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# Densities of Carbon Dioxide + Nitrogen from 225 K to 450 K at Pressures up to 70 MPa

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This paper reports *PVT* measurements for five gravimetrically prepared mixtures of $CO_2 + N_2$ from 225 K to 450 K at pressures up to 70 MPa. These results have been determined using a continuously-weighed pycnometer. A detailed error analysis indicates that the accuracy of the densities is better than ±0.1%. Additional *PVT* data for $CO_2 + N_2$ mixtures have been measured by Netherlandse Gasunie, Ruhrgas, and Gaz de France as reported by Jaeschke and Humphreys (1990).

## Introduction

This paper reports experimental results for the densities of $CO_2 + N_2$ mixtures from 225 K to 450 K at pressures up to 70 MPa using a continuously-weighed pycnometer. Burnett data and derived virial coefficients at 300 K and 320 K for this system have been reported previously by Brugge *et al.* (1989). Esper *et al.* (1989) report Burnett-isochoric measurements from 205 K to 320 K and pressures from 0.1 MPa to 48 MPa. Isochoric *pVT*, vapor pressures and saturation densities have been reported by Esper *et al.* (1989) and Duarte-Garza *et al.* (1995a).

Standard thermodynamic procedures permit evaluation of other properties from the densities. GPA/GRI Research Report RR-140 authored by Duarte-Garza *et al.* (1995b) contains: energies (internal, Helmholtz, and Gibbs), enthalpies, and entropies obtained from the data reduction method described by Duarte-Garza *et al.* (1997); second and third virial coefficients for both the pure compounds and the mixture.

## Experimental Section

***Materials.*** The carbon dioxide was Ultra Pure grade from Scientific Gas Products, Inc., with a purity better than 99.995 mol % with 40 ppm nitrogen and 40 ppm oxygen maximum contaminant concentration. The sample was degassed by evacuating a frozen sample for a least 30 min. The nitrogen was Research Grade from Air Products, with a specified purity of better than 99.9995%. No further purification was performed.

***Measurements.*** The pycnometer consists of a sample cell of known volume suspended from an electronic balance that has been described in detail by Lau (1986) and Lau *et al.* (1997). Pressures are measured using pressure transducers that have been calibrated *in-situ* against an automatic dead-weight gauge pressure standard. The accuracy of the pressure measurements is estimated to be ±0.006 MPa. Temperatures are measured with a four-lead platinum resistance thermometer, which is adjacent to the sample cell on the inside surface of the compartment. The temperature is controlled to ±0.002 K and measured to an accuracy of ±0.005 K on ITS-90. The mixtures are prepared gravimetrically with mole fractions accurate to ±0.000 05, excluding the effects of sample impurity. The uncertainties in the pycnometric density measurements arise from the uncertainties in the mass determinations and the cell volume calibration. The error in the cell volume calibration, which includes random errors introduced by uncertainties in the temperature and pressure measurements, uncertainties from using a calibrating fluid whose equation of state is known, and errors from mass determinations, is about ±0.04%. The estimated accuracy (at 95 % confidence limit) provided by Hwang *et al.* (1997) in the pycnometric density measurements is

$$\Delta\rho = \{(0.15)^2 + (0.0004\rho)^2\}^{1/2}$$

or

$$\frac{\Delta\rho}{\rho} = \left\{\left(\frac{0.15}{\rho}\right)^2 + 1.6 \times 10^{-7}\right\}^{1/2}$$

where the units of density are kg·m$^{-3}$.

## Results and Conclusions

Table 1 contains densities measured with the pycnometer and derived compressibility factors for the five mixtures of $CO_2 + N_2$. These data cover temperatures from 225 K to 450 K and pressures up to 70 MPa.

The experimental data in this project are state-of-the-art measurements and generally accurate within ±0.1%. These results are suitable for both stringent testing and development of models and correlations. These results formed a significant contribution to the development of the American Gas Association Standard AGA-8.

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**Table 1. Experimental $pVT$ Results for $CO_2$ (A) + $N_2$ (B) at Various Mole Fractions Determined by Pycnometer. $M_{r,A}$ = 28.0134, $M_{r,B}$ = 44.0098**

| $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $x_A$ = 0.105 60, $M_r$ = 29.7026 | | | | | | | | | | | |
| $T$ = 225.00 K | | | | | | | | | | | |
| 68.759 | 21 922 | 1.676 61 | 51.819 | 19 990 | 1.385 67 | 34.553 | 16 978 | 1.087 88 | 17.334 | 10 929 | 0.847 81 |
| 62.510 | 21 286 | 1.569 78 | 45.955 | 19 136 | 1.283 70 | 28.832 | 15 503 | 0.994 13 | 11.565 | 7 405 | 0.834 84 |
| 57.402 | 20 706 | 1.481 88 | 40.271 | 18 158 | 1.185 51 | 23.073 | 13 561 | 0.909 48 | 5.789 | 3 470 | 0.891 78 |
| $T$ = 245.00 K | | | | | | | | | | | |
| 68.953 | 20 751 | 1.631 22 | 34.424 | 15 394 | 1.097 76 | 18.586 | 10 022 | 0.910 40 | 8.579 | 4 647 | 0.906 28 |
| 57.208 | 19 395 | 1.447 99 | 29.447 | 14 066 | 1.027 71 | 15.875 | 8 698 | 0.895 97 | 6.223 | 3 302 | 0.925 17 |
| 49.629 | 18 325 | 1.329 51 | 25.196 | 12 702 | 0.973 77 | 13.324 | 7 341 | 0.891 00 | 3.806 | 1 967 | 0.949 87 |
| 40.517 | 16 735 | 1.188 53 | 21.643 | 11 356 | 0.935 60 | 10.939 | 6 004 | 0.894 41 | 1.265 | 631 | 0.984 15 |
| $T$ = 265.00 K | | | | | | | | | | | |
| 68.980 | 19 656 | 1.592 75 | 34.460 | 14 069 | 1.111 66 | 17.697 | 8 484 | 0.946 71 | 8.288 | 3 996 | 0.941 33 |
| 59.626 | 18 547 | 1.459 09 | 30.257 | 12 956 | 1.059 92 | 15.189 | 7 356 | 0.937 14 | 6.015 | 2 867 | 0.952 20 |
| 51.662 | 17 418 | 1.346 15 | 26.580 | 11 838 | 1.019 05 | 12.832 | 6 240 | 0.933 32 | 3.740 | 1 754 | 0.967 75 |
| 45.014 | 16 304 | 1.253 06 | 23.281 | 10 708 | 0.986 76 | 10.538 | 5 118 | 0.934 49 | 1.408 | 647 | 0.987 68 |
| 39.419 | 15 204 | 1.176 70 | 20.372 | 9 599 | 0.963 22 | | | | | | |
| $T$ = 285.00 K | | | | | | | | | | | |
| 69.124 | 18 656 | 1.563 62 | 38.736 | 13 916 | 1.174 68 | 21.802 | 9 171 | 1.003 23 | 10.090 | 4 433 | 0.960 54 |
| 61.286 | 17 705 | 1.460 78 | 34.711 | 12 989 | 1.127 75 | 19.227 | 8 227 | 0.986 26 | 7.932 | 3 472 | 0.964 10 |
| 54.492 | 16 756 | 1.372 41 | 30.952 | 12 027 | 1.086 05 | 16.819 | 7 286 | 0.974 16 | 5.792 | 2 524 | 0.968 41 |
| 48.534 | 15 806 | 1.295 82 | 27.610 | 11 071 | 1.052 45 | 14.481 | 6 326 | 0.966 03 | 3.650 | 1 576 | 0.977 36 |
| 43.343 | 14 858 | 1.231 06 | 24.590 | 10 124 | 1.025 01 | 12.256 | 5 378 | 0.961 72 | 1.477 | 630 | 0.989 37 |
| $T$ = 300.00 K | | | | | | | | | | | |
| 69.055 | 17 936 | 1.543 52 | 39.817 | 13 396 | 1.191 62 | 22.642 | 8 840 | 1.026 85 | 10.413 | 4 272 | 0.977 21 |
| 61.675 | 17 032 | 1.451 73 | 35.681 | 12 476 | 1.146 58 | 19.933 | 7 919 | 1.009 13 | 8.196 | 3 363 | 0.977 05 |
| 55.165 | 16 118 | 1.372 13 | 31.967 | 11 568 | 1.107 87 | 17.400 | 7 007 | 0.995 54 | 5.999 | 2 456 | 0.979 25 |
| 49.506 | 15 219 | 1.304 11 | 28.534 | 10 638 | 1.075 34 | 14.971 | 6 088 | 0.985 87 | 3.767 | 1 534 | 0.984 50 |
| 44.370 | 14 306 | 1.243 41 | 25.493 | 9 743 | 1.048 99 | 12.682 | 5 188 | 0.980 01 | 1.537 | 620 | 0.993 86 |
| $T$ = 320.00 K | | | | | | | | | | | |
| 34.747 | 11 381 | 1.147 50 | 23.668 | 8 451 | 1.052 61 | 14.819 | 5 542 | 1.005 00 | 6.805 | 2 580 | 0.991 34 |
| 30.700 | 10 405 | 1.108 95 | 20.550 | 7 484 | 1.032 03 | 12.114 | 4 567 | 0.996 95 | 4.181 | 1 583 | 0.992 69 |
| 27.037 | 9 428 | 1.077 84 | 17.649 | 6 522 | 1.017 08 | 9.397 | 3 558 | 0.992 65 | 1.740 | 658 | 0.993 89 |
| $T$ = 350.00 K | | | | | | | | | | | |
| 69.189 | 15 932 | 1.492 33 | 42.587 | 11 927 | 1.226 99 | 24.756 | 7 884 | 1.079 02 | 11.366 | 3 857 | 1.012 64 |
| 62.799 | 15 130 | 1.426 30 | 38.449 | 11 112 | 1.189 02 | 21.856 | 7 081 | 1.060 65 | 8.925 | 3 047 | 1.006 54 |
| 57.018 | 14 327 | 1.367 58 | 34.625 | 10 298 | 1.155 40 | 19.062 | 6 271 | 1.044 55 | 6.550 | 2 246 | 1.002 14 |
| 51.735 | 13 520 | 1.314 94 | 31.132 | 9 499 | 1.126 23 | 16.417 | 5 471 | 1.031 15 | 4.182 | 1 439 | 0.998 67 |
| 46.821 | 12 700 | 1.266 88 | 27.855 | 8 693 | 1.101 11 | 13.867 | 4 670 | 1.020 38 | 1.840 | 635 | 0.995 73 |
| $T$ = 400.00 K | | | | | | | | | | | |
| 68.655 | 14 254 | 1.448 24 | 51.633 | 11 939 | 1.300 36 | 34.122 | 8 837 | 1.161 01 | 17.385 | 4 950 | 1.056 03 |
| 63.076 | 13 559 | 1.398 75 | 45.922 | 11 018 | 1.253 21 | 28.750 | 7 698 | 1.122 96 | 11.889 | 3 463 | 1.032 28 |
| 57.528 | 12 807 | 1.350 63 | 40.264 | 10 025 | 1.207 64 | 22.860 | 6 331 | 1.085 70 | 5.747 | 1 708 | 1.011 72 |
| $T$ = 450.00 K | | | | | | | | | | | |
| 68.588 | 12 929 | 1.417 87 | 45.745 | 9 819 | 1.245 17 | 28.416 | 6 734 | 1.127 83 | 11.263 | 2 901 | 1.037 67 |
| 57.394 | 11 523 | 1.331 23 | 40.044 | 8 884 | 1.204 71 | 22.867 | 5 582 | 1.094 89 | 5.828 | 1 532 | 1.016 75 |
| 51.431 | 10 685 | 1.286 48 | 34.451 | 7 895 | 1.166 28 | 17.279 | 4 336 | 1.065 08 | | | |
| $x_A$ = 0.251 47, $M_r$ = 32.0360 | | | | | | | | | | | |
| $T$ = 225.00 K | | | | | | | | | | | |
| 68.723 | 23 105 | 1.589 93 | 54.635 | 21 756 | 1.342 38 | 40.832 | 19 946 | 1.094 28 | 26.560 | 16 925 | 0.838 85 |
| 63.995 | 22 691 | 1.507 56 | 50.028 | 21 224 | 1.259 99 | 36.052 | 19 127 | 1.007 55 | 22.097 | 15 426 | 0.765 71 |
| 59.486 | 22 264 | 1.428 22 | 45.559 | 20 642 | 1.179 79 | 31.521 | 18 196 | 0.925 99 | 17.324 | 13 188 | 0.702 19 |
| $T$ = 245.00 K | | | | | | | | | | | |
| 68.896 | 21 883 | 1.545 56 | 30.934 | 16 208 | 0.936 93 | 16.575 | 10 536 | 0.772 28 | 8.167 | 4 858 | 0.825 28 |
| 55.480 | 20 476 | 1.330 12 | 26.204 | 14 812 | 0.868 47 | 14.379 | 9 182 | 0.768 76 | 6.059 | 3 439 | 0.864 90 |
| 45.088 | 19 053 | 1.161 71 | 22.498 | 13 442 | 0.821 63 | 12.171 | 7 694 | 0.776 56 | 3.737 | 2 005 | 0.914 97 |
| 37.041 | 17 617 | 1.032 17 | 19.130 | 11 922 | 0.787 71 | 10.182 | 6 283 | 0.795 55 | 1.182 | 594 | 0.976 85 |
| $T$ = 265.00 K | | | | | | | | | | | |
| 68.657 | 20 675 | 1.507 16 | 31.649 | 14 752 | 0.973 71 | 16.383 | 8 881 | 0.837 24 | 8.034 | 4 141 | 0.880 53 |
| 58.009 | 19 489 | 1.350 91 | 27.743 | 13 606 | 0.925 43 | 14.202 | 7 695 | 0.837 64 | 5.906 | 2 954 | 0.907 41 |
| 49.373 | 18 309 | 1.223 89 | 24.334 | 12 429 | 0.888 58 | 12.108 | 6 499 | 0.845 56 | 3.669 | 1 772 | 0.939 73 |
| 42.394 | 17 145 | 1.122 24 | 21.323 | 11 229 | 0.861 84 | 10.055 | 5 307 | 0.859 91 | 1.242 | 576 | 0.978 63 |
| 36.542 | 15 953 | 1.039 61 | 18.758 | 10 070 | 0.845 43 | | | | | | |
| $T$ = 285.00 K | | | | | | | | | | | |
| 69.088 | 19 624 | 1.485 71 | 36.619 | 14 619 | 1.057 08 | 20.577 | 9 619 | 0.902 76 | 9.840 | 4 598 | 0.903 12 |
| 60.329 | 18 620 | 1.367 31 | 32.596 | 13 623 | 1.009 74 | 18.220 | 8 615 | 0.892 51 | 7.824 | 3 602 | 0.916 65 |
| 52.977 | 17 622 | 1.268 68 | 29.030 | 12 611 | 0.971 44 | 15.997 | 7 605 | 0.887 69 | 5.730 | 2 589 | 0.933 99 |
| 46.679 | 16 625 | 1.184 90 | 25.912 | 11 614 | 0.941 54 | 13.903 | 6 607 | 0.888 02 | 3.582 | 1 581 | 0.956 12 |
| 41.260 | 15 618 | 1.114 87 | 23.106 | 10 611 | 0.918 94 | 11.843 | 5 594 | 0.893 43 | 1.354 | 584 | 0.978 42 |
| $T$ = 300.00 K | | | | | | | | | | | |
| 69.107 | 18 739 | 1.478 49 | 38.228 | 13 978 | 1.096 43 | 21.667 | 9 189 | 0.945 31 | 10.244 | 4 408 | 0.931 69 |
| 60.931 | 17 774 | 1.374 35 | 34.097 | 13 006 | 1.051 03 | 19.169 | 8 232 | 0.933 55 | 8.099 | 3 448 | 0.941 69 |
| 54.037 | 16 828 | 1.287 37 | 30.514 | 12 054 | 1.014 87 | 16.816 | 7 276 | 0.926 56 | 5.937 | 2 496 | 0.953 60 |
| 48.072 | 15 886 | 1.213 17 | 27.295 | 11 104 | 0.985 48 | 14.565 | 6 319 | 0.924 07 | 3.713 | 1 533 | 0.971 02 |
| 42.827 | 14 930 | 1.150 01 | 24.350 | 10 142 | 0.962 54 | 12.396 | 5 368 | 0.925 79 | 1.436 | 581 | 0.990 88 |

**Table 1 (Continued)**

| $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $x_A = 0.251\ 47$, $M_r = 32.0360$ | | | | | | | | | | | |
| $T = 320.00$ K | | | | | | | | | | | |
| 69.011 | 17 889 | 1.449 93 | 39.687 | 13 356 | 1.116 83 | 22.962 | 8 850 | 0.975 17 | 10.804 | 4 275 | 0.949 87 |
| 61.506 | 16 985 | 1.361 03 | 35.619 | 12 437 | 1.076 42 | 20.261 | 7 913 | 0.962 35 | 8.566 | 3 372 | 0.954 78 |
| 54.928 | 16 066 | 1.284 99 | 32.020 | 11 549 | 1.042 06 | 17.748 | 6 998 | 0.953 21 | 6.308 | 2 462 | 0.962 98 |
| 50.951 | 15 454 | 1.239 16 | 28.675 | 10 630 | 1.013 88 | 15.405 | 6 103 | 0.948 71 | 3.923 | 1 514 | 0.973 88 |
| 45.125 | 14 443 | 1.174 29 | 25.733 | 9 747 | 0.992 28 | 13.081 | 5 191 | 0.947 12 | 1.554 | 589 | 0.991 63 |
| $T = 350.00$ K | | | | | | | | | | | |
| 69.195 | 16 641 | 1.428 87 | 41.551 | 12 414 | 1.150 18 | 24.223 | 8 189 | 1.016 47 | 8.875 | 3 119 | 0.977 80 |
| 62.429 | 15 801 | 1.357 68 | 37.578 | 11 589 | 1.114 25 | 21.446 | 7 354 | 1.002 12 | 6.486 | 2 275 | 0.979 70 |
| 56.348 | 14 958 | 1.294 50 | 33.822 | 10 735 | 1.082 67 | 18.790 | 6 513 | 0.991 39 | 4.097 | 1 430 | 0.984 53 |
| 50.943 | 14 118 | 1.239 96 | 30.428 | 9 895 | 1.056 71 | 16.208 | 5 661 | 0.983 86 | 1.687 | 586 | 0.989 27 |
| 46.046 | 13 270 | 1.192 39 | 27.254 | 9 049 | 1.034 97 | 13.711 | 4 814 | 0.978 72 | | | |
| $T = 400.00$ K | | | | | | | | | | | |
| 68.727 | 14 796 | 1.396 65 | 51.693 | 12 454 | 1.248 04 | 34.456 | 9 299 | 1.114 12 | 16.675 | 4 918 | 1.019 49 |
| 63.061 | 14 085 | 1.346 20 | 45.922 | 11 501 | 1.200 58 | 28.669 | 8 006 | 1.076 72 | 11.547 | 3 455 | 1.004 91 |
| 57.436 | 13 316 | 1.296 93 | 40.281 | 10 470 | 1.156 80 | 23.064 | 6 634 | 1.045 36 | 5.867 | 1 767 | 0.998 35 |
| $T = 450.00$ K | | | | | | | | | | | |
| 68.690 | 13 347 | 1.375 51 | 51.698 | 11 088 | 1.246 16 | 34.454 | 8 160 | 1.128 50 | 17.196 | 4 420 | 1.039 82 |
| 63.105 | 12 664 | 1.331 82 | 45.871 | 10 178 | 1.204 56 | 28.331 | 6 930 | 1.092 65 | 11.652 | 3 050 | 1.021 06 |
| 57.351 | 11 899 | 1.288 20 | 40.112 | 9 201 | 1.165 18 | 23.239 | 5 824 | 1.066 47 | 5.613 | 1 490 | 1.006 84 |
| $x_A = 0.503\ 65$, $M_r = 36.0700$ | | | | | | | | | | | |
| $T = 225.00$ K | | | | | | | | | | | |
| 68.757 | 25 215 | 1.457 61 | 55.490 | 24 328 | 1.219 24 | 42.734 | 23 236 | 0.983 09 | 29.435 | 21 627 | 0.727 53 |
| 64.284 | 24 936 | 1.378 03 | 51.251 | 23 996 | 1.141 68 | 38.334 | 22 777 | 0.899 64 | 25.084 | 20 883 | 0.642 08 |
| 59.971 | 24 649 | 1.300 54 | 47.029 | 23 638 | 1.063 50 | 33.940 | 22 255 | 0.815 20 | | | |
| $T = 245.00$ K | | | | | | | | | | | |
| 69.031 | 23 957 | 1.414 52 | 54.654 | 22 839 | 1.174 75 | 40.137 | 21 298 | 0.925 13 | 25.376 | 18 726 | 0.665 24 |
| 64.442 | 23 631 | 1.338 71 | 49.798 | 22 384 | 1.092 13 | 35.095 | 20 592 | 0.836 65 | 20.573 | 17 307 | 0.583 55 |
| 59.470 | 23 251 | 1.255 61 | 44.823 | 21 858 | 1.006 68 | 30.213 | 19 764 | 0.750 44 | | | |
| $T = 255.00$ K | | | | | | | | | | | |
| 68.418 | 23 282 | 1.386 04 | 55.723 | 22 226 | 1.182 49 | 41.210 | 20 604 | 0.943 36 | 27.634 | 18 181 | 0.716 89 |
| 63.922 | 22 936 | 1.314 49 | 50.245 | 21 680 | 1.093 10 | 36.441 | 19 902 | 0.863 61 | 22.818 | 16 815 | 0.640 04 |
| 59.345 | 22 555 | 1.240 98 | 45.746 | 21 183 | 1.018 57 | 32.023 | 19 128 | 0.789 62 | 18.165 | 14 903 | 0.574 89 |
| $T = 265.00$ K | | | | | | | | | | | |
| 69.001 | 22 729 | 1.377 83 | 24.410 | 16 191 | 0.684 25 | 12.784 | 9 667 | 0.600 20 | 7.181 | 4 428 | 0.736 03 |
| 55.649 | 21 552 | 1.171 90 | 20.995 | 14 913 | 0.638 95 | 11.373 | 8 341 | 0.618 84 | 5.511 | 3 132 | 0.798 60 |
| 43.359 | 20 111 | 0.978 51 | 18.245 | 13 585 | 0.609 54 | 10.049 | 7 048 | 0.647 11 | 3.500 | 1 816 | 0.874 72 |
| 35.192 | 18 811 | 0.849 08 | 16.080 | 12 265 | 0.595 03 | 8.649 | 5 731 | 0.684 94 | 1.140 | 538 | 0.961 70 |
| 29.030 | 17 505 | 0.752 67 | 14.235 | 10 905 | 0.592 45 | | | | | | |
| $T = 275.00$ K | | | | | | | | | | | |
| 69.014 | 22 139 | 1.363 36 | 26.449 | 15 778 | 0.733 14 | 13.921 | 9 416 | 0.646 60 | 7.643 | 4 332 | 0.771 63 |
| 55.386 | 20 861 | 1.161 17 | 22.837 | 14 506 | 0.688 53 | 12.286 | 8 098 | 0.663 54 | 5.790 | 3 063 | 0.826 73 |
| 45.081 | 19 595 | 1.006 19 | 19.987 | 13 241 | 0.660 17 | 10.850 | 6 889 | 0.688 82 | 3.684 | 1 807 | 0.891 65 |
| 37.149 | 18 322 | 0.886 76 | 17.566 | 11 921 | 0.644 45 | 9.299 | 5 612 | 0.724 69 | 1.152 | 522 | 0.965 19 |
| 31.129 | 17 054 | 0.798 31 | 15.661 | 10 692 | 0.640 61 | | | | | | |
| $T = 285.00$ K | | | | | | | | | | | |
| 69.189 | 21 561 | 1.354 22 | 30.659 | 16 028 | 0.807 23 | 16.990 | 10 479 | 0.684 22 | 9.050 | 4 948 | 0.771 86 |
| 57.633 | 20 450 | 1.189 32 | 26.842 | 14 917 | 0.759 37 | 15.270 | 9 375 | 0.687 37 | 7.376 | 3 837 | 0.811 24 |
| 48.491 | 19 343 | 1.057 93 | 23.732 | 13 814 | 0.724 99 | 13.678 | 8 273 | 0.697 72 | 5.543 | 2 732 | 0.856 22 |
| 41.194 | 18 238 | 0.953 18 | 21.142 | 12 705 | 0.702 25 | 12.150 | 7 173 | 0.714 82 | 3.502 | 1 627 | 0.908 34 |
| 35.359 | 17 137 | 0.870 73 | 18.932 | 11 599 | 0.688 80 | 10.616 | 6 055 | 0.739 89 | 1.192 | 522 | 0.963 66 |
| $T = 300.00$ K | | | | | | | | | | | |
| 69.028 | 20 667 | 1.339 03 | 33.118 | 15 368 | 0.863 95 | 18.707 | 10 069 | 0.744 84 | 9.643 | 4 758 | 0.812 51 |
| 58.681 | 19 607 | 1.199 86 | 29.248 | 14 302 | 0.819 87 | 16.744 | 9 007 | 0.745 29 | 7.789 | 3 695 | 0.845 11 |
| 50.230 | 18 541 | 1.086 11 | 26.056 | 13 259 | 0.787 84 | 14.914 | 7 942 | 0.752 85 | 5.819 | 2 645 | 0.882 00 |
| 43.426 | 17 488 | 0.995 53 | 23.267 | 12 195 | 0.764 90 | 13.165 | 6 888 | 0.766 25 | 3.652 | 1 579 | 0.927 24 |
| 37.763 | 16 425 | 0.921 73 | 20.829 | 11 123 | 0.750 74 | 11.413 | 5 818 | 0.786 45 | 1.262 | 516 | 0.980 51 |
| $T = 320.00$ K | | | | | | | | | | | |
| 69.044 | 19 595 | 1.324 33 | 35.685 | 14 568 | 0.920 66 | 20.472 | 9 547 | 0.805 95 | 10.290 | 4 535 | 0.852 81 |
| 59.508 | 18 570 | 1.204 42 | 31.758 | 13 560 | 0.880 25 | 18.276 | 8 532 | 0.805 09 | 8.230 | 3 525 | 0.877 52 |
| 51.900 | 17 566 | 1.110 48 | 28.435 | 12 565 | 0.850 56 | 16.233 | 7 546 | 0.808 53 | 6.074 | 2 518 | 0.906 64 |
| 45.580 | 16 571 | 1.033 81 | 25.458 | 11 549 | 0.828 50 | 14.233 | 6 542 | 0.817 71 | 3.800 | 1 518 | 0.940 86 |
| 40.180 | 15 562 | 0.970 42 | 22.859 | 10 551 | 0.814 29 | 12.261 | 5 537 | 0.832 27 | 1.353 | 518 | 0.981 71 |
| $T = 350.00$ K | | | | | | | | | | | |
| 69.156 | 18 130 | 1.310 78 | 38.917 | 13 499 | 0.990 68 | 22.752 | 8 871 | 0.881 34 | 11.077 | 4 229 | 0.900 08 |
| 61.236 | 17 210 | 1.222 71 | 34.980 | 12 579 | 0.955 59 | 20.228 | 7 930 | 0.876 55 | 8.801 | 3 301 | 0.916 19 |
| 54.438 | 16 287 | 1.148 57 | 31.453 | 11 650 | 0.927 75 | 17.857 | 7 005 | 0.875 99 | 6.454 | 2 370 | 0.935 79 |
| 48.458 | 15 342 | 1.085 38 | 28.285 | 10 720 | 0.906 69 | 15.571 | 6 083 | 0.879 62 | 4.034 | 1 446 | 0.958 66 |
| 43.405 | 14 430 | 1.033 64 | 25.426 | 9 801 | 0.891 47 | 13.325 | 5 157 | 0.887 91 | 1.476 | 5 12 | 0.990 63 |
| $T = 400.00$ K | | | | | | | | | | | |
| 68.619 | 15 943 | 1.294 13 | 51.725 | 13 625 | 1.141 48 | 34.424 | 10 252 | 1.009 62 | 17.447 | 5 539 | 0.947 10 |
| 63.139 | 15 271 | 1.243 18 | 45.830 | 12 615 | 1.092 36 | 28.635 | 8 807 | 0.977 63 | 11.530 | 3 641 | 0.952 17 |
| 57.289 | 14 473 | 1.190 19 | 40.049 | 11 490 | 1.048 04 | 22.930 | 7 212 | 0.955 99 | 6.060 | 1 884 | 0.967 16 |

**Table 1 (Continued)**

| $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $x_A$ = 0.503 65, $M_r$ = 36.0700 | | | | | | | | | | | |
| $T$ = 450.00 K | | | | | | | | | | | |
| 68.770 | 14 241 | 1.290 66 | 51.741 | 11 920 | 1.160 14 | 34.390 | 8 760 | 1.049 25 | 17.215 | 4 659 | 0.987 57 |
| 63.009 | 13 527 | 1.244 95 | 45.854 | 10 950 | 1.119 22 | 28.731 | 7 513 | 1.022 09 | 11.855 | 3 221 | 0.983 70 |
| 57.446 | 12 774 | 1.201 95 | 40.196 | 9 923 | 1.082 66 | 23.022 | 6 148 | 1.000 83 | 5.842 | 1 581 | 0.987 60 |
| $x_A$ = 0.711 05, $M_r$ = 39.3876 | | | | | | | | | | | |
| $T$ = 225.00 K | | | | | | | | | | | |
| 68.765 | 26 795 | 1.371 82 | 52.872 | 26 038 | 1.085 43 | 37.012 | 25 081 | 0.788 82 | 26.429 | 24 251 | 0.5825 5 |
| 63.528 | 26 562 | 1.278 46 | 47.575 | 25 745 | 0.987 80 | 31.663 | 24 690 | 0.685 51 | 20.934 | 23 708 | 0.472 00 |
| 58.351 | 26 316 | 1.185 25 | 42.444 | 25 438 | 0.891 90 | | | | | | |
| $T$ = 245.00 K | | | | | | | | | | | |
| 69.042 | 25 577 | 1.325 14 | 54.941 | 24 802 | 1.087 45 | 39.256 | 23 681 | 0.813 78 | 24.157 | 22 096 | 0.536 70 |
| 64.182 | 25 327 | 1.244 02 | 49.385 | 24 441 | 0.991 92 | 34.043 | 23 217 | 0.719 81 | 18.997 | 21 291 | 0.438 01 |
| 58.841 | 25 034 | 1.153 85 | 44.239 | 24 074 | 0.902 10 | 29.624 | 22 763 | 0.638 87 | | | |
| $T$ = 265.00 K | | | | | | | | | | | |
| 68.931 | 24 364 | 1.284 06 | 34.035 | 21 489 | 0.718 83 | 18.559 | 18 633 | 0.452 05 | 13.579 | 16 527 | 0.372 90 |
| 57.785 | 23 656 | 1.108 65 | 28.869 | 20 782 | 0.630 47 | 16.504 | 17 937 | 0.417 60 | 13.579 | 16 527 | 0.372 90 |
| 48.415 | 22 939 | 0.957 91 | 24.672 | 20 072 | 0.557 87 | 14.781 | 17 194 | 0.390 16 | | | |
| 40.590 | 22 223 | 0.828 96 | 21.376 | 19 375 | 0.500 73 | | | | | | |
| $T$ = 275.00 K | | | | | | | | | | | |
| 68.988 | 23 767 | 1.269 50 | 32.303 | 20 349 | 0.694 28 | 17.915 | 16 944 | 0.462 42 | 13.428 | 14 346 | 0.409 37 |
| 56.724 | 22 918 | 1.082 49 | 27.197 | 19 483 | 0.610 52 | 16.008 | 16 059 | 0.435 96 | 12.490 | 13 475 | 0.405 38 |
| 46.572 | 22 047 | 0.923 86 | 23.293 | 18 633 | 0.546 73 | 14.525 | 15 175 | 0.418 62 | 12.490 | 13 475 | 0.405 38 |
| 38.614 | 21 195 | 0.796 79 | 20.170 | 17 758 | 0.496 76 | | | | | | |
| $T$ = 285.00 K | | | | | | | | | | | |
| 69.080 | 23 187 | 1.257 27 | 21.011 | 16 709 | 0.530 66 | 11.337 | 9 846 | 0.485 91 | 7.189 | 4 491 | 0.675 53 |
| 55.607 | 22 172 | 1.058 39 | 17.501 | 15 193 | 0.486 12 | 10.346 | 8 477 | 0.515 05 | 5.658 | 3 158 | 0.756 09 |
| 44.919 | 21 141 | 0.896 65 | 15.302 | 13 835 | 0.466 76 | 9.405 | 7 147 | 0.555 34 | 3.656 | 1 813 | 0.851 00 |
| 35.358 | 19 920 | 0.749 06 | 13.685 | 12 503 | 0.461 90 | 8.387 | 5 810 | 0.609 19 | 1.088 | 480 | 0.956 55 |
| 26.656 | 18 313 | 0.614 26 | 12.389 | 11 145 | 0.469 11 | | | | | | |
| $T$ = 300.00 K | | | | | | | | | | | |
| 69.024 | 22 289 | 1.241 52 | 26.095 | 16 536 | 0.632 66 | 14.704 | 10 785 | 0.546 59 | 8.735 | 5 069 | 0.690 85 |
| 55.166 | 21 140 | 1.046 19 | 22.632 | 15 389 | 0.589 60 | 13.465 | 9 665 | 0.558 53 | 7.292 | 3 920 | 0.745 77 |
| 44.719 | 19 993 | 0.896 72 | 19.974 | 14 258 | 0.561 63 | 12.271 | 8 495 | 0.579 11 | 5.602 | 2 776 | 0.809 03 |
| 36.720 | 18 843 | 0.781 26 | 17.845 | 13 091 | 0.546 50 | 11.181 | 7 382 | 0.607 23 | 3.567 | 1 620 | 0.882 74 |
| 30.675 | 17 686 | 0.695 34 | 16.111 | 11 921 | 0.541 82 | 9.989 | 6 207 | 0.645 18 | 1.147 | 475 | 0.968 08 |
| $T$ = 320.00 K | | | | | | | | | | | |
| 68.951 | 21 146 | 1.225 54 | 29.742 | 15 577 | 0.717 63 | 16.988 | 10 025 | 0.636 90 | 9.068 | 4 460 | 0.764 17 |
| 56.959 | 20 044 | 1.068 05 | 26.138 | 14 465 | 0.679 15 | 15.338 | 8 906 | 0.647 29 | 7.231 | 3 343 | 0.812 97 |
| 47.500 | 18 927 | 0.943 25 | 23.221 | 13 356 | 0.653 46 | 13.797 | 7 791 | 0.665 59 | 5.144 | 2 228 | 0.867 76 |
| 40.063 | 17 804 | 0.845 75 | 20.797 | 12 248 | 0.638 19 | 12.287 | 6 684 | 0.690 91 | 2.761 | 1 113 | 0.932 37 |
| 34.288 | 16 696 | 0.771 87 | 18.747 | 11 132 | 0.632 96 | 10.719 | 5 567 | 0.723 68 | 1.224 | 472 | 0.974 66 |
| $T$ = 350.00 K | | | | | | | | | | | |
| 69.088 | 19 557 | 1.213 94 | 35.089 | 14 540 | 0.829 28 | 20.562 | 9 524 | 0.741 90 | 10.712 | 4 501 | 0.817 82 |
| 59.363 | 18 546 | 1.099 92 | 31.309 | 13 540 | 0.794 60 | 18.453 | 8 497 | 0.746 27 | 8.374 | 3 369 | 0.854 14 |
| 51.469 | 17 546 | 1.008 01 | 28.076 | 12 538 | 0.769 49 | 16.502 | 7 500 | 0.756 09 | 6.421 | 2 490 | 0.886 14 |
| 45.039 | 16 558 | 0.934 71 | 25.267 | 11 530 | 0.753 05 | 14.597 | 6 506 | 0.770 99 | 3.980 | 1 474 | 0.927 86 |
| 39.580 | 15 541 | 0.875 17 | 22.802 | 10 530 | 0.744 12 | 12.664 | 5 498 | 0.791 52 | 1.333 | 469 | 0.976 68 |
| $T$ = 400.00 K | | | | | | | | | | | |
| 68.723 | 17 122 | 1.206 85 | 51.834 | 14 909 | 1.045 37 | 34.480 | 11 432 | 0.906 88 | 17.097 | 5 912 | 0.869 54 |
| 63.024 | 16 465 | 1.150 93 | 45.987 | 13 915 | 0.993 70 | 28.678 | 9 833 | 0.876 94 | 11.537 | 3 866 | 0.897 30 |
| 57.544 | 15 751 | 1.098 49 | 40.123 | 12 749 | 0.946 29 | 22.998 | 8 013 | 0.862 98 | 5.890 | 1 881 | 0.941 52 |
| $T$ = 450.00 K | | | | | | | | | | | |
| 68.603 | 15 125 | 1.212 27 | 51.741 | 12 816 | 1.079 03 | 34.452 | 9 485 | 0.970 80 | 17.260 | 4 939 | 0.934 02 |
| 62.976 | 14 436 | 1.165 95 | 45.928 | 11 827 | 1.037 90 | 28.755 | 8 106 | 0.948 11 | 11.587 | 3 275 | 0.945 61 |
| 57.406 | 13 678 | 1.121 73 | 40.166 | 10 720 | 1.001 42 | 23.164 | 6 621 | 0.935 07 | 5.867 | 1 622 | 0.966 76 |
| $x_A$ = 0.909 21, $M_r$ = 42.5575 | | | | | | | | | | | |
| $T$ = 225.00 K | | | | | | | | | | | |
| 68.831 | 28 071 | 1.310 72 | 49.927 | 27 446 | 0.972 39 | 34.971 | 26 858 | 0.696 01 | 23.482 | 26 326 | 0.476 80 |
| 63.930 | 27 922 | 1.223 88 | 44.731 | 27 252 | 0.877 39 | 30.735 | 26 672 | 0.615 97 | 15.997 | 25 923 | 0.329 86 |
| 59.307 | 27 772 | 1.141 51 | 40.095 | 27 071 | 0.791 71 | 25.841 | 26 445 | 0.522 33 | 11.238 | 25 636 | 0.234 33 |
| 54.341 | 27 605 | 1.052 26 | | | | | | | | | |
| $T$ = 245.00 K | | | | | | | | | | | |
| 68.926 | 26 926 | 1.256 64 | 52.013 | 26 268 | 0.972 04 | 34.971 | 25 446 | 0.674 66 | 17.497 | 24 311 | 0.353 31 |
| 63.374 | 26 722 | 1.164 24 | 46.110 | 26 007 | 0.870 37 | 29.357 | 25 125 | 0.573 59 | 11.846 | 23 827 | 0.244 06 |
| 57.687 | 26 505 | 1.068 44 | 40.397 | 25 728 | 0.770 80 | 23.315 | 24 738 | 0.462 67 | | | |
| $T$ = 265.00 K | | | | | | | | | | | |
| 68.251 | 25 744 | 1.203 24 | 41.002 | 24 360 | 0.763 92 | 22.907 | 22 978 | 0.452 45 | 13.391 | 21 862 | 0.278 00 |
| 61.833 | 25 466 | 1.101 99 | 36.809 | 24 091 | 0.693 45 | 20.145 | 22 696 | 0.402 84 | 11.756 | 21 611 | 0.246 89 |
| 56.018 | 25 189 | 1.009 34 | 32.721 | 23 801 | 0.623 95 | 17.673 | 22 420 | 0.357 76 | 9.953 | 21 301 | 0.212 07 |
| 50.756 | 24 919 | 0.924 43 | 29.107 | 23 523 | 0.561 60 | 15.450 | 22 147 | 0.316 62 | 8.547 | 21 030 | 0.184 46 |
| 45.612 | 24 633 | 0.840 39 | 25.874 | 23 250 | 0.505 08 | | | | | | |

**Table 1 (Continued)**

| $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ | $p$/MPa | $\rho$/mol·m$^{-3}$ | $Z$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $x_A$ = 0.909 21, $M_r$ = 42.5575 | | | | | | |
| | | | | | $T$ = 285.00 K | | | | | | |
| 69.019 | 24 622 | 1.182 95 | 32.843 | 22 197 | 0.624 41 | 18.648 | 20 368 | 0.386 37 | 11.374 | 18 528 | 0.259 06 |
| 57.355 | 24 004 | 1.008 34 | 27.142 | 21 590 | 0.530 53 | 15.654 | 19 763 | 0.334 27 | 10.034 | 17 939 | 0.236 05 |
| 47.721 | 23 398 | 0.860 70 | 22.447 | 20 981 | 0.451 49 | 13.219 | 19 144 | 0.291 40 | 9.013 | 17 344 | 0.219 30 |
| 39.762 | 22 807 | 0.735 73 | | | | | | | | | |
| | | | | | $T$ = 300.00 K | | | | | | |
| 69.020 | 23 782 | 1.163 51 | 19.704 | 18 760 | 0.421 08 | 9.037 | 10 155 | 0.356 77 | 6.831 | 4 538 | 0.603 48 |
| 55.550 | 22 961 | 0.969 92 | 14.523 | 17 058 | 0.341 33 | 8.608 | 8 614 | 0.400 63 | 5.587 | 3 189 | 0.702 37 |
| 43.810 | 22 057 | 0.796 29 | 11.758 | 15 317 | 0.307 75 | 8.212 | 7 276 | 0.452 48 | 3.708 | 1 815 | 0.819 04 |
| 34.664 | 21 157 | 0.656 85 | 10.406 | 13 659 | 0.305 43 | 7.677 | 5 940 | 0.518 14 | 1.031 | 433 | 0.954 58 |
| 26.591 | 20 089 | 0.530 66 | 9.571 | 11 836 | 0.324 19 | | | | | | |
| | | | | | $T$ = 320.00 K | | | | | | |
| 69.065 | 22 654 | 1.145 85 | 19.987 | 16 109 | 0.466 33 | 11.919 | 9 576 | 0.467 81 | 7.881 | 4 417 | 0.670 61 |
| 55.533 | 21 695 | 0.962 07 | 17.288 | 14 842 | 0.437 79 | 11.058 | 8 274 | 0.502 31 | 6.126 | 3 043 | 0.756 64 |
| 41.924 | 20 402 | 0.772 33 | 15.306 | 13 493 | 0.426 35 | 10.159 | 6 975 | 0.547 42 | 3.955 | 1 746 | 0.851 37 |
| 31.439 | 18 961 | 0.623 19 | 13.907 | 12 176 | 0.429 28 | 9.113 | 5 667 | 0.604 40 | 1.111 | 435 | 0.959 93 |
| 24.524 | 17 533 | 0.525 71 | 12.841 | 10 884 | 0.443 43 | | | | | | |
| | | | | | $T$ = 350.00 K | | | | | | |
| 69.093 | 21 003 | 1.130 45 | 29.105 | 15 591 | 0.641 49 | 17.249 | 10 177 | 0.582 43 | 10.053 | 4 773 | 0.723 77 |
| 56.576 | 19 928 | 0.975 59 | 25.639 | 14 510 | 0.607 20 | 15.798 | 9 097 | 0.596 76 | 8.306 | 3 688 | 0.773 92 |
| 46.868 | 18 849 | 0.854 45 | 22.896 | 13 418 | 0.586 37 | 14.396 | 8 003 | 0.618 14 | 6.290 | 2 598 | 0.831 97 |
| 39.302 | 17 754 | 0.760 70 | 20.684 | 12 336 | 0.576 18 | 13.019 | 6 914 | 0.647 06 | 3.957 | 1 517 | 0.896 35 |
| 33.571 | 16 677 | 0.691 74 | 18.865 | 11 265 | 0.575 47 | 11.601 | 5 849 | 0.681 57 | 1.220 | 434 | 0.965 98 |
| | | | | | $T$ = 400.00 K | | | | | | |
| 68.626 | 18 399 | 1.121 50 | 51.935 | 16 437 | 0.950 04 | 34.588 | 13 100 | 0.793 89 | 17.344 | 6 764 | 0.770 99 |
| 63.073 | 17 828 | 1.063 77 | 45.955 | 15 496 | 0.891 70 | 28.277 | 11 221 | 0.757 72 | 11.728 | 4 263 | 0.827 21 |
| 57.472 | 17 176 | 1.006 10 | 40.612 | 14 494 | 0.842 50 | 23.033 | 9 253 | 0.748 47 | 6.627 | 2 218 | 0.898 38 |
| | | | | | $T$ = 450.00 K | | | | | | |
| 68.731 | 16 183 | 1.135 13 | 51.720 | 13 928 | 0.992 48 | 34.466 | 10 455 | 0.881 09 | 17.241 | 5 291 | 0.870 92 |
| 62.897 | 15 502 | 1.084 41 | 45.919 | 12 928 | 0.949 32 | 28.330 | 8 796 | 0.860 82 | 11.920 | 3 542 | 0.899 46 |
| 57.367 | 14 773 | 1.037 88 | 40.171 | 11 781 | 0.911 35 | 22.817 | 7 111 | 0.857 59 | 5.856 | 1 654 | 0.946 28 |

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