Densities, Viscosities, and Surface Tensions of Aqueous 2-Amino-2-ethyl-1,3-propanediol Solutions

Sang Jun Yoon, Hyun-Song Lee, and Huen Lee*

Department of Chemical Engineering, Korea Advanced Institute of Science and Technology, 373-1 Yusong-gu Kusong-dong, Taejon 305-701, South Korea

Jeom-In Baek, Ji-Ho Yoon, and Hee-Moon Eum

Environmental Research Group, Korea Electric Power Research Institute, 103-16 Munji-dong, Yusong-ku, Taejon 305-380, South Korea

Densities, viscosities, and surface tensions of 2-amino-2-ethyl-1,3-propanediol (AEPD) + water mixtures were measured over wide temperatures ranging from (303.15 to 343.15) K. The concentration ranges of AEPD were (20−100) mass % for density measurements and 20−80 mass % for viscosity and surface tension measurements. The experimental values were correlated as a function of temperature and concentration. The average absolute deviations were found to be 0.07% for density, 0.56% for viscosity, and 0.42% for surface tension.

Introduction

Alkanolamine solutions have been widely used in synthesis, refinery, and other gas stream processes for the removal of CO_2 and H_2S. In particular, a variety of physicochemical property data of monoethanolamine (MEA), diethanolamine (DEA), diglycolamine (DGA), triethanolamine (TEA), *N*-methyldiethanolamine (MDEA), and di-2-propanolamine (DIPA) have been extensively reported by many researchers.[1−4] Recently, the sterically hindered amines have been also proposed as potential absorbents because of their higher absorption capacity, selectivity, and chemical stability.[5] 2-Amino-2-methyl-1-propanol (AMP), 2-piperidineethanol (2-PE), and 2-amino-2-methyl-1,3-propanediol (AMPD) were selected as possible sterically hindered amines.[6,7] However, because of the low carbamate stability of sterically hindered amines, their loading capacity of acid gas becomes generally higher than that of other conventional amines such as MEA, DEA, and MDEA.[5] In the present research the compound selected was 2-amino-2-ethyl-1,3-propanediol (AEPD), which is one of the sterically hindered amines and has a larger bulky group attached to the tertiary carbon atom than either AMP or AMPD. This structure characteristic indicates that AEPD has a lower carbamate stability and a higher CO_2 loading capacity than the others.

In the present study the densities, viscosities, and surface tensions of the AEPD + water mixtures were measured at temperatures ranging from (303.15 to 343.15) K and at amine concentrations of (20, 40, 60, 70, 80, and 100) mass %. These properties must be provided as the basic process variables needed for the better design of acid-gas treatment equipment and can be possibly used for estimating the liquid diffusivity, free-gas solubility, and reaction rate constant.

* Author to whom correspondence should be addressed (e-mail hlee@mail.kaist.ac.kr).

Experimental Section

2-Amino-2-ethyl-1,3-propanediol with a minimum purity of 97% was obtained from Acros Organics and was used without further purification. AEPD solutions were prepared using triple-distilled water.

The densities were measured by using a calibrated pycnometer having a bulb volume of 25 cm^3. A water bath that could be kept constant within ±0.05 K by an externally circulating refrigerator/heater was used. The temperature was measured by a calibrated mercury-filled glass thermometer. A Satorius R120S balance with a precision of ±0.0001 g was used for mass measurements of liquid mixtures. The density values were reproducible within ±0.0002 g·cm^{-3}.

The kinematic viscosities were measured by appropriate calibrated Ubbelohde type viscometers (Witeg) of various capillary sizes. The measurements were performed in a constant-temperature water bath controlled within ±0.05 K. An electronic stopwatch with an accuracy of 0.01 s was used to measure the efflux times of liquid solutions. The efflux times of a liquid sample were measured at least five times. The uncertainty of the measured kinematic viscosity was estimated to be within ±1%. The dynamic viscosities were calculated by multiplying the measured kinematic viscosities with the density values of the same solutions.

The surface tensions were measured by using a cathetometer and capillary tube. The temperature could be kept constant within ±0.05 K by a water circulator. The temperature of the liquid sample was measured directly by the calibrated mercury-filled glass thermometer with a precision of ±0.1 K. The height of liquid rise in the capillary tube was determined by a cathetometer (N.O.W. NCM 30) with an uncertainty of 10^{-5} m. The diameter of the capillary tube was calibrated with benzene at various temperatures, and the averaged value of the diameter was used to calculate the surface tension. The averaged surface tension data were reported with an uncertainty of ±0.8%.

10.1021/je010196y CCC: $22.00
Published on Web 10/20/2001

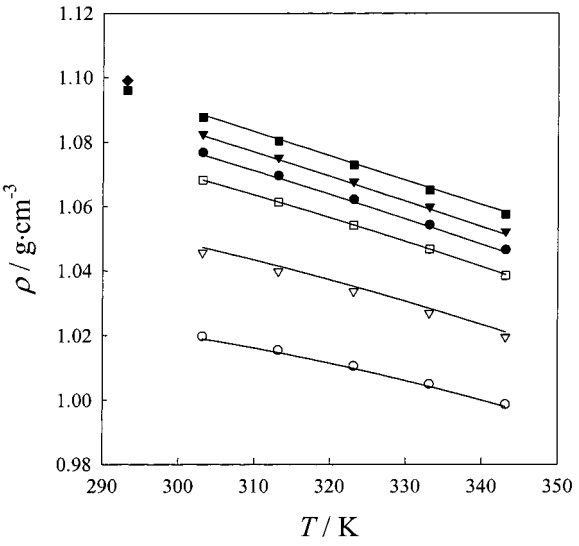

Figure 1. Densities ρ of 2-amino-2-ethyl-1,3-propanediol + water system as a function of temperature (mass % AEPD): ○, 20.0; ▽, 40.0; □, 60.0; ●, 70.0; ▼, 80.0; ■, 100.0; ◆, Susan (1996); solid lines are calculated by eq 1.

Table 1. Densities (ρ/g·cm^{-3}) of 2-Amino-2-ethyl-1,3-propanediol (1) + Water (2) System

	$100w_1$					
T/K	20.0	40.0	60.0	70.0	80.0	100.0
303.15	1.0198	1.0456	1.0683	1.0768	1.0825	1.0877
313.15	1.0155	1.0398	1.0614	1.0696	1.0752	1.0804
323.15	1.0106	1.0336	1.0542	1.0622	1.0677	1.0729
333.15	1.0050	1.0269	1.0467	1.0543	1.0599	1.0651
343.15	0.9987	1.0195	1.0385	1.0465	1.0522	1.0576

Table 2. Parameters and AADs for Density Correlations of 2-Amino-2-ethyl-1,3-propanediol + Water System

	A_i	10^2B_i	10^5C_i
$i = 0$	0.6588	0.2328	−0.4147
$i = 1$	0.8744	−0.3340	0.3633
$i = 2$	−0.2226	0.0298	0.0452
AAD (%)		7.05×10^{-2}	

The detailed procedure and apparatus for measuring the surface tension were described elsewhere.[8]

Results and Discussion

The density of pure AEPD was measured at 293.15 K and compared with the literature value[9] and found to be in good agreement. The densities of AEPD + water mixtures were then measured over the temperatures ranging from (303.15 to 343.15) K and AEPD concentrations of (20, 40, 60, 70, 80, and 100.0) mass %. All data were measured at least three times, and the average values are shown in Table 1. Maximum deviation from the average value is <0.3%. The density values were regressed using the polynomial

$$\rho = \sum_{i=0}^{2}[A_i w^i + B_i w^i(T/\mathrm{K}) + C_i w^i(T/\mathrm{K})^2] \qquad (1)$$

where w is the mass fraction of AEPD. The calculated regression parameters and average absolute deviations (ADD) between measured and calculated values are presented in Table 2. In Figure 1, the experimental and calculated densities of AEPD + water mixtures are plotted with the temperature at various mass percentages of AEPD. The maximum deviation was found to be <0.07%. The densities of binary mixtures decreased linearly with temperature but increased nonlinearly with the concentration of APED.

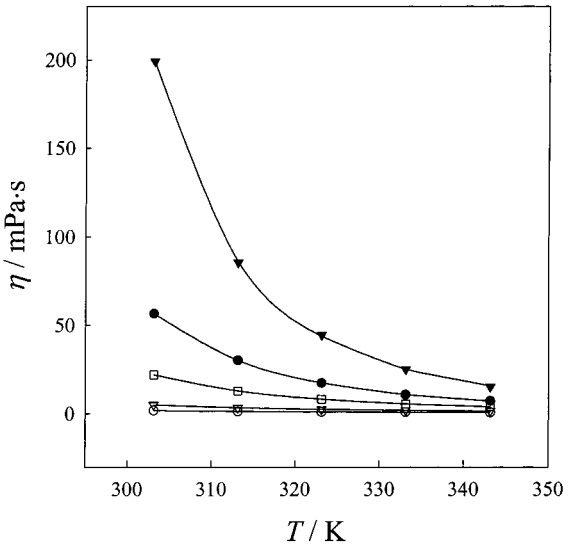

Figure 2. Viscosities η of 2-amino-2-ethyl-1,3-propanediol + water system as a function of temperature (mass % AEPD): ○, 20.0; ▽, 40.0; □, 60.0; ●, 70.0; ▼, 80.0; solid lines are calculated by eq 2.

Table 3. Viscosities (η/mPa·s) of 2-Amino-2-ethyl-1,3-propanediol (1) + Water (2) System

	$100w_1$				
T/K	20.0	40.0	60.0	70.0	80.0
303.15	1.765	4.993	21.96	56.54	199.2
313.15	1.356	3.435	12.89	30.13	85.62
323.15	1.053	2.504	8.220	17.36	44.40
333.15	0.858	1.932	5.561	10.75	25.01
343.15	0.716	1.520	3.963	7.198	15.16

Table 4. Parameters and AADs for Viscosity Correlations of 2-Amino-2-ethyl-1,3-propanediol (1) + Water (2) System

	$100w_1$				
	20.0	40.0	60.0	70.0	80.0
A	−3.7824	−2.6747	−3.4717	−4.6312	−2.5708
B	635.07	447.63	743.68	1102.3	658.12
C	−157.24	−198.63	−189.80	−175.96	−219.47
AAD (%)	0.93	0.24	0.07	0.47	1.09

Viscosities of AEPD + water binary mixtures at (303.15, 313.15, 323.15, 333.15, and 343.15) K were measured with AEPD compositions of (20, 40, 60, 70, and 80) mass %, respectively. The experimental data are presented in Table 3. The following simple expression was used for regressing the data:

$$\eta = \exp\left[b_1 + \frac{b_2}{T/\mathrm{K} + b_3}\right] \qquad (2)$$

Table 4 includes the determined parameters and AADs between the measured and calculated values. The maximum deviation value was found to be ~1%. The measured and calculated viscosity data are compared graphically in Figure 2. The viscosities of AEPD + water mixtures decreased dramatically with temperature at high concentrations of AEPD.

Comparisons between experimental data and literature values[10] of the surface tension for pure water are shown

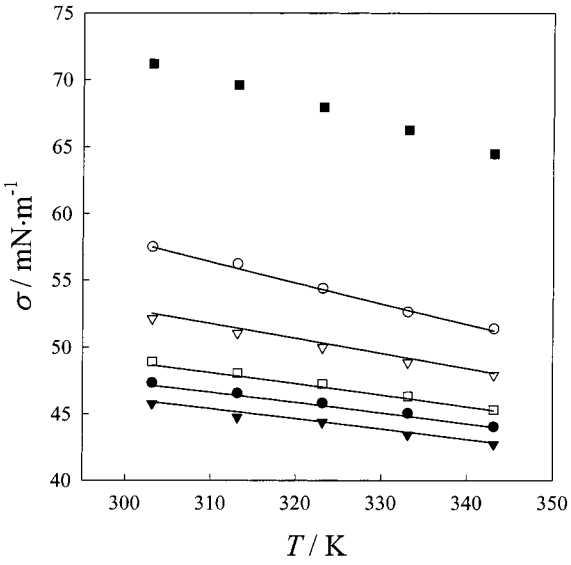

Figure 3. Surface tensions σ of 2-amino-2-ethyl-1,3-propanediol + water system as a function of temperature (mass % AEPD): ○, 20.0; ▽, 40.0; □, 60.0; ●, 70.0; ▼, 80.0; ■, pure water; ◆, David (1995); solid lines are calculated.

Table 5. Surface Tensions (σ/mN·m^{-1}) of 2-Amino-2-ethyl-1,3-propanediol (1) + Water (2) System

	$100w_1$				
T/K	20	40	60	70	80
303.15	57.51	52.12	48.93	47.36	45.78
313.15	56.25	51.04	48.08	46.57	44.75
323.15	54.40	49.97	47.26	45.83	44.37
333.15	52.62	48.85	46.34	45.06	43.43
343.15	51.36	47.93	45.33	44.05	42.72

in Figure 3. Maximum deviations between experimental and literature values were <0.7%, which confirmed the reliability of the experimental procedure. The surface tensions of AEPD + water systems were obtained at the same condition with the viscosity measurements. These experimental results are presented in Table 5 and Figure 3. The experimental data were correlated as a function of temperature and concentration of AEPD by the same expression as eq 1 used in the density correlation. The calculated parameters and AAD values are presented in Table 6. The average absolute deviation value was found to be 0.4% in this correlation.

Table 6. Parameters and AADs for Surface Tension Correlations of 2-Amino-2-ethyl-1,3-propanediol + Water System

	$10^{-3}A_i$	$10^{-1}B_i$	$10^{3}C_i$
$i = 0$	0.1819	−0.0539	0.4920
$i = 1$	−0.3611	0.1711	−2.0772
$i = 2$	0.2565	−0.1299	1.6444
AAD (%)		0.42	

Conclusion

Densities, viscosities, and surface tensions of 2-amino-2-ethyl-1,3-propanediol + water systems were measured at (303.15, 313.15, 323.15, 333.15, and 343.15) K with AEPD concentrations ranging from (20 to 100) mass %. All physical properties were correlated by appropriate equations, and correlation parameters were obtained. Measured and calculated values agreed well within 0.07% for density, 0.56% for viscosity, and 0.42% for surface tension in AADs.

Literature Cited

(1) Li, M.-H.; Lie, Y.-C. Densities and Viscosities of Solutions Monoethanolamine + *N*-Methyldiethanolamine + Water and Monoethanolamine + 2-Amino-2-methyl-1-propanol + Water. *J. Chem. Eng. Data* **1994**, *39*, 444−447.
(2) Versteeg, G. F.; van Swaaij, W. P. M. Solubility and Diffusivity of Acid Gases (CO_2, N_2O) in Aqueous Alkanolamine Solutions. *J. Chem. Eng. Data* **1988**, *33*, 29−34.
(3) Song, J.-H.; Park, S.-B.; Yoon, J.-H.; Lee, H. Densities and Viscosities of Monoethanolamine + Ethylene Glycol + Water. *J. Chem. Eng. Data* **1996**, *41*, 1152−1154.
(4) Digullio, R. M.; Lee, R.-J.; Schaeffer, S. T.; Brasher, L. L.; Teja, A. S. Densities and Viscosities of the Ethanolamines. *J. Chem. Eng. Data* **1992**, *37*, 239−242.
(5) Sartori, G.; Savage, D. W. Sterically Hindered Amines for CO_2 Removal from Gases. *Ind. Eng. Chem. Fundam.* **1983**, *22*, 239−249.
(6) Xiao, J.; Li, C.-W.; Li, M.-H. Kinetics of absorption of carbon dioxide into aqueous solutions of 2-amino-2-methyl-1-propanol + monoethanolamine. *Chem. Eng. Sci.* **2000**, *55*, 161−175.
(7) Baek, J.-I.; Yoon, J.-H.; Eum, H.-M. Physical and Thermodynamic Properties of Aqueous 2-Amino-2-methyl-1,3-propanediol Solutions. *Int. J. Thermophys.* **2000**, *21*, 1175−1184.
(8) Lee, J.-W.; Park, S.-B.; Lee, H. Density, Surface Tension, and Refractive Indices of the Water + 1,3-Propanediol System. *J. Chem. Eng. Data* **2000**, *45*, 166−168.
(9) Susan, B. *The Merck Index*, 12th ed.; Merck & Co.: Whitehouse Station, NJ, 1996.
(10) David, R. L. *CRC Handbook of Chemistry and Physics*, 76th ed.; CRC Press: Boca Raton, FL, 1995−1996.

Received for review July 10, 2001. Accepted September 19, 2001. This work was supported by Grant 2000-C-CD02-P-01 from the Korea Energy Management Corp. R&D Headquarters and also partially by the Brain Korea 21 Project.

JE010196Y