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Studying of Acoustical Parameters of Some Binary Liquid Mixture at 303.15 K and 3 M. Hz

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Abstract:

The ultrasonic velocity, density and viscosity of 1,4- dioxane with alkanols systems have been measured experimentally at 303.15 K over the frequency 3 M. Hz. From these three values, we have calculated thermodynamic and excess thermodynamic parameters such as adiabatic compressibility, deviation in adiabatic compressibility, molar volume excess molar volume, free length, excess free length, Viscosity, deviation in viscosity, internal pressure ,excess internal pressure, acoustic impedance, excess acoustic impedance, excess sound velocity, Rao,s constant, Wada constant, relaxation time and relaxation strength of binary liquid mixture to interpret the nature of the interactions taking place in the binary liquid mixtures. The results analyzed in the sight of molecular interaction between the components. The interaction resulting in the interstitial accommodation of 1, 4- dioxane into alkanols are the predominant factor over dipole-dipole interaction.

Keywords: *1,4- Dioxane, Density, Viscosity, Ultrasonic velocity, Acoustic impedance, Rao's constant, Wada constant, Intermolecular free length, Molar volume, Internal pressure, Relaxation time.*

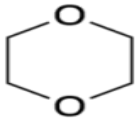
Introduction

The ultrasonic properties of liquid- liquid mixtures play vital role in understanding the thermodynamics, acoustic and transport aspects (Buddiga et al., 2020). Ultrasonic velocities are of liquid mixture are of considerable importance in studying intermolecular interaction between component molecules and used to compute various physical and chemical parameters which have wide applications in several Industrial and engineering processes (Ali, & Nain, 2002; Nath, Sahu, & Paikaray, 2009; Sahu, Nath, & Paikaray, 2012; Nath, Tripathy, & Paikaray, 2013; Natrajan, & Ramesh, 2011). The study of molecular interaction in binary liquid mixtures plays an important role in the development of molecular Sciences. A large number of studies have been made on the intermolecular interaction in the liquid system by various methods like Ultraviolet, Dielectric constant, Infrared, Raman effect, Nuclear Magnetic resonance and Ultrasonic method. In recent years the ultrasonic method has become a powerful tool in providing information regarding the physicochemical- properties of the liquid system. Departure from linearity in the velocity versus concentration in liquid mixture is

taken as an indication of the existence of molecular interaction between different species. The Physico - chemical properties of liquid mixture can be studied by the non-linear variation of ultrasonic velocity and other related parameters with the variation of concentration in the liquid mixture.

The present work is a continuation of systematic experimental studies on thermodynamic properties of binary liquid mixtures of 1,4-Dioxane with alkanols at 303.15 K. In recent years, there has been considerable development in the experimental investigation of the thermodynamic properties of liquid and liquid mixtures are used to study the molecular interactions between the various components of the mixtures. An ultrasonic technique has become a powerful tool for studying the molecular behaviour of liquid mixtures. The ultrasonic velocity along with density and viscosity furnish wealth of information about the interaction between ions, dipoles, hydrogen bonding, multi-polar and dispersive forces (Rawat, & Sangeeta, 2008). The1,4-Dioxine is selected as a solvent in the present work since it finds a variety of application. Alcohols play an important role in many chemical reactions due to the ability to undergo self association with internal structures. 1,4-dioxane cyclic Ether is used as a degreasing agent, as a component of paint and varnish removers and as a wetting and dispersion agent in the textile industries. 1,4-Dioxane is also used as a solvent in the Chemical synthesis. Ultrasonic studies of the solution of the alcohols with 1,4-Dioxane have yielding valuable information regarding the association between the monomers of alcohols and free oxygen of dioxane through hydrogen bonding. Ultrasonic propagation parameters field valuable information regarding the behaviour of liquid systems because intermolecular and intermolecular association, complex formation, dipolar interactions and related structural charges effect the compressibility of the system which in turn produces corresponding variations in ultrasonic velocity (Jasmine et al., 2012). The different acoustical parameters interpret the nature and strength of molecular interaction that exist in the system (Singh, & Bhatt, 2010). The intermolecular interaction that influence the structured arrangement along with the shape of the molecules (Tabhane et al., 2012; Wadekar, 2013; Kaur, & Juglan, 2013). In the present study, density, viscosity and ultrasonic velocity of binary mixture 1,4-dioxane with alkanols at 303.15K at frequencies 3 M.Hz .These measured values are used to calculate different parameters like acoustic impedance (Z), adiabatic compressibility (β_{ad}), intermolecular free length (L_f), Rao's constant (R) , internal pressure (P_i),viscous relaxation time ($\mathfrak{T}$) and relaxation strength (r). The excess parameters of ultrasonic velocity (u^E), molar volume (V^E), acoustic impedance (Z^E), adiabatic compressibility (β_{ad}^E), intermolecular free length (L_f^E), excess viscosity (η^E) excess internal pressure (P_i^E) are computed, which are highly useful in understanding the nature and stand of molecular interaction, internal structure and aggregation behaviour.

1, 4- Dioxane: Molecular formula - $C_4H_8O_2$



Structural formula

Methods

Experimental Details

The chemicals used in the present work were highly purity laboratory reagent grade samples of 1, 4- dioxane, methanol, ethanol, propanol butanol, hexanol and octanol. All purchased from Merck Chem. Ltd India. All Chemicals was stored over Sodium Hydroxide pallets for several days. All the Chemicals were kept in tightly sealed bottles to minimize the absorption of atmospheric moistures. The purity of the solvent was ascertained by comparing the measured density, dynamic viscosities and sound velocity of the pure component at 303.15 K with the available literature (Rodríguez, Canosa, & Tojo, 2001; Nikam, Mahale, & Hasan, 1996; Roy, Sinka, & Biswajit, 2005; Kadam et al., 2006; Nayak, Aralaguppi, & Aminabhavi, 2003; Al-Kandary, Al-Jimaz, & Abdul-Latif, 2009; Dubey,

& Sharma, 2008; Elangovan, & Mullainathan, 2013; Yasmin et al., 2009; Ali, Hyder, & Tariq, 2005; Syal, Gautam, & Chauhan, 1998; Rao et al., 2003) as soon in table 2.

Table 1. Provenance and Purity of the Materials Used

Component	CAS number	Source	Initial mass fraction purity
1,4-Dioxane	17647-74-4	Merck Chem. Ltd India	0.995
Methanol	67-56-1	Merck Chem. Ltd India	0.995
Ethanol	64-17-5	Merck Chem. Ltd India	0.995
Propanol	71-23-8	Merck Chem. Ltd India	0.995
Butanol	71-36-3	Merck Chem. Ltd India	0.995
Hexanol	111-27-3	Merck Chem. Ltd India	0.995
Octanol	111-87-5	Merck Chem. Ltd India	0.995

Measurements

Six binary System 1,4- dioxane + methanol, 1,4-dioxane + ethanol, 1,4- dioxane + propanol, 1,4-dioxane + butanol, 1,4- dioxane + hexanol and 1,4- dioxane + octanol were studied. Each sample mixture was prepared on mass basis, by mixing the calculated volume of liquid components in a specially designed glass stoppered bottles. All binary mixtures were prepared by weight covering the entire mole fraction range. The components of binary mixture were injected by means of syringe in to the glass vials sealed with rubber topper in order to check evaporation losses during sample preparation. The mass measurements were carried out using a single pan analytical balance (Model K – 15 Deluxe, K-Roy Instruments Pvt. Ltd.) with an accuracy ± 0.001 $X10^{-3}$ kg as described elsewhere (Yadava, Singh, & Yadava, 1994). The possible error in the mole fraction was estimated to be less than 1 X 10^{-4}. Five sample were prepared for one system and their density, viscosity and sound velocity were measured on the same day.

Density

Density of pure liquids and their binary mixture were determined by using a double-arm pycnometer (Boodida et al., 2007) with a bulb of 25 cm^3 and a capillary of an internal diameter of about 1 mm is used to measure the densities (ϱ) of pure liquids and their binary mixtures. The pycnometer is calibrated by using conductivity water (having specific conductance less than 1 $X10^6$ ohm^{-1}) with 0.9970 and 0.9940gcm^{-3}, as its densities at T = 303.15K, respectively. The pycnometer filled with air bubbled free liquids is kept in a thermostate water bath (MSI Goyal scientific, Meerut, India.) controlled with a thermal equilibrium. The precision of the density measurements was estimated to be ± 0.0002 g cm^{-3}. The observed values of densities of pure 1,4-Dioxane, methanol, ethanol, propanol, butanol, hexanol and octanol at 3:03.15 K were1.0108,0.7840, 0.7720, 0.8070, 0.8040, 0.8128 and 0.8242 g cm^{-3} which compare well with corresponding literature values respectively.

Sound velocity

The ultrasonic velocity was measured using a multifrequency ultrasonic interferometer (Model F-80D, Mittal Enterprise, New Delhi, India) working at 3 M.Hz. The meter was calibrated with water and benzene at 303.15K. The measured values of ultrasonic velocities of pure 1,4-dioxane, methanol, ethanol, propanol, butanol, hexenol and octanel at 303.15K were 1348, 1084,1141, 1182,1196,1298 and 1327 $m.s^{-1}$ respectively, which compare well with the corresponding literature values.

Viscosity

The viscosity of pure liquids and their binary mixture were measured using suspended ubbelohde type viscometer (Swindells, Coe, & Godfrey, 1952; Nikam, Shirsat, & Hasan, 1998) having a capacity of about 15 ml and the capillary having a length of about 90 mm and 0.5 mm internal diameter has been used to measure the flow time of pure liquids and liquid mixtures and it was celebrated with triply distilled water, methanol and benzene at 303.15 K. The details

of the methods and techniques have been described by researchers (Roy, Dey, & Jha, 2001; Roy, Jha, & Choudhury, 2003). The efflux Time was measured with an electronic stopwatch (Racer) with a time resolution (± 0.015), and an average of at least four flow time readings was taken. Glass stopper was placed at the opening of the viscometer to prevent the loss due to evaporation during measurements. The two bulbs reservoir. one at the top and other at the bottom of the viscometer linked to each other by U type facilitate the free full of liquid at atmospheric pressure. The measured values of viscosities of pure 1,4-Dioxane, methanol, ethanol, propanol, butanol, hexenol and octanel at 303.15K were 1.0303, 0.4949,1.1399, 1.5477, 2 .2045, 4.5642 and 7.8512 m Pa.s which compare well with the corresponding literature values.

Table 2. Physical Properties of Pure Components at 303.15K

Component	Density (ϱ) g.cm^{-3}		Ultrasonic Velocities (u) m.s^{-1}		Viscosity (η) mPa.s	
	Observed	Literature	Observed	Literature	Observed	Literature
1,4-dioxane	1.0108	1.0229 Syal, V.K., Gautam, R., & Chauhan, S. (1998)	1348	1322.3 Rao et al., 2003	1.0303	1.0690 Nayak, J.N., Aralaguppi, M.I. & Aminabhavi, T.M. (2003)
Methanol	0.7840	0.7817 Nikam, P.S., Mahale, T.R. & Hasan, M. (1996)	1084	1084.0 Yasmin et al., 2009	0.4949	0.5040 Roy, M.N., Sinka, A. & Biswajit, S. (2005)
Ethanol	0.7720	0.7807 Rodríguez, A., Canosa, A., & Tojo, J. (2001)	1141	1144.3 Roy, M.N., Sinka, A. & Biswajit, S. (2005)	1.1399	1.3560 Rodríguez, A., Canosa, A., & Tojo, J. (2001)
Propanol	0.8070	0.8003 Elangovan, S., & Mullainathan, S. (2013)	1182	1182.6 Roy, M.N., Sinka, A. & Biswajit, S. (2005)	1.5477	1.6626 Roy, M.N., Sinka, A. & Biswajit, S. (2005)
Butanol	0.8040	0.8020 Roy, M.N., Sinka, A. & Biswajit, S. (2005)	1196	1196.6 Roy, M.N., Sinka, A. & Biswajit, S. (2005)	2.2045	2.2740 Kadam et al., 2006
Hexanol	0.8128	0.8118 Roy, M.N., Sinka, A. & Biswajit, S. (2005)	1298	1282.0 Ali, A., Hyder, S. & Tariq, M. (2005)	4.5642	4.5930 Al-Kandary, A.J., Al-Jimaz, A.S. & Abdul-Latif, A.M. (2009)
Octanol	0.8242	0.8187 Dubey, G.P., & Sharma, M. (2008)	1327	1330.8 Dubey, G.P., & Sharma, M. (2008)	7.8512	7.6630 Al-Kandary, A.J., Al-Jimaz, A.S. & Abdul-Latif, A.M. (2009)

Theoretical

The ultrasonic velocity (u), density (ϱ) and viscosity (η) in pure liquids and liquid mixtures of various concentrations have been measured at 303.15 K.

Thermodynamics and acoustical parameters such as adiabatic compressibility, (β_{ad}) free length (L_f), acoustic impedance (Z), relaxation strength (r), molar compressibility or Wada constant (W), relaxation time (τ) and internal pressure (p_i) were determined using the observed values of sound velocity, density and viscosity using the standard relations given below.

The adiabatic compressibility(β_{ad}) has been determined by using experimentally measured ultrasonic velocity (u) and density (ϱ) by using the following relation:

$$\beta_{ad} = \frac{1}{u^2 \rho} \quad (1)$$

The Mean molar volume (V) of binary liquid mixtures at a given mole fraction is given by:

$$V = \frac{M}{\rho} \quad (2)$$

The excess volume (V^E) at a given mole fraction is the difference between mean molar volume and the average volume is calculated using the given formula:

$$V^E = V - (V_1 x_1 + V_2 x_2) \quad (3)$$

Where V_1 and V_2 are the mean molar volumes of pure liquids 1 and 2 respectively.

The excess adiabatic compressibility (β_{ad}^E) at a given mole fraction is the difference between adiabatic compressibility (β_{ad}) and the sum of the fractional contributes of the two liquids is:

$$\beta_{ad}^E = \beta_{ad} - (\beta_{ad1}\ x_1 + \beta_{ad2}\ x_2) \quad (4)$$

Where β_{ad1} and β_{ad2} are the individual values of pure liquid in the binary mixtures at that temperature.

The molar sound velocity or Rao's constant has been calculating using formula:

$$R = (M/\varrho)\ u^{1/3} \quad (5)$$

Where M is the molecular weight of the solution which can be calculated according to the equation

$$M = M_1\ x_1 + M_2\ x_2 \quad (6)$$

Where X_1 and X_2 are mole fraction of solvent and solute, respectively, M_1 and M_2 are the molecular weight of the solvent and solute respectively.

Molar compressibility or Wada constant (W) can be calculated by the following equation

$$W = (M/\varrho)\beta^{-\frac{1}{7}} \quad (7)$$

Intermolecular free length (L_f) is calculated using the standard expression

$$L_f = K\,\beta_{ad}^{1/2} \quad (8)$$

Where K is Jacobson's constant which is temperature dependent parameter.

The excess viscosity (η^E) at a given mole fraction is the difference between viscosity and the sum of the fraction contribution of the liquid are given by Fort and Moore (Fort, & Moore, 1966) is:

$$\eta^E = \eta_{mix} - (\eta_1\ x_1 + \eta_2\ x_2) \quad (9)$$

Where η_{mix}, η_1 & η_2 are the individual viscosity values of pure liquid in the binary mixture and viscosity of mixture:

The excess mean free length (L_f^E) at given mole fraction is the difference between mean free length and sum of the fraction contribution of the two liquid are given by:

$$L_f^E = L_{f\,mix} - (L_{f1}\ x_1 + L_{f2}\ x_2) \quad (10)$$

Where $L_{f\,mix}$, L_{f1} and L_{f2} are the individual mean free length values of pure liquid in the binary mixture and mean free length of the mixture.

Specific acoustic impedance (Z) is also calculated using the below relation:

$$Z = u.\ \varrho \quad (11)$$

Where ϱ is the density and u is the sound validity of the mixture.

Excess acoustic impedance (Z^E) is difference between the ideal acoustic impedance and acoustic impedance of the pure components i.e.

$$Z^E = Z_{real} - Z_{ideal} \quad (12)$$

Excess sound velocity is the difference between the ideal velocity and velocity of pure components.

$$u^E = u_{real} - u_{ideal} \quad (13)$$

Relaxation strength (r) has been calculated by the following relations:

$$r = 1 - \left[\frac{u}{u_\infty}\right]^2 \quad (14)$$

Where u_∞ = 1600 m/s

Relaxation time (τ) has been calculated by the following relation:

$$\tau = \frac{4}{3}\beta\eta \quad (15)$$

Suryanarayana & Kuppuswami (1976) suggested a method for evaluation of internal pressure from the knowledge of ultrasonic velocity, u, density and viscosity, the relation proposed is expressed as

$$p_i = bRT\left(\frac{k\eta}{u}\right)^{\frac{1}{2}} \frac{\rho^{2/3}}{M_{eff}^{7/6}} \quad (16)$$

Where b is packing factor, which is assumed to be 2 for all liquids and solution. K is a constant, independent of temperature and its value is 4.28 × 10^9 for all liquids, R is universal gas constant and T is absolute temperature.

Results and Discussion

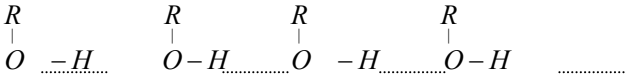
The experimental values of density, viscosity and sound velocity for the binary liquid mixtures of 1,4- dioxane with 1- alkanols in different mole fraction at constant temperature 303.15 K over the frequency 3 M Hz. are given in table 3 (Appendix 1). From the standard parameters the values of derived parameters adiabatic compressibility(β_{ad}), molar volume (V), intermolecular free length (L_f), internal pressure (P_i), Rao's constant (R),Wada constant (W), viscous relaxation time (τ), and relaxation strength (r) are shown in table 4 (Appendix 1). The values of excess viscosity (η^E), excess molar volume (V^E), excess adiabatic compressibility (β_{ad}^E), excess internal pressure (P_i^E) and excess free length (L_f^E) are listed in table 5 (Appendix 1).

All the seven organic compounds namely 1,4 – dioxane, methanol, ethanol, propanol, butanol, hexanol and octanol are a polar organic compounds having dipole moment 0.45 D, 1.70 D,1.69 D, 1.68 D, 1.66 D, 1.60D and 1.68 D respectively. Normally, more the dipole moment, stronger is the intermolecular interaction, which result is decreasing of free space between molecules and an increase in the ultrasonic velocity.

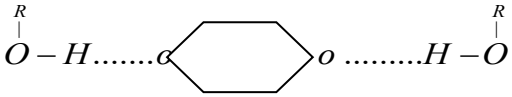
Various type of interaction which are possible and which can operate in the binary liquid mixtures containing 1,4-Dioxane are hydrogen bonded complex formation, that can produce negative deviation in excess viscosity, excess molar volume, excess adiabatic compressibility, excess internal pressure and excess free length. This may be fact that O-H Hydrogen bonded complex formation.

Alkanols are liquids which are associated through the hydrogen bonding and in the pure state, they exhibit an equilibrium between the monomer and multimer species. Also they can be associated with any other group having some degree of polar attraction. Due to polar nature of 1,4-Dioxane and alkanols, the dipole - dipole interaction of hydrogen bombs in pure Ethyl Acetate and also, dipole -dipole interaction equilibria are evidently rupture of hydrogen bonds in pure 1,4-Dioxane and alkanols, dipole-dipole interactions and the formation of O-H……O hydrogen bonds between the components.

The alkanols are associated through hydrogen bonding



and 1,4-Dioxane-alkenols interactions are due to hydrogen bonding between the oxygen atom of the cyclic ether and the proton of hydrogen group of alkanols.



Excess thermodynamic parameters like excess viscosity, excess molar volume, excess adiabatic compressibility, excess internal pressure and excess intermolecular free length were calculated and listed in Table 5 (Appendix 1). Excess viscosity, excess molar volume, excess adiabatic compressibility, excess internal pressure and excess intermolecular free length were shows that the similar behaviour i.e. these are increase up to x = 0.59 continuous increasing mole fraction (X_1). The negative sign due to contractive factors dominate the expensive factors. This is similar to S. Sahakal Ahmed et al (1976) measured excess molar volume values, excess viscosity of binary mixture of 1-butylamine with ethanol and heptanol. Plot of excess viscosity versus mole fraction (X_1) in figure 1. It decreases with an increase in concentration of 1,4-dioxane. It is observed that the converse on the behaviour of adiabatic compressibility and intermolecular free length from the table 4 (Appendix 1). This may be due to self association of the solute molecules and very weak dipole-induced dipole interaction between the component molecules (Rodríguez, Canosa, & Tojo, 2001). The adiabatic compressibility decreases with increasing concentration which is due to the strong molecular interaction among the solute and solvent molecules shown in figure 2. The excess adiabatic compressibility shows the similar behaviour i.e. these are increase up to x = 0.59 then decrease with continuous increasing mole fraction (X_1). In Table 5 (Appendix 1), the excess area adiabatic compressibility(β_{ad}^{E}), are reported for the 1,4- dioxane + alkanols mixtures. From figure- 3 it is evidence that the excess adiabatic compressibility (β_{ad}^{E}) values are negative for lower mono alcohols, but the magnitude of the negative values diminishes and the negative values increase with increasing chain length of the alcohols. the order it follow is:

Me-OH < Et-OH < Pr-OH < Bu-OH < Pen-OH < Hex-OH < Hep-OH < Oct-OH

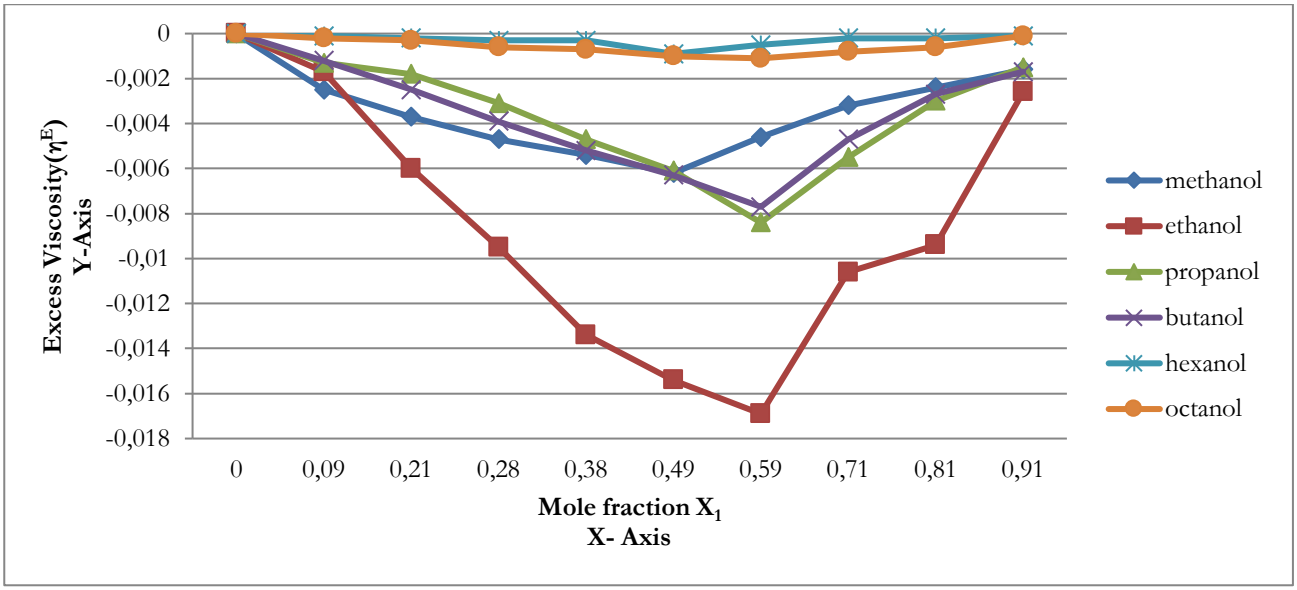


Figure 1. Plot of Excess Viscosity Versus Mole Fraction of 1,4-dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K.

These results can be explained in terms of molecular interactions and structural effects. Interactions between the molecules of cyclic diether and mono alcohol are broken in the mixing process, the breaking of strong dipole-dipole interaction in 1,4- dioxane, which can be considered as a polar fluid. The donor- acceptor interaction between the oxygen and hydrogen atoms of the cyclic diether and the alcohols play and important part for the mixture containing lower alcohols, like Me-OH and Et-OH,, where there is a strong Specific interaction between the component molecules leading to negative value of excess adiabatic compressibility (β_{ad}^{E}).

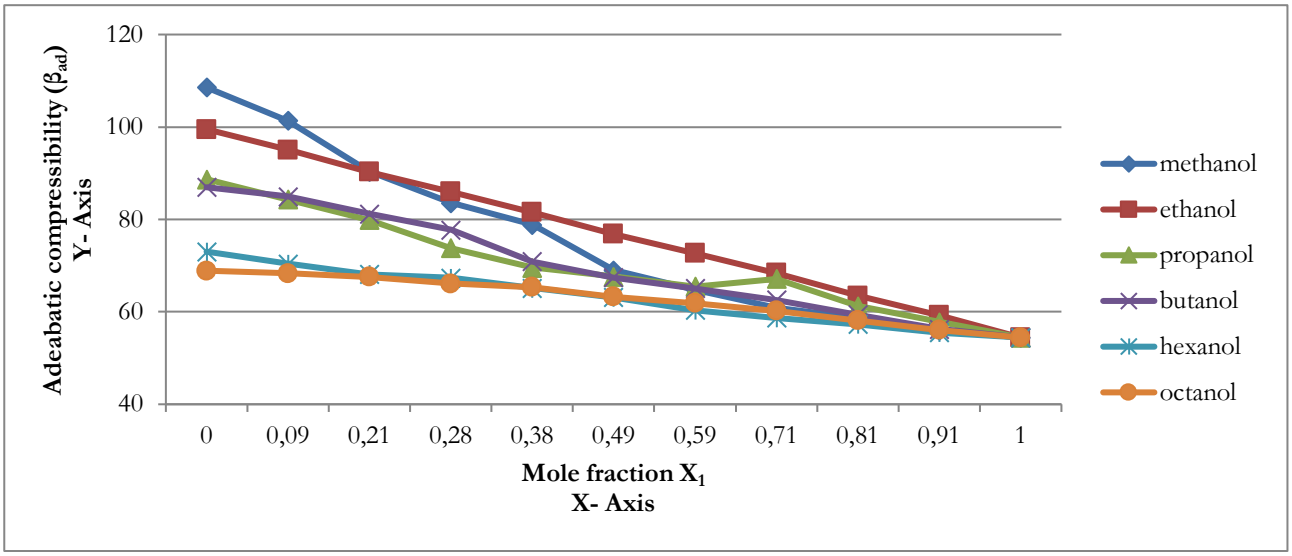


Figure 2. Plot of Adiabatic Compressibility Versus Mole Fraction of 1,4- Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

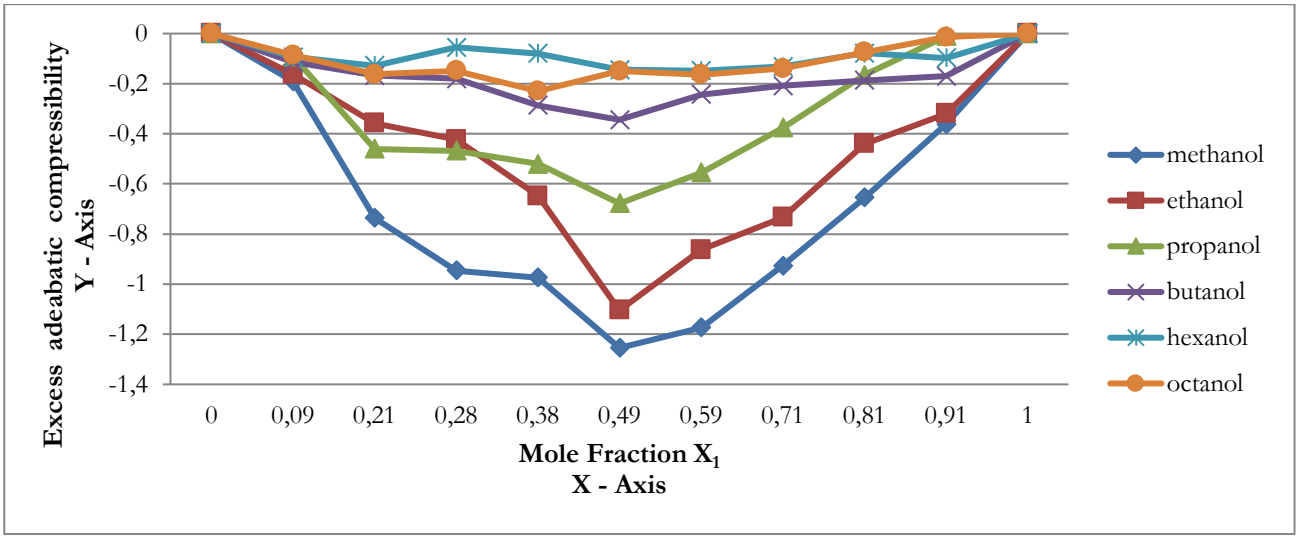


Figure 3. Plot of Excess Adiabatic Aompressibility Versus Mole Fraction of 1,4- Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

From the figure 3 it is clear that the excess adiabatic compressibility values negative indicates the increased strength of interactions between component molecules of liquid mixtures. This negative sign of excess adiabatic compressibility clearly shows the strong interaction through formation of hydrogen bonding between the components. Figure 4 depicts the variation in intermolecular free length. This decrease in free length is due to the decreased adiabatic compatibility which brings the molecules to be closer packing (Nikam, Mahale, & Hasan, 1996). The value of excess free length (L_f^E) are negative over the entire range of composition in system 1,4 - dioxane + methanol, 1,4 - dioxane + ethanol, 1,4 - dioxane + propanol, 1,4 - dioxane + butanol, 1,4 - dioxane + hexanol and 1,4 - dioxane + octanol at 303.15 K of study as evident from Table 5 (Appendix 1). The value of excess free length (L_f^E) are plotted against the mole fraction of 1,4 - dioxane and are shown in figure 5. Table 5 (Appendix 1) shows an increase in excess free length (L_f^E) with the increase in concentration of 1, 4- Dioxane. The structural changes are responsible to affect the variation of intermolecular free length which affects the flow rate of the liquid mixtures. There is small increase in the negative value of excess free length (L_f^E) in all systems increases of mole fraction of 1, 4 - dioxane indicating structural readjustment.

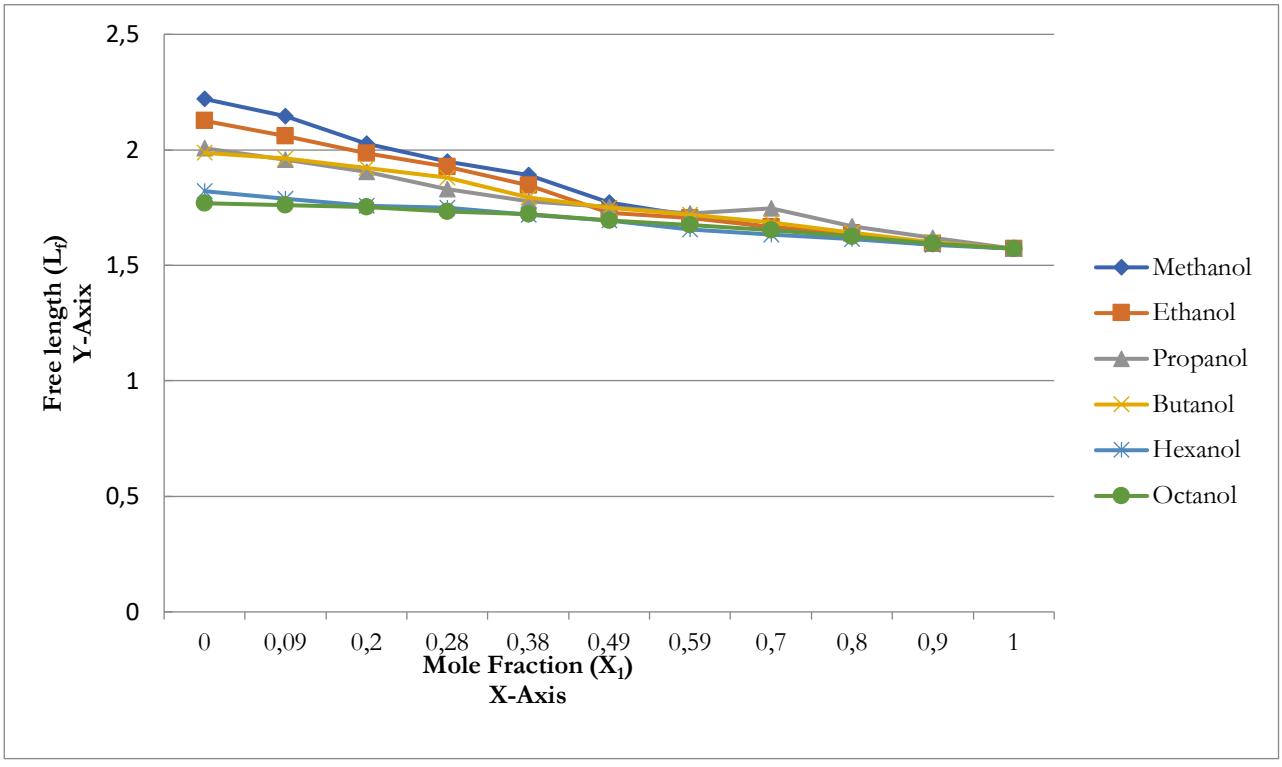


Figure 4. Plot of Free Length Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K.

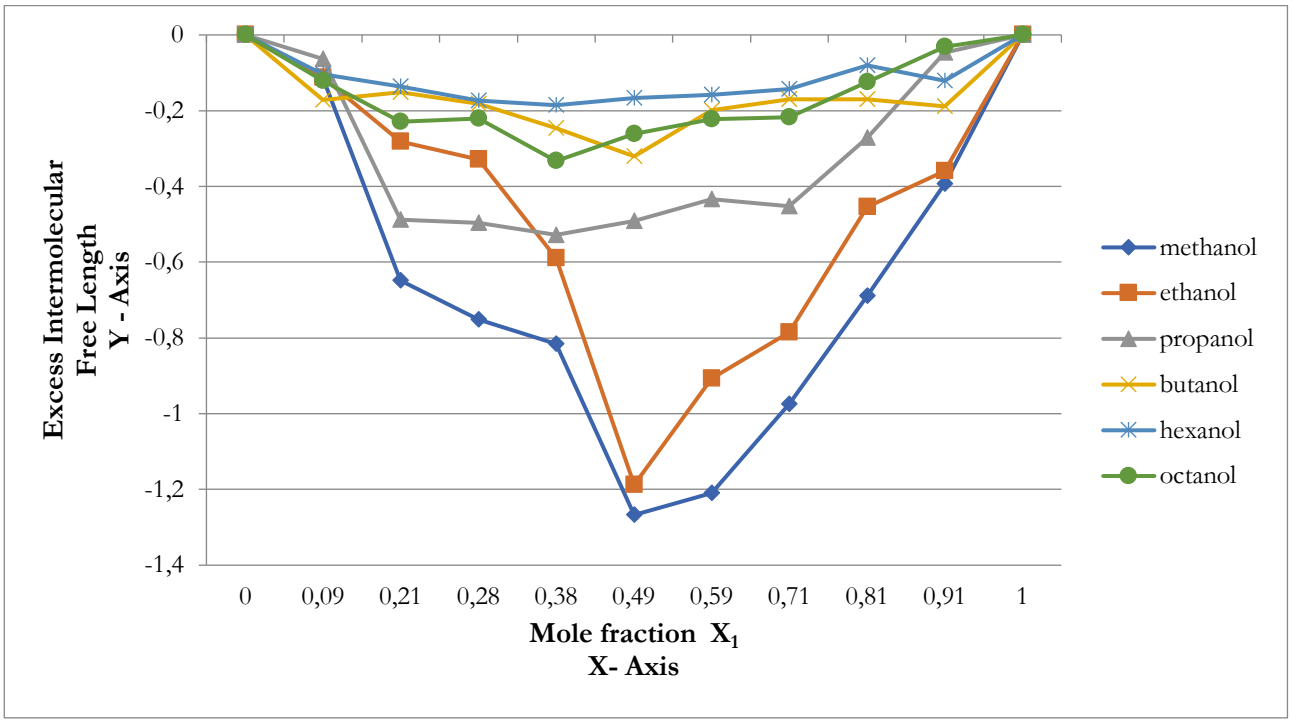


Figure 5. Plot of Excess Free Length Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K.

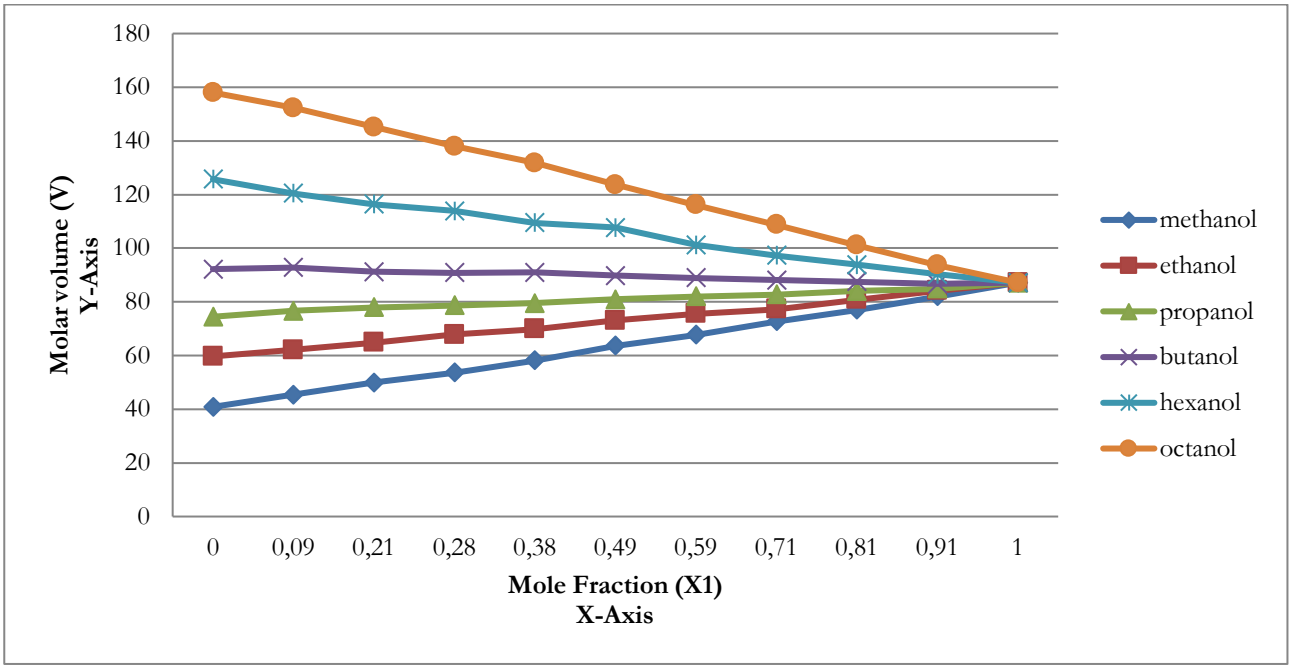


Figure 6. Plot of Molar Volume Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

Figure- 6 it can be seen that the molar volume (V) of the liquid mixture increases. Increase in molar volume shows that presence of strong intermolecular forces. Figure- 7 It can be seen that the value of the excess molar volume (V^E) was found to be negative for the 1,4- dioxane and alkanols mixture, but the magnitude of negative value increases with increasing chain length of the alcohols in the series. The trend is follow is

Me-OH < Et-OH < Pr-OH < Bu-OH < Pen-OH < Hex-OH < Hep-OH < Oct-OH

The negative excess molar volume (V^E) values indicate the presence of strong molecular interactions between the components of the mixture. Several effects may contribute to the value of excess molar volume (V^E), such as (a) dipolar interactions, (b) Interstitial accommodation of one component into the other and (c) possible hydrogen-bond interactions between unlike molecules. The actual volume change, therefore, depends on the relative strength of these three effects. It is known fact that as the number of C-atoms of the alkyl group increases, the electron releasing ability (+I effect) increases, thereby decreasing the polarity of O…..H bonds of the monoalcohols. Consequently, Me-OH having the highest polarity achieves the most favorable intermolecular H- bonded interactions with the cyclic diether molecules.

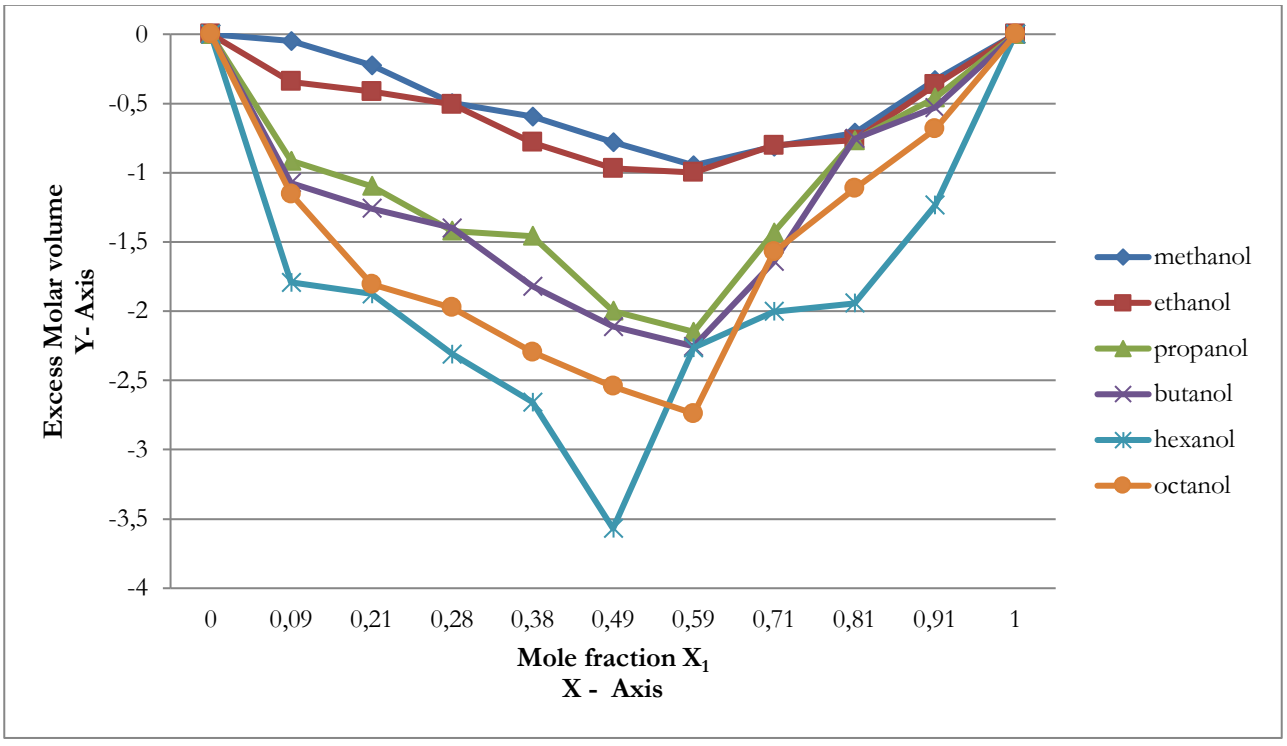


Figure 7. Plot of Excess Molar Volume Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

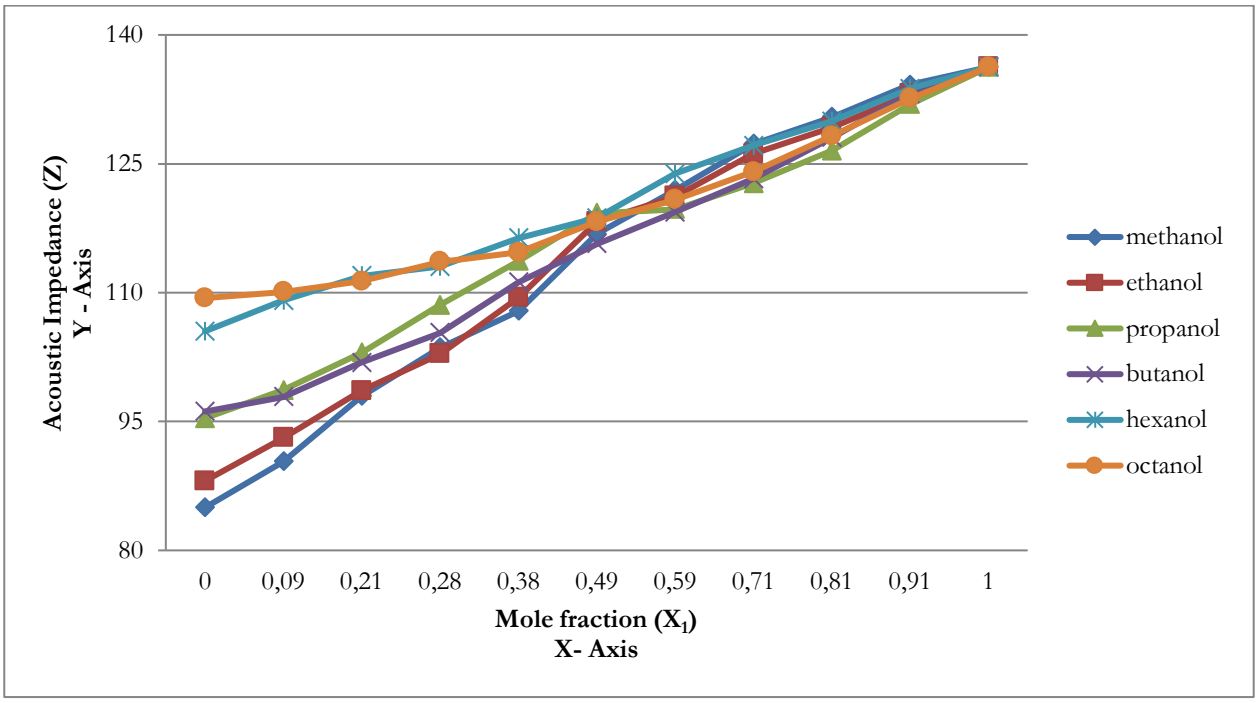


Figure 8. Plot of Acoustic Impedance Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

The liquid variation in acoustic impedance indicates the absence of specific interaction like complex formation in the binary mixture are shown in figure 8. It can be seen from mathematical relation for the acoustic impedance ($Z = u.\rho$) and adiabatic compressibility ($\beta_{ad} = \frac{1}{u^2\rho}$) that they must show opposite behaviour and adiabatic compressibility and intermolecular free length ($L_f = K\ \beta_{ad}^{1/2}$) should exhibit same behaviour which is in agreement with the experimental results (Roy, Sinka, &Biswajit, 2005). Specific acoustic impedance is defined as the impedance offered to the sound wave by the components of the mixture. Acoustic impedance increases with increase in concentration. Increasing trend of acoustic impedance further support the possibility of molecular interaction due to hydrogen bonding between the 1,4-dioxane and alcohol molecule. Specific acoustic impedance is directly proportional to ultrasonic velocity and inversely proportional to adiabatic compressibility and shows similar behaviour to that of ultrasonic velocity and opposite to that of adiabatic compressibility.

Figure 9 and 10 illustrate the linear-behaviour of relaxation time and relaxation strength with mole fraction at the trend of these parameters is almost same with best results obtained between 0.2-0.8 range of mole fraction. As seen from the experimental results ultrasonic velocity increase which results in the decrease of relaxation strength. Viscous relaxation time is the time taken for the excitation energy to appear as transnational energy. The variations in specific relaxation time are mainly due to the change in viscosity of solution due to both concentration and temperature. The non- linear variation of relaxation time with increase in molar concentration is due to the existence of significant molecular interaction between the solute and solvent molecules. The decrease in relaxation time indicates that the viscous force has no effect on it. All the two constant Wada constant and Rao's constant are increasing with increases in mole fraction and display in figure 11 and 12 respectively. It was reported that if the

variation in Wada constant and Rao's constant is linear then it shows that there is an absence of complex formation in two mixtures and so is found in the present investigation which means that there is no complex formation in the mixture of 1, 4-dioxane and alkanols. The Rao's constant increase with increase in concentration which indicates that the magnitude of interactions is enhanced. This increasing trend of Rao's constant indicate that availability of more number of components in a given region of space.

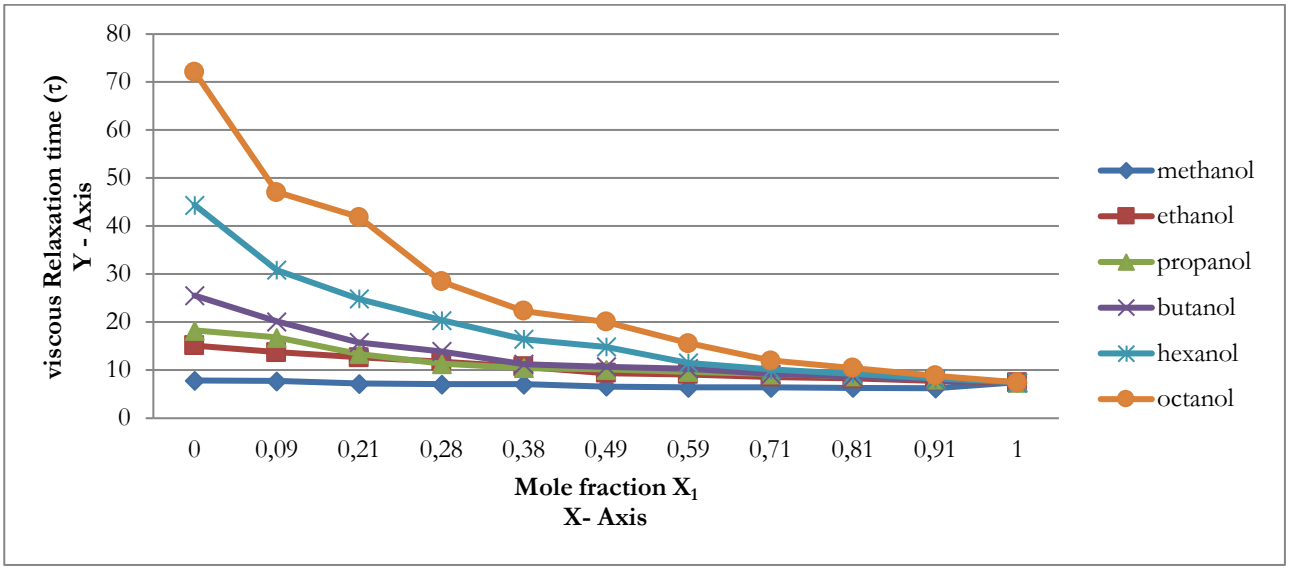


Figure 9. Plot of Viscous Relaxation Time Versus Mole Fraction of 1,4- Dioxane (X_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

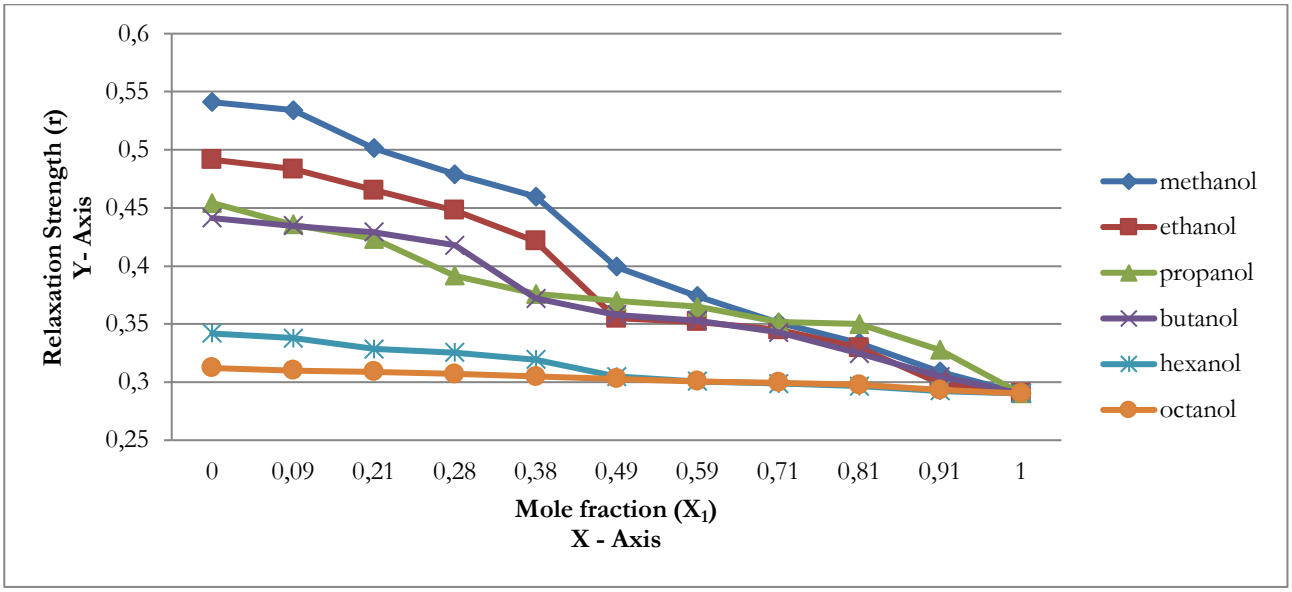


Figure 10. Plot of Relaxation Strength Versus Mole Fraction of 1,4-Dioxane (X_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15K

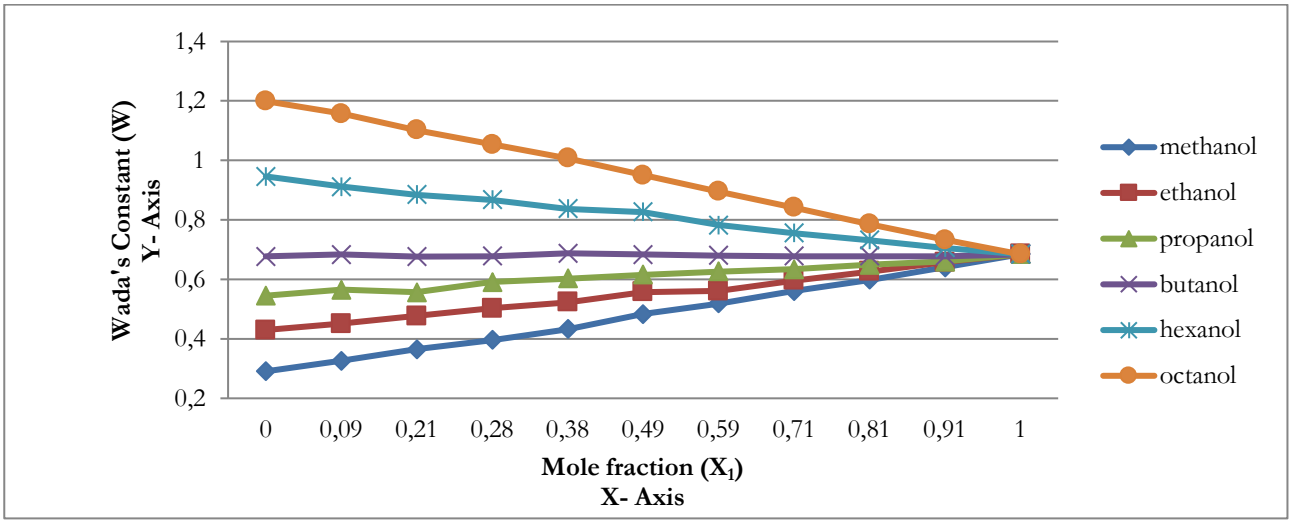


Figure 11. Plot of Wada Constant Versus Mole Fraction of 1,4-dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15K.

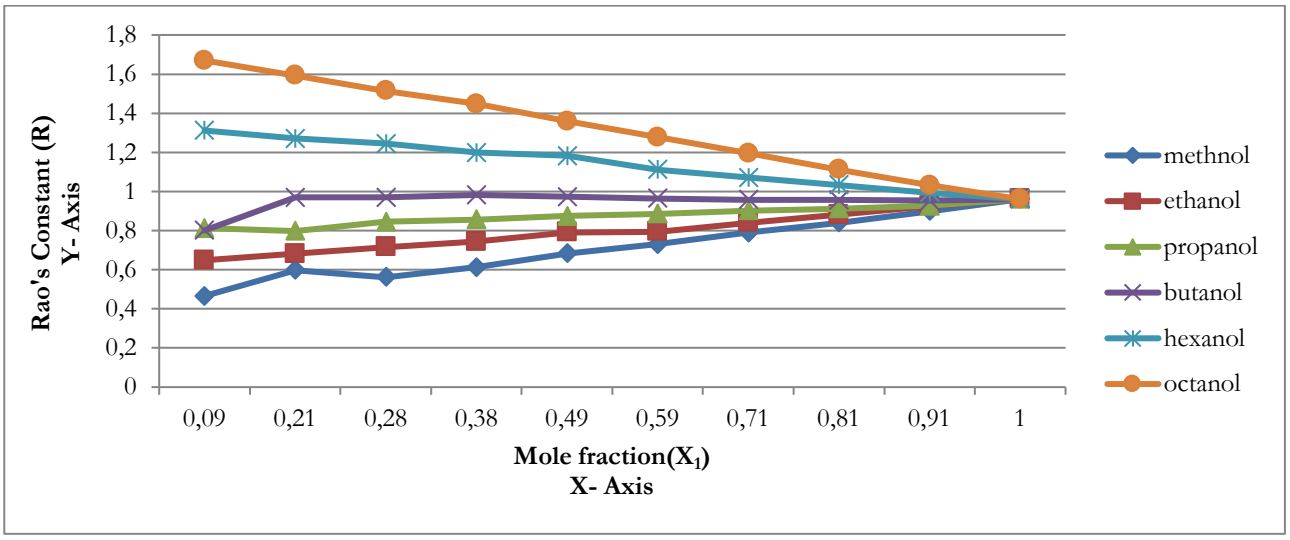


Figure 12. Plot of Rao's Constant Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15 K

The internal pressure (P_i) gives information regarding the nature and strength of force existing between the molecules. Due to decrease in internal pressure (P_i) of the liquid mixture as shown in figure 13. Which shows that the strength of interaction among the molecule decrease gradually with increase in concentration and hence weak interaction between the molecule is formed. The excess internal pressure (P_i^E) is another important parameter through which molecular interaction can be explained. In the present investigation for the six binary systems it is observed that, as the mole fraction of 1,4- dioxane increases, the excess

internal pressure (P_i^E) value decreases. The values of excess internal pressure (P_i^E) are almost negative and gradually decrease. More over the excess internal pressure (P_i^E) decreases with increase in mole fraction (X_1). This situation is observed for all six binary systems under study and can be viewed from figure 14.

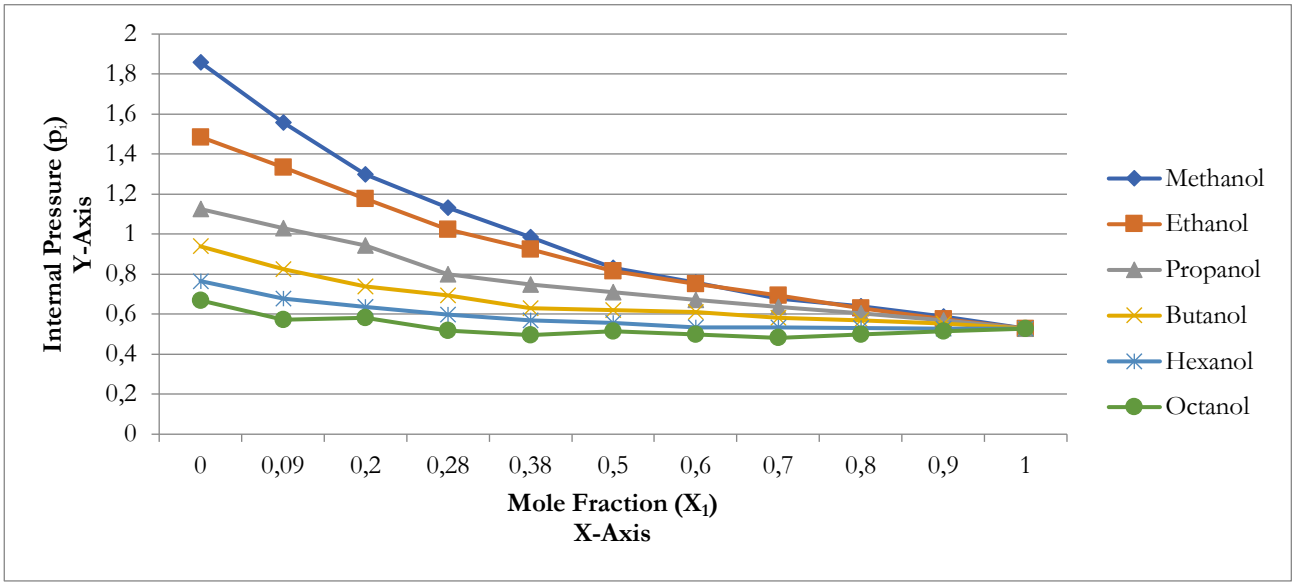


Figure 13. Plot of Internal Pressure Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15K

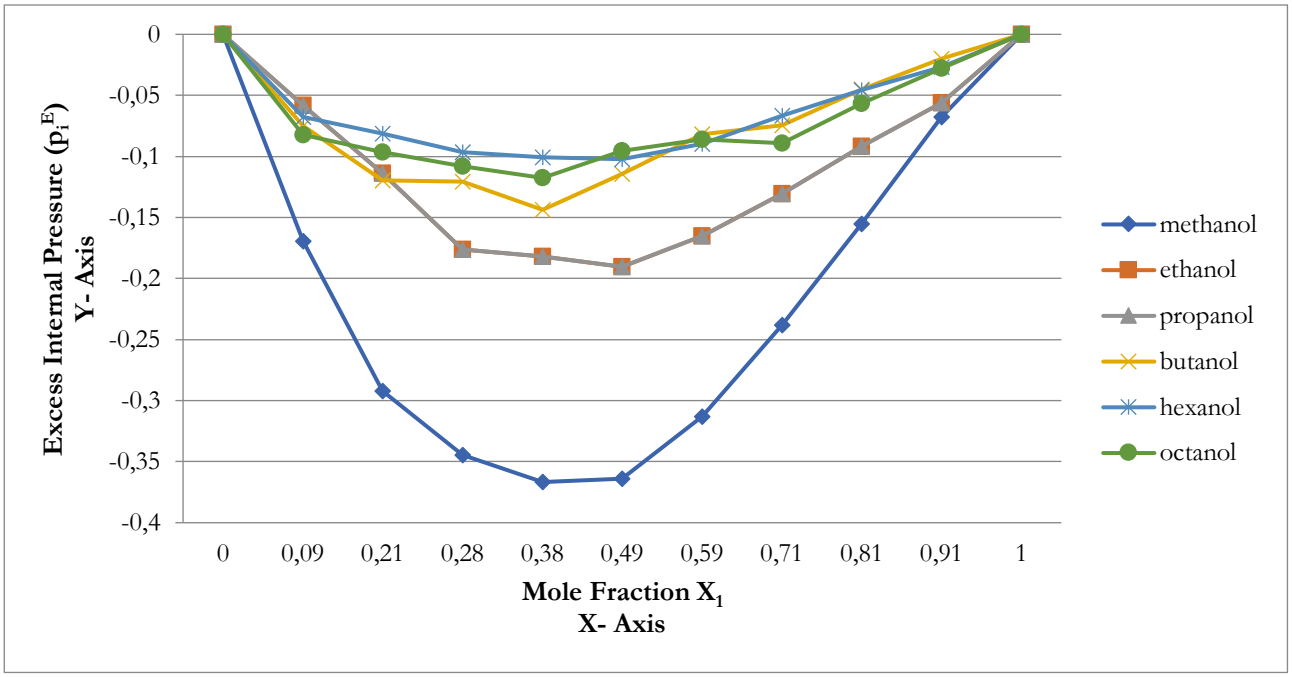


Figure 14. Plot of Excess Internal Pressure Versus Mole Fraction of 1,4-Dioxane (x_1) at 303.15 K for Binary Mixtures of 1,4-Dioxane with Methanol, Ethanol, Propanol, Butanol, Hexanol and Octanol at 303.15K

Alcohols are strongly self -associated liquids with a three dimensional network of hydrogen bonds and can be associated with any other group having some degree of Polar attractions. The associative alcohol molecule acts as a proton donor in enabling hydrogen bonding with 1, 4- dioxane molecule. In the system studied, the complex formation is likely to occur between $H\delta^+$ of alcohol and $O\delta^-$ of -O group of 1,4-dioxane. Hence in the present study there is existence of solute-solvent interaction which are discussed in the above calculated acoustical parameters.

Conclusion

The ultrasonic velocity study of binary liquid mixtures of 1,4-dioxane with alkanlols shows the presence of molecular interaction between the molecules of the mixture. The ultrasonic velocity Increases with increase in concentration which is due to the decrease in intermolecular free length of the mixture. The density increases with increase in mole fraction. Adiabatic compressibility, intermolecular free length, internal pressure, relaxation time and relaxation strength decreases with increase in concentration. This decrease in acoustical parameters indicates that there is a weak interaction between the molecules of the mixture. Wada constant and Rao's constant show linear variation with increase in mole fraction which indicates the absence of complex formation in the mixture. The study of excess property along with the speed of sound has been found to be very useful in understanding the nature of the interactions within binary liquid mixtures. The parameters obtained from the correlating equations have also provided us with valuable information.

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Declarations Conflict of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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Symbol and Description

ϱ, Density of liquid

M, Molecular Weight

K, Jacobson's constant

u, Ultrasonic velocity

u^E, Excess ultrasonic velocity

η, Viscosity

η^E, Excess viscosity

p_i, Internal pressure

p_i^E, Excess internal pressure

X_1, Mole fraction of 1,4-Dioxane

Z, Acoustic impedance impedance

Z^E, Excess Acoustic impedance impedance

V, Molar Volume

V^E, Excess Molar Volume

β_{ad}, Adiabatic compressibility

β_{ad}^E, Excess adiabatic compressibility

R, Rao's constant

W, Wada constant

L_f, Intermolecular free length

τ, Relaxation time

r, Relaxation strength

References

Ali, A., & Nain, A.K. (2002). Ultrasonic study of molecular interaction in binary liquid mixtures at 300 C. *Pramana - Journal of Physics*, *58*(4), 695-701.

Ali, A., Hyder, S. & Tariq, M. (2005). Measurements of the Properties of Binary Mixtures of Dimethylsulphoxide (DMSO) with 1-Alkanols (C_4, C_6, C_7) at 303.15 K. *Journal of Thermophysics*, *26*, 1537–1548. https://doi.org/10.1007/s10765-005-8102-9

Al-Kandary, A.J., Al-Jimaz, A.S. & 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 Liquid, 47,* 210-224. https://doi.org/10.1080/00319100802123152

Boodida, S., Ranjithkumar, B., Jyostna, Savitha & Satyanarayana, N. (2007). Densities and viscosities of binary liquid mixtures of N-methylacetamide with some chloroethanes and chloroethenes at T = 308.15 K. *Journal of Chemical Thermodynamics, 39.* 16-21. https://doi.org/10.1016/j.jct.2006.06.009

Buddiga, L.R., Gara, T., Gajula, G.R., & Chidambara Kumar, K.N. (2020). Ultrasonic studies on the thermodynamic and excess thermodynamic properties of bromo benzene substituted with ethyl methyl ketone at 308.15K. *Journal of Pure and Applied Ultrasonics*, *42*, 26-35.

Dubey, G.P., & 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.

Elangovan, S., & Mullainathan, S. (2013). Ultrasonic Studies of Intermolecular Interaction in Binary Mixture of n-Methyl Formate with 1-Propanol at Various Temperatures, *Indian Journal of Physics*, *87,* 659. https://doi.org/10.1007/s12648-013-0288-2

Fort, R.J., & Moore, W.R. (1966). Viscosities of binary liquid mixtures. *Trans. Faraday Soc.* 62, 1112. https://doi.org/10.1039/TF9666201112

Jasmine, E., Rani, V., Kannagi, K., Padmavathy, R., & Radha, N. (2012). Acoustic and Spectroscopic Study of L-Arginine Derivative in Non-Aqueous Medium, *Journal of Basic and Applied Physics*, *1*, 96-101.

Kadam, B.U., Hiray, P.A., Sawant, B.A. & Hasan, M. (2006) Densities, Viscosities, and Ultrasonic Velocity Studies of Binary Mixtures of Chloroform with Propan-1-ol and Butan-1-ol at (303.15 and 313.15) K. *Journal of Chemical & Engineering Data, 51,* 60-63. https://doi.org/10.1021/je050169y

Kaur, B. & Juglan, K. (2013). Acoustic parameter investigation of polyvinyl acetate with acetic acid using ultrasonic technique. *Journal of Polymer Engineering*, *33*(9), 851-856. https://doi.org/10.1515/polyeng-2013-0125

Nath, G., Sahu, S., & Paikaray, R. (2009). Study of acoustic parameters of binary mixtures of a nonpolar liquid with polar liquid at different frequencies. *Indian Journal of Physics, 83*, 429-436. https://doi.org/10.1007/s12648-009-0024-0

Nath, G., Tripathy, A. & Paikaray, R. (2013). Study of Acoustic Parameters in Binary Mixture at Variable Frequencies. *International Journal of Thermophysics, 34.* https://doi.org/10.1007/s10765-013-1527-7

Natrajan, R. & Ramesh, P. (2011). Ultrasonic velocity determination inbinary liquid mixtures. *Journal of Pure and Applied Ultrasonics*,, *1*(4), 252-258.

Nayak, J.N., Aralaguppi, M.I. & Aminabhavi, T.M. (2003) Density, Viscosity, Refractive Index, and Speed of Sound in the Binary Mixtures of 1, 4-Dioxane + Ethanediol, + Hexane, + Tributylamine, or + Triethylamine at (298.15, 303.15, and 308.15) K. *Journal of Chemical & Engineering Data, 48,* 1152-1156. https://doi.org/10.1021/je030107c

Nikam, P.S., Mahale, T.R. & Hasan, M. (1996) Density and Viscosity of Binary Mixtures of Ethyl Acetate with Methanol, Ethanol, Propan-1-ol, Propan-2-ol, Butan-1-ol, 2-Methylpropan-

1-ol, and 2-Methylpropan-2-ol at (298.15, 303.15, and 308.15) K. *Journal of Chemical & Engineering Data, 41,* 1055-1058. https://doi.org/10.1021/je960090g

Nikam, P.S., Shirsat, L.N. & Hasan, M. (1998) Density and Viscosity Studies of Binary Mixtures of Acetonitrile with Methanol, Ethanol, Propan-1-ol, Propan-2-ol, Butan-1-ol, 2-Methylpropan-1-ol, and 2-Methylpropan-2-ol at (298.15, 303.15, 308.15, and 313.15) K. *Journal of Chemical & Engineering Data, 43,* 732-737. https://doi.org/10.1021/je980028e

Rao, T.S., Veeraiah, N., Rao, G.S., Ramachandran, D. & Rambabu, C. (2003). Temperature dependence of excess thermodynamic properties of binary mixtures consisting of propan-1-ol, butan-1-ol and pentan-1-ol, with 1,2-dibromoethane at different temperatures. *Indian Journal of Chemistry - Section A Inorganic, Physical, Theoretical and Analytical Chemistry, 42,* 1876-1882.

Rawat, M.K., & Sangeeta. (2008). Ultrasonic study of molecular interactions and compressibility behaviour of strontium soap in chloroform-propylene glycol mixture. *Indian Journal of Pure and Applied Physics*, *46*(3), 187-192.

Rodríguez, A., Canosa, A., & Tojo, J. (2001). Physical Properties and Liquid−Liquid Equilibrium of the Ternary Mixture (Dimethyl Carbonate + Methanol + Hexane) at 298.15 K. *Journal of Chemical & Engineering Data, 46*, 184-187. https://doi.org/10.1021/je000336o

Roy, M. N., Jha, a. A., & Choudhury, A. (2003). Densities, viscosities and adiabatic compressibilities of some mineral salts in water at different temperatures. *Journal of Chemical &Amp; Engineering Data, 49*(2), 291-296. https://doi.org/10.1021/je030205y

Roy, M.N., Dey, R., & Jha, A.N. (2001). Study of ion-solvent interactions of some alkali metal chlorides in tetrahydrofuran + water mixture at different temperatures. *Journal of Chemical & Engineering Data, 46*, 1327-1329. https://doi.org/10.1021/je010009w

Roy, M.N., Sinka, A. & Biswajit, S. (2005) Excess Molar Volumes, Viscosity Deviations and Isentropic Compressibility of Binary Mixtures Containing 1,3-Dioxolane and Monoalcohols at 303.15 K. *Journal of Solution Chemistry, 34,* 1311-1325. https://doi.org/10.1007/s10953-005-8022-0

Sahu, S., Nath, G., & Paikaray, R. (2012). Study on Molecular Interactions in Binary Mixture at Variable Frequencies Using Ultrasonic Technique. *Research Journal of Chemical Sciences*, *2*(11), 64-66.

Singh, P.K., & Bhatt, S.C. (2010). Investigation of Acoustical Parameters of Polyvinyl Acetate. *Applied Physics research, 2*, 35. https://doi.org/10.5539/apr.v2n1p35

Suryanarayana, C. V., & Kuppusamy, J. (1976). Free volume and internal pressure of liquids from ultrasonic velocity. *J. Acoust. Soc. India*, *4*, 75-82.

Swindells, I., Coe, J.R., & Godfrey, T.B. (1952). Absolute Viscosity of Water at 20° C. *J. Res. Natd. Bur.Stand*, 48, 1.

Syal, V.K., Gautam, R., & Chauhan, S. (1998). Ultrasonic velocity measurements of Sucrose in binary solvent mixtures of water + Acetonitrile at 25^0, 35^0 and 45^0 C *Indian J. Appl. Phys.*, *36,* 108.

Tabhane, P., Chimankar, O.P., Dudhe, C.M., & Tabhane, V.A. (2012). Ultrasonic studies on molecular interaction in polyvinyl chloride solution. *Der Chemica Sinica*, *3*(4), 944-947.

Wadekar, M.P. (2013). Thermo acoustical molecular interaction study of azomethine and its Fe (III) metal complex using ultrasonic technique. *Journal of Chemical and Pharmaceutical Research*, 5(8), 37-41.

Yadava, R.R., Singh, V.N., & Yadava, S.S. (1994). Excess Volume of Mixing for Binary Mixtures of Some Nitroalkanes and Symmetrical Aromatic Hydrocarbons, *J. Chem. Eng. Data*, *39,* 705. https://doi.org/10.1021/je00016a014

Yasmin, M., Singh, K.P., Parveen, S., Gupta, M. and Shukla, J.P. (2009) Thermoacoustical Excess

Properties of BinaryLiquid Mixtures—A Comparative Experimental and Theoretical Study. *Acta Physica Polonica A, 115,* 890-900. https://doi.org/10.12693/APhysPolA.115.890

Appendix 1

Table 3. Values of Density, Sound Velocity and Viscosity for Binary Liquids Mixtures of 1,4-Dioxane + Methanol, 1,4-Dioxane + Ethanol, 1,4-Dioxane + Propanol, 1,4-Dioxane + Butanol, 1,4-Dioxane + Hexanol and 1,4-Dioxane + Octanol at 303.15 K

Mole fraction of 1,4-dioxane (x_1)	Density (ϱ) g.cm^{-3}	Sound velocity(u) m.s^{-1}	Viscosity (η) mPa.s
1,4-dioxane + Methanol			
0.00000	0.7840	1084.0	0.4949
0.09770	0.82748	1092.0	0.5704
0.20043	0.86692	1130.0	0.6005
0.28674	0.89696	1155.0	0.6339
0.38010	0.91716	1176.0	0.6703
0.49857	0.94224	1240.0	0.7168
0.59198	0.96312	1266.0	0.7802
0.70860	0.98772	1289.0	0.8441
0.80020	0.99876	1306.0	0.9426
0.90362	1.00892	1330.0	1.0244
1.00000	1.0108	1348.0	1.0303
1,4-dioxane + Ethanol			
0.00000	0.7720	1141.0	1.1399
0.09885	0.80944	1150.0	1.1038
0.20465	0.8426	1170.0	1.0986
0.29964	0.8652	1189.0	1.0814
0.39745	0.8990	1217.0	1.0740
0.50220	0.92016	1285.0	1.0710
0.59502	0.94108	1288.0	1.0697
0.69003	0.9720	1298.0	1.0593
0.79934	0.98624	1310.0	1.0485
0.89342	0.99356	1340.0	1.0406
1.00000	1.0108	1348.0	1.0303
1,4-dioxane + Propanol			
0.00000	0.80708	1182.0	1.5477
0.10006	0.82064	1202.0	1.4964
0.12264	0.84796	1215.0	1.2610
0.29821	0.87008	1248.0	1.1498
0.40573	0.89936	1264.0	1.1319
0.50439	0.91672	1270.0	1.1274
0.60251	0.93908	1275.0	1.1097
0.69410	0.9558	1284.0	1.0881
0.79626	0.98084	1290.0	1.0711
0.89926	1.0054	1312.0	1.0534
1.00000	1.0108	1348.0	1.0303
1,4-dioxane + Butanol			
0.00000	0.8040	1196.0	2.2045
0.09734	0.8136	1203.0	1.7804
0.19759	0.84252	1209.0	1.4627
0.30443	0.86264	1221.0	1.3458
0.40480	0.87696	1268.0	1.1934
0.49442	0.90224	1282.0	1.1939
0.59768	0.92744	1287.0	1.1879
0.68628	0.95028	1297.0	1.1044

0.79076	0.97392	1315.0	1.0953
0.89091	0.99836	1334.0	1.0728
1.00000	1.0108	1348.0	1.0303
1,4-dioxane + Hexanol			
0.00000	0.8128	1298.0	4.5642
0.09108	0.83796	1302.0	3.2904
0.19485	0.85408	1311.0	2.7369
0.29842	0.86024	1314.0	2.2727
0.40439	0.88144	1320.0	1.9013
0.45430	0.88996	1334.0	1.7643
0.60286	0.92576	1338.0	1.4365
0.69974	0.9486	1340.0	1.2914
0.80182	0.9684	1342.0	1.2103
0.88834	0.99384	1346.0	1.1144
1.00000	1.0108	1348.0	1.0303
1,4-dioxane + Octanol			
0.00000	0.8242	1327.0	7.8512
0.09780	0.8284	1329.0	5.1466
0.20653	0.83708	1330.0	4.6513
0.29810	0.85292	1332.0	3.2294
0.40275	0.85956	1334.0	2.5625
0.49229	0.88528	1336.0	2.3806
0.60068	0.90304	1338.0	1.8916
0.69888	0.92664	1339.0	1.4950
0.79610	0.95648	1341.0	1.3490
0.89749	0.98596	1345.0	1.1845
1.00000	1.0108	1348.0	1.0303

Table 4. Calculated Values of Adiabatic Compressibility (βad), Molar Volume (V),Iintermolecular Free Length (Lf), Internal Pressure (pi), Acoustic Impedance (Z), Wada Constant (W), Rao's Constant (R), Viscous Relaxation Time (τ) and Relaxation Strength (r) at 303.15 K

Mole Fraction (X_1)	$\beta ad \times 10^{-8}$ ($m^2 N^{-1}$)	$Vm \times 10$ $m^3 mol^{-1}$	$Lf \times 10^{-9}$m	$(p_i \times 10^4)$	R $(m^3/mol)(m/s)^{1/3}$	$Z \times 10^4$ $(kg/m^2 s)$	W $(m^3/mol\ Pa^{1/7})$	$\tau \times 10^{-10}$ sec	r
1,4-dioxane + Methanol									
0.0000	108.54	40.8673	2.22022	1.85827	0.41883	84.9856	0.29074	7.86277	0.54099
0.0977	101.34	45.3365	2.14527	1.55867	0.46571	90.3520	0.32567	7.70821	0.53419
0.2004	90.336	49.9160	2.02542	1.29924	0.59827	97.9597	0.36451	7.23391	0.50121
0.2867	83.572	53.6390	1.94811	1.13200	0.56143	103.591	0.39608	7.06461	0.47889
0.3801	78.838	58.1676	1.89214	0.98575	0.61242	107.850	0.43307	7.04625	0.45977
0.4985	69.023	63.6649	1.77043	0.83121	0.68238	116.832	0.48318	6.59746	0.39937
0.5919	64.781	67.7222	1.71517	0.75747	0.73093	121.928	0.51867	6.43909	0.37392
0.7086	60.934	72.6602	1.66346	0.67723	0.78879	127.314	0.56127	6.40819	0.35096
0.8002	58.701	76.9994	1.63271	0.63839	0.83960	130.430	0.59800	6.3725	0.33373
0.9036	56.032	81.9704	1.59515	0.58824	0.89927	134.183	0.64087	6.2519	0.30902

1.0000	54.444	87.1685	1.57239	0.52793	0.96060	136.255	0.68433	7.47987	0.29019
1,4-dioxane + Ethanol									
0.0000	99.497	59.6761	2.12563	1.48567	0.62212	88.0852	0.42985	15.1222	0.49145
0.0988	95.038	62.0470	2.0596	1.33256	0.64849	93.081	0.45094	13.7489	0.48339
0.2046	90.272	64.8839	1.98420	1.17588	0.68207	98.5842	0.47663	12.7004	0.46527
0.2996	85.991	67.8040	1.92682	1.02250	0.71657	102.872	0.50225	11.7887	0.44776
0.3974	81.590	69.8318	1.84677	0.92291	0.74369	109.408	0.52354	10.7556	0.42144
0.5022	76.861	73.0067	1.72881	0.81416	0.79149	118.240	0.55761	9.39907	0.35499
0.5950	72.681	75.5312	1.70551	0.75046	0.79374	121.200	0.56093	9.13595	0.35197
0.6900	68.402	77.2383	1.66523	0.69393	0.84046	126.165	0.59647	8.62480	0.34491
0.7993	63.484	80.7854	1.63802	0.62849	0.88178	129.192	0.62683	8.26058	0.32964
0.8934	59.246	84.1700	1.59544	0.57388	0.92563	133.129	0.65799	7.77771	0.29859
1.0000	54.444	87.1685	1.57239	0.52793	0.96060	136.255	0.68433	7.47987	0.29019
1,4-dioxane + Propanol									
0.0000	88.684	74.4563	2.00681	1.12536	0.78535	95.3874	0.54517	18.3009	0.45424
0.1000	84.340	76.6390	1.95705	1.02842	0.81289	98.6361	0.56518	16.8286	0.43562
0.1226	79.886	77.9160	1.90466	0.94383	0.79744	103.019	0.55675	13.4319	0.42334
0.2982	73.792	78.6654	1.83058	0.79892	0.84487	108.576	0.59129	11.3130	0.3916
0.4057	69.594	79.4542	1.77774	0.74945	0.85694	113.671	0.60221	10.5034	0.3759
0.5043	67.632	80.9651	1.75251	0.70945	0.87468	119.253	0.61606	10.1672	0.36996
0.6025	65.505	81.9650	1.72473	0.67187	0.88665	119.722	0.62669	9.69287	0.36499
0.6941	67.174	82.6892	1.74656	0.63513	0.90222	122.724	0.63393	9.20750	0.3916
0.7962	61.266	84.0102	1.66799	0.60302	0.91233	126.523	0.64851	8.75025	0.34996
0.8992	57.782	84.8285	1.61987	0.56923	0.92636	131.908	0.66027	8.11630	0.3276
1.0000	54.444	87.1685	1.57239	0.52793	0.96060	136.255	0.68433	7.47987	0.29019
1,4-dioxane + Butanol									
0.0000	86.952	92.1902	1.98712	0.93886	0.97625	96.1584	0.67695	25.5582	0.44124
0.0973	84.929	92.7720	1.96386	0.82365	0.80086	97.8760	0.68353	20.1612	0.43468
0.1975	81.202	91.2552	1.92029	0.73831	0.96979	101.858	0.67662	15.8375	0.42903
0.3044	77.756	90.8593	1.87911	0.69325	0.96859	105.323	0.67784	13.9535	0.41764
0.4048	70.922	90.9767	1.79462	0.62881	0.98231	111.190	0.68774	11.2858	0.37194
0.4944	67.437	89.8172	1.74998	0.62110	0.97330	115.662	0.68385	10.7355	0.35799
0.5976	65.096	88.9342	1.71934	0.61152	0.96505	119.356	0.68060	10.3109	0.35298
0.6862	62.555	88.1010	1.68545	0.58231	0.95848	123.251	0.67807	9.21223	0.34288
0.7907	59.377	87.4632	1.64208	0.56878	0.95590	128.067	0.67818	8.67223	0.32452
0.8909	56.286	86.7254	1.59876	0.55292	0.95237	133.173	0.67761	8.04942	0.30486
1.0000	54.444	87.1685	1.57239	0.52793	0.96060	136.255	0.68433	7.47987	0.29019
1,4-dioxane + Hexanol									
0.0000	73.024	125.691	1.82102	0.76533	1.36781	105.501	0.94625	44.4396	0.34187
0.0910	70.397	120.389	1.78797	0.67619	1.31145	109.102	0.91162	30.8850	0.33781
0.1948	68.123	116.409	1.75886	0.63767	1.27107	111.959	0.88515	24.8602	0.32862
0.2984	67.327	113.884	1.74855	0.59775	1.24438	113.030	0.86736	20.4021	0.32554
0.4043	65.111	109.455	1.71954	0.56874	1.19781	116.344	0.83762	16.5067	0.31937
0.4543	63.141	107.619	1.69333	0.55520	1.18186	118.712	0.82719	14.8541	0.30486
0.6028	60.337	101.202	1.65530	0.53273	1.11250	123.858	0.78294	11.5574	0.30068

0.6997	58.709	97.3310	1.63281	0.53284	1.07047	127.112	0.75594	10.1091	0.29859
0.8018	57.337	93.8597	1.61362	0.52919	1.03281	129.959	0.73144	9.25342	0.29649
0.8883	55.538	90.2338	1.58810	0.52758	0.99389	133.770	0.70640	8.25288	0.29229
1.0000	54.444	87.1685	1.57239	0.52793	0.96060	136.255	0.68433	7.47987	0.29019
1,4-dioxane + Octanol									
0.0000	68.901	158.005	1.76887	0.66872	1.73215	109.371	1.19933	72.1360	0.31213
0.0978	68.345	152.230	1.76172	0.57272	1.66968	110.094	1.15754	47.0410	0.31006
0.2065	67.535	145.177	1.75120	0.58289	1.59276	111.321	1.10251	41.8837	0.30902
0.2981	66.082	137.962	1.73230	0.51855	1.51433	113.606	1.05355	28.4547	0.30694
0.4027	65.375	131.769	1.72301	0.49443	1.44707	114.657	1.00780	22.3197	0.30486
0.4922	63.285	123.674	1.69526	0.51382	1.35892	118.262	0.95034	20.0882	0.30277
0.6006	61.855	116.193	1.67599	0.49788	1.27729	120.821	0.89573	15.6014	0.30068
0.6988	60.190	108.770	1.65328	0.48131	1.19599	124.071	0.84177	11.9981	0.29964
0.7961	58.138	101.096	1.62486	0.49999	1.11216	128.253	0.78628	10.4573	0.29754
0.8974	56.065	93.7423	1.59562	0.51467	1.03228	132.603	0.73287	8.85491	0.29334
1.0000	54.44	87.1685	1.57239	0.52793	0.96060	136.255	0.68433	7.47987	0.29019

Table 5. Excess Values of Viscosity (ηE), Molar Volume (VE) , Adiabatic Compressibility (βadE), Internal Pressure (PiE) and Free Length (LfE) Properties for Binary Liquids Mixtures of 1,4-Dioxane + Methanol, 1,4-Dioxane + Ethanol, 1,4-Dioxane + Propanol, 1,4-Dioxane + Butanol, 1,4-Dioxane +Hexanol and 1,4-Dioxane + Octanol at 303.15 K.

Mole fraction (x_1)	Excess Viscosity(η^E)	Excess Molar volume (V^E) ($cm^{-3}mol^{-1}$)	Excess adiabatic compressibility $\beta_{ad}{}^E \times 10^{-7}$	Excess internal pressure ($p_i{}^E \times 10^4$)	Excessfree length $L_f{}^E \times 10^{-10}$
1,4-dioxane + methanol					
0.00000	0.0000	0.00000	0.00000	0.00000	0.00000
0.09770	-0.0025	-0.05058	-0.19084	-0.16943	-0.11440
0.20043	-0.0037	-0.22597	-0.73591	-0.29226	-0.64799
0.28674	-0.0047	-0.49879	-0.94539	-0.34470	-0.86212
0.38010	-0.0054	-0.59475	-0.91341	-0.36667	-0.81617
0.49857	-0.0062	-0.77944	-1.25438	-0.36374	-1.26727
0.59198	-0.0046	-0.94673	-1.17320	-0.31323	-1.20881
0.70860	-0.0032	-0.81204	-0.92656	-0.23817	-0.97482
0.80020	-0.0024	-0.71401	-0.65418	-0.15515	-0.68894
0.90362	-0.0016	-0.33058	-0.36169	-0.06757	-0.39273
1.00000	0.0000	0.00000	0.00000	0.00000	0.00000
1,4-dioxane + ethanol					
0.00000	0.0000	0.00000	0.00000	0.00000	0.00000
0.09885	-0.0017	-0.34377	-0.16232	-0.05836	-0.11193
0.20465	-0.0060	-0.41559	-0.35747	-0.11371	-0.28102
0.29964	-0.0095	-0.50631	-0.42357	-0.17610	-0.32905
0.39745	-0.0134	-0.78121	-0.64868	-0.18209	-0.58957
0.50220	-0.0154	-0.97014	-1.10460	-0.19038	-1.18769
0.59502	-0.0169	-0.99867	-0.86285	-0.16522	-0.90765
0.69003	-0.0106	-0.80426	-0.73387	-0.13077	-0.78497
0.79934	-0.0094	-0.76595	-0.44002	-0.09162	-0.45380
0.89342	-0.0026	-0.36686	-0.31966	-0.05613	-0.35913

1.00000	0.0000	0.00000	0.00000	0.00000	0.00000
1,4-dioxane + propanol					
0.00000	0.0000	0.00000	0.00000	0.00000	0.00000
0.10006	-0.0013	-0.91399	-0.09167	-0.05836	-0.06274
0.12264	-0.0018	-1.09620	-0.45983	-0.11371	-0.48849
0.29821	-0.0031	-1.42088	0.46806	-0.17610	-0.46664
0.40573	-0.0047	-1.45746	-0.51974	-0.18209	-0.52792
0.50439	-0.0061	-1.99903	-0.37808	-0.19038	-0.35163
0.60251	-0.0084	-2.14871	-0.25484	-0.16522	-0.20317
0.69410	-0.0055	-1.43194	-0.22566	-0.13077	-0.41304
0.79626	-0.0030	-0.56704	-0.01533	-0.09162	-0.07112
0.89926	-0.0015	-0.45833	-0.01109	-0.05613	-0.04737
1.00000	0.0000	0.00000	0.00000	0.00000	0.00000
1,4-dioxane + butanol					
0.00000	0.0000	0.00000	0.00000	0.00000	0.00000
0.09734	-0.0012	-1.07405	-0.11421	-0.07519	-0.17137
0.19759	-0.0025	-1.25808	-0.06737	-0.11934	-0.15147
0.30443	-0.0039	-1.39875	-0.07017	-0.12050	-0.18268
0.40480	-0.0052	-1.82020	-0.28702	-0.14369	-0.24579
0.49442	-0.0063	-2.11069	-0.34414	-0.11458	-0.32065
0.59768	-0.0077	-2.25372	-0.24258	-0.08173	-0.19885
0.68628	-0.0047	-1.64205	-0.20861	-0.07453	-0.17024
0.79076	-0.0027	-0.55516	-0.18677	-0.04512	-0.17063
0.89091	-0.0017	-0.52992	-0.17039	-0.01983	-0.18852
1.00000	0.0000	0.00000	0.00000	0.00000	0.00000
1,4-dioxane + hexanol					
0.00000	0.0000	0.00000	0.00000	0.00000	0.00000
0.09108	-0.0001	-1.79251	-0.09343	-0.06751	-0.10397
0.19485	-0.0002	-1.87459	-0.12798	-0.08139	-0.13703
0.29842	-0.0003	-2.31017	-0.01519	-0.09673	-0.01738
0.40439	-0.0003	-2.65638	-0.03983	-0.10058	-0.00921
0.45430	-0.0009	-3.56962	-0.14408	-0.10227	-0.14722
0.60286	-0.0005	-2.26339	-0.14848	-0.08947	-0.15812
0.69974	-0.0002	-2.00314	-0.13132	-0.06636	-0.14214
0.80182	-0.0002	-1.94200	-0.07883	-0.04578	-0.08020
0.88834	-0.0001	-1.23491	-0.09800	-0.02685	-0.12028
1.00000	0.0000	0.00000	0.00000	0.00000	0.00000
1,4-dioxane + octanol					
0.00000	0.0000	0.00000	0.00000	0.00000	0.00000
0.09780	-0.0002	-1.15434	-0.08590	-0.08222	-0.12088
0.20653	-0.0003	-1.80656	-0.16204	-0.05674	-0.22926
0.29810	-0.0006	-1.97558	-0.14911	-0.10819	-0.22024
0.40275	-0.0007	-2.29511	-0.22970	-0.11758	-0.33295
0.49229	-0.0010	-2.54289	-0.15022	-0.08558	-0.23132
0.60068	-0.0011	-2.73983	-0.16391	-0.08626	-0.25166
0.69888	-0.0008	-1.27332	-0.13934	-0.08901	-0.21745
0.79610	-0.0006	-1.11434	-0.07472	-0.05664	-0.12426
0.89749	-0.0001	-0.68611	- 0.01397	-0.02768	-0.03111
1.00000	0.0000	0.00000	0.00000	0.00000	0.00000