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PVTx Properties of Difluoromethane + Pentafluoroethane (R-32 + 125) and Difluoromethane + Pentafluoroethane + 1,1,1,2-Tetrafluoroethane (R-32 + 125 + 134a)

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The experimental pressure−volume−temperature−composition (*PVTx*) properties of a binary refrigerant, a system of difluoromethane (R-32) + pentafluoroethane (R-125), R-32 + 125, and a ternary refrigerant, a system of R-32, R-125, and 1,1,1,2-tetrafluoroethane (R-134a), R-32 + 125 + 134a, have been measured by a constant-volume method coupled with expansion procedures in an extensive range of temperatures, pressures, and densities. Ninety-four *PVTx* property data of the R-32 + 125 system were measured in a range of temperatures from (330 to 440) K, of pressures from (1.8 to 5.2) MPa, and of densities from (67 to 158) $\mathrm{kg \cdot m^{-3}}$, of the compositions of 20.089 and 39.977 mass % R-32. One hundred and five *PVTx* property data of the R-32 + 125 + 134a system were measured in a range of temperatures from (315 to 440) K, of pressures from (1.6 to 5.7) MPa, and of densities from (67 to 166) $\mathrm{kg \cdot m^{-3}}$, at compositions of (22.993/25.026/51.981), (23.075/25.112/51.813), (30.018/10.059/59.924), (29.996/29.971/40.033), (33.408/33.257/33.335) mass %.

Introduction

Among our previous publications, we have reported the *PVTx* property measurements for several binary refrigerants: R-22+12 (Takaishi *et al.*, 1982a), R-22+114 (Hasegawa *et al.*, 1985), Halon 1301+R-114 (Hosotani *et al.*, 1988), R-152a+114 (Yada *et al.*, 1988), R-115+114 (Yada *et al.*, 1989a,b), R-22+142b (Kumagai *et al.*, 1991), R-152a+134 (Tamatsu *et al.*, 1992), R-32+134a (Sato *et al.*, 1994a), and R-32+125 (Sato *et al.*, 1996), where R-22 is chlorodifluoromethane, R-12 is dichlorodifluoromethane, R-114 is 1,2-dichlorotetrafluoroethane, Halon 1301 is bromotrifluoromethane, R-152a is 1,1-difluoroethane, R-115 is chloropentafluoroethane, R-142b is 1-chloro-1,1-difluoroethane, and R-134 is 1,1,2,2-tetrafluoroethane.

The binary refrigerant R-32+125 and ternary refrigerant R-32+125+134a have zero ODP (ozone depletion potential). Because of its flammable characteristics, pure R-32 is not considered a suitable working fluid for refrigeration systems. A mixture of R-32 with nonflammable refrigerants, such as R-125 and R-134a, however, may overcome such a drawback in practical application. The present work aims to provide precise *PVTx* property measurements for binary and ternary refrigerants that could meet the requirements to replace R-22.

The previous paper on R-32+125 (Sato *et al.*, 1996) has reported *PVTx* properties with compositions of 50.021, 60.004, and 79.988 mass % R-32; so this paper reports additional *PVTx* property measurements for the compositions of 20.089 and 39.977 mass % R-32 for R-32+125 mixtures and also presents results for five compositions of R-32+125+134a.

Sample Purity

The purities of the sample fluids used are 99.998 mass % and 99.98 mass % for R-32, 99.99 mass % for R-125, and 99.99 mass % and 99.95 mass % for R-134a according to the analysis of the suppliers. We did not purify or analyze the samples.

Experimental Section

The apparatus and procedure have been reported (Takaishi *et al.*, 1982b). In principle the *PVTx* measurements of this work were made by the isochoric method coupled with the isothermal expansion procedures at different compositions of mixtures. The apparatus shown in Figure 1 consists of a sample cell (A), an expansion cell (B), a diaphragm type differential pressure detector (C), a platinum resistance thermometer (G) calibrated on ITS-90, a thermostated bath (H), temperature control/measuring devices, and pressure measuring instruments.

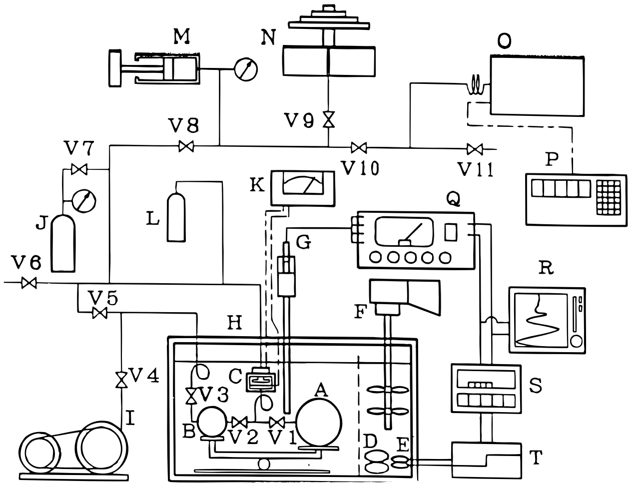

Figure 1. Experimental apparatus: (A) sample cell; (B) expansion cell; (C) differential pressure detector; (D) main heater; (E) auxiliary heater; (F) stirrer; (G) platinum-resistance thermometer; (H) thermostated bath; (I) vacuum pump; (J) nitrogen cylinder; (K) electric resistance detector; (L) nitrogen-gas damper; (M) precise pressure-controller; (N) air-piston type dead-weight pressure gauge; (O) quartz pressure transducer; (P) digital quartz pressure-transducer computer; (Q) thermometer; (R) pen recorder; (S) PID controller; (T) dc power supply; V_1−V_{11} valves.

The sample cell and the expansion cell are thick-walled spherical vessels made of 304 stainless steel, and their inner volumes were carefully calibrated with pure water; they were (283.368 ± 0.027) $\mathrm{cm^3}$ and (55.583 ± 0.007) $\mathrm{cm^3}$ at room temperature. These cells and the differential pressure detector are connected with high-pressure valves (V1, V2, V3) and connecting tubes. Their volumes were

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also calibrated with pure water; it was (17.092 ± 0.007) cm^3 at room temperature. A sample of the mixture is prepared as follows: pure components were carefully filled in the independent vessels which were previously evacuated. The mass of the pure component in each vessel was adjusted to the prescribed mass and weighed by a precise chemical balance. Then the pure components were charged one by one into the sample cell cooled by liquefied nitrogen. The charged mass and composition were determined by the mass difference of each vessel before and after charging the component into the sample cell.

Then the sample cell was connected as shown in Figure 1. After the space of the connecting tube between the sample cell, the expansion cell, and the differential pressure detector was evacuated, the valve V2 was closed, and the valve V1 was opened successively. The temperature in the thermostated bath filled with silicone oil was controlled within ±2 mK. When thermal equilibrium was reached and with the pressure remaining unchanged over several hours, the temperature and the pressure of the sample fluid were measured.

When a series of pressure measurements along an isochore was completed, the expansion cell was evacuated, the valve V3 was closed, and the valve V2 was opened gradually to expand part of the sample fluid into the expansion cell in the single phase. Throughout the expansion procedure, the two cells were agitated by a rocking device to ensure uniform density and to promote homogeneity of the sample. The valve V1 was closed when the temperature and the pressure became stable. By using these procedures, the *PVTx* measurements and the isothermal expansion procedures are repeated for several isochores under the measured composition at a single charge of the sample in this work.

The mass density along the initial isochore, ρ_0, was determined by the following equation:

$$\rho_0 = m_0/(V_a + V_c) \qquad (1)$$

where m_0 denotes the mass of the sample, V_a denotes the inner volume of the sample cell, and V_c denotes that of the connecting tube between the sample cell, the expansion cell, and the differential pressure detector. The density after the Nth expansion, ρ_N, was determined as follows:

$$\rho_N = \prod_{i=1}^{N} k_i m_0/(V_a + V_c) \qquad (2)$$

where k_i denotes the volume ratio defined by the following equation

$$k_i = V_a/(V_a + V_b + V_c) \qquad (3)$$

where V_b denotes the inner volume of the expansion cell. The variations of the inner volumes V_a, V_b, and V_c due to thermal expansion and pressure deformation were included. The experimental error of the density after the Nth expansion procedure is estimated as less than 0.2% after the third expansion, which is the largest N value in the present study: it consisted of 0.103% for the estimated uncertainties of the changed mass of the sample, 0.0097% for the volume $V_a + V_b$, and 0.026% for the k_i ratio.

The overall experimental errors of the present measurements are estimated to be not greater than ±7 mK in temperature, ±2 kPa in pressure, ±0.2% in density for each component, and ±0.02 mass % (R-32 + 125) and ±0.05 mass % (R-32 + 125 + 134a) in the composition.

Table 1. *PVTx* Properties for the R-32 + 125 System

TK	ρ/kg·m^{-3}	*P*/MPa	*Z*	*T*/K	ρ/kg·m^{-3}	*P*/MPa	*Z*
(a) 20.089 mass % R-32 (36.708 mol % R-32)							
330.000	158.08	2.8820	0.6316	330.000	99.78	2.1673	0.7525
340.000	158.01	3.1009	0.6599	340.000	99.73	2.2882	0.7715
350.000	157.93	3.3126	0.6852	350.000	99.68	2.4048	0.7880
360.000	157.86	3.5189	0.7080	360.000	99.64	2.5200	0.8032
370.000	157.78	3.7203	0.7286	370.000	99.59	2.6333	0.8171
380.000	157.70	3.9194	0.7478	380.000	99.54	2.7449	0.8297
390.000	157.63	4.1141	0.7652	390.000	99.49	2.8553	0.8413
400.000	157.55	4.3064	0.7813	400.000	99.44	2.9639	0.8519
410.000	157.47	4.4954	0.7961	410.000	99.40	3.0719	0.8618
420.000	157.39	4.6836	0.8101	420.000	99.35	3.1790	0.8711
430.000	157.31	4.8688	0.8229	430.000	99.30	3.2851	0.8797
440.000	157.23	5.0529	0.8351	440.000	99.25	3.3904	0.8877
330.000	125.59	2.5261	0.6969	330.000	79.27	1.8280	0.7989
340.000	125.53	2.6874	0.7199	340.000	79.23	1.9178	0.8139
350.000	125.47	2.8451	0.7407	350.000	79.20	2.0072	0.8279
360.000	125.41	2.9983	0.7593	360.000	79.16	2.0931	0.8398
370.000	125.35	3.1507	0.7767	370.000	79.12	2.1787	0.8509
380.000	125.29	3.2986	0.7921	380.000	79.08	2.2628	0.8609
390.000	125.23	3.4449	0.8064	390.000	79.04	2.3461	0.8701
400.000	125.17	3.5891	0.8196	400.000	79.01	2.4294	0.8789
410.000	125.11	3.7316	0.8317	410.000	78.97	2.5117	0.8870
420.000	125.04	3.8729	0.8431	420.000	78.93	2.5932	0.8944
430.000	124.98	4.0126	0.8536	430.000	78.89	2.6740	0.9013
440.000	124.92	4.1512	0.8635	440.000	78.85	2.7543	0.9077
(b) 39.977 mass % R-32 (60.576 mol % R-32)							
340.000	135.73	3.2461	0.6669	340.000	85.67	2.3841	0.7760
350.000	135.67	3.4656	0.6920	350.000	85.63	2.5011	0.7912
360.000	135.60	3.6783	0.7144	360.000	85.59	2.6233	0.8072
370.000	135.54	3.8824	0.7340	370.000	85.55	2.7399	0.8207
380.000	135.47	4.0836	0.7521	380.000	85.51	2.8534	0.8326
390.000	135.41	4.2842	0.7692	390.000	85.47	2.9682	0.8443
400.000	135.34	4.4810	0.7848	400.000	85.43	3.0802	0.8547
410.000	135.27	4.6739	0.7990	410.000	85.38	3.1914	0.8643
420.000	135.20	4.8657	0.8124	420.000	85.34	3.3012	0.8732
430.000	135.13	5.0548	0.8248	430.000	85.30	3.4098	0.8814
440.000	135.06	5.2427	0.8364	440.000	85.26	3.5178	0.8891
330.000	107.89	2.6473	0.7050	330.000	68.10	1.9000	0.8016
340.000	107.84	2.8102	0.7267	340.000	68.06	1.9956	0.8176
350.000	107.79	2.9701	0.7465	350.000	68.03	2.0869	0.8310
360.000	107.73	3.1263	0.7643	360.000	68.00	2.1764	0.8429
370.000	107.68	3.2815	0.7809	370.000	67.97	2.2651	0.8540
380.000	107.63	3.4349	0.7963	380.000	67.94	2.3526	0.8640
390.000	107.58	3.5845	0.8100	390.000	67.90	2.4382	0.8729
400.000	107.52	3.7310	0.8225	400.000	67.87	2.5233	0.8812
410.000	107.47	3.8766	0.8341	410.000	67.84	2.6075	0.8889
420.000	107.42	4.0225	0.8453	420.000	67.80	2.6915	0.8961
430.000	107.36	4.1666	0.8557	430.000	67.77	2.7743	0.9027
440.000	107.31	4.3085	0.8652	440.000	67.73	2.8574	0.9090

Results

Ninety-four *PVTx* property data of the R-32 + 125 system were measured along eight isochores at temperatures from (330 to 440) K, at densities from (67 to 158) kg·m^{-3}, at pressures from (1.8 to 5.2) MPa, and at mass fractions of 20.089 mass % (36.708 mol %) and 39.977 mass % (60.576 mol %) R-32, as tabulated in Table 1. Figure 2 shows the distribution of the *PVTx* data on a pressure−temperature plane, where the vapor-pressure curves are calculated from the correlations of both pure components (Sato *et al.*, 1994a,b; Zhang *et al.*, 1995). Twenty-three sets of second and third virial coefficients were also determined from the present measurements and tabulated in Table 2.

One hundred and five *PVTx* property data of the R-32 + 125 + 134a system were measured along eight isochores at temperatures from (315 to 440) K, at densities from (67 to 166) kg·m^{-3}, at pressures from (1.6 to 5.7) MPa, and at mass fractions of 22.993/25.026/51.981 mass % (38.102/17.977/43.921 mol %), 23.075/25.112/51.813 mass % (38.217/18.028/43.755 mol %), 30.108/10.059/59.924 mass % (46.230/6.715/47.055 mol %), 29.996/29.971/40.033 mass % (47.312/20.491/32.196 mol %), and 33.408/33.257/33.335 mass % (51.540/22.239/26.221 mol %), as tabulated in Table 3. Figure 3 shows the distribution of the *PVTx* data on a pressure−temperature plane, where the vapor-pressure curves are calculated from the correlations of each pure component (Sato *et al.*, 1994a,b; Zhang *et al.*, 1995; Piao *et al.*, 1988). Eleven sets of second and third virial coefficients

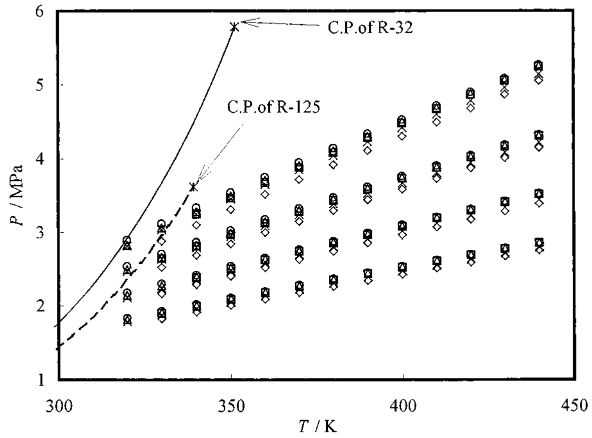

Figure 2. Distribution of the *PVTx* property measurements for the R-32/125 system on a pressure−temperature plane: (◇) 20.089 mass % R-32; (×) 60.004 mass % R-32 (Sato *et al.*, 1994a); (□) 39.977 mass % R-32; (○) 79.988 mass % R-32 (Sato *et al.*, 1994a); (△) 50.021 mass % R-32 (Sato *et al.*, 1994a); (—) R-32 (Sato *et al.*, 1994b); (- - -) R-125 (Zhang *et al.*, 1995). C.P. critical point.

Table 2. Second and Third Virial Coefficients for the R-32 + 125 System

T/K	B/ $\text{cm}^3\cdot\text{mol}^{-1}$	$10^{-6}C$/ $\text{dm}^6\cdot\text{mol}^{-2}$	T/K	B/ $\text{cm}^3\cdot\text{mol}^{-1}$	$10^{-6}C$/ $\text{dm}^6\cdot\text{mol}^{-2}$
(a) 20.089 mass % R-32					
330	−260.5	0.023 45	390	−169.7	0.017 02
340	−241.3	0.022 10	400	−158.6	0.016 17
350	−223.7	0.020 59	410	−148.3	0.015 26
360	−208.6	0.019 73	420	−138.9	0.014 66
370	−194.1	0.018 53	430	−130.1	0.014 01
380	−181.6	0.017 87	440	−121.9	0.013 51
(b) 39.977 mass % R-32					
340	−228.1	0.020 27	400	−149.9	0.014 32
350	−213.4	0.020 08	410	−140.2	0.013 50
360	−197.8	0.018 50	420	−131.2	0.012 81
370	−183.6	0.016 87	430	−123.1	0.012 29
380	−171.2	0.015 75	440	−115.3	0.011 68
390	−160.0	0.014 97			

Table 3. *PVTx* Properties for the R-32 + 125 + 134a System

T/K	ρ/kg·m^{-3}	P/MPa	Z	T/K	ρ/kg·m^{-3}	P/MPa	Z
(a) 22.993/25.026/51.981 mass % (38.102/17.977/43.921 mol %)							
320.000	165.84	1.9456	0.3801	315.000	104.70	1.6650	0.5235
330.000	165.76	2.4200	0.4587	320.000	104.67	1.8616	0.5763
340.000	165.68	2.9708	0.5468	330.000	104.62	2.2573	0.6779
350.000	165.60	3.3409	0.5977	340.000	104.57	2.4077	0.7022
360.000	165.52	3.6014	0.6267	350.000	104.52	2.5547	0.7241
370.000	165.44	3.8544	0.6529	360.000	104.47	2.6985	0.7439
380.000	165.36	4.1004	0.6766	370.000	104.42	2.8391	0.7619
390.000	165.28	4.3395	0.6981	380.000	104.37	2.9786	0.7787
400.000	165.19	4.5753	0.7180	390.000	104.32	3.1150	0.7939
410.000	165.11	4.8082	0.7365	400.000	104.27	3.2477	0.8074
420.000	165.03	5.0370	0.7535	410.000	104.22	3.3788	0.8199
430.000	164.94	5.2634	0.7695	420.000	104.17	3.5081	0.8314
440.000	164.86	5.4874	0.7844	430.000	104.11	3.6361	0.8421
320.000	131.75	1.8898	0.4648	440.000	104.06	3.7629	0.8521
330.000	131.69	2.3459	0.5597	320.000	83.16	1.8107	0.7045
340.000	131.63	2.7469	0.6364	330.000	83.12	1.9505	0.7373
350.000	131.56	2.9572	0.6659	340.000	83.08	2.0628	0.7572
360.000	131.50	3.1501	0.6900	350.000	83.04	2.1699	0.7741
370.000	131.44	3.3382	0.7117	360.000	83.00	2.2789	0.7908
380.000	131.37	3.5213	0.7314	370.000	82.96	2.3839	0.8053
390.000	131.31	3.7003	0.7492	380.000	82.92	2.4885	0.8189
400.000	131.24	3.8789	0.7661	390.000	82.88	2.5907	0.8311
410.000	131.18	4.0528	0.7813	400.000	82.84	2.6917	0.8423
420.000	131.11	4.2248	0.7955	410.000	82.80	2.7906	0.8524
430.000	131.05	4.3943	0.8086	420.000	82.76	2.8892	0.8619
440.000	130.98	4.5621	0.8208	430.000	82.72	2.9862	0.8705
				440.000	82.68	3.0823	0.8786
(b) 23.075/25.112/51.813 mass % (38.217/18.028/43.755 mol %)							
320.000	66.46	1.5743	0.7671	390.000	66.24	2.1491	0.8621
330.000	66.43	1.6617	0.7855	400.000	66.21	2.2264	0.8712
340.000	66.40	1.7463	0.8016	410.000	66.18	2.3058	0.8807
350.000	66.37	1.8352	0.8187	420.000	66.15	2.3814	0.8883
360.000	66.34	1.9165	0.8316	430.000	66.11	2.4554	0.8951
370.000	66.31	1.9966	0.8434	440.000	66.08	2.5307	0.9020
380.000	66.28	2.0751	0.8539				
(c) 30.018/10.059/59.924 mass % (46.230/6.715/47.055 mol %)							
320.000	165.93	1.9221	0.3488	390.000	165.36	4.5190	0.6752
330.000	165.85	2.4021	0.4229	400.000	165.28	4.7707	0.6954
340.000	165.77	2.9291	0.5008	410.000	165.20	5.0127	0.7132
350.000	165.69	3.4506	0.5734	420.000	165.12	5.2535	0.7300
360.000	165.61	3.7313	0.6031	430.000	165.03	5.4885	0.7453
370.000	165.53	4.0032	0.6299	440.000	164.95	5.7179	0.7592
380.000	165.45	4.2639	0.6536				
(d) 20.996/29.971/40.033 mass % (47.312/20.492/32.196 mol %)							
320.000	165.64	2.1460	0.3996	390.000	165.07	4.5499	0.6975
330.000	165.56	2.6628	0.4810	400.000	164.99	4.8001	0.7178
340.000	165.48	3.2506	0.5702	410.000	164.91	5.0390	0.7355
350.000	165.40	3.5202	0.6002	420.000	164.83	5.2723	0.7516
360.000	165.32	3.7894	0.6284	430.000	164.74	5.5210	0.7692
370.000	165.24	4.0569	0.6549	440.000	164.66	5.7488	0.7831
380.000	165.16	4.3040	0.6768				
(e) 33.408/33.257/33.335 mass % (51.540/22.239/26.221 mol %)							
320.000	79.46	1.9145	0.7268	390.000	79.20	2.6788	0.8372
330.000	79.42	2.0284	0.7471	400.000	79.16	2.7784	0.8470
340.000	79.39	2.1426	0.7663	410.000	79.12	2.8672	0.8532
350.000	79.35	2.2508	0.7823	420.000	79.08	2.9742	0.8644
360.000	79.31	2.3577	0.7971	430.000	79.04	3.0828	0.8756
370.000	79.27	2.4751	0.8146	440.000	79.00	3.1779	0.8825
380.000	79.23	2.5778	0.8264				

at mass fractions of 22.993/25.026/51.981 mass % were also determined from the present measurements and tabulated in Table 4.

Discussion

The compressibility factors, Z, of the present binary R-32+125 mixtures with compositions of 20.089 and 39.977 mass % R-32 and the present ternary R-32 + 125 + 134a mixture with a composition of 22.993/25.026/51.981 mass % were derived in the superheated vapor region from the measurements by using the following relations:

$$Z = MP/\rho RT \tag{4}$$

and

$$M = \sum_{i=1}^{n} x_i M_i \tag{5}$$

where P, ρ, R, and T denote pressure, mass density, the universal gas constant and temperature, respectively. M_i and x_i are the molar mass and respective mole fraction of each component. Figure 4 shows a typical example of the compressibility factors thus derived from the present 22.993/25.026/51.981 mass % *PVTx* data. Note that the solid curves in Figure 4 are isotherms.

The present *PVTx* data were represented within the estimated experimental uncertainty by the following truncated virial expression involving the molar density ρ_m:

$$(Z - 1)/\rho_m = B + C\rho_m \tag{6}$$

One of the typical examples of the results represented by eq 6 is shown in Figure 5 for the R-32 + 125 + 134a (22.993/25.026/51.981 mass %) mixture, where the intersection with the ordinate corresponds to the second virial coefficient B and the slope of each isotherm represents the third virial coefficient C. The second and third virial coefficient values thus determined from the present measurements are listed in Tables 2 and 4. We have estimated that the uncertainty for the determined B and C values are not greater than ±3% and ±30% for the present mixtures.

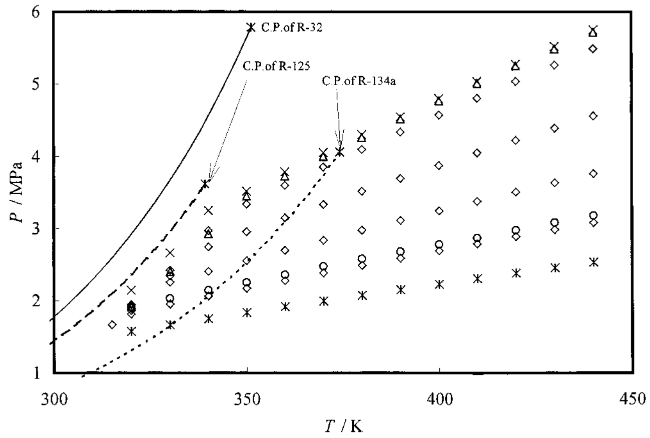

Figure 3. Distribution of the *PVTx* property measurements for the R-32 + 125 + 134a system on a pressure−temperature plane: (◇) 22.993/25.026/51.981 mass %; (∗) 23.075/25.112/51.813 mass %; (×) 29.996/29.971/40.033 mass %; (△) 30.018/10.059/59.924 mass %; (○) 33.408/33.257/33.335 mass %; (—) R-32 (Sato *et al.*, 1994b); (- - -) R-125 (Zhang *et al.* 1995); (···) R-134a (Piao *et al.*, 1988). C.P. critical point.

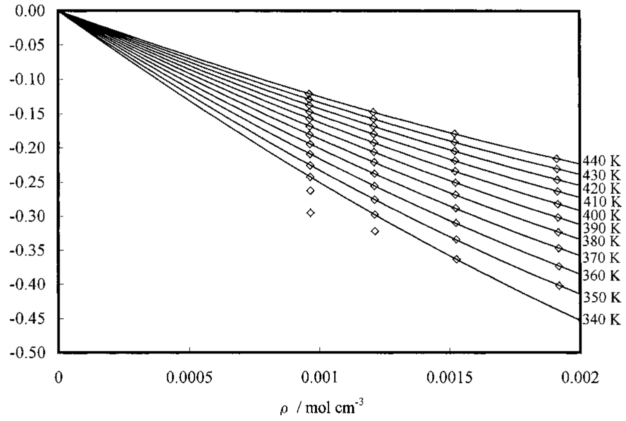

Figure 4. Departure from the ideal gas for R-32 + 125 + 134a (22.993/25.026/51.981 mass %).

Table 4. Second and Third Virial Coefficients for the R-32 + 125 + 134a (22.993/25.026/51.981 mass %) System

T/K	B/cm^3·mol^{-1}	$10^{-6}C$/dm^6·mol^{-2}
340	−275.3	0.024 36
350	−258.9	0.025 83
360	−239.9	0.023 77
370	−223.4	0.022 26
380	−207.5	0.020 35
390	−193.2	0.018 69
400	−180.4	0.017 41
410	−169.1	0.016 52
420	−158.4	0.015 54
430	−148.7	0.014 82
440	−139.8	0.014 20

Figures 6 and 7 show the temperature dependence of the B and C values determined for the binary R-32 + 125 mixtures with different compositions. For R-32, the reported B and C values (Sato *et al.*, 1994b) and B values (Zhang *et al.*, 1995) are included in Figures 6 and 7, while a similar comparison with the reported values for R-125 (Zhang *et al.*, 1995) and those for R-32 + 125 at mass fractions of 50.021, 60.004, and 79.988 mass % (Sato *et al.*, 1996) are also included.

Figures 8 and 9 show the temperature dependence of B and C values determined for the ternary R-32 + 125 + 134a mixtures with 22.993/25.026/51.981 mass % composition. For R-134a, the reported B and C values (Goodwin and Moldover, 1990) are included in Figures 8 and 9.

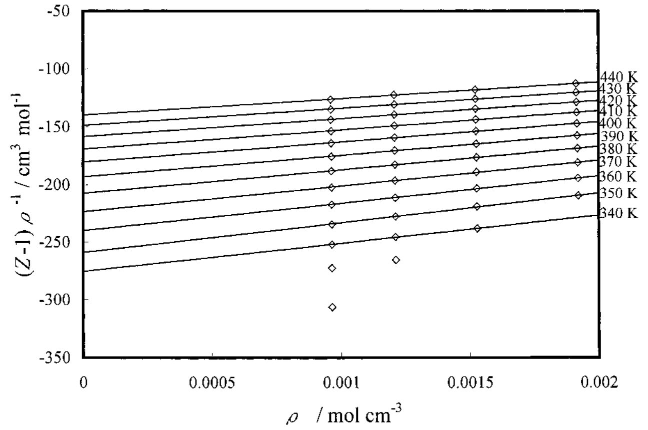

Figure 5. Relation of $(Z - 1)/\rho$ vs ρ for R-32 + 125 + 134a (22.993/25.026/51.981 mass %).

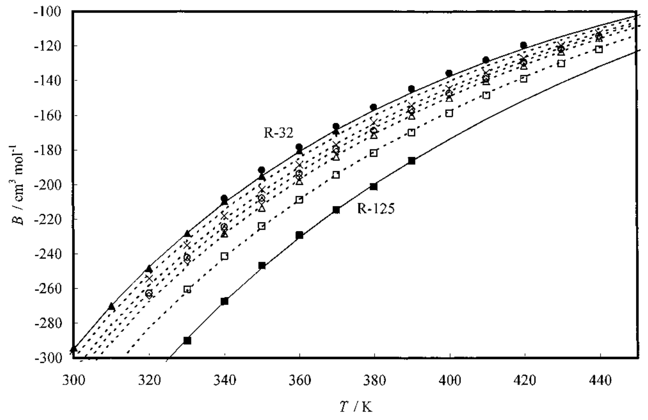

Figure 6. Temperature dependence of second virial coefficients for R-32 + 125: (□) 20.089 mass % R-32; (○) 60.004 mass % R-32 (Sato *et al.*, 1994a); (△) 39.977 mass % R-32; (×) 79.988 mass % R-32 (Sato *et al.*, 1994a); (◇) 50.021 mass % R-32 (Sato *et al.*, 1994a); (●) R-32 (Sato *et al.*, 1994b); (▲) R-32 (Zhang *et al.*, 1995); (■) R-125 (Zhang *et al.*, 1995); (—, ···) Kiyoura *et al.*, 1996.

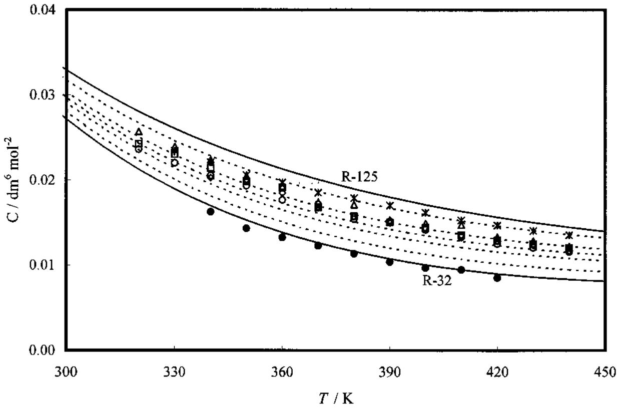

Figure 7. Temperature dependence of third virial coefficients for R-32 + 125: (∗) 20.089 mass % R-32; (△) 60.004 mass % R-32 (Sato *et al.*, 1994a); (◇) 39.977 mass % R-32; (○) 79.988 mass % R-32 (Sato *et al.*, 1994a); (□) 50.021 mass % R-32 (Sato *et al.*, 1994a); (●) R-32 (Sato *et al.*, 1994b); (—, ···) Kiyoura *et al.*, 1996.

Note that the solid and the dashed curves in Figures 6−9 are the calculated results by our own correlations (Kiyoura *et al.*, 1996) developed for each mixture and pure component. The solid curves denote the correlations for the pure components, and the dashed curves, those for the mixture components. These correlations express the *PVTx* measurements of this work within ±0.2% and the virial coefficient values of this work within ±0.7% for B and ±10% for C for R-32 + 125 mixtures, whereas the *PVTx*

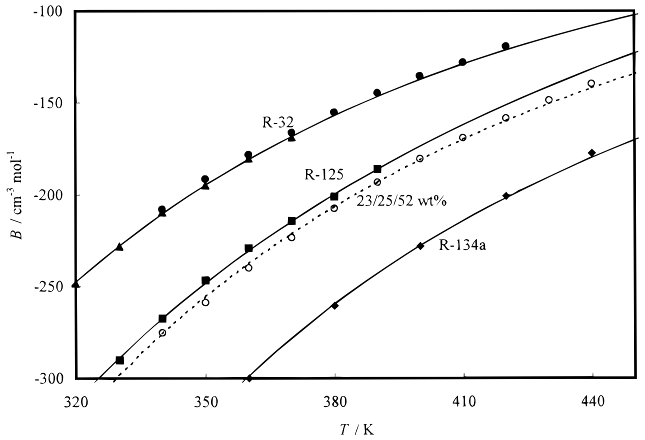

Figure 8. Temperature dependence of second virial coefficients for R-32 + 125 + 134a: (○) 22.993/25.026/51.981 mass %; (●) R-32 (Sato *et al.*, 1994b); (▲) R-32 (Zhang *et al.*, 1995); (■) R-125 (Zhang *et al.*, 1995); (◆) R-134a (Goodwin and Moldover, 1990); (—, ···) Kiyoura *et al.*, 1996.

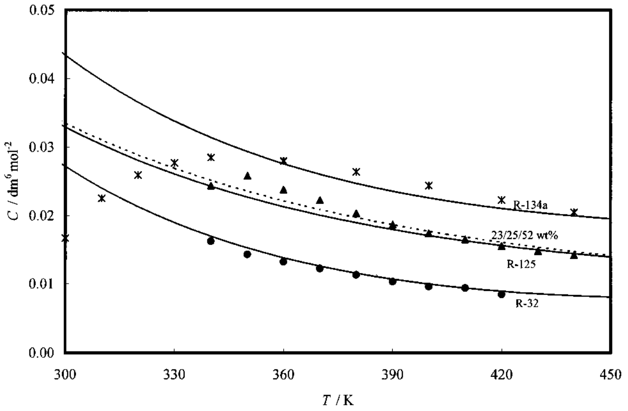

Figure 9. Temperature dependence of determined third virial coefficients for R-32/125/134a: (▲) 22.993/25.026/51.981 mass %; (●) R-32 (Sato *et al.*, 1994b); (∗) R-134a (Goodwin and Moldover, 1990); (—, ···) Kiyoura *et al.*, 1996.

measurements are within ±1.2%, ±1.6% for B, and ±4.8% for C for R-32 + 125 + 134a mixtures.

The *PVTx* measurements in our work also agree within ±0.3% with a recent model for R-32 + 125 mixtures (Zhang *et al.*, 1996), while the second virial efficients agree within ±1.1% and the third virial efficients within ±11% with their model.

Conclusion

Ninety-four *PVTx* property data of the binary R-32 + 125 mixture were measured along eight isochores. One hundred and five *PVTx* property data of the ternary R-32 + 125 + 134a mixture were measured along eight isochores. Twenty-three sets of second and third virial coefficients were determined for this binary mixture with compositions of 20.089 and 39.977 mass % R-32, and eleven sets of second and third virial coefficients were also determined for the R-32 + 125 + 134a mixture with a composition of 22.993/25.026/51.981 mass %.

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