International Journal of Thermophysics, Vol. 20, No. 5, 1999

Measurements of the Thermal Conductivity of HFC-134a in the Temperature Range from 300 to 530 K and at Pressures up to 50 MPa

B. Le Neindre[1,2] and Y. Garrabos[3]

Received November 23, 1998

Measurements of the thermal conductivity of HFC-134a made in a coaxial cylinder cell operating in steady state are reported. The measurements of the thermal conductivity of HFC-134a were performed along several quasi-isotherms between 300 and 530 K in the gas phase and the liquid phase. The pressure ranged from 0.1 to 50 MPa. Based on the experimental data, a background equation is provided to calculate the thermal conductivity outside the critical region as a function of temperature and pressure. A careful analysis of the various sources of errors leads to an estimated uncertainty of $\pm 1.5\%$.

KEY WORDS: coaxial cylinders; HFC-134a; high pressure; high temperature; refrigerant; thermal conductivity.

1. INTRODUCTION

Recently there has been great interest in the determination of the thermophysical properties of alternative refrigerants which are not harmful for the environment. Among them, HFC-134a (1,1,1,2-tetrafluoroethane) is an environmentally acceptable alternative refrigerant to CFC-12 (dichlorodifluoromethane). In our laboratory, we have carried out a series of measurements of the thermal conductivity of several alternative refrigerants over a large range of temperatures and pressures, including subcritical and supercritical regions [1–3]. The measurements allow analysis of the data based

[1] LIMHP–CNRS, Institut Galilée, Université Paris Nord, Av. J. B. Clément, 93430 Villetaneuse, France.
[2] To whom correspondence should be addressed.
[3] Institut de Chimie de la Matière Condensée de Bordeaux, Université de Bordeaux 1, Av. du Dr. Schweitzer, 33608 Pessac, France.

0195-928X/99/0900-1379$16.00/0

on the residual concept. The transport property surface is separated into four regions, the gaseous state (at $P = 1.01325$ bar), the dense state, the subcritical region ($T < T_C$), and the supercritical region ($T > T_C$). The thermal conductivity is expressed as a function of temperature and density:

$$\lambda(T, \rho) = \lambda_0(T) + \delta\lambda(T, \rho) + \Delta\lambda(T, \rho) \quad (1)$$

where $\lambda_0(T)$ is the dilute gas thermal conductivity, $\delta\lambda(T, \rho)$ is the residual thermal conductivity, and $\Delta\lambda(T, \rho)$ is the critical enhancement. In this paper, we use only data in the liquid phase and in the gas phase at atmospheric pressure and far from the supercritical region to determine the background thermal conductivity

$$\lambda(T, \rho) = \lambda_0(T) + \delta\lambda(T, \rho) \quad (2)$$

The thermal conductivity of HFC-134a was measured between vertical coaxial cylinders, operating in the steady-state mode. This method was previously used in the measurement of the thermal conductivity of 1-chloro-1,1-difluoroethane (HCFC-142b) [4]. The density was calculated with an equation of state reported by Tillner-Roth and Baehr [5], where the critical parameters together with the estimated uncertainties are given as follows:

$T_c = (374.18 \pm 0.18)$ K,
$p_c = (4.05629 \pm 0.016)$ MPa, and
$\rho_c = (508 \pm 8)$ $\mathrm{kg \cdot m^{-3}}$.

The sample was provided by Elf-Atochem, and its purity was estimated to be better than 99.9% by the manufacturer's analysis.

2. DILUTE-GAS THERMAL CONDUCTIVITY

The results for the measurement of the thermal conductivity at atmospheric pressure are presented in Table I. The experimental data were fit to a linear equation,

$$\lambda_o = -14.1875 + 0.0905T \quad (3)$$

The relative deviations between experimental data and Eq. (3) are shown in Fig. 1. All deviations are within the uncertainty of the data, less than $\pm 1.5\%$. The temperature dependence of the thermal conductivity of the dilute gas was also represented by an expression derived from the kinetic

Table I. Thermal Conductivity of HFC-134a at Atmospheric Pressure

T (K)	λ $(mW \cdot m^{-1} \cdot K^{-1})$	T (K)	λ $(mW \cdot m^{-1} \cdot K^{-1})$	T (K)	λ $(mW \cdot m^{-1} \cdot K^{-1})$
299.18	12.76	376.16	19.92	453.89	26.88
301.71	13.12	378.44	19.94	453.91	26.78
316.53	14.46	386.30	20.95	454.51	26.89
330.19	15.63	405.82	22.64	465.02	27.97
337.55	16.28	413.53	22.99	465.25	27.90
345.03	17.06	425.02	24.36	473.26	28.42
348.56	17.43	425.22	24.59	473.37	29.04
351.24	17.44	433.32	24.96	493.29	30.95
357.95	18.25	435.36	25.31	513.38	32.45
365.85	18.95	445.12	26.27	533.02	34.62
371.63	19.51	450.00	26.71		

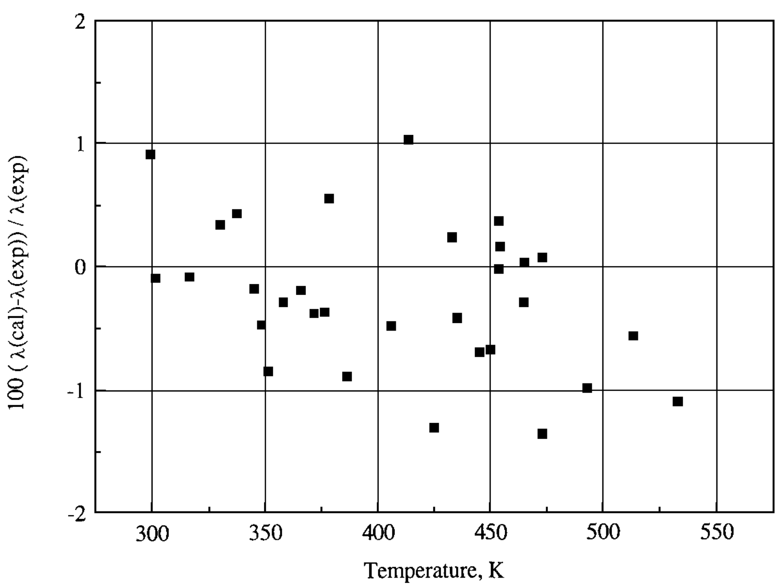

Fig. 1. Relative deviations of the experimental data from the values calculated with Eq. (3).

theory of gases. To calculate the thermal conductivity in the zero-density limit, the practical engineering form was used:

$$\lambda_o(T) = \frac{0.177568(T/M)^{0.5}\, C_P^o/R}{\sigma^2 \Omega_\lambda^*} \tag{4}$$

where $T^* = kT/\varepsilon$, Ω_λ^* is the reduced effective collision cross section for thermal conductivity, and C_P^o is the ideal isobaric heat capacity. The scaling factors σ and ε/k, which are, respectively, the length and the energy parameters of a potential, were determined by Wilhelm and Vogel [6] from a fit of viscosity data of HFC-134a to be $\varepsilon/k = 288.82$ K and $\sigma = 0.50647$ nm. The reduced effective collision cross section Ω_λ^* for thermal conductivity was calculated by the following equation:

$$\Omega_\lambda^* = \sum_{i=0}^{n} a_i / T^{*i} \tag{5}$$

where

$$a_1 = 0.444\,358, \qquad a_2 = 0.327\,867, \qquad a_3 = 0.193\,683\,5$$

The ideal specific heat at constant pressure C_P^o was calculated by

$$C_P^o = \sum_{i=0}^{6} c_i T^{i-1} \tag{6}$$

where

$$c_0 = 29.897917, \qquad c_1 = 0.1258739, \qquad c_2 = 5.0253157 \times 10^{-4},$$

$$c_3 = -1.2811 \times 10^{-6}, \qquad c_4 = 1.144944 \times 10^{-9}, \qquad c_5 = -3.847382 \times 10^{-13},$$

$$c_6 = 1.1471368 \times 10^{-17}$$

The relative deviations between the experimental data and the theoretical values calculated using Eqs. (4)–(6) were found to be less than $\pm 1.5\%$ from 300 to 530 K (Fig. 2). The good agreement between the thermal conductivity calculated by Eq. (3) and the theoretical values given by Eqs. (4)–(6) up to 700 K shows that both equations can be extrapolated up to this temperature within the experimental uncertainty. In Fig. 3 the relative deviations between Eq. (3) and some experimental data from the literature at atmospheric pressure are represented [7–12]. The agreement seems to be better with experimental data obtained by static methods [7, 11] than by other methods.

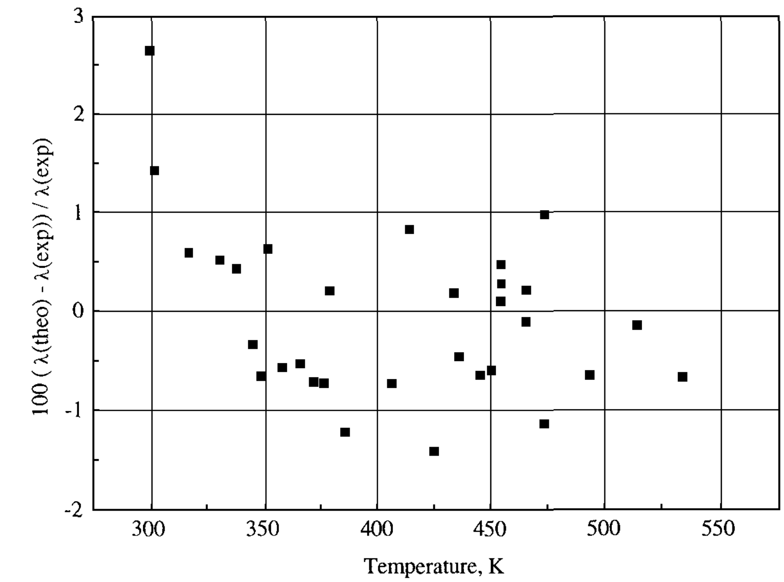

Fig. 2. Relative deviations of the experimental thermal conductivity data from theoretical values calculated from the dilute gas function [Eqs. (4)–(6)].

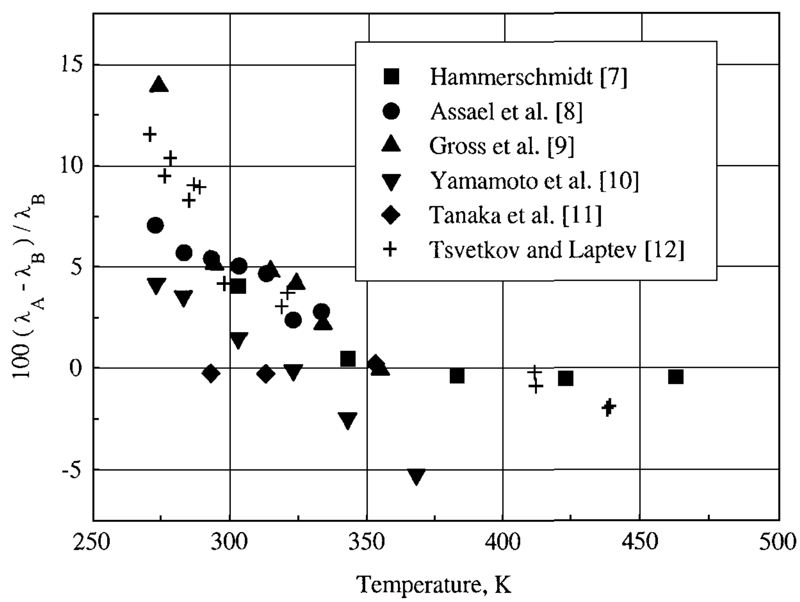

Fig. 3. Relative deviations of experimental data of the thermal conductivity of R134a, at atmospheric pressure, from values calculated with Eq. (3).

Table II. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 299.23 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
299.27	2.00	1210.4	80.88
299.27	3.00	1216.0	81.76
299.27	4.00	1221.5	82.20
299.26	5.00	1226.7	83.10
299.26	6.00	1231.7	83.56
299.26	7.00	1236.5	84.02
299.25	8.00	1241.1	84.97
299.25	9.00	1245.6	85.45
299.25	10.02	1250.0	86.42
299.24	11.00	1254.1	87.42
299.24	12.00	1258.2	87.93
299.24	13.00	1262.1	88.44
299.24	14.00	1266.0	88.96
299.24	15.00	1269.7	89.48
299.23	16.00	1273.3	90.01
299.23	17.00	1276.9	90.56
299.23	18.00	1280.4	91.10
299.23	19.00	1283.8	91.65
299.22	20.21	1287.7	92.20
299.22	21.00	1290.3	92.77
299.22	22.00	1293.5	93.34
299.21	23.00	1296.6	93.92
299.22	24.00	1299.6	94.50
299.22	25.00	1302.6	94.75
299.21	26.00	1305.5	95.09
299.21	27.00	1308.4	95.69
299.21	28.00	1311.2	96.30
299.21	29.00	1314.0	96.91
299.21	30.00	1316.7	97.53
299.20	31.00	1319.4	98.17
299.20	32.00	1322.1	98.81
299.20	33.00	1324.7	99.45
299.20	34.00	1327.2	100.10
299.20	35.00	1329.8	100.77
299.20	36.00	1332.2	100.76
299.19	37.00	1334.7	101.44
299.19	38.00	1337.1	101.44
299.19	39.00	1339.5	102.12
299.19	40.00	1341.8	102.81
299.19	41.00	1344.1	103.51
299.18	42.00	1346.4	104.21
299.18	43.00	1348.6	104.21
299.18	44.00	1350.9	104.93
299.18	45.00	1353.0	104.94

Table III. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 306.42 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
306.47	2.00	1182.4	77.99
306.46	3.00	1188.9	78.39
306.46	4.00	1195.1	79.19
306.46	5.00	1201.0	80.01
306.45	6.00	1206.7	80.85
306.45	7.00	1212.1	81.28
306.45	8.00	1217.2	82.14
306.44	9.00	1222.2	83.02
306.44	10.00	1227.0	83.48
306.43	11.00	1231.6	84.39
306.43	12.00	1236.1	84.86
306.43	13.00	1240.4	85.79
306.42	14.00	1244.6	86.76
306.42	15.00	1248.7	87.25
306.42	16.00	1252.6	87.74
306.42	17.00	1256.5	88.24
306.42	18.00	1260.2	88.75
306.41	19.00	1263.9	89.26
306.41	20.10	1267.8	89.78
306.41	21.00	1270.9	90.83
306.40	22.00	1274.3	91.37
306.40	23.00	1277.7	91.92
306.40	24.00	1280.9	92.46
306.40	25.00	1284.1	93.01
306.40	26.00	1287.3	93.58
306.40	27.00	1290.3	94.15
306.39	28.00	1293.3	94.72
306.39	29.00	1296.3	94.72
306.39	30.17	1299.6	95.30
306.39	31.00	1302.0	95.90
306.39	32.00	1304.8	96.49
306.39	33.00	1307.6	97.10
306.38	34.00	1310.3	97.71
306.38	35.00	1312.9	98.32
306.38	36.00	1315.5	98.95
306.38	37.00	1318.1	99.59
306.38	38.00	1320.7	99.59
306.38	39.74	1325.9	100.23

Table IV. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 315.94 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
315.98	4.00	1158.1	75.92
315.98	5.00	1165.2	77.05
315.98	6.00	1171.9	77.83
315.97	7.00	1178.2	78.61
315.97	8.00	1184.2	79.41
315.96	9.00	1190.0	80.23
315.96	10.00	1195.5	81.07
315.96	11.00	1200.8	81.93
315.95	12.00	1205.9	82.36
315.95	13.00	1210.8	82.80
315.94	14.00	1215.6	83.69
315.94	15.00	1220.1	84.14
315.94	16.00	1224.6	85.06
315.94	17.00	1228.9	85.53
315.94	18.00	1233.0	86.00
315.94	19.00	1237.1	86.48
315.93	20.00	1241.0	86.97
315.93	21.00	1244.9	87.46
315.93	22.00	1248.6	87.95
315.93	23.00	1252.2	88.44
315.93	24.00	1255.9	88.95
315.92	25.00	1259.3	89.46
315.92	26.00	1262.7	89.98
315.92	27.00	1266.1	90.50
315.92	28.00	1269.4	91.03
315.92	29.00	1272.6	91.56
315.92	30.00	1275.7	92.10
315.92	31.00	1278.8	92.37
315.91	32.00	1281.8	92.65
315.91	33.00	1284.7	93.20
315.91	34.00	1287.6	93.76
315.91	35.00	1290.5	94.33
315.91	36.00	1293.3	94.90
315.90	37.00	1296.1	95.48
315.90	38.00	1298.8	96.07
315.90	39.00	1301.5	96.07
315.90	40.00	1304.1	96.67
315.90	41.00	1306.7	97.26
315.89	42.00	1309.3	97.88
315.89	43.00	1311.8	98.49
315.89	44.00	1314.3	99.11
315.89	45.00	1316.7	99.75

Table V. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 335.22 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
335.29	4.00	1071.8	67.95
335.29	5.00	1083.0	68.84
335.28	6.00	1093.2	69.75
335.28	7.00	1102.6	70.68
335.27	8.00	1111.3	71.64
335.27	9.00	1119.4	72.63
335.26	10.00	1127.0	73.63
335.26	11.00	1134.2	74.71
335.25	12.00	1141.0	75.02
335.25	13.00	1147.5	76.10
335.25	14.00	1153.7	76.84
335.25	15.00	1159.6	77.59
335.24	16.00	1165.2	78.35
335.24	17.00	1170.6	79.12
335.23	18.00	1175.9	79.92
335.24	19.00	1180.9	80.74
335.23	20.00	1185.8	81.14
335.22	21.00	1190.5	81.56
335.22	22.00	1195.1	82.40
335.22	23.00	1199.6	82.82
335.22	24.00	1203.9	83.26
335.22	25.00	1208.1	83.69
335.21	26.00	1212.2	84.58
335.21	27.00	1216.1	85.47
335.21	28.00	1220.0	85.49
335.21	29.00	1223.8	85.95
335.21	30.00	1227.5	86.41
335.20	31.00	1231.1	86.88
335.20	32.00	1234.6	87.35
335.20	33.00	1238.1	87.84
335.20	34.00	1241.5	88.32
335.20	35.00	1244.8	89.27
335.20	36.00	1248.0	89.31
335.19	37.00	1251.2	89.81
335.19	38.00	1254.4	90.31
335.19	39.00	1257.4	90.83
335.18	40.00	1260.5	91.34
335.18	41.00	1263.4	91.87
335.18	42.00	1266.3	92.40
335.18	43.00	1269.2	93.42
335.18	44.00	1272.0	93.48
335.17	45.00	1274.8	94.03
335.18	46.00	1277.5	94.58
335.17	47.00	1280.2	95.14
335.17	48.00	1282.9	95.15
335.17	49.00	1285.5	95.71
335.17	50.00	1288.1	96.29

Table VI. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 355.27 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
355.34	8.00	1022.7	65.26
355.33	9.00	1035.3	66.57
355.32	10.00	1046.6	67.94
355.31	11.00	1057.0	69.07
355.31	12.00	1066.6	69.94
355.30	13.00	1075.5	70.84
355.30	14.00	1083.9	71.76
355.30	15.00	1091.8	72.39
355.29	16.00	1099.3	73.02
355.29	17.00	1106.3	73.67
355.28	18.00	1113.0	74.33
355.28	19.00	1119.5	75.00
355.28	20.00	1125.6	75.68
355.28	21.00	1131.6	76.38
355.27	22.00	1137.2	77.08
355.27	23.00	1142.7	77.81
355.26	24.00	1148.0	78.54
355.26	25.00	1153.1	78.91
355.26	26.00	1158.1	79.67
355.26	27.00	1162.9	80.05
355.25	28.00	1167.5	80.82
355.24	29.00	1172.0	81.62
355.24	30.00	1176.4	82.42
355.24	31.00	1180.7	82.83
355.24	32.00	1184.8	83.24
355.24	33.00	1188.9	83.66
355.24	34.00	1192.9	84.51
355.23	35.00	1196.8	84.94
355.23	36.00	1200.5	85.38
355.23	37.00	1204.2	85.81
355.23	38.00	1207.9	86.71
355.22	39.00	1211.4	87.15
355.22	40.00	1214.9	87.61
355.22	41.00	1218.3	88.07
355.22	42.00	1221.6	88.54
355.22	43.00	1224.9	89.49
355.21	44.00	1228.1	89.97

Table VII. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 374.45 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
374.49	10.00	956.5	60.82
374.48	11.00	972.3	62.66
374.47	12.00	986.3	63.86
374.47	13.00	999.0	64.86
374.46	14.00	1010.6	65.63
374.46	15.00	1021.2	66.41
374.45	16.00	1031.1	67.22
374.44	17.00	1040.4	68.05
374.44	18.00	1049.1	68.89
374.44	19.00	1057.3	69.75
374.43	20.00	1065.1	70.64
374.43	21.00	1072.5	71.25
374.42	22.00	1079.5	72.17
374.42	23.00	1086.2	73.12
374.41	24.00	1092.7	73.77
374.41	25.00	1098.9	74.43
374.41	26.00	1104.8	75.10
374.41	27.00	1110.6	75.77
374.41	28.00	1116.1	76.12
374.40	29.00	1121.5	76.47
374.40	30.00	1126.6	77.17
374.40	31.00	1131.7	77.43
374.39	32.00	1136.5	77.89
374.39	33.00	1141.3	78.62
374.39	34.00	1145.9	79.37
374.38	35.00	1150.4	80.12
374.39	36.00	1154.7	80.51
374.38	37.00	1159.0	81.30
374.38	38.00	1163.1	81.69
374.38	39.00	1167.2	82.09
374.38	40.00	1171.1	82.90
374.37	41.00	1175.0	83.32
374.37	42.00	1179.0	84.15
374.37	43.00	1182.5	84.57
374.37	44.00	1186.1	85.00

3. DENSE FLUID THERMAL CONDUCTIVITY

In order to determined the residual term of the thermal conductivity $\delta\lambda(\rho, T)$, we have performed measurements in the liquid phase and in the gas phase far from the critical region along 14 quasi-isotherms at 299.23, 306.42, 315.94, 335.22, 355.27, 374.45, 394.31, 413.68, 433.34, 453.50, 473.10, 493.05, 513.22, and 532.85 K. Experimental results are reported in

Table VIII. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 394.31 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
394.38	13.00	909.6	59.54
394.37	14.00	926.2	60.83
394.36	15.00	941.1	61.73
394.36	16.00	954.6	62.65
394.35	17.00	966.9	63.60
394.34	18.00	978.4	64.82
394.34	19.00	989.0	65.57
394.33	20.00	998.9	66.35
394.33	21.00	1008.2	67.14
394.32	22.00	1017.0	67.96
394.32	23.00	1025.4	68.79
394.31	24.00	1033.3	69.64
394.31	25.00	1040.8	70.21
394.30	26.00	1048.0	71.10
394.30	27.00	1054.9	71.70
394.30	28.00	1061.6	72.31
394.29	29.00	1067.9	72.93
394.29	30.00	1074.1	73.57
394.29	31.00	1080.0	74.21
394.28	32.00	1085.7	74.87
394.28	33.00	1091.2	75.54
394.28	34.00	1096.6	76.22
394.28	35.00	1101.8	76.56
394.27	36.00	1106.8	77.26
394.27	37.00	1111.7	77.97
394.27	38.00	1116.5	78.33
394.27	39.00	1121.1	78.69
394.26	40.00	1125.6	79.05

Tables II–XV. The residual term of the thermal conductivity was represented by a six-order polynomial of the form

$$\frac{\delta\lambda}{\Lambda_c} = \sum_{i=1}^{6} b_i \left(\frac{\rho}{\rho_c}\right)^i \tag{7}$$

where $\rho_c = 508\ \mathrm{kg \cdot m^{-3}}$ is the critical density and $\Lambda_c = 15.8\ \mathrm{mW \cdot m^{-1} \cdot K^{-1}}$.

Table IX. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 413.68 K

Temperature (K)	Pressure (MPa)	Density ($\mathrm{kg \cdot m^{-3}}$)	λ ($\mathrm{mW \cdot m^{-1} \cdot K^{-1}}$)
413.76	13.00	812.3	54.80
413.75	14.00	835.8	55.88
413.74	15.00	856.3	57.01
413.73	16.00	874.5	58.19
413.72	17.00	890.8	59.20
413.72	18.00	905.6	60.25
413.71	19.00	919.1	61.34
413.70	20.00	931.6	62.47
413.69	21.00	943.2	63.39
413.69	22.00	954.1	64.12
413.68	23.00	964.3	64.84
413.68	24.00	973.9	65.60
413.67	25.00	983.0	66.36
413.67	26.00	991.6	67.14
413.66	27.00	999.8	67.94
413.66	28.00	1007.6	68.49
413.66	29.00	1015.1	69.33
413.65	30.00	1022.3	70.18
413.65	31.00	1029.1	70.76
413.65	32.00	1035.8	71.35
413.64	33.00	1042.2	72.87
413.64	34.00	1048.3	72.87
413.63	35.00	1054.3	73.81
413.63	36.00	1060.1	74.45
413.63	37.00	1065.6	75.10
413.62	38.00	1071.0	75.43
413.62	39.00	1076.3	75.76
413.62	40.00	1081.4	76.10

The coefficients b_i in Eq. (4) are

$b_1 = 0.79533728$, $b_2 = -1.1985998 \times 10^{-2}$, $b_3 = 0.43799682$

$b_4 = -0.361399054$, $b_5 = 0.15081745$, $b_6 = -1.8358626 \times 10^{-2}$

The deviations between experimental thermal conductivity data and values calculated using the background equation are always less than the experimental uncertainty ($\pm 1.5\%$). Several measurements of the thermal conductivity of HFC-134a under pressure are reported in the literature. There were performed mainly in the liquid phase at lower temperatures. The comparison between the experimental data of Assael et al. [13] and those calculated using the background equation (Fig. 4) shows that the

Table X. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 433.34 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
433.40	18.00	829.2	57.47
433.39	19.00	846.1	58.45
438.38	20.00	861.5	59.47
433.37	21.00	875.7	60.52
433.37	22.00	888.9	61.38
433.36	23.00	901.2	62.05
433.36	24.00	912.6	62.96
433.35	25.00	923.5	64.00
433.34	26.00	933.6	64.61
433.34	27.00	943.3	65.34
433.34	28.00	952.4	65.85
433.33	29.00	961.1	66.61
433.33	30.00	969.4	67.40
433.32	31.00	977.4	67.92
433.32	32.00	985.0	68.73
433.32	33.00	992.3	69.67
433.31	34.00	999.4	70.41
433.31	35.00	1006.2	70.99
433.30	36.00	1012.7	71.58
433.30	37.00	1019.0	72.48
433.30	38.00	1025.1	73.09
433.29	39.00	1031.0	73.71
433.29	40.00	1036.8	74.34

maximum deviations are generally less than 1%. The deviations are much larger with the data of Gurova et al. [14] (Fig. 5) and reach 4% for the isotherm at 293 K. There is also an excellent agreement between the experimental thermal conductivity data of Ro et al. [15] and the values calculated by the background equation as shown in Fig. 6. This good agreement between the thermal conductivity values calculated by the background equation and these three experimental studies demonstrates that the background equation can be extrapolated up to 213 K and 1500 $kg \cdot m^{-3}$. In Figs. 7 and 8 the comparison is made, respectively, with the data of Gross et al. [9] and those of Laesecke et al. [16] in larger density ranges which include the gas phase.

Table XI. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 453.50 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
453.89	0.10	2.72	26.88
453.87	1.00	28.3	27.52
453.85	2.00	59.3	28.29
453.77	6.00	223.5	32.82
453.68	7.00	277.6	34.90
453.43	17.00	729.5	53.34
453.41	19.00	772.2	55.78
453.40	20.00	790.5	56.70
453.40	21.00	807.4	57.65
453.39	22.00	822.9	58.63
453.38	23.00	837.3	59.45
453.37	24.00	850.7	60.28
453.37	25.00	863.3	60.92
453.36	26.00	875.1	61.79
453.36	27.00	886.2	62.69
453.36	28.00	896.7	63.38
453.35	29.00	906.7	64.08
453.34	30.00	916.2	64.81
453.34	31.00	925.2	65.30
453.34	32.00	933.9	66.05
453.33	33.00	942.2	66.81
453.33	34.00	950.1	67.33
453.33	35.00	957.7	68.12
453.32	36.00	965.1	68.94
453.32	37.00	972.2	69.77
453.31	38.00	979.0	70.34
453.31	39.00	985.6	70.91
453.31	40.00	992.0	71.50

Table XII. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 473.10 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
473.37	0.10	2.61	29.04
473.34	2.01	56.3	30.09
473.32	3.00	87.5	30.99
473.31	4.00	121.8	31.64
473.28	5.00	159.3	32.83
473.30	6.02	200.9	33.90
473.20	7.00	244.0	35.32
473.19	8.00	290.9	36.95
473.17	9.00	339.6	38.64
473.14	10.07	392.4	40.58
473.11	11.00	437.2	42.19
473.09	12.00	482.9	43.93
473.06	13.00	524.9	45.59
473.05	14.00	563.1	47.20
473.03	15.00	597.4	48.53
473.02	16.00	628.1	49.93
473.01	17.00	655.8	50.97
473.00	18.00	680.8	52.05
472.99	19.00	703.4	53.17
472.98	20.02	724.5	54.50
472.97	21.00	743.1	55.20
472.96	22.00	760.6	56.10
472.95	23.00	776.8	57.02
472.94	24.00	791.9	57.97
472.94	25.00	806.1	58.95
472.93	26.00	819.3	60.38
472.92	27.00	831.8	60.80
472.92	28.00	843.6	61.23
472.91	29.00	854.7	61.88
472.91	30.07	866.0	62.77
472.91	31.00	875.4	63.23
472.91	32.00	885.0	63.92
472.90	33.00	894.2	64.87
472.89	34.00	903.0	65.35
472.89	35.00	911.5	66.09
472.88	36.00	919.6	66.85
472.88	37.00	927.4	67.37
472.88	38.00	934.9	67.89
472.88	39.00	942.2	68.42
472.88	40.00	949.2	68.96

Table XIII. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 493.05 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
493.29	0.10	2.50	30.95
493.27	1.97	52.33	31.72
493.26	3.01	82.63	32.21
493.24	4.00	113.51	32.91
493.22	5.00	146.9	33.91
493.20	6.00	182.4	34.90
493.18	7.00	220.4	36.09
493.16	8.00	259.4	37.29
493.14	9.00	300.1	38.66
493.11	10.00	341.4	40.22
493.09	11.00	382.5	41.70
493.06	12.00	422.6	43.29
493.04	13.00	460.9	45.11
493.03	14.00	496.9	46.33
493.02	15.00	530.2	47.61
493.00	16.00	561.2	48.83
492.99	17.00	589.7	50.11
492.98	18.00	615.8	51.00
492.97	19.00	639.7	52.08
492.96	20.00	661.8	52.88
492.96	21.00	682.3	53.53
492.94	22.00	701.2	54.54
492.94	23.00	718.8	55.41
492.93	24.00	735.3	56.31
492.93	25.00	750.7	57.24
492.92	26.00	765.2	58.00
492.91	27.00	778.8	58.99
492.91	28.20	794.1	60.00
492.90	29.00	803.9	60.63
492.90	30.00	815.4	61.27
492.89	31.00	826.4	61.92
492.89	32.00	836.9	62.59
492.89	33.00	847.0	63.27
492.88	34.00	856.6	63.97
492.88	35.00	865.7	64.68
492.87	36.00	874.6	65.16
492.87	37.00	883.1	65.64
492.87	38.00	891.3	66.14
492.87	39.00	899.2	66.65
492.86	39.91	906.1	67.16

Table XIV. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 513.22 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
513.40	0.10	2.40	32.45
513.38	1.00	24.6	33.02
513.38	2.99	77.5	34.39
513.36	4.00	106.5	34.83
513.36	5.00	136.8	35.75
513.33	6.04	170.0	36.62
513.32	7.00	201.8	37.45
513.31	8.00	236.1	38.50
513.29	9.03	272.4	39.60
513.27	10.00	307.0	40.57
513.26	11.00	342.7	41.69
513.24	12.00	377.8	42.77
513.23	13.00	412.1	44.64
513.21	14.00	445.0	45.57
513.20	15.00	476.2	46.71
513.18	16.00	505.8	48.06
513.17	17.00	533.5	49.04
513.16	18.00	559.4	50.21
513.15	19.12	586.4	51.28
513.14	20.00	606.2	52.89
513.14	21.00	627.2	53.52
513.13	22.00	646.9	53.90
513.12	23.00	665.4	54.77
513.12	24.00	682.6	55.67
513.11	25.00	698.9	56.42
513.10	26.00	714.3	57.37
513.09	27.00	728.8	58.36
513.09	28.40	747.7	59.69
513.09	29.00	755.5	59.79
513.08	30.00	767.9	60.43
513.08	31.00	779.6	61.08
513.07	32.00	790.9	61.74
513.07	33.00	801.6	62.42
513.06	34.00	811.9	63.12
513.06	35.00	821.7	63.82
513.06	36.00	831.2	64.63
513.06	37.00	840.3	64.55
513.05	38.00	849.0	65.04
513.05	39.00	857.5	65.80
513.05	40.00	865.6	66.30

Table XV. Thermal Conductivity of HFC-134a Along the Quasi-Isotherm 532.85 K

Temperature (K)	Pressure (MPa)	Density ($kg \cdot m^{-3}$)	λ ($mW \cdot m^{-1} \cdot K^{-1}$)
533.02	0.10	2.31	33.97
533.01	1.00	23.6	34.62
533.02	2.00	48.2	35.29
533.00	3.00	73.6	35.98
532.98	4.00	100.8	36.70
532.96	5.00	128.7	37.45
532.95	6.02	158.2	38.14
532.94	7.00	187.7	39.03
532.93	8.00	218.5	39.98
532.91	9.05	251.5	40.86
532.90	10.00	281.5	41.78
532.89	11.00	313.2	42.85
532.87	12.00	344.6	43.87
532.86	13.00	375.5	44.92
532.85	14.00	405.4	45.90
532.84	15.00	434.3	46.93
532.83	16.07	464.0	47.86
532.82	17.00	488.3	48.83
532.81	18.00	513.3	49.84
532.8	19.00	536.9	50.89
532.79	20.09	561.2	51.83
532.78	21.00	580.3	52.63
532.78	22.00	600.1	53.46
532.77	23.00	618.8	54.31
532.76	24.07	637.8	55.20
532.75	25.00	653.2	55.92
532.75	26.00	669.1	56.48
532.75	27.00	684.0	57.43
532.74	28.00	698.3	58.22
532.74	29.00	711.8	58.83
532.73	30.14	726.4	59.64
532.72	31.00	737.1	60.06
532.72	32.00	748.8	60.70
532.72	33.00	760.1	61.36
532.72	34.00	770.9	61.81
532.71	35.00	781.3	62.26
532.71	36.00	791.2	62.94
532.71	37.00	800.8	63.64
532.70	38.00	810.0	64.12
532.70	39.00	818.9	64.84
532.69	39.90	826.7	65.34

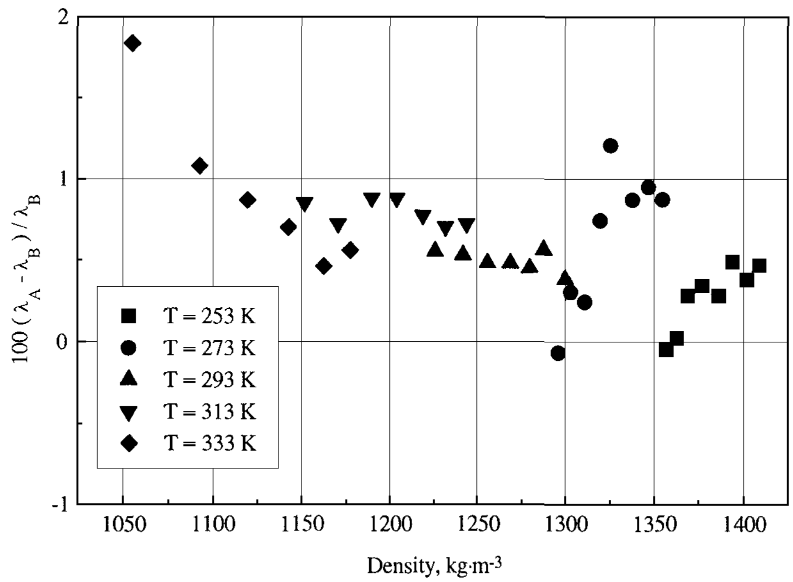

Fig. 4. Relative deviations of the experimental thermal conductivity data of Assael et al. [13] from the background equation [Eq. (2)].

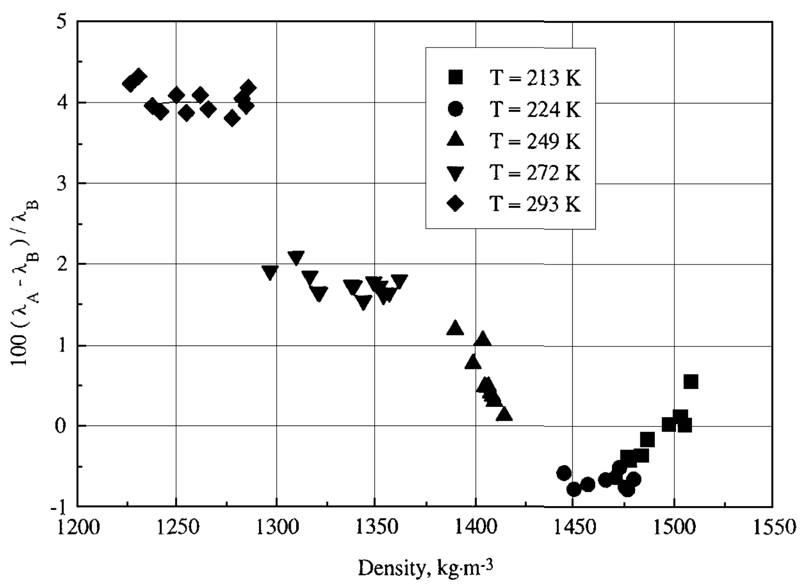

Fig. 5. Relative deviations of the experimental thermal conductivity data of Gurova et al. [14] from the background equation [Eq. (2)].

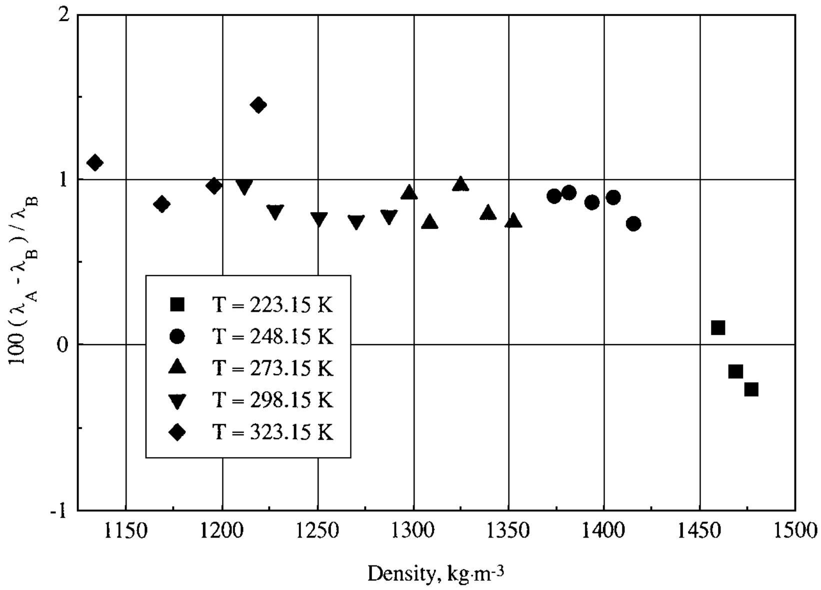

Fig. 6. Relative deviations of the experimental thermal conductivity data of Ro et al. [15] from the background equation [Eq. (2)].

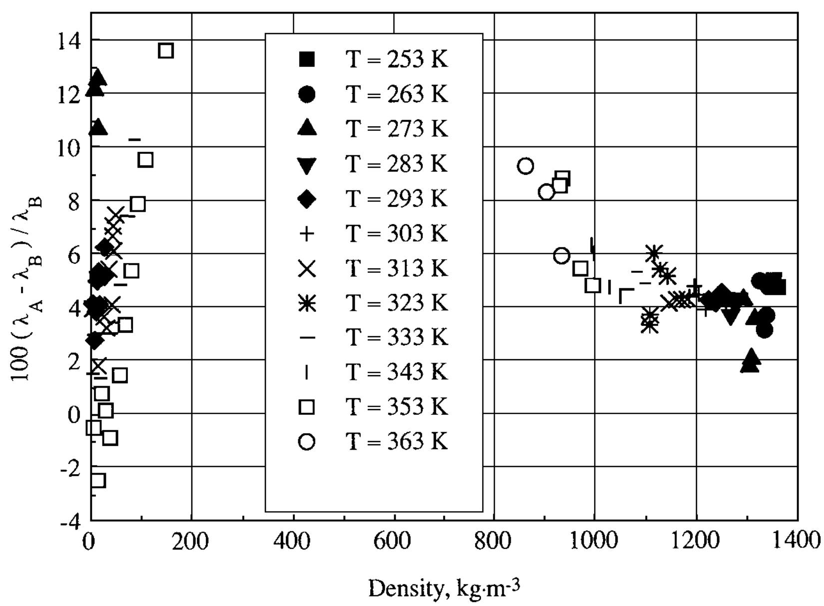

Fig. 7. Relative deviations of the experimental data of Gross et al. [9] from values calculated by the background equation.

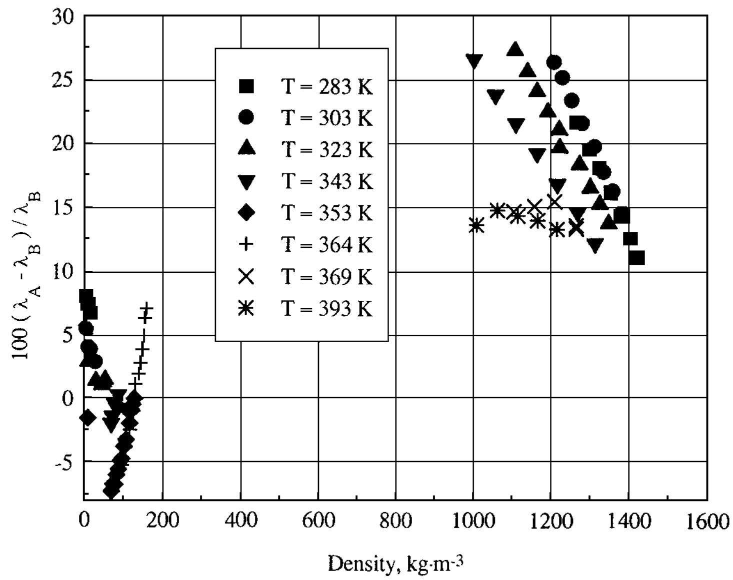

Fig. 8. Relative deviations of the experimental data of Laesecke et al. [16] from the background equation.

4. CONCLUSION

New measurements of the thermal conductivity of HFC-134a are presented in the temperature range from 300 to 530 K along 14 quasi-isotherms and at pressures up to 50 MPa with an estimated uncertainty of $\pm 1.5\%$. A background equation was determined which can be used to calculate the thermal conductivity of HFC-134a, outside the critical region, in a temperature range from 213 to 700 K, and at densities up to 1500 $Kg \cdot m^{-3}$, with an uncertainty of $\pm 1.5\%$. Further comparisons with the tables reported in Ref. 17 indicate larger deviations, and we suggest that these tables must be revised.

REFERENCES

1. B. Le Neindre and Y. Garrabos, *Rev. High Pres. Sci. Technol.* 7:1183 (1998).
2. B. Le Neindre and Y. Garrabos, *Proc. Fifth Asian Thermophys. Prop. Conf.*, M. S. Kim and S. T. Ro, eds. (Seoul, 1998), p. 415.
3. B. Le Neindre and Y. Garrabos, *Measurements of the Thermal Conductivity of R22 in the Temperature Range from 300 to 515 K and at Pressures up to 55 MPa*, AIChE 1998 Spring National Meeting, New Orleans, Louisiana (1998).

4. A. T. Sousa, P. S. Fialho, C. A. Nieto de Castro, R. Tufeu, and B. Le Neindre, *Int. J. Thermophys.* **13**:363 (1992).
5. R. Tillner-Roth and H. D. Baehr, *J. Phys. Chem. Ref. Data* **23**:657 (1994).
6. J. Wilhem and E. Vogel, *Proc. Fourth Asian Thermophys. Prop. Conf.*, A. Nagashima, ed. (Tokyo, 1995), p. 627.
7. U. Hammerschmidt, *Int. J. Thermophys.* **16**:1203 (1995).
8. M. J. Assael, N. Malamataris, and L. Karagiannidis, *Int. J. Thermophys.* **18**:341 (1997).
9. U. Gross, Y. W. Song, and E. Hahne, *Int. J. Thermophys.* **13**:957 (1992).
10. R. Yamamoto, S. Matsuo, and Y. Tanaka, *Int. J. Thermophys.* **14**:73 (1993).
11. Y. Tanaka, S. Matsuo, and S. Taya, *Int. J. Thermophys.* **16**:121 (1995).
12. O. B. Tsvetkov and Yu. A. Laptev, *in 14 ECTP*, P. Claudy, M. Laurent, and J. F. Sacadura, eds. (INSA, Lyon, 1996), p. 77.
13. M. J. Assael and E. Karagiannidis, *Int. J. Thermophys.* **14**:183 (1993).
14. A. N. Gurova, U. V. Mardolcar, and C. A. Nieto de Castro, *Int. J. Thermophys.* **18**:1077 (1997).
15. S. T. Ro, J. Y. Kim, and D. S. Kim, *Int. J. Thermophys.* **16**:1193 (1995).
16. A. Laesecke, R. A. Perkins, and C. A. Nieto de Castro, *Fluid Phase Equil.* **80**:263 (1992).
17. R. Krauss, J. Luettmer-Strathmann, J. V. Sengers, and K. Stephan, *Int. J. Thermophys.* **14**:965 (1993).