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Thermal Conductivity and *PVT* Measurements of Pentafluoroethane (Refrigerant HFC-125)[1]

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By means of the transient and steady-state coaxial cylinder methods, the thermal conductivity of pentafluoroethane was investigated at temperatures from 187 to 419 K and pressures from atmospheric to 6.0 MPa. The estimated uncertainty of the measured results is ±(2–3)%. The operation of the experimental apparatus was validated by measuring the thermal conductivity of R22 and R12. Determinations of the vapor pressure and *PVT* properties were carried out by a constant-volume apparatus for the temperature range 263 to 443 K, pressures up to 6 MPa, and densities from 36 to 516 kg m^{-3}. The uncertainties in temperature, pressure, and density are less than ±10 mK, ±0.08%, and ±0.1%, respectively.

KEY WORDS: coaxial cylinders; constant-volume apparatus; pentafluoroethane; *PVT* properties; R125; refrigerant, thermal conductivity vapor pressure.

1. INTRODUCTION

A need exists for reliable thermophysical properties of promising chlorofluorocarbon (CFC) alternatives to replace the fully halogenated CFCs. Pentafluoroethane (CHF_2–CF_3) is a promising substitute for R22 in course of the next few years [1]. Due to the application of pentafluoroethane (known as R125), as a working fluid for refrigerating engineering, it is

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necessary to have detailed information about the density, vapor pressure, and thermal conductivity.

As a part of the study of the thermodynamic and transport properties of R125, the thermal conductivity, vapor pressure, and pressure–volume–temperature behavior in the temperature range from 187 to 443 K have been determined in the present study.

2. EXPERIMENTS

The experiments were performed with three apparatuses. The thermal conductivity measurements were carried out applying the transient and steady-state coaxial-cylinder methods. The thermal conductivity was determined in the liquid and gaseous regions from 187 to 419 K.

The vapor pressure and *PVT* measurements were carried out with a constant-volume apparatus. Measurements of this kind were performed for temperatures up to 443 K.

2.1. Sample

The sample used in the experiments was supplied by the State Institute of Applied Chemistry (St. Petersburg, Russia). The purity specified by the manufacturer is 99.85% of the total mass. The sample was degassed at normal boiling temperature and stored in a stainless-steel vessel. The residual air was removed by a technique of repeated freezing, pumping, and thawing. The sample was confined to the measuring cells of the different experimental setups after sufficient evacuation and flushing of the sample into and from the cells. The purity of refrigerant HFC-125 was confirmed by gas chromatographic analysis.

2.2. Thermal Conductivity Measurements

The instrument used to measure the thermal conductivity of gaseous and liquid pentafluoroethane was a transient coaxial-cylinder apparatus described previously [2]. The thermal conductivity data at temperatures ranging from 187 to 336 K and at pressures up to 6.0 MPa with this equipment were assigned an uncertainty of ±(2–3)%.

This estimate agrees with results of test measurements carried out on gaseous R12 (CF_2Cl_2) and R22 (CHF_2Cl). These results have been compared-with our previously reported data [3] and data which have been reported by Altunin et al. [4] and Vargaftik et al. [5]. The average absolute discrepancy in this case was about 1%, which is within the mutual uncertainties of present measurements and the correlations.

The thermal conductivity of gaseous pentafluoroethane was also determined from steady-state coaxial-cylinder experiments. The design and apparatus were described in a previous work [6]. The cylinders are set up in a vertical position and are made of copper. The gap between the cylinders is 0.220 mm. A heater is placed in an axial well of the inner cylinder of 14.50-mm external diameter. The outer cylinder has an external diameter of about 100 mm and the outer cylinder was used as the pressure vessel. The assembly was placed in a constant-temperature liquid bath whose temperature was thermostatically controlled within ±10 mK. The thermal conductivities of gaseous R125 in the temperature range from 298 to 419 K have been measured at pressures from 0.10 to 1.45 MPa. Total uncertainty is estimated to be less than 2.5%.

To check the reliability of the apparatus, the thermal conductivity of gaseous R12 and R22 was measured from 300 to 400 K and compared with data mentioned above [3–5]. These data agree with this work within the mutual limits of uncertainty.

2.3. *PVT* and Vapor Pressure Measurements

Determinations of the vapor pressure and the *PVT* properties of HFC-125 were carried out with a constant-volume method. A quantity of gas is filled into the thermostated spherical stainless-steel measuring cell of 12.0-cm outer diameter. The volume of the measuring cell was determined by weighing with pure water. By gas expansion, the inner volume was determined to be 533.20 cm^3. The uncertainty of the determination of the volume is estimated to be 0.01%.

The measuring cell is connected with a diaphragm differential pressure indicator, which transfers the pressure of the sample to a pressure-transfer medium, nitrogen gas. The pressure measurement system included a precision tranducer pressure gauge IPDZ, an oil-piston-type deadweight pressure gauge (range 0.6–6.0 MPa; uncertainty of 0.02%) and an oil-nitrogen gas separator.

The cell was immersed in an liquid bath with stirrer, heater and temperature sensors. The temperature of the liquid bath is measured by a 10-Ω platinum resistance thermometer which was calibrated at the Russian Institute of Metrology according to IPTS-68. The uncertainty of temperature measurement was estimated to be less than ±10 mK.

The vapor pressures at various temperatures are measured by filling the cell to approximately critical density. Pressure–temperature isochores (quasi-constant-density runs) are measured by loading a known quantity of sample into the cell. On each isochore pressure measurements were made by varying the cell temperature. After the isochore determination the refrigerant was evacuated into a small tared vessel and reweighed.

3. RESULTS

3.1. Thermal Conductivity

Table I lists values of the thermal conductivity data λ as a function of pressure and temperature. The uncertainty was evaluated as $\pm(2\text{–}3)\%$ for 95% of the data.

Table I. The Thermal Conductivity of R125[a]

T (K)	P (MPa)	$10^4\lambda$ $(\mathrm{W \cdot m^{-1} \cdot K^{-1}})$
187.43	5.21	1075
191.39	6.04	1065
195.97	4.32	1042
198.39	4.37	1036
200.93	4.41	1025
203.88	3.63	1010
206.95	3.32	1000
209.85	5.15	996
219.14	4.55	957
223.22	4.31	946
227.79	4.08	929
236.51	0.10	99
249.81	0.19	110
257.21	0.30	115
264.90	0.31	121
269.71	0.31	123
273.87	0.32	127
279.41	0.32	131
285.02	0.32	136
306.17	0.34	153
314.21	0.18	157*
321.30	0.52	165*
320.04	0.34	172
336.44	0.34	178
348.86	0.19	189*
349.68	1.42	203*
377.07	0.20	216*
378.12	1.44	231*
413.61	0.57	253*
419.38	1.45	268*

[a] Values with an asterisk superscript were measured by the steady-state method. Other values were measured by the transient coaxial-cylinder method.

The values for the vapor thermal conductivity $\lambda(T)$ at low density were correlated by a polynomial expression,

$$\lambda(T) = A_0 + A_1 T + A_2 T^2 \tag{1}$$

with $A_0 = 7.200 \times 10^{-4}$, $A_1 = 1.227 \times 10^{-5}$, and $A_2 = 1.1407 \times 10^{-7}$, where T is in K and λ is in $W \cdot m^{-1} \cdot K^{-1}$, for temperatures $236 < T < 420$ K and

Table II. Vapor Pressure of R125

T (K)	P (Pa)
263.152	0.48330
268.151	0.57060
273.150	0.67057
273.150	0.67090
273.150	0.67098
278.149	0.78309
283.148	0.90913
283.148	0.90920
288.146	1.0493
293.145	1.2052
293.145	1.2055
293.145	1.2057
298.145	1.3777
298.145	1.3781
298.145	1.3787
303.143	1.5666
303.144	1.5683
303.144	1.5684
303.143	1.5688
303.143	1.5690
303.143	1.5696
308.141	1.7783
313.140	2.0081
313.139	2.0095
313.140	2.0098
323.137	2.5377
328.136	2.8387
328.136	2.8384
333.134	3.1679
333.134	3.1696
333.134	3.1708
333.134	3.1714
338.133	3.5342
338.133	3.5344

Table III. Gas-Phase Measured P–ρ–T Data of R125

T (K)	P (MPa)	ρ ($\mathrm{kg \cdot m^{-3}}$)
273.148	0.60095	36.827
283.149	0.63173	36.809
293.146	0.66185	36.791
323.138	0.74926	36.737
373.124	0.88880	36.643
443.112	1.0788	36.507
323.138	1.3125	70.320
348.130	1.4596	70.231
373.124	1.6036	70.140
403.121	1.7727	70.029
443.110	1.9905	69.879
323.137	1.8983	115.66
333.135	2.0109	115.60
348.130	2.1745	115.51
373.124	2.4378	115.36
403.121	2.7425	115.18
433.115	3.0370	114.99
323.137	2.4369	179.45
348.130	2.9300	179.22
373.127	3.3892	178.99
403.118	3.9155	178.70
443.114	4.5878	178.32
348.130	3.2405	214.13
373.124	3.8193	213.85
403.118	4.4804	213.51
433.113	4.1174	213.16
443.111	5.3261	213.05
348.130	3.6990	286.04
373.126	4.5475	285.66
403.118	5.5072	285.20
348.130	3.8920	332.04
373.126	4.9223	331.60
393.121	5.7116	331.24
373.126	5.2355	375.55
348.130	4.0302	376.05
348.130	4.0567	388.14
373.124	5.3181	387.67
339.362	3.6160	423.60
348.130	4.1340	423.40
358.128	4.7022	423.17
373.124	5.5383	422.83
343.132	3.9100	516.90
353.128	4.6382	516.09
373.124	6.0866	515.52

pressures of 0.10–0.60 MPa. The maximum deviation of measurements from the above equation is 1.03%, whereas the standard deviation is 0.64%.

3.2. Vapor Pressure

Thirty-four data points were measured between 263 and 338 K and fitted by an equation of the type

$$\tau \ln(P_s/P_c) = B_1(1-\tau) + B_2(1-\tau)^{1.5} + B_3(1-\tau)^{2.5} + B_4(1-\tau)^4 + B_5(1-\tau)^{4.5} \tag{2}$$

Here P_s is the vapor pressure of R125 in MPa; $\tau = TT_c^{-1}$; T is in K; T_c and P_c are critical temperature and pressure, respectively; B_1 through B_5 are fitting constants. We find that $B_1 = -7.441537$, $B_2 = 1.485459$, $B_3 = -1.926777$, $B_4 = -1.762571$, and $B_5 = -0.9787495$.

Critical temperature obtained from the survey of McLinden [7] and Wilson et al. [8] is $T_c = 339.35$ K. The pressure calculated at the critical temperature was determined to be the critical pressure as $P_c = 3.629$ MPa. The deviations of the data from the equation are random and the standard deviation is 0.06% in pressure. Experimental data are given in Table II. These data agree with work by McLinden [7], by Wilson et al. [8], and by Watanabe et al. [9] within the mutual limits of uncertainty.

3.3. Pressure–Volume–Temperature Behavior

The PVT surface was measured at 44 points between 263 and 443 K along isochores in the range of 36 to 516 $\text{kg} \cdot \text{m}^{-3}$ and at pressures between 0.60 and 6.1 MPa. The results are given in Table III. The temperature values in Tables II and III have been converted to ITS-90 temperatures.

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