# Density and Viscosity for Monoethanolamine + Water, + Ethanol, and + 2-Propanol

**Ming-Jer Lee* and Ting-Kuei Lin**

Department of Chemical Engineering, National Taiwan Institute of Technology, Taipei 106, Taiwan

Densities and viscosities were measured for monoethanolamine (MEA) + water, MEA + ethanol, and MEA + 2-propanol at 303.15, 313.15, and 323.15 K. The excess volumes and viscosity deviations from the mole fraction average were calculated and correlated by a Redlich-Kister type equation. McAllister's models were also applied to correlate the kinematic viscosities.

## Introduction

Monoethanolamine (MEA) is a widely used agent in carbon dioxide and hydrogen sulfide removal processes. The viscosity of MEA is larger than that of conventional solvents such as water and lower alcohols by an order of magnitude. It is of interest to investigate the composition and temperature effects on volumetric and transport properties of the mixtures containing MEA and these conventional solvents. This paper reports density, viscosity, and kinematic viscosity data for binary systems of MEA + water, MEA + ethanol, and MEA + 2-propanol at atmospheric pressure (nominal value 0.1 MPa) and temperatures from 303.15 to 323.15 K over the entire composition range. No data are available in the literature for these mixtures at comparable conditions.

## Experimental Section

Monoethanolamine (99 mass %) was purchased from Janssen Chimica, ethanol (99.8 mass %) from Ferak, and 2-propanol (99.5 mass %) from Aldrich. The purity of the chemicals was checked by gas chromatography analysis. No impurity peak was detected. All these compounds were used without further purification. Deionized distilled water, conductivity better than $2 \times 10^{-6}\ \Omega^{-1} \times \text{cm}^{-1}$, was prepared in our laboratory.

Pycnometers and a Haake falling-ball viscometer were employed to measure density and viscosity, respectively. To prevent the viscometer from being corroded by MEA, the metal surfaces in contact with the sample were gold plated. The detailed experimental procedure has been described elsewhere (*1*). In general, the accuracy of the measurements is estimated to be ±0.1% for density, ±1.5% for viscosity, ±0.1 K for temperature, and ±0.0004 in mole fraction for mixture preparation. The following equation converts falling time ($t$) into viscosity ($\eta$):

$$\eta = K(\varrho_b - \varrho)t \qquad (1)$$

where $\varrho_b$ is the density of the ball and, $\varrho$ is the density of the liquid determined at the measuring temperature. The ball constant $K$ was determined from the falling-time measurements with the literature viscosity values of 1-butanol at 307.69 K, 2-methyl-2-propanol at 313.15 K (*2*), methanol + water at 283.15 K, 1-propanol + water at 303.15 K (*3*), and MEA at 298.15 K (*4*) and 313.15 K (*5*) and expressed as a function of liquid density over a density range of 0.7632-1.002 g·cm$^{-3}$.

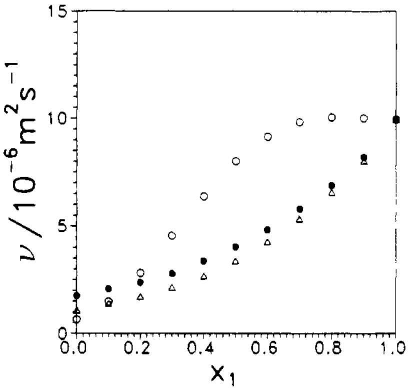

**Figure 1.** Kinematic viscosities at 313.15 K: (○) MEA (1) + water (2); (△) MEA (1) + ethanol (2); (●) MEA (1) + 2-propanol (2).

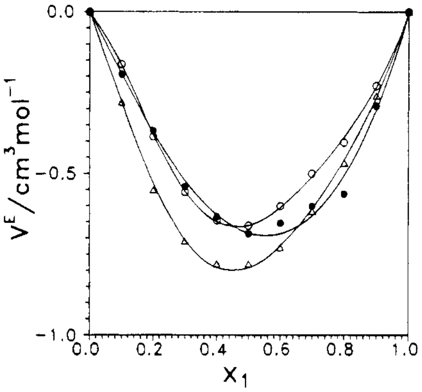

**Figure 2.** Excess volumes at 313.15 K: (○) MEA (1) + water (2); (△) MEA (1) + ethanol (2); (●) MEA (1) + 2-propanol (2); (—) calculated from eq 6.

$$K = 0.05226 + 0.003062(\varrho/(\text{g·cm}^{-3})) \qquad (2)$$

The average absolute deviation (AAD) of the above correlation is 0.80%, and the maximum deviation is −1.26% by comparing with the literature data.

## Results and Discussion

The observed densities ($\varrho$) and viscosities ($\eta$) for the pure components are compared with literature values in Table 1, which shows that the measurements agree with literature values within the experimental errors. Tables 2-4 list the experimental results of MEA + water, MEA + ethanol, and MEA + 2-propanol, respectively. Figure 1

---

* To whom correspondence should be addressed.

0021-9568/95/1740-0336$09.00/0

**Table 1. Comparison of Density and Viscosity of Pure Components from This Work with the Literature Values**

| | | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | | $\eta/(\mathrm{mPa{\cdot}s})$ | |
|---|---|---|---|---|---|
| compd | $T$/K | this work | lit. | this work | lit. |
| monoethanolamine | 303.15 | 1.009 | 1.008 (*5*)<br>1.00889 (*6*) | 15.0 | 15.1 (*5*) |
| | 313.15 | 0.9999 | 1.000 (*5*)<br>1.00020 (*6*) | 9.94 | 10.0 (*5*) |
| | 323.15 | 0.9918 | 0.9924 (*5*)<br>0.99179 (*6*) | 6.87 | 6.97 (*5*) |
| water | 303.15 | 0.9957 | 0.9957 (*7*)<br>0.99565 (*6*) | 0.800 | 0.7975 (*8*)<br>0.7966 (*6*)<br>0.8005 (*3*)<br>0.7971 (*9*)<br>0.802 (*10*) |
| | 313.15 | 0.9923 | 0.9923 (*7*)<br>0.99219 (*6*) | 0.655 | 0.6530 (*8*)<br>0.6521 (*6*)<br>0.6568 (*3*)<br>0.6531 (*9*)<br>0.656 (*10*) |
| | 323.15 | 0.9881 | 0.9981 (*7*)<br>0.98804 (*6*) | 0.549 | 0.5469 (*8*)<br>0.5463 (*6*)<br>0.5514 (*3*)<br>0.5441 (*9*)<br>0.555 (*10*) |
| ethanol | 303.15 | 0.7807 | 0.7808 (*6*) | 0.990 | 0.987 (*6*)<br>0.9817 (*11*)<br>0.994 (*12*)<br>0.990 (*13*)<br>1.000 (*14*)<br>0.999 (*3*) |
| | 313.15 | 0.7722 | 0.7721 (*6*) | 0.834 | 0.826 (*6*)<br>0.835 (*15*)<br>0.834 (*14*)<br>0.833 (*3*) |
| | 323.15 | 0.7635 | 0.7636 (*6*) | 0.701 | 0.696 (*6*)<br>0.702 (*3*)<br>0.702 (*14*)<br>0.702 (*15*) |
| 2-propanol | 303.15 | 0.7768 | 0.7770 (*6*) | 1.78 | 1.767 (*6*)<br>1.791 (*14*)<br>1.783 (*13*) |
| | 313.15 | 0.7680 | 0.7683 (*6*) | 1.35 | 1.340 (*6*)<br>1.358 (*9*) |
| | 323.15 | 0.7593 | 0.7593 (*6*) | 1.04 | 1.033 (*6*)<br>1.045 (*9*) |

**Table 2. Density ($\varrho$), Viscosity ($\eta$), and Kinematic Viscosity ($\nu$) for Monoethanolamine (1) + Water (2)**

| | 303.15 K | | | 313.15 K | | | 323.15 K | | |
|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | $\eta/(\mathrm{mPa{\cdot}s})$ | $\nu/(10^{-6}\ \mathrm{m^2{\cdot}s^{-1}})$ | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | $\eta/(\mathrm{mPa{\cdot}s})$ | $\nu/(10^{-6}\ \mathrm{m^2{\cdot}s^{-1}})$ | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | $\eta/(\mathrm{mPa{\cdot}s})$ | $\nu/(10^{-6}\ \mathrm{m^2{\cdot}s^{-1}})$ |
| 0.1000 | 1.007 | 1.91 | 1.90 | 1.002 | 1.48 | 1.48 | 0.9972 | 1.21 | 1.21 |
| 0.2000 | 1.017 | 3.87 | 3.81 | 1.010 | 2.84 | 2.81 | 1.004 | 2.16 | 2.15 |
| 0.3000 | 1.021 | 6.67 | 6.53 | 1.015 | 4.62 | 4.55 | 1.008 | 3.36 | 3.33 |
| 0.4000 | 1.024 | 9.68 | 9.45 | 1.016 | 6.48 | 6.38 | 1.009 | 4.62 | 4.58 |
| 0.5000 | 1.023 | 12.3 | 12.0 | 1.015 | 8.13 | 8.01 | 1.008 | 5.65 | 5.61 |
| 0.6000 | 1.020 | 14.0 | 13.7 | 1.013 | 9.26 | 9.14 | 1.005 | 6.38 | 6.35 |
| 0.7000 | 1.018 | 15.2 | 14.9 | 1.010 | 9.92 | 9.82 | 1.002 | 6.84 | 6.83 |
| 0.8000 | 1.015 | 15.4 | 15.2 | 1.007 | 10.1 | 10.0 | 0.9992 | 6.94 | 6.95 |
| 0.9000 | 1.012 | 15.3 | 15.1 | 1.004 | 10.0 | 9.96 | 0.9961 | 6.93 | 6.96 |

**Table 3. Density ($\varrho$), Viscosity ($\eta$), and Kinematic Viscosity ($\nu$) for Monoethanolamine (1) + Ethanol (2)**

| | 303.15 K | | | 313.15 K | | | 323.15 K | | |
|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | $\eta/(\mathrm{mPa{\cdot}s})$ | $\nu/(10^{-6}\ \mathrm{m^2{\cdot}s^{-1}})$ | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | $\eta/(\mathrm{mPa{\cdot}s})$ | $\nu/(10^{-6}\ \mathrm{m^2{\cdot}s^{-1}})$ | $\varrho/(\mathrm{g{\cdot}cm^{-3}})$ | $\eta/(\mathrm{mPa{\cdot}s})$ | $\nu/(10^{-6}\ \mathrm{m^2{\cdot}s^{-1}})$ |
| 0.1000 | 0.8080 | 1.33 | 1.65 | 0.7992 | 1.11 | 1.39 | 0.7900 | 0.967 | 1.22 |
| 0.2000 | 0.8345 | 1.73 | 2.07 | 0.8262 | 1.42 | 1.72 | 0.8174 | 1.19 | 1.46 |
| 0.8000 | 0.8600 | 2.30 | 2.67 | 0.8517 | 1.83 | 2.15 | 0.8430 | 1.47 | 1.74 |
| 0.4000 | 0.8844 | 3.05 | 3.45 | 0.8759 | 2.34 | 2.67 | 0.8670 | 1.85 | 2.13 |
| 0.5000 | 0.9077 | 3.96 | 4.36 | 0.8990 | 3.05 | 3.39 | 0.8900 | 2.34 | 2.63 |
| 0.6000 | 0.9296 | 5.37 | 5.78 | 0.9212 | 3.93 | 4.27 | 0.9123 | 2.95 | 3.23 |
| 0.7000 | 0.9505 | 7.03 | 7.40 | 0.9423 | 5.03 | 5.34 | 0.9338 | 3.70 | 3.96 |
| 0.8000 | 0.9705 | 9.05 | 9.33 | 0.9626 | 6.32 | 6.57 | 0.9541 | 4.54 | 4.76 |
| 0.9000 | 0.9898 | 11.6 | 11.7 | 0.9818 | 7.87 | 8.02 | 0.9735 | 5.57 | 5.72 |

illustrates the kinematic viscosities ($\nu = \eta/\varrho$) of these three binary solutions varying with composition at 313.15 K. For the aqueous system, the viscosity increases markedly with the mole fraction of MEA ($x_1$), reaches a weak maximum at about $x_1 = 0.8$, and then decreases slightly to the value of pure MEA. Unlike the aqueous system, the viscosities of alcohol-containing mixtures increase monotonically with the mole fraction of MEA. The excess volume ($V^{\mathrm{E}}$) was

**Table 4. Density ($\rho$), Viscosity ($\eta$), and Kinematic Viscosity ($\nu$) for Monoethanolamine (1) + 2-Propanol (2)**

| | 303.15 K | | | 313.15 K | | | 323.15 K | | |
|---|---|---|---|---|---|---|---|---|---|
| $x_1$ | $\rho$/(g·cm$^{-3}$) | $\eta$/(mPa·s) | $\nu$/(10$^{-6}$ m$^2$·s$^{-1}$) | $\rho$/(g·cm$^{-3}$) | $\eta$/(mPa·s) | $\nu$/(10$^{-6}$ m$^2$·s$^{-1}$) | $\rho$/(g·cm$^{-3}$) | $\eta$/(mPa·s) | $\nu$/(10$^{-6}$ m$^2$·s$^{-1}$) |
| 0.1011 | 0.7972 | 2.11 | 2.65 | 0.7884 | 1.63 | 2.07 | 0.7794 | 1.27 | 1.63 |
| 0.2002 | 0.8181 | 2.53 | 3.09 | 0.8093 | 1.92 | 2.37 | 0.8004 | 1.49 | 1.86 |
| 0.3001 | 0.8403 | 3.08 | 3.67 | 0.8315 | 2.31 | 2.78 | 0.8228 | 1.78 | 2.16 |
| 0.4003 | 0.8623 | 3.86 | 4.48 | 0.8541 | 2.88 | 3.37 | 0.8452 | 2.21 | 2.61 |
| 0.5001 | 0.8860 | 4.90 | 5.53 | 0.8773 | 3.55 | 4.05 | 0.8687 | 2.65 | 3.05 |
| 0.5999 | 0.9090 | 6.12 | 6.73 | 0.9007 | 4.35 | 4.83 | 0.8924 | 3.22 | 3.61 |
| 0.7001 | 0.9337 | 7.70 | 8.25 | 0.9252 | 5.37 | 5.80 | 0.9169 | 3.89 | 4.24 |
| 0.8000 | 0.9582 | 9.55 | 9.97 | 0.9512 | 6.54 | 6.88 | 0.9421 | 4.69 | 4.98 |
| 0.9000 | 0.9839 | 11.9 | 1.21 | 0.9751 | 7.97 | 8.17 | 0.9671 | 5.64 | 5.83 |

**Table 5. Coefficients of Eq 6**

| mixture | $T$/K | $A_0$ | $A_1$ | $A_2$ | $A_3$ | AAD[a]/% |
|---|---|---|---|---|---|---|
| MEA + water | 303.15 | −2.5962 | 0.6670 | 0.9623 | −1.2220 | 0.02 |
| | 313.15 | −2.6417 | 0.5192 | 0.6854 | −1.5542 | 0.01 |
| | 323.15 | −2.6109 | 0.4010 | 0.3067 | −1.3942 | 0.01 |
| MEA + ethanol | 303.15 | −2.9975 | 0.6109 | 0.4261 | 0.0117 | 0.00 |
| | 313.15 | −3.1583 | 0.6958 | 0.2359 | −0.9169 | 0.01 |
| | 323.15 | −3.1914 | 0.8971 | 0.4217 | −1.4779 | 0.03 |
| MEA + 2-propanol | 303.15 | −2.1544 | −0.1155 | −0.0698 | −0.8473 | 0.02 |
| | 313.15 | −2.7368 | −0.6094 | −0.0364 | −0.2580 | 0.03 |
| | 323.15 | −2.4599 | −0.4765 | 1.5985 | −0.8996 | 0.01 |

[a] AAD = $(100/n)\sum_{k=1}^{n}|\varrho_k^{\mathrm{cal}} - \varrho_k^{\mathrm{exp}}|/\varrho_k^{\mathrm{exp}}$.

**Table 6. Coefficients of Eq 7**

| mixture | $T$/K | $B_0$ | $B_1$ | $B_2$ | $B_3$ | AAD[a]/% |
|---|---|---|---|---|---|---|
| MEA + water | 303.15 | 16.9447 | 17.3791 | −15.3004 | −5.4789 | 1.08 |
| | 313.15 | 11.0221 | 9.8989 | −9.3797 | −3.0882 | 0.64 |
| | 323.15 | 7.6099 | 5.7710 | −5.8297 | −1.7287 | 0.68 |
| MEA + ethanol | 303.15 | −15.7096 | −4.6399 | −2.1424 | −3.2077 | 0.93 |
| | 313.15 | −9.2627 | −2.2000 | −0.9187 | −2.2382 | 0.53 |
| | 323.15 | −5.7585 | −1.2236 | 0.0382 | −1.6695 | 0.22 |
| MEA + 2-propanol | 303.15 | −13.9995 | −3.6520 | −2.2402 | −3.0370 | 0.30 |
| | 313.15 | −8.3692 | −1.9261 | −1.5537 | −2.5882 | 0.27 |
| | 323.15 | −5.1931 | −1.1325 | −0.5921 | −1.3493 | 0.42 |

[a] AAD = $(100/n)\sum_{k=1}^{n}|\eta_k^{\mathrm{cal}} - \eta_k^{\mathrm{exp}}|/\eta_k^{\mathrm{exp}}$.

**Table 7. Coefficients of McAllister's Models**

| | | three-body model | | | four-body model | | | |
|---|---|---|---|---|---|---|---|---|
| mixture | $T$/K | $\nu_{12}$ | $\nu_{21}$ | AAD[a]/% | $\nu_{1112}$ | $\nu_{1122}$ | $\nu_{2221}$ | AAD[a]/% |
| MEA + water | 303.15 | 15.4285 | 25.012 | 0.65 | 15.1034 | 19.5929 | 10.1246 | 0.62 |
| | 313.15 | 10.0327 | 16.0719 | 0.37 | 10.1889 | 11.8967 | 7.2443 | 0.17 |
| | 323.15 | 6.9091 | 10.9906 | 0.82 | 7.1227 | 7.7867 | 5.3617 | 0.32 |
| MEA + ethanol | 303.15 | 7.0466 | 2.8598 | 0.74 | 8.4519 | 4.5258 | 2.3188 | 0.73 |
| | 313.15 | 5.1096 | 2.3199 | 0.75 | 6.0572 | 3.3938 | 1.9418 | 0.73 |
| | 323.15 | 3.7546 | 1.9289 | 1.34 | 4.5072 | 2.4433 | 1.7565 | 1.20 |
| MEA + 2-propanol | 303.15 | 8.1025 | 3.5256 | 0.71 | 8.7621 | 5.9872 | 2.9915 | 0.60 |
| | 313.15 | 5.5486 | 2.8474 | 0.80 | 6.0780 | 4.3047 | 2.3899 | 0.51 |
| | 323.15 | 4.0207 | 2.3041 | 0.81 | 4.4385 | 3.2817 | 1.9134 | 0.64 |

[a] AAD = $(100/n)\sum_{k=1}^{n}|\nu_k^{\mathrm{cal}} - \nu_k^{\mathrm{exp}}|/\nu_k^{\mathrm{exp}}$.

calculated from the density data by

$$V^{\mathrm{E}} = V - (x_1V_1 + x_2V_2) \qquad (3)$$

with

$$V = (x_1M_1 + x_2M_2)/\varrho \qquad (4)$$

where $V$ is the molar volume of the mixture and $V_1$, $M_1$, $V_2$, and $M_2$ are the molar volumes and molecular weights of components 1 and 2, respectively. The viscosity deviation from a mole fraction average ($\delta\eta$) is given by

$$\delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \qquad (5)$$

where $\eta_1$ and $\eta_2$ are the viscosities of pure components 1 and 2, respectively. Figure 2 presents the excess volumes at 313.15 K, indicating negative volume changes of mixing for those three systems. The volume contraction in MEA + ethanol is slightly greater than those in MEA + 2-propanol and MEA + water. The comparison of viscosity deviations is made as shown in Figure 3. It reveals a positive deviation for MEA + water except in the range of low MEA concentrations and a negative deviation for the alcohol-containing systems over the entire composition range.

The isothermal excess volumes and viscosity deviations were correlated by a Redlich–Kister type equation:

$$V^{\mathrm{E}}/(\mathrm{cm^3 \cdot mol^{-1}}) = x_1x_2\sum_{k=0}^{3}A_k(x_1 - x_2)^k \qquad (6)$$

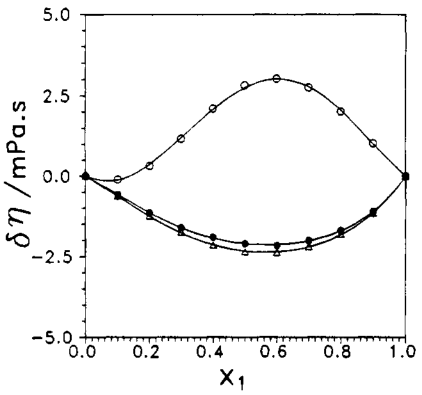

**Figure 3.** Viscosity deviations at 313.15 K: (○) MEA (1) + water (2); (△) MEA (1) + ethanol (2); (●) MEA (1) + 2-propanol (2); (—) calculated from eq 7.

$$\delta\eta/(\mathrm{mPa{\cdot}s}) = x_1x_2\sum_{k=0}^{3}B_k(x_1 - x_2)^k \qquad (7)$$

The coefficients of $A_k$ and $B_k$ were obtained by fitting the equations to the experimental values with a least-squares algorithm. Tables 5 and 6 give the coefficients together with the AAD of the calculated density and viscosity.

McAllister's multibody interaction model (*16*) is widely used for correlating the kinematic viscosity of liquid mixtures. The three-body model is defined as

$$\ln \nu = x_1^3 \ln \nu_1 + 3x_1^2x_2 \ln \nu_{12} + 3x_1x_2^2 \ln \nu_{21} + x_2^3 \ln \nu_2 - \ln[x_1 + x_2(M_2/M_1)] + 3x_1^2x_2 \ln[(2 + M_2/M_1)/3] + 3x_1x_2^2 \ln[(1 + 2M_2/M_1)/3] + x_2^3 \ln(M_2/M_1) \qquad (8)$$

and the four-body model is given by

$$\ln \nu = x_1^4 \ln \nu_1 + 4x_1^3x_2 \ln \nu_{1112} + 6x_1^2x_2^2 \ln \nu_{1122} + 4x_1x_2^3 \ln \nu_{2221} + x_2^4 \ln \nu_2 - \ln[x_1 + x_2(M_2/M_1)] + 4x_1^3x_2 \ln[(3 + M_2/M_1)/4] + 6x_1^2x_2^2 \ln[(1 + M_2/M_1)/2] + 4x_1x_2^3 \ln[(1 + 3M_2/M_1)/4] + x_2^4 \ln(M_2/M_1) \qquad (9)$$

where $\nu_{12}$, $\nu_{21}$, $\nu_{1112}$, $\nu_{1122}$, and $\nu_{2221}$ are the model parameters. Table 7 reports the calculated results. It shows that the three-body model is adequate enough for those three MEA-containing systems.

## Literature Cited

(1) Lee, M. J.; Wei, M. C. *J. Chem. Eng. Data* **1992**, *37*, 209.

(2) Senanyake, P. C.; Gee, N.; Freeman, G. R. *Can. J. Chem.* **1987**, *65*, 2441.

(3) Dizechi, M.; Marschall, E. *J. Chem. Eng. Data* **1982**, *27*, 358.

(4) Timmermans, J. *Physico-Chemical Constants of Pure Organic Substances*, 2nd ed.; Elsevier: New York, 1965.

(5) Diguillo, R. M.; Lee, R. J.; Schaeffer, S. T.; Brasher, L. L.; Teja, A. S. *J. Chem. Eng. Data* **1992**, *37*, 239.

(6) *TRC Data Bases for Chemistry and Engineering-TRC Thermodynamic Tables*, Version 1.1; Thermodynamic Research Center, The Texas A&M University System: College Station, TX, 1994.

(7) Haar, L.; Gallagher, J. S.; Kell, G. S. *NBS/NRC Steam Tables:* Thermodynamic and Transport Properties and Computer Programs for Vapor and Liquid States of Water in SI Units; Hemisphere Publishers: New York, 1984.

(8) Marsh, K. N. *IUPAC-Recommended Reference Material for the Realization of Physicochemical Properties*; Blackwell Scientific Publications: Boston, MA, 1986.

(9) Vargaftik, N. B. *Tables of the Thermophysical Properties of Liquids and Gases*, 2nd ed.; Hemisphere: Washington, DC, 1975.

(10) Al-Ghawas, H. A.; Hagewiesche, D. P.; Ruiz-Ibanez, G.; Sandall, O. C. *J. Chem. Eng. Data* **1989**, *34*, 385.

(11) Crabtree, A. M.; O'Brien, J. F. *J. Chem. Eng. Data* **1991**, *36*, 140.

(12) Pikkarainen, L. *J. Chem. Eng. Data* **1983**, *28*, 344.

(13) Pikkarainen, L. *J. Chem. Eng. Data* **1988**, *33*, 299.

(14) Sollman, K.; Marschall, E. *J. Chem. Eng. Data* **1990**, *35*, 375.

(15) Sivaramprasad, G.; Rao, M. V. *J. Chem. Eng. Data* **1990**, *35*, 122.

(16) McAllister, R. A. *AIChE J.* **1960**, *6*, 427.

Received for review August 10, 1994. Accepted October 9, 1994.[⊗]

JE940168Y

---

[⊗] Abstract published in *Advance ACS Abstracts*, December 1, 1994.