

Excess Thermodynamic and Acoustic Properties for Equimolar Mixture of Ethyl Benzoate and 1-Alkanols with Benzene At 303.15 K

S. Sreehari Sastry^{a,*}, S. M. Ibrahim^a, L. Tanuj Kumar^{a,b}, Shaik Babu^a and Ha Sie Tiong^c

^a Department of Physics, Acharya Nagarjuna University, Nagarjunanagar -522510, India

^b Department of Physics, Sree Vahini Institute of Science and Technology, Tiruvuru, 521235, India

^c Department of Chemical Science, Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia

Abstract— Densities (ρ), viscosity (η) and speed of sound (U) values for the liquid mixture systems of ethyl benzoate + 1-propanol/1-butanol/1-pentanol with benzene including those of pure liquids were measured over the entire mole fraction range at $T=303.15$ K. From these experimentally determined values, various thermo-acoustic parameters such as excess isentropic compressibility (K_s^E), excess molar volume (V^E) and excess free length (L_f^E), excess Gibbs free energy (ΔG^{*E}) and excess enthalpy (H^E) have been calculated. The excess functions have been fitted to the Redlich–Kister type polynomial equation. The deviations for excess thermo-acoustic parameters have been explained on the basis of the intermolecular interactions present in these liquid mixtures. The theoretical values of speed of sound in these mixtures have been evaluated using various theories and has been compared with experimentally determined speed of sound values in order to check the applicability of such theories to the liquid mixture systems under study. Viscosity data has been used to test the applicability of standard viscosity models of Grunberg-Nissan, Hind-Mc Laughlin, Katti-Chaudhary, Heric and Brewer, Frenkel and Tamura and Kurata for the liquid systems under study.

Keywords— Speed of sound, density, excess molar volume, Gibbs free energy, Enthalpy, isentropic compressibility.

1. INTRODUCTION

In recent years, ultrasonic investigations find extensive applications in characterizing of thermodynamic and physico-chemical aspects of binary and ternary liquid mixtures [1-2]. Thermodynamic and transport properties [3-4] of liquid mixtures provide important information with which to speculate the molecular liquid structure. These properties have been widely used to study the intermolecular interactions between various species present in the liquid mixtures. The excess thermodynamic functions [5] are sensitively dependent not only on the differences in intermolecular forces, but also on the differences in the size of the molecules. The study of excess values provides important information on molecular forces existing in the binary liquid mixtures. The variation of these excess values with temperature and composition for mixtures containing polar molecules and hydrogen bonded components may be complex due to a decrease or

an increase in hydrogen bonding interaction due to mixing, depending upon the nature of the liquids whether they are polar or non-polar, the signs and magnitudes of these excess values can throw light on the strength of interactions. Several researchers [6-10] have measured the density, viscosity, and speed of sound for a wide range of liquid mixtures containing alcohols as one of the components, and these properties were interpreted in terms of specific or nonspecific interactions. Even though considerable work has been reported on alcohols as one of the component in binary and ternary mixtures, the data on liquid mixtures of alcohols and alkylbenzoates with benzene is scanty. The molecules containing $-OH$ group form associative liquids due to hydrogen bonding. The effect shown by the molecules with other functional groups on these molecules plays a vital role in understanding the behavior of hydrogen bonding. Alcohols are strongly associated in solution because of dipole-dipole interaction and hydrogen bonding. They are of great importance for their vital role in chemistry, biology and studies on hydrogen bonding in liquid mixtures. Alcohols are widely used as solvents. On the other hand alkyl benzoates are non-associated in solution, good hydrogen bonding acceptors. They are widely used in perfumery and pesticides. Also hydrocarbons are among the most important chemicals used in hydrocarbon processing industries. The investigations regarding the molecular association in liquid mixtures having aromatic group as one of the components is of particular interest, since aromatic group is highly non-polar and can associate with any other group having some degree of polar attractions. In continuation of our earlier reported work on molecular interactions of liquid mixtures [11-14] using excess thermodynamic and acoustic properties, the present study gives further investigations on molecular interactions in the commercially important liquid mixtures of Ethyl benzoate and 1-propanol/1-butanol/1-pentanol that are mixed in equimolar ratio. Further these equimolar mixtures are added to benzene making it a multi component liquid mixture. The study of thermodynamic properties of multi component liquid mixtures and data on the analysis in terms of various models are important for industrial and

pharmaceutical applications [15]. So we have selected ethyl benzoate as non associative liquid and 1-propanol, 1-butanol and 1-pentanol as associative liquid and benzene as the hydrocarbon. Considering these aspects the authors have made an attempt to study the thermodynamic and acoustic properties of liquid mixtures involving alcohols and ethyl benzoate with benzene. Hence in our present study we report the results of density, viscosity and speed of sound for the liquid mixtures of ethyl benzoate + 1-propanol/1-butanol/1-pentanol with benzene at 303.15 K. From these results, the excess isentropic compressibility (K_s^E), excess molar volume (V^E), excess free length (L_f^E), excess Gibb's free energy of activation for viscous flow (ΔG^*E), and Excess enthalpy (H^E), have been calculated. The results of excess values were fitted to the Redlich-Kister [16] polynomial equation. The intermolecular interactions have been estimated in the light of the excess parameters. In the present study, theoretical speed of sound and dynamic viscosity values have been evaluated using several empirical relations in the liquid mixtures considering Ethyl benzoate+1-propanol or 1-butanol or 1-pentanol as one component and benzene as the other component at $T=303.15K$. This kind of evaluation of theoretical speed of sound values proves to be useful to verify the applicability of various postulates of these theories of liquid mixtures and to arrive at some useful inferences regarding the strength of molecular interactions between component liquids in some cases.

II. EXPERIMENTAL DETAILS

2.1. Materials

The chemicals used in the present study are, Ethyl benzoate, 1-propanol, 1-butanol, 1-pentanol and benzene which are of AR grade obtained from Merck Co. Inc., Germany, with purities of greater than 99%. All the chemicals were further purified by standard methods [17] and only middle fractions were collected. The density, viscosity and speed of sound were experimentally determined at a temperature of 303.15 K and compared with the literature values [18-26]. Comparison of experimental densities (ρ), viscosities (η) and speed of sound (U) of pure liquids with literature values are given in Table 1.

Table I. Comparison of experimental densities (ρ), viscosities (η) and speed of sound (U) of pure liquids with literature values.

Liquid	T/K	$\rho \cdot 10^{-3} / (\text{kg} \cdot \text{m}^{-3})$		$\eta \cdot 10^{-3} / (\text{kg} \cdot \text{m}^{-1} \cdot \text{s}^{-1})$		$U / (\text{m} \cdot \text{s}^{-1})$	
		Exp	Lit	Exp	Lit	Exp.	Lit
1-Propanol	303.15	0.798	0.7962 [8]	1.610	1.607 [22]	1189.2	1190.2 [23]
1-Butanol	303.15	0.804	0.8020 [8]	2.054	2.067 [23]	1228.4	1225.8 [24]
1-Pentanol	303.15	0.810	0.8127 [25]	3.012	3.008 [8]	1252.4	1254.9 [24]
Ethyl Benzoate	303.15	1.042	1.0380 [26]	1.749	1.751 [26]	1345.4	1345.4 [2]
Benzene	303.15	0.8771	0.8748 [28]	0.563	0.563 [29]	1276.4	1281.0 [30]

Liquid	α (K^{-1})	C_p ($\text{J mol}^{-1} \text{K}^{-1}$)
1-Propanol	1.237	149 [27]
1-Butanol	1.228	179 [27]
1-Pentanol	1.215	209 [27]
Ethyl Benzoate	1.077	250 [27]
Benzene	1.172	137 [27]

2.2. Method

All liquid mixtures were prepared gravimetrically in air-tight bottles and adequate precautions have been taken to minimize evaporation losses. Before use, the chemicals were stored over 0.4nm molecular sieves approximately for 72h to remove water content and then degassed. Equimolar mixture of Ethyl benzoate and 1-propanol/1-butanol/1-pentanol is first prepared and this solution has been used to prepare the liquid mixtures with benzene so that the entire composition range is covered (0-100% of benzene). The mass measurements were performed on a digital electronic balance (Mettler Toledo AB 135, Switzerland) with an uncertainty of $\pm 0.00001\text{g}$. The binary mixtures were prepared just before use. The uncertainty in mole fraction was estimated to be less than ± 0.0001 .

The viscosities were measured with Ostwald viscometer. The viscometer was calibrated at each temperature using redistilled water. The uncertainty in viscosity measurement is up to $0.001\text{mPa} \cdot \text{s}$. The flow time has been measured after the attainment of bath temperature by each mixture. The flow measurements were made with an electronic stop watch with a precision of 0.01s. For all the pure components and mixtures, 3 to 4 readings were taken and the average of these values were used in all the calculations.

The densities of the pure compounds and their mixtures were determined accurately using 10 ml specific gravity bottles in digital electronic balance (Mettler Toledo AB 135, Switzerland) with an uncertainty of $\pm 0.00001\text{g}$. The average uncertainty in the measured density was $\pm 0.001\text{ kg/m}^3$.

The speed of sound was measured with a single-crystal variable path interferometer (Mittal Enterprises, New Delhi, India) operating at a frequency of 2 MHz that had been calibrated with water and benzene. The uncertainty in the speed of sound was found to be $\pm 0.1\text{m/s}$. In all property measurements the temperature was controlled within $\pm 0.1\text{ K}$ using a constant temperature bath (M/s Sakti Scientific Instruments Company, India) by circulating water from the thermostat.

2.3. Theoretical Details

The values of experimentally determined density, viscosity and speed of sound for the liquid mixtures of ethyl benzoate+1-propanol or 1-butanol or 1-pentanol with benzene at 303.15K over the entire composition range are given in Table 2.

Using the experimentally determined values of density, viscosity and speed of sound, various thermodynamic parameters like excess isentropic compressibility (K_s^E), excess molar volume (V^E), excess free length (L_f^E), excess Gibbs free energy of activation (ΔG^{*E}) and excess Enthalpy (H^E), were calculated.

Table II. Densities (ρ), Viscosities (η), and Speed of sound(U) for the liquid mixtures at T=303.15 K

X_1	ρ kg·m ⁻³	U m·s ⁻¹	$\eta \times 10^3$ kg·m ⁻¹ ·s ⁻¹	X_1	ρ kg·m ⁻³	U m·s ⁻¹	$\eta \times 10^3$ kg·m ⁻¹ ·s ⁻¹
(EB+1-Propanol) + Benzene							
0.000 0	0.877 1	1276. 4	0.563 2	0.538 5	0.907 1	1266. 8	1.176 2
0.079 6	0.882 6	1274. 6	0.660 0	0.644 8	0.910 8	1265. 3	1.291 5
0.162 8	0.888 0	1272. 8	0.760 0	0.756 8	0.914 1	1263. 9	1.405 7
0.250 0	0.893 2	1271. 2	0.847 0	0.875 0	0.916 7	1262. 6	1.533 0
0.341 5	0.898 2	1269. 7	0.953 9	1.000 0	0.918 5	1261. 4	1.678 8
0.437 6	0.902 8	1268. 2	1.062 0				
(EB+1-Butanol) + Benzene							
0.000 0	0.877 1	1276. 4	0.563 2	0.523 0	0.907 8	1281. 3	1.284 3
0.075 1	0.882 5	1277. 3	0.690 0	0.630 4	0.911 8	1282. 1	1.418 9
0.154 5	0.888 0	1278. 2	0.800 1	0.745 2	0.915 3	1282. 8	1.573 9
0.238 6	0.893 4	1278. 9	0.914 3	0.868 1	0.918 2	1283. 4	1.736 1
0.327 7	0.898 5	1279. 8	1.028 4	1.000 0	0.920 6	1284. 0	1.902 4
0.422 3	0.903 3	1280. 5	1.142 6				
(EB+1-Pentanol) + Benzene							
0.000 0	0.877 1	1276. 4	0.563 2	0.508 7	0.909 3	1295. 5	1.519 8
0.071 2	0.882 7	1280. 1	0.700 0	0.616 9	0.913 5	1298. 1	1.721 7
0.147 2	0.888 2	1283. 5	0.850 0	0.734 1	0.917 4	1300. 1	1.938 0
0.228 3	0.893 9	1286. 6	0.994 8	0.861 3	0.920 6	1302. 0	2.166 3
0.315 1	0.899 3	1289. 9	1.170 2	1.000 0	0.923 6	1303. 2	2.404 0
0.408 4	0.904 5	1292. 8	1.331 2				

Benson and Kiyohara [27, 28] stated that the thermodynamic properties of an ideal mixture must be mutually related in the same way as for those of pure substances and real mixtures. Also Douheret et al. [29] suggested that the interpretation of the nature of molecular interactions in mixtures require a correct calculation of a thermodynamic property of the ideal liquid mixtures by the application of correct ideal mixing rules. In the present work the authors have calculated the excess values of isentropic compressibility and excess free length values to check the applicability of thermo dynamical ideality (the ideal mixing rules) to the components under study. The excess values of isentropic compressibility K_s^E were calculated as follows,

$$K_s^E = K_s - K_s^{id} \quad (1)$$

Where K_s^E is its excess value, K_s^{id} is the ideal isentropic compressibility value and K_s represent the calculated value

of isentropic compressibility for the mixture ($K_s = \frac{1}{\rho U^2}$

), ρ is the density and U represents the speed of sound. K_s^{id} for an ideal mixture was calculated from the relation recommended by Benson and Kiyohara [31, 32] and Douheret et al [33].

$$K_s^{id} = \sum \phi_i \left\{ K_{s,i}^o + \frac{TV_i^o (\alpha_i^o)^2}{C_{p,i}^o} \right\} - T \left(\sum x_i V_i^o \right) \left(\frac{\sum \phi_i \alpha_i^o}{\sum x_i C_{p,i}^o} \right) \quad (2)$$

in which $K_{s,i}^o$, V_i^o , α_i^o , $C_{p,i}^o$ are the isentropic compressibility, molar volume, isobaric thermal expansion coefficient and molar isobaric heat capacity of pure component i, T represents temperature, ϕ_i is the volume fraction and x_i represents the mole fraction of i in the mixture.

The excess values of free length L_f^E were calculated by using the expression,

$$L_f^E = L_f - K_T (K_s^{id})^{1/2} \quad (3)$$

Where L_f represents the calculated value for the mixture and K_T represent a temperature dependent constant whose value is $K_T = (91.368 + 0.3565T) \times 10^{-8}$.

The density values have been used to calculate the excess volumes, V^E , using the following equation,

$$V^E = \frac{X_1 M_1 + X_2 M_2}{\rho} - \left(\frac{X_1 M_1}{\rho_1} + \frac{X_2 M_2}{\rho_2} \right) \quad (4)$$

where ρ is the density of the mixture and X_1 , M_1 , and ρ_1 and X_2 , M_2 , and ρ_2 are the mole fraction, molar mass, and density of pure components 1 and 2, respectively.

Excess Gibbs free energy of activation ΔG^{*E} was calculated as follows,

$$\Delta G^{*E} = RT \left[\ln \left(\frac{\eta V}{\eta_2 V_2} \right) - x_1 \ln \left(\frac{\eta_1 V_1}{\eta_2 V_2} \right) \right] \quad (5)$$

Where R represents gas constant, T is absolute temperature, η is the viscosity of the mixture and η_1, η_2 are the viscosities of the pure compounds, V is the molar volume of mixture and V_1, V_2 are the molar volumes of the pure compounds,

Excess enthalpy H^E was calculated from usual relation.

$$H^E = H - (X_1 H_1 + X_2 H_2) \quad (6)$$

Where H represents the calculated value of enthalpy for the mixture and H_1, H_2 represent enthalpy of pure components 1 and 2, respectively

The excess values for the above parameters were fitted by the method of nonlinear least-squares to a Redlich-Kister type polynomial [20].

$$Y^E = x_1 (1-x_1) \sum_{i=1}^n A_i (2x_1 - 1)^{i-1} \quad (7)$$

Where $Y^E = K_s^E, V^E, \Delta G^{*E}, H^E$. The values of coefficient A_i were determined by a regression analysis based on the least-squares method and are reported along with the corresponding standard deviations between the experimental and the calculated values of the respective functions in Table 4.

The standard deviation (σ) was calculated using the relation

$$\sigma(Y^E) = \left[\sum (Y_{obs}^E - Y_{cal}^E)^2 / n-m \right]^{1/2} \quad (8)$$

Where n represents the number of experimental points and m is the number of adjustable parameters.

III. RESULTS AND DISCUSSION

The experimental values of density, viscosity and speed of sound in case of all the liquid mixtures under study over the entire range of composition and at $T=303.15$ K are given in Table 2. From this available data of speed of sound, density and viscosity, values of excess isentropic compressibility (K_s^E), excess molar volume (V^E), excess free length (L_f^E), excess Gibbs free energy of activation (ΔG^{*E}) and excess Enthalpy (H^E), were calculated. These excess parameters were plotted against mole fraction of Ethyl benzoate+1-propanol or 1-butanol or 1-pentanol over the entire mole fraction range and at $T=303.15$ K. The plots are shown in Fig 1-5. The excess parameters of isentropic compressibility (K_s^E), molar volume (V^E), free length (L_f^E), Gibbs free energy of activation (ΔG^{*E}) and Enthalpy (H^E), are fitted to the Redlich-Kister type polynomial equation and the coefficients A_i evaluated by the method of least squares, along with standard deviation (σ) are given in Table 3.

Table III. Coefficients of RedlichKister equation A_i , and standard deviations σ , for excess molar volumes (V^E), excess isentropic compressibility (K_s^E), excess free length (L_f^E), excess Gibb's free energy (ΔG^{*E}) and excess enthalpy (H^E) at $T=303.15$ K for the liquid mixtures under study.

Properties	A_0	A_1	A_2	σ
(EB+1-Propanol) + Benzene				
$10^6 \cdot V^E / (m^3 \cdot mol^{-1})$	-2.307	-0.386	0.108	0.04
$10^{12} \cdot K_s^E / (m^2 \cdot N^{-1})$	-17.97	0.042	1.850	0.07

$10^{13} \cdot L_f^E / (m)$	-6.821	-0.020	0.711	0.02
$\Delta G^{*E} / (J \cdot mol^{-1})$	1520	-791.3	362.1	0.36
$H^E / (J \cdot mol^{-1})$	6904	-3774	1054	1.05
(EB+1-Butanol) + Benzene				
$10^6 \cdot V^E / (m^3 \cdot mol^{-1})$	-2.154	-0.267	0.395	0.02
$10^{12} \cdot K_s^E / (m^2 \cdot N^{-1})$	-22.70	3.472	1.300	0.12
$10^{13} \cdot L_f^E / (m)$	-8.749	1.203	0.544	0.04
$\Delta G^{*E} / (J \cdot mol^{-1})$	1889	-1240	1346	1.04
$H^E / (J \cdot mol^{-1})$	8782	-5988	7626	1.16
(EB+1-Pentanol) + Benzene				
$10^6 \cdot V^E / (m^3 \cdot mol^{-1})$	-2.046	-0.219	0.597	0.02
$10^{12} \cdot K_s^E / (m^2 \cdot N^{-1})$	-35.34	7.701	-0.156	0.12
$10^{13} \cdot L_f^E / (m)$	-13.71	2.666	0.094	0.11
$\Delta G^{*E} / (J \cdot mol^{-1})$	2696	-1307	893.2	0.28
$H^E / (J \cdot mol^{-1})$	13174	-4918	3475	0.88

The deviations observed in the excess parameters indicate the strength of interactions present between the component molecules of the binary mixtures under study [30]. The variations in these excess parameters may be the result of contributions from several effects such as (a) The Specific forces that exist between the molecules, like the charge transfer complexes and existence of hydrogen bonds result in the negative excess values [31]. (b) Physical interatomic forces. (c) The structural contribution arising from the geometrical fitting of one component into the other because of the differences in the size and shape of the component molecules.

Fig.1 shows the excess isentropic compressibility (K_s^E) for the liquid mixtures of Ethyl benzoate + 1-propanol or 1-butanol or 1-pentanol with benzene over the entire mole fraction range at $T=303.15$ K. It is clear from figure 1 that the

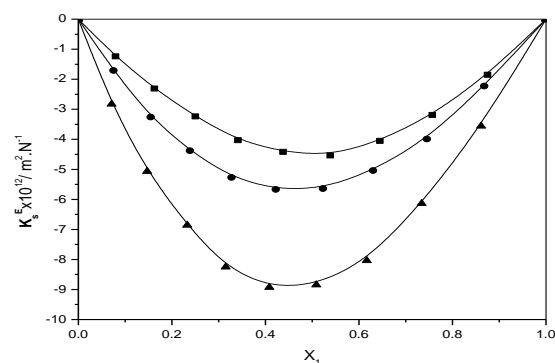


Fig. 1. Excess isentropic compressibility, K_s^E , with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X_1 , for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at $T/K=303.15$

K_s^E values are negative over the entire mole fraction range. The negative values of K_s^E are of the order (Ethyl benzoate + 1-pentanol)+benzene > (Ethyl benzoate + 1-butanol)+benzene > (Ethyl benzoate + 1-propanol)+benzene. The sign of excess isentropic compressibility plays a vital role in assessing the compactness due to molecular interaction in liquid mixtures through charge transfer, dipole-dipole interactions, and dipole induced dipole interactions interstitial accommodation and orientational ordering leading to more compact structure making, which enhances excess isentropic compressibility to have negative values. Fort and Moore [32] suggested that the liquids having different molecular sizes and shapes mix well there by reducing the volume which causes the values of K_s^E to be negative. It also suggests that the liquids are less compressible when compared to their ideal mixtures signifying the chemical effects including charge transfer forces, formation of H bond and other complex forming interactions. It can also be said that the molecular interactions are strong in these binary liquid mixtures and that the medium is highly packed. Similar results were obtained by earlier workers [33]. The negative values of K_s^E in these mixtures can be associated with a structure forming tendency.

The variation of excess molar volume (V_m^E), with respect to mole fraction, x_1 , is given in Fig.2 over the entire composition range at $T = 303.15$ K. The strength of the

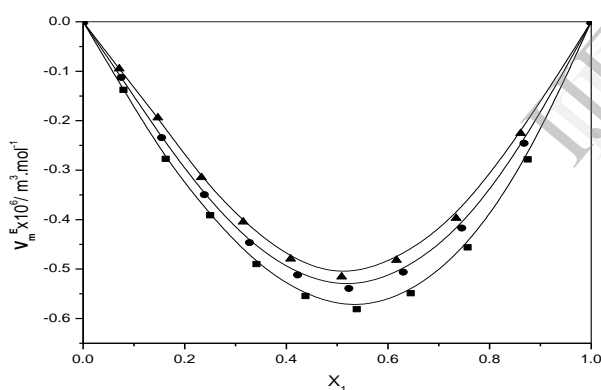


Fig.2.Excess molar volume, V_m^E , with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X_1 , for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at $T/K=303.15$

intermolecular interactions in binary liquid mixtures can be explained using the sign and magnitude of the V^E values. The sign of V^E depends upon the relative magnitude of expansion and contraction of liquids during mixing process. The V^E values are more negative in case of (Ethyl benzoate + 1-propanol) + benzene but as the alcohol chain increases the negative V^E values decreases, this suggests that the sign and magnitude of the V^E values are sensitive to the carbon chain lengths of the 1-alkanol molecules. As the length of the 1-alkanols chain increases the V^E values also increase and may become positive. The negative values of V^E are due to strong specific interactions like the formation of H-bond, association through weaker physical forces and accommodation of one component molecules

into the voids in the network of the other component molecules. So in the present study we observed that the behavior of V^E can be ascribed to the formation of H-bond, disruption of alcohol self-associations and the structural characteristics like geometrical fitting of one component into the other as a result of the increase in difference of size and shape of the component molecules. It is clear from Fig.2 that the negative values of V^E are in the following order, (Ethyl benzoate + 1-propanol) + benzene > (Ethyl benzoate + 1-butanol) + benzene > (Ethyl benzoate + 1-pentanol) + benzene. The expansion in molar volume can be attributed to the presence of weak intermolecular forces of attraction [34]. Similar results were reported by Garcia et al [35]. The negative values of V^E indicate that there is more compact packing of the molecules which implies that the molecular interactions are strong in these mixtures compared to those in the pure component. The negative values of V^E decrease for the liquid mixtures under study as the interactions between unlike molecules become weaker as the alkanol chain increases. This confirms the predictions drawn from the values of K_s^E . Similar results were observed by the studies of researchers [35].

It can be observed from Fig.3 that the L_f^E values have a negative trend similar to what we have observed in case of the K_s^E at $T=303.15$ K. The negative values of L_f^E suggest that

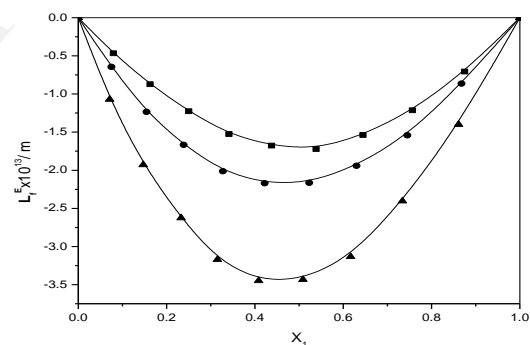


Fig. 3.Excess free length, L_f^E , with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X_1 , for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at $T/K=303.15$ specific interactions are present between unlike molecules in these liquid systems [36].

Fig.4 represent the excess Gibb's free energy of activation (ΔG^{*E}) with respect to mole fraction x_1 , over the entire composition range and at $T = 303.15$ K. It can be seen

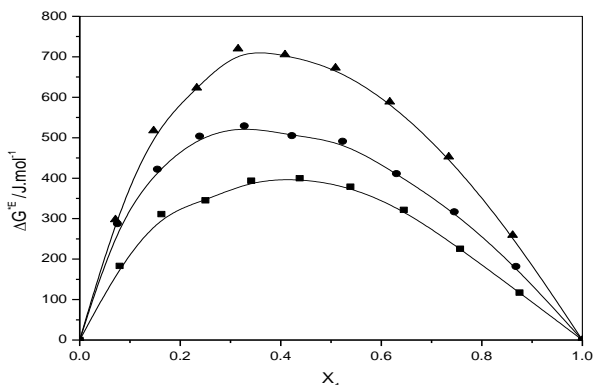


Fig.4.Excess Gibb's free energy, ΔG^E , with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X_1 , for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at T/K=303.15.

from figure 4 that the ΔG^{*E} values are positive over the entire range of mole fraction. These positive values indicate the existence of strong intermolecular interaction through hydrogen bonding between the component molecules of the liquid mixtures under study. Similar results were observed by earlier workers [37]

From Fig.5 it is clear that the excess values of Enthalpy (H^E) are positive with respect to the mole fraction, x_1 , over the entire composition range and at $T = 303.15K$. The positive values of H^E insist the fact that there are strong specific interactions between unlike molecules in these liquid mixtures [38]. The positive H^E values also suggest the existence of inter molecular hydrogen bond and the breaking of associated structures in case of Ethyl benzoate + 1-propanol or 1-butanol or 1-pentanol with benzene.

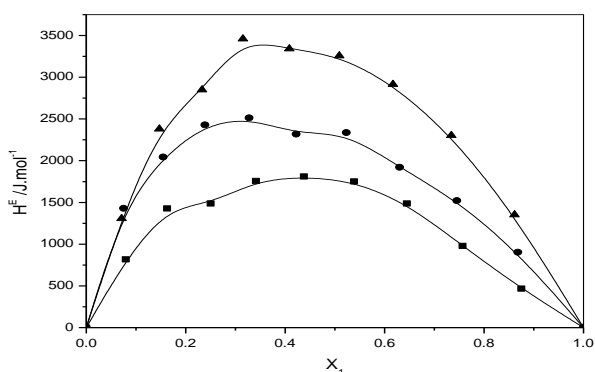


Fig. 5.Excess Enthalpy, K_s^E , with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X_1 , for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at T/K=303.15.

In the present study, theoretical speed of sound values have been evaluated in the liquid mixtures considering Ethyl benzoate+1-propanol or 1-butanol or 1-pentanol as one component and benzene as the other component at $T=303.15K$. This kind of evaluation of theoretical speed of sound values proves to be useful to verify the applicability of various postulates of these theories of liquid mixtures and to arrive at some useful inferences regarding the strength of molecular interactions

between component liquids in some cases. The theories due to Nomoto [39], Impedance relation [40], Van Dael and Vangeel [41], Junjie's [42], free length theory [43] and Rao's [44] are employed and the Average percentage error along with the Chi square fit values described elsewhere [3] for the liquid mixtures are compiled in Table 4. The average percentage error values are small. On comparison, the Nomoto's relation and free length theory relation are found to give some valuable estimate of the experimental values of speed of sound values in these binary mixtures at all the temperatures.

Table IV. Experimental and computed values of Speed of sound at $T=303.15 K$.

(EB+1-Propanol) + Benzene							
X_1	U_{exp}	U_{NOM}	U_{IMP}	U_{VDV}	U_{JM}	U_{FLT}	U_R
	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}
0	1276.4	1276.4	1261.4	1276.4	1276.4	1276.4	1276.4
0.0796	1274.6	1274.6	1261.4	1271.3	1273.9	1274.6	1285.4
0.1628	1272.8	1272.8	1261.4	1266.8	1271.5	1272.8	1293.3
0.25	1271.2	1271.2	1261.4	1262.9	1269.2	1271.2	1299.1
0.3415	1269.7	1269.7	1261.4	1259.6	1267.1	1269.7	1303.1
0.4376	1268.2	1268.2	1261.4	1257.2	1265.3	1268.2	1304.6
0.5385	1266.8	1266.8	1261.4	1255.6	1263.7	1266.8	1303.3
0.6448	1265.3	1265.3	1261.4	1255	1262.5	1265.3	1298.5
0.7568	1263.9	1263.9	1261.4	1255.6	1261.7	1263.9	1290.4
0.875	1262.6	1262.6	1261.4	1257.7	1261.3	1262.6	1278.1
1	1261.4	1261.4	1261.4	1261.4	1261.4	1261.4	1261.4
APE	0	-0.0721	0.5261	0.1344	0	-	1.7261
Chi square	0	0.0096	0.5274	0.0351	0	5.4938	
(EB+1-Butanol) + Benzene							
X_1	U_{exp}	U_{NO_M}	U_{IMP}	U_{VDV}	U_{JM}	U_{FLT}	U_R
	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}	ms^{-1}
0	1276.4	1276.4	1276.4	1276.4	1276.4	1276.4	1276.4
0.0751	1277.3	1277.3	1277	1271	1276.4	1277.3	1287

0.15	1278	1278	1277.6	1266.4	1276.3	1278	1297
45	.2	.2				.2	
0.23	1278	1278	1278.3	1262.7	1276.4	1278	1305.
86	.9	.9				.9	5
0.32	1279	1279	1279	1260.1	1276.6	1279	1311.
77	.8	.8				.8	9
0.42	1280	1280	1279.7	1258.8	1277	1280	1315.
23	.5	.5				.5	8
0.52	1281	1281	1280.5	1259.1	1277.7	1281	1316.
3	.3	.3				.3	9
0.63	1282	1282	1281.3	1261.2	1278.7	1282	1314.
04	.1	.1				.1	2
0.74	1282	1282	1282.1	1265.7	1280.1	1282	1308.
52	.8	.8				.8	2
0.86	1283	1283	1283	1273	1281.9	1283	1298
81	.4	.4				.4	
1	1284	1284	1284	1284	1284	1284	1284
APE		0	0.0409	1.0388	0.1648	0	-
Chi square		0	0.0031	2.0866	0.0527	0	5.024
(EB+1-Pentanol) + Benzene							
X ₁	U _{exp}	U _{NOM}	U _{IM} _P	U _{VDV}	U _{JM}	U _{FLT}	U _R
	ms ⁻¹	ms ⁻¹	ms ⁻¹	ms ⁻¹	ms ⁻¹	ms ⁻¹	ms ⁻¹
0	1276	1276.4		1276.	1276	1276	1276.
	.4			4	.4	.4	4
0.07	1280	1280.1		1274.	1277	1280	1288.
12	.1			1	.7	.1	7
0.14	1283	1283.5		1272.	1279	1283	1300.
72	.5			3	.2	.5	1
0.22	1286	1286.6		1271.	1280	1286	1311.
83	.6			2	.7	.6	2
0.31	1289	1289.9		1270.	1282	1289	1319.
51	.9			9	.6	.9	6
0.40	1292	1292.8		1271.	1284	1292	1326
84	.8			7	.8	.8	
0.50	1295	1295.5		1273.	1287	1295	1329.
87	.5			8	.4	.5	3
0.61	1298	1298.1		1277.	1290	1298	1328.
69	.1			4	.6	.1	5
0.73	1300	1300.1		1283.	1294	1300	1324.
41	.1			1	.3	.1	2
0.86	1302	1302		1291.	1298	1302	1315.
13				5	.5		4
1	1303	1303.2		1303.	1303	1303	1303.
	.2			2	.2	.2	2
APE		0		1.003	0.37	0	-
Chi square		0		2	92	0	4.351

The variation of theoretical speed of sound with mole fraction for these theories is shown in Fig. 6(a-c).

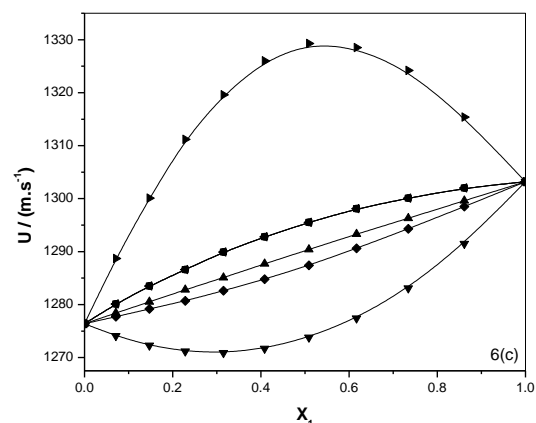
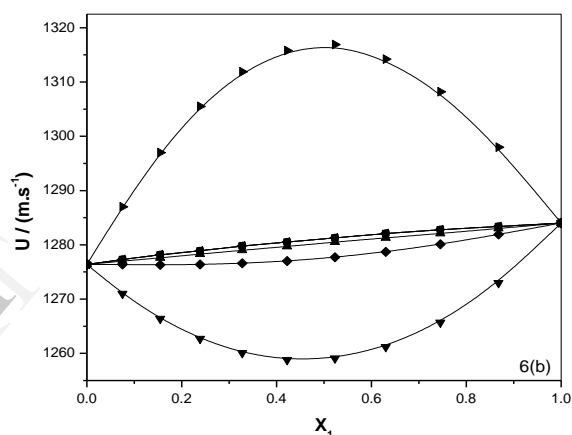
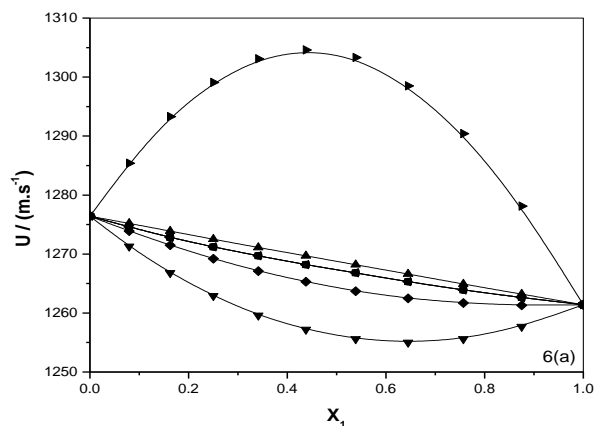


Fig.6.Variation of theoretical Speed of sound, U, with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X₁, for liquid mixture of (a) (EB+1-propanol) +Benzene (b) (EB+1-butanol) +Benzene and (c) (EB+1-pentanol) +Benzene at T/K=303.15.

TableV. Experimental and computed values of Viscosity, $\eta \times 10^{-3} / \text{N.s.m}^{-2}$, various interaction parameters and their corresponding standard deviations (σ) at T=303.15 K.

(EB+1-Propanol) + Benzene							
X_1	η_{exp}	Grunberg and Nissan	Hind and Ubbelohde	Katti and Chaudari	Heric and Brewer	Frenkel	Tamura and Kurata
0.0000	0.5632	0.5632	0.5632	0.5632	0.5632	0.5632	0.5632
0.0796	0.6600	0.6449	0.4879	0.6394	0.6394	0.6452	0.6549
0.1628	0.7600	0.7363	0.4396	0.7284	0.7283	0.7370	0.7502
0.2500	0.8470	0.8378	0.4222	0.8303	0.8303	0.8389	0.8493
0.3415	0.9539	0.9490	0.4405	0.9450	0.9449	0.9506	0.9526
0.4376	1.0620	1.0689	0.5002	1.0709	1.0708	1.0709	1.0604
0.5385	1.1762	1.1953	0.6073	1.2048	1.2048	1.1976	1.1728
0.6448	1.2915	1.3253	0.7696	1.3417	1.3418	1.3276	1.2905
0.7568	1.4057	1.4538	0.9953	1.4739	1.4740	1.4559	1.4137
0.8750	1.5330	1.5745	1.2944	1.5906	1.5907	1.5758	1.5430
1.0000	1.6788	1.6788	1.6788	1.6788	1.6788	1.6788	1.6788
Interaction Parameter	G_{12}	H_{12}	W_{vis}/RT	Δ_{12}	F_{12}	T_{12}	
	0.6615	0.0011	1.0546	1.0897	1.3587	1.0778	
σ	0.0285	0.4628	0.0406	0.0406	0.0296	0.0062	
(EB+1-Butanol) + Benzene							
X_1	η_{exp}	Grunberg and Nissan	Hind and Ubbelohde	Katti and Chaudari	Heric and Brewer	Frenkel	Tamura and Kurata
0.0000	0.5632	0.5632	0.5632	0.5632	0.5632	0.5632	0.5632
0.0751	0.6900	0.6579	0.4927	0.6528	0.6527	0.6591	0.6742
0.1545	0.8001	0.7668	0.4484	0.7589	0.7588	0.7694	0.7891
0.2386	0.9143	0.8904	0.4353	0.8827	0.8825	0.8946	0.9084
0.3277	1.0284	1.0284	0.4594	1.0241	1.0238	1.0343	1.0323
0.4223	1.1426	1.1793	0.5279	1.1815	1.1812	1.1868	1.1612
0.5230	1.2843	1.3399	0.6492	1.3505	1.3504	1.3486	1.2958
0.6304	1.4189	1.5040	0.8336	1.5228	1.5231	1.5132	1.4365
0.7452	1.5739	1.6622	1.0935	1.6857	1.6862	1.6704	1.5841
0.8681	1.7361	1.8007	1.4437	1.8199	1.8206	1.8061	1.7391

X_1	η_{exp}	Grunberg and Nissan	Hind and Ubbelohde	Katti and Chaudari	Heric and Brewer	Frenkel	Tamura and Kurata
0.0000	0.5632	0.5632	0.5632	0.5632	0.5632	0.5632	0.5632
0.0712	0.7000	0.6755	0.4982	0.6705	0.6704	0.6765	0.7021
0.1472	0.8500	0.8093	0.4621	0.8013	0.8011	0.8116	0.8486
0.2283	0.9948	0.9667	0.4612	0.9587	0.9583	0.9706	1.0030
0.3151	1.1702	1.1492	0.5035	1.1444	1.1440	1.1549	1.1664
0.4084	1.3312	1.3567	0.5988	1.3590	1.3585	1.3643	1.3400
0.5087	1.5198	1.5848	0.7588	1.5972	1.5970	1.5940	1.5245
0.6169	1.7217	1.8247	0.9983	1.8477	1.8482	1.8346	1.7215
0.7341	1.9380	2.0600	1.3359	2.0899	2.0910	2.0693	1.9325
0.8613	2.1663	2.2648	1.7946	2.2900	2.2914	2.2711	2.1593
1.0000	2.4040	2.4040	2.4040	2.4040	2.4040	2.4040	2.4040
Interaction Parameter	G_{12}	H_{12}	W_{vis}/RT	Δ_{12}	F_{12}	T_{12}	
	1.1858	0.0015	1.5813	1.6197	2.1295	1.3885	
σ	0.0738	0.6184	0.0910	0.0916	0.0794	0.0058	

The dynamic viscosities of the liquid mixtures have been calculated using several empirical relations due to Grunberg-Nissan [45], Hind et al. [46], Katti and Chaudari [47], Heric and Brewer [48], Frenkel [49] and Tamura and Kurata [50]. The experimental and theoretical values of viscosity with their corresponding interaction terms and standard deviation values for the liquid mixtures at T=303.15K are compiled in Table 5. All the empirical models gave a reasonable fit but there is good agreement between the theoretical and experimental values in case of (Ethyl benzoate+1-propanol) +benzene mixture. The estimated standard deviations are smaller in all cases indicating that the present mixture viscosities are well correlated by these viscosity models. The variation of theoretical viscosity with mole fraction for these theories is shown in Fig. 7(a-c).

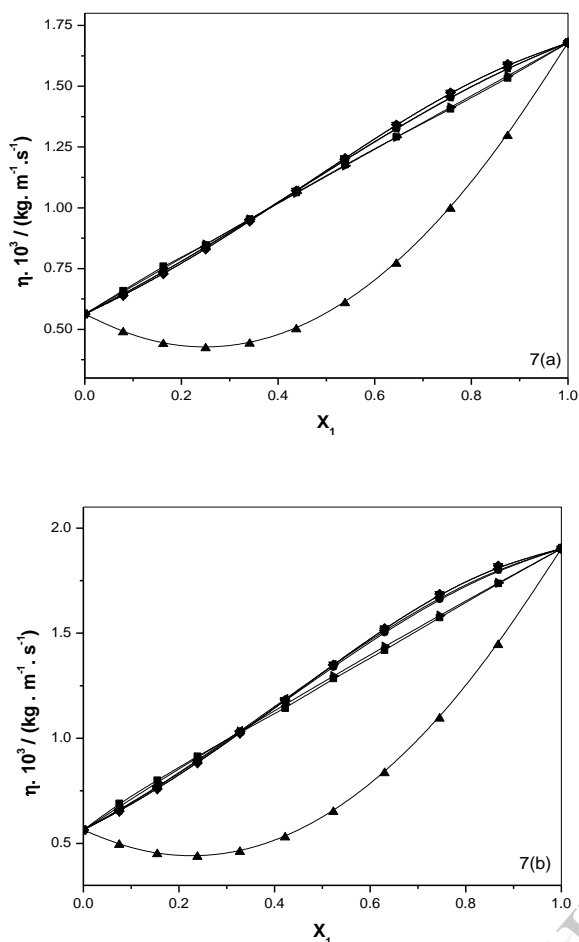


Fig. 7. Variation of theoretical viscosity, η , with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X_1 , for liquid mixture of (a) (EB+1-propanol) +Benzene (b) (EB+1-butanol) +Benzene and (c) (EB+1-pentanol) +Benzene at $T/K=303.15$. \blacksquare , η_{exp} ; \bullet , Grunberg and Nissan; \blacktriangle , Hind and Ubbelohde; \blacktriangledown , Katti and Chaudari; \blacklozenge , Heric and Brewer; \blacktriangleleft , Frenkel; \blacktriangleright , Tamura and Kurata

V. CONCLUSIONS

The values of excess molar volume, excess isentropic compressibility, excess free length are found to be negative, excess Gibb's free energy of activation and excess enthalpy are positive over the entire range of composition for all the liquid mixture systems considered in the present study. This is a clear indication for the presence of hydrogen bonding between the component molecules. The difference in molar masses of the liquid molecules is also responsible for the existing specific interactions between the molecules of the component liquids. The strength of specific interactions between unlike molecules is decreasing with increase in chain length of alcohol in these mixtures and they are in the order of (Ethyl benzoate + 1-propanol) +benzene > (Ethyl benzoate + 1-butanol) +benzene > (Ethyl benzoate + 1-pentanol) +benzene. Besides, the computed speed of sound values from different theories have been correlated with the experimentally measured values. Speed of sound values obtained from Nomoto's and free length theory relations are in good agreement with the experimental values. The experimental viscosity values are compared with the

viscosity values obtained from different empirical relations and these are in good agreement with the experimental values.

VI. ACKNOWLEDGEMENTS

The authors gratefully acknowledge University Grants Commission Departmental Research Scheme at Level III program No. F.530/1/DRS/2009 (SAP-1), dated 9 February 2009, and Department of Science and Technology -Fund for Improving Science and Technology program No. DST/FIST/PSI -002/2011 dated 20-12-2011, New Delhi, to the department of Physics, Acharya Nagarjuna University for providing financial assistance.

REFERENCES:

- [1] M. Gowrisankar, P. Venkateswarlu, S. Sivakumar, and S. Sivarambabu "Ultrasonic Studies On Molecular Interactions In Binary Mixtures Of N-Methyl Aniline With Methyl Isobutylketone, +3-Pentanone, And +Cycloalkanones At 303.15 K" J. Solution Chem. Vol. 42, Pp.916-935 (2013).
- [2] R. Ahluwalia, R. Gupta, J. L. Vasisht, and R. K. Wancho, "Excess Molar Volumes And Viscosities Of Binary Mixtures Of Some Polyethers With 1-Propanol At 288.15, 298.15, And 308.15 K" J. Solution Chem. vol. 42, pp. 945 -966 (2013).
- [3] V.G.Hernandez,P.G.Gimenez, J.M.Embid, M.Artal, andI.Velasco, Temperature And PressureDependence Of The Volumetric Properties Of Binary Liquid Mixtures Containing 1-Propanol And Dihaloalkanes" Phys. Chem. Liq. Vol. 43, pp. 523-533 (2005).
- [4] Sk. Md Nayeem, M. Kondaiah, K. Sreekanth, and D. Krishna Rao "Thermoacoustic, Volumetric, and Viscometric Investigations in Binary Liquid System of Cyclohexanone with Benzyl Benzoate at $T = 308.15, 313.15,$ and 318.15 K " Journal of Thermodynamics, Vol. 2014 Article ID 487403, 13 pages (2014).
- [5] S. Sharma, B. Jasmin, J. Ramani, and R. Patel, "Density, Excess Molar Volumes and Refractive Indices Of B-Pinene With O, M, P-Xylene And Toluene At 303.15, 308.15 and 313.15 K" Phys. Chem. Liq. vol.49, pp.765-776 (2011).
- [6] M. Kondaiah, K. Sreekanth, D. Saravaan Kumar, Sk. Md Nayeem, and D. Krishna Rao "Densities, Viscosities and excess properties for binary mixtures of ethylene glycol with amidesat 308.15K" J Therm. Anal. Calorim. vol.118, pp.475-483, (2014)
- [7] S. K. Dash, S. K. Pradhan, B. Dalai, L. Moharana, and B. B. Swain, "Studies On Molecular Interaction In Binary Mixtures Of Diethyl Ether With Some Alkanols—An Acoustic Approach" Phys. Chem. Liq. vol.50, pp.735-749 (2012).
- [8] Z. H. Yu, H. Y. Gao, H. Wang, and L. Chen, "Densities, Excess Molar Volumes, And Refractive Properties Of The Binary Mixtures Of The Amino Acid Ionic Liquid [Bmim][Gly] With 1-Butanol Or Isopropanol At $T = (298.15\text{ To }313.15\text{ K})$ ". J. Chem. Eng. Data. vol.56, pp.4295 -4300 (2011).
- [9] Anil K. Nain, Sana Ansari, Anwar Ali, "Densities, Refractive Indices, Ultrasonic Speeds and Excess Properties of Acetonitrile + Poly(ethylene glycol) Binary Mixtures at Temperatures from 298.15 to 313.15 K" Journal of Solution Chemistry Vol. 43, pp 1032-1054, (2014)
- [10] T. S. Khasanshin, N. V. Golubeva, V. S. Samuilov, A. P. Shchemelev, "Acoustic and Thermodynamic Properties of the Binary Liquid Mixture n-Octane + n-Dodecane" Journal of Engineering Physics and Thermophysics .. Vol. 87, pp.213-224, (2014)
- [11] S. Sreehari Sastry, S. Babu, T. Vishwam, and K. Parvateesam, And H. S. Tiong, "Excess Parameters For Binary of Ethyl Benzoate With 1-Propanol, 1-Butanol And 1-Pentanol At $T = 303, 308, 313, 318,$ And 323 K " Physica B. vol.420, pp.40 -48 (2013).
- [12] S. Babu, S. V. Kumara Sastry, H. S. Tiong, and S. Sreehari Sastry, "Experimental And Theoretical Studies Of Ultrasonic Velocity In Binary Liquid Mixtures Of Ethyl Benzoate" E-J. Chem. vol.9(4), pp.2309-2314 (2012).
- [13] S. V. Kumara Sastry, S. Babu, H. S. Tiong, and S. Sreehari Sastry, "Molecular Interaction Studies In Ternary Mixture Of Ethyl

- Hydroxy Benzoate By Ultrasonic Velocity Measurements” Res. J. Pharm. Biol. Chem. Sci. vol.3(2), pp.500-5 (2012).
- [14] S.V.Kumara Sastry, S. Babu, H. S. Tiong, and S.SreehariSastry, “Ultrasonic Investigation Of Molecular Interactions In Ternary Mixtures At 303 K.” J Chem Pharm Res. vol.4(4) pp.2122-2127 (2012).
- [15] Edward Zorębski, Paweł Góralski, Bożena Godula, Michał Zorębski, “Thermodynamic and acoustic properties of binary mixtures of 1-butanol with 1,2-butanediol. The comparison with the results for 1,3-, and 1,4-butanediol” The Journal of Chemical Thermodynamics, vol. 68, pp. 145-152, (2014)
- [16] O. Redlich, and A. T. Kister, “Algebraic Representation Of Thermodynamic Properties And The Classification Of Solutions” Ind. Eng. Chem. vol.40, pp.345-348 (1948).
- [17] A. I. Vogel Text Book Of Organic Chemistry, 5th Ed., John Wiley, New York, (1989).
- [18] Zubin R. Master, Naved I. Malek “Molecular interaction study through experimental and theoretical volumetric, acoustic and refractive properties of binary liquid mixtures at several temperatures 1. N,N-dimethylaniline with aryl, and alkyl ethers”, Journal of Molecular Liquids, vol. 196, pp.120-134,(2014)
- [19] R. Palani, S. Saravanan, and R. Kumar, “Ultrasonic Studies On Some Ternary Organic Liquid Mixtures At 303, 308 And 313 K” Rasayan J. Chem. vol.2 (3) pp.622-629 (2009).
- [20] R. Palani, and S. Balakrishnan, “Acoustical Properties Of Ternary Mixtures Of 1-Alkanols In Diisopropyl Ether And 2, 2, 2-Trifluoroethanol Mixed Solvent” Indian J. Pure Appl. Phys. vol.48, pp.644 -650 (2010).
- [21] S. Thirumaran, and J. Earnest Jayakumar, Ultrasonic Study Of N-Alkanols in Toluene With Nitrobenzene, Indian J. Pure Appl. Phys. vol.47, pp.265 -272 (2009).
- [22] T. M. Aminabhavi, T. S. Hemant Phayde, S. Rajashekar Khinnavar, B. Gopalakrishna, and Hansen Keith, “Densities, Refractive Indices, Speeds Of Sound, And Shear Viscosities Of Diethylene Glycol Dimethyl Ether With Ethyl Acetate, Methyl Benzoate, Ethyl Benzoate, And Diethyl Succinate In The Temperature Range From 298.15 To 318.15 K J. Chem. Eng. Data vol.39, pp.251-260 (1994).
- [23] R. C. Reid, J. M. Prausnitz, and B. E. Poling, The Properties Of Gases And Liquids, 4th Ed., Mcgraw Hill, New York, (1987).
- [24] G. Munendra Kumar, and S. Ashish Kumar, “Ultrasonic Study Of Molecular Interactions In Binary Mixtures Of Isopropylbenzene (Cumene) With Benzene, Toluene And Acetone At 303K” Res. J.Chem.Sci. 3(2), pp.27-30 (2013).
- [25] A. Ali, A. K. Nain, D. Chand, and R. Ahmad, “Viscosities and Refractive Indices Of Binary Mixtures Of Dimethylsulphoxide With Some Aromatic Hydrocarbons At Different Temperatures: An Experimental And Theoretical Study” J.Chin.Chem. Soc. vol.53(3), pp.531-543, (2006).
- [26] M. Chandra Sekhar T. Madhu Mohan, T. Vijaya Krishna, “Excess thermodynamic and FT-IR spectroscopic studies on binary liquid mixtures of 2-chloroaniline with isomeric butanols at $T = (303.15 \text{ to } 318.15) \text{ K}$ ” Journal of Molecular Liquids, vol.200, pp. 263-272, (2014)
- [27] O. Kiyohara, and G. C. Benson. “Ultrasonic Speeds And Isentropic Compressibilities Of N-Alkanol N-Heptane Mixtures At 298.15 K” J. Chem. Thermodyn. vol.11, pp.861-873 (1979).
- [28] G. C. Benson, and O. Kiyohara. “Evaluation Of Excess Isentropic Compressibilities And Isochoric Heat Capacities” J.Chem. Thermodyn. vol.11, pp.1061-1064 (1979).
- [29] G. Douheret, A. Pal, and M. I. Davis. “Ultrasonic Speeds And Isentropic Functions Of (A 2-Alkoxyethanol (Water) At 298.15 K” J.Chem. Thermodyn. vol.22, pp.99-108 (1990).
- [30] J. D. Pandey, R. D. Rai, R. K. Shukla, A. K. Shukla, and N. Mishra. “Ultrasonic And Thermodynamic Properties Of Quaternary Liquid System At 298.15 K” Indian J. Pure Appl. Phys. vol.31, pp.84-90 (1993).
- [31] R. J. Fort, and W. R. Moore. “Adiabatic Compressibilities In Binary Liquid Mixtures” Trans. Faraday Soc. vol.61, pp.2102-2110 (1965).
- [32] H. Iloukhani, N. Zoorasna, and R. Sloeimani. “Excess Molar Volumes And Speeds Of Sound Of Tetrahydrofuran With Chloroethanes Or Chloroethenes At 298.15 K” Phys. Chem. Liq. vol.43, pp.391-401 (2005).
- [33] S. C. Bhatia, R. Rani, R. Bhatia, and H. Anand “Volumetric And Ultrasonic Behaviour Of Binary Mixtures Of 1-Nonanol With O-Cresol, M-Cresol, P-Cresol And Anisole At $T = (293.15 \text{ And } 313.15) \text{ K}$ ” J. Chem. Thermodyn. vol.43, pp. 479-486 (2011).
- [34] B. Garcio, S. Aparicio, A. M. Navarro, R. Alcalde, and J. M. Leal, “Measurements And Modeling Of Thermophysical Behavior Of (C1-C4) Alkylbenzoate/(C1-C11) Alkan-1-Ol Mixed Solvents” J.Phys.Chem.B. vol.108, pp.15841-15850 (2004).
- [35] S. L. Oswal, V. Pandiyan, B. Krishna Kumar, and P. Vasantharani, “Thermodynamic And Acoustic Properties Of Binary Mixtures Of Oxolane With Aniline And Substituted Anilines At 303.15, 313.15 And 323.15 K” Thermochimica Acta. vol.507-508, pp.27-34 (2010).
- [36] M. C. S. Subha, G. N. Swamy, M. E. Bal, and K. S. K. V. Rao. “Excess Volume And Viscosity Of Ethoxy Ethanol With N-Butylamine, Sec-Butylamine, Tert-Butylamine, N-Hexylamine, N-Octylamine And Cyclohexylamine” Indian J. Chem. Sect. A. 43, pp.1876-1881 (2004).
- [37] K. Narendra, Ch. Srinivasu, and P. Narayanamurthy. “Excess Properties Of Binary Mixtures Of O-Xylene, M-Xylene And P-Xylene With Anisaldehyde At Different Temperatures” J. Appl. Sci. vol.12(2), pp.136-144 (2012).
- [38] O. Nomoto. “Empirical Formula For Sound Velocity In Binary Liquid Mixtures” J. Phys. Soc. (Japan.) vol.13, pp.1528-1532 (1958).
- [39] S. Baluja, and P. H. Parrania. “Acoustical Properties Of 3-A-Furyl Acrylic Acid In Protic And Aprotic Solvents” Asian J.Chem. vol.7, pp.417-423 (1995).
- [40] W. Van Deal. “Theory Of Ultrasound. In: Van Deal W. Thermodynamic Properties And Velocity Of Sound, London: Butterworth; 1975,
- [41] G. Savaroglu, and E. Aral. “Densities, speed of sound and isentropic compressibilities of the ternary mixture 2-propanol+acetone+cyclohexane and the constituent binary mixtures at 298.15 and 313.15 K” Fluid Phase Equilib. vol. 215, pp. 253-262 (2004)
- [42] B. Jacobson. “Ultrasonic Velocity In Liquids And Liquid Mixtures” J.Chem.Phys. vol.20, pp.927-935 (1952).
- [43] G. V. Rama Rao, A. V. Viswanatha Sarma, J. Sivarama Krishna, and C. Rambabu. “Theoretical Evaluation Of Ultrasonic Velocities In Binary Liquid Mixtures Of O-Chlorophenol At Different Temperatures” Indian J. Pure Appl. Phys. vol. 43, pp.345-354 (2005).
- [44] L. Grunberg, and A. H. Nissan. “Mixture Law For Viscosity. Nature” Mixture Law For Viscosity. Nature. vol.164, pp.799-800 (1949).
- [45] R. K. Hind, E. Mc Laughlin, and A. R. Ubbelohde. “Structure And Viscosity Of Liquids Camphor Pyrene Mixtures” Trans. Faraday Soc. vol.56, pp.328 -30 (1960).
- [46] P. K. Katti, and M. M. Chaudari. “Viscosities Of Binary Mixtures Of Benzyl Acetate With Dioxane, Aniline And M-Cresol” J.Chem Eng. Data. vol.9, pp.442 -445 (1964).
- [47] E. L. Heric, and J. C. Brewer. “On The Viscosity Of Ternary Mixtures” J.Chem Eng. Data. vol.11, pp.66-74 (1966).
- [48] Y. I. Frenkel. “ Theory Of The Viscosity Of Liquid Mixtures. Petroleum” Petroleum. vol.9, pp.27-33 (1946).
- [49] M. Tamura, and M. Kurata. “On The Viscosity Of Binary Mixture Of Liquids” Bull. Chem. Soc. (Japan) vol. 25, pp.32-40 (1952).