# Solubility and Diffusivity of $N_2O$ and $CO_2$ in (Diethanolamine + *N*-Methyldiethanolamine + Water) and in (Diethanolamine + 2-Amino-2-methyl-1-propanol + Water)

**Meng-Hui Li* and Wen-Cheng Lee**

Department of Chemical Engineering, Chung Yuan Christian University, Chung Li, Taiwan 32023, R.O.C.

The solubility and diffusivity of $N_2O$ in (diethanolamine + *N*-methyldiethanolamine + water) and in (diethanolamine + 2-amino-2-methyl-1-propanol + water) were measured at (30, 35, and 40) °C and at atmospheric pressure. Five (diethanolamine + *N*-methyldiethanolamine + water) and four (diethanolamine + 2-amino-2-methyl-1-propanol + water) systems were studied. The total amine mass percent in all cases was 30. A solubility apparatus was used to measure the solubility of $N_2O$ in amine solutions. The diffusivity was measured by a wetted wall column absorber. The $N_2O$ analogy was used to estimate the solubility and diffusivity of $CO_2$ in (diethanolamine + *N*-methyldiethanolamine + water) and in (diethanolamine + 2-amino-2-methyl-1-propanol + water).

## Introduction

Acid gases such as $CO_2$ and $H_2S$ are frequently removed from natural gas, synthetic natural gas, and other process gas streams by means of absorption into aqueous alkanolamine solutions. The use of blended amines, a solution of two or more amines in varying compositions, shows considerable improvement in absorption and savings in energy requirements (Chakravarty et al., 1985). Blends of primary and tertiary amines, such as mixtures of monoethanolamine (MEA) and *N*-methyldiethanolamine (MDEA) have been suggested for $CO_2$ removal (Chakravarty et al., 1985). Besides the (MEA + MDEA + $H_2O$) system, (MEA + 2-amino-2-methyl-1-propanol (AMP) + $H_2O$) has also been suggested as a potential attractive new solvent for the acid gas treating process (Li and Chang, 1994). Compared to MEA, diethanolamine (DEA) has the same thermodynamic capacity to absorb $CO_2$ (Sartori and Savage, 1983) but with a better thermal stability and favorable reaction kinetics with $CO_2$ (Davis et al., 1993). Thus, MEA may be substituted by DEA in blends of alkanolamine aqueous solutions. Consequently, (DEA + MDEA + $H_2O$) and (DEA + AMP + $H_2O$) may be potential solvents for acid gas removal.

For the rational design of the gas absorption units, physical properties such as solubility and diffusivity of acid gases in amine solutions are required to model the rate of absorption. Due to the chemical reaction between $CO_2$ and amines, neither the free-gas solubility nor the diffusivity of $CO_2$ in amine solutions can be measured directly. The $N_2O$ analogy has been frequently used to estimate the solubility and the diffusivity of $CO_2$ in amine solutions (Haimour and Sandall, 1984; Versteeg and van Swaaij, 1988; Al-Ghawas et al., 1989; Xu et al., 1991; Saha et al., 1993).

The $N_2O$ analogy for the solubility and diffusivity of $CO_2$ in amine solution has the following relations

$$H_{CO_2} = H_{N_2O}(H_{CO_2}/H_{N_2O})_{\text{in water}} \quad (1)$$

$$D_{CO_2} = D_{N_2O}(D_{CO_2}/D_{N_2O})_{\text{in water}} \quad (2)$$

where $H_{N_2O}$ is the solubility of $N_2O$ in amine solution and $D_{N_2O}$ is the diffusivity of $N_2O$ in amine solution.

Versteeg and van Swaaij (1988) proposed, based on the available data of solubility and diffusivity of $N_2O$ and $CO_2$ in water, four convenient equations as follows

$$H_{N_2O}/\text{kPa m}^3\text{ kmol}^{-1} = 8.5470 \times 10^6 \exp(-2284/(T/\text{K})) \quad (3)$$

$$H_{CO_2}/\text{kPa m}^3\text{ kmol}^{-1} = 2.8249 \times 10^6 \exp(-2044/(T/\text{K})) \quad (4)$$

$$D_{N_2O}/\text{m}^2\text{ s}^{-1} = 5.07 \times 10^{-6} \exp(-2371/(T/\text{K})) \quad (5)$$

$$D_{CO_2}/\text{m}^2\text{ s}^{-1} = 2.35 \times 10^{-6} \exp(-2119/(T/\text{K})) \quad (6)$$

Some solubility and diffusivity of $N_2O$ and $CO_2$ in amine aqueous solutions were reported in the literature such as MEA (Sada et al., 1978; Wang et al., 1992), MDEA (Haimour and Sandall, 1984; Versteeg and van Swaaij, 1988; Al-Ghawas et al., 1989), AMP (Xu et al., 1991; Saha et al., 1993), and (MEA + MDEA) (Hagewiesche et al., 1995; Li and Lai, 1995) and (MEA + AMP) (Li and Lai, 1995). The diffusivities of $N_2O$ in 50 mass % blends of DEA and MDEA aqueous solutions at (40 to 80) °C have also been reported (Rinker et al., 1995). However, the solubility and diffusivity of $N_2O$ and $CO_2$ in 30 mass % (DEA + MDEA + $H_2O$) and in 30 mass % (DEA + AMP + $H_2O$) have not been reported in the literature. Therefore, it was the objective of this research to measure the solubility and diffusivity of $N_2O$ in (DEA + MDEA + $H_2O$) and in (DEA + AMP + $H_2O$). The $N_2O$ analogy was then applied to estimate the solubility and diffusivity of $CO_2$ in (DEA + MDEA + $H_2O$) and in (DEA + AMP + $H_2O$).

## Experimental Section

Alkanolamine aqueous solutions were prepared from distilled water. The distilled water was degassed by boiling. DEA is Riedel-de Haën reagent grade with a 99 mol % purity, MDEA is Riedel-de Haën reagent grade with a 98.5 mol % purity and AMP is Riedel-de Haën reagent grade with a 98 mol % purity. The gases $N_2O$ and $CO_2$ were supplied from commercial cylinders with purities of 99.7 mol % and 99.9 mol %, respectively.

***1. Solubility Measurement.*** The solubility of $N_2O$ in amine aqueous solutions was measured by using a solubil-

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* Author to whom correspondence should be addressed.

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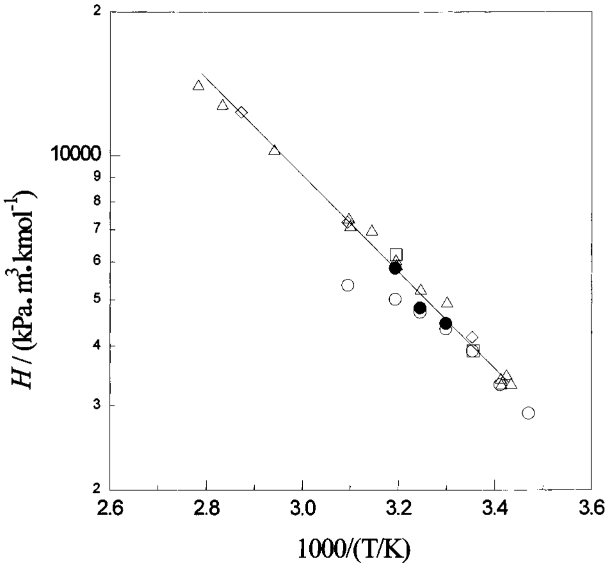

**Figure 1.** Solubility of $N_2O$ in water as a function of temperature: (●) this study; (○) data of Al-Ghawas et al. (1989); (□) data of Duda and Vrentas (1968); (△) data of Versteeg and van Swaaij (1988); (◇) data of Xu et al. (1991); (solid line) calculated using eq 3.

**Table 1. Measured Solubility of $CO_2$ and $N_2O$ in Water**

| | $H$/kPa m$^3$ kmol$^{-1}$ | |
|---|---|---|
| $t$/°C | $CO_2$ in water | $N_2O$ in water |
| 30 | 3420 | 4465 |
| 35 | 3835 | 4813 |
| 40 | 4226 | 5822 |

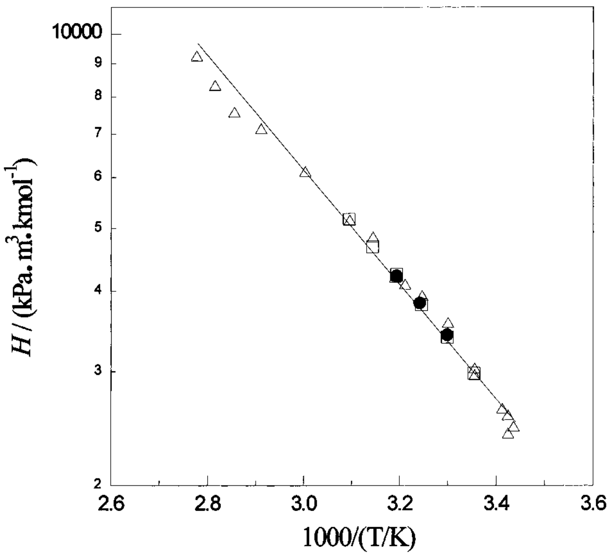

**Figure 2.** Solubility of $CO_2$ in water as a function of temperature: (●) this study; (□) data of Al-Ghawas et al. (1989); (△) data of Versteeg and van Swaaij (1988); (solid line) calculated using eq 4.

**Table 2. Estimated Solubility of $CO_2$ in (DEA + MDEA + $H_2O$) Using the $N_2O$ Analogy**

| | in water (kPa m$^3$ kmol$^{-1}$) | | in (DEA + MDEA + $H_2O$) | | |
|---|---|---|---|---|---|
| | | | mass % DEA + | (kPa m$^3$ kmol$^{-1}$) | |
| $t$/°C | $H_{CO_2}$$^a$ | $H_{N_2O}$$^b$ | mass % MDEA | $H_{N_2O}$ | $H_{CO_2}$ |
| 30 | 3332.40 | 4568.17 | 30 + 0 | 6889.8 | 5026.0 |
| | | | 24 + 6 | 6585.7 | 4804.2 |
| | | | 18 + 12 | 6081.4 | 4436.3 |
| | | | 12 + 18 | 5938.3 | 4331.9 |
| | | | 6 + 24 | 5422.3 | 3955.5 |
| 35 | 3717.66 | 5162.19 | 30 + 0 | 9612.6 | 6922.7 |
| | | | 24 + 6 | 8480.2 | 6107.2 |
| | | | 18 + 12 | 7662.7 | 5518.5 |
| | | | 12 + 18 | 6797.1 | 4895.1 |
| | | | 6 + 24 | 6089.7 | 4385.6 |
| 40 | 4133.01 | 5810.73 | 30 + 0 | 14377 | 10226 |
| | | | 24 + 6 | 11537 | 8206.0 |
| | | | 18 + 12 | 9632.3 | 6851.2 |
| | | | 12 + 18 | 7979.2 | 5675.4 |
| | | | 6 + 24 | 6886.5 | 4898.2 |

[a] Calculated using eq 4. [b] Calculated using eq 3.

ity apparatus, similar to those presented by Al-Ghawas et al. (1989) and Haimour (1990). The accuracy of the temperature of the system is estimated to be ±0.5 deg. The reproducibility between the various experiments is always within 3%. The estimated experimental error in the measured solubility is about ±2%. The apparatus, experimental procedure, and methods of analysis are essentially the same as those used in our previous work (Li and Lai, 1995).

***2. Diffusivity Measurement.*** The diffusivity of a gas in amine solutions was measured in a short wetted wall column absorber. A short, stainless steel cylinder of outside diameter 2.54 cm and a height of 10 cm was used as the wetted wall column. The apparatus and the experimental procedure are the same as those described by Yih and Shen (1988) and Li and Lai (1995). The reproducibility between the various experiments is always within 3%. The estimated experimental error in the measured diffusivity is estimated as ±2%.

## Results and Discussion

***1. Solubility.*** To examine the applicability of the present experimental solubility measurement, the solubilities of $N_2O$ in water and $CO_2$ in water were measured. The measured solubilities of $CO_2$ in water and $N_2O$ in water at (30, 35, and 40) °C are presented in Table 1. In Figure 1, the comparison between the literature values (Duda and Vrentas, 1968; Versteeg and van Swaaij, 1988; Al-Ghawas et al., 1989; Xu et al., 1991) and values obtained in this study for the solubility of $N_2O$ in water are shown. Also in Figure 2, the comparison between the values obtained in this study and literature values (Versteeg and van Swaaij, 1988; Al-Ghawas et al., 1989) for the solubility of $CO_2$ in water are shown. In Figures 1 and 2, the solid lines are calculated values using eqs 3 and 4 (Versteeg and van Swaaij, 1988). From Figure 1, it is seen that the measured solubilities of $N_2O$ in water are in good agreement with the literature values. Also, the measured solubility of $CO_2$ in water shows quite satisfactory agreement with the values reported by Versteeg and van Swaaij (1988), as shown in Figure 2. The solubilities of $N_2O$ in (DEA + MDEA + $H_2O$) and in (DEA + AMP + $H_2O$) at (30, 35, and 40) °C are presented in Tables 2 and 3 and plotted in Figures 3 and 4. As shown in Figure 3, at a constant temperature the solubility of $N_2O$ in (DEA + MDEA + $H_2O$) decreases systematically from 30 mass % DEA to 6 mass % DEA + 24 mass % MDEA. Also, the solubilities of $N_2O$ in 30 mass % DEA are higher than those in (DEA + AMP) (a total of 30 mass %) solutions, as shown in Figure 4. It has been pointed out by Wang and co-authors (1992) that the $N_2O$ solubility in amines may be affected not only by the number of carbon and hydrogen atoms but also by the structures of the amine. At 30 °C, the order of the $N_2O$ solubility in 30 mass % amines is DEA (6889.8 kPa m$^3$ kmol$^{-1}$), AMP (5855.5 kPa m$^3$ kmol$^{-1}$), and MDEA (5168.9 kPa m$^3$ kmol$^{-1}$) (Li and Lai, 1995).

A semiempirical model proposed by Wang et al. (1992) was used to correlate the solubility of $N_2O$ in amine

**Table 3. Estimated Solubility of $CO_2$ in (DEA + AMP + $H_2O$) Using the $N_2O$ Analogy**

| | in water (kPa m$^3$ kmol$^{-1}$) | | in (DEA + AMP + $H_2O$) | | |
|---|---|---|---|---|---|
| | | | | (kPa m$^3$ kmol$^{-1}$) | |
| $t$/°C | $H_{CO_2}$[a] | $H_{N_2O}$[b] | mass % DEA + mass % AMP | $H_{N_2O}$ | $H_{CO_2}$ |
| 30 | 3332.40 | 4568.17 | 24 + 6 | 6578.6 | 4799.0 |
| | | | 18 + 12 | 6292.6 | 4590.3 |
| | | | 12 + 18 | 6163.8 | 4496.4 |
| | | | 6 + 24 | 6037.1 | 4404.0 |
| 35 | 3717.66 | 5162.19 | 24 + 6 | 8580.3 | 6179.3 |
| | | | 18 + 12 | 7970.3 | 5740.0 |
| | | | 12 + 18 | 7439.0 | 5357.4 |
| | | | 6 + 24 | 7006.7 | 5046.0 |
| 40 | 4133.01 | 5810.73 | 24 + 6 | 11520 | 8193.9 |
| | | | 18 + 12 | 10174 | 7236.5 |
| | | | 12 + 18 | 9054.3 | 6440.1 |
| | | | 6 + 24 | 8193.9 | 5828.1 |

[a] Calculated using eq 4. [b] Calculated using eq 3.

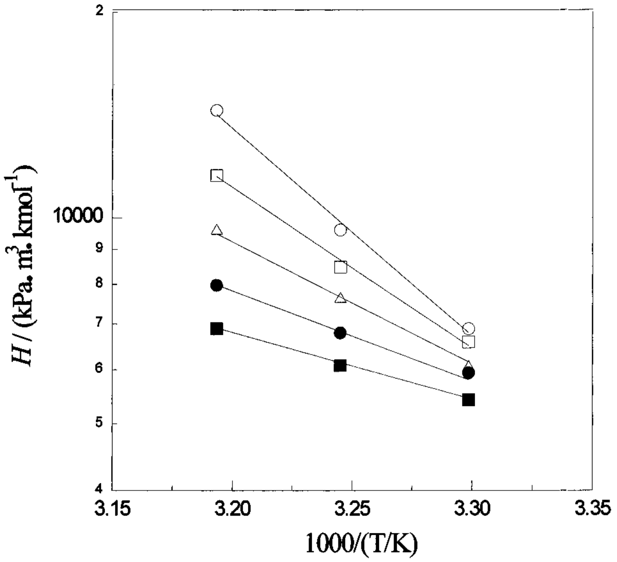

**Figure 3.** Solubility of $N_2O$ in (DEA + MDEA + $H_2O$): (○) 30 mass % DEA; (□) 24 mass % DEA + 6 mass % MDEA; (△) 18 mass % DEA + 12 mass % MDEA; (●) 12 mass % DEA + 18 mass % MDEA; (■) 6 mass % DEA + 24 mass % MDEA; (solid line) calculated using eq 7.

solutions. In this method, the excess Henry's coefficient for the mixed solvent system has the following form

$$R = \ln H_{1,\mathrm{m}} - \sum_{i=2}^{n} \Phi_i \ln H_{1,i} \tag{7}$$

where $H_{1,\mathrm{m}}$ is Henry's constant of the absorbed gas in the mixed solvent, $H_{1,i}$ is Henry's constant of the absorbed gas in pure solvent $i$, and $\Phi_i$ is the volume fraction of solvent $i$.

For binary solvent systems, the excess Henry's constant has the following form

$$R_{ij} = \Phi_i \Phi_j \alpha_{ij} \tag{8}$$

where $\alpha_{ij}$ is temperature dependent and is assumed in this study to be the expression

$$\alpha_{ij} = a_1 + a_2/T \tag{9}$$

where $a_1$ and $a_2$ are constants and were determined using the $N_2O$ solubility in (DEA + $H_2O$), (MDEA + $H_2O$), and (AMP + $H_2O$).

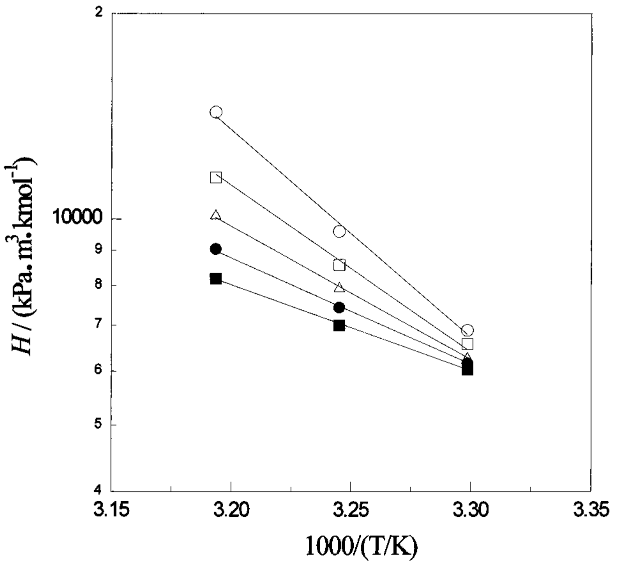

**Figure 4.** Solubility of $N_2O$ in (DEA + AMP + $H_2O$): (○) 30 mass % DEA; (□) 24 mass % DEA + 6 mass % AMP; (△) 18 mass % DEA + 12 mass % AMP; (●) 12 mass % DEA + 18 mass % AMP; (■) 6 mass % DEA + 24 mass % AMP; (solid line) calculated using eq 7.

**Table 4. Parameters in Excess Henry's Constant for Binary and Ternary Solvent Systems**

| system | $a_1$ | $a_2$ | $\alpha_{234}$ | AAD %[a] |
|---|---|---|---|---|
| (DEA + $H_2O$) | 83.9487 | −24729.4 | | 1.83 |
| (MDEA + $H_2O$) | −2.8999 | 1405.43 | | 0.64 |
| (AMP + $H_2O$) | 9.41882 | −2056.59 | | 0.74 |
| (DEA + MDEA) | −198.632 | 36470.5 | | |
| (DEA + AMP) | −26.1332 | 26805.4 | | |
| (DEA + MDEA + $H_2O$) | | | 110.738 | 0.97 |
| (DEA + AMP + $H_2O$) | | | −89.4207 | 0.68 |

[a] AAD %: average absolute percent deviation.

For ternary solvent systems, the excess Henry's constant has the form

$$R_{ijk} = \Phi_i \Phi_j \alpha_{ij} + \Phi_i \Phi_k \alpha_{ik} + \Phi_j \Phi_k \alpha_{jk} + \Phi_i \Phi_j \Phi_k \alpha_{ijk} \tag{10}$$

In this study, $\alpha_{ij}$ for (DEA + MDEA) and (DEA + AMP) and $\alpha_{ijk}$ were determined from the solubility of $N_2O$ in (DEA + MDEA + $H_2O$) and in (DEA + AMP + $H_2O$) and are presented in Table 4. The $\alpha_{ijk}$, in eq 10, is set to be a constant. The comparisons of the calculated and experimental solubilities of $N_2O$ in amine solutions are shown in Figures 3 and 4. The overall average absolute percent deviation for the calculation of solubility of $N_2O$ in amine solutions is 1.0%. The results are satisfactory. When the $N_2O$ analogy and the solubilities of $N_2O$ in water and $CO_2$ in water, calculated by eqs 3 and 4, are applied, the solubilities of $CO_2$ in (DEA + MDEA + $H_2O$) and (DEA + AMP + $H_2O$) were estimated and presented in Tables 2 and 3, respectively.

***2. Diffusivity.*** The diffusivity of $N_2O$ in amine solution was measured by the wetted wall column absorber. To confirm the correct operation of the apparatus and the experimental procedure, the diffusivities of $N_2O$ and $CO_2$ in water were measured at (30, 35, and 40) °C. The results are presented in Table 5. The comparison between the literature values (Davidson and Cullen, 1957; Unver and Himmelblau, 1964; Thomas and Adams, 1965; Versteeg and van Swaaij, 1988) and the values obtained in this study

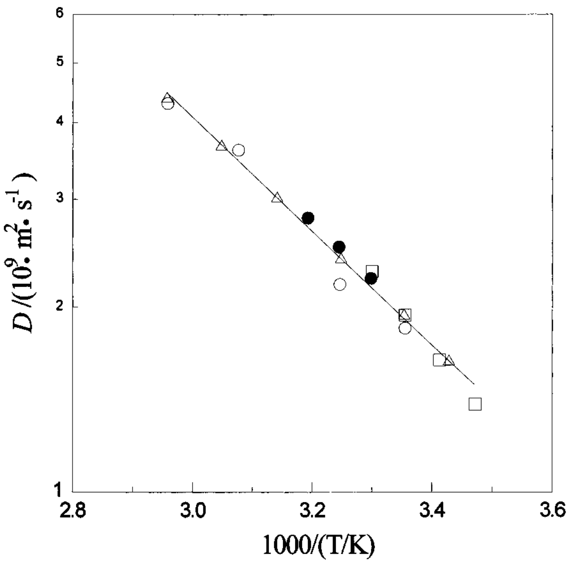

**Figure 5.** Diffusivity of $CO_2$ in water as a function of temperature: (●) this study; (□) data of Davidson and Cullen (1957); (○) Unver and Himmelblau (1964); (△) data of Thomas and Adams (1965); (solid line) calculated using eq 6.

**Table 5. Measured Diffusivity of $CO_2$ and $N_2O$ in Water**

| | $10^9 D/m^2\ s^{-1}$ | |
|---|---|---|
| $t$/°C | $CO_2$ in water | $N_2O$ in water |
| 30 | 2.229 | 2.114 |
| 35 | 2.511 | 2.338 |
| 40 | 2.800 | 2.701 |

**Table 6. Estimated Diffusivity of $CO_2$ in (DEA + MDEA + $H_2O$) Using the $N_2O$ Analogy**

| | in water ($10^9\ m^2\ s^{-1}$) | | in (DEA + MDEA + $H_2O$) | ($10^9\ m^2\ s^{-1}$) | |
|---|---|---|---|---|---|
| $t$/°C | $D_{CO_2}$[a] | $D_{N_2O}$[b] | mass % DEA + mass % MDEA | $D_{N_2O}$ | $D_{CO_2}$ |
| 30 | 2.165 | 2.034 | 30 + 0 | 1.162 | 1.237 |
| | | | 24 + 6 | 1.151 | 1.225 |
| | | | 18 + 12 | 1.140 | 1.213 |
| | | | 12 + 18 | 1.123 | 1.195 |
| | | | 6 + 24 | 1.109 | 1.180 |
| 35 | 2.425 | 2.309 | 30 + 0 | 1.320 | 1.386 |
| | | | 24 + 6 | 1.300 | 1.365 |
| | | | 18 + 12 | 1.273 | 1.337 |
| | | | 12 + 18 | 1.247 | 1.310 |
| | | | 6 + 24 | 1.221 | 1.282 |
| 40 | 2.706 | 2.611 | 30 + 0 | 1.501 | 1.556 |
| | | | 24 + 6 | 1.454 | 1.507 |
| | | | 18 + 12 | 1.412 | 1.463 |
| | | | 12 + 18 | 1.382 | 1.432 |
| | | | 6 + 24 | 1.344 | 1.393 |

[a] Calculated using eq 6. [b] Calculated using eq 5.

**Table 7. Estimated Diffusivity of $CO_2$ in (DEA + AMP + $H_2O$) Using the $N_2O$ Analogy**

| | in water ($10^9\ m^2\ s^{-1}$) | | in (DEA + AMP + $H_2O$) | ($10^9\ m^2\ s^{-1}$) | |
|---|---|---|---|---|---|
| $t$/°C | $D_{CO_2}$[a] | $D_{N_2O}$[b] | mass % DEA + mass % AMP | $D_{N_2O}$ | $D_{CO_2}$ |
| 30 | 2.165 | 2.034 | 24 + 6 | 1.149 | 1.223 |
| | | | 18 + 12 | 1.120 | 1.192 |
| | | | 12 + 18 | 1.106 | 1.177 |
| | | | 6 + 24 | 1.080 | 1.150 |
| 35 | 2.425 | 2.309 | 24 + 6 | 1.298 | 1.363 |
| | | | 18 + 12 | 1.270 | 1.334 |
| | | | 12 + 18 | 1.235 | 1.297 |
| | | | 6 + 24 | 1.201 | 1.261 |
| 40 | 2.706 | 2.611 | 24 + 6 | 1.462 | 1.515 |
| | | | 18 + 12 | 1.431 | 1.483 |
| | | | 12 + 18 | 1.393 | 1.444 |
| | | | 6 + 24 | 1.354 | 1.403 |

[a] Calculated using eq 6. [b] Calculated using eq 5.

**Table 8. Determined Parameters of the Diffusivity of $N_2O$ in Amine Solutions Using Eq 11**

| params | (DEA + MDEA + $H_2O$) | (DEA + AMP + $H_2O$) |
|---|---|---|
| $b_0$ | $-1.28392 \times 10^{-6}$ | $-5.7883 \times 10^{-7}$ |
| $b_{11}$ | $1.60979 \times 10^{-5}$ | $1.37498 \times 10^{-5}$ |
| $b_{12}$ | $-1.61431 \times 10^{-5}$ | $-1.4068 \times 10^{-5}$ |
| $b_{21}$ | $-3.33168 \times 10^{-5}$ | $-1.6855 \times 10^{-6}$ |
| $b_{22}$ | $6.07263 \times 10^{-5}$ | $6.09552 \times 10^{-6}$ |
| $c_{12}$ | $3.71434 \times 10^{-5}$ | $-5.4051 \times 10^{-6}$ |
| $c$ | $2.26938 \times 10^{3}$ | $2.27953 \times 10^{3}$ |
| AAD % | 0.2 | 0.3 |

for the diffusivity of $CO_2$ in water are also shown in Figure 5. The solid lines in Figure 5 are calculated values using eq 6. As shown in Figure 5, the diffusivities of $CO_2$ in water obtained in this study are in good agreement with the literature values. The diffusivities of $N_2O$ in amine solutions are presented in Tables 6 and 7 for (DEA + MDEA + $H_2O$) and (DEA + AMP + $H_2O$), respectively. At the same temperature, the diffusivities of $N_2O$ in 30 mass % DEA are higher than that in both 30 mass % (DEA + MDEA) and 30 mass % (DEA + AMP), as shown in Tables 6 and 7. At 30 °C, the viscosity of 30 mass % DEA solution is 2.5419 mPa s (Rinker et al., 1994), which is smaller than that of either 30 mass % MDEA (2.626 mPa s) or 30 mass % AMP (3.053 mPa s) (Li and Lie, 1994). This may explain why diffusivities of $N_2O$ in 30 mass % DEA are higher than that in either 30 mass % (DEA + MDEA) or 30 mass % (DEA + AMP) solutions.

To correlate the diffusivity of $N_2O$ in the blended amine solutions, the following form is assumed

$$D = (b_0 + b_{11}M_1 + b_{12}M_1^{\,2} + b_{21}M_2 + b_{22}M_2^{\,2} + c_{12}M_1M_2)\exp(-c/T) \quad (11)$$

where $M_1$ is the molarity of DEA and $M_2$ is the molarity of MDEA or AMP. The parameters in eq 11 were determined using the diffusivity data in Tables 6 and 7, and are presented in Table 8. The overall average absolute percentage deviations for the calculations of the diffusivity of $N_2O$ in amine solutions are 0.2 and 0.3% for (DEA + MDEA + $H_2O$) and (DEA + AMP + $H_2O$), respectively. Figures 6 and 7 show the comparison between the experimental values and calculated values using eq 11 for the diffusivity of $N_2O$ in amine solutions. As shown in Figures 6 and 7, the calculations of the diffusivity of $N_2O$ in amine solutions are satisfactory. When the $N_2O$ analogy and eqs 5 and 6 are applied, the diffusivities of $CO_2$ in amine solutions are estimated and presented in Tables 6 and 7 for (DEA + MDEA + $H_2O$) and (DEA + AMP + $H_2O$), respectively.

The Stokes–Einstein relation ($D\eta/T$ = a constant, $\eta$ is viscosity) has often been used to correlate the diffusivity of $N_2O$ in single amine aqueous solutions (Haimour and Sandall, 1984; Saha et al., 1993). The viscosity, $\eta$, of the blend amines solutions is required to calculate the Stokes–Einstein relation, i.e., $D\eta/T$. Thus, the viscosities of (DEA + AMP + $H_2O$) have been measured and reported in Table 9. The $D\eta/T$ for the systems are also calculated in Table 9. The method of viscosity measurement is the same as that used in our previous work (Li and Lie, 1994). It is observed from Table 9 that the experimental diffusivities of $N_2O$ in (DEA + AMP + $H_2O$) at 30 and 40 °C do not follow the Stokes–Einstein relation strictly. Figure 8 shows the diffusivity of $N_2O$ in (DEA + AMP + $H_2O$) plotted as $D/T$ vs $\eta$. From Figure 8 it is seen that the

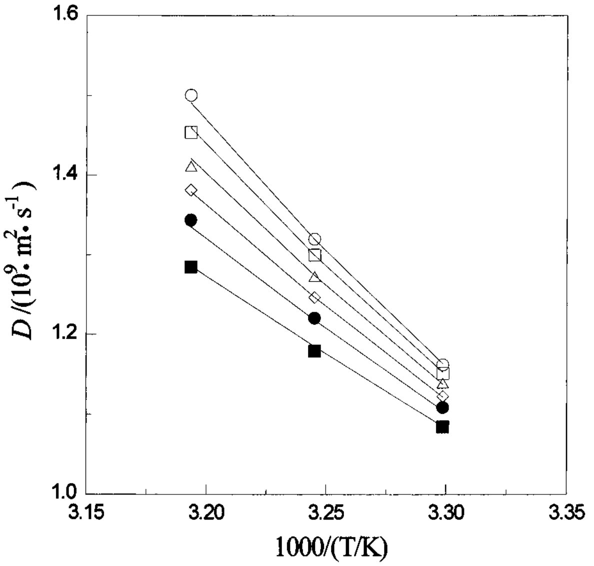

**Figure 6.** Diffusivity of $N_2O$ in (DEA + MDEA + $H_2O$): (○) 30 mass % DEA; (□) 24 mass % DEA + 6 mass % MDEA; (△) 18 mass % DEA + 12 mass % MDEA; (◇) 12 mass % DEA + 18 mass % MDEA; (●) 6 mass % DEA + 24 mass % MDEA; (■) 30 mass % MDEA (data of Li and Lai, 1995); (solid line) calculated using eq 11.

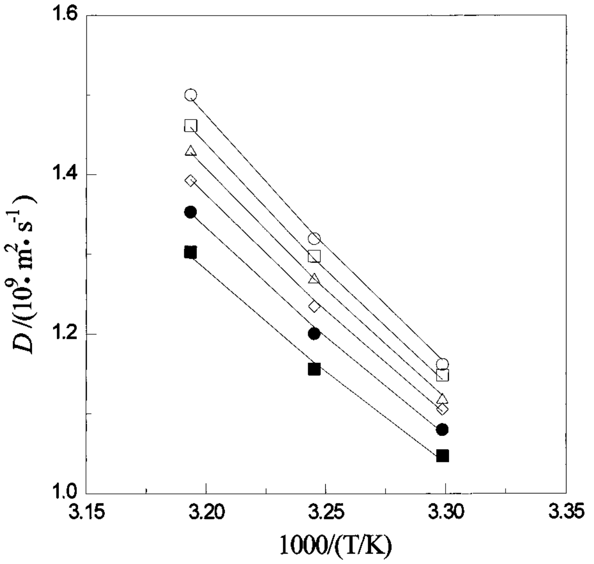

**Figure 7.** Diffusivity of $N_2O$ in (DEA + AMP + $H_2O$): (○) 30 mass % DEA; (□) 24 mass % DEA + 6 mass % AMP; (△) 18 mass % DEA + 12 mass % AMP; (◇) 12 mass % DEA + 18 mass % AMP; (●) 6 mass % DEA + 24 mass % AMP; (■) 30 mass % AMP (data of Li and Lai, 1995); (solid line) calculated using eq 11.

diffusivity of $N_2O$ in blend amines, (DEA + AMP + $H_2O$), cannot be well represented by the Stokes–Einstein relation.

## Conclusion

The solubility and diffusivity of $N_2O$ in (diethanolamine + *N*-methyldiethanolamine + water) and in (diethanolamine + 2-amino-2-methyl-1-propanol + water) were measured at (30, 35, and 40) °C and at atmospheric pressure. Five (diethanolamine + *N*-methyldiethanolamine + water) and four (diethanolamine + 2-amino-2-methyl-1-propanol + water) systems were studied. The $N_2O$ analogy was used to estimate the solubility and diffusivity of $CO_2$ in (diethanolamine + *N*-methyldiethanolamine + water) and in (diethanolamine + 2-amino-2-methyl-1-propanol + water).

**Table 9. Diffusivity of $N_2O$ in (DEA + AMP + $H_2O$) for the Stokes–Einstein Relation**

| $t$/°C | mass % DEA + mass % AMP | $D_{N_2O}$/ $10^9$ m$^2$ s$^{-1}$ | $\eta$/ $10^3$ N s m$^{-2}$ | $D\eta/T$/ ($10^{15}$ N K$^{-1}$) |
|---|---|---|---|---|
| 30 | 30 + 0 | 1.162 | 2.542 | 9.744 |
| | 24 + 6 | 1.149 | 2.644 | 10.02 |
| | 18 + 12 | 1.120 | 2.746 | 10.15 |
| | 12 + 18 | 1.106 | 2.849 | 10.39 |
| | 6 + 24 | 1.080 | 2.951 | 10.51 |
| | 0 + 30 | 1.047[a] | 3.053[b] | 10.54 |
| 40 | 30 + 0 | 1.501 | 1.930 | 9.251 |
| | 24 + 6 | 1.462 | 1.978 | 9.235 |
| | 18 + 12 | 1.431 | 2.025 | 9.254 |
| | 12 + 18 | 1.393 | 2.073 | 9.221 |
| | 6 + 24 | 1.354 | 2.121 | 9.171 |
| | 0 + 30 | 1.303[a] | 2.168[b] | 9.021 |

[a] Data of Li and Lai, 1995. [b] Data of Li and Lie, 1994.

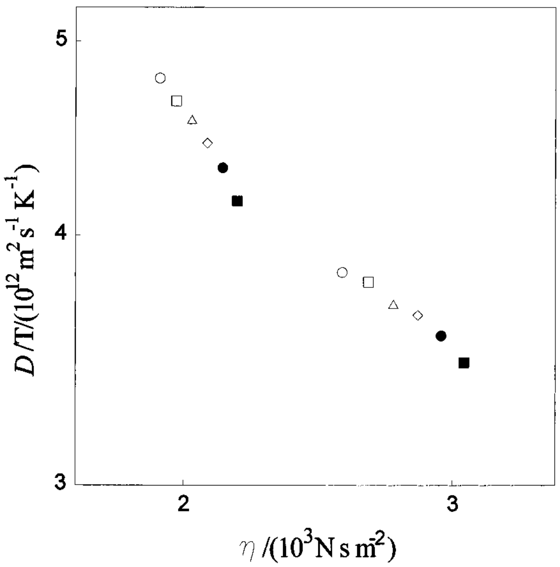

**Figure 8.** Plot of $D/T$ versus $\eta$ for the diffusivity of $N_2O$ in (DEA + AMP + $H_2O$): (○) 30 mass % DEA; (□) 24 mass % DEA + 6 mass % AMP; (△) 18 mass % DEA + 12 mass % AMP; (◇) 12 mass % DEA + 18 mass % AMP; (●) 6 mass % DEA + 24 mass % AMP; (■) 30 mass % AMP.

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