

Ultrasonic Velocity, Density, and Acoustic Properties of Aqueous Ethylene Glycol Solutions in Methanol, Ethanol, and 1-Propanol at 308.15 K

M. Kondaiah^{1*} and K. Sreekanth²,

¹ Department of Physics, Tara Govt. College (A), Sangareddy, 502 001, Sangareddy Dist., Telangana, India

² Department of Physics, PBN College, Nidubrolu, 522 124, Guntur District, AP, India

*Corresponding Author: Dr M Kondaiah;

Abstract:

The ultrasonic velocities (u) and densities (ρ) of 0.3 and 0.9 m aqueous ethylene glycol solutions in methanol, ethanol, and 1-propanol have been measured over the entire composition range at 308.15 K. The ultrasonic velocity increases with increasing alkanol mole fraction in the range, $0 < x < 0.15$ followed by a decrease at higher mole fractions. From the experimental data, the deviation in ultrasonic velocity (Δu), deviation in isentropic compressibility (Δk_s), excess intermolecular free length (L_f^E), and excess acoustic impedance (Z^E) have been calculated to investigate the nature of molecular interactions in the

mixtures. The negative values of Δk_s and L_f^E , together with the positive values of Δu and Z^E , indicate the presence of significant intermolecular interactions in the investigated solutions. The excess properties have been correlated using the Redlich–Kister polynomial equation, and the corresponding standard deviations have been evaluated to assess the quality of the correlations. Furthermore, the experimental ultrasonic velocities have been compared with those predicted by various theoretical models, including the Nomoto, Van Dael–Vangeel, impedance, Junjie, Jacobson, and Rao (specific sound velocity) relations, to evaluate their applicability to the studied systems.

Keywords: Ultrasonic velocity, Excess/Deviation properties, Redlich-Kister type polynomial, Acceptor-donor interactions, Hydrogen bonding, Ultrasonic empirical relations

1 Introduction

The characteristics of liquid mixes and solutions can be modified progressively within a feasible range by adjusting the concentration until an ideal value of a certain parameter is reached. The unadulterated liquids exhibit no such adaptability. The examination of characteristics of liquid mixes and solutions has direct relevance in the chemical, biochemical, and medical sectors [1-5]. The velocity of sound is acutely responsive to the arrangement and interactions within liquid systems, as it is intrinsically linked to the binding forces among the medium's components [6]. The assessment of sound velocity in liquids facilitates the identification of valuable acoustic and thermodynamic characteristics that exhibit significant sensitivity to molecular interactions [7-16]. Consequently, these measurements are valuable for examining the characteristics and intensity of molecular interactions in liquid mixtures.

Mixtures of water and alcohol exhibit distinct maxima and minima in their thermodynamic and acoustic characteristics at low concentrations of alcohol [17-25]. The emergence of such maxima/minima in certain aqueous electrolyte solutions [26] and in non-aqueous solutions [27,28] has also been documented in scholarly articles. Masso Sakura [29] documented the partial molar volumes of ethylene glycol and aqueous solutions at various temperatures: 15, 25, 35, and 45°C. Pal and Wazir Singh [30] reported the sound velocities and viscosities in aqueous poly(ethylene glycol) solutions at temperatures of 303.15 K and 308.15 K. Kanhekar et al [31] investigated the thermodynamic characteristics of glycine in aqueous solution across several temperatures. Thirumaran and Sathish [32] conducted investigations on

the molecular interionic interactions of divalent transition metal sulphates in aqueous ethylene glycol across various temperatures. Peiming et al. [33] investigated the thermodynamic characteristics of sand transport in ethylene glycol and its combinations with water and electrolytes. Zafarani-Moattar et al [34] documented the volumetric and transport properties of glycol+water solutions. We have previously documented the volumetric and viscometric characteristics of aqueous solutions of ethylene glycol/propylene glycol in alkanols [35,36] and propanoic acid combined with an equimolar combination of N,N-dimethyl formamide and alkanols at different temperatures [37].

Keeping in view, the ultrasonic and volumetric study of molecular interactions in the solutions of aqueous ethylene glycol with methanol/ ethanol/1-propanol is presented in this chapter at 308.15 K. The properties like, deviation in ultrasonic velocity (Δu), deviation in isentropic compressibility (Δk_s), excess

inter molecular free length (L_f^E) and excess acoustic impedance (Z^E) have been calculated using the experimental results of ultrasonic velocity and density. The variation of these properties over the entire composition range yields the information about molecular interaction in these systems. The excess/deviation properties are fitted to Redlich-Kister type polynomial equation. Besides, the experimental values of ultrasonic speed for all the aqueous solutions measured and compared with the theoretically estimated values using different empirical relations such as, Nomoto's, Van Dael and Vangeel's ideal mixing relation; Impedance dependence relation, Junjie's relation, Rao's specific sound velocity and Jacobson's equations. The percentage deviations of theoretical velocities from experimental values have been calculated. The corresponding standard deviations are also computed. The deviation of ultrasonic velocity from its experimental value is further utilized to study molecular interactions. Special types of polynomial equations are fitted to experimental data.

2 Experimental

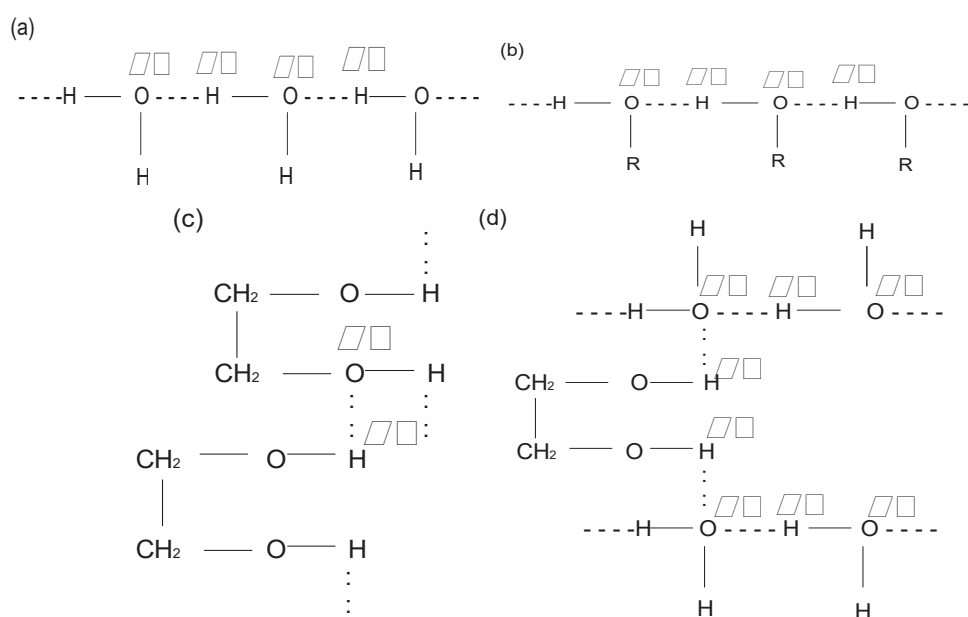
The substances utilised in the current investigation include ethylene glycol (purity mass fraction 0.99), methanol (purity mass fraction 0.99), ethanol (purity mass fraction 0.99) sourced from Changshu Yangyuan Chemicals, China, and 1-propanol (purity mass fraction 0.99) of G.R Grade procured from LOBA Chemicals, Mumbai, India. These were subsequently refined using conventional techniques [38]. The 0.3 m and 0.9 m aqueous solutions of ethylene glycol are formulated using triply distilled deionised water. These formulations are subsequently employed to create liquid blends containing methanol, ethanol, and 1-propanol, ensuring comprehensive coverage of the composition spectrum. All mixes have been formulated in specially crafted glass containers with airtight seals, and sufficient measures have been implemented to reduce evaporation losses. The measurement of solutions was conducted utilising a METTER TOLEDO (Swiss manufacture) ABB5-S/FACT digital balance with a precision of 0.01mg. The ultrasonic velocities and densities of the pure liquids examined in this study are recorded at 308.15 K and are presented in Table 1 alongside the existing literature data [39-46].

Table 1 Comparison of ultrasonic velocities (u) and densities (ρ) of pure liquids with the corresponding literature values at 308.15 K

Liquid	u/ m.s ⁻¹		ρ / kg.m ⁻³	
	Expt.	Lit.	Expt.	Lit.
Water	1520.22	1519.36 ³⁹	994.06	994.10 ⁴⁰
Ethylene glycol	1632.32	1632.10 ⁴¹	1105.85	1103.10 ⁴¹
Methanol	1072.65	1072.40 ⁴²	776.63	776.70 ⁴²
Ethanol	1115.10	1111.00 ⁴³	776.49	776.41 ⁴⁴
1-propanol	1175.60	1175.10 ⁴⁵	791.41	791.40 ⁴⁶

3 Results and discussion

The variation of ultrasonic velocity (u) at two different molalities of aqueous ethylene glycol with mole fraction of methanol/ethanol/1-propanol is shown in Figures 1 – 3 respectively. The ultrasonic velocity increases in the $0 < x < 0.15$ mole fraction of alkanol and it is found to decrease beyond 0.15 mole fraction of alkanol. The ultrasonic velocity shows a maximum value at about 0.15 m mole fraction of methanol/ethanol/1-propanol for 0.3 m and 0.9 m aqueous solutions of ethylene glycol. Water and ethylene glycol are both associated liquids, through the formation of hydrogen bonding. When ethylene glycol is added to water, association between ethylene glycol and water molecules takes place through hydrogen bonding which is shown in schema I. This leads to the increase of open structures in the solution as diol acts as a structure maker.



Schema I : Representation of inter molecular interactions in (a) water (b) alcohols (c) ethylene glycol (d) between water and ethylene glycol molecules

The maximum value in ultrasonic velocity is observed in the low concentration region of alkanols added to the aqueous ethylene glycol. The origin of maximum in the low concentration region of alkanol is due to long-range order in water giving rise to hydrogen bonded structure [17]. Such a structure possesses many cavities and these cavities can accommodate solute such as alkanol molecules. This is further supported by the observed large differences in the molar volume between the components of the solution. As alkanol is added to the aqueous ethylene glycol, alkanol molecules go on occupying the cavities created in the aqueous ethylene glycol structure. This gives rise to a denser packing of molecules resulting in the increase of ultrasonic velocity of solutions. This process continues until all the cavities are filled with solute molecules. Further addition of alkanol, leads to gradually for the formation of unassociated monomer structures in the solution and at the same time there are some alkanol molecules which disrupts the hydrogen bonding existing between the water + ethylene glycol molecules resulting in unassociated ethylene glycol molecules in the solution. Thus, the structure of solution becomes more and more loosely packed by increasing the concentration of alkanol molecules. As a result, the ultrasonic velocity in the solution decreases. This might be the possible reason to explain the ultrasonic velocity behaviour in the present investigated solutions.

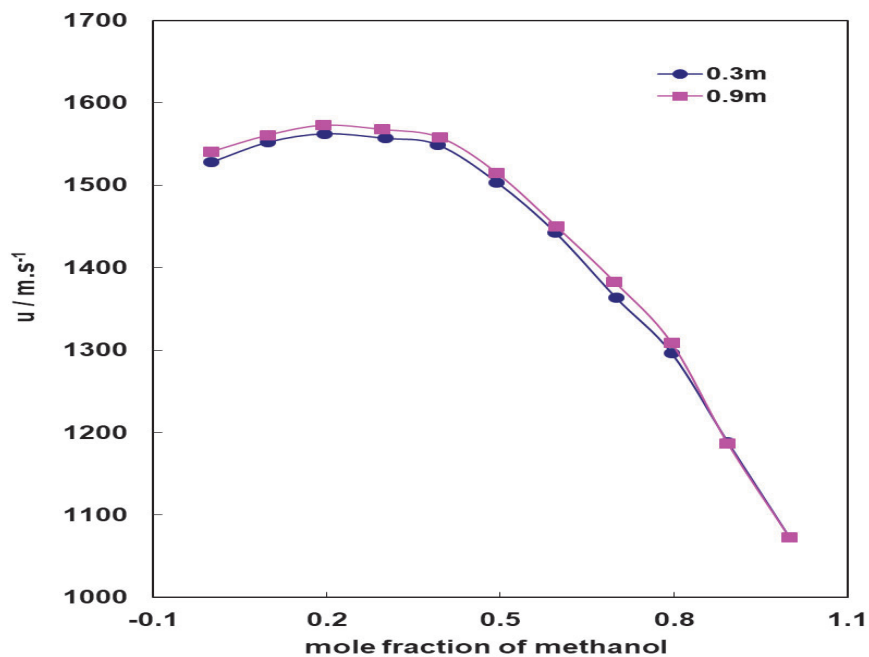


Figure 1 Variation of ultrasonic velocity (u) in the mixtures of methanol with aqueous ethylene glycol

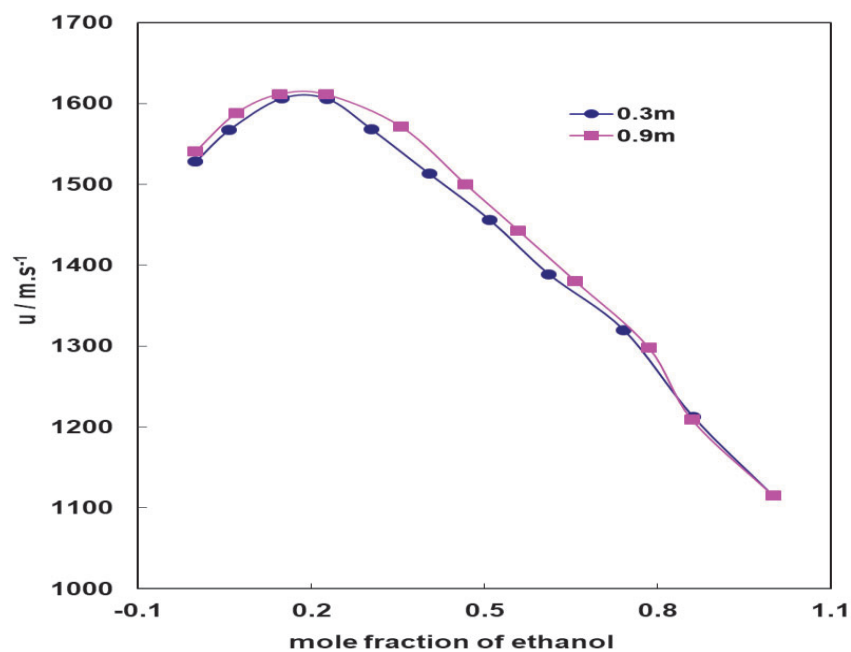


Figure 2 Variation of ultrasonic velocity (u) in the mixtures of ethanol with aqueous ethylene glycol

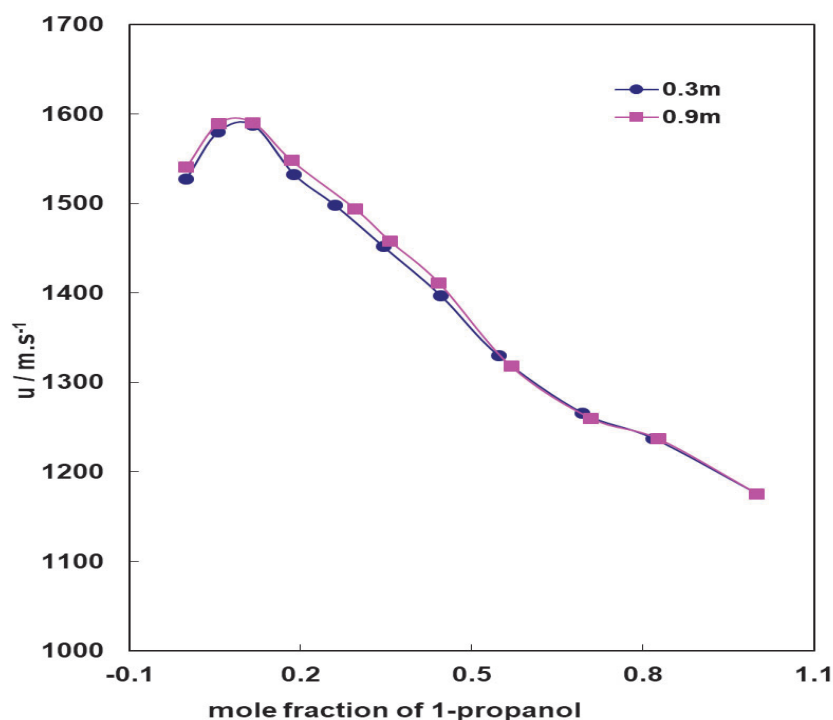


Figure 3 Variation of ultrasonic velocity (u) in the mixtures of 1-propanol with aqueous ethylene glycol

The deviation in ultrasonic velocity (Δu), deviation in isentropic compressibility (Δk_s), excess inter molecular free length (L_f^E) and excess acoustic impedance (Z^E) have been calculated from the experimental results of ultrasonic velocity (u) and density (ρ) and the data for the above properties are listed in Tables 2 - 4 for methanol, ethanol and 1-propanol with aqueous ethylene glycol solution respectively.

The values of Δu , Δk_s , L_f^E and Z^E have been fitted to Redlich-Kister type polynomial equation [47,48]. The Redlich-Kister coefficients and the corresponding standard deviations of all the liquid solutions have been presented in Table 5.

The sign and magnitude of Δu , and Δk_s played an important role to describe the molecular rearrangement and is resulted to the existence of molecular interactions among the component molecules in the solutions. Generally, negative values of Δu and positive values of Δk_s indicate dispersion forces due to weak interactions where as positive values of Δu and negative values of Δk_s indicating strong interactions [45, 49]. The isentropic compressibility is a measure of ease with which the system can be compressed. Positive values of Δu and negative values of Δk_s are observed in the present investigated systems. The negative values of Δk_s indicate the molecules in the solutions are less compressible than that of the pure liquids during its formation. Therefore, such negative values of Δk_s indicate strong interactions between component molecules. The strong interactions include inter molecular hydrogen bonding between alkanol and water + ethylene glycol molecules, dipole-induced dipole interactions, interstitial accommodation of smaller molecules in to bigger molecules. The internal structural properties of ethylene glycol and alcohols suggest that the observed behaviour is attributed to the intermolecular interactions between $-OH$ group of the alcohol and the oxygen atom ($-O-$) of the

ethylene glycol. When alkanols are added to the aqueous ethylene glycol the existing inter molecular hydrogen bonds between water and ethylene glycol molecules and intra molecular hydrogen bonds in water and ethylene glycol may be broken and new hydrogen bonds might be formed in the mixtures. Such similar studies were reported by Amalendu Pal et al [41] in aqueous solutions of glycols and Kinart et al [50] glycols with 2-ethoxyethanol.

Table 2 Calculated properties of deviation in ultrasonic velocity, Δu , deviation in isentropic compressibility, Δk_s , excess intermolecular free length, L_f^E , excess acoustic impedance, Z^E with mole fraction of methanol (x) in aqueous ethylene glycol solution at T = 308.15 K

x	volume fraction of methanol	Δu / $m.s^{-1}$	Δk_s / $10^{-10}Pa^{-1}$	L_f^E / $10^{-10}m$	Z^E / $10^6kg.m^{-2}.s^{-1}$
0.3 m aqueous ethylene glycol					
0.0000	0.0000	0.00	0.0000	0.0000	0.0000
0.0987	0.0981	69.32	-0.7406	-0.0296	0.0670
0.1968	0.1937	124.27	-1.4004	-0.0558	0.1249
0.3009	0.2937	166.15	-1.9896	-0.0784	0.1669
0.3915	0.3803	199.59	-2.4663	-0.0966	0.1967
0.4944	0.4774	200.68	-2.7687	-0.1061	0.1980
0.5947	0.5707	185.88	-2.9005	-0.1091	0.1871
0.7001	0.6713	154.25	-2.7953	-0.1022	0.1564
0.7963	0.7652	130.64	-2.6003	-0.0933	0.1330
0.8932	0.8744	67.19	-1.6557	-0.0555	0.0637
1.0000	1.0000	0.00	0.0000	0.0000	0.0000
0.9 m aqueous ethylene glycol					
0.0000	0.0000	0.00	0.0000	0.0000	0.0000
0.0986	0.0978	66.21	-0.7285	-0.0290	0.0668
0.1937	0.1905	122.68	-1.3816	-0.0551	0.1247
0.2965	0.2885	165.73	-1.9781	-0.0785	0.1708
0.3956	0.3816	202.40	-2.5076	-0.0992	0.2086
0.4939	0.4741	205.42	-2.8117	-0.1091	0.2103
0.5969	0.5717	188.64	-2.9358	-0.1108	0.1910
0.6972	0.6672	168.59	-2.9326	-0.1083	0.1705
0.7957	0.7634	140.71	-2.7214	-0.0984	0.1425
0.8934	0.8765	63.85	-1.6140	-0.0535	0.0585
1.0000	1.0000	0.00	0.0000	0.0000	0.0000

Table 3 Calculated properties of deviation in ultrasonic velocity, Δu , deviation in isentropic compressibility, Δk_s , excess intermolecular free length, L_f^E , excess acoustic impedance, Z^E with mole fraction of ethanol (x) in aqueous ethylene glycol solution at T = 308.15 K

x	volume fraction of ethanol	Δu / $m.s^{-1}$	Δk_s / $10^{-10}Pa^{-1}$	L_f^E / $10^{-10}m$	Z^E / $10^6 kg.m^{-2}.s^{-1}$
0.3 m aqueous ethylene glycol					
0.0000	0.0000	0.00	0.0000	0.0000	0.0000
0.0579	0.0576	62.97	-0.5059	-0.0219	0.0564
0.1485	0.1456	139.49	-1.1839	-0.0512	0.1329
0.2275	0.2216	171.74	-1.5783	-0.0667	0.1597
0.3038	0.2931	165.85	-1.7650	-0.0723	0.1565
0.4045	0.3884	152.14	-1.9199	-0.0757	0.1397
0.5094	0.4893	138.43	-2.0143	-0.0766	0.1203
0.6114	0.5869	113.52	-1.9505	-0.0720	0.0982
0.7413	0.7132	98.13	-1.8745	-0.0681	0.0872
0.8611	0.8434	40.48	-1.0662	-0.0358	0.0311
1.0000	1.0000	0.00	0.0000	0.0000	0.0000
0.9 m aqueous ethylene glycol					
0.0000	0.0000	0.00	0.0000	0.0000	0.0000
0.0703	0.0696	77.13	-0.6220	-0.0272	0.0741
0.1447	0.1420	132.13	-1.1278	-0.0485	0.1254
0.2265	0.2202	166.62	-1.5468	-0.0653	0.1569
0.3562	0.3395	181.83	-2.0024	-0.0827	0.1813
0.4675	0.4429	158.21	-2.1139	-0.0842	0.1577
0.5585	0.5264	139.95	-2.1104	-0.0824	0.1345
0.6578	0.6243	119.20	-2.0762	-0.0786	0.1162
0.7845	0.7500	91.16	-1.8284	-0.0676	0.0902
0.8593	0.8397	33.95	-1.0017	-0.0337	0.0272
1.0000	1.0000	0.00	0.0000	0.0000	0.0000

Table 4 Calculated properties of deviation in ultrasonic velocity, Δu , deviation in isentropic compressibility, Δk_s , excess intermolecular free length, L_f^E , excess acoustic impedance, Z^E with mole fraction of 1-propanol (x) in aqueous ethylene glycol solution at T = 308.15 K

x	volume fraction of 1-propanol	Δu / $m.s^{-1}$	Δk_s / $10^{-10}Pa^{-1}$	L_f^E / $10^{-10}m$	Z^E / $10^6 kg.m^{-2}.s^{-1}$
0.3 m aqueous ethylene glycol					
0.0000	0.0000	0.00	0.0000	0.0000	0.0000
0.0548	0.0545	71.30	-0.4835	-0.0222	0.0617
0.1167	0.1150	100.97	-0.7649	-0.0339	0.0862
0.1886	0.1852	71.22	-0.7197	-0.0287	0.0467
0.2606	0.2553	61.98	-0.7607	-0.0285	0.0297
0.3448	0.3373	45.64	-0.7440	-0.0258	0.0087
0.4456	0.4371	26.14	-0.6583	-0.0204	-0.0157
0.5471	0.5387	-5.31	-0.3874	-0.0083	-0.0457
0.6934	0.6860	-17.58	-0.1577	-0.0001	-0.0539
0.8179	0.8106	-2.19	-0.2662	-0.0062	-0.0231
1.0000	1.0000	0.00	0.0000	0.0000	0.0000
0.9 m aqueous ethylene glycol					
0.0000	0.0000	0.00	0.0000	0.0000	0.0000
0.0561	0.0556	69.29	-0.4755	-0.0218	0.0621
0.1159	0.1142	92.07	-0.7117	-0.0312	0.0773
0.1842	0.1805	74.47	-0.7388	-0.0298	0.0520
0.2956	0.2875	61.15	-0.8278	-0.0310	0.0333
0.3565	0.3474	47.39	-0.8569	-0.0308	0.0297
0.4427	0.4327	31.87	-0.7330	-0.0237	-0.0083
0.5687	0.5592	-15.11	-0.3947	-0.0085	-0.0401
0.7086	0.7000	-22.02	-0.2642	-0.0043	-0.0360
0.8276	0.8209	-1.76	-0.2745	-0.0064	-0.0233
1.0000	1.0000	0.00	0.0000	0.0000	0.0000

Table 5 Coefficients A_i of Redlich-Kister type polynomial equation and the corresponding standard deviations (σ) of all the systems at $T = 308.15$ K

	A_0	A_1	A_2	A_3	A_4	σ
methanol with 0.3 m aqueous ethylene glycol						
$\Delta u/m.s^{-1}$	-0.7339	775.4850	-583.4590	-473.8260	283.0740	6.2634
$\Delta k_s/10^{-10}Pa^{-1}$	0.0208	-9.0326	11.2156	-15.0753	12.8395	0.0669
$L_f^E/10^{-10}m$	0.0005	-0.3441	0.3262	-0.2820	0.2993	0.0027
$Z^E/10^6kg.m^{-2}.s^{-1}$	-0.0010	0.7689	-0.5721	-0.4624	0.2659	0.0062
methanol with 0.9 m aqueous ethylene glycol						
$\Delta u/m.s^{-1}$	-0.7213	736.1740	-386.7110	-695.8330	345.4900	7.6853
$\Delta k_s/10^{-10}Pa^{-1}$	0.0171	-8.7452	9.8755	-13.9014	12.7652	0.0835
$L_f^E/10^{-10}m$	0.0004	-0.3279	0.2314	-0.1613	0.2584	0.0038
$Z^E/10^6kg.m^{-2}.s^{-1}$	-0.0007	0.7305	-0.2347	-1.0250	0.5276	0.0094
ethanol with 0.3 m aqueous ethylene glycol						
$\Delta u/m.s^{-1}$	5.1166	1443.0700	-4178.0200	4579.0000	-1852.9700	10.3535
$\Delta k_s/10^{-10}Pa^{-1}$	0.0108	-10.7162	21.9214	-23.3536	12.1648	0.0838
$L_f^E/10^{-10}m$	6.3106	-0.4657	1.0703	-1.1638	0.5608	0.0042
$Z^E/10^6kg.m^{-2}.s^{-1}$	-0.0033	1.3946	-3.9915	4.2704	-1.6733	0.0100
ethanol with 0.9 m aqueous ethylene glycol						
$\Delta u/m.s^{-1}$	0.2318	1306.4400	-3120.1000	2739.2200	-928.8410	9.9971
$\Delta k_s/10^{-10}Pa^{-1}$	-0.0086	-9.6389	15.0820	-12.4295	7.0315	0.1224
$L_f^E/10^{-10}m$	-0.0005	-0.4184	0.6807	-0.4859	0.2257	0.0053
$Z^E/10^6kg.m^{-2}.s^{-1}$	0.0007	1.2065	-2.6822	2.0886	-0.6168	0.0119
1-propanol with 0.3 m aqueous ethylene glycol						
$\Delta u/m.s^{-1}$	12.3389	1062.2400	-4613.9900	6235.0600	-2696.5100	13.2329
$\Delta k_s/10^{-10}Pa^{-1}$	-0.0445	-8.4592	29.2346	-35.2776	14.5375	0.0883
$L_f^E/10^{-10}m$	-0.0026	-0.3733	1.4244	-1.8053	0.7567	0.0040
$Z^E/10^6kg.m^{-2}.s^{-1}$	0.0117	0.9274	-4.6125	6.5118	-2.8389	0.0135
1-propanol with 0.9 m aqueous ethylene glycol						
$\Delta u/m.s^{-1}$	8.4480	1103.2400	-4635.9300	6093.4300	-2568.8900	11.0380
$\Delta k_s/10^{-10}Pa^{-1}$	-0.0254	-8.4340	27.1398	-31.0240	12.3380	0.0750
$L_f^E/10^{-10}m$	-0.0016	-0.3737	1.3284	-1.5992	0.6459	0.0033
$Z^E/10^6kg.m^{-2}.s^{-1}$	0.0091	0.9274	-4.2661	5.7640	-2.4352	0.0110

Ethylene glycol is highly polar (dipole moment $\mu = 2.36$ D) when compared to water ($\mu = 1.86$ D) and alkanols (methanol $\mu = 1.70$ D, ethanol $\mu = 1.69$ D, 1-propanol $\mu = 1.58$ D). Mixing of alkanols to aqueous ethylene glycol molecules leads to breaking of ethylene glycol – ethylene glycol dipolar association release of several dipoles. Consequently, the free dipoles of ethylene glycol would induce moments in the neighbouring of alkanol molecules resulting dipole-induced interactions. The larger negative Δk_s values are observed in 1-propanol system compared to remaining systems. This is due to the longer the chain of the alkanol, the higher the polarity of the –OH group decreases and weaker the corresponding dipole-dipole interactions. Moreover, increasing the alkanol chain length reduces the concentration of –OH groups in higher alkanols and thereby lowers dipole moment in higher alkanols which causes weaker interactions. The strength of interactions in the solutions follow the order methanol > ethanol > 1-propanol.

The L_f^E and Z has resembled the same trend as we observed in deviation in isentropic compressibility and deviation in ultrasonic velocity. From the table it has been observed L_f^E is negative over the entire range of composition. This indicates structural readjustment in the liquid mixtures towards a less compressible phase of fluid and closer packing of molecules [27, 51]. These aspects further support the variation of other deviation/excess properties. When compared between 0.3 m and 0.9 m aqueous ethylene glycol solutions, the ultrasonic velocity, u , is found to maximum in case of 0.9 m aqueous ethylene glycol solution. In all the observed properties the strength of interactions is stronger in 0.9 m aqueous ethylene glycol solution compared to 0.3 m solution.

The calculated ultrasonic velocities from various theories like, Nomoto [52], Van Dael and Vangeel [53], Impedance [54], Junjie's [55], Jacobson's [56] and Rao's (specific sound velocity) relation [57] are presented in Tables 6 - 8 for methanol/ethanol/1-propanol respectively. The percentage errors of theoretical values from experimental values are presented in Tables 9 - 11 for methanol/ethanol/1-propanol in the aqueous solution of ethylene glycol respectively. Such an evaluation offers a simple method to investigate molecular interactions besides verifying the applicability of various theories to liquid solutions.

The experimental results have been fitted to two types of polynomials, $f(x)$ and $g(x)$ which describe the ultrasonic velocity data quantitatively as well as qualitatively even in the specific interaction predominant region where non-ideal behavior of the system is noticed. The values of sound velocities and percentage deviation, (after determining the co-efficients in these polynomials by applying least squares method) have been compiled in Tables 6 - 11. The standard deviations of ultrasonic velocities corresponding to polynomial equations have been evaluated using the relation and are given in Table 12. Among all the empirical theories Jacobson's relation gave better estimate of experimental values of sound velocity in all the systems followed by Rao's specific sound velocity relation in all the systems investigated.

Table 6 Experimental and theoretical values of ultrasonic velocity in the mixtures of methanol and aqueous ethylene glycol

mole fraction of methanol	U_{exp}	U_N	U_V	U_{Imp}	U_{Jun}	U_J	U_R	$f(x)$	$g(x)$
$m.s^{-1}$									
0.3 m aqueous ethylene glycol									
0.0000	1527.80	1527.80	1527.80	1527.80	1527.80	1527.80	1527.80	1527.07	1526.97
0.0987	1552.20	1476.82	1437.98	1492.03	1433.21	1552.20	1515.07	1552.57	1552.78
0.1968	1562.50	1427.54	1366.00	1454.88	1358.91	1562.39	1517.38	1564.33	1564.37
0.3009	1557.00	1376.75	1303.36	1413.56	1295.39	1556.83	1507.49	1560.04	1559.89
0.3915	1549.20	1333.76	1257.63	1375.90	1249.71	1549.10	1484.27	1541.27	1541.05
0.4944	1503.45	1286.29	1213.43	1331.07	1206.16	1503.56	1459.52	1502.48	1502.31
0.5947	1443.00	1241.35	1176.73	1285.11	1170.50	1443.05	1435.03	1446.97	1446.93
0.7001	1363.40	1195.53	1143.66	1234.22	1138.81	1363.37	1382.13	1370.77	1370.86
0.7963	1296.00	1154.92	1117.57	1185.24	1114.15	1295.95	1320.94	1286.75	1286.89
0.8932	1188.45	1115.17	1094.62	1133.29	1092.78	1188.53	1198.48	1190.23	1190.32
1.0000	1072.65	1072.65	1072.65	1072.65	1072.65	1072.65	1072.65	1073.19	1073.00
0.9 m aqueous ethylene glycol									
0.0000	1540.80	1540.80	1540.80	1540.80	1540.80	1540.80	1540.80	1540.08	1540.11
0.0986	1560.85	1488.10	1447.62	1504.17	1441.95	1560.88	1536.03	1562.11	1562.29
0.1937	1572.80	1438.73	1375.26	1467.26	1366.95	1572.88	1533.25	1572.91	1572.87
0.2965	1567.72	1386.92	1311.10	1425.47	1301.76	1567.78	1531.90	1570.08	1569.90
0.3956	1558.00	1338.47	1259.71	1383.17	1250.45	1558.04	1522.11	1550.97	1550.90
0.4939	1515.00	1291.83	1216.58	1339.13	1208.08	1515.10	1493.73	1514.85	1514.95
0.5969	1450.00	1244.43	1178.07	1290.57	1170.84	1449.98	1446.80	1458.16	1458.36
0.6972	1383.00	1199.68	1145.91	1240.73	1140.22	1382.92	1395.10	1384.78	1384.87
0.7957	1309.00	1157.05	1118.58	1189.13	1114.61	1309.03	1329.55	1296.44	1296.30
0.8934	1186.40	1116.02	1094.99	1135.12	1092.86	1186.48	1191.94	1194.79	1194.53
1.0000	1072.65	1072.65	1072.65	1072.65	1072.65	1072.65	1072.65	1071.05	1071.18

Table 7 Experimental and theoretical values of ultrasonic velocity in the mixtures of ethanol and aqueous ethylene glycol

mole fraction of ethanol	U_{exp}	U_N	U_V	U_{Imp}	U_{Jun}	U_J	U_R	$f(x)$	$g(x)$
$m.s^{-1}$									
0.3 m aqueous ethylene glycol									
0.0000	1527.80	1527.80	1527.80	1527.80	1527.80	1527.80	1527.80	1525.92	1526.36
0.0579	1566.87	1490.09	1494.11	1508.95	1458.76	1566.73	1508.11	1572.85	1572.28
0.1485	1606.00	1436.11	1444.77	1478.46	1377.19	1605.82	1508.94	1603.05	1602.88
0.2275	1605.65	1393.45	1404.76	1450.83	1323.75	1605.70	1490.88	1597.20	1597.24
0.3038	1568.27	1355.65	1368.49	1423.15	1282.82	1568.43	1489.03	1571.95	1571.84
0.4045	1513.00	1310.24	1323.82	1385.05	1240.20	1512.92	1458.37	1520.36	1520.11
0.5094	1456.00	1267.64	1280.72	1343.33	1205.67	1456.10	1408.26	1455.68	1455.83
0.6114	1389.00	1230.18	1241.78	1300.61	1179.04	1389.05	1371.47	1389.81	1390.42
0.7413	1320.00	1187.33	1195.93	1242.87	1152.31	1319.95	1319.07	1306.14	1306.31
0.8611	1212.90	1151.93	1156.91	1185.97	1132.92	1212.85	1217.53	1225.65	1224.37
1.0000	1115.10	1115.10	1115.10	1115.10	1115.10	1115.10	1115.10	1111.98	1112.56
0.9 m aqueous ethylene glycol									
0.0000	1540.80	1540.80	1540.80	1540.80	1540.80	1540.80	1540.80	1541.03	1541.65
0.0703	1588.00	1493.64	1498.37	1517.20	1454.94	1588.07	1530.97	1588.46	1587.68
0.1447	1611.33	1447.95	1456.39	1491.41	1386.41	1611.49	1519.94	1611.04	1610.60
0.2265	1611.00	1402.12	1413.31	1462.01	1328.70	1610.97	1508.08	1609.84	1610.00
0.3562	1571.00	1337.52	1350.80	1412.99	1261.75	1570.96	1521.02	1567.72	1568.12
0.4675	1500.00	1288.74	1302.05	1368.38	1219.99	1500.11	1492.58	1506.37	1506.57
0.5585	1443.00	1252.74	1265.10	1330.01	1193.13	1442.94	1443.22	1446.52	1446.63
0.6578	1379.97	1216.88	1227.44	1286.04	1169.31	1380.03	1404.39	1376.07	1376.12
0.7845	1298.00	1175.64	1182.95	1226.49	1145.11	1298.11	1332.84	1282.45	1282.17
0.8593	1208.95	1153.37	1158.36	1189.35	1133.34	1208.92	1227.82	1225.60	1225.03
1.0000	1115.10	1115.10	1115.10	1115.10	1115.10	1115.10	1115.10	1112.05	1112.37

Table 8 Experimental and theoretical values of ultrasonic velocity in the mixtures of 1-propanol and aqueous ethylene glycol

mole fraction of 1-propanol	U_{exp}	U_N	U_V	U_{Imp}	U_{Jun}	U_J	U_R	$f(x)$	$g(x)$
$m.s^{-1}$									
0.3 m aqueous ethylene glycol									
0.0000	1527.80	1527.80	1527.80	1527.80	1527.80	1527.80	1527.80	1540.14	1539.28
0.0548	1579.80	1490.22	1502.10	1512.30	1464.14	1579.89	1500.22	1566.20	1566.44
0.1167	1587.67	1452.42	1474.27	1494.37	1409.42	1587.82	1485.04	1569.58	1570.33
0.1886	1532.60	1413.68	1443.42	1472.95	1361.16	1532.45	1447.08	1548.35	1548.54
0.2606	1498.00	1379.52	1413.99	1450.82	1324.02	1498.04	1411.82	1509.74	1509.03
0.3448	1452.00	1344.42	1381.30	1424.05	1290.33	1451.87	1376.65	1453.89	1452.88
0.4456	1397.00	1308.01	1344.37	1390.65	1259.52	1396.87	1327.09	1385.73	1385.77
0.5471	1329.80	1276.34	1309.42	1355.43	1235.73	1329.90	1282.63	1327.00	1328.48
0.6934	1266.00	1237.65	1262.53	1301.64	1210.02	1266.08	1221.82	1269.40	1270.43
0.8179	1237.55	1209.83	1225.52	1252.79	1193.61	1237.60	1216.10	1239.06	1237.09
1.0000	1175.60	1175.60	1175.60	1175.60	1175.60	1175.60	1175.60	1174.74	1175.23
0.9 m aqueous ethylene glycol									
0.0000	1540.80	1540.80	1540.80	1540.80	1540.80	1540.80	1540.80	1549.25	1548.20
0.0561	1589.60	1500.72	1513.47	1524.39	1472.29	1589.77	1519.34	1577.11	1577.44
0.1159	1590.54	1462.70	1485.54	1506.49	1417.00	1590.58	1496.20	1581.54	1582.56
0.1842	1548.00	1424.25	1455.05	1485.48	1368.79	1548.12	1466.37	1563.03	1563.61
0.2956	1494.00	1370.70	1408.25	1449.83	1312.05	1494.12	1430.62	1500.11	1499.23
0.3565	1458.00	1345.34	1384.07	1429.58	1288.71	1458.03	1446.84	1457.76	1456.70
0.4427	1411.00	1313.32	1351.41	1399.94	1261.99	1411.06	1346.37	1397.43	1397.11
0.5687	1318.00	1273.15	1306.67	1354.44	1232.38	1318.01	1331.11	1321.68	1323.10
0.7086	1260.00	1235.84	1260.71	1300.60	1208.31	1260.05	1297.83	1264.83	1265.79
0.8276	1236.80	1208.80	1224.35	1251.79	1192.74	1236.75	1213.02	1233.70	1292.72
1.0000	1175.60	1175.60	1175.60	1175.60	1175.60	1175.60	1175.60	1175.91	1176.29

Table 9 Percentage deviation of theoretical ultrasonic velocities from experimental ultrasonic velocities in the mixtures of methanol and aqueous ethylene glycol

mole fraction of methanol	%U _N	%U _V	%U _{Imp}	%U _{Jun}	%U _J	%U _R	%f(x)	%g(x)
0.3 m aqueous ethylene glycol								
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.048	-0.054
0.0987	-4.856	-7.359	-3.876	-7.666	0.000	-2.392	0.024	0.037
0.1968	-8.637	-12.576	-6.888	-13.030	-0.007	-2.888	0.117	0.120
0.3009	-11.577	-16.290	-9.213	-16.802	-0.011	-3.180	0.195	0.186
0.3915	-13.907	-18.821	-11.186	-19.332	-0.006	-4.191	-0.512	-0.526
0.4944	-14.444	-19.290	-11.466	-19.774	0.007	-2.922	-0.065	-0.076
0.5947	-13.974	-18.453	-10.942	-18.884	0.003	-0.552	0.275	0.272
0.7001	-12.313	-16.117	-9.475	-16.473	-0.002	1.374	0.541	0.547
0.7963	-10.886	-13.768	-8.546	-14.032	-0.004	1.924	-0.714	-0.703
0.8932	-6.166	-7.895	-4.641	-8.050	0.007	0.844	0.150	0.157
1.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.033
0.9 m aqueous ethylene glycol								
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.047	-0.045
0.0986	-4.661	-7.254	-3.631	-7.618	0.002	-1.590	0.081	0.092
0.1937	-8.524	-12.560	-6.710	-13.088	0.005	-2.515	0.007	0.004
0.2965	-11.533	-16.369	-9.074	-16.965	0.004	-2.285	0.151	0.139
0.3956	-14.091	-19.146	-11.221	-19.740	0.003	-2.304	-0.451	-0.456
0.4939	-14.731	-19.698	-11.609	-20.259	0.007	-1.404	-0.010	-0.003
0.5969	-14.177	-18.754	-10.995	-19.252	-0.001	-0.221	0.563	0.577
0.6972	-13.255	-17.143	-10.287	-17.555	-0.006	0.875	0.129	0.135
0.7957	-11.608	-14.547	-9.157	-14.850	0.002	1.570	-0.960	-0.970
0.8934	-5.932	-7.705	-4.322	-7.884	0.007	0.467	0.707	0.685
1.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.149	-0.137

Table 10 Percentage deviation of theoretical ultrasonic velocities from experimental ultrasonic velocities in the mixtures of ethanol and aqueous ethylene glycol

mole fraction of ethanol	%U _N	%U _V	%U _{Imp}	%U _{Jun}	%U _J	%U _R	%f(x)	%g(x)
0.3 m aqueous ethylene glycol								
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.123	-0.094
0.0579	-4.900	-4.644	-3.697	-6.900	-0.009	-3.750	0.382	0.345
0.1485	-10.578	-10.039	-7.941	-14.247	-0.011	-6.044	-0.184	-0.194
0.2275	-13.216	-12.511	-9.642	-17.557	0.003	-7.148	-0.526	-0.524
0.3038	-13.558	-12.739	-9.254	-18.202	0.010	-5.053	0.235	0.228
0.4045	-13.401	-12.504	-8.457	-18.030	-0.005	-3.611	0.486	0.470
0.5094	-12.937	-12.038	-7.738	-17.193	0.007	-3.279	-0.022	-0.012
0.6114	-11.434	-10.599	-6.364	-15.116	0.004	-1.262	0.058	0.102
0.7413	-10.051	-9.399	-5.843	-12.704	-0.004	-0.070	-1.050	-1.037
0.8611	-5.027	-4.616	-2.220	-6.594	-0.004	0.382	1.051	0.946
1.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.280	-0.228
0.9 m aqueous ethylene glycol								
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.055
0.0703	-5.942	-5.644	-4.458	-8.379	0.004	-3.591	0.029	-0.020
0.1447	-10.139	-9.616	-7.442	-13.959	0.010	-5.672	-0.018	-0.045
0.2265	-12.966	-12.271	-9.248	-17.523	-0.002	-6.389	-0.072	-0.062
0.3562	-14.862	-14.017	-10.058	-19.685	-0.003	-3.181	-0.209	-0.183
0.4675	-14.084	-13.197	-8.775	-18.667	0.007	-0.495	0.425	0.438
0.5585	-13.185	-12.328	-7.830	-17.316	-0.004	0.015	0.244	0.252
0.6578	-11.819	-11.053	-6.807	-15.266	0.004	1.769	-0.283	-0.279
0.7845	-9.427	-8.864	-5.509	-11.779	0.008	2.684	-1.198	-1.220
0.8593	-4.597	-4.185	-1.621	-6.254	-0.002	1.561	1.377	1.330
1.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.274	-0.245

Table 11 Percentage deviation of theoretical ultrasonic velocities from experimental ultrasonic velocities in the mixtures of 1-propanol and aqueous ethylene glycol

mole fraction of 1-propanol	%U _N	%U _V	%U _{Imp}	%U _{Jun}	%U _J	%U _R	%f(x)	%g(x)
0.3 m aqueous ethylene glycol								
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.808	0.751
0.0548	-5.670	-4.918	-4.273	-7.321	0.006	-5.037	-0.861	-0.846
0.1167	-8.519	-7.143	-5.877	-11.227	0.009	-6.464	-1.139	-1.092
0.1886	-7.759	-5.819	-3.892	-11.186	-0.010	-5.580	1.028	1.040
0.2606	-7.909	-5.608	-3.150	-11.614	0.003	-5.753	0.784	0.736
0.3448	-7.409	-4.869	-1.925	-11.134	-0.009	-5.189	0.130	0.061
0.4456	-6.370	-3.767	-0.455	-9.841	-0.009	-5.004	-0.807	-0.804
0.5471	-4.020	-1.533	1.927	-7.074	0.008	-3.547	-0.211	-0.099
0.6934	-2.239	-0.274	2.815	-4.422	0.006	-3.490	0.269	0.350
0.8179	-2.240	-0.972	1.231	-3.551	0.004	-1.733	0.122	-0.037
1.0000	0.000	0.000	0.000	0.000	0.000	0.000	-0.073	-0.031
0.9 m aqueous ethylene glycol								
0.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.548	0.480
0.0561	-5.591	-4.789	-4.102	-7.380	0.011	-4.420	-0.786	-0.765
0.1159	-8.038	-6.602	-5.284	-10.911	0.003	-5.931	-0.566	-0.502
0.1842	-7.994	-6.005	-4.039	-11.577	0.008	-5.273	0.971	1.008
0.2956	-8.253	-5.740	-2.956	-12.179	0.008	-4.242	0.409	0.350
0.3565	-7.727	-5.071	-1.949	-11.611	0.002	-0.765	-0.016	-0.089
0.4427	-6.923	-4.223	-0.784	-10.561	0.004	-4.580	-0.962	-0.984
0.5687	-3.403	-0.860	2.765	-6.496	0.001	0.995	0.279	0.387
0.7086	-1.917	0.056	3.222	-4.102	0.004	3.002	0.383	0.460
0.8276	-2.264	-1.007	1.212	-3.562	-0.004	-1.923	-0.251	4.521
1.0000	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.059

Table 12 Standard deviation of sound velocities calculated using polynomial equations from experimental values

Name of the liquid system	Polynomial form $\sigma/\text{m.s}^{-1}$	Standard deviation
Mixtures of methanol and 0.3 m aqueous ethylene glycol	f(x)	4.634
	g(x)	4.654
Mixtures of methanol and 0.9 m aqueous ethylene glycol	f(x)	5.702
	g(x)	5.726
Mixtures of ethanol and 0.3 m aqueous ethylene glycol	f(x)	7.086
	g(x)	6.759
Mixtures of ethanol and 0.9 m aqueous ethylene glycol	f(x)	7.441
	g(x)	7.376
Mixtures of 1-propanol and 0.3 m aqueous ethylene glycol	f(x)	10.459
	g(x)	10.159
Mixtures of 1-propanol and 0.9 m aqueous ethylene glycol	f(x)	8.541
	g(x)	18.875

Conclusions

1. The ultrasonic velocities and densities of aqueous ethylene glycol (0.3m and 0.9m) with methanol/ethanol/1-propanol are measured over the entire composition range of alkanols at $T = 308.15 \text{ K}$.
2. From this data Δu , Δk_s , L_f^E and Z^E have been calculated. The values of Δk_s , L_f^E are found to be negative, Δu , Z^E are positive indicating the presences of strong interactions exist in the solutions investigated.
3. The reason for existence of specific interactions is attributed to the disruption of intra molecular hydrogen bond in water and ethylene glycol molecules and inter molecular chemical interactions between water and ethylene glycol molecules consequently, formation of new hydrogen bonds between alkanol and aqueous ethylene glycol molecules and dipole-induced dipole interactions between the components of molecules in the solutions. The difference in molar masses of the liquid molecules is also responsible to the existing specific interactions between the molecules of the component liquids.
4. As the chain length of alkanol molecules increases the strength of interactions decreases and follows the order water + ethylene glycol +, methanol > ethanol > 1-propanol. It has been also observed that the strength of interactions is stronger in 0.9 m aqueous ethylene glycol solution when compared to 0.3 m with alkanols.
5. The ultrasonic velocities computed from different velocity theories were correlated with the experimentally measured ultrasonic velocities. Among these theories, Jacobson's equation gives the good agreement between the theoretical and experimental ultrasonic velocity values and also the percentage deviations of ultrasonic velocities calculated from polynomial equations are found to be small.

References

1. Ali A and Soghra H, Indian J. Phys., 76B (1) (2002) 23.
2. Ali A, Abida, Hyder S and Nain A K, Indian J. Phys., 76B (2002) 661.
3. Singh S, Prasad N, Kushwaha R M, Sivanarayana K and Prakash S, Indian J. Pure & Appl. Phys., 18 (1980) 254.
4. Anwar Ali, Anil Kumar Nain, Narender Kumar and Mohammad Ibrahim, J. Pure and Appl. Ultrasonics, 24 (2002) 27.
5. Ali A, Yasmin Y and Nain A K, Indian J. Pure & Appl. Phys., 40 (2002) 315.
6. Arul G and Palaniyappan L, Indian J. Pure & Appl. Phys., 39 (2001) 561.
7. Wankaede D S, Wankhede NN, Lande M K and Arbad B R, Indian J. Pure & Appl. Phys., 44 (2006) 909.
8. Maria M Palaologou, George K Arianas and Nikos G Tsierkezos, J. Sol. Chem., 35 (2006) 1551.
9. Ana B Pereiro and Ana Rodriguez, J. Chem. Eng. Data, 52 (2007) 600.
10. Ana Francisca Ribeiro, Elisa Langa, Ana M Mainar, Juan J Pardo and Jose S Urieta, J. Chem. Eng. Data., 52 (2006) 1846.
11. Satyanarayana Nallani, Satyanarayana Boodida and Savitha J Tangeda, J. Chem. Eng. Data., 52 (2007) 405.
12. Monica Gepert and Barbara Stachowska, J. Sol. Chem., 35 (2006) 425.
13. Sharma V K and Satish Kumar, J. Sol. Chem., 34 (2005) 713.
14. Sanjeevan J Kharat and Pandharinath S Nikam, J. Mol. Liq., 81(2007) 131.
15. Kannappan V, Askar Ali S J and Abdul Mahaboob P A, Indian J. Pure & Appl. Phys., 44 (2006) 903.
16. Mirosław Chorożewski, J. Chem. Eng. Data., 52 (2007) 154.

17. Rao N P and Ronal E Verrall, Can. J.Chem., 65 (1987) 810.
18. Franks F and Desnoyers J E, Water Sci. Rev., 1 (1985) 175.
19. Franks F and Read D J, Water, a comprehensive treatise, Vol.2, Plenum Press, New York, 1973.
20. Tamura K, Mackawa M and Yasunaga T, J. Phys. Chem., 81 (1977) 2122.
21. Muller N, J. Magn. Reson. 28 (1977) 203.
22. Iwasaki N and Fujiyama T, J. Phys. Chem., 81 (1977) 1908.
23. Rouy G, Roberts D, Perron G and Desnoyers J E, J. Sol. Chem., 9 (1980) 629.
24. Lara J and Desnoyers J E, J. Sol. Chem., 10 (1981) 465.
25. Patil K J and Ali S I, Indian J. Pure & Appl. Phys., 19 (1981) 617.
26. Ravichandran G, Indian J. Phys., 76B(3) (2002) 277.
27. Rama Rao G V, Viswanatha Sarma A and Rambabu C, Indian J. Pure & Appl. Phys., 42 (2004) 820.
28. Satyanarayana Rao T, Veeraiah N and Rambabu C, Indian J. Pure & Appl. Phys., 40 (2002) 850.
29. Sakurai M. J Chem Eng Data. 1991;36:424-427.
30. Pal A and Singh W. J Chem Eng Data. 1997;42:234-237.
31. Kanhekar SR, Pravina Pawar and Bichille GK. Ind J Pure & Applied Phys. 2010;48:95-99.
32. Thirumaran S and Sathish K. Research J of Chem Sci. 2011;1:63-71.
33. Peiming W, Kosinski JJ, Anderko A, Springer RD, Lencka MM and Liu J. Ind Eng Chem Res. 2013;52:15968-15987.
34. Zafarani-Moattar MT and Tohidifar N. Fluid Phase Equilib. 2013;343:43-57.
35. Kondaiah M, Sreekanth K, Nayeem Sk Md and Krishna Rao D, International Journal Of Pharmaceutical, Chemical and Biological Sciences, 2014, 4(3), 691-705
36. Nayeem Sk Md, Kondaiah M, Sreekanth K and Krishna Rao D, Journal of Chemical, Biological and Physical Sciences, 2014, Vol. 4, No. 4; 3092-3108.
37. Kondaiah M, Sreekanth K, Sravana Kumar D and Krishna Rao D. J Sol Chem. 2013;42:494-515.
38. Vogel, A.I. (1989) Text Book of Practical Organic Chemistry; London: Longman Green.
39. Victor, P.J. and Hazra, D.K, J. Chem. Eng. Data., 47 (2002) 79-82.
40. Mikhail, S.Z. and Kimel, W.R, J. Chem. Eng. Data., 6 (1961) 533.
41. Pal, A. and Singh, W, J. Chem. Eng. Data., 42 (1997) 234.
42. Rajagopal K and Jayabalakrishnan SS, J. Chem. Thermodyn., 42 (2010) 984.
43. Ujjan Kdam, B., Apoorva Hiray, P., Arun Sawant, B., and Hasan, M. J. Chem. Thermodyn., 38 (2006) 1675.
44. Nikam, P.S., Shirsat, L.N., and Hasan, M, J. Chem. Eng. Data., 43 (1998) 732.
45. Nain, A.K, J. Mol. Liq., 140 (2008) 108.
46. Mikhail, S.Z. and Kimel, W.R, J. Chem. Eng. Data., 8 (1963) 323.
47. Iloukhani, H. and Rostami, Z, J. Solution Chem., 32 (1963) 451.
48. Redlich, O. and Kister, A.T, Ind. Eng. Chem., 40 (1948) 345.
49. Kawaizumi, F., Ohno, M., and Miyahara, Y, Bull. Chem. Soc. Jpn., 50 (1977) 2229.
50. Kinart, C.M., Miecznik, P., and Klimczak, M, J. Mol. Liq., 149 (2009) 81.
51. Oswal, S.L. and Pater, N.B, J. Chem. Eng. Data., 45 (2000) 225.
52. Nomoto, O. J. Phys. Soc. Jpn., 13 (1958) 1528.
53. Van Dael, W. (1975) Thermodynamic Properties and Velocity of Sound, London: Butterworth.
54. Baluja, S. and Parrania, M.H. Asian J. Chem., 7(1995) 417.
55. Junjie, Z, J. China Univ. Sci. Technol., 14 (1984) 298.
56. Jacobson, B, J. Chem. Phys., 20 (1952) 927.
57. Ramarao, G.V., Viswanatha Sarma, A.V., Sivarama Krishna, J., Rambabu, C, Indian J. Pure and Appl. Phys., 43 (2005) 345.