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# Analysis of Thermo Physical Properties of Binary Liquid Mixtures Containing Cyclic Diether with n-Alkanols ($C_5$-$C_{10}$) at 298.15 K: By Ultrasonic Velocity Measurements

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## Abstract

Ultrasonic velocity, viscosity and density measurements were calculated at 298.15 K for binary mixtures of cyclic diether ($X_1$) with primary alcohols. Based on the experimental data, several acoustical parameters were computed, including adiabatic compressibility ($\beta_{ad}$), specific acoustic impedance (Z), and molar volume ($V_m$). These parameters provide valuable insights into molecular interactions, structural modifications, and deviations from ideal behavior in the all studied mixtures. The excess properties have been fitted in Redlich-Kister equation. The results suggest the presence of molecular interactions in the studied mixtures, with dipole-induced interactions being the dominant force. These findings provide insight into the intermolecular interaction present in the studied mixtures, highlighting the influence of structural and electronic factors on their behavior.

## Keywords

1,3-Dioxolane, Density, Inter Molecular Interactions, Acoustical Impedance, Molar Volume, Ultrasonic Velocity

## 1. Introduction

Ultrasonic velocity measurements are widely recognized as a powerful tool for studying molecular interactions, structural properties, and thermodynamic behavior in both components [1]-[5]. Sound velocity is a key parameter for understanding molecular interactions and complex formation in liquid mixtures [6] [7].

The main use of cyclic diether and alkanols in many industrial processes such as pharmaceutical and cosmetics has greatly stimulated the need for extensive information on the thermodynamic, acoustic and transport properties of cyclic diether, alkanols and their mixtures. The work described in this paper belongs to a systematic study program concerning the measurement and mathematical description of various thermodynamic properties of binary liquid mixtures containing important compounds. The study of thermodynamic properties of binary mixtures of alkanols with 1,3-dioxolane is of great importance both from a practical and theoretical point of view. The experimental determined parameters in solute-solvent mixtures provide critical data for computing various thermodynamic and acoustical parameters. These parameters provide valuable information regarding interactions in the mixtures [8] [9]. Many researchers have extensively studied transport and thermodynamic properties of binary liquids, structural effects, and deviation from ideal behaviour [10]-[12]. The ultrasonic method is widely applicable in investigating the molecular interactions in liquid mixtures, because it provides insights into structural changes, compressibility, and bonding interactions at a molecular level. Density, sound velocity and viscosity determined have been widely utilized in liquid and liquid mixtures. Present paper investigates behavior of binary solutions, providing insights into their intermolecular forces and structural modifications.

## 2. Experimental Procedure

### 2.1. Materials

Cyclic diether (1,3-dioxolane) and primary alcohols (pentanol, hexanol, heptanol, octanol, nonanol and decanol) were purchased from CDH Ltd., New Delhi, India. All the chemicals were stored in dark bottles over freshly activated molecular sieve to minimize adsorption of moisture. All chemicals were purified by standard methods like distillation and fractional distillation under reduce pressure, and only the middle fractions were collected. Before use, the chemicals were stored over 0.4 nm molecular sieves for about 48 h to remove water and gas. It sounds like you're ensuring the reliability of your experimental data by comparing the density, viscosity, and ultrasonic velocity of the studied chemicals with different citations [13]-[22]. This verification process is crucial for validating the liquid and liquid mixtures.

### 2.2. Apparatus and Procedure

Binary liquid mixtures are prepared by mixing appropriate volumes of the liquid components in the specially designed glass bottles with air tight Teflon coated caps and mass measurements performed on a analytical single pan balance (Model K-15 Deluxe, K Roy Instruments Pvt. Ltd.) with an accuracy of $\pm$ 0.00001 $\times$ $10^{-3}$ kg. The possible error in the mole fraction was estimated to be less than $1 \times 10^{-4}$. Five samples were prepared for one system, and their density, viscosity and sound velocity were measured on the same day (**Table 1**).

**Table 1.** Practically values and Quoted data for densities ($\rho$), sound velocity ($u$), viscosity ($\eta$) of pure components at T = 298.15 K.

| Chemical | Density, $\rho$ (g.cm$^{-3}$) | | Sound velocity, $u$ (m.s$^{-1}$) | | Viscosity, $\eta$ (mPa s) | |
|---|---|---|---|---|---|---|
| | Experimental | Quote Values | Experimental | Quote Values | Experimental | Quote Values |
| 1,3-Dioxolane | 1.0616 | 1.0577[17] | 1340 | 1338[17] | 0.5885 | 0.5878[17] |
| | | 1.0586[17] | | 1338[18] | | 0.5873[17] |
| Pentanol | 0.8124 | 0.8108[13] | 1198 | 1197[16] | 3.3978 | 3.5411[13] |
| | | 0.8107[13] | | 1268[22] | | 3.5424[13] |
| Hexanol | 0.8176 | 0.8187[13] | 1306 | 1304[15] | 4.6091 | 4.5924[13] |
| | | 0.8152[15] | | 1303[15] | | 4.5932[13] |
| Heptanol | 0.8196 | 0.8187[13] | 1325 | 1327[15] | 5.9066 | 5.9443[13] |
| | | 0.8197[19] | | 1327.37[24] | | 5.94432[24] |
| Octanol | 0.8236 | 0.8216[13] | 1350 | 1348[14] | 7.1508 | 7.6605[13] |
| | | 0.8218[13] | | 1347[22] | | 7.5981[13] |
| Nonanol | 0.8248 | 0.8244[15] | 1366 | 1365[15] | 8.9258 | 9.0230[21] |
| | | 0.824224[15] | | 1364[24] | | 9.0200[24] |
| Decanol | 0.8292 | 0.8267[15] | 1378 | 1380[15] | 11.8027 | 11.825[15] |
| | | 0.8264[19] | | 1379[24] | | 11.829[15] |

### 2.3. Measurements

**Density:** The density was determined at the experimental temperature using a 25 mL capacity specific gravity bottle immersed in the thermostatic bath. The volume of the bottle at the experimental temperature viz 298.15K was ascertained using distilled water.

**Sound velocity:** Sound velocity determined by the multi-frequency interferometer at 3 MHz and 298.15 K, A fixed frequency generator working at 3 MHz. its resonant frequency, the crystal undergoes rapid mechanical oscillations, generating ultrasonic waves. These waves can propagate through the liquid in the vessel, creating effects like cavitation, acoustic streaming, or enhanced mixing.

The ultrasonic velocity (U) was determined using the following formula:

$$U = \lambda . f \tag{1}$$

**Viscosity:** An experimental setup for measuring the viscosity by Ostwald viscometer. The viscometer was calibrated using distilled water at 298.15 K, and multiple measurements (five repetitions) were taken for each sample to ensure accuracy. The uncertainty in viscosity measurement is given as ± 0.005 × 10$^{-3}$ mPa·s, indicating high precision.

## 3. Theoretical

The molar volume ($V_m$) has been determined as:

$$V_m = \frac{\left(X_1 M_1 + X_2 M_2\right)}{\rho} \tag{2}$$

The adiabatic compressibility $(\beta_{ad})$ is typically measuring the equation:

$$\beta_{ad} = \frac{1}{u^2 \rho} \tag{3}$$

where $\rho$ in (g/cm³ or kg/m³), $u$ in (m/s or cm/s).

This equation is based on the relationship between compressibility and the propagation of sound waves in a medium. The lower the speed of sound in a liquid, the higher its compressibility.

The acoustic impedance was determined by

$$Z = \rho . u \tag{4}$$

To calculate the excess parameters of all acoustical properties were computed using the relation:

$$A^E = A_{exp.} - A_{ideal} \tag{5}$$

where $A_{ideal} = (X_1A_1 + X_2A_2)$, A is any acoustical parameter and $X_1A_1$ and $X_2A_2$ is mole fractions of cyclic diether and primary alcohols.

## 4. Result and Discussion

The practically determined density (ρ), viscosity ($\eta$) and sound velocity (u) for the binary liquid at 298.15K are reported in Table 2. Table 2 represents the calculated values of adiabatic compressibility ($\beta_{ad}$), molar volume ($V_m$) and acoustic impedance (Z) for the binary mixtures and their excess data are presented in Table 3.

A perusal of Table 2 shows the mole fraction ($X_1$) of cyclic diether increases, density and ultrasonic velocity increase, while viscosity decreases. This trend can be explained by molecular interactions in the system: When 1,3-Dioxolane is added, it likely leads to closer packing of molecules due to molecular interactions, such as dipole-induced dipole forces.

**Table 2.** Density ($\rho$), sound velocity ($u$), viscosity ($\eta$), calculated adiabatic compressibility ($\beta_{ad}$), molar volume ($V_m$), and acoustic impedance (Z), of liquid mixtures of cyclic diether vs alkanols at experimental temperature.

| Mole fraction 1,3-Dioxolane ($x_1$) | Density ($\rho$) g.cm$^{-3}$ | Speed of Sound ($u$) ms$^{-1}$ | Viscosity ($\eta$) mPa.s | Adiabatic compressibility ($\beta_{ad}$) $\times 10^{-7}$Pa$^{-1}$ | Molar volume ($V_m$) $\times 10^{-3}$ cm$^3$.mole$^{-1}$ | Acoustic impedance (Z) $\times 10^{-4}$ g.cm..s$^{-1}$ |
|---|---|---|---|---|---|---|
| 1,3-Dioxolane + Pentanol | | | | | | |
| 0 | 0.8124 | 1198 | 3.3978 | 8.5770 | 0.1085 | 0.0973 |
| 0.0939 | 0.8276 | 1284 | 2.3973 | 7.3290 | 0.1049 | 0.1062 |
| 0.1942 | 0.8436 | 1290 | 1.8970 | 7.1233 | 0.1012 | 0.1088 |
| 0.2941 | 0.8640 | 1296 | 1.4437 | 6.8909 | 0.0972 | 0.1119 |
| 0.3942 | 0.8836 | 1300 | 1.1866 | 6.6966 | 0.0934 | 0.1148 |
| 0.4787 | 0.9068 | 1304 | 1.0904 | 6.4853 | 0.0897 | 0.1182 |
| 0.5999 | 0.9316 | 1310 | 0.9311 | 6.2551 | 0.0855 | 0.1220 |
| 0.6972 | 0.9596 | 1318 | 0.7717 | 5.9991 | 0.0816 | 0.1264 |
| 0.7928 | 0.9876 | 1324 | 0.7171 | 5.7762 | 0.0779 | 0.1307 |
| 0.9035 | 1.0260 | 1332 | 0.6489 | 5.4934 | 0.0735 | 0.1366 |
| 1.0000 | 1.0616 | 1340 | 0.5885 | 5.246 | 0.0697 | 0.1422 |
| 1,3-Dioxolane + Hexanol | | | | | | |
| 0 | 0.8176 | 1306 | 4.6091 | 7.1709 | 0.1249 | 0.1067 |
| 0.0912 | 0.8252 | 1317 | 3.3826 | 6.9867 | 0.1207 | 0.1086 |

**Continued**

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.1955 | 0.8432 | 1320 | 2.3306 | 6.8065 | 0.1146 | 0.1113 |
| 0.2923 | 0.8584 | 1322 | 1.9839 | 6.6657 | 0.1094 | 0.1134 |
| 0.3982 | 0.8792 | 1325 | 1.5720 | 6.4786 | 0.1034 | 0.1164 |
| 0.4942 | 0.8992 | 1327 | 1.3059 | 6.3154 | 0.0981 | 0.1193 |
| 0.6059 | 0.9264 | 1330 | 1.0343 | 6.1024 | 0.0919 | 0.1232 |
| 0.6976 | 0.9508 | 1332 | 0.9131 | 5.9279 | 0.0868 | 0.1266 |
| 0.8018 | 0.9836 | 1335 | 0.7680 | 5.7045 | 0.0809 | 0.1313 |
| 0.8914 | 1.0168 | 1337 | 0.7304 | 5.5018 | 0.0758 | 0.1359 |
| 1.0000 | 1.0616 | 1340 | 0.5885 | 5.2460 | 0.0697 | 0.1422 |
| 1,3-Dioxolane + Heptanol | | | | | | |
| 0 | 0.8196 | 1325 | 5.9066 | 6.9497 | 0.1417 | 0.1085 |
| 0.0928 | 0.8304 | 1334 | 4.3181 | 6.7671 | 0.1352 | 0.1107 |
| 0.1905 | 0.8412 | 1334 | 3.2577 | 6.6802 | 0.1286 | 0.1122 |
| 0.2939 | 0.8592 | 1335 | 2.5895 | 6.5304 | 0.1208 | 0.1147 |
| 0.3894 | 0.8740 | 1335 | 1.9926 | 6.4199 | 0.1141 | 0.1166 |
| 0.4818 | 0.8916 | 1336 | 1.5315 | 6.2837 | 0.1075 | 0.1191 |
| 0.6021 | 0.9184 | 1337 | 1.2190 | 6.0912 | 0.0989 | 0.1227 |
| 0.6952 | 0.9420 | 1337 | 1.0959 | 5.9387 | 0.0922 | 0.1259 |
| 0.7892 | 0.9756 | 1338 | 0.9903 | 5.7255 | 0.0850 | 0.1305 |
| 0.9006 | 1.0156 | 1339 | 0.7057 | 5.4918 | 0.0770 | 0.1359 |
| 1.0000 | 1.0616 | 1340 | 0.5885 | 5.2460 | 0.0697 | 0.1422 |
| 1,3-Dioxolane + Octanol | | | | | | |
| 0 | 0.8296 | 1350 | 7.1508 | 6.6622 | 0.1581 | 0.1111 |
| 0.0885 | 0.8296 | 1350 | 5.6095 | 6.6139 | 0.1509 | 0.1119 |
| 0.1967 | 0.8464 | 1349 | 3.9321 | 6.4923 | 0.1408 | 0.1141 |
| 0.2998 | 0.8560 | 1348 | 3.2616 | 6.4291 | 0.1324 | 0.1153 |
| 0.3902 | 0.8712 | 1348 | 2.4284 | 6.3168 | 0.1243 | 0.1174 |
| 0.4963 | 0.8876 | 1348 | 1.9058 | 6.2002 | 0.1153 | 0.1196 |
| 0.6008 | 0.9140 | 1347 | 1.3631 | 6.0301 | 0.1055 | 0.1231 |
| 0.6925 | 0.9340 | 1348 | 1.1376 | 5.8921 | 0.0978 | 0.1259 |
| 0.7975 | 0.9676 | 1348 | 0.9141 | 5.6875 | 0.0883 | 0.1304 |
| 0.8940 | 1.0104 | 1348 | 0.7652 | 5.4466 | 0.0792 | 0.1362 |
| 1.0000 | 1.0616 | 1340 | 0.5885 | 5.2460 | 0.0697 | 0.1422 |
| 1,3-Dioxolane + Nonanol | | | | | | |
| 0 | 0.8248 | 1366 | 8.9258 | 6.4976 | 0.1749 | 0.1126 |
| 0.0876 | 0.8336 | 1366 | 6.8601 | 6.4289 | 0.1656 | 0.1138 |
| 0.1913 | 0.8404 | 1363 | 5.8531 | 6.4051 | 0.1556 | 0.1145 |
| 0.2942 | 0.8504 | 1359 | 4.4022 | 6.3671 | 0.1453 | 0.1155 |
| 0.3963 | 0.8692 | 1355 | 3.1558 | 6.2662 | 0.1339 | 0.1177 |
| 0.4959 | 0.8844 | 1352 | 2.3340 | 6.1859 | 0.1237 | 0.1195 |
| 0.6050 | 0.9092 | 1349 | 1.7321 | 6.0439 | 0.1119 | 0.1226 |
| 0.6947 | 0.9332 | 1346 | 1.3334 | 5.9145 | 0.1023 | 0.1256 |
| 0.7993 | 0.9648 | 1343 | 0.9642 | 5.7466 | 0.0913 | 0.1295 |
| 0.9013 | 1.0084 | 1340 | 0.8031 | 5.5228 | 0.0803 | 0.1351 |
| 1 | 1.0616 | 1340 | 0.5885 | 5.2460 | 0.0697 | 0.1422 |
| 1,3-Dioxolane + Decanol | | | | | | |
| 0 | 0.8292 | 1378 | 11.8027 | 6.4976 | 0.1908 | 0.1142 |
| 0.0881 | 0.8364 | 1374 | 8.5615 | 6.4289 | 0.1803 | 0.1149 |
| 0.191 | 0.8396 | 1370 | 7.8207 | 6.4051 | 0.1693 | 0.1150 |

**Continued**

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.2921 | 0.8560 | 1366 | 5.5340 | 6.3671 | 0.1561 | 0.1169 |
| 0.3937 | 0.8672 | 1362 | 4.2319 | 6.2662 | 0.1442 | 0.1181 |
| 0.4956 | 0.8824 | 1358 | 3.4173 | 6.1859 | 0.1320 | 0.1198 |
| 0.604 | 0.9076 | 1353 | 2.5370 | 6.0439 | 0.1183 | 0.1227 |
| 0.7129 | 0.9308 | 1348 | 1.5262 | 5.9145 | 0.1055 | 0.1254 |
| 0.7983 | 0.9616 | 1344 | 1.1637 | 5.7466 | 0.0946 | 0.1292 |
| 0.8971 | 1.0040 | 1340 | 0.8623 | 5.5228 | 0.0824 | 0.1345 |
| 1 | 1.0616 | 1340 | 0.5885 | 5.246 | 0.0697 | 0.1422 |

### 4.1. Excess Molar Volume ($V_m^E$)

Calculation of molar volume ($V_m$) and deviation in molar volume ($V_m^E$) for liquid mixtures of cyclic diether with primary alcohols at experimental temperature using experimental density values ($\rho$). These values reported in Table 2 and Table 3. As the mole fraction of cyclic diether ($X_1$) increases, molar volume (Vm) decreases for all binary mixtures. This suggests that 1,3-Dioxolane molecules may be filling the voids between alcohol molecules. The reduction in molar volume often points to dipole-induced dipole interactions, where the presence of 1,3-Dioxolane alters the hydrogen bonding network of the alcohols.

These positive values of $V_m^E$ are indicate volume expansion upon mixing. This suggests that intermolecular interactions are weaker in the pure components. The hydrogen bonds in primary alcohols are break and the formation of new, but weaker dipole-induced dipole interactions with 1,3-Dioxolane contribute to positive excess molar volumes. The physical contributions comparing of dispersive forces or weak dipole-dipole interaction lead to positive $V_m^E$ values. Chemical contributions include breaking up of associate present in pure liquids resulting in positive $V_m^E$ and specific interaction like formation of strong hydrogen bonds, charge-transfer complex and other complex forming interactions including strong dipole-dipole interaction between component molecules. The trend is consistent across all liquid mixtures. From Marcus [23], alkanols molecules are joined by hydrogen bonding in pure liquid state (Figure 1). The graphical analysis of ($V_m^E$) vs. $X_1$ in Figure 2 should exhibit a positive deviation, possibly showing a peak, indicating the strongest deviation at a particular composition. This behavior highlights that molecular interactions change non-linearly with composition.

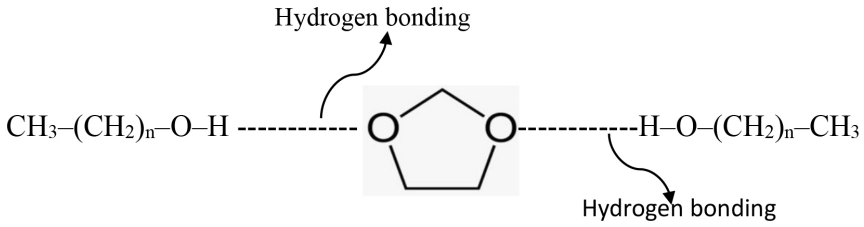


**Figure 1.** Hydrogen bonding present in cyclic diether—n-Alkanols.

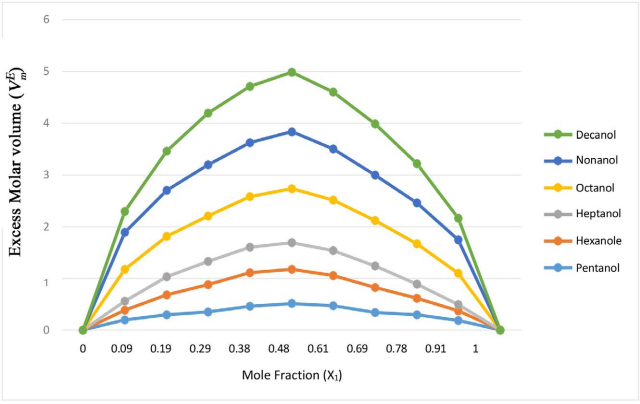


**Figure 2.** Excess molar volume ( $V_m^E$ ) versus mole fraction ($X_1$) of the 1,3-dioxolane at experimental temperature.

## 4.2. Excess Adiabatic Compressibility ( $\beta_{ad}^E$ )

The deviation of adiabatic compressibility ( $\beta_{ad}^E$ ) of liquid mixtures provides valuable insights into the intermolecular interactions between cyclic diether and primary alcohols at experimental temperature. When excess adiabatic compressibility ( $\beta_{ad}^E$ ) values is positive. This suggests that weaker intermolecular forces (such as dipole-induced dipole interactions) dominate over stronger hydrogen bonds. When excess adiabatic compressibility ( $\beta_{ad}^E$ ) values is negative [24] then, the mixture is less compressible than expected. This indicates stronger molecular interactions. Tighter molecular packing reduces compressibility [25]. When considering excess adiabatic compressibility ( $\beta_{ad}^E$ ), then it is known that contributions heptanol, octanol, nonanol and decanol gives positive values, while pentanol and hexanol contribute negative values. Having in mind the various contributions operating in the studied systems, then the positive values of excess adiabatic compressibility ( $\beta_{ad}^E$ ), in **Figure 3** can be attributed mainly to the disruption of the H-bonded structures as the alkanol molecule. The negative values of excess adiabatic compressibility ( $\beta_{ad}^E$ ), in the lack of c-atom region indicate that complex formation occurred through π… HO bonding between the π electron cloud of the aromatic ring of 1,3-dioxolane and the hydroxyl group of alkanol.

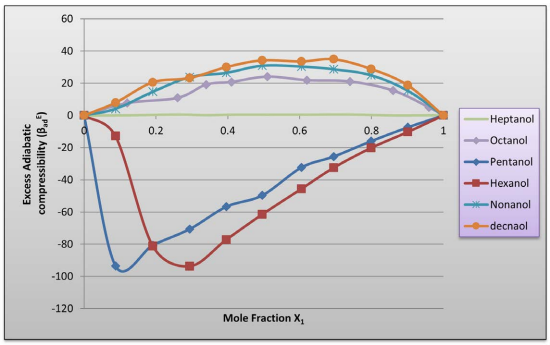


**Figure 3.** Excess adiabatic compressibility ( $\beta_{ad}^E$ ) versus mole fraction ($X_1$) of the 1,3-dioxolane at experimental temperature.

The excess adiabatic compressibility ( $\beta_{ad}^{E}$ ) values of 1,3-dioxolane and primary alkanols is insightful or aligns well with molecular interaction principles. When excess adiabatic compressibility ( $\beta_{ad}^{E}$ ) is negative, it shows that the experimental liquid mixture is less compressible from ideal mixing. When excess adiabatic compressibility ( $\beta_{ad}^{E}$ ) values is positive, it means the mixture is more compressible than expected. This occurs when dispersion forces (van der Waals interactions) dominate over specific hydrogen bonding, leading to: (1) Weaker inter molecular forces in the mixture than in pure components. (2) Increased free volume and looser packing, allowing the liquid to be more compressible. (3) Possible disruption of alcohol-alcohol hydrogen bonding without strong alternative interactions.

The excess adiabatic compressibility ( $\beta_{ad}^{E}$ ) values of 1,3-Dioxolane with alcohols are expected to follow a trend based on the strength of intermolecular interactions and molecular packing efficiency. Given your previous observations values of ( $\beta_{ad}^{E}$ ) negative or positive, order is reflected to relative dominance of dipole-dipole interactions, hydrogen bonding, and dispersion forces in each binary mixture.

Since shorter alcohols have stronger hydrogen bonding interactions, leading to more negative ( $\beta_{ad}^{E}$ ) and longer alcohols exhibit increased dispersion forces, leading to more positive ( $\beta_{ad}^{E}$ ).

**Table 3.** Calculated excess adiabatic compressibility ( $\beta_{ad}^{E}$ ), excess molar volume ( $V_{m}^{E}$ ), and excess specific acoustic impedance ($Z^{E}$) and excess viscosity ($\eta^{E}$), of liquid mixtures of cyclic diether vs alkanols at experimental temperature.

| Mole fraction 1,3-Dioxolane ($x_1$) | Excess adiabatic compressibility ( $\beta_{ad}^{E}$ ) × $10^{-7}$ $Pa^{-1}$ | Excess viscosity ($\eta^{E}$) mPa.s | Excess molar volume ( $V_{m}^{E}$ ) × $10^{-3}$ $cm^3.mole^{-1}$ | Excess acoustic impedance ($Z^{E}$) × $10^{-4}$ $g.cm.s^{-1}$ |
|---|---|---|---|---|
| **1,3-Dioxolane + Pentanol** | | | | |
| 0 | - | - | - | - |
| 0.0939 | −93.514 | −0.7367 | 0.0469 | −47.19498 |
| 0.1942 | −80.677 | −0.9552 | 0.2682 | −27.73692 |
| 0.2941 | −70.644 | −1.1280 | 0.1192 | −14.35296 |
| 0.3942 | −56.727 | −1.1038 | 0.2446 | −1.68484 |
| 0.4787 | −49.711 | −0.9627 | 0.1860 | −5.86255 |
| 0.5999 | −32.372 | −0.7815 | 0.2867 | −22.3876 |
| 0.6972 | −25.563 | −0.6675 | 0.1314 | −21.7466 |
| 0.7928 | −15.997 | −0.4535 | 0.1568 | −21.869 |
| 0.9035 | −7.400 | −0.2108 | 0.0076 | −12.5556 |
| 1.0000 | - | - | - | - |
| **1,3-Dioxolane + Hexanol** | | | | |
| 0 | - | - | - | - |
| 0.0912 | −12.864 | −0.8597 | 0.7779 | −13.3654 |
| 0.1955 | −11.193 | −1.4925 | 0.4810 | −24.1169 |
| 0.2923 | −93.762 | −1.4500 | 0.6245 | −36.6767 |
| 0.3982 | −77.201 | −1.4361 | 0.4952 | −44.1104 |

Continued

| | | | | |
|---|---|---|---|---|
| 0.4942 | −61.541 | −1.3162 | 0.4919 | −49.8688 |
| 0.6059 | −45.638 | −1.1387 | 0.3860 | −50.6217 |
| 0.6976 | −32.537 | −0.8912 | 0.3783 | −48.7995 |
| 0.8018 | −20.169 | −0.6174 | 0.2564 | −39.1249 |
| 0.8914 | −1.060 | −0.2947 | 0.0816 | −24.5556 |
| 1.0000 | - | - | - | - |
| **1,3-Dioxolane + Heptanol** | | | | |
| 0 | - | - | - | - |
| 0.0928 | 2.457 | −1.0951 | 0.1293 | −9.44037 |
| 0.1905 | 5.504 | −1.6358 | 0.5357 | −27.9265 |
| 0.2939 | 8.146 | −1.7541 | 0.2168 | −37.8571 |
| 0.3894 | 13.359 | −1.8431 | 0.4437 | −50.2419 |
| 0.4818 | 15.486 | −1.8128 | 0.4770 | −56.9538 |
| 0.6021 | 16.733 | −1.4856 | 0.4818 | −60.7204 |
| 0.6952 | 17.334 | −1.1136 | 0.5437 | −60.5022 |
| 0.7892 | 12.039 | −0.7193 | 0.0752 | −46.2414 |
| 0.9006 | 7.647 | −0.4114 | 0.1264 | −29.2001 |
| 1.0000 | - | - | - | - |
| **1,3-Dioxolane + Octanol** | | | | |
| 0 | - | - | - | - |
| 0.0885 | 7.713 | −1.0951 | 0.6846 | −19.3955 |
| 0.1967 | 10.869 | −1.6358 | 0.0682 | −31.1779 |
| 0.2998 | 19.142 | −1.7541 | 0.8340 | −51.1151 |
| 0.3902 | 20.728 | −1.8431 | 0.6824 | −58.7113 |
| 0.4963 | 24.082 | −1.8128 | 1.0462 | −69.5677 |
| 0.6008 | 21.867 | −1.4856 | 0.5270 | −67.3609 |
| 0.6925 | 21.066 | −1.1136 | 0.8545 | −67.9767 |
| 0.7975 | 15.476 | −0.7193 | 0.6410 | −55.3057 |
| 0.8940 | 5.051 | −0.4114 | 0.0624 | −27.5923 |
| 1.0000 | - | - | - | - |
| **1,3-Dioxolane + Nonanol** | | | | |
| 0 | - | - | - | - |
| 0.0876 | 4.101 | −1.3354 | −0.0127 | −13.8972 |
| 0.1913 | 14.688 | −1.4778 | 0.8880 | −37.811 |
| 0.2942 | 23.767 | −2.0708 | 1.3824 | −58.0273 |
| 0.3963 | 26.458 | −2.4659 | 0.7277 | −66.163 |
| 0.4959 | 30.889 | −2.4573 | 0.9917 | −77.6885 |
| 0.6050 | 30.351 | −2.1496 | 0.6632 | −79.1657 |
| 0.6947 | 28.662 | −1.8005 | 0.4673 | −76.1285 |
| 0.7993 | 24.941 | −1.2976 | 0.5023 | −67.4371 |
| 0.9013 | 15.325 | −0.6083 | 0.1749 | −42.0859 |
| 1 | - | - | - | - |
| **1,3-Dioxolane + Decanol** | | | | |
| 0 | - | - | - | - |
| 0.0881 | 7.94 | −2.2532 | 0.2115 | −18.0838 |
| 0.191 | 20.585 | −1.8401 | 1.6598 | −45.848 |

**Continued**

| | | | | |
|---|---|---|---|---|
| 0.2921 | 23.249 | −2.9930 | 0.7076 | −55.1023 |
| 0.3937 | 30.026 | −3.1558 | 1.1236 | −71.7103 |
| 0.4956 | 34.182 | −2.8276 | 1.2487 | −83.06 |
| 0.604 | 33.522 | −2.4923 | 0.6457 | −83.7183 |
| 0.7129 | 34.915 | −2.2819 | 1.0260 | −87.4645 |
| 0.7983 | 28.826 | −1.6867 | 0.5040 | −73.6965 |
| 0.8971 | 18.727 | −0.8801 | 0.1778 | −48.3816 |
| 1 | - | - | - | - |

### 4.3. Deviation of Viscosity ($\eta^E$)

A deviation in viscosity ($\eta^E$) of 1,3-dioxolane + n-alkanol of liquid mixtures at experimental temperature are important for understanding molecular interactions in these systems. Based on Edward Peters' principle, higher density or viscosity reflects stronger intermolecular interactions. A perusal of Figure 4 show that the excess viscosity ($\eta^E$) is negative for all prepared liquid mixtures at experimental temperature. The excess viscosity ($\eta^E$) can be positive or negative. Negative excess viscosity ($\eta^E < 0$), implies weaker interactions. It suggests the disruption of alcohol-alcohol hydrogen bonding by 1,3-dioxolane molecules, leading to lower resistance to flow and decreased viscosity.

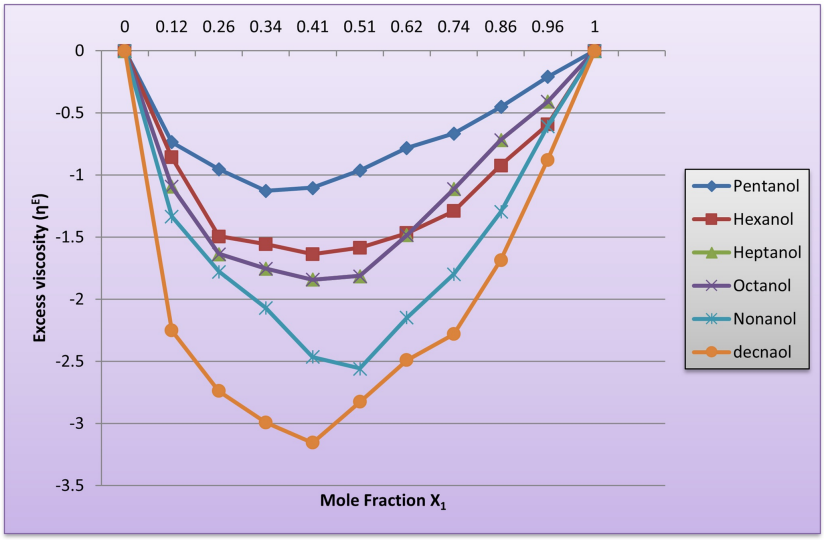


Figure 4. Excess viscosity ($\eta^E$) versus mole fraction ($X_1$) of the 1,3-dioxolane at experimental temperature.

### 4.4. Acoustic Impedance (Z)

An specific impedance (Z) of liquid mixtures investigated in this study showed either positive or negative at experimental temperature. These values are presented in Table 3 and Figure 5. A perusal of Table 3 indicates the specific acoustic impedance (Z) values of all liquid are decrease but the increase in the mole fraction of dicyclic ether ($X_1$).

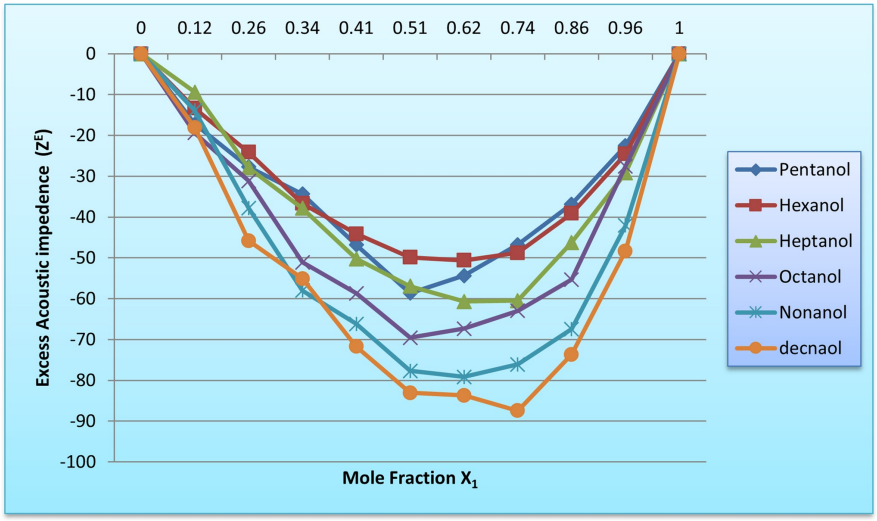


**Figure 5.** Excess acoustic impedance ($Z^E$) versus mole fraction ($X_1$) of the 1,3-dioxolane at experimental temperature.

**Figure 4** illustrates the differences of excess specific acoustic impedance (Z) for six binary liquid mixtures, A perusal of **Figure 4** indicates the values of acoustic impedance (Z) is negative for all experimental liquid mixtures at experimental temperature.

## 5. Conclusion

This research article reports experimental study of sound velocity, viscosity and density and its derived excess parameters. The positive value of excess molar volume shows the presence of weak molecular interactions between the two components. All the computed parameters and its values show the presence of hydrogen bonding and dipole-dipole interaction in liquid mixtures.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] Blitz, J. (1963) Fundamental of Ultrasonics. Butterworth. https://www.sciepub.com/reference/98799

[2] Nithiyanantham, S. and Palaniappan, L. (2005) Ultrasonic Study on Glucose with *α*-Amylase in Aqueous Media. *Acta Ciencia Indica*, **31**, 533-538. https://www.researchgate.net/publication/356037509

[3] Nithiyanantham, S. and Palaniappan, L. (2006) Molecular Interaction Studies of Fructose in Aqueous Amylase Solution. *Acta Ciencia Indica*, **32**, 387-391.

https://www.researchgate.net/publication/288971191

[4] Nithya, R., Nithiyanantham, S., Mullainathan, S. and Rajasekaran, M. (2008) Ultrasonic Investigation of Molecular Interactions in Binary Mixtures at 303 K. *Journal of Chemistry*, **6**, 138-140. https://doi.org/10.1155/2009/589542

[5] Nithiyanantham, S. and Palaniappan, L. (2008) Acoustical Studies on Some Disaccharides (Sucrose, Lactose, Maltose) in Aqueous Media at Room Temperature. *Metals Materials and Processes*, **20**, 203-208. https://www.researchgate.net/publication/356039302

[6] Prabakar, S. and Rajagopal, K. (2005) Study of Molecular Interactions in Aprotic—Aprotic Binary Mixtures through Ultrasonic Measurements. *Journal of Pure and Applied Ultrasonics*, **27**, 41-48. http://www.ultrasonicsindia.org/jpau2723c.pdf

[7] Rajagopal, K. and Chenthilnath, S. (2010) Molecular Interaction Studies and Theoretical Estimation of Ultrasonic Speeds Using Scaled Particle Theory in Binary Mixtures of Toluene with Homologous Nitriles at Different Temperatures. *Thermochimica Acta*, **498**, 45-53. https://doi.org/10.1016/j.tca.2009.10.001

[8] Velusamy, V., Nithyanandham, S. and Palaniappan, L. (2007) Ultrasonic Study of Adsorption in Polysaccharide Metabolism. *Main Group Chemistry*, **6**, 53-61. https://doi.org/10.1080/10241220701697924

[9] Bhandakkar, V.D., Bedare, G.R., Muley, V.D. and Suryavanshi, B.M. (2011) Molecular Interactions of Acrylonitrile and Methylmethacrylate in Methanol, Cyclohexane & P-Dioxane. *Advances in Applied Science Research*, **2**, 338-342. https://www.researchgate.net/publication/268255971

[10] Ramteke, J.N. (2012) Ultrasonic Study of Molecular Interaction in Binary Liquid Mixture Containing *α*-Picolin in Ethanol at 301.15K and 305.15K. *Advances in Applied Science Research*, **3**, 1832-1838. https://www.primescholars.com/articles/ultrasonic-study-of-molecular-interaction-in-binary-liquid-mixture-containinga--picolin-in-ethanol-at-30115-k-and-30515k.pdf

[11] Yang, C., Lai, H., Liu, Z. and Ma, P. (2006) Density and Viscosity of Binary Mixtures of Diethyl Carbonate with Alcohols at (293.15 to 363.15) K and Predictive Results by UNIFAC-VISCO Group Contribution Method. *Journal of Chemical & Engineering Data*, **51**, 1345-1351. https://doi.org/10.1021/je0600808

[12] Bhatia, S.C., Bhatia, R. and Dubey, G.P. (2010) Thermophysical and Sonochemical Behavior of Binary Mixtures of Hexan-1-ol with Halohydrocarbons at 303.15K. *Journal of Molecular Liquids*, **152**, 39-52. https://doi.org/10.1016/j.molliq.2010.01.001

[13] Al-Dulaimy, Z.A.H., Al-Heetimi, D.T.A., Saleem Khalaf, H. and Mohammed Abbas, A. (2018) Excess Molar Quantities of Binary Mixture of Dipropyl Amine with Aliphatic Alcohols at 298.15 K. *Oriental Journal of Chemistry*, **34**, 2074-2082. https://doi.org/10.13005/ojc/3404047

[14] Dubey, G.P. and Sharma, M. (2008) Excess Volumes, Densities, Speeds of Sound, and Viscosities for the Binary Systems of 1-Octanol with Hexadecane and Squalane at (298.15, 303.15 and 308.15) K. *International Journal of Thermophysics*, **29**, 1361-1375. https://doi.org/10.1007/s10765-008-0491-0

[15] Al-Kandary, J.A., Al-Jimaz, A.S. and Abdul-Latif, A.M. (2009) Densities, Viscosities, Speeds of Sound and Refractive Indices of Binary Mixtures of Tetrahydrofuran with 1-Hexanol, 1-Heptanol, 1-Octanol, 1-Nonanol and 1-Decanol at 298.15, 303.15, 308.15 and 313.15 K. *Physics and Chemistry of Liquids*, **47**, 210-224. https://doi.org/10.1080/00319100802123152

[16] Indumati, M., Meenakshi, G., Priyadharshini, V.J., Kayalvizhi, R. and Thiyagaraj, S. (2013) Theoretical Evaluation of Ultrasonic Velocity and Excess Parameters in Binary Liquid Mixtures of Bromobenzene with Alkanols. *Research Journal of Pharmaceutical, Biological and Chemical Science*, **4**, 1332-1384. https://www.researchgate.net/publication/315796636

[17] Chanda, R., Banerjee, A. and Roy, N. (2010) Studies of Viscous Antagonism, Excess Molar Volumes, Viscosity Deviation and Isentropic Compressibility of Ternary Mixtures Containing N, N-Dimethylformamide, Benzene and Some Ethers at 298.15K. *Journal of the Serbian Chemical Society*, **75**, 1721-1732. https://doi.org/10.2298/jsc090806132c

[18] Giner, I., Villares, A., Haro, M., Gascón, I. and Lafuente, C. (2007) Thermodynamic Properties of Binary Mixtures Formed by Cyclic Ethers and Chloroalkanes. *Journal of Thermal Analysis and Calorimetry*, **90**, 587-595. https://doi.org/10.1007/s10973-006-8179-9

[19] Koneti, A.K. and Chintalapati, S. (2014) Speeds of Sound and Excess Molar Volume for Binary Mixture of 1, 4-Dioxane with 1-Heptanol at Five Temperatures. *Advances in Chemistry*, **2014**, Article ID: 343012. https://doi.org/10.1155/2014/343012

[20] Bhatia, S.C., Rani, R., Sangwan, J. and Bhatia, R. (2011) Densities, Viscosities, Speeds of Sound, and Refractive Indices of Binary Mixtures of 1-Decanol with Isomeric Chlorotoluenes. *International Journal of Thermophysics*, **32**, 1163-1174. https://doi.org/10.1007/s10765-011-0995-x

[21] Banipal, P.K., Singh, V., Kaur, N., Sharma, R., Thakur, S., Kaur, M., *et al.* (2017) Physico-Chemical Studies on Binary Mixtures of 1,4-Dioxane and Alkan-1-Ols at 298.15 K. *Proceedings of the National Academy of Sciences, India Section A: Physical Sciences*, **88**, 479-490. https://doi.org/10.1007/s40010-017-0387-0

[22] Venkatalakshmi, V., Gowrisankar, M., Venkateswarlu, P. and Reddy, K.S. (2013) Density, Ultrasonic Velocity and Their Excess Parameters of the Binary Mixtures of 2-Methyl-Aniline with 1-Alkanols (C3-C8) at Different Temperatures. *International Journal of Physics and Research*, **5**, 33-44. https://www.academia.edu/5282133

[23] Marcus, Y. (1977) Introduction of Liquid State Chemistry. Wiley. https://archive.org/details/introductiontoli0000marc

[24] Sri Devi, U., Samatha, K. and Visvanantasarma, K. (2004) Excess Thermodynamic Properties in Liquid Mixtures. *Journal of Pure and Applied Ultrasonics*, **26**, 1-11. https://www.i-scholar.in/index.php/Ultrasonics/issue/view/16921

[25] Fort, R.J. and Moore, W.R. (1965) Adiabatic Compressibilities of Binary Liquid Mixtures. *Transactions of the Faraday Society*, **61**, 2102-2111. https://doi.org/10.1039/tf9656102102