285.06	9.8	143.0
284.99	19.9	151.7
294.43	3.7	127.8
294.45	9.8	134.1
294.36	20.3	143.2
294.23	28.4	149.2
304.23	3.7	120.2
304.04	10.2	127.9
303.92	20.4	135.8
303.80	30.0	144.7
314.27	3.4	111.3
314.14	9.9	119.6
313.95	19.6	129.7
313.83	29.4	137.1
324.33	10.1	111.1
324.23	19.9	122.7
324.09	30.0	131.5

Table II. Experimental Results for the Thermal Conductivity of HFC-125

Temperature (K)	Pressure (MPa)	Thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
257.13	1.1	77.6
257.05	10.0	83.7
257.20	20.0	89.0
258.09	29.6	94.3
267.00	1.7	73.6
266.82	10.1	79.3
266.52	19.7	85.1
266.46	29.7	90.1
275.65	1.8	69.4
275.65	10.3	75.2
275.84	19.7	81.3
275.72	29.7	86.2
285.45	2.1	65.0
285.31	10.2	71.5
285.23	19.8	77.0
285.12	30.4	82.8
295.08	2.2	60.2
294.95	9.8	66.9
294.87	19.7	73.5
294.87	30.2	79.7
304.70	3.0	56.9
304.56	9.8	63.2
304.45	19.9	70.4
304.36	30.9	76.6

Table III. Experimental Results for the Thermal Conductivity of HFC-143a

Temperature (K)	Pressure (MPa)	Thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
268.82	2.4	83.2
268.63	10.4	89.1
268.54	20.3	95.4
268.44	30.6	100.6
279.00	2.4	77.4
278.99	10.1	83.6
279.05	20.5	90.3
279.02	30.7	96.3
288.44	2.4	72.9
288.30	9.8	78.9
288.32	20.5	86.9
288.33	30.2	91.5

Table III. *(Continued)*

Temperature (K)	Pressure (MPa)	Thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
297.78	2.7	68.0
297.77	10.0	74.7
297.76	20.2	82.0
297.81	31.1	88.2
307.70	3.4	64.0
307.70	10.1	70.4
307.66	20.5	77.8
307.63	30.2	83.3
313.51	4.3	62.8
313.49	9.8	67.7
314.19	19.5	75.0
314.26	30.1	81.0

Table IV. Experimental Results for the Thermal Conductivity of HCFC-225ca

Temperature (K)	Pressure (MPa)	Thermal conductivity ($mW \cdot m^{-1} \cdot K^{-1}$)
267.44	0.7	78.3
267.32	10.4	81.6
267.16	20.1	84.4
267.15	31.2	87.0
285.62	1.2	74.6
285.78	10.2	77.4
285.35	20.0	80.6
285.22	30.8	83.4
305.05	0.8	70.0
304.89	10.0	73.6
304.74	19.8	76.6
304.49	29.6	79.5
325.10	0.9	65.4
324.90	9.9	68.9
324.73	19.9	72.6
324.56	29.3	75.6

Table V. Experimental Results for the Thermal Conductivity of HCFC-225cb

Temperature (K)	Pressure (MPa)	Thermal conductivity ($\mathrm{mW \cdot m^{-1} \cdot K^{-1}}$)
286.08	0.8	75.6
285.75	10.4	78.7
286.11	20.0	81.6
305.21	0.9	71.3
304.51	10.3	74.6
303.80	20.7	77.8
303.92	30.0	80.8
325.70	0.9	67.0
325.49	10.2	70.7
325.23	20.2	74.4
324.62	30.7	77.7
344.83	0.9	62.9
344.66	10.4	66.9
344.51	20.3	70.5
344.45	30.1	73.8

4. DISCUSSION

The experimental results for the thermal conductivity of each substance have been correlated by the following equation:

$$\lambda = A_{0,0} + A_{0,1} T + (A_{1,0} + A_{1,1} T + A_{1,2} T^2) p + (A_{2,0} + A_{2,1} T + A_{2,2} T^2) p^2 \tag{1}$$

where λ is thermal conductivity in $\mathrm{mW \cdot m^{-1} K^{-1}}$, T is temperature in K (ITS90); and p is pressure in MPa. The numerical values of the coefficients

Table VI. Numerical Values of Coefficients in Eq. (1)

	HFC-32	HFC-125	HFC-143a
$A_{0,0}$	3.8397×10^{2}	2.0210×10^{2}	2.2021×10^{2}
$A_{0,1}$	-8.8074×10^{-1}	-4.8629×10^{-1}	-5.1830×10^{-1}
$A_{1,0}$	-9.3375×10^{0}	3.7007×10^{0}	1.2533×10^{1}
$A_{1,1}$	6.1250×10^{-2}	-2.7582×10^{-2}	-8.5959×10^{-2}
$A_{1,2}$	-8.7057×10^{-5}	6.1400×10^{-5}	1.5811×10^{-4}
$A_{2,0}$	4.0721×10^{-1}	4.7055×10^{-2}	-3.9017×10^{-1}
$A_{2,1}$	-2.7360×10^{-3}	-2.4968×10^{-4}	2.7399×10^{-3}
$A_{2,2}$	4.4805×10^{-6}	2.2010×10^{-7}	-4.8878×10^{-6}

Table VII. Numerical Values of Coefficients in Eq. (1)

	HCFC-225ca	HCFC-225cb
$A_{0,0}$	1.3833×10^{2}	1.3719×10^{2}
$A_{0,1}$	-2.2513×10^{-1}	-2.1667×10^{-1}
$A_{1,0}$	-6.9901×10^{-1}	4.8890×10^{0}
$A_{1,1}$	6.4031×10^{-3}	-3.0215×10^{-2}
$A_{1,2}$	-9.2508×10^{-6}	5.0349×10^{-5}
$A_{2,0}$	2.6921×10^{-2}	-2.1119×10^{-1}
$A_{2,1}$	-2.0501×10^{-4}	1.3322×10^{-3}
$A_{2,2}$	3.5898×10^{-7}	-2.1108×10^{-6}

for each substance are listed in Tables VI and VII. The average and maximum deviations of the experimental data from the equation do not exceed 0.4 and 1.0%, respectively. The thermal conductivity equation at saturated liquid state is also correlated as follows:

$$\lambda_s = B_0 + B_1 T \tag{2}$$

and the numerical values of the coefficients are listed in Table VIII.

The experimental values of HFC-125 in the liquid phase were reported by Wilson et al. [3], Fellows et al. [4], and Yamada et al. [5]. Wilson et al. reported four points of data in the range 216–333 K, and Fellows et al. reported six points of data in the range 305–328 K. Yamada et al. reported graphical data of 29 points in the range 193–333 K and 2–30 MPa. The present results seem to agree well with those of Fellows et al. and Yamada et al., while the results of Wilson et al. are higher by several percent.

HFC-32, HFC-125, and HFC-143a are future alternatives to HCFC-22, and the saturated liquid thermal conductivity values of these substances are compared with those of HCFC-22 and HFC-134a in Fig. 6. Among these substances, it proved that the value of HFC-32 is the highest, while that of HFC-125 is the lowest.

The values of HCFC-123 ($CHCl_2 \cdot CF_3$), HCFC-124 ($CHClF \cdot CF_3$), and HFC-125 ($CHF_2 \cdot CF_3$), which have the same number of carbon

Table VIII. Numerical Values of Coefficients in Eq. (2)

	HFC-32	HFC-125	HFC-143a	HCFC-225ca	HCFC-225cb
B_0	370.84	195.14	210.95	138.16	136.85
B_1	−0.82942	−0.45866	−0.48278	−0.22447	−0.21547

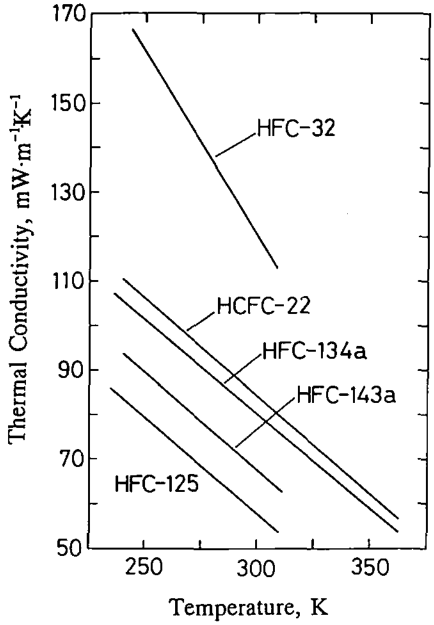

Fig. 6. Comparison of thermal conductivity of various refrigerants in the saturated liquid state.

and hydrogen atoms, are also compared. At the same temperature, the thermal conductivity of saturated liquid decreases with increasing number of fluorine atoms. The same is true in the group of HCFC-141b ($CCl_2F \cdot CH_3$), HCFC-142b ($CClF_2 \cdot CH_3$), and HFC-143a ($CF_3 \cdot CH_3$).

HCFC-225ca and HCFC-225cb are substitutes for CFC-113. It is shown that the saturated liquid values of the thermal conductivities of these three substances are almost the same.

5. CONCLUSION

The thermal conductivity of HFC-32, HFC-125, HFC-143a, and HCFC-225ca and HCFC-225cb has been measured in the wide range of temperature and pressure in liquid phase with an accuracy of the order of 1%. The experimental results of the thermal conductivity of each substance have been correlated by an equation with an average deviation less than 0.4%. The saturated liquid thermal conductivity values of HFC-32, HFC-125, and HFC-143a have been compared with those of HCFC-22 and HFC-134a and it is shown that the value of HFC-32 is highest, while that of HFC-125 is lowest, among these substances.

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