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Density, Viscosity, and Excess Properties for 1,2-Diaminoethane + 1,2-Ethanediol at (298.15, 303.15, and 308.15) K

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Density (ρ) and viscosity (η) were determined over the whole concentration range for the binary mixtures of 1,2-diaminoethane + 1,2-ethanediol at (298.15, 303.15, and 308.15) K. The experimental results are compared with data published in the previous literature. The density values were used to calculate the excess molar volume (V_m^E). The calculated results are fitted to a Redlich−Kister equation to obtain the coefficients and estimate the standard deviations between the experimental and the calculated quantities. The values of V_m^E are negative over the entire composition range.

Introduction

This paper is a continuation of the systematic program on the properties of solution containing 1,2-ethanediol. 1,2-Ethanediol is an important industrial solvent with the potential gas scrubbing because of its favorable properties such as low vapor pressure, low toxicity, low viscosity, and low melting temperature. 1,2-Ethanediol and its similar solvents, including diethylene glycol (DEG) and poly(ethylene glycol) (PEG), present native hydrogen bonding sites[1,2] so that the potential desorption characters are presented in the regenerative processes of solutions dissolving SO_2; therefore, in previous studies, great attention has been paid to aqueous 1,2-ethanediol and its similar solvents for SO_2 removal.[3−7]

In recent months, 1,2-diaminoethane had been put into 1,2-ethanediol to boost the absorption capacity of SO_2 in solutions containing 1,2-ethanediol in our research group. The main advantages of 1,2-diaminoethane and 1,2-ethanediol are also a high solubility capability for SO_2, which leads to lower energy requirements for absorption processes of SO_2. In actual use, the physical properties of 1,2-diaminoethane + 1,2-ethanediol mixtures are extremely important. Especially, the density and viscosity data of aqueous solutions are significant from the practical and theoretical viewpoint. Previously published data[8−16] showed the density and viscosity data of pure 1,2-diaminoethane and pure 1,2-ethanediol, but the density and viscosity data over the whole concentration range for the binary mixtures of 1,2-diaminoethane + 1,2-ethanediol are generally limited to ambient temperatures.

In the present work, the density and viscosity of 1,2-diaminoethane and 1,2-ethanediol were determined over the whole concentration range for the binary mixtures of 1,2-diaminoethane + 1,2-ethanediol at (298.15, 303.15, and 308.15) K. Meanwhile, the excess molar volume was derived.

Experimental Section

Materials. The analytical grade 1,2-diaminoethane and 1,2-ethanediol were purchased from Beijing Reagent Company (Beijing, China). It was used after drying over molecular sieves (type 4A) and decompression filtration before measurements. The purity of the samples was checked by density determination at 298.15 K. The density of 1,2-ethanediol at 298.15 K was found to be 1.1096 g·cm^{-3}, in good agreement with literature,[13−15] and the density of 1,2-diaminoethane at 298.15 K was found to be 0.8945 g·cm^{-3}, in good agreement with literature.[14] Bidistilled water and high-performance liquid chromatography (HPLC) grade ethanol were used.

Measurements. Solvent mixtures were prepared by mass using an analytical balance with a precision of ± 0.0001 g (Sartorius BS 224S). The uncertainty in the mole fraction for each binary mixture is less than 0.0001.

Densities of pure liquids and their mixtures were determined using a bicapillary pycnometer having a bulb volume of 10 cm^3. The volume of the pycnometer was calibrated as a function of temperature using distilled, deionized, and desgassed water at various temperatures.[17−19] The pycnometer filled with liquid was kept in a thermostatically controlled and well-stirred water bath (maintained constant to ± 0.01 K) for (25 to 30) min to attain thermal equilibrium. The density measurements were carried out at (298.15, 303.15, and 308.15) K. Each experimental density value was an average of at least three measurements. The uncertainty of the density measurement was estimated to be ± 0.02 %.

The kinematic viscosity in both the pure components and their mixtures was determined with a commercial capillary viscometer of the Ubbelohde type with a 0.6 mm diameter, which was calibrated with high pure water and ethanol (HPLC grade) at the experimental temperature range whose viscosity and density were well-known, as has been described in literature.[17−22] A thoroughly cleaned and perfectly dried viscometer, filled with experimental solution, was placed exactly vertical in an insulated jacket, wherein constant temperature (± 0.02 K) was maintained by circulating water from a thermoelectric controller at the required temperature. After thermal stability was attained, the flow times of the

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Table 1. Comparison of Experimental Densities (ρ) and Viscosities (η) of 1,2-Ethanediol and 1,2-Diaminoethane with Literature Values at Various Temperatures

	$\rho/(\mathrm{g \cdot cm^{-3}})$		$\eta/(\mathrm{mPa \cdot s})$	
T/K	expt.	lit.	expt.	lit.
		1,2-Ethanediol		
298.15	1.1096	1.10987[11] 1.1085[13] 1.1100[14,16] 1.10988[15] 1.11009[23]	16.795	15.312[16] 18.6826[24]
303.15	1.1058	1.10636[11] 1.10640[15] 1.10665[23]	13.396	13.646[13] 13.8678[24]
308.15	1.1030	1.10282[11] 1.1032[13] 1.10289[15] 1.10296[23]	11.333	11.6956[24]
		1,2-Diaminoethane		
298.15	0.8945	0.891[12] 0.8948[14] 0.8952[26]	1.276	
303.15	0.8908	0.890325[25] 0.8906[26]	1.211	1.290[25]
308.15	0.8856	0.885616[25] 0.8859[26]	1.107	1.167[25]

Table 2. Experimental Densities (ρ) of 1,2-Diaminoethane (1) + 1,2-Ethanediol (2)

	$\rho/(\mathrm{g \cdot cm^{-3}})$		
x_1	T/K = 298.15	T/K = 303.15	T/K = 308.15
0.0000	1.1096	1.1058	1.1030
0.1027	1.0966	1.0898	1.0844
0.1541	1.0866	1.0809	1.0738
0.2052	1.0784	1.0724	1.0624
0.2561	1.0685	1.0622	1.0538
0.3066	1.0614	1.0535	1.0429
0.3568	1.051	1.0428	1.0338
0.4078	1.0404	1.0348	1.0266
0.5080	1.0185	1.0139	1.0072
0.5579	1.0066	1.0007	0.9947
0.6065	0.9954	0.9883	0.9818
0.6573	0.9831	0.9762	0.9687
0.7071	0.9701	0.9645	0.9561
0.7560	0.9573	0.9517	0.9444
0.8051	0.9462	0.9388	0.9317
0.8542	0.9334	0.9249	0.9175
0.9003	0.9191	0.9134	0.9072
0.9438	0.9088	0.9034	0.8975
1.0000	0.8945	0.8908	0.8856

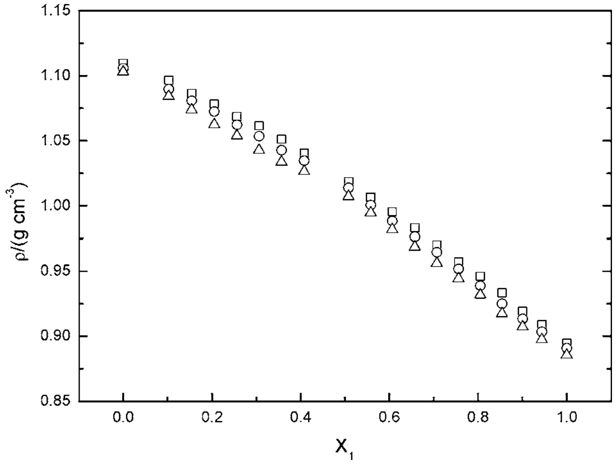

Figure 1. Experimental densities with mole fraction for 1,2-diaminoethane (1) + 1,2-ethanediol (2): □, 298.15 K; ○, 303.15 K; △, 308.15 K.

Table 3. Excess Molar Volumes (V_m^E) for 1,2-Diaminoethane (1) + 1,2-Ethanediol (2)

	$V_m^E/(\mathrm{cm^3 \cdot mol^{-1}})$		
x_1	T/K = 298.15	T/K = 303.15	T/K = 308.15
0.0000	0.0000	0.0000	0.0000
0.1027	−0.6756	−0.5249	−0.4109
0.1541	−0.8272	−0.7332	−0.5371
0.2052	−1.0621	−0.9523	−0.6060
0.2561	−1.1979	−1.0708	−0.8165
0.3066	−1.4746	−1.2595	−0.8872
0.3568	−1.5604	−1.3248	−1.0458
0.4078	−1.6345	−1.5436	−1.3169
0.5080	−1.6897	−1.6540	−1.5248
0.5579	−1.6394	−1.5231	−1.4397
0.6065	−1.6016	−1.4074	−1.2961
0.6573	−1.5093	−1.3219	−1.1493
0.7071	−1.3428	−1.2334	−1.0029
0.7560	−1.1574	−1.0430	−0.8855
0.8051	−1.0703	−0.8290	−0.6849
0.8542	−0.8495	−0.5218	−0.3547
0.9003	−0.4620	−0.3232	−0.2431
0.9438	−0.3018	−0.1801	−0.1240
1.0000	0.0000	0.0000	0.0000

Table 4. Coefficients and Standard Deviations of Excess Molar Volumes, V_m^E, for 1,2-Diaminoethane + 1,2-Ethanediol

T/K	A_0	A_1	A_2	A_3	A_4	$\sigma/\mathrm{cm^3 \cdot mol^{-1}}$
298.15	−6.788	−0.058	0.824	0.528	−0.522	0.0475
313.15	−6.294	−0.298	2.741	2.194	−0.584	0.0438
308.15	−5.761	−1.519	7.698	3.964	−7.112	0.0529

solutions were recorded with an electronic digital stopwatch correct to ± 0.01 s. At least 16 repetitions of each datum point obtained were reproducible to 0.06 s, and the results were averaged. Because all flow times were greater than 15 s and the capillary diameter (0.6 mm) was far less than its length (120 mm), the kinetic energy and end corrections, respectively, were found to be negligible. The viscosity was then calculated from the fundamental relationship.

The kinematic viscosity (ν) was calculated from the following equation

$$\nu = At - \frac{B}{t} \tag{1}$$

where ν is the kinematic viscosity, A and B are viscometer contents, and t is its flow time in the viscometer, respectively. A and B are determined from measurements with the calibration fluids of water and ethanol. The absolute viscosity (η) was obtained by multiplying the determined kinematic viscosity (ν) by the measured density ($\eta = \nu\rho$). Each experimental point was the average of 16 sets with a maximum deviation of ± 0.02 % in the flow time.

The experimental densities and viscosities of pure 1,2-diaminoethane and 1,2-ethanediol are compared with the available literature values are given in Table 1.

Results and Discussion

Experimental densities of the binary solutions of 1,2-diaminoethane (1) + 1,2-ethanediol (2) at (298.15, 303.15, and 308.15) K throughout the whole concentration range are summarized in Table 2. The values of the measured density at different temperatures are shown in Figure 1.

Table 2 shows that the density values decrease with the increasing 1,2-diaminoethane concentration in binary solutions over the whole concentration range. The density values decrease with the augment of temperature at the same concentration.

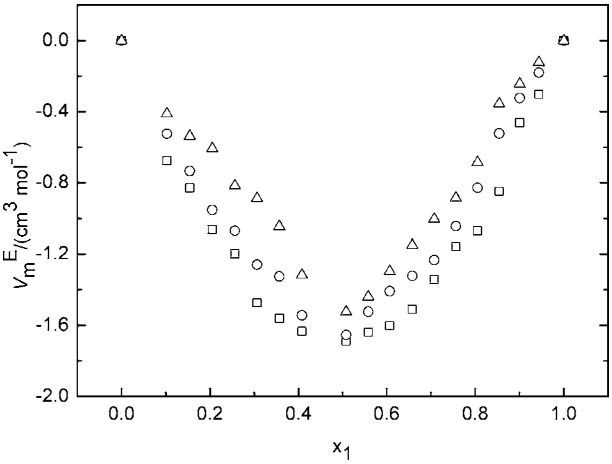

Figure 2. Excess molar volumes with mole fraction for 1,2-diaminoethane (1) + 1,2-ethanediol (2): □, 298.15 K; ○, 303.15 K; △, 308.15 K.

Table 5. Experimental Viscosities (η) of 1,2-Diaminoethane (1) + 1,2-Ethanediol (2)

	η/(mPa·s)		
x_1	T/K = 298.15	T/K = 303.15	T/K = 308.15
0.0000	16.795	13.396	11.333
0.1027	22.284	17.598	14.049
0.1541	25.541	20.556	16.928
0.2052	28.368	22.441	18.213
0.2561	30.733	23.153	19.284
0.3066	31.457	23.656	19.196
0.3568	30.700	22.853	18.495
0.4078	28.318	21.307	17.004
0.5080	20.173	15.184	11.891
0.5579	16.057	12.272	8.772
0.6065	12.509	9.748	6.254
0.6573	9.028	7.157	4.674
0.7071	6.882	5.681	4.008
0.7560	5.154	4.177	3.547
0.8051	3.787	3.154	2.683
0.8542	3.199	2.552	2.128
0.9003	2.273	1.920	1.713
0.9438	1.800	1.561	1.422
1.0000	1.276	1.211	1.107

The excess molar volume, V_m^E, was calculated from density measurements according to the following equation

$$V_m^{\ E} = \frac{x_1M_1 + x_2M_2}{\rho_m} - \left(x_1\frac{M_1}{\rho_1} + x_2\frac{M_2}{\rho_2}\right) \qquad (2)$$

where ρ_m is the density of the mixture and x_1, ρ_1, M_1, x_2, ρ_2, and M_2 are the mole fractions, densities, and molecular weights of pure 1,2-diaminoethane and pure 1,2-ethanediol, respectively. The results of V_m^E are listed in Tables 3 and 4, and the dependence of V_m^E at various temperatures is displayed in Figure 2.

Figure 2 shows that V_m^E is negative for all of the mixtures over the entire mole fraction range at each temperature. The maximum is at about $x_1 = 0.50$. Additionally, these V_m^E values become less negative with the increasing temperature.

A Redlich−Kister relation was used to correlate the excess volume data.

$$V_m^{\ E}/\text{cm}^3\cdot\text{mol}^{-1} = x_1x_2\sum_{i=0}^{n}A_i(2x_1 - 1)^i \qquad (3)$$

where x_1 is the mole fraction of 1,2-diaminoethane, x_2 is the mole fraction of 1,2-ethanediol, A_i are the polynomial coefficients which were evaluated from the least-squares method, and n is the polynomial degree.

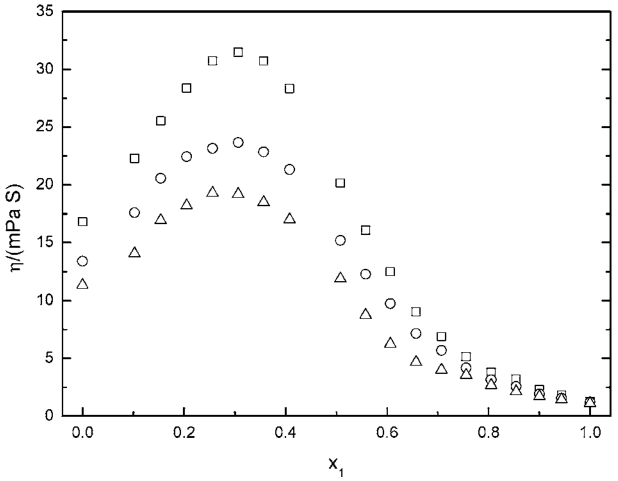

Figure 3. Experimental viscosities with mole fraction for 1,2-diaminoethane (1) + 1,2-ethanediol (2): □, 298.15 K; ○, 303.15 K; △, 308.15 K.

The standard deviation values, σ, between the calculated and the experimental data points are obtained by the following equation

$$\sigma_{V_m^E} = \left[\sum\left(V_{\text{calc}}^{\ E} - V_m^{\ E}\right)^2/(N - m)\right]^{1/2} \qquad (4)$$

where N is the total number of experimental points and m is the number of A_i coefficients considered. The coefficients A_i and corresponding standard deviations, σ, are listed in Table 4.

Experimentally measured viscosities of the binary solutions of 1,2-diaminoethane + 1,2-ethanediol at (298.15, 303.15, and 308.15) K are listed in Table 5 and shown in Figure 3. In all cases, the viscosities increase with the increasing 1,2-diaminoethane concentration in the range of 0 to 0.3, decrease with the increasing 1,2-diaminoethane concentration in the range of 0.3 to 1.0, and decrease with the increasing temperature.

Conclusion

This paper reports experimental data for the densities and viscosities of the binary system of 1,2-diaminoethane + 1,2-ethanediol at (298.15, 303.15, and 308.15) K. The data of pure 1,2-diaminoethane and pure 1,2-ethanediol generally agreed with available literature data. These data have been used to compute excess properties of the system. The calculated V_m^E values for 1,2-diaminoethane + 1,2-ethanediol were negative at all temperatures and compositions.

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