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

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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 have been obtained 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 ($K_e$), excess molar volume ($V^E$), excess free length ($L^E$), excess Gibb’s free energy of activation for viscous flow ($\Delta G^E$), 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 ($\rho$), viscosities ($\eta$) and speed of sound ($U$) of pure liquids with literature values are given in Table 1.

| Liquid | T/K   | $\rho \cdot 10^3$ (kg/m$^3$) | $\eta \cdot 10^3$ (kg/m$^3$.s$^{-1}$) | U/(m.s$^{-1}$) |
|--------|-------|----------------------------|--------------------------------------|--------------|
|        | Exp.  | Lit.                       | Exp.                                | Lit.         |
| 1-Propanol | 303.15 | 0.79                         | 0.7962                              | 1.61        |
|         | 3.00   | 1.607(22)                   | 1189.2                              | 1190.2(23)  |
| 1-Butanol | 303.15 | 0.80                         | 0.8020                              | 2.05        |
|         | 4.00   | 2.067(23)                   | 1228.4                              | 1225.8(24)  |
| 1-Pentanol | 303.15 | 0.81                         | 0.8127                              | 3.03        |
|         | 0.25   | 3.008[8]                    | 1252.4                              | 1254.9(24)  |
| Ethyl Benzoate | 303.15 | 1.04                         | 1.0308[26]                          | 1.74        |
|         | 2.00   | 1.751[26]                   | 1345.4                              | 1345.4(2)   |
| Benzene | 303.15 | 0.87                         | 0.8748                              | 0.56        |
|         | 1.00   | 0.560[29]                   | 1276.4                              | 1281.0(30)  |

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 ±0.00001g. 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 0.001mPa.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 ±0.00001g. The average uncertainty in the measured density was ±0.001 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 ±0.1m/s. In all property measurements the temperature was controlled within ± 0.1 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 ($K_e$), excess molar volume ($V_e$), excess free length ($L_e$), excess Gibbs free energy of activation ($\Delta G^E$) and excess Enthalpy ($H^E$), were calculated.

### Table II. Densities ($\rho$), Viscosities ($\eta$), and Speed of sound ($U$) for the liquid mixtures at $T=303.15$ K

| $X_i$  | $\rho$ kg m$^{-3}$ | $U$ m s$^{-1}$ | $\eta$ x 10$^3$ kg m$^{-1}$ | $X_i$  | $\rho$ kg m$^{-3}$ | $U$ m s$^{-1}$ | $\eta$ x 10$^3$ kg m$^{-1}$ |
|-------|---------------------|----------------|-----------------------------|-------|---------------------|----------------|-----------------------------|
| 0.000 | 0.877               | 1276. 4        | 0.563                       | 0.000 | 0.877               | 1276. 4        | 0.563                       |
| 0.079 | 0.882               | 1276. 6        | 0.660                       | 0.079 | 0.882               | 1276. 6        | 0.660                       |
| 0.162 | 0.888               | 1272. 0        | 0.760                       | 0.162 | 0.888               | 1272. 0        | 0.760                       |
| 0.250 | 0.893               | 1271. 6        | 0.847                       | 0.250 | 0.893               | 1271. 6        | 0.847                       |
| 0.341 | 0.908               | 1269. 7        | 0.953                       | 0.341 | 0.908               | 1269. 7        | 0.953                       |
| 0.437 | 0.902               | 1268. 2        | 1.062                       | 0.437 | 0.902               | 1268. 2        | 1.062                       |

(EB+1-Propanol) + Benzene

### Calculations

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 $K_e$ were calculated as follows,

$$K_e = K - K_{id}$$  \hspace{1cm} (1)

Where $K_e$ is its excess value, $K_{id}$ is the ideal isentropic compressibility value and $K$ represent the calculated value of isentropic compressibility for the mixture ($K = \frac{1}{\rho U^2}$). $\rho$ is the density and $U$ represents the speed of sound. $K_{id}$ for an ideal mixture was calculated from the relation recommended by Benson and Kiyohara [31, 32] and Douheret et al [33].

$$K_{id} = \sum \phi_i \left( K_{s,i}^o + \frac{T V_i^o (a_i^o)^2}{C_{p,i}} \right) T \left( \sum X_i V_i^o \right) \left( \sum X_i a_i^{o2} \right)$$  \hspace{1cm} (2)

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

The excess values of free length $L_e$ were calculated by using the expression,

$$L_e = L - K_e \frac{L_{id}^{1/2}}$$  \hspace{1cm} (3)

Where $L$ represents the calculated value for the mixture and $K_e$ represent a temperature dependent constant whose value is $K_e \approx \{91.368+0.35657T\} \times 10^6$.

The density values have been used to calculate the excess volumes, $V_e$, using the following equation,

$$V_e = \frac{X_1 M_1 + X_2 M_2 + (X_1 M_1 + X_2 M_2)}{\rho_1 + \rho_2}$$  \hspace{1cm} (4)

where $\rho$ is the density of the mixture and $X_1$, $M_1$, and $\rho_1$ and $X_2$, $M_2$, and $\rho_2$ are the mole fraction, molar mass, and density of pure components 1 and 2, respectively.

Excess Gibbs free energy of activation $\Delta G^E$ was calculated as follows,

$$\Delta G^E = RT \ln \left( \frac{\eta V}{\eta_2 V_2} \right) - x_1 \ln \left( \frac{\eta V_1}{\eta_2 V_2} \right)$$  \hspace{1cm} (5)

Where R represents gas constant, $T$ is absolute temperature, $\eta$ is the viscosity of the mixture and $\eta_1$, $\eta_2$ 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.

$$H^E = H - (X_1H_1 + X_2H_2)$$  \[(6)\]

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].

$$Y_i^E = x_i (1-x_i) \sum_{i=1}^{n} A_i (2x_i - 1)^{i-1}$$  \[(7)\]

Where $Y_i^E = K_s^E$, $V_i^E$, $\Delta G^E$, $H^E$. 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 ($\sigma$) was calculated using the relation

$$\sigma(Y) = \sqrt{\frac{\sum(Y_{obs} - Y_{cal})^2}{n-m}}$$  \[(8)\]

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 ($K_i^E$), excess molar volume ($V_i^E$), excess free length ($L_i^E$), excess Gibbs free energy of activation ($\Delta G^E$) 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 ($K_i^E$), molar volume ($V_i^E$), free length ($L_i^E$), Gibbs free energy of activation ($\Delta G^E$) 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 ($\sigma$) are given in Table 3.

Table III. Coefficients of Redlich-Kister equation $A_i$ and standard deviations $\sigma$, for excess molar volumes ($V^E$), excess isentropic compressibility ($K^E$), excess free length ($L^E$), excess Gibbs’s free energy ($\Delta G^E$) and excess enthalpy ($H^E$) at $T=303.15$K for the liquid mixtures under study.

| Properties                  | $A_0$ | $A_1$ | $A_2$ | $\sigma$ |
|-----------------------------|-------|-------|-------|----------|
| $10^3 \cdot V^E$ (m$^3$ mol$^{-1}$) | -2.307 | -0.386 | 0.108 | 0.04     |
| $10^{12} K^E$ (m$^{-2}$ mol$^{-1}$) | -17.97 | 0.042 | 1.850 | 0.07     |

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 ($K_i^E$) 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...
Ks^E values are negative over the entire mole fraction range. The negative values of Ks^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 Ks^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 Ks^E in these mixtures can be associated with a structure forming tendency.

The variation of excess molar volume (V^E), with respect to mole fraction, x1, is given in Fig.2 over the entire composition range at T = 303.15 K. The strength of the 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 Garcio 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 Ks^E. Similar results were observed by the studies of researchers [35].

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

![Fig.2. Excess molar volume, V^E, with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X1, for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at T/K=303.15](image)

Fig.2. Excess molar volume, V^E, with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X1, for liquid mixture of (EB+1-propanol/1-butanol/1-pentanol)+Benzene at T/K=303.15

![Fig.3. Excess free length, Lf^E, with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X1, 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](image)

Fig.3. Excess free length, Lf^E, with respect to mole fraction of (EB+1-propanol/1-butanol/1-pentanol), X1, 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 x1, over the entire composition range and at T = 303.15K. It can be seen

![Fig.4. Excess Gibb’s free energy of activation (ΔG^E) with respect to mole fraction x1](image)
from figure 4 that the $\Delta G^E$ 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 $T = 303.15 K$. 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.

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 $T=303.15\text{ K}$.

| $X_1$ | $U_{exp}$ | $U_{ном}$ | $U_{IMP}$ | $U_{CDV}$ | $U_{IM}$ | $U_{FLT}$ | $U_s$ |
|-------|------------|-----------|-----------|-----------|---------|----------|------|
|       | 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 |
| 0.07  | 1274.6     | 1274.6    | 1261.4    | 1274.6    | 1274.6  | 1274.6   | 1274.6 |
| 0.16  | 1272.8     | 1272.8    | 1261.4    | 1272.8    | 1272.8  | 1272.8   | 1272.8 |
| 0.25  | 1271.2     | 1271.2    | 1261.4    | 1271.2    | 1271.2  | 1271.2   | 1271.2 |
| 0.34  | 1269.7     | 1269.7    | 1261.4    | 1269.7    | 1269.7  | 1269.7   | 1269.7 |
| 0.43  | 1268.6     | 1268.6    | 1261.4    | 1268.6    | 1268.6  | 1268.6   | 1268.6 |
| 0.53  | 1266.8     | 1266.8    | 1261.4    | 1266.8    | 1266.8  | 1266.8   | 1266.8 |
| 0.64  | 1265.3     | 1265.3    | 1261.4    | 1265.3    | 1265.3  | 1265.3   | 1265.3 |
| 0.75  | 1263.9     | 1263.9    | 1261.4    | 1263.9    | 1263.9  | 1263.9   | 1263.9 |
| 0.87  | 1262.6     | 1262.6    | 1261.4    | 1262.6    | 1262.6  | 1262.6   | 1262.6 |
| 1     | 1261.4     | 1261.4    | 1261.4    | 1261.4    | 1261.4  | 1261.4   | 1261.4 |
| APE   | 0          | 0.0721    | 0.526     | 0.13      | 0       | 1.72     | 0.61  |
| Chi square | 0          | 0.0096   | 0.527     | 0.03      | 0       | 0.58     | 0.38  |

![Graph](Fig4.Excess Gibb’s free energy, $\Delta G^E$, 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 $T/K=303.15$.)

![Graph](Fig5.Excess Enthalpy, $H^E$, 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 $T/K=303.15$.)
The mole fraction of (EB+1-pentanol) + Benzene is shown in Fig. 6(a). The variation of theoretical speed of sound, $U$, with respect to mole fraction for these theories is shown in Fig. 6(a-c).
Table V. Experimental and computed values of Viscosity $\eta \times 10^3$ / N.s.m$^{-2}$, various interaction parameters and their corresponding standard deviations ($\sigma$) at $T=303.15$ K.

| $X_1$ | $\eta_{exp}$ | Grunberg and Nissan | Hind and Ubbelohde | Katti and Chaudari | Herc and Brewer | Frenkel | Tamura and Kurata |
|-------|--------------|---------------------|-------------------|-------------------|---------------|--------|-------------------|
| 0.000 | 0.5632       | 0.5632              | 0.5632            | 0.5632            | 0.5632        | 0.5632 | 0.5632            |
| 0.079 | 0.6690       | 0.6449              | 0.4879            | 0.694             | 0.694         | 0.6452 | 0.6549            |
| 0.162 | 0.7600       | 0.7363              | 0.4396            | 0.7284            | 0.7283        | 0.7370 | 0.7502            |
| 0.250 | 0.8470       | 0.8378              | 0.4222            | 0.8303            | 0.8303        | 0.8389 | 0.8493            |
| 0.341 | 0.9539       | 0.9490              | 0.4405            | 0.9490            | 0.9494        | 0.9506 | 0.9526            |
| 0.437 | 1.0620       | 1.0689              | 0.5002            | 1.0708            | 1.0708        | 1.0604 |                  |
| 0.538 | 1.1762       | 1.1953              | 0.6073            | 1.2048            | 1.2048        | 1.1976 | 1.1728            |
| 0.644 | 1.2915       | 1.3253              | 0.7064            | 1.3417            | 1.3418        | 1.3276 | 1.2905            |
| 0.756 | 1.4057       | 1.4538              | 0.9053            | 1.4739            | 1.4740        | 1.4559 | 1.4137            |
| 0.875 | 1.5330       | 1.5745              | 1.2944            | 1.5906            | 1.5907        | 1.5758 | 1.5430            |
| 1.000 | 1.6788       | 1.6788              | 1.6788            | 1.6788            | 1.6788        | 1.6788 | 1.6788            |

| Interaction Parameter | $G_{12}$ | $H_{12}$ | $W_{RT}$ | $\Delta_{12}$ | $F_{12}$ | $T_{12}$ |
|-----------------------|----------|----------|----------|---------------|---------|---------|
| $\sigma$              | 0.0258   | 0.4262   | 0.0406   | 0.0406        | 0.0296  | 0.0062  |

The dynamic viscosities of the liquid mixtures have been calculated using several empirical relations due to Gronberg-Nissan [45], Hind et al. [46], Katti and Chaudari [47], Herc 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 molar fraction for these theories is shown in Fig. 7(a-c).
he Binary Mixtures - Properties of, D.Saravaan Kumar, obtained values. Speed of sound values are compared with the experimental viscosity values are obtained from different empirical relations and these are in good agreement with the experimental values.

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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. 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.

Fig. 7. Variation of theoretical viscosity, n, 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. ●, Grunberg and Nissan; ▲, Hind and Ubbelohde; ▼, Katt and Chaudhari; ◦, Heric and Brewer; ◻, Frenkel; ▲, Tamura and Kurata.
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