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Densities of Liquid R 114 at Temperatures from 310 to 400 K and Pressures up to 10 MPa

H. Fukuizumi[1] **and M. Uematsu**[1]

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Density measurements for liquid R 114 (dichlorotetrafluoroethane) have been obtained with a variable-volume method. The results cover the high-density region from 1007 to 1462 $kg \cdot m^{-3}$ along ten isotherms between 310 and 400 K at 16 pressures from 0.5 to 10.0 MPa. The experimental uncertainty in the density measurements was estimated to be no greater than 0.2%. Based on the present results the derivatives with respect to temperature and pressure were calculated, and numerical values of the volume expansion coefficient and of the isothermal compressibility are tabulated as a function of temperature and pressure.

KEY WORDS: density; isothermal compressibility; R 114; volume expansion coefficient.

1. INTRODUCTION

We have measured the density of liquid R 114 at various temperatures and pressures. The PVT properties in the supercritical region [1], the critical parameters [2], and the saturated liquid densities [3] have been reported in previous publications. In this paper, we report the experimental results for the density of R 114 in the liquid region along 10 isotherms between 310 and 400 K at 16 pressures from 0.5 to 10.0 MPa. The values of the volume expansion coefficient and of the isothermal compressibility are also presented. The purity of the sample was 99.97 wt% R 114 (dichlorotetrafluoroethane), being an isomeric blend of 95% $CClF_2CClF_2$ and 5% CCl_2FCF_3.

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[1] Department of Mechanical Engineering, Keio University, Yokohama 223, Japan.

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2. EXPERIMENTAL

The density measurements have been obtained with a variable-volume method using a metal bellows. The apparatus and the experimental procedures have been described in detail in a previous publication [4]. A metal bellows of stainless steel (AM 350) was chosen as the vessel in which the sample of known mass was filled and whose volume could be varied. The dimensions of the bellows were 75 mm in length, 0.15 mm in thickness, 30 mm in outer diameter, and 4.3 cm^2 in effective area. The bellows was hanging vertically downward in a pressure vessel made of 304 stainless steel and moved longitudinally upward to a maximum distance of 16 mm. The volume of the bellows at the reference position was about 27 cm^3. The volume change of the bellows was detected by measuring the bellows displacement with the aid of a linear variable differential transformer with a resolution of better than 1 μm. The inner volume of the bellows and its variation with the bellows displacement were calibrated with an uncertainty of $\pm 0.2\%$.

Nitrogen gas was supplied to the inside of the pressure vessel and it surrounded the bellows. By increasing or reducing the pressure of the nitrogen gas, the bellows was compressed or expanded. The pressure of the nitrogen gas was measured with two different air-piston pressure gauges (Ruska Models 2465 and 2470) depending on the pressure range. The precision of the two air-piston pressure gauges used was guaranteed by the supplier to be 0.015% for high pressures, above 5 MPa, and 0.010% for low pressures, below 5 MPa, respectively. These pressure gauges were used also as the device for generating a constant pressure. Even if the bellows is held in balance, the pressure of the sample confined in the bellows is different from that of the nitrogen gas exerted on the bellows, mainly because of the reaction of the bellows against the compression. Prior to the experiments, the difference of the internal and external pressure of the bellows was calibrated in the experimental range of temperatures and pressures with an uncertainty of ± 0.5 kPa. The pressure of the sample was set at the desired values within ± 2 kPa.

In the body of the pressure vessel, a well was drilled for inserting a 25-Ω platinum resistance thermometer (Chino Model R 800-2) calibrated with a precision of 2 mK on IPTS-68. The temperature was measured with the aid of this thermometer by thermometer bridge (Tinsley Type 5840). The resistance of the thermometer at the triple point of water was measured periodically. The pressure vessel was immersed in a circulating silicone oil bath. The temperature detected at the well drilled in the pressure vessel was set at the desired values within ± 3 mK and it was kept constant within ± 3 mK during the measurements at a given isotherm.

The mass of the sample, prepared in a supply vessel, was weighed with a precision chemical balance (Chyo Model C_2-3000) with an uncertainty of 2 mg, and the sample was then supplied to the bellows after being evacuated to around 0.5 mPa. After the establishment of thermodynamic equilibrium of the sample was verified, the temperature, the pressure, and the bellows position were measured. The uncertainty in the density measurements was estimated to be no greater than $\pm 0.2\%$.

3. RESULTS AND DISCUSSION

We performed four experimental runs along 10 isotherms between 310 and 400 K at 16 pressures from 0.5 to 10.0 MPa. The results given in Table I cover the high-density region from 1007 to 1462 $\mathrm{kg \cdot m^{-3}}$. The uncertainties in the temperatures and pressures in Table I are estimated to be less than 8 mK and 5 kPa, respectively. Duplicating the experimental runs with another sample indicated that the present results are reproducible within 0.1 %. The present results were compared with the literature data by obtained deviation plots of both density and pressure from an equation of state proposed by Kagawa et al. [5]. As a typical illustration of this comparison, Figs. 1–3 show the deviation plots for the density along the 320, 350, and 400 K isotherms, respectively. Our results

Table I. Experimental Densities in $\mathrm{kg \cdot m^{-3}}$

	Temperature (K)									
P (MPa)	310	320	330	340	350	360	370	380	390	400
0.5	1417.2	1383.1	—	—	—	—	—	—	—	—
1.0	1420.0	1386.5	1351.2	1314.5	1271.9	—	—	—	—	—
1.5	1422.8	1389.7	1354.7	1318.9	1277.4	1234.1	1185.2	—	—	—
2.0	1425.4	1392.8	1358.6	1323.0	1282.6	1240.6	1193.9	1140.8	1073.1	—
2.5	1428.2	1395.8	1362.2	1327.2	1287.7	1246.9	1201.9	1151.9	1090.4	1007.9
3.0	1430.8	1398.8	1365.6	1331.3	1292.8	1252.8	1209.5	1161.9	1105.1	1033.8
3.5	1433.3	1401.7	1369.0	1335.3	1297.2	1258.5	1216.5	1170.9	1117.8	1054.1
4.0	1435.6	1404.4	1372.2	1339.1	1301.7	1263.9	1223.1	1179.6	1129.2	1070.7
4.5	1438.0	1407.2	1375.4	1342.7	1306.0	1269.0	1229.4	1187.5	1139.5	1084.9
5.0	1440.4	1410.0	1378.7	1346.4	1310.1	1273.9	1235.5	1194.7	1148.8	1097.5
5.5	1442.8	1412.7	1381.7	1349.9	1314.3	1278.8	1241.1	1202.0	1157.9	1109.1
6.0	1445.2	1415.4	1384.7	1353.2	1318.3	1283.4	1246.6	1208.5	1165.9	1119.4
7.0	1449.8	1420.5	1390.4	1359.9	1325.7	1292.2	1256.9	1220.6	1180.9	1137.9
8.0	1454.3	1425.4	1396.0	1366.3	1332.8	1300.4	1266.4	1232.2	1194.0	1154.2
9.0	1458.6	1430.2	1401.5	1372.3	1339.8	1308.2	1275.3	1242.5	1206.7	1168.2
10.0	1462.8	1434.8	1406.5	1378.1	1346.4	1315.6	1283.8	1252.1	1217.6	1181.5

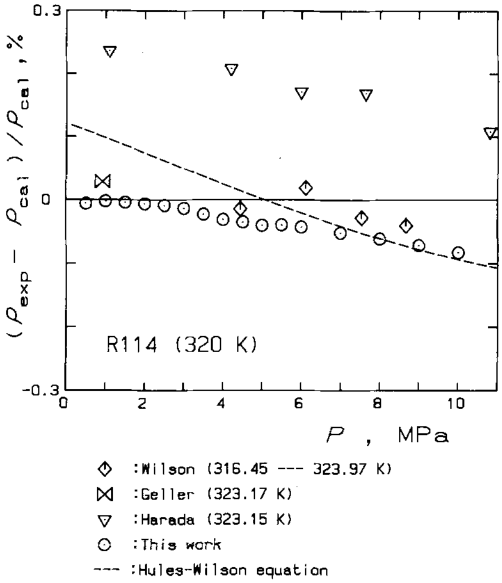

Fig. 1. Deviation plots of the density data from the equation of state by Kagawa et al. [5] at 320 K.

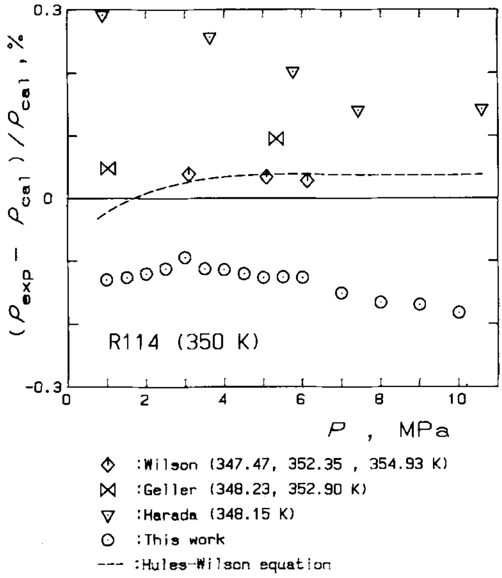

Fig. 2. Deviation plots of the density data from the equation of state by Kagawa et al. [5] at 350 K.

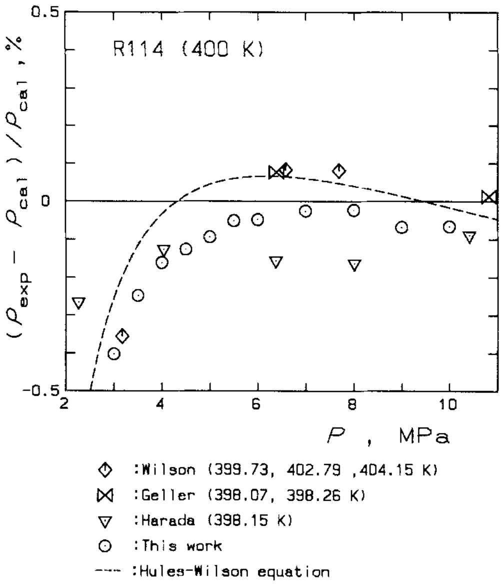

Fig. 3. Deviation plots of the density data from the equation of state by Kagawa et al. [5] at 400 K.

agree with the data reported by Wilson and Hules [6] and those by Geller and Porichanskii [7] within ±0.2% in density. The differences between the data reported by Harada et al. [8] and our results are within 0.4% in density. The present results were also compared with the calculated values from an equation of state proposed by Hules and Wilson [9]. The dashed lines in Figs. 1–3 show the density deviations for the calculated values by the Hules–Wilson equation from those by the Kagawa equation. Hules–Wilson equation represents the present results within about ±0.2%. Although most of the present results are smaller than the values calculated by the Hules–Wilson equation, those along the 310 K isotherm are larger than the calculated values. The differences of these measurements from the Hules–Wilson equation increase with pressure from 0 to about 0.2%. The Kagawa equation represents most of the present results as well as the Hules–Wilson equation except for five measurements at low pressures along the 390 and 400 K isotherms. The differences of these measurements from the Kagawa equation increase with decreasing pressure to about 0.4% at 390 K and 0.6% at 400 K.

We calculated the derivatives of the density with respect to temperature at constant pressure and with respect to pressure at constant

Table II. Volume Expansion Coefficient in $1000^{-1} \cdot K^{-1}$

	Temperature (K)							
P (MPa)	320	330	340	350	360	370	380	390
1.0	2.48	2.66	3.01	—	—	—	—	—
1.5	2.45	2.61	2.93	3.32	3.73	—	—	—
2.0	2.40	2.57	2.87	3.21	3.58	4.18	5.29	—
2.5	2.36	2.52	2.81	3.12	3.44	3.95	4.84	6.60
3.0	2.33	2.47	2.73	3.04	3.32	3.76	4.49	5.80
3.5	2.29	2.42	2.69	2.96	3.21	3.60	4.21	5.22
4.0	2.26	2.38	2.63	2.89	3.11	3.45	3.98	4.82
4.5	2.22	2.35	2.59	2.82	3.02	3.32	3.78	4.50
5.0	2.19	2.31	2.55	2.77	2.93	3.21	3.63	4.23
5.5	2.16	2.27	2.50	2.70	2.86	3.09	3.46	4.01
6.0	2.14	2.24	2.45	2.65	2.79	3.01	3.34	3.82
7.0	2.09	2.18	2.38	2.56	2.66	2.85	3.11	3.50
8.0	2.04	2.12	2.31	2.47	2.55	2.69	2.94	3.27
9.0	2.00	2.06	2.25	2.39	2.47	2.57	2.76	3.08
10.0	1.96	2.01	2.18	2.32	2.38	2.47	2.64	2.90

Table III. Isothermal Compressibility in GPa^{-1}

	Temperature (K)									
P (MPa)	310	320	330	340	350	360	370	380	390	400
1.0	3.94	4.72	—	—	—	—	—	—	—	—
1.5	3.79	4.54	5.51	6.46	8.37	—	—	—	—	—
2.0	3.80	4.43	5.48	6.22	8.06	10.30	13.97	—	—	—
2.5	3.74	4.31	5.11	6.22	7.87	9.77	13.01	18.31	29.3	—
3.0	3.58	4.15	4.98	6.11	7.33	9.29	12.04	16.34	24.8	44.7
3.5	3.37	4.02	4.84	5.82	6.88	8.84	11.16	15.09	21.6	35.1
4.0	3.29	3.98	4.69	5.54	6.75	8.32	10.57	14.09	19.20	28.8
4.5	3.34	3.92	4.70	5.45	6.48	7.89	10.11	12.75	17.21	24.7
5.0	3.36	3.89	4.57	5.30	6.35	7.66	9.49	12.12	16.05	22.1
5.5	3.35	3.83	4.33	5.08	6.20	7.44	8.94	11.48	14.76	19.73
6.0	3.27	3.72	4.23	5.01	5.90	7.11	8.59	10.71	13.76	18.08
7.0	3.11	3.54	4.07	4.80	5.49	6.55	7.88	9.70	11.90	15.30
8.0	3.00	3.40	3.96	4.54	5.30	6.16	7.26	8.90	10.78	13.11
9.0	2.91	3.26	3.74	4.31	5.04	5.82	6.82	8.00	9.77	11.69

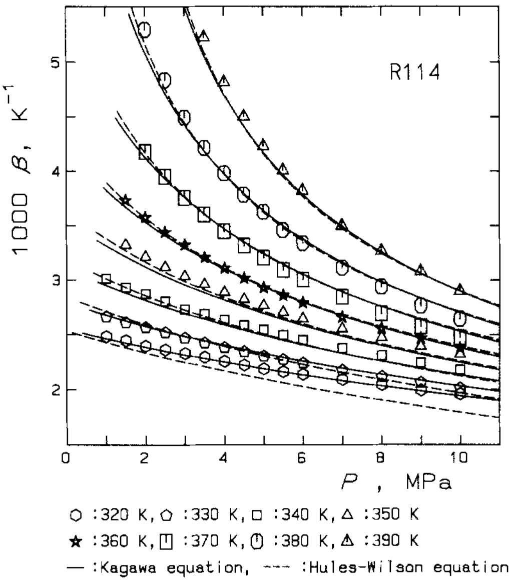

Fig. 4. Comparison of the volume expansion coefficient between the present results and the calculated values from the equations of state by Kagawa et al. [5] and by Hules and Wilson [9].

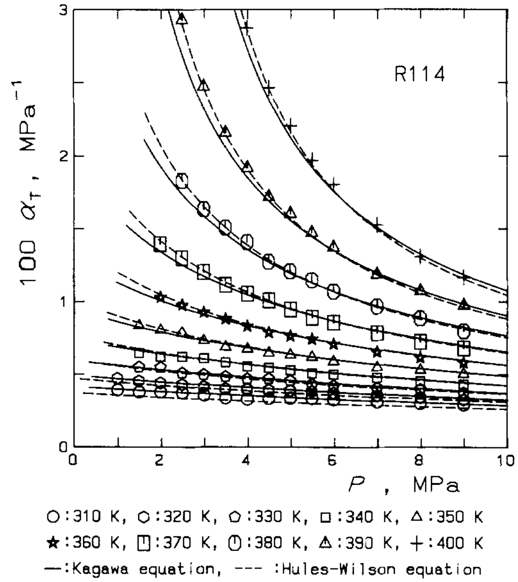

Fig. 5. Comparison of the isothermal compressibility between the present results and the calculated values from the equations of state by Kagawa et al. [5] and by Hules and Wilson [9].

temperature from the data given in Table I numerically. The values of the volume expansion coefficient, $\beta = -\rho^{-1}(\partial\rho/\partial T)_P$, and of the isothermal compressibility, $\alpha_T = \rho^{-1}(\partial\rho/\partial P)_T$, thus obtained are presented in Tables II and III, respectively. These values were compared with the calculated values by the Hules–Wilson equation and by the Kagawa equation. Figure 4 shows the comparison for the volume expansion coefficient, and Fig. 5 for the isothermal compressibility. The Hules–Wilson equation represents these properties better in the low-pressure range at temperatures above 330 K than the Kagawa equation. The 310 and 320 K isotherms of these two properties calculated by the Hules–Wilson equation do not agree with the present results, whereas the Kagawa equation represents these two isotherms well.

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