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Densities and Viscosities of Binary Mixtures Containing the Polyhydric Protic Ionic Liquid(2-hydroxy-*N*-(2-hydroxyeth yl)-*N*-methylethanaminium methanesulfonate) and Water or Alcohols

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Abstract

2-hydroxy-*N*-(2-hydroxyethyl)-*N*-methylethanaminium methanesulfonate ([BHEM][mesy]) displayed good ability for separating cellulose from biomass material in previous works. In order to have a better understanding of the structure–property relationship and facilitate further potential applications in industry, it is necessary to obtain more data for the physicochemical properties of [BHEM][mesy] and its mixtures. In this work, the densities (ρ) and viscosities (η) of [BHEM][mesy] + solvents (water, methanol, ethanol, *n*-propanol and isopropanol) mixtures were measured at six temperatures from (298.15 to 323.15) K over the full molar composition range and fitted by an empirical quadratic equation and Vogel–Fucher–Tammann (VFT) equation. Moreover, the excess molar volumes (V^E) and viscosity deviation ($\Delta\eta$) of five binary mixtures were calculated and correlated by the Redlich–Kister equation. In addition, the apparent molar volumes (V_φ) and partial molar volumes (V) of [BHEM][mesy] and solvents were also calculated and all these physicochemical property data (density, viscosity, excess molar properties as well as the apparent molar properties) are discussed in terms of the structure and interaction of binary mixtures.

Keywords Polyhydric protic ionic liquid · Water · Alcohols · Density · Viscosity

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1 Introduction

In order to make use of cellulose from various biomass sources more effectively, a number of techniques with different solvent systems have been used in the past few decades, including dilute acid treatment [1], alkaline treatment [2], the sulfite pulping process [3], organosolv isolation [4], etc. All these systems can promote cellulose separation from biomass materials to some extent, but they also generate severe consequences to the environment. Therefore, finding media that can extract cellulose effectively, in environmentally friendly manner, is extremely important for the utilization of biomass. In the last decades, ionic liquids (ILs) have attracted a lot of attention from both academia and industry as they are regarded as a kind of promising green solvent for the separation of cellulose owing to their unique characteristics, like high thermal stability, designability, recyclable as well as non-volatile properties [5–10].

Protic ILs, containing hydroxy groups, are drawing more and more attention because the formation of strong hydrogen bonds between the ILs and lignocelluloses facilitates the disruption of inter-/intra-molecular hydrogen bonds among biomass [11]. In addition, protic ILs are prepared by a one-step protonation reaction without any by-products, thus reducing the cost for multi-ton IL production [12]. Based on previous work [13], it was found that the polyhydric protic IL 2-hydroxy-N-(2-hydroxyethyl)-N-methylethanaminium methanesulfonate ([BHEM][mesy]) had good efficiency in the pretreatment of corn straw. The content of cellulose was up to 90 wt% in the cellulose material obtained at 413 K for 6 h in [BHEM][mesy]. Therefore, [BHEM][mesy] displayed a promising future in the biomass pretreatment industry.

In order to promote academic research and industrial applications of ILs, knowledge of binary systems containing ILs and solvents is of great significance. On the one hand, the relevant properties of IL mixtures can reveal useful information about the interaction forces between molecules and assist researchers in establishing theoretical models to predict the behaviors of pure components and their mixtures. On the other hand, as the properties directly affect the processes of mixing, stirring and pumping, they are important to the design of processing units and heat and mass transfer processes in industrial applications [14]. In recent years, a large amount of work has focused on the physical and chemical properties of hydroxyl-type protic ILs and their mixtures including density [15–21], viscosity [16–22], refraction index [15, 17, 21], vapor–liquid equilibria [15, 23], ionic conductivity [20, 22], acid–base properties [20], as well as acoustical properties [21, 24]. The anions mainly center on formate [16, 18, 19, 22], propionate [23], butyrate [24], hexanoate [15], various carboxylic acid anions [21], trifluoromethanesulfonate [20], bis(trifluoromethanesulfonyl)amide [20] and so on. However, what deserves our attention is that there is almost no relevant literatures in the field of physicochemical properties about the hydroxyl-type of protic ILs containing methanesulfonate, which can be applied to the field of pretreatment of biomass. Therefore, it is necessary to explore the physicochemical properties of binary system consisting of [BHEM][mesy] for potential applications in industry.

In this work, the density and viscosity of [BHEM][mesy] mixtures with water, methanol, ethanol, *n*-propanol, and isopropanol are first reported at temperatures from (298.15 to 323.15) K over the full molar composition and were fitted with an empirical quadratic equation and Vogel–Fucher–Tammann (VFT) equation, respectively. More than that, the excess molar volumes ($V^{\mathbf{E}}$) and viscosity deviation ($\Delta\eta$) of five binary mixtures were calculated and fitted with the Redlich–Kister equation. In addition, apparent molar volumes (V_{φ})

and partial molar volumes ($\bar{V}$) of the IL and solvents were also calculated. These physicochemical property data could provide useful information for the applications of [BHEM][mesy] in the biomass pretreatment industry.

2 Experimental Section

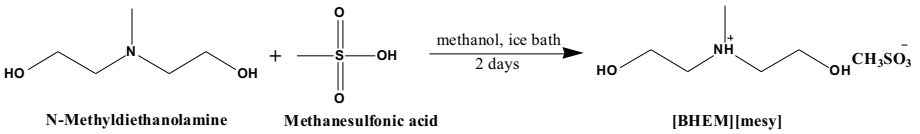
2.1 Chemicals Used

N-methyldiethanolamine (> 99%) and methanesulfonic acid (> 99%), ethanol (> 99.9%) and propanol (> 99.9%) were purchased from Aladdin Industrial Corporation. Methanol (> 99.9%) and isopropanol (> 99.9%) were purchased from Fisher chemical. The water of the experiments was deionized by a reverse osmosis unit with an ion-exchange system (Milli-Q, French). [BHEM][mesy] was synthesized and purified based on the previous work, the synthetic procedure and structures of the [BHEM][mesy] are displayed in Scheme 1 [13].

2.2 Measurement of Density and Viscosity

[BHEM][mesy] was dried in a vacuum drying oven (DZG-6021, Shanghai Sumsung Laboratory Instrument Co., Ltd., China) under the condition of using the water absorbent P_2O_5 at temperature 323 K for 120 h. The P_2O_5 was replaced every 10 h in order to keep its best water absorption capability. All solvents were degassed in an ultrasonic bath (KQ-400KDE, Kunshan Ultrasonic Instruments Co., Ltd., China) at 100 W and the temperature about 320 K for 2 h. Binary mixtures were prepared by weight, using an electronic analytical balance (Mettler Toledo, Switzerland, ± 0.0001 g) in a drying shed. The uncertainty of mole fraction was estimated as being ± 0.0001.

The density and viscosity of pure [BHEM][mesy], solvents (water, methanol, ethanol, n-propanol and isopropanol) and binary mixtures ([BHEM][mesy] + water/alcohols) were measured by an Anton Paar DMA™ 4500 M density meter and an Anton Paar micro viscometer Lovis 2000 ME at temperatures from (298.15 to 323.15) K, respectively. The density meter's uncertainty is ± 0.00005 g·cm^{-3} and the uncertainty of temperature in the density chamber is ± 0.02 K. The uncertainty of the viscosities measurements is 5×10^{-3} mPa·s and the temperature of glass capillaries can be precise to ± 0.02 K. There were three kinds of glass capillaries used with diameters 1.59 mm, 1.8 mm and 2.5 mm. The viscosity ranges for the capillary diameters of 1.59 mm, 1.8 mm, 2.5 mm are (0.3–15, 10–100 and 100–10,000) mPa·s, respectively. The viscosity over the full molar fraction at setting temperature was determined to confirm which capillary should be chosen. In the course of normal measurments, the glass capillary with diameter of 1.59 mm was selected to measure the samples with viscosity of 0.3–12.5 mPa·s, of 1.8 mm for 12.5–100 mPa·s and of



Scheme 1 Synthetic procedure and structures of the [BHEM][mesy] studied in this work

2.5 mm for 100–10,000 mPa·s. The capillaries were calibrated by the Anton Paar company before use.

About 5 mL samples of binary mixtures were added in 10 mL sample bottles, and then heated to temperature of 320 K in the ultrasonic instrument for 2 h to mix samples well. The density and viscosity tubes were repeatedly cleaned and dried, and then about 4 mL of samples were drawn into a 5 mL disposable syringe and slowly injected into the density and viscosity tubes, ensuring that no bubbles were generated. The temperature program run (from (298.15 to 323.15) K with one data point every 5 K) was used for measurements. When the temperature program ended and the temperature returned to 298.15 K, the injection syringe was slowly pushed to refresh the mixtures in the density chamber and viscosity glass capillary the temperature program was run again to make the second measurements, followed by a third measurement with the same procedures. The final data were obtained by calculation of the average of these three replicate measurements.

The measured densities and viscosities values of five pure solvents at different temperatures are compared with data provided in the literature in Table 1. In order to evaluate the accuracy and precision of collected data comparing with literature data, the relative deviations of density and viscosity were calculated and are displayed in the same table. The results indicate that all deviations of density data are less than 0.1% and of viscosity did not exceed 5% for most of data; thus the measuring systems used here are credible.

3 Results and Discussion

3.1 Characterizations of [BHEM][mesy]

The structure and purity of the [BHEM][mesy] were identified by ^{1}H NMR (av-600 MHz, DMSO-d_6, Bruker, Switzerland), FT-IR (10,000–370 cm^{-1}, Nicolet 380, America) and Karl Fisher titration (C20 Coulometric KF Titrator, Mettler Toledo, Switzerland). All peaks and chemical shifts could be assigned to [BHEM][mesy] (Figs. S1, S2). No impurity peaks were found in the ^{1}H NMR and FT-IR spectra, which indicated that the only impurity was water. The water content was measured by Karl Fisher titration and the result displayed that the water content was less than 1000 ppm. According to these analyses, the purity of [BHEM][mesy] was above 99%.

3.2 Densities

The density data of five pure components and binary mixtures are collected in Table 2. The following function is used to correlate the density of mixtures and temperatures at constant mole fraction [37, 38]:

$$\rho = A + BT + CT^2 \tag{1}$$

where ρ is the density of the binary mixtures at a given molar fraction. T is the absolute temperature in Kelvin from (298.15 to 323.15) K. A (g·cm^{-3}), B (g·cm^{-3}·K^{-1}) and C (g·cm^{-3}·K^{-2}) are the fitting coefficients.

The data of fitting coefficients are collected in Table 3 and the fitting curves are displayed in Fig. S3. The coefficients of determination (R^2) of all five binary mixtures all approach 1, which indicates that Eq. 1 represents the experimental data very well. It is

Table 1 Comparison of measured densities (ρ) and viscosities (η) of pure compounds with literature values at temperatures from (298.15 to 323.15) K

Compound	T (K)[a]	ρ (g·cm^{-3})[b]			η (mPa·s)[c]		
		Exp	Lit	100 $(\rho_{exp}-\rho_{lit})/\rho_{lit}$ (%)	Exp	Lit	100 $(\eta_{exp}-\eta_{lit})/\eta_{lit}$ (%)
Water	298.15	0.9971	0.99707[d]	0.003	0.8774	0.884[e]	− 0.75
			0.99706[e]	0.004		0.894[f]	− 1.86
			0.9971[f]	0.00		0.890[l]	− 1.42
	303.15	0.9957	0.995897[g]	− 0.02	0.7885	0.7974[g]	− 1.12
			0.99567[e]	0.003		0.796[e]	− 0.94
			0.9957[f]	0.00		0.801[f]	− 1.56
	308.15	0.9941	0.99406[d]	0.004	0.716	0.723[e]	− 0.97
			0.99406[e]	0.004		0.726[f]	− 1.38
			0.9940[f]	0.01		0.740[l]	− 3.24
	313.15	0.9923	0.992287[g]	0.001	0.6538	0.6535[g]	0.05
			0.99222[e]	0.01		0.662[e]	− 1.24
			0.9922[f]	0.01		0.656[f]	− 0.34
	318.15	0.9903	0.99023[d]	0.01	0.6023	0.608[e]	− 0.94
			0.99012[e]	0.02		0.599[f]	0.55
			0.9902[f]	0.01		0.630[l]	− 4.40
	323.15	0.9881	0.988105[g]	− 0.0005	0.5578	0.5465[g]	2.07
			0.98796[e]	0.01		0.566[e]	− 1.45
			0.9881[f]	0.00		0.554[f]	0.69
Methanol	298.15	0.787	0.78662[e]	0.05	0.5762	0.552[e]	4.38
			0.78664[h]	0.05		0.577[h]	− 0.14
			0.7866[f]	0.05		0.532[m]	8.31
	303.15	0.7824	0.78189[e]	0.07	0.5387	0.52[e]	3.60
			0.7818[f]	0.08		0.515[m]	4.60
			0.7822[m]	0.03		0.50[n]	7.74
	308.15	0.7776	0.77714[e]	0.06	0.5063	0.491[e]	3.12
			0.77715[h]	0.06		0.525[h]	− 3.56
			0.7771[f]	0.06		0.465[m]	8.88
	313.15	0.7728	0.77237[e]	0.06	0.4773	0.465[e]	2.65
			0.7723[f]	0.06		0.441[m]	8.23
			0.7729[m]	− 0.01		0.44[n]	8.48
	318.15	0.768	0.76756[e]	0.06	0.4526	0.442[e]	2.40
			0.76759[h]	0.05		0.41[n]	10.39
			0.7675[f]	0.07			
	323.15	0.7632	0.76272[e]	0.06	0.4302	0.421[e]	2.19
			0.7626[f]	0.08		0.40[n]	7.55

Table 1 (continued)

Compound	T (K)[a]	ρ (g·cm^{-3})[b]			η (mPa·s)[c]		
		Exp	Lit	100 $(\rho_{exp}-\rho_{lit})/\rho_{lit}$ (%)	Exp	Lit	100 $(\eta_{exp}-\eta_{lit})/\eta_{lit}$ (%)
Ethanol	298.15	0.7852	0.78528[e]	− 0.01	1.1019	1.071[e]	2.89
			0.78517[h]	0.004		1.09[h]	1.09
			0.7858[f]	− 0.08		1.09[n]	1.09
	303.15	0.781	0.78096[e]	0.01	1.0023	0.978[e]	2.49
			0.7815[f]	− 0.06		0.95[n]	5.51
			0.7808[n]	0.03			
	308.15	0.7766	0.77661[e]	− 0.001	0.9146	0.895[e]	2.19
			0.77649[h]	0.01		0.912[h]	0.29
			0.7772[f]	− 0.08		0.87[n]	5.13
	313.15	0.7722	0.77223[e]	− 0.004	0.8366	0.822[e]	1.78
			0.7728[f]	− 0.08		0.79[n]	5.90
			0.7722[n]	0.00			
	318.15	0.7678	0.76786[e]	− 0.01	0.7678	0.756[e]	1.56
			0.76767[h]	0.02		0.774[h]	− 0.80
			0.7683[f]	− 0.07		0.72[n]	6.64
	323.15	0.7634	0.7633[e]	0.01	0.7064	0.698[e]	1.20
			0.7639[f]	− 0.07		0.673[f]	4.96
			0.7632[n]	0.03		0.63[n]	12.13
n-Propanol	298.15	0.7997	0.79952[h]	0.02	1.9478	1.94[h]	0.40
			0.7997[i]	0.00		1.974[i]	− 1.33
			0.799765[j]	− 0.01		1.967[j]	− 0.98
	303.15	0.7956	0.79547[k]	0.02	1.7328	1.728[k]	0.28
			0.7959[i]	− 0.04		1.761[i]	− 1.60
			0.795833[j]	− 0.03		1.745[j]	− 0.70
	308.15	0.7915	0.79141[h]	0.01	1.5452	1.54[h]	0.34
			0.7918[i]	− 0.04		1.575[i]	− 1.89
			0.791619[j]	− 0.02		1.542[j]	0.21
	313.15	0.7874	0.7873[k]	0.01	1.3834	1.370[k]	0.98
			0.7877[i]	− 0.04		1.416[i]	− 2.30
			0.787776[j]	− 0.05		1.391[j]	− 0.55
	318.15	0.7832	0.78315[h]	0.01	1.2474	1.24[h]	0.60
			0.7836[i]	− 0.05		1.273[i]	− 2.01
			0.7832[n]	0.00		1.1[n]	13.40
	323.15	0.779	0.77893[k]	0.01	1.136	1.098[k]	3.46
			0.7794[i]	− 0.05		1.150[i]	− 1.22
			0.7790[n]	0.00		0.92[n]	23.48

Table 1 (continued)

Compound	T (K)[a]	ρ (g·cm^{-3})[b]			η (mPa·s)[c]		
		Exp	Lit	100 $(\rho_{exp}-\rho_{lit})/\rho_{lit}$ (%)	Exp	Lit	100 $(\eta_{exp}-\eta_{lit})/\eta_{lit}$ (%)
Isopropanol	298.15	0.781	0.78116[k]	− 0.02	2.0825	2.134[i]	− 2.41
			0.7811[i]	− 0.01		2.081[j]	0.07
			0.780942[j]	0.01		2.018[o]	3.20
	303.15	0.7768	0.77678[k]	0.003	1.7882	1.769[k]	1.09
			0.7768[i]	0.00		1.845[i]	− 3.08
			0.776601[j]	0.03		1.792[j]	− 0.21
	308.15	0.7724	0.7724[i]	0.00	1.5457	1.603[i]	− 3.37
			0.772559[j]	− 0.02		1.550[j]	− 0.28
			0.77223[o]	0.02		1.507[o]	2.57
	313.15	0.768	0.76798[k]	0.003	1.3432	1.330[k]	0.99
			0.7680[i]	0.00		1.400[i]	− 4.06
			0.768128[j]	− 0.02		1.352[j]	− 0.65
	318.15	0.7635	0.7635[i]	0.00	1.189	1.228[i]	− 3.18
			0.76327[o]	0.03		1.150[o]	3.39
	323.15	0.7588	0.75882[k]	− 0.003	1.0564	1.015[k]	4.08
			0.7589[i]	− 0.01		1.083[i]	− 2.46

[a]Uncertainty in temperature for $\rho = \pm 0.02$ K; uncertainty in temperature for $\eta = \pm 0.02$ K

[b]Uncertainty in density $= \pm 0.00005$ g·cm^{-3}

[c]Uncertainty in viscosity $= \pm 5 \times 10^{-3}$ mPa·s

[d]Reference [25]

[e]Reference [26]

[f]Reference [27]

[g]Reference [28]

[h]Reference [29]

[i]Reference [30]

[j]Reference [31]

[k]Reference [32]

[l]Reference [33]

[m]Reference [34]

[n]Reference [35]

[o]Reference [36]

observed that the pure [BHEM][mesy] has the largest density in all binary mixtures and the densities of mixtures at given molar fraction decrease with the increase of temperature as displayed in Fig. S3. In addition, from Fig. S4, the densities of mixtures gradually decrease with the decrease of molar fraction of [BHEM][mesy] at each given temperature and the

Table 2 Densities for the mixtures of [BHEM][mesy] with water or alcohols at temperatures from (298.15 to 323.15) K

T (K)[a]	ρ/(g·cm^{-3})[c]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy] + x_2 water						
0.0000	0.9971	0.9957	0.9941	0.9923	0.9903	0.9881
0.0989	1.1584	1.1558	1.1532	1.1506	1.1479	1.1451
0.1991	1.2164	1.2134	1.2106	1.2078	1.2049	1.2020
0.2989	1.2449	1.2419	1.2389	1.2360	1.2330	1.2301
0.3971	1.2616	1.2585	1.2555	1.2525	1.2495	1.2464
0.4797	1.2711	1.2680	1.2649	1.2619	1.2588	1.2557
0.5983	1.2807	1.2776	1.2745	1.2714	1.2681	1.2650
0.6984	1.2865	1.2833	1.2802	1.2771	1.2740	1.2709
0.7942	1.2910	1.2879	1.2847	1.2816	1.2785	1.2754
0.8928	1.2946	1.2914	1.2882	1.2851	1.2820	1.2788
1.0000	1.2982	1.2950	1.2917	1.2886	1.2855	1.2823
x_1 [BHEM][mesy] + x_2 methanol						
0.0000	0.7870	0.7824	0.7776	0.7728	0.7680	0.7632
0.1000	0.9677	0.9638	0.9596	0.9555	0.9514	0.9473
0.1996	1.0695	1.0659	1.0620	1.0582	1.0545	1.0508
0.3001	1.1355	1.1321	1.1287	1.1251	1.1216	1.1180
0.4004	1.1810	1.1777	1.1741	1.1706	1.1672	1.1638
0.5005	1.2143	1.2110	1.2075	1.2041	1.2008	1.1974
0.5976	1.2391	1.2359	1.2323	1.2290	1.2258	1.2224
0.7022	1.2599	1.2568	1.2534	1.2501	1.2469	1.2439
0.8012	1.2756	1.2726	1.2692	1.2660	1.2628	1.2596
0.9012	1.2890	1.2860	1.2826	1.2794	1.2763	1.2732
1.0000	1.2982	1.2950	1.2917	1.2886	1.2855	1.2823
x_1 [BHEM][mesy] + x_2 ethanol						
0.0000	0.7852	0.7810	0.7766	0.7722	0.7678	0.7634
0.0990	0.9184	0.9146	0.9106	0.9065	0.9026	0.8987
0.2000	1.0115	1.0079	1.0041	1.0004	0.9967	0.9929
0.2984	1.0807	1.0772	1.0736	1.0702	1.0666	1.0629
0.4000	1.1354	1.1320	1.1285	1.1250	1.1215	1.1180
0.5005	1.1781	1.1747	1.1713	1.1679	1.1646	1.1613
0.6011	1.2123	1.2090	1.2059	1.2025	1.1993	1.1961
0.7008	1.2404	1.2372	1.2339	1.2306	1.2274	1.2245
0.7993	1.2635	1.2603	1.2571	1.2538	1.2507	1.2476
0.8954	1.2829	1.2797	1.2765	1.2733	1.2702	1.2671
1.0000	1.2982	1.2950	1.2917	1.2886	1.2855	1.2823
x_1 [BHEM][mesy] + x_2 propanol						
0.0000	0.7997	0.7956	0.7915	0.7874	0.7832	0.7790
0.0999	0.9028	0.8990	0.8951	0.8912	0.8873	0.8833
0.1996	0.9838	0.9801	0.9764	0.9726	0.9689	0.9651
0.2999	1.0508	1.0473	1.0437	1.0401	1.0365	1.0324
0.3987	1.1047	1.1012	1.0977	1.0942	1.0907	1.0872
0.4980	1.1511	1.1477	1.1443	1.1409	1.1375	1.1341
0.5975	1.1903	1.1869	1.1835	1.1799	1.1766	1.1733

Table 2 (continued)

T (K)[a]	ρ/(g·cm^{-3})[c]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15
0.6972	1.2238	1.2206	1.2173	1.2140	1.2107	1.2074
0.7982	1.2533	1.2500	1.2468	1.2436	1.2403	1.2371
0.8978	1.2784	1.2751	1.2718	1.2686	1.2654	1.2623
1.0000	1.2982	1.2950	1.2917	1.2886	1.2855	1.2823
x_1 [BHEM][mesy] + x_2 isopropanol						
0.0000	0.7810	0.7768	0.7724	0.7680	0.7635	0.7588
0.0998	0.8866	0.8827	0.8785	0.8746	0.8706	0.8663
0.2001	0.9710	0.9674	0.9635	0.9598	0.9553	0.9523
0.3002	1.0401	1.0366	1.0329	1.0293	1.0258	1.0222
0.4004	1.0977	1.0943	1.0907	1.0872	1.0838	1.0802
0.4982	1.1447	1.1419	1.1384	1.1350	1.1317	1.1282
0.5999	1.1869	1.1836	1.1802	1.1767	1.1734	1.1700
0.6997	1.2218	1.2186	1.2152	1.2120	1.2088	1.2055
0.7978	1.2518	1.2486	1.2453	1.2422	1.2390	1.2357
0.8994	1.2786	1.2754	1.2721	1.2690	1.2659	1.2626
1.0000	1.2982	1.2950	1.2917	1.2886	1.2855	1.2823

[a]Uncertainty in temperature = ±0.02 K

[b]Uncertainty in molar fraction = ±0.0001

[c]Uncertainty in density = ±0.00005 g·cm^{-3}

slopes become smaller with the increase of the mole composition of [BHEM][mesy]. These results indicate that the magnitude of density change becomes smaller as the molar fraction of [BHEM][mesy] increases and also illustrates that a small amount of ionic liquid can have a large effect on the density of the solvent.

3.3 Apparent Molar Volumes

The apparent molar volume is considered as the molar volume of the solute in the solvent. It is generally different from the molar volume of pure material and can provide useful information to unveil the interactions between different molecules in mixtures, such as interactions between ion–ion, ion–solvent and solvent–solvent [39]. The apparent molar volumes of [BHEM][mesy] and solvents (water, methanol, ethanol, *n*-propanol and isopropanol) were calculated based on the following equations [39, 40]:

$$V_{\varphi,1} = \frac{x_2 M_2}{x_1} \times \frac{\rho_2 - \rho_m}{\rho_2 \rho_m} + \frac{M_1}{\rho_m} \tag{2}$$

$$V_{\varphi,2} = \frac{x_1 M_1}{x_2} \times \frac{\rho_1 - \rho_m}{\rho_1 \rho_m} + \frac{M_2}{\rho_m} \tag{2}$$

where $V_{\varphi,1}$ and $V_{\varphi,2}$, x_1 and x_2, M_1 and M_2 are the apparent molar volumes, the molar fractions and molar mass of the [BHEM][mesy] and solvents, respectively. ρ_1, ρ_2 and ρ_m are the densities of [BHEM][mesy], solvents and their mixtures, respectively.

Table 3 Fitted values of the empirical parameters, A, B, and C for the density of binary mixtures based on Eq. 1

x_1 [a]	A (g·cm^{-3})	10^{-4} B (g·cm^{-3}·K^{-1})	10^{-7} C (g·cm^{-3}·K^{-2})	R^2
x_1 [BHEM][mesy] + x_2 water				
0.0000	0.726	20.8	− 39.2	0.9999
0.0989	1.225	0.59	− 9.48	1.0000
0.1991	1.372	− 5.14	− 0.97	0.9999
0.2989	1.414	− 5.42	− 0.81	1.0000
0.3971	1.449	− 6.53	− 0.78	1.0000
0.4797	1.468	− 7.05	1.49	1.0000
0.5983	1.440	− 4.48	− 2.90	0.9999
0.6984	1.478	− 6.58	0.56	1.0000
0.7942	1.497	− 7.50	2.01	1.0000
0.8928	1.537	− 9.84	5.70	1.0000
1.0000	1.548	− 10.3	6.35	1.0000
x_1 [BHEM][mesy] + x_2 methanol				
0.0000	1.000	− 4.89	− 7.51	0.9999
0.1000	1.183	− 6.33	− 2.97	0.9999
0.1996	1.284	− 6.89	− 1.03	0.9999
0.3001	1.265	− 1.91	− 8.21	1.0000
0.4004	1.399	− 7.67	1.21	0.9998
0.5005	1.431	− 7.76	1.63	0.9998
0.5976	1.488	− 9.90	5.18	0.9997
0.7022	1.538	− 11.9	8.81	0.9997
0.8012	1.467	− 6.38	− 0.06	0.9998
0.9012	1.518	− 8.86	4.01	0.9999
1.0000	1.543	− 9.90	5.71	0.9999
x_1 [BHEM][mesy] + x_2 ethanol				
0.0000	0.992	− 5.26	− 5.58	1.0000
0.0990	1.144	− 7.23	− 1.13	1.0000
0.2000	1.206	− 5.67	− 2.87	1.0000
0.2984	1.255	− 4.67	− 3.91	0.9999
0.4000	1.339	− 6.68	− 0.46	1.0000
0.5005	1.429	− 9.96	5.22	1.0000
0.6011	1.398	− 6.00	− 7.98	0.9999
0.7008	1.572	− 15.5	14.6	0.9997
0.7993	1.495	− 9.01	4.22	1.0000
0.8954	1.551	− 11.5	8.25	1.0000
1.0000	1.543	− 9.90	5.71	0.9999
x_1 [BHEM][mesy] + x_2 *n*-propanol				
0.0000	0.961	− 2.80	− 8.83	1.0000
0.0999	1.102	− 5.64	− 3.48	1.0000
0.1996	1.181	− 5.87	− 2.56	1.0000
0.2999	1.113	2.72	− 16.1	0.9998
0.3987	1.320	− 7.43	0.74	1.0000
0.4980	1.371	− 7.90	1.75	1.0000
0.5975	1.420	− 8.51	2.69	0.9997
0.6972	1.430	− 7.26	1.11	1.0000

Table 3 (continued)

x_1 [a]	A (g·cm^{-3})	10^{-4} B (g·cm^{-3}·K^{-1})	10^{-7} C (g·cm^{-3}·K^{-2})	R^2
0.7982	1.459	− 7.29	1.32	1.0000
0.8978	1.520	− 9.67	5.22	1.0000
1.0000	1.543	− 9.90	6.35	1.0000
x_1 [BHEM][mesy] + x_2 isopropanol				
0.0000	0.855	3.40	− 19.8	0.9999
0.0998	1.064	− 4.01	− 6.55	0.9998
0.2001	1.222	− 9.16	2.47	0.9977
0.3002	1.267	− 8.01	1.34	0.9999
0.4004	1.287	− 5.78	− 1.92	0.9999
0.4982	1.168	4.60	− 1.81	0.9994
0.5999	1.382	− 6.31	− 7.38	0.9998
0.6997	1.428	− 7.32	1.31	0.9999
0.7978	1.445	− 6.53	1.57	0.9999
0.8994	1.507	− 8.84	4.00	0.9998
1.0000	1.543	− 9.90	5.71	0.9999

[a]Uncertainty in molar fraction = ± 0.0001

All these experimental results are presented in Table 4 and displayed in Fig. 1. In general, the apparent molar volumes increase with the increase of temperature and of molar fraction in binary mixtures [41]. The same trend can be seen for the five sets of mixtures. For all these mixtures, [BHEM][mesy] has the biggest apparent molar volumes compared with water, methanol, ethanol, *n*-propanol and isopropanol at all compositions. In addition, with the increase of molar fraction of [BHEM][mesy], a clear trend of increasing apparent molar volumes of [BHEM][mesy] and decreasing apparent molar volumes of solvents can be observed from Fig. 1. What's more, the apparent molar volumes of both [BHEM][mesy] and solvents increase with the increase of temperature just as displaying in Fig. 1.

3.4 Viscosity

The dynamic viscosity values of all five binary mixtures at all molar compositions at temperatures from (298.15 to 323.15) K are collected in Table 5. The viscosities of each mixture were fitted with the Vogel–Fulcher–Tammann equation (VFT, Eq. 4), which can precisely describe the relationship between dynamic viscosity and temperature at constant molar composition [14, 37, 42]:

$$\eta = A\left\{\exp\left[\frac{B}{T - T_0}\right]\right\} \tag{4}$$

In this equation, the A (mPa·s), B (K) and T_0 (K) are adjustable parameters. All these adjustable parameters and the correlation coefficients (R^2) obtained and are listed in Table 6.

As can be seen from Fig. S5, the experimental data are well represented with the Vogel–Fulcher–Tammann equation and the viscosities of mixtures sharply decrease as the

Table 4 Apparent molar volumes for the mixtures of [BHEM][mesy] with water or alcohols at temperatures from (298.15 to 323.15) K

T (K)[a]	$V_{\varphi,1}$(cm^3·mol^{-1})[c]						$V_{\varphi,2}$(cm^3·mol^{-1})[d]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy]+x_2 water												
0.0000	–	–	–	–	–	–	18.1	18.1	18.1	18.2	18.2	18.2
0.0989	162.9	163.4	163.9	164.3	164.8	165.2	17.8	17.8	17.8	17.9	17.9	17.9
0.1991	163.9	164.3	164.8	165.2	165.6	166.1	17.6	17.6	17.7	17.7	17.7	17.8
0.2989	164.5	164.9	165.4	165.8	166.2	166.6	17.5	17.5	17.6	17.6	17.7	17.7
0.3971	164.9	165.3	165.7	166.1	166.6	167.0	17.5	17.5	17.5	17.6	17.6	17.6
0.4797	165.1	165.6	166.0	166.4	166.8	167.2	17.4	17.5	17.5	17.5	17.6	17.6
0.5983	165.4	165.8	166.2	166.6	167.1	167.5	17.4	17.5	17.5	17.5	17.6	17.7
0.6984	165.6	166.0	166.4	166.8	167.2	167.6	17.5	17.5	17.6	17.6	17.6	17.7
0.7942	165.7	166.1	166.5	166.9	167.3	167.7	17.5	17.6	17.6	17.6	17.6	17.7
0.8928	165.8	166.2	166.6	167.0	167.4	167.8	17.7	17.8	17.8	17.8	17.9	17.9
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	–	–	–	–	–	–
x_1 [BHEM][mesy]+x_2 methanol												
0.0000	–	–	–	–	–	–	40.7	41.0	41.2	41.5	41.7	42.0
0.1000	154.0	154.0	154.0	154.0	153.9	153.8	39.4	39.6	39.8	40.0	40.2	40.4
0.1996	158.2	158.3	158.4	158.6	158.7	158.8	38.8	39.0	39.2	39.4	39.5	39.7
0.3001	160.4	160.7	160.8	161.1	161.3	161.5	38.4	38.6	38.7	38.9	39.1	39.2
0.4004	161.9	162.2	162.5	162.8	163.1	163.3	38.1	38.3	38.4	38.6	38.8	39.0
0.5005	163.0	163.3	163.6	164.0	164.3	164.6	37.9	38.0	38.2	38.4	38.5	38.7
0.5976	163.7	164.1	164.5	164.8	165.1	165.5	37.6	37.7	37.9	38.1	38.3	38.4
0.7022	164.4	164.7	165.1	165.5	165.9	166.2	37.3	37.4	37.6	37.8	37.9	38.0
0.8012	164.9	165.3	165.7	166.0	166.4	166.8	36.9	37.0	37.1	37.3	37.5	37.6
0.9012	165.3	165.6	166.1	166.5	166.8	167.2	35.6	35.6	35.7	36.0	36.1	36.2
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	–	–	–	–	–	–

Table 4 (continued)

T (K)[a]	$V_{\varphi,1}$(cm^3·mol^{-1})[c]						$V_{\varphi,2}$(cm^3·mol^{-1})[d]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy]+x_2 ethanol												
0.0000	–	–	–	–	–	–	58.7	59.0	59.3	59.7	60.0	60.4
0.0990	156.9	157.0	157.0	157.0	157.0	156.9	57.7	58.0	58.3	58.6	58.9	59.1
0.2000	160.3	160.4	160.6	160.7	160.9	161.0	57.3	57.5	57.8	58.1	58.4	58.6
0.2984	161.5	161.7	161.9	162.1	162.3	162.5	56.8	57.1	57.3	57.6	57.8	58.1
0.4000	162.5	162.7	163.0	163.3	163.6	163.8	56.4	56.7	56.9	57.2	57.4	57.7
0.5005	163.2	163.5	163.8	164.2	164.4	164.7	56.1	56.3	56.5	56.7	57.0	57.2
0.6011	163.9	164.2	164.5	164.8	165.2	165.5	55.7	55.9	56.1	56.3	56.6	56.8
0.7008	164.4	164.7	165.1	165.4	165.8	166.1	55.2	55.4	55.6	55.9	56.1	56.2
0.7993	164.8	165.2	165.6	165.9	166.3	166.7	54.6	54.8	54.9	55.2	55.4	55.6
0.8954	165.1	165.5	165.9	166.3	166.7	167.1	52.9	53.0	53.1	53.4	53.6	53.6
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	–	–	–	–	–	–
x_1 [BHEM][mesy]+x_2 *n*-propanol												
0.0000	–	–	–	–	–	–	75.2	75.5	75.9	76.3	76.7	77.2
0.0999	161.1	161.2	161.3	161.5	161.5	161.6	74.6	75.0	75.3	75.7	76.1	76.5
0.1996	162.4	162.6	162.8	163.0	163.2	163.4	74.3	74.6	75.0	75.3	75.7	76.0
0.2999	162.9	163.2	163.4	163.7	163.9	164.3	73.9	74.2	74.6	74.9	75.2	75.6
0.3987	163.6	163.9	164.2	164.5	164.7	165.0	73.7	74.0	74.3	74.6	74.9	75.3
0.4980	163.9	164.2	164.5	164.9	165.2	165.5	73.2	73.5	73.8	74.1	74.5	74.8
0.5975	164.3	164.6	164.9	165.3	165.7	166.0	72.8	73.1	73.4	73.8	74.1	74.4
0.6972	164.6	165.0	165.3	165.7	166.0	166.4	72.3	72.6	72.8	73.2	73.5	73.8
0.7982	164.9	165.3	165.7	166.0	166.4	166.8	71.5	71.7	71.9	72.3	72.6	72.8
0.8978	165.2	165.6	166.0	166.4	166.8	167.2	69.6	70.0	70.1	70.5	70.8	71.0
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	–	–	–	–	–	–

Table 4 (continued)

T (K)[a]	$V_{\varphi,1}$(cm^3·mol^{-1})[c]						$V_{\varphi,2}$(cm^3·mol^{-1})[d]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy] + x_2 isopropanol												
0.0000	–	–	–	–	–	–	77.0	77.4	77.8	78.3	78.7	79.2
0.0998	160.2	160.2	160.3	160.1	160.0	159.8	76.3	76.7	77.1	77.5	77.9	78.3
0.2001	161.5	161.6	161.7	161.8	162.2	161.7	75.9	76.2	76.6	76.9	77.4	77.7
0.3002	162.3	162.5	162.7	162.8	163.0	163.0	75.4	75.8	76.1	76.4	76.8	77.1
0.4004	162.9	163.1	163.4	163.6	163.8	164.0	75.0	75.3	75.6	75.9	76.3	76.6
0.4982	163.4	163.6	163.9	164.2	164.4	164.7	74.6	74.8	75.1	75.4	75.7	76.0
0.5999	163.8	164.1	164.5	164.8	165.1	165.4	74.0	74.2	74.5	74.9	75.2	75.5
0.6997	164.3	164.6	165.0	165.3	165.6	166.0	73.4	73.6	73.9	74.2	74.5	74.8
0.7978	164.6	165.0	165.4	165.7	166.1	166.5	72.3	72.5	72.8	73.0	73.3	73.6
0.8994	165.0	165.4	165.8	166.2	166.6	167.0	69.7	69.9	70.2	70.5	70.7	71.0
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	–	–	–	–	–	–

[a]Uncertainty in temperature = ± 0.02 K

[b]Uncertainty in molar fraction = ± 0.0001

[c] $V_{\varphi,1}$ stands for the apparent molar volumes of the [BHEM][mesy]

[d] $V_{\varphi,2}$ stands for the apparent molar volumes of the solvents

temperature increases at constant mole composition. Compared with Fig. S3, temperature has greater influence on viscosity than it has on density. This is because the viscosity of the liquid is generated by the cohesion of molecules; the higher of their temperature, the stronger of molecular vibration, the smaller is cohesion between them, and the viscosity goes down. In addition, from Fig. 2, the viscosities of all five binary mixtures rapidly increase with the increase of molar fraction of [BHEM][mesy] at constant temperature. As the molar concentration of [BHEM][mesy] goes up, the distance of cation and anion becomes smaller. Thus, the interaction forces, especially the electrostatic interaction, become stronger, which leads to the viscosity becoming larger.

3.5 Excess Molar Volume and Viscosity Deviation

The excess molar volume is an important thermodynamic property, which indicates the difference of molar volumes between the experimental binary mixture and the corresponding ideal mixture fluid as well as providing useful information to the molecular interactions [43]. Thus, it is necessary to evaluate the excess molar volume (V^{E}) and viscosity deviation ($\Delta\eta$) of binary mixtures to obtain the difference between the real solution and the corresponding ideal one. Among them, the ideal viscosity of binary mixtures is obtained by the Arrhenius expression [44]; thus V^{E} and $\Delta\eta$ can be calculated by the following equations [45–48]:

$$V^{\mathrm{E}} = x_1 M_1 \left(\frac{1}{\rho_m} - \frac{1}{\rho_1} \right) + x_2 M_2 \left(\frac{1}{\rho_m} - \frac{1}{\rho_2} \right) \tag{5}$$

$$\Delta\eta = \eta_m - \eta_1^{x_1} * \eta_2^{x_2} \tag{6}$$

where x_1 and x_2, ρ_1 and ρ_2, η_1 and η_2, M_1 and M_2 are the molar fraction, density and viscosity of a pure component at a certain temperature and the molar masses of [BHEM][mesy] and solvent, respectively. ρ_m and η_m are the experimental data at a certain composition and temperature. The results of the calculations are displayed in Table 7.

The experimental values of V^{E} and $\Delta\eta$ were fitted with Redlich–Kister type polynomials [47, 48]:

$$Y^{\mathrm{E}} = x_1 (1 - x_1) \sum_{i=0}^{k} A_i (2x_1 - 1)^i \tag{7}$$

where the adjustable parameters (A_i) were obtained by fitting the equation with the experimental values with a least-squares type algorithm. The standard deviation (σ) is defined by the following equation [47, 48]:

$$\sigma(Y) = \left[\sum_{i=1}^{n} \left(Y_{\mathrm{exptl}} - Y_{\mathrm{calc}} \right)^2 / (n - p) \right]^{0.5} \tag{8}$$

where n is the number of experimental values and p is the number of parameters. The subscripts, exptl and calc, stand for the experimental and the calculated values, respectively. V^{E} and $\Delta\eta$ were fitted perfectly with the Redlich–Kister equation just as displayed

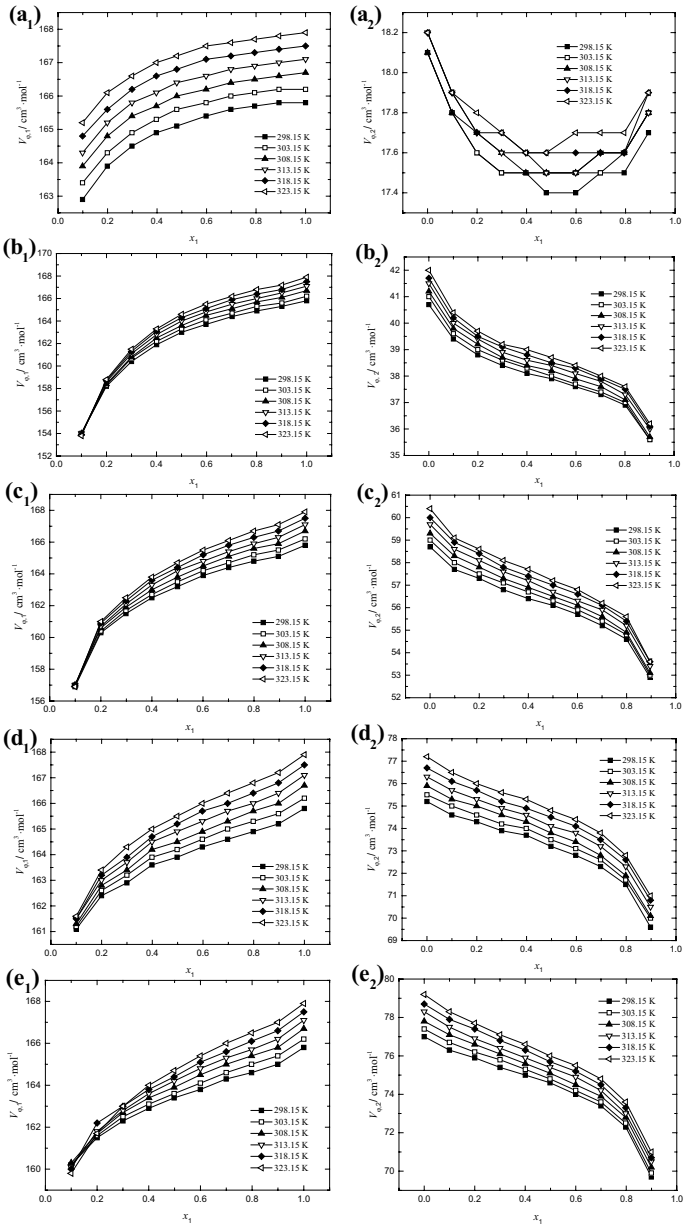


Fig. 1 Apparent molar volumes of [BHEM][mesy] and solvent molecules over the full molar fraction range at temperatures from (298.15–323.15) K. **a1**–e1 are the apparent molar volumes of [BHEM][mesy] in water, methanol, ethanol, *n*-propanol and isopropanol, respectively. **a2–e2** are the apparent molar volumes of water, methanol, ethanol, *n*-propanol and isopropanol, respectively

in Figs. 3 and 4. The values of the parameters A_i and standard deviations σ are listed in Table 8.

From Fig. 3, it is clear that all binary mixtures at all temperatures have negative excess molar volumes. The values decrease first and then begin to increase at a particular molar fraction. Especially, the binary mixtures, [BHEM][mesy] + water and [BHEM][mesy] + methanol have a minimum V^E at a molar fraction of [BHEM][mesy] between 0.2 and 0.3, the mixture of [BHEM][mesy] + ethanol has a minimum V^E at molar fraction about 0.3–0.4, and the mixtures containing propanol and isopropanol have a minimum V^E at 0.4–0.5. The negative V^E values indicate the interactions between [BHEM][mesy] and solvents are strong, thus making the deviations between real mixtures and ideal ones large [49]. These interaction forces include van der Waals' forces, strong dipole–dipole, charge transfer complexes and ion–dipole interactions. But the most important factor in these binary mixtures may be hydrogen bonds because each component has one or more hydroxyl group, which can generate strong hydrogen bonds between each other. At the same time, the difference of size between ionic liquid and solvents is also significant in the course of determining V^E because the large volume of [BHEM][mesy] provide enough space for small molecules of solvents to embed in it, thus giving rise to negative V^E values. Furthermore, the deviations of all five binary mixtures become smaller with increasing temperature from (298.15 to 323.15) K. This trend can be attributed to the reason that the movement of molecules become more intense with increasing temperature, which leads to weaker interaction among molecules. Moreover, the binary mixtures containing water have smaller V^E values than the mixtures containing alcohols. This phenomenon may be attributed to the fact that the molecules of alcohols have alkyl (methyl, ethyl, propyl) groups, which generate stronger dispersion interactions in the mixtures due to their alkyl chains [50].

As for viscosity deviations of binary mixtures, they are displayed in Fig. 4 and a similar overall change trend can be observed. From this figure, all five mixtures have positive $\Delta\eta$ values that increase first and then decrease at any particular molar fraction. What is different from the V^E is that the turning point appearing in the molar fraction is at about $x_1 = 0.9$, which is larger than the corresponding point in V^E. Particularly, the binary mixtures containing water have larger $\Delta\eta$ values in general and its maximum is about 500 mPa·s compared to the maximum $\Delta\eta$ about 250 mPa·s for the binary mixtures containing alcohols. In addition, at low molar fraction of [BHEM][mesy] (about $x_1 = 0$–0.5), the intensity of change of $\Delta\eta$ is small. However, when x_1 exceeds 0.5, the intensity of change of $\Delta\eta$ becomes very large. At the same time, the viscosity deviations of the binary mixtures change very rapidly from the turning point, and they decrease to zero from the maximum in a very narrow range (about 0.9–1.0); this phenomenon indicates that very small amounts of impurities can have a great effect on the viscosity of pure ionic liquids. Also, the regularity of $\Delta\eta$ is similar with the V^E with regards to the influence of temperature. With the increase of temperature, the $\Delta\eta$ become smaller in all binary mixtures.

3.6 Partial Molar Volumes

In general, the partial molar volume represents the change in volume caused by the addition of one mole of matter to a mixed solution under the condition of constant pressure and temperature. The partial molar volume of [BHEM][mesy] and solvent compounds of binary mixtures can be calculated basing on the following equations [51, 52]:

$$\overline{V_1} = V^E + V_1^0 + \left(1 - x_1\right)\left(\partial V^E / \partial x_1\right)_{p,T} \tag{9}$$

Table 5 Experimental viscosities for the mixtures of [BHEM][mesy] with water or alcohols at temperatures from (298.15 to 323.15) K

T (K)[a]	η (mPa·s)[c]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy] + x_2 water						
0.0000	0.877	0.789	0.716	0.654	0.602	0.558
0.0989	4.545	3.913	3.450	3.064	2.737	2.506
0.1991	14.87	12.42	10.56	9.062	7.849	6.855
0.2989	36.91	29.89	24.57	20.51	17.31	14.75
0.3971	77.51	60.62	48.26	39.04	32.07	26.68
0.4797	147.9	113.0	78.69	62.43	50.08	40.90
0.5983	288.0	211.8	160.1	123.5	86.95	69.36
0.6984	459.6	333.0	245.8	185.7	142.8	112.1
0.7942	795.7	558.3	402.7	296.3	223.4	171.0
0.8928	1034	718.4	509.8	374.0	279.0	212.2
1.0000	1495	1021	716.3	513.1	377.6	282.4
x_1 [BHEM][mesy] + x_2 methanol						
0.0000	0.576	0.539	0.506	0.477	0.453	0.430
0.1000	2.033	1.851	1.692	1.553	1.431	1.323
0.1996	5.812	5.123	4.546	4.063	3.641	3.290
0.3001	14.80	12.57	10.99	9.612	8.355	7.370
0.4004	34.36	28.09	23.26	19.55	16.59	14.24
0.5005	74.08	58.30	46.69	37.97	31.31	26.15
0.5976	164.1	125.1	86.56	68.43	54.94	44.72
0.7022	316.2	231.3	175.0	134.1	105.2	75.75
0.8012	566.3	402.4	296.1	222.0	170.0	132.2
0.9012	939.5	655.9	469.2	344.2	258.3	196.8
1.0000	1495	1021	716.3	513.1	377.6	282.4
x_1 [BHEM][mesy] + x_2 ethanol						
0.0000	1.102	1.002	0.915	0.837	0.768	0.706
0.0990	3.207	2.886	2.605	2.325	2.125	1.901
0.2000	8.150	7.016	6.130	5.384	4.763	4.237
0.2984	18.49	15.54	13.16	11.40	9.915	8.576
0.4000	39.67	32.20	26.52	22.11	18.64	15.85
0.5005	80.67	63.32	50.55	41.00	33.66	28.03
0.6011	175.6	133.2	92.71	73.17	58.61	47.63
0.7008	319.2	236.4	178.2	136.8	106.9	76.49
0.7993	556.2	399.3	293.5	221.1	168.7	132.1
0.8954	947.5	664.2	476.4	350.3	261.9	200.9
1.0000	1495	1021	716.3	513.1	377.6	282.4
x_1 [BHEM][mesy] + x_2 *n*-propanol						
0.0000	1.948	1.733	1.545	1.383	1.247	1.136
0.0999	4.967	4.336	3.804	3.361	2.985	2.661
0.1996	11.64	9.878	8.452	7.293	6.348	5.556
0.2999	25.46	20.89	17.41	14.66	12.49	10.92
0.3987	50.86	40.59	32.88	26.99	22.47	18.91
0.4980	97.47	75.53	59.56	47.73	38.84	32.03
0.5975	195.8	149.0	114.8	79.84	63.73	51.47

Table 5 (continued)

T (K)[a]	η (mPa·s)[c]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15
0.6972	337.1	248.5	187.0	142.8	111.4	79.75
0.7982	575.9	414.5	304.5	228.2	174.5	135.8
0.8978	965.0	675.8	484.5	355.0	266.6	202.7
1.0000	1495	1021	716.3	513.1	377.6	282.4
x_1 [BHEM][mesy] + x_2 isopropanol						
0.0000	2.082	1.788	1.546	1.343	1.189	1.056
0.0998	5.619	4.782	4.129	3.601	3.364	2.827
0.2001	13.50	11.45	9.674	8.135	6.962	6.019
0.3002	30.07	24.13	19.72	16.35	13.70	11.86
0.4004	61.00	47.70	37.97	30.71	25.24	20.99
0.4982	123.0	86.70	67.42	53.38	42.96	35.07
0.5999	227.2	167.6	128.7	89.65	70.75	56.69
0.6997	384.7	281.3	210.1	158.7	123.6	87.0
0.7978	628.1	445.3	323.9	243.0	185.9	143.8
0.8994	1025	711.5	507.4	370.0	277.7	211.0
1.0000	1495	1021	716.3	513.1	377.6	282.4

[a]Uncertainty in temperature = ±0.02 K

[b]Uncertainty in molar fraction = ±0.0001

[c]Uncertainty in viscosities = $\pm 5 \times 10^{-3}$ mPa·s

$$\overline{V}_2 = V^{\mathrm{E}} + V_2^0 + x_1(\partial V^{\mathrm{E}}/x_1)\partial_{(p,T)} \tag{10}$$

where V^{E} represents the excess molar volume of the binary mixture, V_1^0 and V_2^0 denote for molar volume of pure [BHEM][mesy] and solvents at constant temperature, respectively.

The calculated partial molar volumes are listed in Table 9 and all of them are positive over the full mole composition range at temperatures from (298.15 to 323.15) K. With the increase of temperature, the partial molar volumes of both [BHEM][mesy] and solvent compounds (water and alcohols) increase at constant molar fraction. However, at constant temperature, the partial molar volumes of [BHEM][mesy] decrease and the partial molar volumes of solvent compounds increase with the increase of the molar fraction of [BHEM][mesy]. In addition, the partial molar volumes of [BHEM][mesy] are commonly much larger than the solvent compounds, as [BHEM][mesy] has larger molecular weight and volume. What's more, [BHEM][mesy] has smaller partial molar volumes in water compared to its values in alcohols at the corresponding mole fraction. For binary mixtures containing alcohols, [BHEM][mesy] has similar partial molar volumes, which indicates that there are no significant difference in the influences of methanol, ethanol, propanol and isopropanol in terms of partial molar volumes of [BHEM][mesy]. For partial molar volumes of solvents, their order is water < methanol < ethanol < *n*-propanol ≈ isopropanol, which corresponds with their molecular weight and volume.

Table 6 Fitted values of the empirical parameters, A, B, and T_0 for the viscosity of binary mixtures based on VFT equation

x_1 [a]	A (mPa·s)	B (K)	T_0 (K)	R^2
x_1 [BHEM][mesy] + x_2 water				
0.0000	0.076	268.1	188.4	1.0000
0.0989	0.353	209.2	216.3	0.9997
0.1991	0.130	607.8	169.8	1.0000
0.2989	0.135	719.1	170.0	1.0000
0.3971	0.124	809.5	172.4	1.0000
0.4797	0.160	714.9	193.6	0.9942
0.5983	0.000	6567	− 27.30	1.0000
0.6984	0.061	1188	165.2	1.0000
0.7942	0.069	1190	171.0	1.0000
0.8928	0.083	1168	174.3	1.0000
1.0000	0.036	1428	163.8	1.0000
x_1 [BHEM][mesy] + x_2 methanol				
0.0000	0.098	223.3	171.9	1.0000
0.1000	0.034	865.8	85.91	1.0000
0.1996	0.053	853.0	116.7	1.0000
0.3001	0.047	1051	115.4	0.9992
0.4004	0.136	730.2	166.2	1.0000
0.5005	0.125	820.2	169.8	1.0000
0.5976	0.166	720.3	193.8	0.9938
0.7022	0.000	3154	71.63	0.9988
0.8012	0.173	926.4	183.7	1.0000
0.9012	0.070	1206	171.2	1.0000
1.0000	0.036	1428	163.8	1.0000
x_1 [BHEM][mesy] + x_2 ethanol				
0.0000	0.003	1743	− 2.581	1.0000
0.0990	0.000	18,748	− 638.3	1.0000
0.2000	0.083	690.5	147.5	1.0000
0.2984	0.115	720.9	156.3	0.9997
0.4000	0.087	869.4	156.1	1.0000
0.5005	0.100	891.6	164.9	1.0000
0.6011	0.195	697.2	195.7	0.9948
0.7008	0.000	5410	− 0.060	1.0000
0.7993	0.088	1113	171.1	1.0000
0.8954	0.054	1291	166.0	1.0000
1.0000	0.036	1428	163.8	1.0000
x_1 [BHEM][mesy] + x_2 *n*-propanol				
0.0000	0.018	901.7	106.4	0.9999
0.0999	0.013	1283	83.56	1.0000
0.1996	0.033	1021	124.4	1.0000
0.2999	0.224	539.6	184.2	0.9999
0.3987	0.085	872.3	161.7	1.0000
0.4980	0.093	912.4	167.0	1.0000
0.5975	0.010	1522	144.0	1.0000
0.6972	0.000	5455	0.079	1.0000
0.7982	0.045	1310	159.7	1.0000

Table 6 (continued)

x_1 [a]	A (mPa·s)	B (K)	T_0 (K)	R^2
0.8978	0.046	1338	163.7	1.0000
1.0000	0.036	1428	163.8	1.0000
x_1 [BHEM][mesy] + x_2 isopropanol				
0.0000	0.024	623.5	158.8	0.9999
0.0998	0.243	294.6	204.3	0.9921
0.2001	0.000	3135	0.007	1.0000
0.3002	0.233	508.8	193.5	0.9999
0.4004	0.102	797.6	173.3	1.0000
0.4982	2.769	197.5	246.1	0.9988
0.5999	0.030	1185	165.6	1.0000
0.6997	0.000	5622	0.152	1.0000
0.7978	0.199	902.9	186.1	1.0000
0.8994	0.092	1142	175.7	1.0000
1.0000	0.036	1428	163.8	1.0000

[a]Uncertainty in molar fraction = ± 0.0001

4 Conclusions

The density and viscosity of five binary mixtures including [BHEM][mesy] and water or alcohols (methanol, ethanol, *n*-propanol and isopropanol) were systematically measured. The data of density and viscosity were correlated by an empirical polynomial and the Vogel–Fulcher–Tammann equations, respectively. The calculated standard deviations indicate that all fitting equations accurately reproduce the experimental data. It is clearly shown that density and viscosity of all binary mixtures decrease with increasing temperature and decrease with the [BHEM][mesy] molar fraction. It was also observed that the influences of temperature and molar composition are larger for viscosity than for density in all mixtures. Then, excess molar volumes and viscosity deviations were calculated and fitted with Redlich–Kister type polynomials. The excess molar volumes vary similarly in all five binary mixtures; all values are negative and decrease first but then have an increasing trend at a particular mole fraction. For the viscosity deviations, they increased slowly at first but then increased rapidly above a particular molar fraction. At the same time, the deviations of mixtures become smaller with increasing temperature for both density and viscosity. In addition, apparent molar volumes of [BHEM][mesy] and the organic solvents were also calculated; the results indicate that [BHEM][mesy] has larger apparent molar volumes than the solvents under the experimental conditions. With the increase of molar fraction of [BHEM][mesy], the apparent molar volumes increased for the ionic liquid but decreased for the solvents. Moreover, partial molar volumes of [BHEM][mesy] and solvents were calculated and the results indicate that all values are positive and they all increase with increase of temperature. However, the partial molar volumes of [BHEM][mesy] decrease and the partial molar volumes of solvents increase with the increase of molar fraction of [BHEM][mesy] at constant temperature.

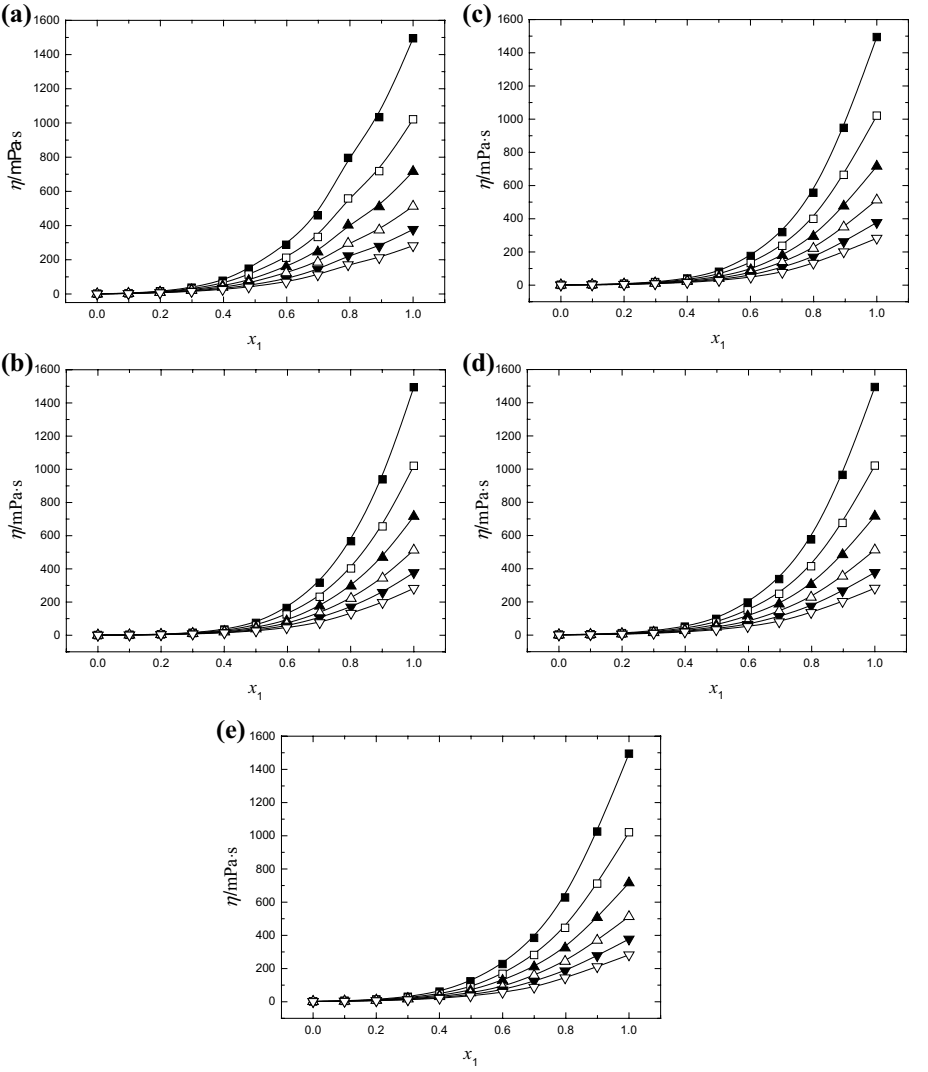


Fig. 2 Viscosity for mixtures of **a** x_1 [BHEM][mesy]+x_2 water, **b** x_1 [BHEM][mesy]+x_2 methanol, **c** x_1 [BHEM][mesy]+x_2 ethanol, **d** x_1 [BHEM][mesy]+x_2 *n*-propanol, **e** x_1 [BHEM][mesy]+x_2 isopropanol as a function of mole fractions of x_1 [BHEM][mesy] at six different temperatures. Filled square, 298.15 K; open square, 303.15 K; filled triangle, 308.15 K; open triangle, 313.15 K; filled inverted triangle, 318.15 K; open inverted triangle, 323.15 K. The solid curves are trendlines and the symbols denote experimental values

Table 7 Excess molar volumes and viscosity deviations for the mixture of [BHEM][mesy] with water or alcohols at temperatures from (298.15 to 323.15) K

T (K)	298.15	303.15	308.15	313.15	318.15	323.15
x_1						
x_1 [BHEM][mesy] + x_2 water						
V^E ($cm^3 \cdot mol^{-1}$)						
0.0989	− 0.29	− 0.28	− 0.27	− 0.27	− 0.27	− 0.26
0.1991	− 0.39	− 0.38	− 0.37	− 0.37	− 0.36	− 0.36
0.2989	− 0.40	− 0.39	− 0.39	− 0.39	− 0.38	− 0.38
0.3971	− 0.37	− 0.37	− 0.36	− 0.36	− 0.36	− 0.36
0.4797	− 0.33	− 0.32	− 0.32	− 0.32	− 0.32	− 0.32
0.5983	− 0.25	− 0.25	− 0.25	− 0.25	− 0.23	− 0.23
0.6984	− 0.17	− 0.17	− 0.17	− 0.17	− 0.17	− 0.16
0.7942	− 0.11	− 0.11	− 0.12	− 0.12	− 0.12	− 0.11
0.8928	− 0.04	− 0.03	− 0.03	− 0.04	− 0.04	− 0.03
$\Delta\eta$ (mPa·s)						
0.0989	2.71	2.31	2.03	1.80	1.60	1.47
0.1991	11.0	9.13	7.73	6.60	5.68	4.93
0.2989	28.8	23.2	18.9	15.7	13.2	11.2
0.3971	60.7	47.0	37.1	29.8	24.3	20.1
0.4797	116.8	88.4	59.0	46.4	36.8	29.8
0.5983	212.7	154.4	115.4	88.3	58.5	46.2
0.6984	301.1	215.4	156.6	117.0	88.6	68.9
0.7942	472.5	324.6	229.9	166.2	123.1	92.6
0.8928	360.6	244.7	168.2	122.9	89.7	67.4
x_1 [BHEM][mesy] + x_2 methanol						
V^E ($cm^3 \cdot mol^{-1}$)						
0.1000	− 1.18	− 1.22	− 1.27	− 1.31	− 1.36	− 1.41
0.1996	− 1.53	− 1.59	− 1.64	− 1.69	− 1.75	− 1.81
0.3001	− 1.61	− 1.67	− 1.75	− 1.80	− 1.86	− 1.92
0.4004	− 1.55	− 1.61	− 1.66	− 1.70	− 1.76	− 1.82
0.5005	− 1.42	− 1.47	− 1.51	− 1.55	− 1.60	− 1.65
0.5976	− 1.25	− 1.30	− 1.32	− 1.35	− 1.39	− 1.43
0.7022	− 1.01	− 1.05	− 1.08	− 1.10	− 1.13	− 1.19
0.8012	− 0.75	− 0.79	− 0.81	− 0.82	− 0.84	− 0.87
0.9012	− 0.51	− 0.53	− 0.54	− 0.54	− 0.56	− 0.58
$\Delta\eta$ (mPa·s)						
0.1000	0.77	0.71	0.65	0.59	0.54	0.50
0.1996	3.04	2.69	2.39	2.14	1.91	1.72
0.3001	8.70	7.38	6.52	5.73	4.95	4.36
0.4004	21.0	17.0	14.0	11.7	9.90	8.47
0.5005	44.6	34.8	27.6	22.3	18.2	15.1
0.5976	100.9	76.1	47.9	37.5	29.7	24.0
0.7022	172.4	123.4	92.4	69.9	54.2	34.8
0.8012	253.0	174.6	126.8	93.9	70.8	54.4
0.9012	252.0	171.5	119.5	86.8	64.0	48.0
x_1 [BHEM][mesy] + x_2 ethanol						
V^E ($cm^3 \cdot mol^{-1}$)						
0.0990	− 0.88	− 0.92	− 0.96	− 1.00	− 1.04	− 1.09

Table 7 (continued)

T (K)	298.15	303.15	308.15	313.15	318.15	323.15
x_1						
0.2000	− 1.10	− 1.16	− 1.21	− 1.26	− 1.32	− 1.37
0.2984	− 1.30	− 1.35	− 1.41	− 1.48	− 1.54	− 1.59
0.4000	− 1.35	− 1.40	− 1.46	− 1.51	− 1.56	− 1.62
0.5005	− 1.31	− 1.36	− 1.41	− 1.46	− 1.51	− 1.58
0.6011	− 1.18	− 1.23	− 1.30	− 1.33	− 1.38	− 1.43
0.7008	− 1.03	− 1.07	− 1.11	− 1.13	− 1.17	− 1.25
0.7993	− 0.82	− 0.85	− 0.88	− 0.90	− 0.92	− 0.96
0.8954	− 0.61	− 0.62	− 0.65	− 0.65	− 0.67	− 0.70
$\Delta\eta$ (mPa·s)						
0.0990	0.96	0.90	0.84	0.75	0.71	0.62
0.2000	3.49	3.01	2.66	2.36	2.11	1.90
0.2984	9.00	7.62	6.48	5.72	5.03	4.35
0.4000	19.9	16.2	13.4	11.2	9.47	8.10
0.5005	39.9	31.2	24.9	20.2	16.6	13.9
0.6011	91.5	68.7	42.5	33.5	26.7	21.8
0.7008	146.5	107.8	80.6	61.6	47.8	29.5
0.7993	204.7	145.0	105.5	79.6	59.8	47.2
0.8954	244.6	169.4	119.6	88.2	64.5	50.0
x_1 [BHEM][mesy] + x_2 *n*-propanol						
V^E ($cm^3 \cdot mol^{-1}$)						
0.0999	− 0.47	− 0.51	− 0.53	− 0.56	− 0.60	− 0.63
0.1996	− 0.68	− 0.72	− 0.76	− 0.81	− 0.85	− 0.90
0.2999	− 0.87	− 0.91	− 0.96	− 1.01	− 1.06	− 1.08
0.3987	− 0.90	− 0.94	− 0.99	− 1.04	− 1.09	− 1.15
0.4980	− 0.97	− 1.01	− 1.06	− 1.10	− 1.15	− 1.20
0.5975	− 0.94	− 0.98	− 1.02	− 1.02	− 1.06	− 1.11
0.6972	− 0.86	− 0.90	− 0.94	− 0.96	− 0.99	− 1.0
0.7982	− 0.75	− 0.77	− 0.80	− 0.82	− 0.84	− 0.87
0.8978	− 0.56	− 0.57	− 0.59	− 0.60	− 0.61	− 0.63
$\Delta\eta$ (mPa·s)						
0.0999	1.18	1.06	0.95	0.86	0.78	0.69
0.1996	4.30	3.69	3.19	2.79	2.45	2.14
0.2999	11.2	9.16	7.67	6.50	5.57	4.98
0.3987	23.3	18.5	15.0	12.4	10.3	8.67
0.4980	44.2	34.0	26.7	21.4	17.4	14.3
0.5975	92.7	70.7	54.3	32.4	25.9	20.8
0.6972	137.1	100.5	75.3	57.3	44.4	26.6
0.7982	184.7	132.7	96.9	72.7	55.2	43.0
0.8978	206.9	143.7	102.0	74.7	56.0	41.9
x_1 [BHEM][mesy] + x_2 isopropanol						
V^E ($cm^3 \cdot mol^{-1}$)						
0.0998	− 0.57	− 0.60	− 0.64	− 0.69	− 0.75	− 0.81
0.2001	− 0.86	− 0.93	− 0.99	− 1.06	− 1.06	− 1.23
0.3002	− 1.06	− 1.13	− 1.20	− 1.27	− 1.35	− 1.46

Table 7 (continued)

T (K)	298.15	303.15	308.15	313.15	318.15	323.15
x_1						
0.4004	− 1.18	− 1.25	− 1.32	− 1.39	− 1.47	− 1.56
0.4982	− 1.19	− 1.31	− 1.37	− 1.44	− 1.52	− 1.59
0.5999	− 1.20	− 1.26	− 1.31	− 1.34	− 1.41	− 1.47
0.6997	− 1.08	− 1.13	− 1.18	− 1.22	− 1.28	− 1.33
0.7978	− 0.95	− 0.99	− 1.02	− 1.06	− 1.10	− 1.13
0.8994	− 0.73	− 0.75	− 0.76	− 0.78	− 0.81	− 0.83
$\Delta\eta$ (mPa·s)						
0.0998	1.60	1.41	1.28	1.17	1.25	0.98
0.2001	5.73	5.08	4.39	3.72	3.20	2.79
0.3002	15.1	12.1	10.0	8.35	7.00	6.21
0.4004	32.0	25.0	19.9	16.2	13.3	11.1
0.4982	67.9	44.5	34.5	27.4	22.0	18.0
0.5999	119.6	87.1	67.2	42.1	33.1	26.5
0.6997	177.3	129.5	96.8	72.7	56.7	34.2
0.7978	232.7	162.4	116.9	88.8	68.1	52.6
0.8994	253.9	172.3	121.1	87.9	66.2	50.1

[a]Uncertainty in temperature for $V^E = \pm 0.02$ K; uncertainty in temperature for $\Delta\eta = \pm 0.02$ K

[b]Uncertainty in molar frication = ± 0.0001

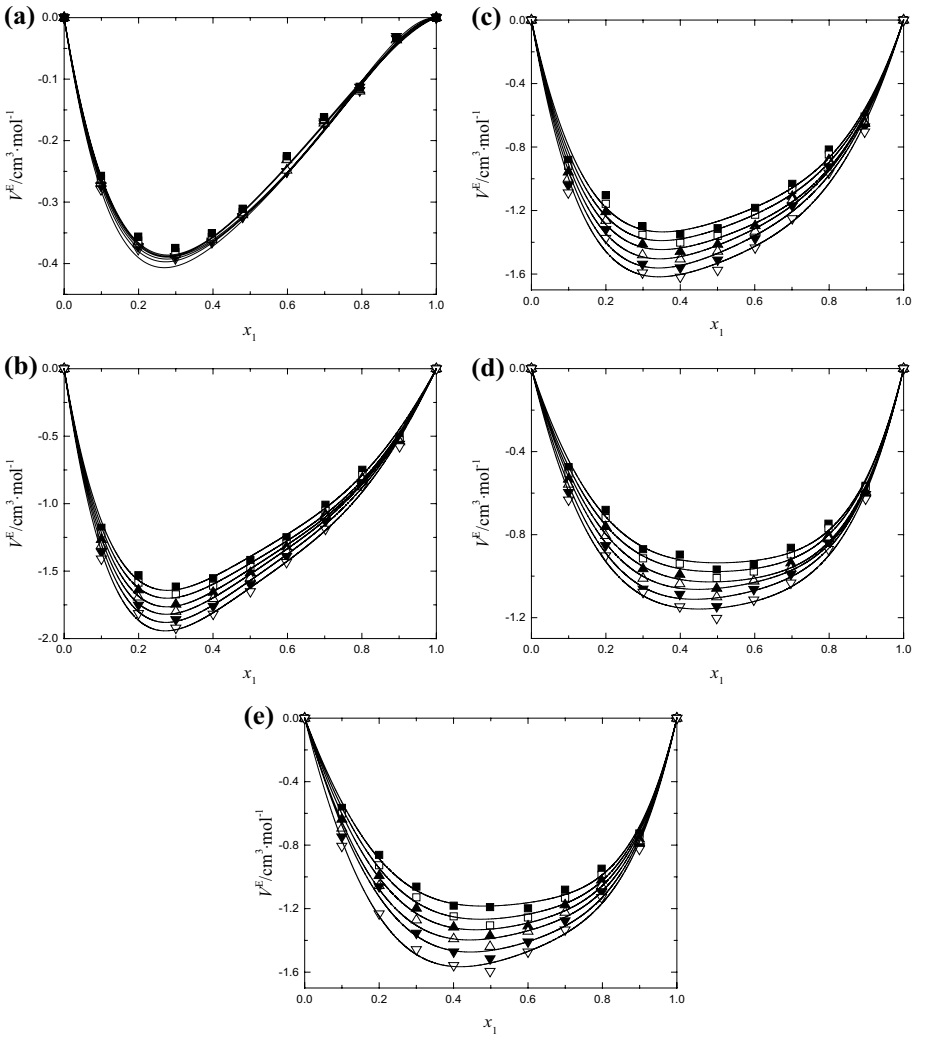


Fig. 3 Excess molar volumes for mixtures of **a** x_1 [BHEM][mesy]+x_2 water, **b** x_1 [BHEM][mesy]+x_2 methanol, **c** x_1 [BHEM][mesy]+x_2 ethanol, **d** x_1 [BHEM][mesy]+x_2 *n*-propanol, **e** x_1 [BHEM][mesy]+x_2 isopropanol at different temperatures. Open inverted triangle, 298.15 K; filled inverted triangle, 303.15 K; open triangle, 308.15 K; filled triangle, 313.15 K; open square, 318.15 K; filled square, 323.15 K; the solid curves were calculated with the Redlich – Kister equation, and the symbols represent experimental values

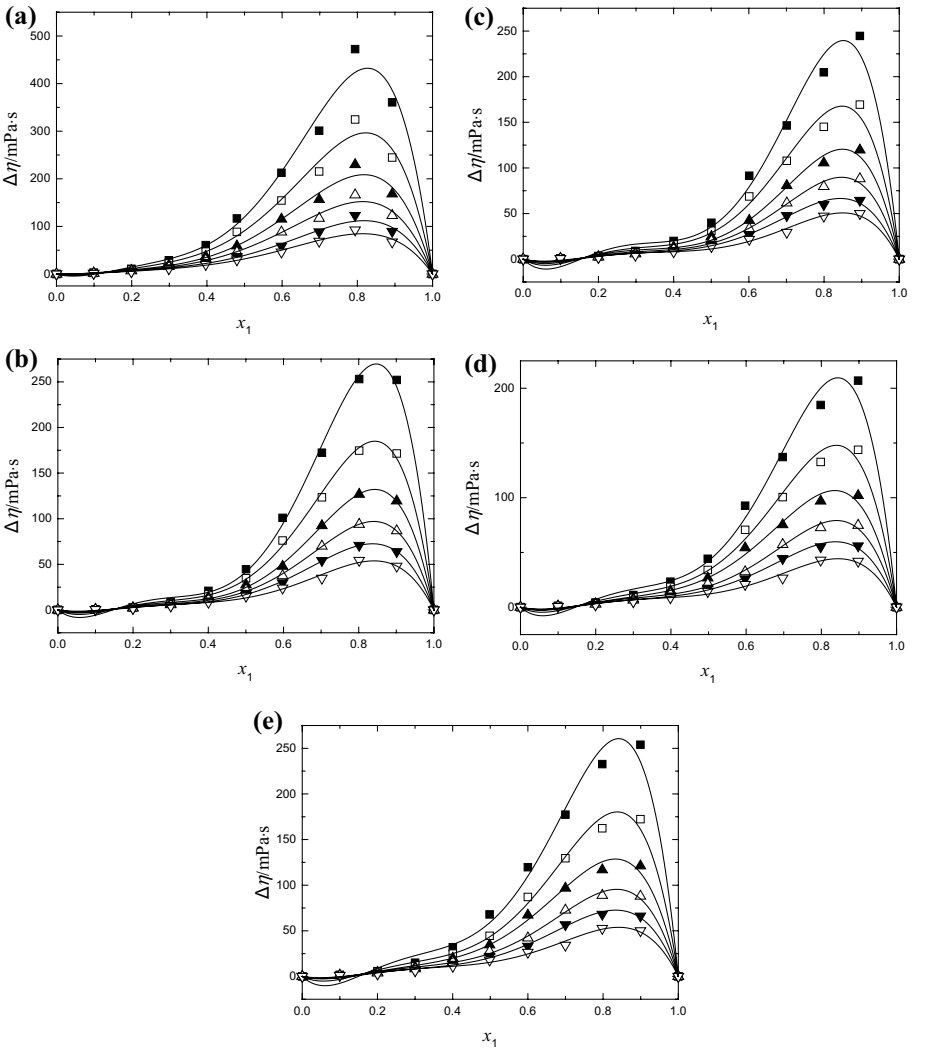


Fig. 4 Viscosity deviations for mixtures of **a** x_1 [BHEM][mesy] + x_2 water, **b** x_1 [BHEM][mesy] + x_2 methanol, **c** x_1 [BHEM][mesy] + x_2 ethanol, **d** x_1 [BHEM][mesy] + x_2 *n*-propanol, **e** x_1 [BHEM][mesy] + x_2 isopropanol at different temperatures. Open inverted triangle, 323.15 K; filled inverted triangle, 318.15 K; open triangle, 313.15 K; filled triangle, 308.15 K; open square, 303.15 K; filled square, 298.15 K; the solid curves were calculated with the Redlich – Kister equation, and the symbols represent experimental values

Table 8 Coefficients of the Redlich – Kister equation and standard deviations for excess molar volume for [BHEM][mesy] with water or alcohols

Mixtures	T (K)[a]	A_0	A_1	A_2	A_3	$\sigma(Y)$
V^E ($cm^3 \cdot mol^{-1}$)						
x_1 [BHEM][mesy] + x_2 water	298.15	− 1.27	1.19	− 0.77	0.81	0.0081
	303.15	− 1.26	1.15	− 0.70	0.82	0.0073
	308.15	− 1.26	1.11	− 0.70	0.77	0.0072
	313.15	− 1.25	1.12	− 0.70	0.70	0.0074
	318.15	− 1.22	1.18	− 0.72	0.52	0.0089
	323.15	− 1.21	1.19	− 0.70	0.51	0.0088
x_1 [BHEM][mesy] + x_2 methanol	298.15	− 5.57	3.20	− 5.01	2.35	0.0399
	303.15	− 5.77	3.27	− 5.28	2.44	0.0406
	308.15	− 5.94	3.53	− 5.50	2.34	0.0394
	313.15	− 6.09	3.70	− 5.65	2.51	0.0406
	318.15	− 6.28	3.83	− 5.87	2.64	0.0425
	323.15	− 6.49	3.88	− 6.11	2.97	0.0425
x_1 [BHEM][mesy] + x_2 ethanol	298.15	− 5.07	1.50	− 3.68	0.41	0.0582
	303.15	− 5.27	1.58	− 3.85	0.52	0.0578
	308.15	− 5.50	1.59	− 3.99	0.71	0.0601
	313.15	− 5.68	1.81	− 4.12	0.73	0.0593
	318.15	− 5.88	1.92	− 4.30	0.84	0.0611
	323.15	− 6.13	1.80	− 4.55	1.23	0.0629
x_1 [BHEM][mesy] + x_2 *n*-propanol	298.15	− 3.74	0.00	− 2.55	− 0.91	0.0318
	303.15	− 3.91	0.04	− 2.62	− 0.72	0.0312
	308.15	− 4.11	0.10	− 2.75	− 0.79	0.0313
	313.15	− 4.24	0.35	− 2.87	− 1.03	0.0300
	318.15	− 4.42	0.44	− 2.95	− 0.85	0.0309
	323.15	− 4.62	0.35	− 3.05	− 0.50	0.0335
x_1 [BHEM][mesy] + x_2 isopropanol	298.15	− 4.73	0.14	− 3.10	− 1.84	0.0347
	303.15	− 5.06	0.25	− 3.02	− 1.81	0.0379
	308.15	− 5.32	0.40	− 3.12	− 1.82	0.0366
	313.15	− 5.55	0.61	− 3.38	− 1.86	0.0379
	318.15	− 5.85	0.68	− 3.29	− 1.93	0.0491
	323.15	− 6.17	1.06	− 3.80	− 1.73	0.0366
$\Delta\eta$ (mPa·s)						
x_1 [BHEM][mesy] + x_2 water	298.15	479.8	1557	2495	1631	25.0
	303.15	364.1	1108	1638	1011	16.4
	308.15	270.4	816.2	1128	605.4	11.5
	313.15	211.8	600.3	792.5	418.8	7.6
	318.15	156.8	415.0	591.4	360.9	6.1
	323.15	127.2	317.7	429.6	255.0	4.3
x_1 [BHEM][mesy] + x_2 methanol	298.15	166.8	730.2	1821	1585	6.4
	303.15	134.7	537.2	1210	1006	4.4
	308.15	98.77	378.1	864.3	722.9	2.1
	313.15	81.3	289.5	618.1	501.9	1.5
	318.15	67.7	226.9	448.9	349.7	1.1
	323.15	52.8	145.2	327.4	309.6	2.1

Table 8 (continued)

Mixtures	T (K)[a]	A_0	A_1	A_2	A_3	$\sigma(Y)$
x_1 [BHEM][mesy] + x_2 ethanol	298.15	141.2	545.3	1625	1632	12.9
	303.15	115.1	414.4	1109	1069	8.6
	308.15	83.4	283.2	799.7	791.7	5.0
	313.15	69.4	219.7	583.1	567.9	3.5
	318.15	58.9	174.5	419.3	392.5	2.4
	323.15	44.9	102.6	317.6	365.1	2.7
x_1 [BHEM][mesy] + x_2 *n*-propanol	298.15	169.6	561.3	1333	1242	10.1
	303.15	135.2	427.3	912.1	803.1	6.7
	308.15	108.7	327.3	635.8	531.2	4.5
	313.15	76.8	216.7	485.6	445.8	2.4
	318.15	63.4	168.7	356.9	322.4	1.8
	323.15	48.1	97.3	262.0	298.5	2.3
x_1 [BHEM][mesy] + x_2 isopropanol	298.15	237.8	722.9	1598	1496	12.3
	303.15	175.4	538.2	1093	936.7	7.2
	308.15	140.6	413.8	750.5	594.9	5.0
	313.15	101.3	282.0	569.0	488.5	2.6
	318.15	82.1	221.3	425.5	351.8	2.0
	323.15	62.0	128.0	312.5	339.9	2.5

[a]Uncertainty in temperature for $V^E = \pm 0.02$ K; uncertainty in temperature for $\Delta\eta = \pm 0.02$ K

Table 9 Partial molar volumes of the mixtures of [BHEM][mesy] with water or alcohols at temperatures from (298.15 to 323.15) K

T (K)[a]	$\bar{V}_1$ ($cm^3 \cdot mol^{-1}$)[c]						$\bar{V}_2$ ($cm^3 \cdot mol^{-1}$)[d]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy]+x_2 water												
0.0000	215.9	216.2	216.6	216.9	217.4	217.9	18.1	18.1	18.1	18.2	18.2	18.2
0.0989	185.8	186.3	186.7	187.1	187.5	188.0	20.0	20.1	20.1	20.1	20.2	20.2
0.1991	177.0	177.4	177.8	178.2	178.7	179.1	20.6	20.6	20.6	20.7	20.7	20.8
0.2989	172.9	173.3	173.8	174.2	174.6	175.0	20.9	20.9	20.9	21.0	21.0	21.1
0.3971	170.6	171.1	171.5	171.9	172.3	172.7	21.1	21.2	21.2	21.2	21.3	21.3
0.4797	169.4	169.8	170.2	170.6	171.0	171.4	21.3	21.3	21.4	21.4	21.4	21.5
0.5983	168.1	168.5	168.9	169.3	169.8	170.2	21.6	21.6	21.6	21.7	21.7	21.8
0.6984	167.3	167.7	168.2	168.6	169.0	169.4	21.8	21.8	21.8	21.9	21.9	22.0
0.7942	166.7	167.2	167.6	168.0	168.4	168.8	22.0	22.0	22.0	22.0	22.1	22.1
0.8928	166.3	166.7	167.1	167.5	167.9	168.3	22.2	22.2	22.2	22.2	22.3	22.3
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	22.3	22.3	22.3	22.3	22.4	22.4
x_1 [BHEM][mesy]+x_2 methanol												
0.0000	273.5	275.1	276.9	278.6	280.3	282.1	40.7	41.0	41.2	41.5	41.7	42.0
0.1000	222.5	223.4	224.3	225.3	226.3	227.2	46.0	46.2	46.5	46.8	47.0	47.3
0.1996	201.3	202.0	202.7	203.4	204.1	204.9	48.4	48.7	49.0	49.3	49.6	49.9
0.3001	189.6	190.2	190.7	191.3	191.9	192.6	50.0	50.3	50.5	50.8	51.2	51.5
0.4004	182.3	182.8	183.4	183.9	184.4	185.0	51.2	51.5	51.8	52.1	52.5	52.8
0.5005	177.3	177.8	178.3	178.8	179.3	179.8	52.2	52.5	52.9	53.2	53.6	53.9
0.5976	173.7	174.2	174.7	175.2	175.6	176.1	53.1	53.4	53.8	54.2	54.5	54.9
0.7022	170.9	171.3	171.8	172.2	172.6	173.1	54.0	54.3	54.7	55.1	55.5	55.8
0.8012	168.8	169.2	169.6	170.0	170.5	170.9	54.8	55.2	55.6	56.0	56.4	56.8
0.9012	167.0	167.4	167.8	168.3	168.7	169.1	55.6	55.9	56.4	56.8	57.2	57.6
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	56.7	57.2	57.6	58.1	58.5	59.0

Table 9 (continued)

T (K)[a]	$\bar{V}_1$ ($cm^3 \cdot mol^{-1}$)[c]						$\bar{V}_2$ ($cm^3 \cdot mol^{-1}$)[d]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy] + x_2 ethanol												
0.0000	274.2	275.6	277.2	278.8	280.4	282.0	58.7	59.0	59.3	59.7	60.0	60.4
0.0990	234.4	235.4	236.4	237.5	238.5	239.5	65.4	65.8	66.1	66.5	66.9	67.3
0.2000	212.8	213.6	214.4	215.2	216.0	216.8	69.6	70.0	70.4	70.7	71.1	71.6
0.2984	199.2	199.8	200.5	201.2	201.8	202.5	72.1	72.5	72.9	73.3	73.7	74.2
0.4000	189.6	190.2	190.8	191.4	192.0	192.6	74.1	74.5	74.9	75.4	75.8	76.3
0.5005	182.7	183.3	183.8	184.3	184.8	185.4	75.6	76.0	76.5	77.0	77.4	77.9
0.6011	177.6	178.1	178.5	179.0	179.5	180.0	77.0	77.4	77.9	78.4	78.8	79.3
0.7008	173.5	174.0	174.5	174.9	175.4	175.8	78.1	78.6	79.1	79.6	80.1	80.6
0.7993	170.4	170.8	171.3	171.7	172.1	172.6	79.3	79.7	80.2	80.8	81.3	81.8
0.8954	167.8	168.2	168.7	169.1	169.5	169.9	80.2	80.7	81.3	81.8	82.4	82.9
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	81.9	82.4	83.0	83.6	84.2	84.8
x_1 [BHEM][mesy] + x_2 *n*-propanol												
0.0000	269.2	270.6	272.0	273.4	274.9	276.4	75.2	75.5	75.9	76.3	76.7	77.2
0.0999	238.4	239.5	240.5	241.6	242.6	243.7	82.8	83.2	83.7	84.1	84.5	85.0
0.1996	218.8	219.7	220.5	221.3	222.2	223.1	87.9	88.3	88.8	89.3	89.7	90.2
0.2999	204.9	205.6	206.3	207.0	207.7	208.5	91.4	91.9	92.4	92.9	93.4	93.9
0.3987	194.9	195.5	196.1	196.7	197.4	198.0	94.1	94.6	95.1	95.7	96.2	96.7
0.4980	187.0	187.6	188.1	188.7	189.3	189.8	96.2	96.7	97.2	97.8	98.3	98.9
0.5975	180.9	181.4	181.9	182.5	183.0	183.5	97.9	98.5	99.0	99.7	100.3	100.9
0.6972	175.9	176.4	176.9	177.3	177.8	178.3	99.5	100.1	100.6	101.2	101.9	102.5
0.7982	171.8	172.2	172.7	173.1	173.6	174.0	100.9	101.5	102.1	102.7	103.3	104.0
0.8978	168.4	168.8	169.3	169.7	170.1	170.5	102.2	102.8	103.4	104.1	104.8	105.4
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	104.0	104.7	105.3	106.0	106.7	107.4

Table 9 (continued)

T (K)[a]	$\bar{V}_1$ ($cm^3 \cdot mol^{-1}$)[c]						$\bar{V}_2$ ($cm^3 \cdot mol^{-1}$)[d]					
x_1[b]	298.15	303.15	308.15	313.15	318.15	323.15	298.15	303.15	308.15	313.15	318.15	323.15
x_1 [BHEM][mesy] + x_2 isopropanol												
0.0000	275.6	277.1	278.7	280.3	281.9	283.7	77.0	77.4	77.8	78.3	78.7	79.2
0.0998	242.8	243.9	245.1	246.1	247.3	248.5	85.0	85.4	85.9	86.4	86.9	87.4
0.2001	221.7	222.5	223.4	224.3	225.3	226.1	90.3	90.8	91.3	91.8	92.4	92.8
0.3002	207.0	207.7	208.4	209.1	209.9	210.6	94.0	94.5	95.0	95.6	96.1	96.7
0.4004	196.1	196.7	197.4	198.0	198.6	199.3	96.8	97.3	97.9	98.5	99.0	99.7
0.4982	188.1	188.5	189.1	189.7	190.2	190.8	99.0	99.5	100.1	100.7	101.3	102.0
0.5999	181.4	181.9	182.4	182.9	183.5	184.0	100.9	101.5	102.1	102.8	103.4	104.1
0.6997	176.2	176.7	177.1	177.6	178.1	178.6	102.5	103.2	103.8	104.5	105.2	105.9
0.7978	172.0	172.4	172.9	173.3	173.7	174.2	104.0	104.6	105.3	106.0	106.7	107.5
0.8994	168.4	168.8	169.2	169.6	170.1	170.5	105.4	106.1	106.9	107.6	108.3	109.2
1.0000	165.8	166.2	166.7	167.1	167.5	167.9	107.6	108.3	109.1	109.9	110.7	111.5

[a]Uncertainty in temperature = ±0.02 K

[b]Uncertainty in molar fraction = ±0.0001

[c] $\bar{V}_1$ denotes the molar volume of pure [BHEM][mesy]

[d] $\bar{V}_2$ denotes the molar volume of pure solvents

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