# DENSITY OF HCFC 142b AND OF ITS MIXTURE WITH HCFC 22

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## ABSTRACT

The density of the binary mixture 40/60 wt% of monochlorodifluoromethane (HCFC 22) and 1-chloro-1,1-difluoroethane (HCFC 142b) in the liquid phase, has been measured between 300 and 370 K and pressures up to 19 MPa, with an oscillating fork densimeter, operating in a relative mode. Toluene and vacuum have been used as calibrating fluids. The accuracy of the data is 0.08 %.

An equation for the dependence of density in temperature and pressure for HCFC 142b and for this mixture is also presented.

## INTRODUCTION

Thermodynamic data on refrigerant mixtures are very important for the correct design of refrigerant equipment or heat pumps, both in industrial and domestic uses. Mixtures data are needed to allow an assessment of near azeotropic mixtures as

chlorinated fluorocarbons (CFC's) replacements and to aid in the identification of possible azeotropic mixtures (McLinden and Didion, 1989). However the data available restrain to mixtures that involve one fully halogenated compound which is not desirable as replacements because they have high ozone depletion potentials. The mixture of monochlorodifluoromethane and 1-chloro-1,1-difluoroethane involves two hydrochloro-fluorocarbons (HCFC 22 and HCFC 142b, respectively) which has a low ozone depletion potential of 0.06[1] and a low global warming potential of 0.39[1] is considered to be a good replacement of CFC 12, dichlorodifluoromethane (o.d.p. = 1.0 and g.w.p. = 2.9).

Recently we have measured the density of HCFC 142b in the liquid and gaseous states, for temperatures between 293 and 403 K and pressures up to 18 MPa, with an oscillating fork densimeter (Sousa et al 1990). It is the purpose of this paper to report on the density of the mixture of HCFC 22 + HCFC 142b with a composition 40/60 wt%, between 300 and 370 K and pressures up to 19 MPa, obtained with the same instrument.

## EXPERIMENTAL

A densimeter (Anton Paar DMA 60) equipped with a high temperature-high pressure cell (DMA 512) was used for the present measurements. Details of the instrument and of the measuring principle were fully described the in reference of (Sousa et al 1990). This type of densimeters operates in relative mode and the density of a sample at a given temperature and pressure, can be obtained from the measured period of vibration of the mechanical oscillator filled with the sample, $\tau$, through the equation

$$\rho = \frac{(\rho_1 - \rho_2)(\tau^2 - \tau_2^2)}{\tau_1^2 - \tau_2^2} + \rho_2 \tag{1}$$

where $\rho_1$, $\rho_2$, $\tau_1$, $\tau_2$ are the densities and the vibration periods of the samples of two calibrating fluids, at the same temperature and pressures, respectively.

In a recent work (Sousa et al 1990), the densimeter was calibrated with toluene and sulfurhexafluoride. This procedure was found to have some problems, introducing unnecessary uncertainty in the obtained density data, mainly caused by the fact that the critical point of $SF_6$ falls in to the temperature and pressure range of the measurements. Vacuum was chosen as the second calibrating environment, and eq. (1) can be then written

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[1]Relative to CFC 11 a per pound basis and for the 40/60 wt% mixture.

$$\rho = \frac{\rho_1\left(\tau^2 - \tau_0^2\right)}{\tau_1^2 - \tau_0^2} \tag{2}$$

where the $\tau_0$ indicate the vibration period of the mechanical oscillator in vacuum. This period was expressed by the equation

$$\tau_0 = 3.49428 + 7.67 \times 10^{-4} T \tag{3}$$

with an error of 0.004 %. The vibration period of toluene was calculated using a Tait type equation, fitted to the experimental data,

$$\tau_1^2 = \frac{\tau_R^2}{1 - A \ln\left[(B + P)/(B + P_R)\right]} \tag{4}$$

with

$$\tau_R^2 = 14.386 + 3.36 \times 10^{-3} T + 2.03 \times 10^{-6} T^2 \tag{5}$$

$$B = 394.29 - 1.17T + 8.89 \times 10^{-4} T^2 \tag{6}$$

and $A = 0.01546$, and $\tau_R$ is the value of $\tau$ at a reference state, chosen to have a pressure of 0.1 MPa. Equation (4) can reproduce the experimental values of $\tau_1^2$ to within 0.005 %. The density of toluene was obtained from the work of Kashiwagi et al (1982), with an error of 0.06 %.

Pressure was measured with a Bourdon type gauge (Heise Co.) accurate to 5 kPa. The temperature of the densimeter cell was thermostated to within 0.01 K and measured to within 0.07 K with a Thermocoax type I thermocouple.

The mixture HCFC 22 + HCFC 142b was obtained from ATOCHEM, France, with a composition of 40/60 wt% and with a purity of 99.85 %.

Prior to the measurements with the mixture, the calibration previously performed by Sousa et al (1990), was checked by introducing pure HCFC 142b in the cell and measuring its density at 330 K. The deviation from the previous measurements (Sousa et al 1990), did not exceed 0.02 %, which is within the uncertainty of the experimental data.

# RESULTS

The densities of HCFC 142b measured by the authors, have been presented in a recent publication (Sousa et al 1990). As explained previously we have decided to change the calibration procedure, using vacuum and toluene. For the sake of the consistency with the present work, the densities of HCFC 142b have been recalculated, using eq. (2) to (6) and are presented in Table 1. The data has an estimated uncertainty of 0.02 % in the liquid phase and up to 1 % in the vapour phase.

TABLE 1

Density of 1-chloro-1,1-difluoroethane (HCFC 142b)

| T/K | P / MPa | $\tau$ / s | $\rho$ / kg.m$^{-3}$ | $\sigma_\rho$ / % |
|------|---------|-----------|---------------------|-------------------|
| 293.37 | 17.512 | 4.019449 | 1171.07 | 0.017 |
| 293.24 | 16.439 | 4.018711 | 1168.74 | 0.017 |
| 293.21 | 14.575 | 4.017515 | 1164.42 | 0.017 |
| 293.25 | 11.619 | 4.015514 | 1156.85 | 0.017 |
| 293.08 | 9.149 | 4.013731 | 1150.74 | 0.017 |
| 293.12 | 6.589 | 4.011806 | 1143.40 | 0.017 |
| 293.03 | 4.545 | 4.010181 | 1137.60 | 0.018 |
| 293.00 | 2.512 | 4.008536 | 1131.51 | 0.018 |
| 293.04 | 0.479 | 4.006784 | 1124.77 | 0.018 |
| 329.61 | 17.208 | 4.031209 | 1095.27 | 0.018 |
| 329.63 | 14.667 | 4.028970 | 1086.88 | 0.018 |
| 329.63 | 12.328 | 4.026759 | 1078.57 | 0.018 |
| 329.64 | 9.726 | 4.024128 | 1068.67 | 0.018 |
| 329.65 | 7.095 | 4.021223 | 1057.66 | 0.019 |
| 329.66 | 5.051 | 4.018767 | 1048.32 | 0.019 |
| 329.66 | 3.018 | 4.016086 | 1038.09 | 0.019 |
| 329.67 | 0.984 | 4.013138 | 1026.79 | 0.019 |
| 329.66 | 0.792 | 4.012820 | 1025.58 | 0.019 |
| 329.66 | 0.580 | 3.754025 | 25.41 | 0.68 |
| 368.20 | 15.932 | 4.041486 | 1002.40 | 0.019 |
| 368.24 | 12.976 | 4.037481 | 987.30 | 0.019 |
| 368.12 | 10.728 | 4.033818 | 973.95 | 0.019 |
| 368.12 | 8.229 | 4.029343 | 957.05 | 0.020 |
| 368.11 | 6.053 | 4.024783 | 939.78 | 0.020 |
| 368.18 | 4.019 | 4.019610 | 919.84 | 0.020 |
| 368.15 | 1.986 | 4.013155 | 895.20 | 0.020 |
| 368.11 | 1.783 | 3.799641 | 84.42 | 0.20 |
| 368.17 | 1.480 | 3.795826 | 70.19 | 0.24 |
| 368.18 | 1.166 | 3.790309 | 49.80 | 0.35 |
| 368.17 | 0.742 | 3.785458 | 31.98 | 0.55 |
| 368.18 | 0.377 | 3.781554 | 17.59 | 1.02 |
| 369.50 | 16.033 | 4.042161 | 1000.48 | 0.019 |
| 369.52 | 13.158 | 4.037879 | 984.34 | 0.019 |
| 369.48 | 13.153 | 4.037870 | 984.45 | 0.019 |

TABLE 1 (cont.)

Density of 1-chloro-1,1-difluoroethane (HCFC 142b)

| T/K | P / MPa | $\tau$ / s | $\rho$ / kg.m$^{-3}$ | $\sigma_\rho$ / % |
|---|---|---|---|---|
| 369.53 | 10.728 | 4.034064 | 970.00 | 0.019 |
| 403.16 | 14.899 | 4.048581 | 907.37 | 0.020 |
| 403.09 | 12.409 | 4.042953 | 886.79 | 0.012 |
| 403.10 | 10.111 | 4.036675 | 863.37 | 0.020 |
| 403.13 | 8.471 | 4.030628 | 840.64 | 0.020 |
| 403.10 | 6.974 | 4.024115 | 816.34 | 0.020 |
| 403.09 | 5.345 | 4.014334 | 779.54 | 0.021 |
| 403.09 | 3.786 | 3.996039 | 710.57 | 0.021 |
| 403.17 | 3.422 | 3.866472 | 228.17 | 0.061 |
| 403.08 | 2.765 | 3.839767 | 131.07 | 0.12 |
| 403.10 | 2.097 | 3.828739 | 90.99 | 0.18 |
| 403.08 | 1.480 | 3.820708 | 61.95 | 0.28 |
| 403.08 | 0.873 | 3.814094 | 38.04 | 0.47 |

For the 40/60 wt% mixture of HCFC 22 and HCFC 142b the period of vibration of the densimeter cell filled with this mixture was measured at the approximate temperatures of 300, 310, 330, 349 and 369 K and pressures up to 19 MPa. The calculated densities, using again eq. (2) to (6), are presented in Table 2, and have an estimated uncertainty of 0.08 %.

TABLE 2

Density of mixture HCFC 22 + HCFC 142b (40/60 wt%), $\sigma_\rho = 0.08\%$

| T/K | P/MPa | $\tau$ / s | $\rho$ / kg.m$^{-3}$ |
|---|---|---|---|
| 300.01 | 18.687 | 4.032918 | 1203.0 |
| 300.04 | 17.704 | 4.032328 | 1200.7 |
| 300.04 | 15.547 | 4.030662 | 1194.5 |
| 299.68 | 13.249 | 4.028711 | 1188.3 |
| 299.99 | 12.227 | 4.027933 | 1184.4 |
| 299.92 | 11.457 | 4.026664 | 1179.6 |
| 300.05 | 10.799 | 4.026622 | 1179.2 |
| 299.92 | 9.585 | 4.025529 | 1175.5 |
| 299.91 | 7.166 | 4.023280 | 1167.0 |
| 299.96 | 5.577 | 4.021705 | 1160.8 |
| 299.91 | 4.434 | 4.020531 | 1156.5 |
| 300.02 | 3.018 | 4.019010 | 1150.3 |
| 299.92 | 2.188 | 4.018075 | 1147.1 |
| 299.91 | 1.409 | 4.017155 | 1143.6 |
| 299.91 | 0.731 | 4.016355 | 1140.5 |
| 309.84 | 17.633 | 4.034806 | 1177.4 |
| 309.86 | 17.198 | 4.034517 | 1176.3 |
| 309.89 | 16.661 | 4.034059 | 1174.5 |
| 309.88 | 15.061 | 4.032752 | 1169.6 |
| 309.92 | 14.221 | 4.031937 | 1166.4 |
| 309.91 | 13.249 | 4.031034 | 1163.0 |

TABLE 2 (cont.)

Density of mixture HCFC 22 + HCFC 142b (40/60 wt%), $\sigma_\rho = 0.08\%$

| T/K | P/MPa | $\tau$ / s | $\rho$ / kg.m$^{-3}$ |
|---|---|---|---|
| 309.90 | 12.227 | 4.030089 | 1159.4 |
| 309.92 | 11.113 | 4.029012 | 1155.3 |
| 309.91 | 10.162 | 4.028057 | 1151.7 |
| 309.92 | 9.149 | 4.027024 | 1147.7 |
| 309.91 | 8.127 | 4.025948 | 1143.7 |
| 309.91 | 7.075 | 4.024788 | 1139.2 |
| 309.91 | 6.053 | 4.023633 | 1134.8 |
| 309.89 | 5.517 | 4.023022 | 1132.6 |
| 309.89 | 3.625 | 4.020788 | 1124.0 |
| 309.88 | 2.046 | 4.018541 | 1115.4 |
| 309.89 | 0.964 | 4.017088 | 1109.7 |
|  |  |  |  |
| 329.77 | 16.874 | 4.039120 | 1126.5 |
| 329.76 | 15.203 | 4.037339 | 1119.8 |
| 329.77 | 15.193 | 4.037321 | 1119.7 |
| 329.75 | 14.221 | 4.036228 | 1115.6 |
| 329.75 | 14.211 | 4.036220 | 1115.6 |
| 329.75 | 12.611 | 4.034368 | 1108.5 |
| 329.74 | 11.761 | 4.033328 | 1104.6 |
| 329.75 | 10.101 | 4.031296 | 1096.9 |
| 329.76 | 7.621 | 4.027758 | 1083.3 |
| 329.77 | 6.640 | 4.026293 | 1077.6 |
| 329.76 | 5.021 | 4.023717 | 1067.7 |
| 329.76 | 3.827 | 4.021651 | 1059.8 |
| 329.74 | 2.825 | 4.019789 | 1052.7 |
| 329.74 | 1.996 | 4.018147 | 1046.3 |
| 329.73 | 1.470 | 4.017035 | 1042.0 |
|  |  |  |  |
| 349.47 | 16.226 | 4.042462 | 1071.6 |
| 349.49 | 15.173 | 4.041026 | 1066.1 |
| 349.48 | 14.160 | 4.039617 | 1060.7 |
| 349.49 | 13.117 | 4.038079 | 1054.9 |
| 349.48 | 12.146 | 4.036595 | 1049.3 |
| 349.48 | 10.688 | 4.034231 | 1040.3 |
| 349.49 | 9.129 | 4.031469 | 1029.7 |
| 349.49 | 7.611 | 4.028530 | 1018.4 |
| 349.48 | 6.053 | 4.025146 | 1005.4 |
| 349.48 | 5.031 | 4.022669 | 995.9 |
| 349.48 | 4.019 | 4.020002 | 985.6 |
| 349.49 | 3.018 | 4.017018 | 974.0 |
| 349.47 | 2.299 | 4.014621 | 964.8 |
|  |  |  |  |
| 369.38 | 19.325 | 4.050806 | 1033.9 |
| 369.38 | 19.132 | 4.050558 | 1033.0 |
| 369.24 | 18.008 | 4.048870 | 1027.2 |
| 369.48 | 16.216 | 4.046011 | 1015.6 |
| 369.51 | 15.011 | 4.043908 | 1007.5 |
| 369.51 | 13.148 | 4.040357 | 994.1 |
| 369.45 | 11.700 | 4.037306 | 982.7 |
| 369.48 | 10.111 | 4.033645 | 968.7 |

TABLE 2 (cont.)

Density of mixture HCFC 22 + HCFC 142b (40/60 wt%), $\sigma_\rho = 0.08\%$

| T/K | P/MPa | $\tau$ / s | $\rho$ / kg.m$^{-3}$ |
|---|---|---|---|
| 369.50 | 8.633 | 4.029591 | 953.1 |
| 369.52 | 7.075 | 4.024712 | 934.4 |
| 369.47 | 6.063 | 4.021074 | 920.6 |
| 369.51 | 4.039 | 4.011191 | 882.4 |
| 369.45 | 3.169 | 4.005072 | 859.0 |

The densities data obtained for HCFC 142b and for its mixture with HCFC 22 can be represented by an equation of the type

$$\rho = A_0 + A_1 T + A_2 T^2 + A_3 \frac{\tau^2}{\tau_0^2} + A_4 \frac{\tau^2}{\tau_0^2} T + A_5 \frac{\tau^2}{\tau_0^2} T^2 + A_6 P \tag{7}$$

with standard deviation of 0.1 kg.m$^{-3}$ and 0.14 kg.m$^{-3}$ respectively, which is commensurate with the experimental error. Equation (7) is an explicit form of equation (2), with temperature and pressure dependent coefficients. The values of the coefficients $A_i$ obtained are presented in Table 3 and Fig. 1a) and b) show the departures of the experimental data from the eq. (7) for HCFC 142b and the mixture, respectively.

TABLE 3

Coefficients of equation (7)

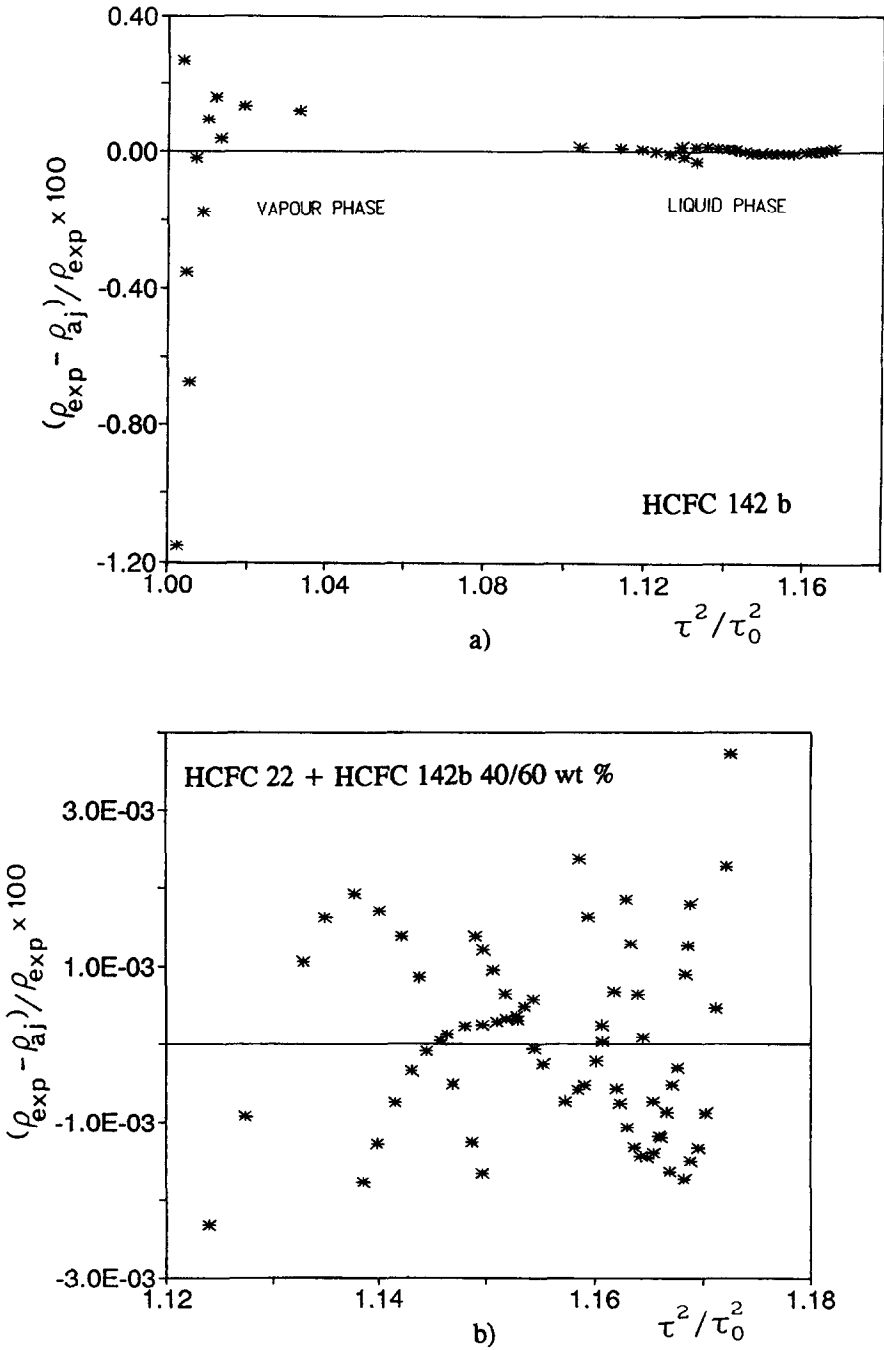| | HCFC 142b | HCFC 22 + HCFC 142b (40/60 wt%) |
|---|---|---|
| $A_0$ / kg.m$^{-3}$ | -5811.00 | -6715.83 |
| $A_1$ / kg.m$^{-3}$.K$^{-1}$ | -8.028 | -3.317 |
| $A_2$ / kg.m$^{-3}$.K$^{-2}$ | 0.01352 | 0.007368 |
| $A_3$ / kg.m$^{-3}$ | 5807.8 | 6576.04 |
| $A_4$ / kg.m$^{-3}$.K$^{-1}$ | 8.041 | 4.045 |
| $A_5$ / kg.m$^{-3}$.K$^{-2}$ | -0.01353 | -0.00831 |
| $A_6$ / kg.m$^{-3}$.MPa$^{-1}$ | -0.24846 | -0.27176 |
| $\sigma$ / kg.m$^{-3}$ | 0.11 | 0.014 |

Fig. 1. The departure of experimental data from eq. (7); a) for HCFC 142 b; b) for the mixture HCFC 22 + HCFC 142b 40/60 wt %.

# DATA CORRELATION

The experimental data $(P,T,\rho)$ of HCFC 142b were fitted to an equation of state where the repulsive part is the tenth virial equation of state of hard spheres, with $C_i$ representing the virial coefficients obtained for molecular dynamics simulation, and the attractive part is the DeSantis term, herein designated by HSDS:

$$\frac{PV}{RT} = \sum_{i=1}^{10} C_i \left(\frac{b}{V}\right)^{i-1} - \frac{a}{RT(V+b)} \tag{8}$$

where V is the molar volume. The coefficients a and b were assumed temperature dependent in the form

$$a = A_0 + A_1 T + A_2 T^2 \tag{9}$$

$$b = B_0 + B_1 T + B_2 T^2 \tag{10}$$

The saturation line data of the HCFC 142b (liquidus line) obtained by Maezawa et al (1989), and the critical point constants ($T_C$ =410.25 K, $P_C$ =4.246 MPa, $\rho_C$ =435 kg.m$^{-3}$ ) were also included in the fit.

The equation of state for HCFC 142b reproduces the experimental data with a maximum deviation of 0.3 % for temperatures between 200 and 400 K and pressures up to 18 MPa, except near the critical point where density data in the saturation line are not available.

The equation used for the mixture is of the same form of eq. (8), but the parameters a and b are replaced by the mixture parameters $b_{mix}$ and $a_{mix}$ and V is replaced by the molar volume of the mixture. The temperature dependence of $a_{mix}$ and $b_{mix}$ was assumed to be given by eq. (9) and (10). Mixture parameters are also composition dependent and the dependences are assumed to be given by the quadratic van der Waals mixing rules

$$a_{mix} = x_1^2 a_{11} + 2 x_1 x_2 a_{12} + x_2^2 a_{22} \tag{11}$$

$$b_{mix} = x_1^2 b_{11} + 2 x_1 x_2 b_{12} + x_2^2 b_{22} \tag{12}$$

Also included in the fit of the mixture data was the saturation line of the this mixture obtained by Maezawa et al (1990).

Equation (8) reproduces the experimental data of the mixture studied with a maximum error of 1 % for the temperatures between 280 and 390 K and pressures up to 19 MPa.

Using eq. (11) and (12) the values of the interaction parameters $a_{12}$ and $b_{12}$, and the temperature dependences can be obtained. The coefficients of eq. (9) and (10) for the interaction parameters are temperature and composition independent and, therefore, permit the estimation of the densities of the binary mixture of HCFC 22 + HCFC 142b for any composition, temperature and pressure, through the eq. (8). For this calculations an estimate of the values of the parameters $a_{22}$ and $b_{22}$ is needed. With this purpose, density data of pure HCFC 22, obtained from the compilation of JSME Data Book, were adjusted to the eq. (8), and its temperature dependence was determined by eq. (9) and (10), with a maximum deviation of 0.3 % (except near the critical point), for temperatures between 170 and 360 K and pressures up to 15 MPa.

All the coefficients needed to use the equation of state for the pure components and for its binary mixture are presented in Table 4.

TABLE 4

Coeficients of equations (8), (9) and (10)

| | HCFC 142b | HCFC 22 | HCFC 22 + HCFC 142b | |
| --- | --- | --- | --- | --- |
| | | | 40/60 wt% | interaction Parameters |
| $A_0$ / J.m$^3$.mol$^{-2}$ | 16.12587 | 9.14762 | 11.64413 | 9.71321 |
| $A_1$ / J.m$^3$.mol$^{-2}$.K$^{-1}$ | $-5.86 \times 10^{-2}$ | $-3.63 \times 10^{-2}$ | $-4.10 \times 10^{-2}$ | $-3.15 \times 10^{-2}$ |
| $A_2$ / J.m$^3$.mol$^{-2}$.K$^{-2}$ | $5.69 \times 10^{-5}$ | $3.94 \times 10^{-5}$ | $3.82 \times 10^{-5}$ | $2.57 \times 10^{-5}$ |
| $B_0$ / m$^3$.mol$^{-1}$ | $1.83 \times 10^{-4}$ | $1.38 \times 10^{-4}$ | $1.64 \times 10^{-4}$ | $1.62 \times 10^{-4}$ |
| $B_1$ / m$^3$.mol$^{-1}$.K$^{-1}$ | $6.76 \times 10^{-9}$ | $-6.59 \times 10^{-8}$ | $-3.46 \times 10^{-8}$ | $-4.92 \times 10^{-8}$ |
| $B_2$ / m$^3$.mol$^{-1}$.K$^{-2}$ | $-4.96 \times 10^{-10}$ | $-2.86 \times 10^{-10}$ | $-3.76 \times 10^{-10}$ | $-3.33 \times 10^{-10}$ |

Virial coefficients of the hard-spheres, taken from Ree and Hoover (1964) and Erpenbeck and Wood (1984):

| | | | | |
| --- | --- | --- | --- | --- |
| $C_1$ | 1 | | $C_6$ | $0.0386 \pm 0.0004$ |
| $C_2$ | 1 | | $C_7$ | $0.0137 \pm 0.006$ |
| $C_3$ | 5/8 | | $C_8$ | 0.00421 |
| $C_4$ | 0.28695 | | $C_9$ | 0.00131 |
| $C_5$ | $0.1103 \pm 0.0003$ | | $C_{10}$ | 0.00040 |

Figures 2 and 3 show that, for the HCFC 142b and for its mixture 60/40 wt% with HCFC 22, a good fit was obtained for the zone where the high pressure data was hooked to the saturation boundary data. Figures 4a) and b) presented the corresponding scattering diagrams.
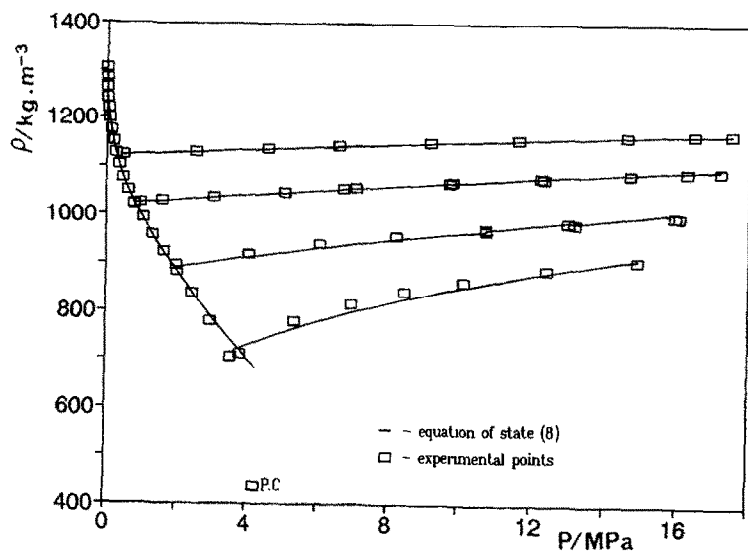
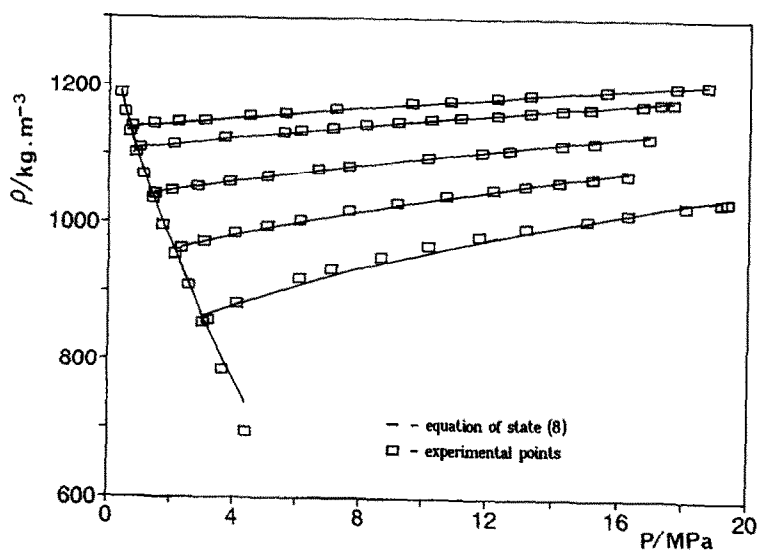Fig. 2. The density of HCFC 142b as function of temperature and pressure.



Fig. 3. The density of the mixture HCFC 22 + HCFC 142b 40/60 wt%, as function of temperature and pressure.
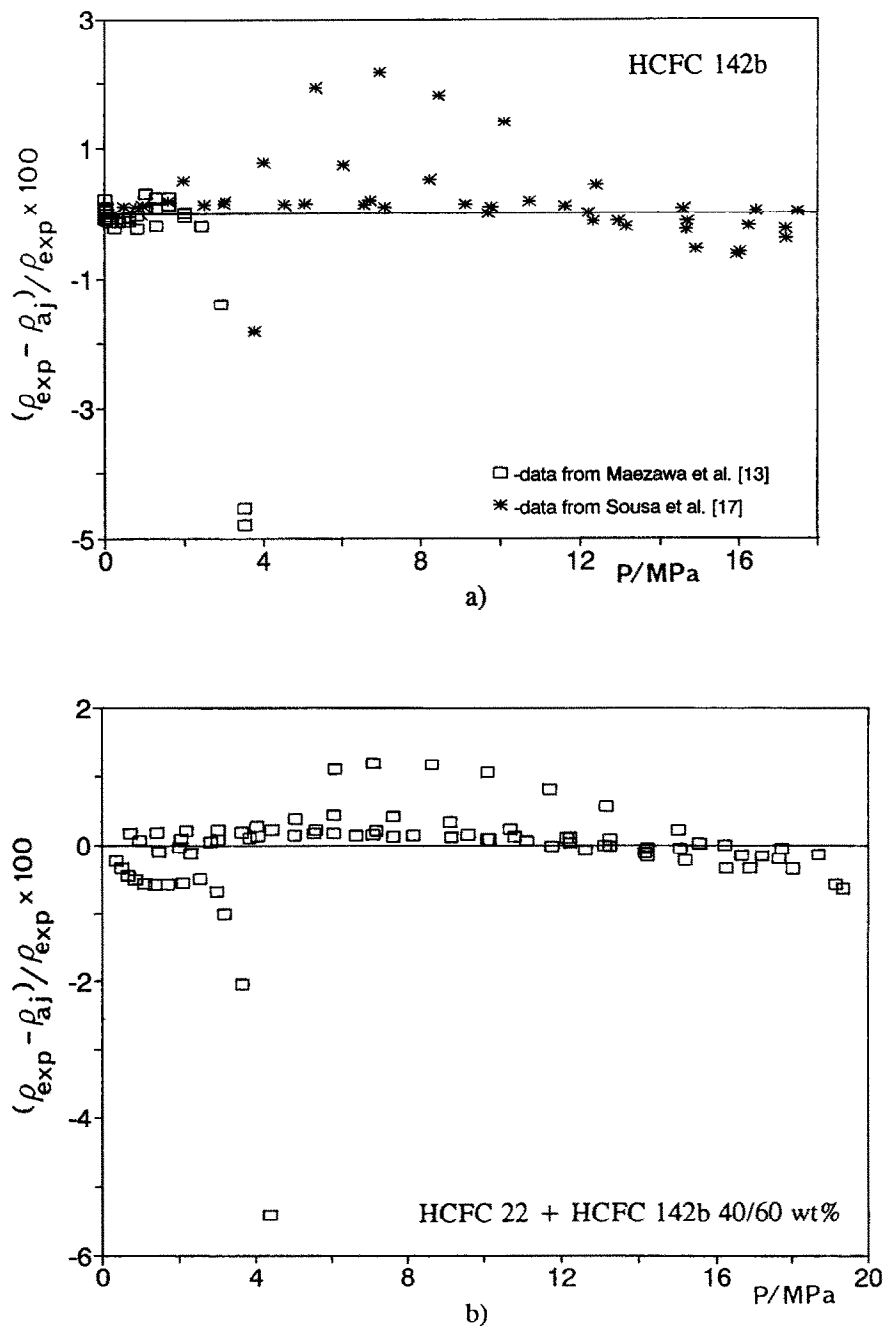
Fig. 4. The departures of experimental data from eq.(8): a) for HCFC 142b; b) for the mixture HCFC 22 + HCFC 142b 40/60 wt%.

# CONCLUSION

This paper presents density data for HCFC 142b and its binary mixture 60/40 wt% with HCFC 22 obtained with a relative densimeter with an accuracy of 0.08 %.

The experimental data for the liquid phase of pure HCFC 142b and of its mixture with HCFC 22 were fitted to an equation of state, based on the exact hard spheres 10 virial repulsive term, added to a DeSantis attractive term, HSDS. This equation of state is capable of reproducing the data better than 1 %.

The work in progress will demonstrate the validity of known mixing rules and the predictability capacity of the equation of state herein presented.

# ACKNOWLEDGMENTS

# REFERENCES

DeSantis R, Gironi F, Marreli L, 1976, Ind. Eng. Chem. Fundam., 15:183
Erpenbeck J, Wood W W, 1984, J. Stat. Phys., 35:321-340
*Thermophysical Properties of Fluids*, 1983, JSME Data Book
Kashiwagi H, Hashimoto T, Tanaka Y, Kubota H, Makita T, 1982, Int. J. Thermophysics, 3:201-215
McLinden M O, Didion D A, 1989, Int. J. Thermophys., 10:563-576
Maezawa Y, Sato H, Watanabe K, 1989, Proc. 10 th Symp. Thermophys. Prop., (Ed JSME, Tokyo) , 71-74
Ree F H, Hoover W G, 1964, J. Chem. Phys., 40: 939-950
Sousa A T, Castro C A N, Tufeu R, Le Neindre B, 1991, High Temp.-High Pres., in press