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Densities, refractive index and excess properties of bis(2-hydroxyethyl)ammonium acetate ([bheaa]) + monoethanolamine + water system at temperatures from 303.15 to 353.15 K

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ABSTRACT

The densities and refractive indices of ternary system of bis(2-hydroxyethyl)ammonium acetate ([bheaa]) + monoethanolamine + water have been measured at $T = (303.15$ to $353.15)$ K. The measured density and refractive index data were correlated as a function of concentration and temperature. Excess molar volumes and refractive index deviations were calculated from the measured densities and refractive indices at each temperature. The excess molar volumes are negative and the refractive index deviations are positive at all conditions.

1. Introduction

Ionic liquids (ILs) are highly stable at room temperature and their possible applications towards new commercial chemical processes have been explored, since they were introduced in early 1914 [1]. A wide range of ILs can be synthesized by varying the cations and anions, since ILs solely comprised of ions *i.e.*, organic cations and organic/inorganic anions [2]. Some of the common cations that have been found include: imidazolium, pyrrolidinium, quaternary ammonium, and pyridium, *etc.* while for anion, tetraflouroborate [BF_4], hexaflourophosphate [PF_6], bis(triflouromethylsulfonyl) imide [Tf_2N], triflate [CF_3SO_3], and acetate [CH_3CO_3] are often been used [3–6]. Recently, ILs have received a considerable attention as green solvents and also considered as a potential environmentally friendly replacement for the traditional volatile organic solvents. ILs with the properties such as low melting point, high solubility with both polar and non-polar substances, negligible vapor pressure, and high thermal stability that avoid loss of absorbents, are believed to be a more suitable alternative for volatile organic compounds. However, large scale commercial usage of ILs seems to be not viable due to some disadvantages especially on their high viscosity that can hinder their application in the separation process.

The usage of binary and ternary mixtures is believed to have many potential advantages. The advantages of using the mixture of the pure components include the utilization of the unique qualities of each component and combine them in such a way that the expected properties could not be extracted by using a single component system. Since no chemical changes are involved during the mixing of the components, their chemical properties can be maintained, thus making it possible to tune their physical properties, resulting in a highly effective new solvent for various chemical processes with appreciable properties. ILs have been found to be miscible with various organic and inorganic compounds. In our previous study [7], binary mixture of bis(2-hydroxyethyl)ammonium acetate ([bheaa]) − water and [bheaa] − MEA was prepared for potential application towards effective CO_2 capture. The densities of the mentioned mixtures have been measured and the excess molar volumes have been deduced at temperature range from 303.15 to 353.15 K [8]. Binary and ternary mixtures were also being commonly used by many other researchers for CO_2 capture [9–14]. This research is a part of our ongoing research to measure and establish the physical properties of the binary/ternary mixtures involving ILs, amine and water for the absorption of CO_2. In the present work, [bheaa], MEA and water were mixed to form ternary system and their physical properties, namely, density and refractive index have been measured at temperatures from 303.15 to 353.15 K. Excess molar volumes and refractive index deviations were calculated on the basis of the measured densities and refractive indices of the ternary system, respectively.

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Table 1
Comparison of measured physical properties for pure components at temperatures from 303.15 to 353.15 K.

Properties	MEA			BHEAA	
	T/K	This work	Lit.	This work	Lit.
ρ/g.cm^{-3}	303.15	1.01067	1.0082 [23] 1.0091 [24]	1.16862	1.16639 [15]
	313.15	1.00277	1.0010 [23] 1.0013 [24]	1.16229	1.16012 [15]
	323.15	0.99480	0.9927 [21] 0.99219 [22] 0.994 [23] 0.9934 [24]	1.15584	1.15396 [15]
	333.15	0.98675	0.9850 [21] 0.98410 [22]	1.14928	1.14764 [15]
	343.15	0.97862	0.9773 [21] 0.97594 [22]	1.14276	1.14122 [15]
	353.15	0.97040	0.9696 [21] 0.96768 [22]	1.13612	1.13466 [15]
n_D	303.15	1.45273	1.4503 [25]	1.48008	1.43238 [15]
	313.15	1.44913	N/A	1.47793	1.43029 [15]
	323.15	1.44561	N/A	1.47575	1.42798 [15]
	333.15	1.44213	N/A	1.47313	1.42547 [15]
	343.15	1.43862	N/A	1.47086	N/A
	353.15	1.43472	N/A	1.46849	N/A

2. Experiment section

2.1. Chemicals

For the present research, IL used, namely, bis(2-hydroxyethyl)ammonium acetate [bheaa] was synthesized in our laboratory. The structure and characterizations of [bheaa] were established earlier [15,16]. The [bheaa] used in the present study was ≥99% pure (determined by HPLC). The water content in the IL used was determined using a coulometer Karl Fischer titrator, DL 39 (Mettler Toledo) using the Hydranal coulomat AG reagent (Riedel-de-Haen) and the value was found to be 166 ppm. Monoethanolamine (MEA) was obtained from Aldrich (AR grade) with a purity of ≤99% (GC, area %) and double distilled deionized water was used. Three constant ratios, z (mole fraction of IL x_1 / mole fraction of water x_3) have been chosen with varying mole fraction of MEA (x_2) in order to cover the entire range of compositions of all components involved. All samples were prepared freshly and retained at room temperature for 24 h to ensure their solubility at the desired temperature. The samples were kept in airtight glass vials and sealed with parafilm to prevent any possible humid effects on the samples. The samples were prepared based on mass fraction using an analytical balance (model AS120S, Mettler Toledo) with a precision of ±0.0001 g and later were converted to mole fraction. The uncertainty in the mole fractions prepared was estimated to be $\pm 1 \times 10^{-4}$.

2.2. Apparatus and procedures

The density of the ternary mixtures including pure MEA and pure [bheaa] was measured using the Anton Paar, Oscillating U-tube density meter (DMA-5000), at temperatures from 303.15 to 353.15 K with an uncertainty of ±0.01 K. Millipore quality water and dry air were used to calibrate the density meter and validated using several ILs for which the data were already established [7,15–20]. The apparatus was precise within $1 \cdot 10^{-5}$ g · cm^{-3} and the uncertainty of the measurements was better than $4 \cdot 10^{-5}$ g · cm^{-3}. The density measurements for the ternary mixture samples were made in triplicate and the average values are reported for further analysis.

A digital refractometer (model ATAGO RX-5000) with a measuring accuracy of $\pm 4.10^{-5}$ has been used to measure the refractive indices of the ternary mixtures including the pure MEA and [bheaa] in the temperature range of 303.15 to 353.15 K. The refractometer was equipped with water bath and the temperature of the apparatus was controlled to within ±0.05 K. The apparatus was calibrated by measuring the refractive index of Millipore quality water and again

Table 2
Experimental densities (ρ) of [bheaa] + MEA + water system at temperatures from 303.15 to 353.15 K.

x_1	x_2	T = 303.15	T = 313.15	T = 323.15	T = 333.15	T = 343.15	T = 353.15
		z (x_1 / x_3) = 0.11					
0.0892	0.1003	1.08505	1.07953	1.07369	1.06773	1.06156	1.05519
0.0790	0.1999	1.07531	1.06942	1.06323	1.05695	1.05048	1.04382
0.0694	0.3002	1.06600	1.05970	1.05327	1.04669	1.03995	1.03303
0.0594	0.3999	1.05663	1.05001	1.04327	1.03640	1.02938	1.02221
0.0495	0.4997	1.04795	1.04104	1.03403	1.02691	1.01965	1.01225
0.0396	0.5997	1.03950	1.03234	1.02510	1.01775	1.01029	1.00268
0.0299	0.7000	1.03183	1.02445	1.01700	1.00946	1.00182	0.99405
0.0199	0.7994	1.02398	1.01640	1.00876	1.00104	0.99322	0.98528
0.0099	0.9007	1.01625	1.00849	1.00066	0.99277	0.98478	0.97669
		z (x_1 / x_3) = 0.62					
0.3439	0.0998	1.14201	1.13618	1.13031	1.12440	1.11841	1.11231
0.3064	0.2001	1.12898	1.12315	1.11728	1.11136	1.10536	1.09926
0.2680	0.3000	1.11580	1.10990	1.10396	1.09795	1.09187	1.08569
0.2297	0.4001	1.10267	1.09660	1.09049	1.08431	1.07806	1.07171
0.1915	0.4993	1.08872	1.08246	1.07615	1.06978	1.06333	1.05679
0.1531	0.5999	1.07405	1.06754	1.06099	1.05437	1.04767	1.04088
0.1149	0.6998	1.05948	1.05265	1.04578	1.03883	1.03181	1.02470
0.0760	0.7948	1.04409	1.03694	1.02973	1.02247	1.01512	1.00769
0.0381	0.8974	1.02725	1.01973	1.01217	1.00453	0.99682	0.98902
		z (x_1 / x_3) = 4.03					
0.7208	0.0995	1.15642	1.15039	1.14434	1.13835	1.13201	1.12562
0.6405	0.1999	1.14878	1.14291	1.13700	1.13108	1.12492	1.11850
0.5610	0.3001	1.13972	1.13390	1.12806	1.12213	1.11616	1.11014
0.4681	0.3895	1.12840	1.12260	1.11671	1.11077	1.10478	1.09873
0.3989	0.4977	1.11617	1.11014	1.10415	1.09800	1.09172	1.08557
0.3191	0.5972	1.10143	1.09519	1.08902	1.08270	1.07634	1.07001
0.2392	0.6966	1.08454	1.07801	1.07156	1.06508	1.05855	1.05195
0.1594	0.7968	1.06479	1.05781	1.05121	1.04436	1.03746	1.03048
0.0803	0.9011	1.04043	1.03318	1.02589	1.01855	1.01115	1.00368