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# An Experimental Study of *pVTx* Properties for Binary Mixtures of HFC-32 and HFC-125[1]

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An experimental study of the pressure-volume-temperature-composition (*pVTx*) properties for binary mixtures of HFC-32($CH_2F_2$) and HFC-125($C_2HF_5$) was conducted in the range of temperatures from 343 to 423 K, pressures from 4.0 to 15.6 MPa, densities from 485 to 491 kg·m$^{-3}$, and compositions from 0.05 to 0.90 mole fraction of HFC-32, with uncertainties of 4.4 mK, 1.6 kPa, 0.02%, and 0.0004 mole fraction, respectively. The available experimental data for *pVTx* properties of binary mixtures of HFC-32 and HFC-125 have been compared with the equation of state developed by Tillner-Roth et al. From the critical evaluation, this equation of state should be revised in the range of low mole fractions of HFC-32.

**KEY WORDS:** data evaluation; experimental study; HFC-32/125 mixtures; *pVTx* properties.

## 1. INTRODUCTION

When blended HFC refrigerants are used for refrigerators and air-conditioning machines, the compositions of the mixtures vary the most during liquid–vapor equilibrium changes. Therefore, the thermodynamic properties of refrigerant mixtures should be studied over a wide range of temperatures, pressures, and compositions.

This paper deals with an experimental study of pressure–volume–temperature–composition (*pVTx*) properties for binary mixtures of HFC-32

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($CH_2F_2$) and HFC-125 ($C_2HF_5$) conducted in the range of temperatures from 343 to 423 K, pressures from 4.0 to 15.6 MPa, densities from 485 to 491 kg·m$^{-3}$, and compositions from 0.05 to 0.90 mole fraction of HFC-32. The available experimental data including the present measured data were compared with the equation of state developed by Tillner-Roth et al. [1] for these mixtures.

## 2. SURVEY OF AVAILABLE DATA OF *pVTx* PROPERTIES

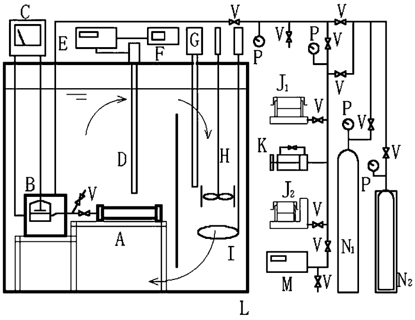
The available experimental studies of the *pVTx* properties for binary mixtures of HFC-32 and HFC-125 have been compiled in the range of temperatures from 200 to 440 K, pressures from 0.09 to 35.3 MPa, densities from 2.6 to 1497 kg·m$^{-3}$, and compositions from 0.20 to 0.90 mole fraction of HFC-32 as shown in Table I.

## 3. EXPERIMENTAL METHOD AND UNCERTAINTIES

A constant-volume apparatus with a cylindrical vessel of approximately 173 cm$^3$ internal volume was used for the present measurements of *pVTx* properties, as shown in Fig. 1. This experimental method was described in other publications [11–13]. The temperature was measured with the use of a platinum resistance thermometer calibrated within 2 mK at the National Physical Laboratory in the United Kingdom, based on the International Temperature Scale of 1990. The Ruska Series 6000 quartz Bourdon-type pressure gage was used for the measurements of pressure. The density was determined from the mass of the sample divided by the internal volume of the vessel. Uncertainties of temperature, pressure,

**Table I.** Available *pVTx* Properties for Binary Mixtures of HFC-32 and HFC-125

| First author | Data points | Temperature range (K) | Pressure range (MPa) | Density range (kg·m$^{-3}$) | Mole fraction of HFC-32 |
|---|---|---|---|---|---|
| Widiatmo [2] | 24 | 280–310 | 0.88–2.3 | 940–1254 | 0.20–0.90 |
| Weber [3] | 17 | 338–373 | 0.3–4.2 | 8.8–158.1 | 0.55 |
| Bivens [4] | 111 | 280–373 | 0.49–4.8 | 13.7–206.5 | 0.65–0.78 |
| Zhelezny [5] | 136 | 280–338 | 0.67–3.6 | 20–184 | 0.26–0.75 |
| Kiyoura [6] | 104 | 320–440 | 1.72–5.2 | 67.7–158.1 | 0.37–0.61 |
| Sato [7] | 156 | 320–440 | 1.78–5.3 | 50.4–125.1 | 0.70–0.90 |
| Zhang [8] | 124 | 300–380 | 0.09–4.6 | 2.6–151.7 | 0.50–0.70 |
| Magee [9] | 228 | 200–399 | 4.27–35.3 | 91.5–1497 | 0.5 |
| Kleemiß [10] | 415 | 243–413 | 0.019–17.1 | 0.6–1391 | 0.5 |



A: Piezometer

B: Diaphragm-type pressure balance detector

C: Transformer bridge

D: Platinum resistance thermometer

E: Thermometer bridge

F: dc null indicator

G: Cooler

H: Circular pump

I: Heater

$J_{1,2}$: Air piston pressure gage

K: Pressure controller

L: Thermostated bath

M: Digital pressure gage

$N_{1,2}$:Nitrogen bottles

P: Bourdon-type pressure gauges

V: High-pressure valves

←: Flow pattern of brine

**Fig. 1.** Schematic diagram of *pVTx* apparatus.

density, and composition measurements were within 4.4 mK, 1.6 kPa, 0.02% in density, and 0.0004 mole fraction, respectively. The purities of the samples of HFC-32 and HFC-125 were 0.99983 and 0.99962 mole fraction, respectively, as furnished by Mitui-du Pont Fluorochemical Co. Ltd.

## 4. RESULTS

Measurements of 79 data points of *pVTx* properties for binary mixtures of HFC-32 and HFC-125 were made in the range of temperatures from 343 to 423 K, pressures from 4.0 to 15.6 MPa, densities from 485 to 491 $\mathrm{kg{\cdot}m^{-3}}$, and compositions from 0.05 to 0.90 mole fraction of HFC-32, as shown in Table II.

**Table II.** Experimental Results for $pVTx$ Properties of Binary Mixtures of HFC-32 and HFC-125

| Temp. (K) | Press. (MPa) | Density ($kg \cdot m^{-3}$) | Mole fract. of HFC-32 | Temp. (K) | Press. (MPa) | Density ($kg \cdot m^{-3}$) | Mole fract. of HFC-32 |
|---|---|---|---|---|---|---|---|
| 343.233 | 3.9784 | 491.33 | 0.0520 | 413.140 | 9.4705 | 487.04 | 0.2009 |
| 353.149 | 4.6786 | 491.04 | 0.0520 | 423.286 | 10.2215 | 486.75 | 0.2009 |
| 363.143 | 5.3771 | 490.75 | 0.0520 | 343.160 | 4.3240 | 489.15 | 0.3005 |
| 373.219 | 6.0772 | 490.46 | 0.0520 | 353.150 | 5.1417 | 488.86 | 0.3005 |
| 383.129 | 6.7624 | 490.17 | 0.0520 | 363.148 | 5.9537 | 488.57 | 0.3005 |
| 393.094 | 7.4481 | 489.89 | 0.0520 | 373.150 | 6.7652 | 488.28 | 0.3005 |
| 403.277 | 8.1443 | 489.60 | 0.0520 | 383.160 | 7.5743 | 488.00 | 0.3005 |
| 413.154 | 8.8178 | 489.32 | 0.0520 | 393.140 | 8.3783 | 487.71 | 0.3005 |
| 423.073 | 9.4897 | 489.04 | 0.0520 | 403.171 | 9.1839 | 487.42 | 0.3005 |
| 343.313 | 4.0256 | 489.12 | 0.0819 | 413.181 | 9.9840 | 487.14 | 0.3005 |
| 353.195 | 4.7326 | 488.83 | 0.0819 | 423.244 | 10.7856 | 486.85 | 0.3005 |
| 363.150 | 5.4355 | 488.55 | 0.0819 | 343.269 | 4.5922 | 487.42 | 0.5013 |
| 373.150 | 6.1381 | 488.26 | 0.0819 | 353.169 | 5.5145 | 487.13 | 0.5013 |
| 383.150 | 6.8362 | 487.98 | 0.0819 | 363.176 | 6.4492 | 486.85 | 0.5013 |
|  |  |  |  | 372.779 | 7.3474 | 486.57 | 0.5013 |
| 393.158 | 7.5313 | 487.69 | 0.0819 | 383.322 | 8.3327 | 486.26 | 0.5013 |
| 403.093 | 8.2168 | 487.41 | 0.0819 | 393.001 | 9.2375 | 485.99 | 0.5013 |
| 413.073 | 8.9013 | 487.13 | 0.0819 | 403.127 | 10.1828 | 485.70 | 0.5013 |
| 423.245 | 9.5952 | 486.84 | 0.0819 | 412.948 | 11.0952 | 485.42 | 0.5013 |
| 343.078 | 4.0377 | 489.99 | 0.1015 | 423.081 | 12.0358 | 485.13 | 0.5013 |
| 353.197 | 4.7715 | 489.70 | 0.1015 | 353.160 | 5.8422 | 488.40 | 0.6998 |
| 363.150 | 5.4850 | 489.41 | 0.1015 | 363.155 | 6.9396 | 488.10 | 0.6998 |
| 373.184 | 6.2000 | 489.13 | 0.1015 | 373.150 | 8.0475 | 487.81 | 0.6998 |
| 383.158 | 6.9066 | 488.84 | 0.1015 | 383.141 | 9.1602 | 487.52 | 0.6998 |
| 393.151 | 7.6108 | 488.56 | 0.1015 | 393.161 | 10.2782 | 487.23 | 0.6998 |
| 403.182 | 8.3142 | 488.27 | 0.1015 | 403.161 | 11.3959 | 486.94 | 0.6998 |
| 413.159 | 9.0094 | 487.99 | 0.1015 | 413.163 | 12.5138 | 486.65 | 0.6998 |
| 423.162 | 9.7032 | 487.70 | 0.1015 | 423.129 | 13.6256 | 486.37 | 0.6998 |
| 343.150 | 4.1123 | 489.38 | 0.1508 | 353.160 | 6.0454 | 488.45 | 0.8992 |
|  |  |  |  | 363.181 | 7.3705 | 488.15 | 0.8992 |
| 353.181 | 4.8602 | 489.09 | 0.1508 | 373.160 | 8.7219 | 487.86 | 0.8992 |
| 363.142 | 5.5956 | 488.80 | 0.1508 | 383.169 | 10.0931 | 487.56 | 0.8992 |
| 373.172 | 6.3327 | 488.51 | 0.1508 | 393.161 | 11.4715 | 487.27 | 0.8992 |
| 383.141 | 7.0611 | 488.23 | 0.1508 | 403.178 | 12.8607 | 486.98 | 0.8992 |
| 393.185 | 7.7923 | 487.94 | 0.1508 | 413.186 | 14.2517 | 486.68 | 0.8992 |
| 403.122 | 8.5126 | 487.66 | 0.1508 | 423.181 | 15.6405 | 486.40 | 0.8992 |
| 413.209 | 9.2392 | 487.37 | 0.1508 |  |  |  |  |
| 423.142 | 9.9520 | 487.09 | 0.1508 |  |  |  |  |
| 343.156 | 4.1854 | 489.05 | 0.2009 |  |  |  |  |
| 353.171 | 4.9553 | 488.76 | 0.2009 |  |  |  |  |
| 363.150 | 5.7147 | 488.47 | 0.2009 |  |  |  |  |
| 373.165 | 6.4731 | 488.18 | 0.2009 |  |  |  |  |
| 383.118 | 7.2237 | 487.89 | 0.2009 |  |  |  |  |
| 393.150 | 7.9775 | 487.61 | 0.2009 |  |  |  |  |
| 403.119 | 8.7235 | 487.32 | 0.2009 |  |  |  |  |

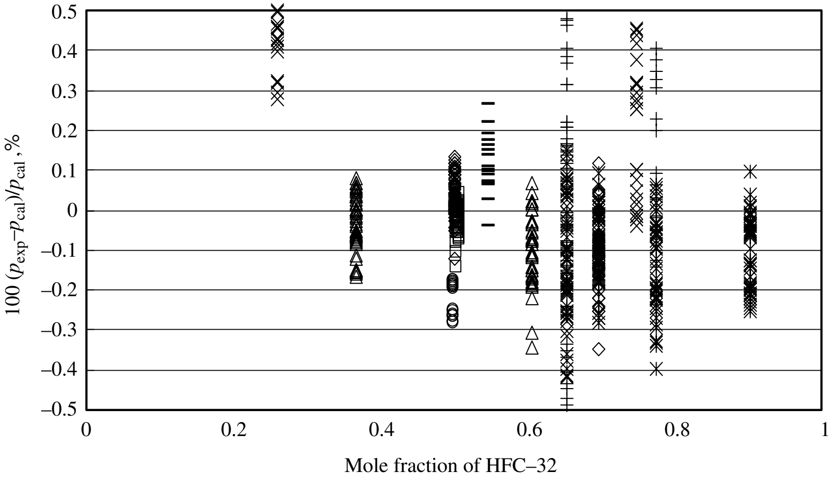


**Fig. 2.** Pressure deviations of available $pVTx$ properties [3–10] from the equation of state [1] (densities from 30 to 220 kg·m$^{-3}$); (–)Weber and Defibaugh [3], (+) Bivens et al. [4], (×) Zheleznyy et al. [5], (△) Kiyoura et al. [6], (✱) Sato et al. [7],(◇) Zhang et al. [8], (○) Magee and Haynes [9], (□)Kleemiß [10].

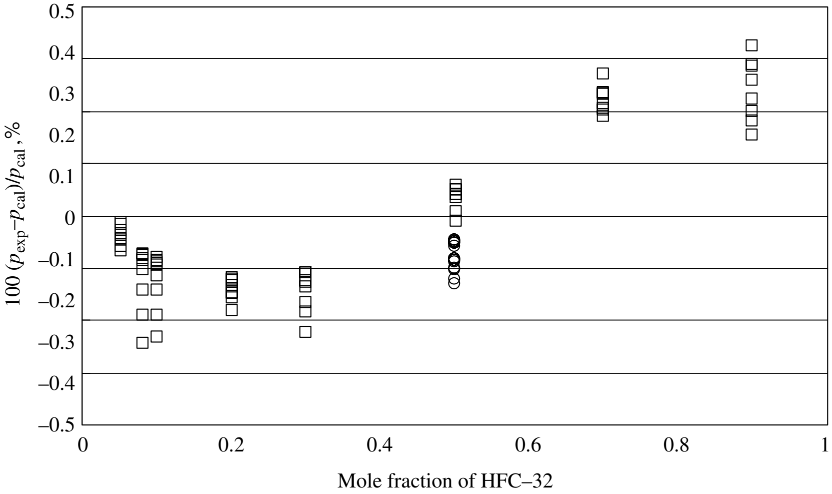


**Fig. 3.** Pressure deviations of the present results and Magee and Haynes result [9] from the equation of state [1]; (□) this work, densities from from 485 to 491 kg·m$^{-3}$; (○) Magee and Haynes [9], densities from 406 to 592 kg·m$^{-3}$.

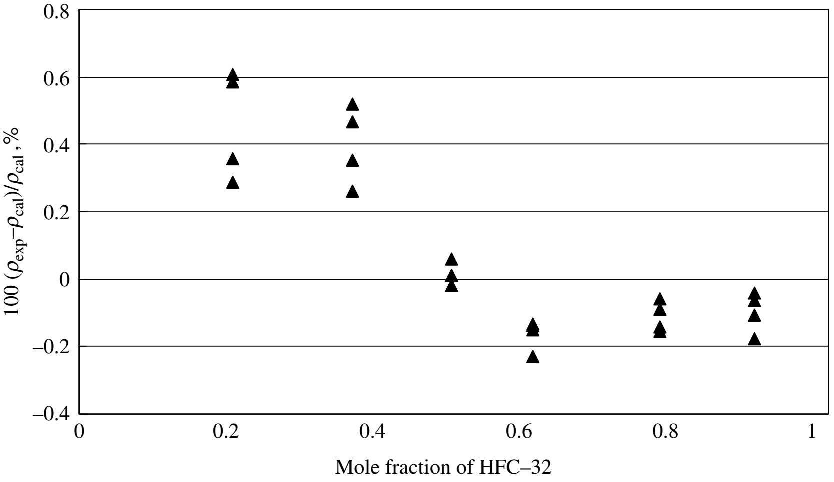


**Fig. 4.** Density deviations of Widiatmo et al. results [2] from the equation of state [1]; (▲) Widiatmo et al. [2], densities from 940 to 1254 kg·m$^{-3}$.

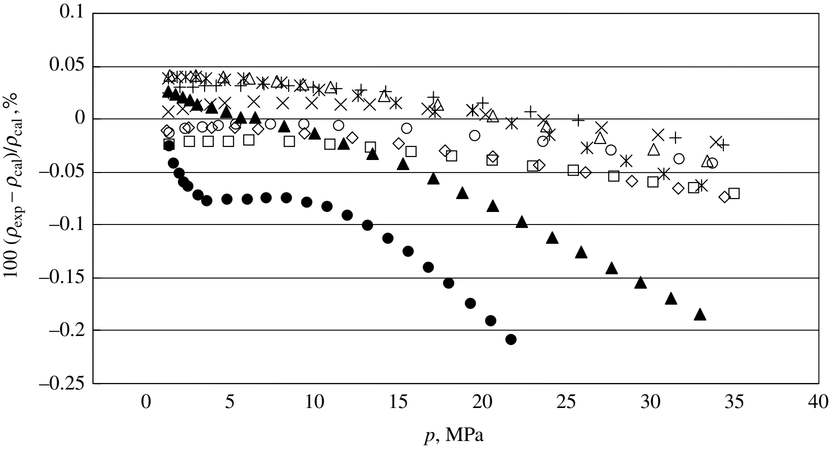


**Fig. 5.** Density deviations of Magee and Haynes results [9] from the equation of state [1]; (△) densities from 1493 to 1497 kg·m$^{-3}$, (◇) densities from 1443 to 1447 kg·m$^{-3}$, (□) densities from 1392 to 1396 kg·m$^{-3}$, (○) densities from 1330 to 1335 kg·m$^{-3}$, (×) densities from 1270 to 1276 kg·m$^{-3}$, (+) densities from 1206 to 1211 kg·m$^{-3}$, (✳) densities from 1121 to 1127 kg·m$^{-3}$, (▲) densities from 1026 to 1033 kg·m$^{-3}$, (•) densities from 888 to 893 kg·m$^{-3}$.

## 5. DISCUSSION

Comparisons of the available experimental data of *pVTx* properties with the equation of state [1] are shown in Figs. 2–5. Most of the available data between 0.6 and 0.8 mole fraction HFC-32 in the gaseous region agree within ±0.5% in pressure as compared to the equation of state of Tillner-Roth [1]. The present measured data agree with the data by Magee et al. [9] within ±0.1% in pressure, as shown in Fig. 3.

## 6. CONCLUSION

Experimental *pVTx* data for binary mixtures of HFC-32 and HFC-125 were obtained with the use of a constant-volume apparatus in the range of temperatures from 343 to 423 K, pressures from 4.0 to 15.6 MPa, densities from 485 to 491 $\text{kg·m}^{-3}$, and compositions from 0.05 to 0.90 mole fraction of HFC-32. The available data are compared with the equation of state of Ref. 1, and it is revealed that the equation of state does not represent the experimental *pVTx* properties data in the range of low mole fractions of HFC-32 within experimental uncertainty. Additional experimental data of thermodynamic properties for these mixtures are required for developing a more accurate equation of state.

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