



Interactions of 1-butyl-3-methylimidazolium bromide with isopropyl alcohol binary system: Spectroscopic and Volumetric measurements at T (303.15, 313.15 and 323.15)K

Victoria Bennett¹, Ikechukwu P. Ejidike^{2*},
Donbebe Wankasi¹, Ezekiel D. Dikio²

¹Department of Chemical Sciences, Faculty of Science, Niger Delta University, Wilberforce Island, P. M. B. 23 Yenagoa, Nigeria.

²Department of Chemistry, Faculty of Applied and Computer Sciences, Vaal University of Technology, P. O. Box X021, Vanderbijlpark 1911, South Africa.

Abstract: The ionic liquid, 1-butyl-3-methylimidazolium bromide [BMIm][Br] was synthesized and characterized. Density (ρ), viscosity (η) and physicochemical properties, at 303.15, 313.15 and 323.15 K were measured over the entire range of mixture composition. These data have been used to calculate the excess volume (V_m^E), deviations in viscosity ($\Delta\eta$) and excess Gibbs free energy of activation of viscous flow (ΔG^{*E}). These results were fitted to the Redlich-Kister polynomial equation to derive the binary coefficients and standard deviations. The experimental and calculated quantities were used to study the nature of the intermolecular interactions between the mixture components. The viscosities were correlated with single parameter Grunberg and Nissan model, Hind model, Frenkel model and Kendall and Monroe model.

Keywords : Ionic Liquid, Spectroscopic, Density, Viscous flow, Viscosity, FTIR, NMR spectra.

1. Introduction

An ionic liquid is any salt that is liquid below 100°C [1-7]. Ionic liquids are usually quaternary ammonium salts. Cations such as tetraalkylammonium [R_4N^+] or cyclic amines (imidazolium, pyridinium, pyrrolidinium, and Guanidinium) are known. Anions may be based on bromo-, cyano-, chloro-, and hexafluorophosphate groups. [4] Soon after the first reports on the synthesis and applications in organometallic catalysis of the air stable room temperature ionic liquids (RTIL), 1-butyl-3-methylimidazolium tetrafluoroborate (BMI.BF₄), hexafluorophosphate (BMImPF₆) and their analogues, in the middle of the 1990s a renaissance of the rich chemistry of molten salts was begun and continues to flourish [6]. There is then no doubt that research into the use of ionic liquids as solvents, reagents, catalysts, and materials will continue to grow. Ionic liquids possess a unique array of physicochemical properties that make them important candidates for a number of energy-related task-specific applications. The following are some physicochemical properties of

ionic liquids: High polarity, high viscosity, low vapor pressure, non-flammability, low combustibility, excellent thermal stability [8-11]. However, mixtures of ionic liquids have been known to have different properties from the properties of the pure liquids. In thermodynamics, various intermolecular interactions may take place between the component molecules. The types and strength of such interactions are most times evaluated through some thermodynamic excess functions which are usually described to be either positive or negative. This classification is used to develop statistical theories based on fluid models to interpret the deviations from ideal behaviour of the binary liquid systems. The thermodynamic functions are used to give a more quantitative understanding of the nature of intermolecular interactions of binary liquid systems. Density and viscosity of liquid mixtures are important in most engineering calculations and different analytical applications [12]. Hence, evaluation and prediction of these properties of solvent mixtures as functions of temperature and composition are of theoretical and practical importance [13]. In the chemical industry, knowledge of the thermodynamic properties of liquids is essential in designs involving chemical separation, heat transfer, and fluid flow. Moreover, thermodynamic properties of binary mixtures containing components capable of undergoing specific interactions exhibit significant deviations from ideality arising from differences in molecular size, shape, and structural changes. The characterization of the mixtures through their thermodynamic and transport properties is important from the fundamental point of view to understand their molecular interactions as well as in practical applications.

An extensive literature survey showed that a limited number of research studies have been reported on the viscosity of Isopropyl alcohol with [BMIm][Br] binary mixtures. 1-Butyl-3-methylimidazolium Bromide ionic liquid [BMIm][Br] is one of the most important traditional ionic liquids and has been widely used in the fields of separation, catalysis, synthesis [14-16]. Isopropyl alcohol is a protic polar solvent. It is popular for pharmaceutical applications because of the low toxicity of any residues [17]. There have been separate reports on the binary derivatives of 1-butyl-3-methylimidazolium bromide [18-21].

This paper presents the thermodynamic properties of binary mixtures containing 1-butyl-3-methylimidazolium bromide and Isopropyl alcohol. In this research, 1-butyl-3-methylimidazolium bromide was synthesized and the experimental measurements of density, viscosity and excess molar volume of Isopropyl alcohol and [BMIm][Br] were obtained at four different temperatures ranging from 303.15 to 323.15 K. The density(ρ), corresponding viscosity deviation($\Delta\eta$), excess molar volume(V_m^E), and excess Gibbs free energy of activation of viscous flow (ΔG^{*E}), were calculated. Further, the excess Gibbs free energy of activation of viscous flow, and deviation functions were fitted to the Redlich and Kister type polynomial to estimate the coefficients and the standard deviations. The viscosities were correlated with single parameter Grunberg and Nissan model, Hind model, Frenkel model and Kendall and Monroe model.

2. Experimental

2.1. Materials

Isopropyl alcohol, 1-methylimidazole, and bromobutane were purchased from Alfa Aesar, South Africa and used without further purification.

2.2. Density measurement

Density measurement of Isopropyl alcohol and synthesized ionic liquid was carried out with an Anton Paar DMA-4500 M digital densitometer thermostatted at different temperatures. In order to achieve good precision in temperature control internally ($T \pm 0.01$ K), two integrated Pt 100 platinum thermometers were used. The densimeter protocol includes an automatic correction for the viscosity of the sample. The apparatus is precise to within 1.0×10^{-5} g/cm³, and the uncertainty of the measurements was estimated to be better than 1.0×10^{-4} g/cm³. Calibration of the densitometer was performed at atmospheric pressure using doubly distilled and degassed water.

2.3. Viscosity measurement

Viscosity measurements were carried out using Anton Paar SVM 3000 Stabinger Viscometer. The viscometer has a dynamic viscosity range of 0.2 - 20 000 mPa.s, a kinematic viscosity range of 0.2 - 20 000 mm²/s and a density range of 0.65 - 3 g/cm³. The instrument was equipped with a maximum temperature range

of 105 °C and a minimum of 20 °C below ambient. Instrument viscosity reproducibility is 0.35% of measured value and density reproducibility 0.0005 g/cm.

2.4. Infrared measurement

FT-IR spectra of the ionic liquid within the range 400 – 4000 cm⁻¹ were documented using Perkin-Elmer Spectrum 400 FT-IR/FT-NIR spectrometer.

2.5. NMR measurement

¹H-NMR spectra of the ionic liquid in DMSO were measured using a Bruker Avance 400 NMR spectrometer operating at a proton frequency of 300 MHz and 75.48 MHz for ¹³C. The proton chemical shifts were recorded relative to an internal TMS standard.

2.6. Thermogravimetric analysis

The thermal behavior of the ionic liquid was investigated using a Perkin Elmer Simultaneous Thermal Analyzer (STA 6000) under the nitrogen environment. The ionic liquid sample was heated in platinum crucibles with nitrogen gas flow rate of 19.7 mL/min and a gas pressure of 4.0 bars. The dynamic measurement was made from 30 °C to 950 °C with a ramp rate of 30 °C/min.

2.7. Preparation of 1-Butyl-3-methylimidazolium Bromide [BMIm][Br]

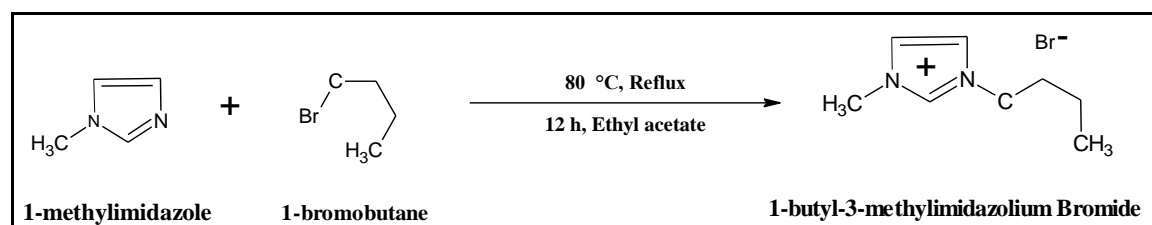
In a 500 ml three-necked round-bottomed flask, 81.89 g (1.0 mol) of 1-methylimidazole and 128.95 g (1.0 mol) of 1-bromobutane were stirred with a magnetic stirrer under a reflux condenser at 80 °C for 12 h. The resultant orange color oil was washed with 60ml acetonitrile. The volatile substance was evaporated in a vacuum oven at 120 °C for 2 h. A light-yellow oil was obtained. Yield (85%). The ionic liquid was characterized by ¹H and ¹³C-NMR, FTIR.

FTIR (pure liquid); v/cm⁻¹: 3035 (b, CH₂/CH₃ stretching), 1591 (b, C=C), 1229 (w, C=N stretching), 1094 (b, C-N-H stretch), 913 (s, C-C skeletal), 817 (s, C-N vibration), 725 (s, C-H bending) [22]. ¹H NMR of the ionic liquid sample (300 MHz, *d*₆-DMSO) contains peaks at δ (ppm): 0.85 (t, methyl), 1.21 (s, CH₂), 1.76 (s, CH₂), 3.8 (s, N-CH₂), 4.3 (s, N-CH₃), 7.76 (s, 1H-imidazole), 7.78 (s, 1H-imidazole), 9.07 (s, 1H-imidazole). ¹³C NMR (300 MHz, *d*₆-DMSO) δ: 19.0 (*qt*, CH₃), 33.0 (*q*, CH₂), 35.69, (*q*, CH₂), 40.0 (*t*, N-methyl), 48.5 (*t*, N-CH₂), 120.3 (*d*, imidazole CH), 122.5 (*d*, imidazole CH), 135.4 (*d*, imidazole CH) [22].

3. Results and discussion

3.1. Synthesis of the ionic liquid: 1-Butyl-3-methylimidazolium Bromide [BMIm][Br]

1-bromobutane is a solvent with low evaporation rate. The reaction of this reagent with N-methylimidazole in a stoichiometric 1:1-mole ratio as expressed in Scheme 1. The expected product of 1-Butyl-3-methylimidazolium Bromide [BMIm][Br] was obtained in a good yield as a one-pot reaction.



Scheme 1. Synthesis pathway of 1-Butyl-3-methylimidazolium Bromide [BMIm][Br]

3.2. Characterization of [BMIm][Br] and its interaction with Isopropyl alcohol

To investigate the molecular interaction between Isopropyl alcohol and [BMIm][Br], excess molar volume (V_m^E) and deviation in viscosity ($\Delta\eta$) data of the binary mixtures were computed from measured densities using the equation 1 and 2 respectively.

$$V^E = \frac{x_1M_1+x_2M_2}{\rho_m} - \left(\frac{x_1M_1}{\rho_1} + \frac{x_2M_2}{\rho_2} \right) \quad 1$$

$$\Delta\eta = \eta_m - (x_1\eta_1 + x_2\eta_2) \quad 2$$

Where x_1 and x_2 are the mole fractions calculated from mass fractions. M_1 and M_2 are molar masses, ρ_1 and ρ_2 are densities, η_1 and η_2 are the viscosities of pure component (1) and (2) [(Isopropyl alcohol) and [BMIm][Br]] respectively. ρ_m and η_m are the density and viscosity of the mixtures.

The excess Gibbs free energy of activation of viscous flow (ΔG^{*E}) for the mixtures was obtained from equation 3.

$$\Delta G^{*E} = RT[\ln\eta_m V_m - (x_1 \ln\eta_1 V_1 + x_2 \ln\eta_2 V_2)] \quad 3$$

where R is the universal constant of gases, T is the absolute temperature, V_1 and V_2 are the molar volumes of component 1 and 2, x_1 and x_2 represent the mole fraction of component 1 and 2. V_m is obtained from equation 4. η_1 , η_2 and η_m are the viscosity of component 1 and 2 and mixture respectively.

$$V_m = \frac{x_1M_1+x_2M_2}{\rho_m} \quad 4$$

The values of V_m^E , $\Delta\eta$, and ΔG^{*E} were correlated by a Redlich-Kister, 1948 [22] type polynomial equation 5 and 6.

$$\Delta Y = x_1x_2 \sum_{k=1}^n A_k (2x_1 - 1)^{k-1} \quad 5$$

$$\Delta Y = x_1x_2 [A_0 + A_1(2x_1 - 1)^1 + A_2(2x_1 - 1)^2 + A_3(2x_1 - 1)^3] \quad 6$$

The values of parameter A_k were obtained by fitting the equation to the experimental values with the Least Square method.

The standard deviations $\sigma(\Delta Y)$ were calculated from equation 7.

$$\sigma(\Delta Y) = \left[\frac{\sum (Y_{\text{expt}} - Y_{\text{calc}})^2}{N-n} \right]^{1/2} \quad 7$$

Where ΔY is the excess volume (V_m^E), deviation in viscosity ($\Delta\eta$) and excess Gibbs free energy of activation of viscous flow (ΔG^{*E}). The subscripts *expt.* and *calc.* represent the experimental and calculated values respectively. N and m are the numbers of experimental data points and the number of coefficients in the Redlich-Kister, 1948 [22] polynomial equation.

Kendall and Monroe derived equation 8 for analyzing the viscosity of binary mixtures based on zero adjustable parameters.

$$E\eta_m = x_1x_2 \left(x_1\eta_1^{1/3} + x_2\eta_2^{1/3} \right)^3 \quad 8$$

where $E\eta_m$ is a modified Kendall-Monroe equation.

The predictive ability of some selected viscosity models such as the one parameter model of Frenkel equation 9 and hind equation 10, apply to the investigated binary systems.

$$\ln \eta = x_1^2 \ln\eta_1 + x_2^2 \ln\eta_2 + 2x_1x_2 \ln\eta_{12} \quad 9$$

$$\eta = x_1^2\eta_1 + x_2^2\eta_2 + 2x_1x_2\eta_{12} \quad 10$$

Where η_{12} is a constant attributed to, unlike pair interactions. Its value was obtained from equation 11.

$$\eta_{12} = 0.5\eta_1 + 0.5\eta_2 \quad 11$$

Grunberg and Nissan, formulated equation 12 to determine the molecular interactions leading to viscosity changes.

$$\ln \eta_m = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 x_2 d' \quad 12$$

Where d' is an interaction parameter which is a function of the composition and temperature of the binary liquid systems.

The correlating ability of equations 8, 9, 10 and 12 was tested by calculating the average percentage deviations (APD) between the experimental and the calculated viscosities were calculated using equation 13.

$$APD = \frac{100}{N} \sum_{i=1}^N \left[\frac{(\eta_{expt} - \eta_{calc})}{\eta_{expt}} \right] \quad 13$$

Where η_{expt} and η_{calc} represent the viscosity of experimental and calculated data, N is the number of experimental data points. The APD values for the binary mixtures of Isopropyl alcohol with [BMIm][Br] are presented in table 5.

3.3. Thermogravimetric Analysis (TGA)

The TGA of the ionic liquid presented in figures 1 shows a single decomposition step. The decomposition of the as-synthesized ionic liquid started at 304 °C. This is an indication that the ionic liquid was thermally stable from 0 °C – 304 °C. This result is in agreement with the report of Ngoyi, *et al.*, (2011) [21].

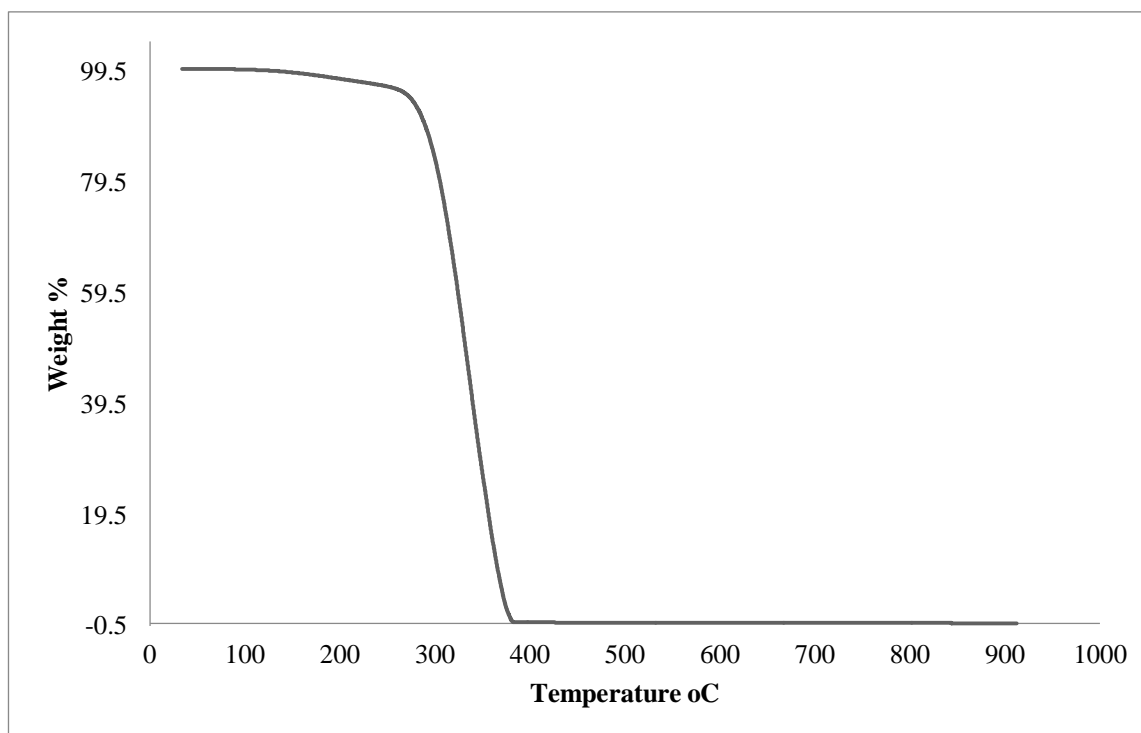


Fig. 1: Thermogravimetric analysis (TGA) pattern of 1-butyl-3-methylimidazolium Bromide.

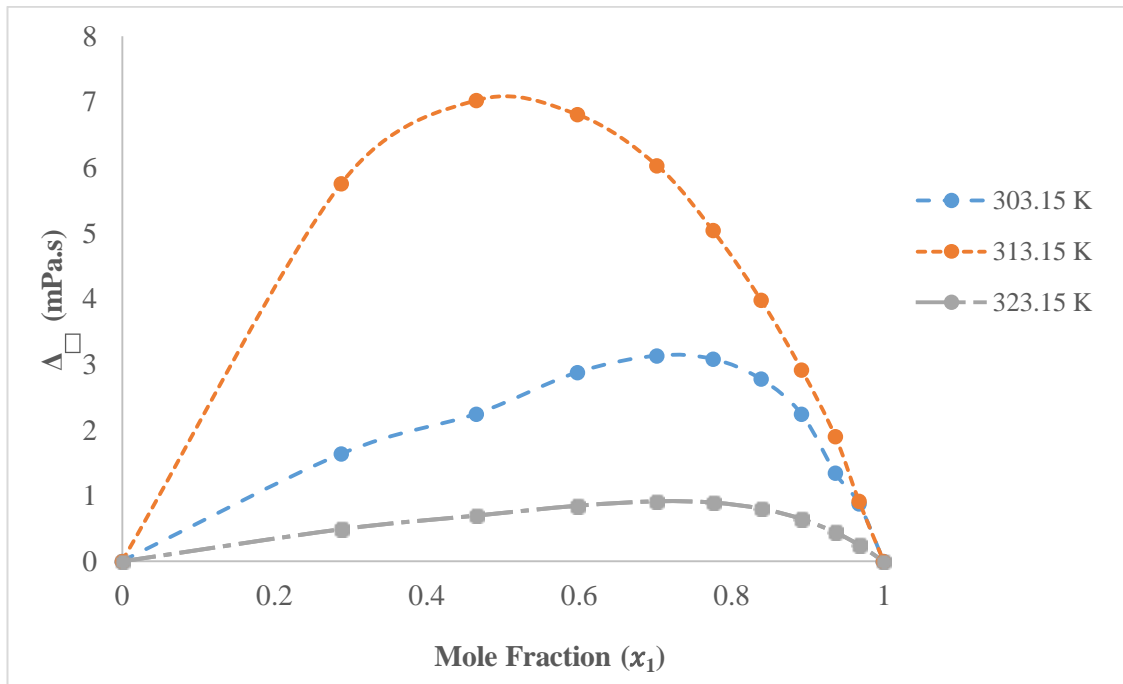


Fig. 2: Deviation in viscosity, $\Delta\eta$ with mole fraction (x_1) Isopropyl alcohol in a binary mixture of Isopropyl alcohol with [BMIm][Br] at 303.15, 313.15 and 323.15 K.

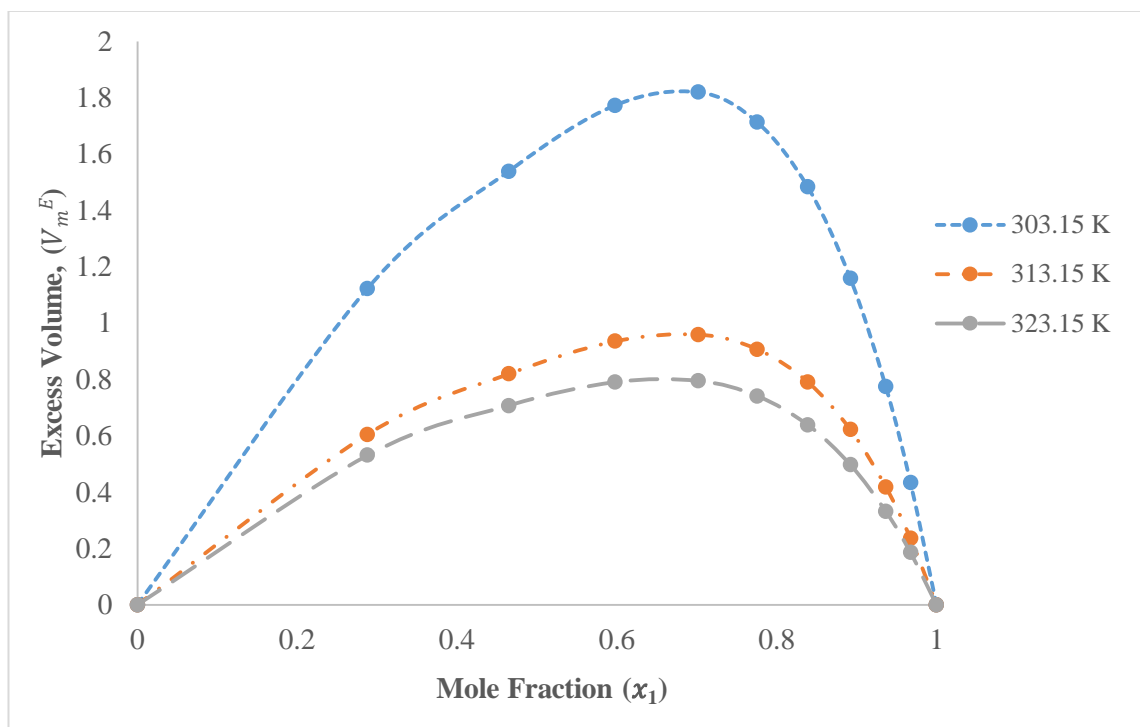


Fig. 3: Plots of excess molar volume (V_m^E) against mole fraction (x_1) Isopropyl alcohol in a binary mixture of Isopropyl alcohol with [BMIm][Br] at 303.15, 313.15 and 323.15 K.

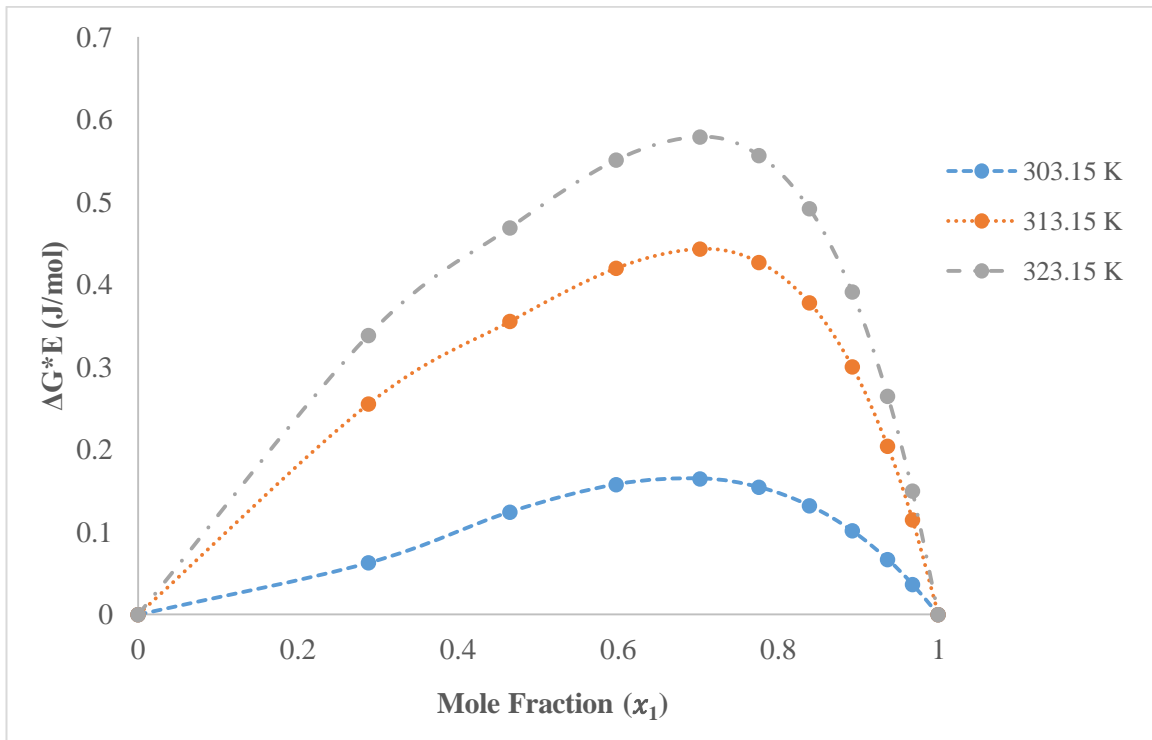


Fig. 4: Plots of excess Gibbs free energy of activation of viscous flow (ΔG^{*E}) against mole fraction (x_1) Isopropyl alcohol in a binary mixture of Isopropyl alcohol with [BMIm][Br] at 303.15, 313.15 and 323.15 K.

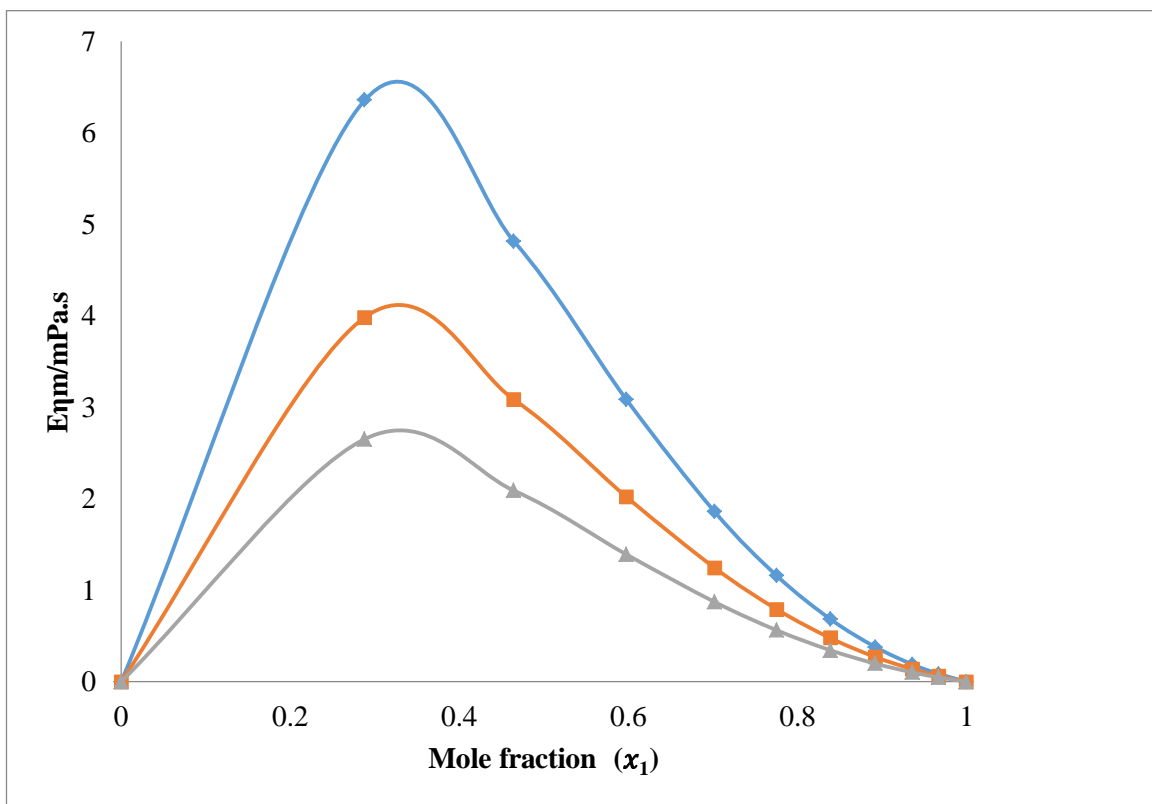


Fig. 5: Plots of modified Kendall and Monroe viscosity correlation $E_{\eta m}$ (mPa.s) against mole fraction (x_1) Isopropyl alcohol in a binary mixture of Isopropyl alcohol with [BMIm][Br] at 303.15 K, 313.15 K and 323.15 K.

3.4. Density and Viscosity measurements

A comparison of our measurements of density and viscosity with the data from literature is shown in Table 1. Deviations in viscosity were found to be positive all through the composition range. The positive values of viscosity deviation for the binary mixtures investigated suggest that the viscosities of associates formed between unlike molecules were relatively less than those of the pure components [23]. Figure 2 clearly shows a deviation in viscosity, i.e. increase with an increase in temperature. The plots of excess molar volume against mole fraction at 303.15, 313.15 and 323.15 K Isopropyl alcohol + [BMIm][Br] are presented in Fig.3. Excess parameters associated with a liquid mixture are a quantitative measure of deviation in the behavior of the liquid mixture from ideality. These functions are found to be sensitive towards the intermolecular forces and on the difference in size and shape of the molecules. Excess volumes of liquid mixtures reflect the result of different contributions arising from structural changes undergone by the pure co-solvent. Positive contributions arise from the breakup of interactions between molecules namely, the rupture of hydrogen-bonded chains and the loosening of dipole interactions [24]. The values of V_m^E for the mixtures of Isopropyl alcohol + [BMIm][Br] are positive all through the entire composition. The values of V_m^E are the result of contributions from several opposing effects. Positive excess volume values observed could be attributed to weak interactions between [BMIm][Br] and Isopropyl alcohol molecules. The plots of excess Gibbs free energy of activation of viscous flow against mole fraction at 303.15, 313.15 and 323.15 K for Isopropyl alcohol + [BMIm][Br] are presented in Fig.4. Excess properties provide information about the molecular interactions and macroscopic behavior of fluid mixtures which can be used to test and improve thermodynamic models for calculating and predicting fluid phase equilibria. The magnitude of ΔG^{*E} represents the strength of interaction between unlike molecules [25]. Excess Gibbs free energy of activation of viscous flow was found to be positive for all plots. In all plots, ΔG^{*E} increased with increase in temperature. The positive values of excess Gibbs free energy of activation of viscous flow indicate the presence of specific and strong interactions in the system under investigation [26]. The excess Gibbs free energy of activation of viscous flow attains a maximum at mole fraction 0.7021.

A comparison of experimental thermodynamic data of multicomponent mixtures with that calculated by means of various predictive methods is very useful from different points of view: (i) it suggests which model is more appropriate to the characteristics of the system, (ii) it may indicate which parameters should be improved when the model involves group contributions and (iii) it may allow the identification of some model as a convenient reference for the interpretation of the deviations observed. The viscosity data have been correlated with semi-empirical equations of modified Kendall and Monroe, Frenkel, Hind, and Grunberg-Nissan. The values of the Grunberg and Nissan constant (d') and modified Kendall-Monroe ($E\eta m$) for the system under study are presented in Tables 2 - 4. Grunberg-Nissan interaction parameters are both positive and negative while the modified Kendall-Monroe viscosity correlation data are all positive. Plots for the modified Kendall-Monroe viscosity correlation are presented in Fig.5. Plots of modified Kendall-Monroe viscosity correlation at different temperatures show a decrease in viscosity with an increase in temperature. The values of Frenkel and Hind are presented in Table 5.

Table 1: Comparison of experimental densities (ρ) and viscosities (η) with literature values

Component	T = 303.15 K		T = 313.15 K		T = 323.15 K	
	ρ (gcm ⁻³) (mPa.s)	η	ρ (gcm ⁻³) (mPa.s)	η	ρ (gcm ⁻³) (mPa.s)	η
[BMIm][Br] Experiment	1.249758.70		1.2427	35.86	1.2356	23.42
Literature	1.288 ²¹ 78.50 ²¹		1.280 ²¹ 51.10 ²¹		1.277 ²¹ 25.20 ²¹	
Isopropyl alcohol Experiment	0.7787	1.6480	0.7699	1.2492	0.7607	0.7607
Literature	N/A	1.77 ²⁷	N/A	N/A	N/A	N/A

N/A = Not available

Table 2: Mole fraction (x_1) of Isopropyl alcohol, density (ρ), viscosity (η), deviation in viscosities ($\Delta\eta$), molar volume (V_m), excess molar volume (V_m^E), excess Gibbs free energy of activation of viscous flow (ΔG^{*E}), Kendall-Monroe ($E\eta_m$) and Grunberg-Nissan (d') parameters for binary mixture of Isopropyl alcohol (x_1) + 1-butyl-3-methylimidazolium Bromide (x_2) at 303.15 K

(x_1)	(ρ) g.cm ⁻³	η mPa.s	$\Delta\eta$ mPa.s	V_m cm.mol ⁻¹	V_m^E cm.mol ⁻¹	ΔG^{*E} J.mol ⁻¹	$E\eta_m$	d'
0.0000	1.2497	58.697	0.0000	175.36	0.0000	0.0000	0.0000	0.0000
0.2881	1.1562	25.092	1.6363	146.83	1.1232	0.0629	6.3548	0.4709
0.4648	1.0732	13.137	2.2453	129.33	1.5387	0.1247	4.8095	0.1204
0.5976	1.0222	9.2003	2.8764	116.18	1.7725	0.1581	3.0834	0.4574
0.7021	0.9665	6.4799	3.1299	105.83	1.8192	0.1652	1.8561	0.4913
0.7757	0.9311	5.444	3.0798	98.543	1.7126	0.1547	1.1562	0.9791
0.839	0.8953	4.1339	2.7732	92.274	1.4825	0.1323	0.6829	0.7626
0.8923	0.8617	3.4036	2.2395	86.996	1.1576	0.1018	0.3780	0.8711
0.9366	0.8344	2.8741	1.3390	82.609	0.7738	0.0671	0.1863	1.0128
0.9675	0.8107	2.5686	0.8782	79.549	0.4334	0.0371	0.0353	1.5671
1.0000	0.7873	2.1975	0.0000	76.331	0.0000	0.0000	0.0000	0.0000

Table 3: Mole fraction (x_1) of Isopropyl alcohol, density (ρ), viscosity (η), deviation in viscosities ($\Delta\eta$), molar volume (V_m), excess molar volume (V_m^E), excess Gibbs free energy of activation of viscous flow (ΔG^{*E}), Kendall-Monroe ($E\eta_m$) and Grunberg-Nissan (d') parameters for binary mixture of Isopropyl alcohol (x_1) + 1-butyl-3-methylimidazolium Bromide (x_2) at 313.15 K

(x_1)	(ρ) g.cm ⁻³	η mPa.s	$\Delta\eta$ mPa.s	V_m cm.mol ⁻¹	V_m^E cm.mol ⁻¹	ΔG^{*E} J.mol ⁻¹	$E\eta_m$	d'
0.0000	1.2427	35.855	0.0000	176.34	0.0000	0.0000	0.0000	0.0000
0.2881	1.1538	17.228	5.7578	147.77	0.6049	0.2554	3.9811	0.7527
0.4648	1.0921	11.142	7.0190	130.25	0.8192	0.3554	3.0807	1.0564
0.5976	1.0131	6.726	6.8055	117.08	0.9349	0.4199	2.0195	0.6947
0.7021	0.9642	4.9365	6.0295	106.71	0.9588	0.4433	1.2433	0.8586
0.7757	0.9273	4.0486	5.0370	99.418	0.9068	0.4273	0.7898	1.1937
0.839	0.8928	3.298	3.9762	93.140	0.7904	0.3781	0.4761	1.4649
0.8923	0.8534	2.5978	2.9166	87.854	0.6214	0.3009	0.2689	1.2840
0.9366	0.8239	2.1817	1.8967	83.461	0.4181	0.2042	0.1351	1.4361
0.9675	0.8025	1.8976	0.9167	80.396	0.2350	0.1155	0.0614	1.3017
1.0000	0.7787	1.648	0.0000	77.173	0.0000	0.0000	0.0000	0.0000

Table 4: Mole fraction (x_1) of Isopropyl alcohol, density (ρ), viscosity (η), deviation in viscosities ($\Delta\eta$), molar volume (V_m), excess molar volume (V_m^E), excess Gibbs free energy of activation of viscous flow (ΔG^{*E}), Kendall-Monroe ($E\eta m$) and Grunberg-Nissan (d') parameters for binary mixture of Isopropyl alcohol (x_1) + 1-butyl-3-methylimidazolium Bromide (x_2) at 323.15 K

(x_1)	(ρ) g.cm ⁻³	η mPa.s	$\Delta\eta$ mPa.s	V_m cm.mol ⁻¹	V_m^E cm.mol ⁻¹	ΔG^{*E} J.mol ⁻¹	$E\eta m$	d'
0.0000	1.2356	23.42	0.0000	177.36	0.0000	0.0000	0.0000	0.0000
0.2881	1.1512	11.885	0.4904	148.75	0.5304	0.3389	2.6511	0.5984
0.4648	1.0997	8.4535	0.6973	131.21	0.7073	0.4691	2.0861	1.1446
0.5976	1.0067	5.0816	0.8476	118.02	0.7902	0.5511	1.3903	1.4088
0.7021	0.9592	3.8338	0.9155	107.63	0.7948	0.5792	0.8702	1.5879
0.7757	0.9151	2.9708	0.8963	100.33	0.7410	0.5569	0.5667	1.7666
0.8390	0.8778	2.3704	0.8032	94.044	0.6381	0.4920	0.3429	1.8991
0.8923	0.8427	1.9391	0.6457	88.751	0.4967	0.3911	0.1964	1.5232
0.9366	0.8149	1.6814	0.4417	84.351	0.3313	0.2653	1.0008	1.4990
0.9675	0.7936	1.4540	0.2511	81.283	0.1851	0.1499	0.0459	0.3085
1.0000	0.7699	1.2492	0.0000	78.055	0.0000	0.0000	0.0000	0.0000

Table 5: Fitting parameters with Average Percentage Deviation (APD) for the binary mixtures at different temperatures

Temperature K	Frenkel		Hind	
	η_{12}	APD	η_{12}	APD
303.15	30.45	7.506	30.45	6.559
313.15	18.75	7.282	18.75	3.614
325.15	12.34	7.161	12.33	1.943

4. Conclusions

Experimental data of density and viscosity for the mixture of Isopropyl alcohol + [BMIm][Br] were measured over the entire range of compositions at atmospheric pressure from (303.15 to 323.15) K, from which the excess molar volumes V_m^E were calculated and the Redlich-Kister polynomial equation was applied successfully for the correlation of the excess molar volumes. The estimated coefficients and standard deviation values were also presented. It was found that density and viscosity for pure components or mixtures decreased with increasing temperature and viscosity was more sensitive than density to temperature or composition change. It was found that all of these calculated quantities were positive, and the Redlich-Kister fitting curves were asymmetric. Positive V_m^E values suggest that the rupturing of hydrogen bonds and the cleavage of dipole-dipole interactions played a significant role in the mixing behavior which indicated weak interactions of the component molecules of the binary system. Positive $\Delta\eta$ indicates that there was a loss of dipolar association between unlike components because of the size and shape of the mixing components. Positive ΔG^{*E} suggests the formation of a heterogeneous interaction between unlike components.

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