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Volumetric Properties, Viscosities, and Refractive Indices for Aqueous 2-((2-Aminoethyl)amino)ethanol Solutions from (298.15 to 343.15) K

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Densities and viscosities at six temperatures in the range (298.15 to 343.15) K and refractive indices at five temperatures in the range (298.15 to 333.15) K are reported for the aqueous 2-((2-aminoethyl)amino)ethanol solutions. Excess molar volumes, viscosity deviations, and molar refraction changes are calculated from the measurement results and correlated as a function of the mole fractions. Partial molar volumes at infinite dilutions are determined from apparent molar volumes. Negative values for both excess molar volumes and molar refraction changes are observed over the entire range of mole fractions, whereas viscosity data exhibit both negative and positive deviations.

Introduction

2-((2-Aminoethyl)amino)ethanol ($H_2N(CH_2)_2NH(CH_2)_2OH$, AEEA) is commonly used in the production of fuel additives, lube oil additives, chelating agents, surfactants, and fabric softeners among other applications. It is an organic base with unique properties that make it an invaluable intermediate. The primary and secondary amine groups, together with the hydroxyl group, combine the features of an ethyleneamine and an ethanolamine.

Alkanolamine solutions have been extensively studied during the last 25 years because of their industrial importance for natural gas; synthetic ammonia plants; fossil-fuel-fired power plants; steel production; chemical, petrochemical, and cement industries for removal of acid gas impurities such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sulfur dioxide (SO_2) from gas streams.[1] In 2006, Ma'mun et al.[2] found by a screening test that 2-((2-aminoethyl)amino)ethanol could be a potential absorbent for capturing carbon dioxide from post-combustion exhaust gases as it shows a high absorption rate combined with high net cyclic capacity. The net cyclic capacity of AEEA is significantly higher than that of monoethanolamine (MEA), and it maintains its absorption power at higher loadings. In terms of the vapor pressure, AEEA has a much lower vapor pressure (0.969 kPa) as compared to the industry standard MEA (15.9 kPa) at the regeneration temperature of 120 °C.[3]

The objective of this work is to determine the densities, viscosities, and refractive indices for the binary systems of 2-((2-aminoethyl)amino)ethanol (1) + water (2). We found that no literature data of these properties are available for 2-((2-aminoethyl)amino)ethanol (1) + water (2). These data are required for the development of proper design for absorption and stripping operations. The experimental density data are used to calculate excess molar volumes. Partial molar volumes at infinite dilutions are determined from apparent molar volumes. Viscosity deviations and molar refraction changes are also calculated from the experimental viscosity and refractive index data. The calculated binary data are fitted to the Redlich−Kister equation.

Experimental Section

2-((2-Aminoethyl)amino)ethanol (99 % pure by mass) was purchased from Sigma Aldrich and was used without further purification. The uncertainty in the mole fractions prepared with an analytical balance is estimated to be less than 2×10^{-4}. Densities of the binary mixtures were measured with an Anton Paar DMA-4500 density meter. Calibration was done using air and water at ambient temperature. The densities of deionized and then distilled water were measured in the temperature range (288.15 to 353.15) K and were compared with values provided by Anton Parr in the instruction manual. Density measurements were reproducible to $\pm 2 \times 10^{-5}$ g·cm^{-3}. The calibration was accepted if the measurements were within $\pm 5 \times 10^{-5}$ g·cm^{-3}. The uncertainty in density measurements was about $\pm 5 \times 10^{-5}$ g·cm^{-3} as compared with the densities of pure MDEA published in the literature.[10]

The density can be determined by the two-parameter equation:

$$\rho = A + B\tau^2 \tag{1}$$

where ρ is the liquid density and τ is the period of oscillation. The measured values of densities were checked at each temperature using deionized water,[4] and an air equation for the determination of the density of dry air was taken from the annual book of ASTM standards.[5]

U-tube glass Cannon-Ubbelohde viscometers (Cole-Parmer) were used for the measurement of viscosities. To measure the viscosities of aqueous AEEA at different temperatures, viscometers were placed in a well-stirred constant-temperature bath (model CT 500, Cannon Instrument Company, State College, PA). The uncertainty of water bath temperature was less than 0.01 °C as measured by the Ertco-Hart RTD high-precision digital thermometer (model 850 C, West Patterson, NJ).

Viscosities were determined with nine different viscometers to cover in the range of temperatures from (298.15 to 343.15) K. The efflux time was measured with a hand-held certified digital stopwatch capable of measuring time to within 0.01 s. Experiments were repeated a minimum of three times at each temperature for all concentrations. The equation for kinematic viscosity, according to Poiseuille's law, is

$$\nu = k_1 t - k_2/t \tag{2}$$

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Table 1. Density, ρ, for AEEA (1) + Water (2) Mixtures from (298.15 to 343.15) K

	ρ/g·cm^{-3}					
x_1	T = 298.15 K	T = 303.15 K	T = 313.15 K	T = 323.15 K	T = 333.15 K	T = 343.15 K
0.0000	0.99704	0.99564	0.99221	0.98803	0.98319	0.97775
0.0500	1.01565	1.01365	1.00922	1.00424	0.99875	0.99277
0.0700	1.02228	1.02001	1.01513	1.00976	1.00389	0.99734
0.0999	1.03085	1.02824	1.02270	1.01680	1.01053	1.00389
0.1992	1.04737	1.04402	1.03713	1.03003	1.02269	1.01509
0.3000	1.05066	1.04705	1.03970	1.03215	1.02444	1.01653
0.3997	1.04818	1.04450	1.03701	1.02937	1.02157	1.01360
0.4991	1.04405	1.04033	1.03279	1.02513	1.01735	1.00942
0.5990	1.03962	1.03589	1.02836	1.02071	1.01296	1.00510
0.6991	1.03548	1.03174	1.02421	1.01659	1.00888	1.00106
0.7997	1.03183	1.02811	1.02057	1.01296	1.00530	0.99754
0.9002	1.02828	1.02457	1.01706	1.00948	1.00184	0.99411
1.0000	1.02528	1.02153	1.01402	1.00644	0.99883	0.99115

Table 2. Viscosity, η/mPa·s, for AEEA (1) + Water (2) Mixtures from (298.15 to 343.15) K

	η/mPa·s					
x_1	T = 298.15 K	T = 303.15 K	T = 313.15 K	T = 323.15 K	T = 333.15 K	T = 343.15 K
0.0000	0.882	0.804	0.659	0.551	0.470	0.407
0.0500	2.45	2.16	1.63	1.26	1.01	0.839
0.0700	3.87	3.24	2.29	1.75	1.38	1.11
0.0999	6.76	5.50	3.83	2.80	2.05	1.60
0.1992	30.0	22.6	13.5	8.7	5.9	4.2
0.3000	70.9	50.4	27.8	16.5	10.5	7.0
0.3997	104	72.8	38.9	22.5	13.8	9.1
0.4991	121	83.9	44.8	25.6	15.8	10.3
0.5990	124	87.0	46.5	26.7	16.5	10.8
0.6991	121	84.8	45.7	26.4	16.5	10.8
0.7997	116	82.5	44.8	26.0	16.4	10.8
0.9002	109	78.1	44.4	26.0	16.5	10.7
1.0000	98.6	70.5	39.4	23.4	14.8	10.1

Table 3. Refractive Index, n_D, for AEEA (1) + Water (2) Mixtures from (298.15 to 333.15) K

	n_D				
x_1	T = 298.15 K	T = 303.15 K	T = 313.15 K	T = 323.15 K	T = 333.15 K
0.0000	1.33258	1.33202	1.33067	1.32909	1.32730
0.0500	1.37012	1.36931	1.36749	1.36542	1.36367
0.0700	1.38204	1.38110	1.37909	1.37696	1.37507
0.1000	1.39796	1.39682	1.39453	1.39214	1.38992
0.2000	1.43314	1.43180	1.42890	1.42583	1.42264
0.3000	1.45253	1.45087	1.44762	1.44425	1.44087
0.4000	1.46321	1.46158	1.45811	1.45463	1.45107
0.5000	1.47030	1.46857	1.46502	1.46146	1.45777
0.5996	1.47498	1.47321	1.46961	1.46604	1.46223
0.7011	1.47851	1.47671	1.47308	1.46938	1.46560
0.8002	1.48101	1.47918	1.47552	1.47177	1.46805
0.8979	1.48289	1.48103	1.47734	1.47359	1.46977
1.0000	1.48454	1.48269	1.47884	1.47516	1.47128

where t is the efflux time and k_1 and k_2 are the viscometer constants. The second term in the equation represents the correction due to the kinetic energy, and it was found to be negligible.[6] The absolute viscosity (η) was obtained by multiplying the measured kinematic viscosity (ν) by the measured density (ρ). Calibration was done as in previous work using high-purity ethylene glycol and diethylene glycol. The uncertainty in the absolute viscosity is estimated to be 1.5 %.

Refractive indices of aqueous 2-((2-aminoethyl)amino)ethanol solutions were measured by Atago RX-5000-α refractometer. Refractive indices of deionized water were measured and compared with the available literature data. The uncertainty in refractive index measurements was about ± 0.00001.

Results and Discussion

The measured values of densities and viscosities of the aqueous AEEA solutions at (298.15, 303.15, 313.15, 323.15, 333.15, and 343.15) K for the entire range of mole fractions are listed in Table 1 and Table 2, respectively. Refractive indices of the aqueous AEEA solutions at five different temperatures (298.15, 303.15, 313.15, 323.15, and 333.15) K for the entire range of mole fractions are listed in Table 3. Refractive indices were measured to a maximum temperature of 333.15 K due to the limitation of the refractometer.

As shown in Figure 1, the density curves increase as AEEA is added to water, and a maximum occurs at around $x_1 = 0.3$ for all temperatures.

The excess molar volume (V^E) is calculated from the measured density values by

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

with

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

where V is the molar volume of the mixture; x_i, V_i, and M_i (i = 1, 2) are the mole fraction, molar volume, molecular weight of

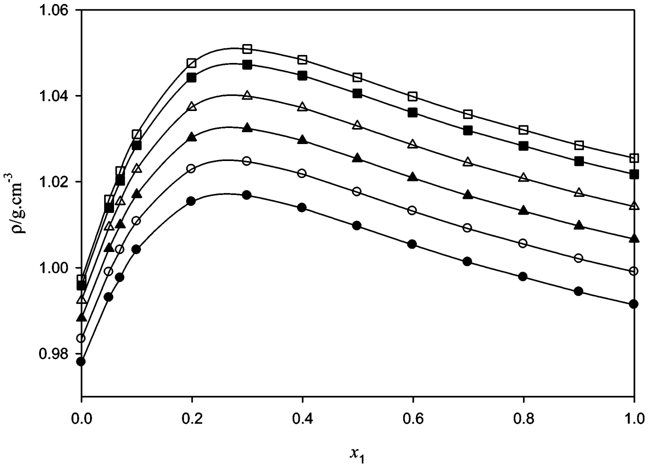

Figure 1. Densities of AEEA (1) + water (2) system at various temperatures: □, 298.15 K; ■, 303.15 K; △, 313.15 K; ▲, 323.15 K; ○, 333.15 K; ●, 343.15 K.

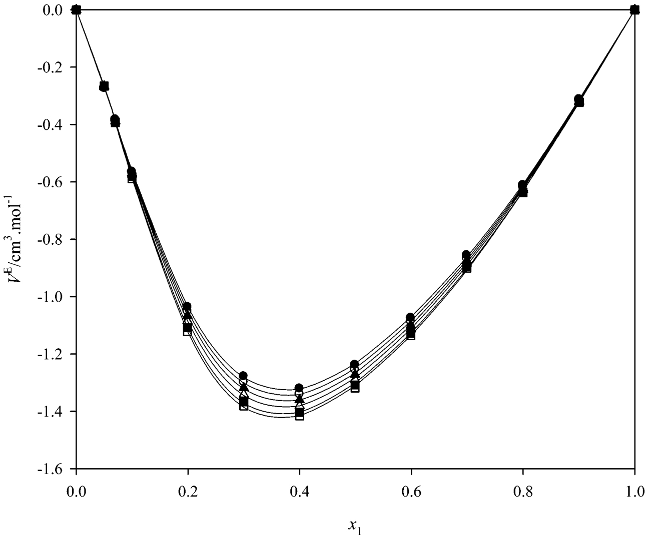

Figure 2. Excess molar volumes of AEEA (1) + water (2) system at various temperatures: □, 298.15 K; ■, 303.15 K; △, 313.15 K; ▲, 323.15 K; ○, 333.15 K; ●, 343.15 K; −, eq 5.

the components 2-((2-aminoethyl)amino)ethanol and water, respectively; and ρ is the liquid density. Figure 2 shows the concentration dependency of the molar excess volumes at various temperatures. At all the temperatures, the excess molar volume curves are negative with a minimum at around $x_1 = 0.4$. These V^E values became less negative as temperature increases. Figures 1 and 2 shows sharp changes in the density and excess volumes in the water-rich region. Negative excess molar volume values indicate a volume contraction and can be explained by the large difference in the molar specific volumes. Pal and Singh[7] concluded that volume contraction is due to the ability of the -OH group to form hydrogen bonds with water molecules. The second interpretation given was that such a marked change in excess volumes might also be due to the accommodation of the nonaqueous molecules occupying in the structured water lattice a void space. A Redlich−Kister relation was used to correlate the molar excess volume data:

$$V^E/\text{cm}^3\cdot\text{mol}^{-1} = x_1 x_2 \sum_{i=0}^{n} a_i (x_1 - x_2)^i \tag{5}$$

The coefficients and the standard deviations are presented in Table 4.

Table 4. Redlich−Kister Equation Fitting Coefficients for the Excess Molar Volume, V^E (eq 5), for AEEA (1) + Water (2) Mixtures from (298.15 to 343.15) K

T/K	a_0	a_1	a_2	a_3	a_4	a_5	σ/cm^3·mol^{-1}
298.15	−5.2411	2.9467	−1.9377	−0.1903	3.4746	−2.4106	0.0059
303.15	−5.2005	2.9119	−1.8538	−0.3439	3.2996	−2.2081	0.0058
313.15	−5.1300	2.8430	−1.6796	−0.5184	2.9946	−1.8505	0.0047
323.15	−5.0654	2.7718	−1.5586	−0.6112	2.7292	−1.5823	0.0041
333.15	−4.9984	2.7189	−1.4988	−0.7430	2.5624	−1.2528	0.0043
343.15	−4.9303	2.6778	−1.4610	−0.8949	2.4632	−0.9254	0.0056

Table 5. Partial Molar Volumes of AEEA at Infinite Dilution in Water, V_1^∞, and of Water at Infinite Dilution in AEEA, V_2^∞, from (298.15 to 343.15) K

T/K	V_1^∞/cm^3·mol^{-1}	V_2^∞/cm^3·mol^{-1}
298.15	97.6	15.0
303.15	97.9	15.0
313.15	98.5	15.0
323.15	99.0	15.1
333.15	99.6	15.3
343.15	100.3	15.5

Hepler[8] and Neal and Goring[9] recognized the usefulness of thermal expansion data for revealing correlations between molecular structure of solutes and their effects on water structure. They suggested using the sign of the second derivative of the partial molar volume at infinite dilution of the solute with respect to the temperature ($d^2V_1^0/dT^2$) to classify solutes as "structure makers" or "structure breakers". A positive sign corresponds to structure-making solute while a negative sign corresponds to structure-breaking solute.

Both the partial molar volume of AEEA at infinite dilution (V_1^∞) in water and the partial molar volume of water at infinite dilution (V_2^∞) in AEEA were obtained using the method proposed by Maham et al.[10] The apparent molar volume of AEEA ($V_{\phi,1}$) and the apparent molar volume of water ($V_{\phi,2}$) were first calculated as

$$V_{\phi,1} = V_1^{\,0} + (V^E/x_1) \tag{6}$$

$$V_{\phi,2} = V_2^{\,0} + [V^E/(1 - x_1)] \tag{7}$$

where V_1^0 and V_2^0 are the molar volumes of pure AEEA and water, respectively. An analytical extrapolation of $V_{\phi,2}$ to $x_1 = 1$ led to V_2^∞ and a similar extrapolation to $x_1 = 0$ led to V_1^∞. Partial molar volumes at infinite dilution are listed in Table 5. V_1^∞ values varied linearly with temperature. According to the criterion described above, the solute (AEEA) would be considered as having no net effect on the structure of water. This is consistent with the conclusion of Maham et al.[10,11] concerning other alkanolamines (MEA, DEA, and TEA). All the values of the molar volumes at infinite dilution (V_1^∞) were smaller than the corresponding molar values of pure AEEA (V_1^0). The change in the excess volume can be explained by the AEEA molecule fitting (partially) into the open or empty space in liquid water.

Having fewer values of V^E for x_1 near unity means that the accuracy of V_2^∞ may be lower. It is still clear that (dV_2^∞/dT) was positive. All values of V_2^∞ were smaller than the corresponding molar volumes of pure water (V_2^0) at the same temperature. As mentioned by Maham et al.,[11] this is consistent with the idea that the molar volume of pure water is the sum of the actual molecular volumes plus the "empty" volume that arises from the hydrogen-bonded open structure of water. Values of the apparent molar volumes of AEEA in water ($V_{\phi,1}$) are shown in Figure 3, and they increased with the increase in temperature. Each of the curves shown in Figure 3 has a

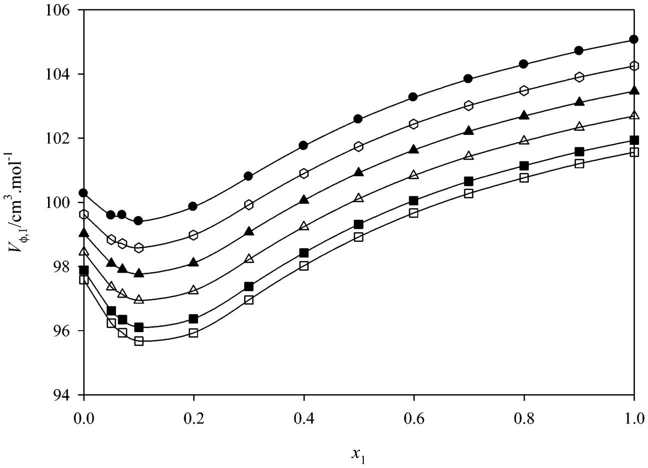

Figure 3. Apparent molar volumes of AEEA in water at various temperatures: □, 298.15 K; ■, 303.15 K; △, 313.15 K; ▲, 323.15 K; ○, 333.15 K; ●, 343.15 K.

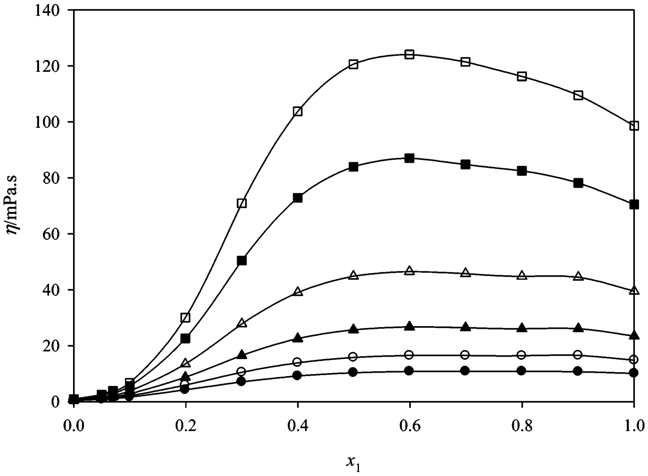

Figure 4. Viscosities of AEEA (1) + water (2) system at various temperatures: □, 298.15 K; ■, 303.15 K; △, 313.15 K; ▲, 323.15 K; ○, 333.15 K; ●, 343.15 K.

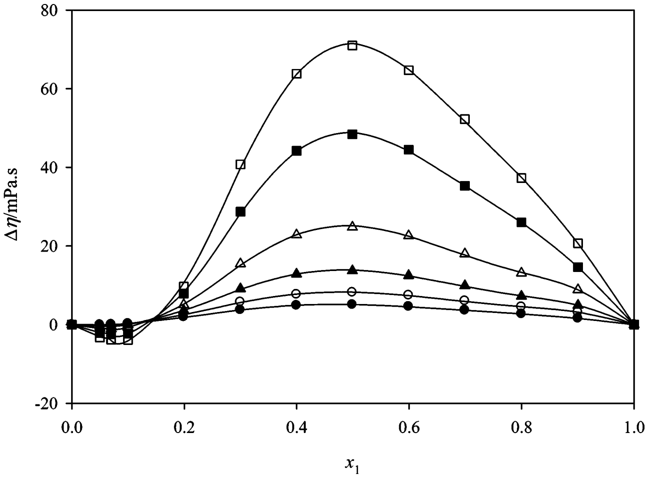

Figure 5. Viscosity deviations for AEEA (1) + water (2) system at various temperatures: □, 298.15 K; ■, 303.15 K; △, 313.15 K; ▲, 323.15 K; ○, 333.15 K; ●, 343.15 K; —, eq 10.

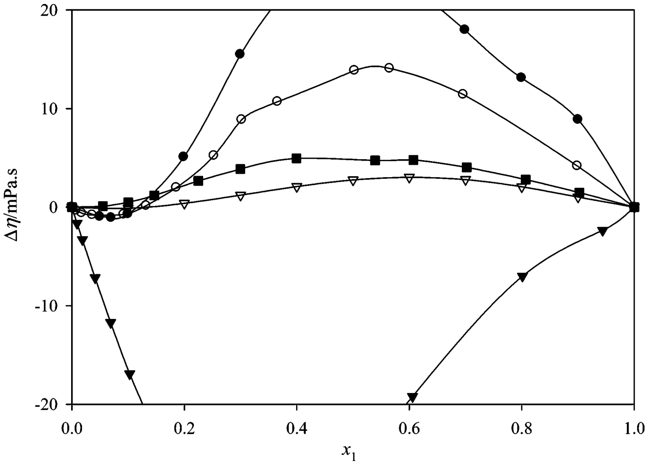

Figure 6. Comparison of the viscosity deviations of various aqueous alkanolamine solutions at 313.15 K: ●, AEEA, ○, MDEA;[16] ■, DGA;[14] ▽, MEA;[17] ▼, DEA.[10]

minimum, which is similar to that observed by Zhang et al.[12] for aqueous diethylethanolamine and dimethylethanolamine solutions.

Experimentally measured viscosities of the aqueous AEEA solutions at (298.15, 303.15, 313.15, 323.15, 333.15, and 343.15) K are listed in Table 2 and shown in Figure 4. Curves for the system AEEA + water are S-shaped with a maximum at $x_1 = 0.6$. Aqueous MDEA[13] and DGA[14] and other alkanolamine solutions were also shown to have this S-shaped form. Fort and Moore[15] and Liler and Kosanović[16] state that an S-shaped viscosity curve and the presence of a maximum indicate the formation of stable complexes. Figure 4 shows a sharp increase in the viscosity of the mixture after the addition of AEEA. The effect of the mole fraction on viscosity decreases with an increase in temperature.

The viscosities of pure AEEA are well represented by the Arrhenius equation:

$$\eta/\text{mPa·s} = A\text{e}^{E/RT} \qquad (8)$$

where A is a system-dependent constant, E is the activation energy for viscous flow, R is the gas constant, and T is the temperature. The activation energy value regressed from the data was found to be equal to 45.9 kJ·mol^{-1}. This value is higher than that of MEA (29.2 kJ·mol^{-1}) and could be due to stronger hydrogen bonding. The activation energy for flow for AEEA was closer to the activation energy of DEA (51.5 kJ·mol^{-1}) and TEA (50.2 kJ·mol^{-1}) than that of MDEA (38.0 kJ·mol^{-1}). The activation energies of flow for the mentioned alkanolamines were reported by Maham et al.[10] from different sources.

Experimental viscosity values of the binary mixtures were used to calculate the viscosity deviation, defined by

$$\Delta\eta/\text{mPa·s} = \eta - \eta_1 x_1 - \eta_2 x_2 \qquad (9)$$

where η is the viscosity of the binary mixture; η_1 and η_2 are those of pure AEEA and pure water, respectively; and x_1 and x_2 are the mole fractions of the pure components. The viscosity deviation represents deviations from a rectilinear dependence of viscosity on mole fractions. Figure 5 displays the dependence of $\Delta\eta$ on the mole fractions of AEEA and temperatures. The viscosity deviations ($\Delta\eta$) for AEEA (1) + water (2) were negative for $x_1 = 0.05$, 0.07, and 0.1 for the temperatures from (298.15 to 323.15) K, were negative for $x_1 = 0.05$ and 0.07 at 333.15 K, and were negative for $x_1 = 0.05$ at 343.15 K. The results are compared with those of aqueous MDEA,[17] aqueous MEA,[18] and aqueous DGA[14] solutions at 313.15 K in Figure 6. Viscosity deviations for MDEA and MEA are negative in the water-rich region ($< x_1 = 0.2$) at all temperatures and then become positive, while for DGA viscosity deviations are positive

Table 6. Redlich−Kister Equation Fitting Coefficients of the Viscosity Deviations, $\Delta\eta$ (eq 10), for AEEA (1) + Water (2) Mixtures from (298.15 to 343.15) K

T/K	a_0	a_1	a_2	a_3	a_4	a_5	σ/mPa·s
298.15	285.93	−10.84	−468.33	578.81	258.27	−457.35	0.72
303.15	195.49	−16.00	−302.49	409.51	161.94	−312.25	0.41
313.15	100.61	−11.47	−159.33	180.14	114.11	−91.40	0.28
323.15	55.61	−8.911	−78.15	90.795	53.04	−36.600	0.15
333.15	33.08	−6.29	−39.80	52.33	27.30	−16.61	0.105
343.15	20.41	−5.38	−18.68	33.63	4.40	−17.40	0.04

for the entire range of mole fractions. DEA viscosity deviations calculated from Teng et al.[17] were negative for all mole fractions at all temperatures except at 343.15 K and 353.15 K where they became positive in the DEA-rich region.

The calculated values of $\Delta\eta$ were correlated with a Redlich−Kister[17] relation:

$$\Delta\eta/\text{mPa·s} = x_1 x_2 \sum_{i=0}^{n} a_i (x_1 - x_2)^i \tag{10}$$

The coefficients and the standard deviations are presented in Table 6.

Experimentally measured refractive indices of the aqueous AEEA solutions at (298.15, 303.15, 313.15, 323.15, and 333.15) K are listed in Table 3. Measured refractive indices values indicate a sharp increase in its values after the addition of AEEA at all temperatures. The molar refraction changes (ΔR) at various temperatures were calculated from the following relations employing refractive indices and molar volumes:[19]

$$\Delta R/\text{cm}^3\text{·mol}^{-1} = R - \phi_1 R_1 - \phi_2 R_2 \tag{11}$$

$$R = \left(\frac{n_D^{\,2} - 1}{n_D^{\,2} + 1}\right)\left(\frac{x_1 M_1 + x_2 M_2}{\rho}\right) \tag{12}$$

$$R_i = \left(\frac{n_D^{\,2} - 1}{n_D^{\,2} + 1}\right)\left(\frac{M_i}{\rho_i}\right) \tag{13}$$

$$\phi_i = \frac{x_i V_i}{\sum_{i=1}^{2} x_i V_i} \tag{14}$$

where, R and R_i are the molar refractions of the mixture and the pure component liquids, respectively; x_1 and x_2 are the mole fractions of AEEA and water, respectively; ρ, ρ_1, and ρ_2 are the densities; and n_D and $n_D^{\,i}$ are the measured refractive indices of the mixture and the pure component liquids, respectively; M_1 and M_2 are the molecular weights of AEEA and water; V_i is the molar volume of the ith component liquid; and ϕ_1 and ϕ_2 are the volume fractions of AEEA and water, respectively. There is no general rule for the calculation of molar refraction changes. Therefore, for the sake of completeness, we calculated molar refraction changes (ΔR) as a function of volume fractions and as a function of mole fractions by using the Redlich−Kister expression:

$$\Delta R = \phi_1 \phi_2 \sum_{i=0}^{n} a_i (\phi_1 - \phi_2)^i \tag{15}$$

$$\Delta R = x_1 x_2 \sum_{i=0}^{n} a_i (x_1 - x_2)^i \tag{16}$$

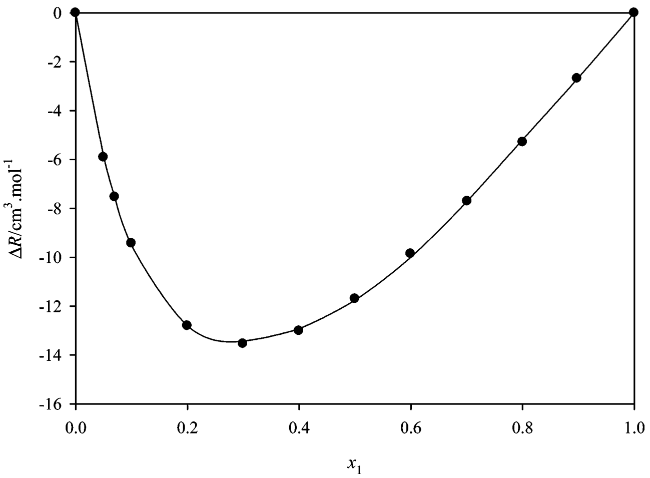

Figure 7. Molar refraction changes of AEEA (1) + water (2) system at ●, 298.15 K; −, eq 16.

Table 7. Redlich−Kister Equation Fitting Coefficients of the Molar Refraction Changes, ΔR (eq 15), in Terms of Volume Fractions for AEEA (1) + Water (2) Mixtures from (298.15 to 333.15) K

T/K	a_0	a_1	a_2	a_3	a_4	σ/cm^3·mol^{-1}
298.15	−46.82	−32.06	−14.79	−20.10	−35.29	0.05
303.15	−46.93	−32.18	−14.52	−19.91	−36.19	0.05
313.15	−47.03	−32.23	−14.93	−20.32	−35.74	0.05
323.15	−47.21	−32.46	−14.45	−19.89	−37.38	0.05
333.15	−47.30	−32.58	−14.56	−20.02	−37.45	0.05

Table 8. Redlich−Kister Equation Fitting Coefficients of the Molar Refraction Changes, ΔR (eq 16), in Terms of Mole Fractions for AEEA (1) + Water (2) Mixtures from (298.15 to 333.15) K

T/K	a_0	a_1	a_2	a_3	a_4	σ/cm^3·mol^{-1}
298.15	−47.04	29.35	−17.19	28.62	−23.45	0.10
303.15	−47.12	29.41	−17.21	28.75	−23.69	0.10
313.15	−47.24	29.51	−17.196	29.09	−24.04	0.10
323.15	−47.39	29.61	−17.23	29.31	−24.39	0.10
333.15	−47.49	29.72	−17.30	29.43	−24.48	0.10

The coefficients and the standard deviations are presented in Table 7 and Table 8 for the expression in terms of volume fractions and in terms of mole fractions, respectively. As shown in Figure 7, molar refraction changes are negative for the system studied over the entire range of mole fractions for all five temperatures. ΔR shows negligible temperature dependence; however, this dependence is not shown graphically to avoid overcrowding of graphs. Figure 7 shows that there is a minimum in ΔR, which occurs at $x_1 = 0.3$.

Conclusions

This paper reports experimental data for the densities and viscosities of the aqueous AEEA solutions over a range of temperatures from (298.15 to 343.15) K and refractive indices over a range of temperatures from (298.15 to 333.15) K. The calculated excess molar volume (V^E) values for the aqueous AEEA solutions were negative at all temperatures and mole fractions. The criterion proposed by Hepler[8] suggests that the addition of AEEA to water had no effect on its structure, a conclusion similar to that of Maham et al.[10,11] for MEA, DEA, and TEA. The viscosity deviations ($\Delta\eta$) for aqueous AEEA solutions were negative for $x_1 = 0.05$, 0.07, and 0.1 for the temperatures from 298.15 K to 323.15 K; for $x_1 = 0.05$ and 0.07 at 333.15 K; and for $x_1 = 0.05$ at 343.15 K. The calculated molar refraction changes for the aqueous AEEA solutions were all negative at all temperatures and mole fractions.

Aqueous AEEA, DGA,[14] and MDEA[15] solutions exhibited an S-shaped viscosity curves and a change in the sign of the viscosity deviations from negative to positive in the water-rich region. Aqueous DEA viscosities[16] did not have an S-shaped curve but still exhibited a change in the sign of the viscosity deviations from negative to positive in the DEA-rich region. The conclusion arrived at by using Hepler's criterion seems to be in contradiction with the suggestion by Fort and Moore that there is a possible formation of complexes in aqueous AEEA solutions around $x_1 = 0.6$.

Molar refraction changes are negative for the system studied over the entire range of mole fractions for all five temperatures, and a minimum in ΔR occurs at $x_1 = 0.3$. Molar refraction changes exhibited negligible temperature dependency.

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