Densities and Viscosities of Binary Mixture of the Ionic Liquid Bis(2-hydroxyethyl)ammonium Propionate with Methanol, Ethanol, and 1-Propanol at T = (293.15, 303.15, 313.15, and 32...

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Densities and Viscosities of Binary Mixture of the Ionic Liquid Bis(2-hydroxyethyl)ammonium Propionate with Methanol, Ethanol, and 1-Propanol at T = (293.15, 303.15, 313.15, and 323.15) K and at P = 0.1 MPa

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In this work, density and viscosity were determined over the whole concentration range for the binary mixtures ionic liquid bis(2-hydroxyethyl)ammonium propionate [BHEAP] with methanol, ethanol, and 1-propanol at (293.15, 303.15, 313.15, and 323.15) K and 0.1 MPa. Excess molar volume and viscosity deviations for the binary system were calculated and well fitted to a Redlich−Kister equation.

Introduction

Hydroxyl ammonium ionic liquids are relative new ionic liquids with the potential gas scrubbing. In previous studies, great attention has been paid to hydroxyl ammonium ionic liquids as solvent for SO_2 and CO_2 removal.[1−4] In some current studies, the problem of high viscosity of the ionic liquid can be resolved partially by means of adding organic solvents to pure ionic liquid.[5−8] The main advantages of a binary mixture formed by hydroxyl ammonium ionic liquids and a molecular solvent are lower viscosity of solution, which leads to lower energy requirements for absorption processes of CO_2.[5,7] In actual use, the physical properties of hydroxyl ammonium ionic liquids + molecular solvents mixtures are extremely important. Especially, the density and viscosity data are significant from a practical and theoretical viewpoint.

This work is a continuation of the systematic program on the physical properties of solution containing hydroxyl ammonium ionic liquid. In the present work, the density and viscosity of binary mixtures of ionic liquid bis(2-hydroxyethyl)-ammonium propionate [BHEAP] with methanol, ethanol, and 1-propanol were determined over the whole concentration at (293.15, 303.15, 313.15, and 323.15) K and 0.1 MPa. Meanwhile, the excess molar volume and viscosity deviation were calculated from experimental densities and viscosities data, respectively.

Experimental Section

Chemicals. Bis(2-hydroxylethyl)ammonium propionate [BHEAP] was synthesized in our laboratory according to the standard methods developed and reported in the literature.[3,9] The structure of [BHEAP] is shown in Figure 1. The synthesized [BHEAP] was characterized using two techniques: ^{1}H NMR and elemental analysis. ^{1}H NMR spectra were measured on a JEOL JNM-ECA400 spectrometer, using dimethyl sulfoxide (DMSO) as solvent with tetramethylsilane (TMS) as the internal standard. Elemental analyses were measured using CHNS-932 (LECO Instruments) elemental analyzer. [BHEAP]: ^{1}H NMR (400 MHz, DMSO) δ 5.86 ppm (broad, 4H, −NH and −OH), 3.55 (t, 4H, $-CH_2-N$), 2.78 (t, 4H, $-CH_2-N$), 2.04 (m, 2H, $-CH_2-COO^-$), 0.98 (t, 3H, H_3C-C). Analysis % found (% calculated): C, 46.9 (46.9); H, 9.5 (9.6); N, 7.8 (7.8). The water content was determined using a coulometer Karl Fischer titrator, DL 39 (Mettler Toledo) using the Hydranal coulomat AG reagent (Riedel-de Haen). It was found that the water content of [BHEAP] was 115 ppm. A Methanol (high-performance liquid chromatography (HPLC) grade, w = 0.999), ethanol (analytical grade, w = 0.997), and 1-propanol (HPLC grade, w = 0.995) were purchased from Merck (Merck Sdn. Bhd., Malaysia). All alcohol above was dried with molecular sieves type 4 Å, (supplied by Aldrich). The purities of these alcohols were determined by its water content and were found to be less than $4 \cdot 10^{-5}$ mass fraction. All chemicals were kept in bottles with PTFE septum under vacuum until further use.

Apparatus and Procedure. Binary mixtures were prepared in glass vials with PTFE septum. Samples were taken from the vial with a syringe through a PTFE septum. The samples were prepared in an inert atmosphere glovebox, using an analytical balance (Mettler Toledo, model AS120S, ± 0.01 mg). The uncertainty of the composition on a mole fraction basis was 0.0001. The viscosity and density of the binary mixtures were measured simultaneously at temperatures from (293.15 to 323.15) K using a rotational automated Anton Paar Stabinger Viscometer SVM3000. The reproducibility of the viscosity and density measurements are 0.35 % and ± 0.5 kg·m^{-3}, respectively. The accuracy of the temperature measurement is ± 0.02 K. All of the measurements were done in triplicate and the average value is considered for further study. The viscometer was calibrated using standard calibration fluid provided by the supplier followed and Millipore quality water. The calibrated viscometer was verified by measuring the viscosity of selected imidazolium ionic liquid with known viscosity.[10−12] The experimental densities and viscosities of pure chemicals are compared with the available literature values[13−16] are given in Table 1.

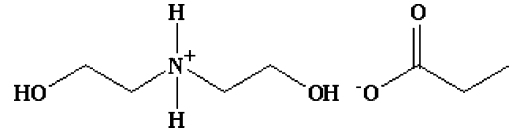

Figure 1. Structure of bis(2-hydroxyethyl)ammonium propionate [BHEAP].

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Table 1. Comparison of Density (ρ) and Viscosity (η) with Literature for Pure Components at $T = 298.15$ K

		$10^{-3}\cdot\rho$		η	
	M	kg·m^{-3}		mPa·s	
chemical	g·mol^{-1}	this work	lit.	this work	lit.
[BHEAP]	179.21	1.13940	N/A	480.18	N/A
methanol	32.04	0.7865	0.78664[13]	0.5768	0.577[13]
			0.78664[11]		0.543[11]
ethanol	46.07	0.7855	0.78517[13]	1.0961	1.09[13]
			0.78522[11]		1.085[11]
			0.7855[14]		1.082[14]
			0.7890[15]		1.0569[15]
1-propanol	60.10	0.7994	0.79952[13]	1.9468	1.94[13]
			0.79940[11]		1.951[11]
			0.7996[14]		2.017[14]
			0.8036[15]		2.1178[15]

Table 2. Experimental Densities (ρ) of the Binary Mixtures [BHEAP] (1) + Alcohols (2)

	$10^{-3}\cdot\rho$			
	kg·m^{-3}			
x_1	293.15 K	303.15 K	313.15 K	323.15 K
	[BHEAP](1) + Methanol(2)			
0.0000	0.7912	0.7818	0.7723	0.7651
0.0437	0.8512	0.8423	0.8333	0.8268
0.1045	0.9134	0.9052	0.8969	0.8911
0.2138	0.9878	0.9803	0.9726	0.9678
0.2957	1.0246	1.0174	1.0100	1.0055
0.4000	1.0581	1.0512	1.0440	1.0397
0.5038	1.0824	1.0756	1.0686	1.0646
0.6125	1.1018	1.0952	1.0883	1.0845
0.6981	1.1140	1.1076	1.1009	1.0971
0.8026	1.1264	1.1200	1.1133	1.1097
0.9121	1.1365	1.1301	1.1234	1.1197
0.9587	1.1400	1.1335	1.1268	1.1230
1.0000	1.1427	1.1361	1.1292	1.1252
	[BHEAP](1) + Ethanol(2)			
0.0000	0.7893	0.7807	0.7725	0.7636
0.0536	0.8427	0.8344	0.8266	0.8185
0.1087	0.8872	0.8792	0.8717	0.8642
0.2052	0.9470	0.9394	0.9322	0.9255
0.3168	0.9975	0.9901	0.9830	0.9771
0.4238	1.0345	1.0273	1.0202	1.0148
0.5084	1.0583	1.0512	1.0442	1.0391
0.5946	1.0788	1.0718	1.0649	1.0600
0.6965	1.0991	1.0923	1.0854	1.0808
0.8040	1.1168	1.1100	1.1031	1.0988
0.8895	1.1288	1.1220	1.1151	1.1110
0.9458	1.1360	1.1293	1.1224	1.1183
1.0000	1.1427	1.1361	1.1292	1.1252
	[BHEAP](1) + 1-Propanol(2)			
0.0000	0.8032	0.7955	0.7876	0.7787
0.0585	0.8465	0.8390	0.8313	0.8231
0.1031	0.8753	0.8679	0.8604	0.8526
0.2292	0.9422	0.9350	0.9277	0.9209
0.3021	0.9736	0.9665	0.9593	0.9529
0.4017	1.0103	1.0033	0.9962	0.9903
0.5009	1.0412	1.0343	1.0273	1.0219
0.6360	1.0762	1.0694	1.0625	1.0576
0.7135	1.0931	1.0864	1.0795	1.0748
0.8018	1.1102	1.1035	1.0965	1.0921
0.8979	1.1266	1.1199	1.1130	1.1088
0.9568	1.1360	1.1293	1.1224	1.1184
1.0000	1.1427	1.1361	1.1292	1.1252

Table 3. Experimental Viscosities (η) of the Binary Mixtures [BHEAP] (1) + Alcohols (2)

	η			
	mPa·s			
x_1	293.15 K	303.15 K	313.15 K	323.15 K
	[BHEAP](1) + Methanol(2)			
0.0000	0.6075	0.5535	0.5010	0.4601
0.0437	23.191	13.008	4.2418	2.6389
0.1045	52.440	20.180	8.9027	5.5091
0.2138	109.39	42.758	19.003	11.762
0.2957	153.61	62.122	27.333	16.990
0.4000	210.82	86.115	38.581	24.155
0.5038	269.65	109.07	50.820	32.041
0.6125	337.06	135.36	65.917	41.764
0.6981	399.51	162.04	80.808	51.212
0.8026	496.91	208.61	104.49	65.817
0.9121	636.96	276.64	135.75	84.159
0.9587	692.41	301.08	147.67	91.460
1.0000	740.28	322.17	157.97	96.542
	[BHEAP](1) + Ethanol(2)			
0.0000	1.1802	1.0191	0.8424	0.7081
0.0536	28.358	14.198	5.2706	3.3091
0.1087	55.190	21.361	9.6024	5.9737
0.2052	105.81	41.433	18.597	11.535
0.3168	167.85	68.598	30.487	18.985
0.4238	231.31	95.161	43.458	27.199
0.5084	284.44	116.45	54.872	34.452
0.5946	343.18	140.21	68.080	42.814
0.6965	428.04	177.51	88.082	55.217
0.8040	531.61	226.45	112.51	70.069
0.8895	626.32	271.72	133.71	82.607
0.9458	686.37	298.35	146.49	90.376
1.0000	740.28	322.17	157.97	96.542
	[BHEAP](1) + 1-Propanol(2)			
0.0000	2.1412	1.7880	1.3907	1.0977
0.0585	31.598	15.366	6.1456	3.8968
0.1031	53.286	21.148	9.6328	6.0394
0.2292	120.07	47.979	21.603	13.442
0.3021	161.50	66.192	29.623	18.459
0.4017	221.90	91.873	41.983	26.244
0.5009	288.32	119.16	56.396	35.314
0.6360	393.08	163.50	80.351	50.214
0.7135	461.84	194.52	96.415	60.050
0.8018	547.50	234.75	116.23	72.003
0.8979	646.69	281.11	138.08	84.926
0.9568	701.08	304.98	149.64	92.030
1.0000	740.28	322.17	157.97	96.542

Results and Discussions

The experimental data of density and viscosity for the binary systems [BHEAP](1) + methanol(2), ethanol(2), or 1-propanol(2) at different $T = (293.15, 303.15, 313.15,$ and $323.15)$ K and 0.1 MPa are reported in Tables 2 and 3, respectively. The densities and viscosities are highest for the ionic liquid than for alcohol and its values decreases with increasing mole fraction of alcohol. As also observed, both density and viscosity are decrease with increasing temperature. We found no previous data as a function of temperature for these systems as comparison.

The excess molar volume, V_m^E, and viscosity deviation, $\Delta\eta$, were calculated by the following equations:

$$V_m^E = \sum_{i=1}^{N} x_i M_i (\rho^{-1} - \rho_i^{-1}) \quad (1)$$

$$\Delta\eta = \eta - \sum_{i=1}^{N} x_i \eta_i \quad (2)$$

where ρ and ρ_i are densities of the mixture and the density of pure components, respectively; M_i is the molar mass of the pure components; x_i represents the mole fraction of the component i; and η and η_i are the dynamic viscosity of the mixture and pure components, respectively. The value of excess molar volume and viscosity deviation for [BHEAP](1) + methanol(2),

Table 4. Excess Molar Volume (V_m^E) of the Binary Mixtures [BHEAP](1) + Alcohols(2)

	$10^6 \cdot V_m^E$ / $m^3 \cdot mol^{-1}$			
x_1	293.15 K	303.15 K	313.15 K	323.15 K
[BHEAP](1) + Methanol(2)				
0.0000	0.0000	0.0000	0.0000	0.0000
0.0437	−0.3859	−0.4154	−0.4480	−0.4811
0.1045	−0.7434	−0.8025	−0.8671	−0.9333
0.2138	−1.0818	−1.1669	−1.2593	−1.3542
0.2957	−1.1559	−1.2462	−1.3439	−1.4444
0.4000	−1.1181	−1.2068	−1.3025	−1.4011
0.5038	−1.0039	−1.0889	−1.1800	−1.2745
0.6125	−0.8539	−0.9360	−1.0233	−1.1148
0.6981	−0.7270	−0.8066	−0.8910	−0.9801
0.8026	−0.5509	−0.6231	−0.6991	−0.7801
0.9121	−0.2984	−0.3477	−0.3989	−0.4538
0.9587	−0.1511	−0.1822	−0.2141	−0.2483
1.0000	0.0000	0.0000	0.0000	0.0000
[BHEAP](1) + Ethanol(2)				
0.0000	0.0000	0.0000	0.0000	0.0000
0.0536	−0.5084	−0.5410	−0.5822	−0.6320
0.1087	−0.8298	−0.8836	−0.9509	−1.0319
0.2052	−1.0736	−1.1439	−1.2311	−1.3351
0.3168	−1.0927	−1.1644	−1.2526	−1.3573
0.4238	−1.0146	−1.0805	−1.1613	−1.2571
0.5084	−0.9308	−0.9902	−1.0634	−1.1501
0.5946	−0.8270	−0.8790	−0.9430	−1.0191
0.6965	−0.6639	−0.7051	−0.7557	−0.8158
0.8040	−0.4308	−0.4577	−0.4902	−0.5283
0.8895	−0.2175	−0.2316	−0.2480	−0.2668
0.9458	−0.0885	−0.0947	−0.1016	−0.1090
1.0000	0.0000	0.0000	0.0000	0.0000
[BHEAP](1) + 1-Propanol(2)				
0.0000	0.0000	0.0000	0.0000	0.0000
0.0585	−0.3870	−0.4130	−0.4485	−0.4936
0.1031	−0.5835	−0.6224	−0.6755	−0.7428
0.2292	−0.8554	−0.9112	−0.9867	−1.0820
0.3021	−0.9055	−0.9642	−1.0428	−1.1413
0.4017	−0.9145	−0.9736	−1.0513	−1.1477
0.5009	−0.8772	−0.9341	−1.0075	−1.0975
0.6360	−0.7427	−0.7911	−0.8524	−0.9267
0.7135	−0.6114	−0.6510	−0.7011	−0.7617
0.8018	−0.4167	−0.4431	−0.4768	−0.5176
0.8979	−0.1834	−0.1944	−0.2087	−0.2263
0.9568	−0.0638	−0.0674	−0.0722	−0.0783
1.0000	0.0000	0.0000	0.0000	0.0000

Table 5. Viscosity Deviation ($\Delta\eta$) of the Binary Mixtures [BHEAP](1) + Alcohols(2)

	$\Delta\eta$ / mPa·s			
x_1	293.15 K	303.15 K	313.15 K	323.15 K
[BHEAP](1) + Methanol(2)				
0.0000	0	0	0	0
0.0437	−9.7146	−1.5894	−3.1350	−2.0167
0.1045	−25.4370	−13.9700	−8.0475	−4.9880
0.2138	−49.3680	−26.5613	−15.1660	−9.2418
0.2957	−65.7075	−33.5267	−19.7273	−11.8799
0.4000	−85.6377	−43.0742	−24.9001	−14.7347
0.5038	−103.6178	−53.5134	−29.0135	−16.8260
0.6125	−116.6227	−62.1967	−31.0359	−17.5500
0.6981	−117.4682	−63.0380	−29.6200	−16.3241
0.8026	−97.3824	−50.0769	−22.3988	−11.7614
0.9121	−38.3358	−17.2750	−8.3832	−3.9409
0.9587	−17.3500	−7.8183	−3.7941	−1.1172
1.0000	0	0	0	0
[BHEAP](1) + Ethanol(2)				
0.0000	0	0	0	0
0.0536	−12.4094	−4.0225	−3.9876	−2.5320
0.1087	−26.3183	−14.5615	−8.3167	−5.1500
0.2052	−47.0707	−25.4998	−14.4940	−8.8426
0.3168	−67.4462	−34.1473	−20.1248	−12.0791
0.4238	−83.1385	−41.9771	−23.9803	−14.1283
0.5084	−92.4997	−47.8442	−25.8521	−14.9781
0.5946	−97.4568	−51.7609	−26.1835	−14.8743
0.6965	−87.9420	−47.1999	−22.2003	−12.2417
0.8040	−63.7953	−32.7701	−14.6532	−7.6877
0.8895	−32.2760	−14.9534	−6.8890	−3.3435
0.9458	−13.8469	−6.4153	−2.9555	−0.9719
1.0000	0	0	0	0
[BHEAP](1) + 1-Propanol(2)				
0.0000	0	0	0	0
0.0585	−13.7486	−5.1745	−4.4098	−2.7875
0.1031	−24.9754	−13.6791	−7.9043	−4.9009
0.2292	−51.2214	−27.2283	−15.6692	−9.5284
0.3021	−63.6283	−32.3799	−19.0675	−11.4711
0.4017	−76.7576	−38.6157	−22.3053	−13.1951
0.5009	−83.5572	−43.1117	−23.4239	−13.5926
0.6360	−78.5508	−42.0678	−20.6278	−11.5905
0.7135	−66.9873	−35.8740	−16.6971	−9.1508
0.8018	−46.5072	−23.9306	−10.7059	−5.6244
0.8979	−18.2689	−8.3627	−3.9094	−1.8760
0.9568	−7.3075	−3.3451	−1.5638	−0.3886
1.0000	0	0	0	0

ethanol(2), or 1-propanol(2) are given in Tables 4 and 5, respectively.

As Tables 4 and 5 show, the excess molar volume and viscosity deviations are negative in the whole range of concentration. This behavior can be attributed to the packing effect and ion−dipole interaction of alcohol molecules with the protic ionic liquid. The molar volume of [BHEAP] is greater than the molar volume of the alcohol, and the difference between these molar volumes implies that the alcohol molecules fit in the available volume of the protic ionic liquid upon mixing. Also, the negative value of the excess molar volume shows that the ion-dipole interactions between the protic ionic liquid and alcohol are dominating.

The binary deviations at several temperatures were fitted to a Redlich−Kister[17] type equation

$$\Delta Q_{ij} = x_i x_j \sum_{p=0}^{N} A_p (x_i - x_j)^p \qquad (3)$$

where ΔQ_{ij} is the excess properties, x_i is the mole fraction of the components i and j, respectively, A_p is the polynomial coefficient and N is the degree of the polynomial expansion that was optimized using F-Test. These coefficients are summarized in Table 6, along with the corresponding standard deviations calculated using eq 2.

The values of V_m^E, as well as the Redlich−Kister fits are plotted in Figures 2 to 4 for the concentration dependence of the excess molar deviation. The graphs of V_m^E indicate that all mixture of [BHEAP](1) + alcohol(2) exhibit negative deviations from ideality over the entire composition range. The negative excess molar volumes indicate a more efficient packing and/or attractive interaction occurred when the ionic liquid and alcohol are mixed. The high negative deviations from ideality, observed for these systems have to be a result of strong intermolecular interactions of the ionic liquid with alcohols.[13,18] Graphs depict also the unsymmetrical behavior of these excess molar volumes with composition for these systems. The highest excess molar volumes for these mixture is reached when moles fraction of the ionic liquid in the region of 0.2 to 0.4. It seems that the highest packing between the ionic liquid and alcohol is reached when moles fraction of the ionic liquid in the region of 0.2 to 0.4. The values of V_m^E become more negative from 1-propanol to methanol. The excess molar volume in these mixtures

Table 6. Fitting Parameters, A_p, of the Redlich−Kister eq 3 with Standard Deviation (σ) eq 2 for Binary Mixtures at T = (293.15, 303.15, 313.15, and 323.15) K

	T/K	A_0	A_1	A_2	A_3	A_4	σ
			[BHEAP](1) + Methanol(2)				
$10^6 \cdot V_m^E$/m^3·mol^{-1}	293.15	−4.0386	2.4999	−2.6690	0.3843	−0.3080	0.0036
	303.15	−4.3805	2.5835	−3.0325	0.2849	−0.4221	0.0031
	313.15	−4.7469	2.6808	−3.4239	0.1999	−0.5351	0.0029
	323.15	−5.1268	2.7686	−3.8435	0.1015	−0.6454	0.0028
$\Delta\eta$/mPa·s	293.15	−409.6	−353.8	−264.1	293.5	445.2	1.57
	303.15	−210.6	−201.5	−196.4	196.8	359.5	1.19
	313.15	−115.4	−69.3	−29.1	77.2	83.1	0.24
	323.15	−66.9	−33.8	−12.5	51.6	53.7	0.09
			[BHEAP](1) + Ethanol(2)				
$10^6 \cdot V_m^E$/m^3·mol^{-1}	293.15	−3.7591	2.1231	−2.6457	3.1754	−0.0080	0.0019
	303.15	−3.9998	2.2838	−2.8208	3.3419	−0.0109	0.0022
	313.15	−4.2956	2.4767	−3.0386	3.5783	−0.0156	0.0029
	323.15	−4.6464	2.7020	−3.2992	3.8848	−0.0223	0.0021
$\Delta\eta$/mPa·s	293.15	−368.3	−176.4	0.1	220.3	178.3	1.56
	303.15	−189.4	−105.8	−45.1	151.2	184.7	1.01
	313.15	−103.4	−25.4	25.5	55.5	25.4	0.23
	323.15	−59.9	−9.1	16.3	35.2	18.6	0.09
			[BHEAP](1) + 1-Propanol(2)				
$10^6 \cdot V_m^E$/m^3·mol^{-1}	293.15	−3.5124	1.2185	−0.9652	2.3517	−0.1156	0.0009
	303.15	−3.7403	1.2927	−1.0247	2.5326	−0.1297	0.0010
	313.15	−4.0342	1.4134	−1.1315	2.7564	−0.1420	0.0011
	323.15	−4.3948	1.5810	−1.2810	3.0234	−0.1588	0.0012
$\Delta\eta$/mPa·s	293.15	−334.2	−58.8	101.7	145.2	74.3	1.45
	303.15	−171.6	−42.4	17.6	102.2	107.7	1.05
	313.15	−93.8	4.5	43.9	31.3	2.6	0.27
	323.15	−54.3	7.7	25.4	19.4	4.4	0.05

decreases as the chain length of alcohol decreases. This implies that the ion-dipole interactions and packing effects are stronger in methanol systems than in the other alcohol systems. The same behavior is also reported for the binaries mixture of the other ionic liquid with alcohol.[14,16,19]

In Figures 5 to 7, the viscosity deviations are negative over the whole composition range. The viscosity deviations are negative over the whole composition range. The viscosity deviations are less negative as the temperature increases, and this behavior is similar in all systems. The viscosity deviation is particularly strong in solutions with a few quantities of alcohol due to the high difference viscosity of pure compounds. The viscosity deviation at 293.15 K is greater than at 303.15 K, 313.15 K, or 323.15 K due to the viscosity of the pure ionic liquid decrease quickly when the temperature increase.[13]

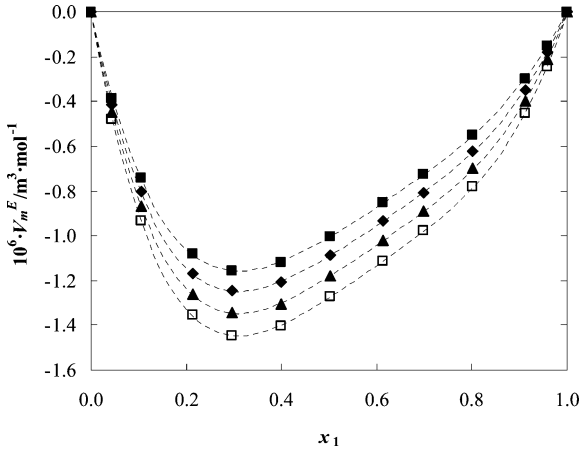

Figure 2. Excess molar volumes, V_m^E, for the system [BHEAP](1) + methanol(2) as function of mole fraction, x_1, at several temperatures. Symbols: ■, T = 293.15 K; ♦, T = 303.15 K; ▲, T = 313.15 K; □, T = 323.15 K. The dash lines were calculated using Redlich−Kister eq 3.

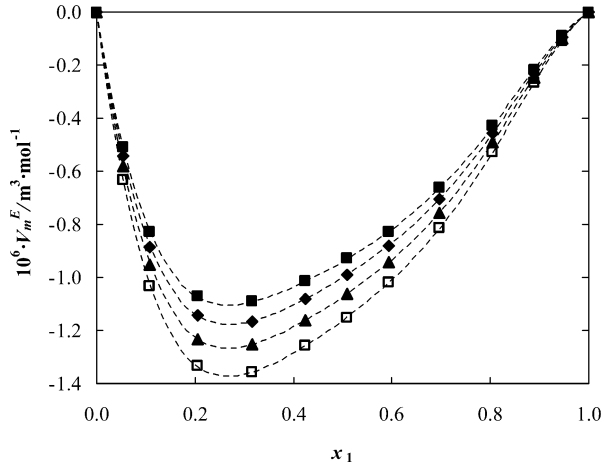

Figure 3. Excess molar volumes, V_m^E, for the system [BHEAP](1) + ethanol(2) as function of mole fraction, x_1, at several temperatures. Symbols: ■, T = 293.15 K; ♦, T = 303.15 K; ▲, T = 313.15 K; □, T = 323.15 K. The dash lines were calculated using Redlich−Kister eq 3.

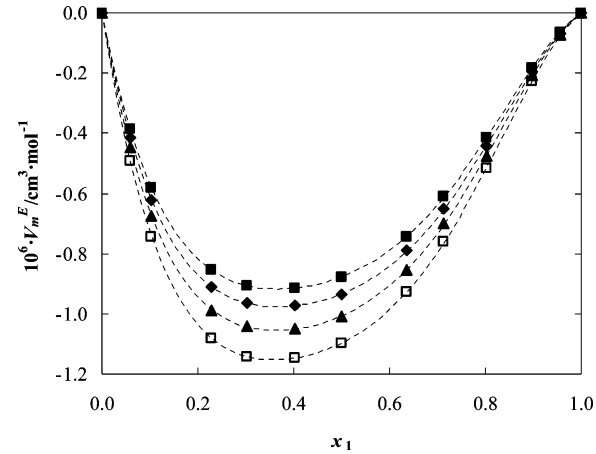

Figure 4. Excess molar volumes, V_m^E, for the system [BHEAP](1) + 1-propanol(2) as function of mole fraction, x_1, at several temperatures. Symbols: ■, T = 293.15 K; ♦, T = 303.15 K; ▲, T = 313.15 K; □, T = 323.15 K. The dash lines were calculated using Redlich−Kister eq 3.

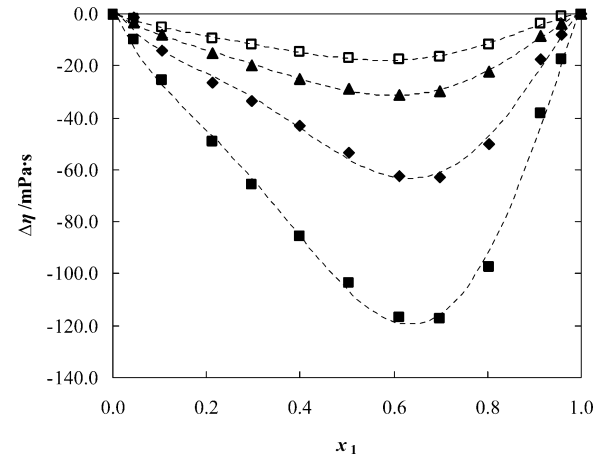

Figure 5. Viscosity deviation, $\Delta\eta$, for the system [BHEAP](1) + methanol(2) as function of mole fraction, x_1, at several temperatures. Symbols: ■, T = 293.15 K; ♦, T = 303.15 K; ▲, T = 313.15 K; □, T = 323.15 K. The dash lines were calculated using Redlich−Kister eq 3.

Conclusions

This paper reports experimental data for the densities and viscosities of the binary system of bis(2-hydroxyethyl)ammo-

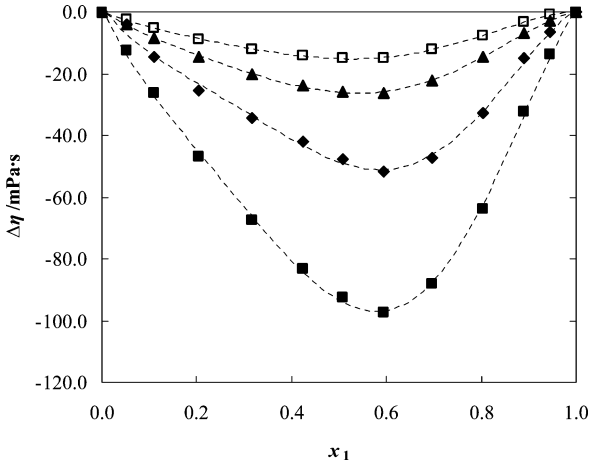

Figure 6. Viscosity deviation, $\Delta\eta$, for the system [BHEAP](1) + ethanol(2) as function of mole fraction, x_1, at several temperatures. Symbols: ■, T = 293.15 K; ♦, T = 303.15 K; ▲, T = 313.15 K; □, T = 323.15 K. The dash lines were calculated using Redlich−Kister eq 3.

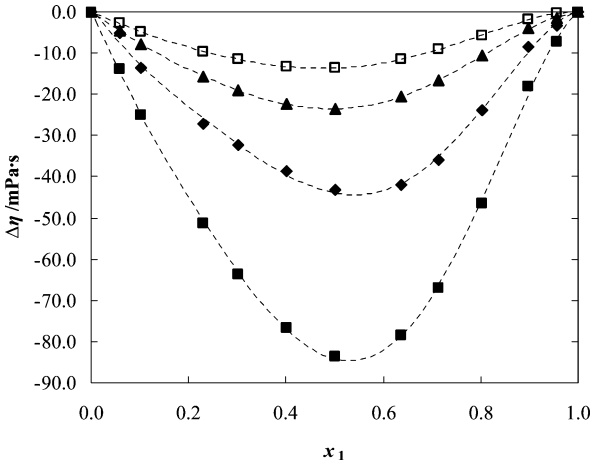

Figure 7. Viscosity deviation, $\Delta\eta$, for the system [BHEAP](1) + 1-propanol(2) as function of mole fraction, x_1, at several temperatures. Symbols: ■, T = 293.15 K; ♦, T = 303.15 K; ▲, T = 313.15 K; □, T = 323.15 K. The dash lines were calculated using Redlich−Kister eq 3.

nium propionate [BHEAP] with methanol, ethanol, and 1-propanol at (293.15, 303.15, 313.15, and 323.15) K. The densities and viscosities values increase with increasing mole fraction of ionic liquid and are decrease with increasing temperature. Excess molar volumes, V_m^E, and viscosity deviation, $\Delta\eta$, values of these binary mixtures were calculated from experimental density and viscosity data. The negative V_m^E values for these mixtures indicate that ion-dipole interactions and packing between ionic liquid and alcohols are present. The $\Delta\eta$ values are also negative over the whole composition range, and their values are less negative as the temperature increase. The viscosity deviation is particularly strong in dilute solutions of alcohol in the ionic liquid.

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