Acoustical studies on binary liquid mixtures of cyclic diether with 1-alkanols at 298.15K and 3 MHz.

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Abstract: In the present study density (ρ), viscosity (η) and sound velocity (u) have been measured at 3 MHz in the binary mixtures of 1,3-dioxolane + 1-alkanols at T= 298.15 K using ultrasonic interferometer technique. From these experimental values, various thermodynamic and excess thermodynamic properties were calculated. The adiabatic compressibility (β_{ad}), excess adiabatic compressibility (β_{ad}^{E}), inter molecular free length (L_f), excess inter molecular free length (L_f^E) , enthalpy (H), excess enthalpy (H^E), free volume (V_f), excess free volume (V_f^E), internal pressure (P_i), excess internal pressure (p_i^E) have been investigated from density (ρ), viscosity (η) and sound velocity (u) measurements of six binary liquid mixtures of 1,3-Dioxolane with pentanol, hexanol, heptanol, octanol, nonanol and decanol over the entire composition range of mole fractions at 298.15K. An excess values of adiabatic compressibility (β_{ad}^{E}), inter molecular free length (L_f^E), excess enthalpy (H^E), excess free volume (V_f^E) and excess internal pressure (p_i^E) were plotted against the mole fraction of 1,3-dioxolane over the whole composition range. The values of (β_{ad}^{E}), (L_f^E), (H^E), (V_f^E) and (p_i^E) for six binary liquid mixtures have been found to be negative which suggest the presence of weak molecular interaction in all the six binary mixtures. The obtained result support the occurrence of molecular association through hydrogen bonding in the binary liquid mixtures.

Keywords: Binary mixtures, adiabatic compressibility, enthalpy, free volume, internal pressure, hydrogen bonding, molecular interaction.

1. Introduction:

Molecular interaction in liquid mixtures has been extensively studied using ultrasonic technique many research scholars [1-7]. The excess thermodynamic property of binary liquid mixtures of cyclic ether with alkanols is of great importance both from practical and theoretical point of view. We can interpret the interactions and predict the application of the liquid mixture using the thermodynamic and physical properties of liquid and liquid mixtures. The ultrasonic velocity, density and viscosity of liquid mixtures are used to understand the theory of a mixture in liquid state. The intermolecular forces among the molecules in a liquid mixture alter the physical and chemical properties like dipole moment in the heat of mixing [8-12]. The experimental values of sound velocity (u), density (ρ) and viscosity (η) are useful in evaluating thermodynamic properties such as adiabatic compressibility (β_{ad}), inter molecular free length (L_f), enthalpy (H), free volume (V_f), internal pressure (P_i) and several excess parameters which will be very much useful in concerning the nature of intermolecular forces between the component molecules. Over the last four decades, research has been focused on measuring the ultrasonic velocity of liquid system and interpreting their molecular structures. In the present paper, sound velocity (u) , density (ρ) and viscosity (η) of six binary liquid mixtures of 1,3-dioxolane + pentanol, 1,3-dioxolane + hexanol, 1,3-dioxolane + heptanol, 1,3-dioxolane + octanol, 1,3-dioxolane + nonanol and 1,3-dioxolane + decanol, have been studied at 298.15 K over the entire composition range of mole fractions. From these experimental

values, adiabatic compressibility (β_{ad}), inter molecular free length (L_f), enthalpy (H), free volume (V_f), internal pressure (P_i) and their deviations excess adiabatic compressibility (β_{ad}^E), excess inter molecular free length(L_f^E), excess enthalpy (H^E), excess free volume (V_f^E) and excess internal pressure(p_i^E) have been calculated and interpreted in term of molecular interaction between the components of the binary liquid mixtures. We know that excess thermodynamic properties such as excess adiabatic compressibility (β_{ad}^E), excess inter molecular free length (L_f^E), excess enthalpy (H^E), excess free volume (V_f^E) and excess internal pressure(p_i^E) good information provide a understanding the intermolecular interaction between component molecules of the liquid mixtures. This work is the first to report a combined study of sound velocity (u), density (ρ) and viscosity (η) of six binary liquid mixtures of practical importance in soaps, detergents, cosmetics and perfumes.

2. Materials and Methods

2.1 Materials 1,3-dioxolane (CDH New Delhi) was supplied with purity ≥ 99.7 %, pentanol (CDH New Delhi) with ≥ 99.7 %, hexanol (CDH New Delhi) with ≥ 99.5 %, heptanol (CDH New Delhi) with ≥ 99 %, octanol (CDH New Delhi) with ≥ 99.7 %, nonanol (CDH New Delhi) with ≥ 99 %, decanol (CDH New Delhi) with ≥ 99 %, respectively with corresponding literature values [13-24]. Since the agreement with the literature values is very good.

Table 1. Density (ρ), sound velocity (u) and viscosity (η) of pure Components at T = 298.15K and frequency 3 MHz.

Compound	ρ (g.cm^{-3})		u (m.s^{-1})		η (mPa s)	
	Observed	**Literature**	**Observed**	**Literature**	**Observed**	**Literature**
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[23]
		0.8152[15]		1303[15]		4.5932[20]
Heptanol	0.8196	0.8187[13]	1325	1327[15]	5.9066	5.9443[13]
		0.8197[19]		1327[24]		5.9443[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]
		0.8242[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]

2.2 Methods 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 ± 0.00001×10^{-3} kg. The possible error in the mole fraction was estimated to be less than 1×10^{-4}. Five samples were prepared for one system, and their density, viscosity and sound velocity were measured on the same day. 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 determined by the Multi-frequency interferometer (Model F-80D, Mittal Enterprise, New Delhi, India) 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. 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. Results and Discussion

The experimental values of ultrasonic velocity (u), density (ρ) and viscosity (η) of 1,3-dioxolane with 1-alkanol mixtures at 298.15K are listed in Table 2.From these values, we have computed Intermolecular free length (L_f), adiabatic compressibility (β_{ad}), Enthalpy (H), internal pressure (P_i) and Free Volume (V_f) are presented in table 2.

Table 2. Density (ρ), ultrasonic velocity (u), and viscosity (η), Intermolecular free length (L_f), adiabatic compressibility (β_{ad}), Internal pressure (P_i) and Free Volume (V_f) of binary mixture of 1,3-dioxolane (1) + 1-alkanol (2) at 298.15K and frequency 3 MHz.

Mole fraction 1,3-Dioxolane (x_1)	Density (ρ) / g.cm^{-3}	Sound velocity (u) / ms^{-1}	Viscosity (η) / mPas.	Intermolecular free length (L_f) × 10^{-4} /m	adiabatic compressibility (β_{ad}) × 10^{-7}/ Pa^{-1}	Internal pressure (P_i) × 10^9/ N m^{-2}	Free Volume (V_f) × 10^{-7} M^{3}mol^{-1}	Enthalpy (H) × 10^6
1,3-Dioxolane + Pentanol								
0.0000	0.8124	1198	3.3978	2.6732	8.5770	2.9099	1.9568	0.3156
0.0939	0.8276	1284	2.3973	2.2842	7.3290	3.2892	3.5817	0.3450
0.1942	0.8436	1290	1.8970	2.2201	7.1233	3.3763	4.9996	0.3468
0.2941	0.8640	1296	1.4437	2.1477	6.8909	3.4821	9.9265	0.3384
0.3942	0.8836	1300	1.1866	2.0872	6.6966	3.5776	11.0374	0.3341
0.4787	0.9068	1304	1.0904	2.0213	6.4853	3.6885	10.8499	0.33.8
0.5999	0.9316	1310	0.9311	1.9495	6.2551	3.8155	13.4125	0.3262
0.6972	0.9596	1318	0.7717	1.8697	5.9991	3.9663	17.4788	0.3236
0.7928	0.9876	1324	0.7171	1.8003	5.7762	4.1099	17.4788	0.3201
0.9035	1.0260	1332	0.6489	1.7121	5.4934	4.3085	19.1422	0.3166
1.0000	1.0616	1340	0.5885	1.6350	5.2460	4.4982	21.7624	0.3135
1,3-Dioxolane + Hexanol								
24.74130	0.8176	1306	4.6091	2.2349	7.1709	3.3333	1.7591	0.4163
0.0912	0.8252	1317	3.3826	2.1775	6.9867	3.4069	2.7275	0.4112
0.1955	0.8432	1320	2.3306	2.1214	6.8065	3.4931	4.5760	0.4003
0.2923	0.8584	1322	1.9839	2.0775	6.6657	3.5642	5.5951	0.3899
0.3982	0.8792	1325	1.5720	2.0192	6.4786	3.6629	7.5845	0.3787
0.4942	0.8992	1327	1.3059	1.9619	6.3154	3.7548	9.5968	0.3683
0.6059	0.9264	1330	1.0343	1.9019	6.1024	3.8815	12.9396	0.3567
0.6976	0.9508	1332	0.9131	1.8475	5.9279	3.9927	14.9307	0.465
0.8018	0.9836	1335	0.7680	1.7779	5.7045	4.1444	18.3980	0.3352
0.8914	1.0168	1337	0.7304	1.7147	5.5018	4.2939	18.9465	0.3254
1.0000	1.0616	1340	0.5885	1.6350	5.2460	4.4982	24.7413	0.3135
1,3-Dioxolane + Heptanol								
0.0000	0.8196	1325	5.9066	2.1660	6.9497	3.4147	1.5030	0.4838
0.0928	0.8304	1334	4.3181	2.1091	6.7671	3.4949	2.3075	0.4725
0.1905	0.8412	1334	3.2577	2.0820	6.6802	3.5404	3.3296	0.4552
0.2939	0.8592	1335	2.5895	2.0353	6.5304	3.6202	4.4224	0.4373
0.3894	0.8740	1335	1.9926	2.0009	6.4199	3.6826	6.1746	0.4201
0.4818	0.8916	1336	1.5315	1.9584	6.2837	3.7609	8.6425	0.4042
0.6021	0.9184	1337	1.2190	1.8984	6.0912	3.8784	11.2315	0.3835
0.6952	0.9420	1337	1.0959	1.8509	5.9387	3.9780	12.3322	0.3667
0.7892	0.9756	1338	0.9903	1.7845	5.7255	4.1245	13.4017	0.3505
0.9006	1.0156	1339	0.7057	1.7116	5.4918	4.2985	20.4381	0.3309
1.0000	1.0616	1340	0.5885	1.6350	5.2460	4.4982	24.7413	0.3135
1,3-Dioxolane + Octanol								
0.0000	0.8296	1350	7.1508	2.0764	6.6622	3.5546	1.3767	0.5619

0.0885	0.8296	1350	5.6095	2.0614	6.6139	3.5585	1.8692	0.5363
0.1967	0.8464	1349	3.9321	2.0235	6.4923	3.6225	2.9529	0.5100
0.2998	0.8560	1348	3.2616	2.0038	6.4291	3.6596	3.6234	0.4845
0.3902	0.8712	1348	2.4284	1.9688	6.3168	3.7245	5.2656	0.4629
0.4963	0.8876	1348	1.9058	1.9324	6.2002	3.7947	6.9577	0.4375
0.6008	0.9140	1347	1.3631	1.8794	6.0301	3.9032	10.5160	0.4117
0.6925	0.9340	1348	1.1376	1.8364	5.8921	3.9930	12.7180	0.3905
0.7975	0.9676	1348	0.9141	1.7726	5.6875	4.1367	15.9753	0.3652
0.8940	1.0104	1348	0.7652	1.6975	5.4466	4.3197	18.9060	0.3421
1.0000	1.0616	1340	0.5885	1.6350	5.2460	4.4982	24.7413	0.3135
	1,3-Dioxolane + Nonanol							
0.0000	0.8248	1366	8.9258	2.0251	6.4976	3.5970	1.1714	0.6291
0.0876	0.8336	1366	6.8601	2.0037	6.4289	3.6354	1.6286	0.6020
0.1913	0.8404	1363	5.8531	1.9963	6.4051	3.6530	1.899	0.5684
0.2942	0.8504	1359	4.4022	1.9844	6.3671	3.6802	2.6620	0.5347
0.3963	0.8692	1355	3.1558	1.9529	6.2662	3.7449	3.9924	0.5014
0.4959	0.8844	1352	2.3340	1.9279	6.1859	3.7978	5.7014	0.4697
0.6050	0.9092	1349	1.7321	1.8837	6.0439	3.8913	7.9725	0.4354
0.6947	0.9332	1346	1.3334	1.8434	5.9145	3.9807	10.6902	0.4072
0.7993	0.9648	1343	0.9642	1.7910	5.7466	4.1018	15.3683	0.3744
0.9013	1.0084	1340	0.8031	1.7213	5.5228	4.2372	17.3683	0.3402
1.0000	1.0616	1340	0.5885	1.6350	5.2460	4.4982	24.7413	0.3135
	1,3-Dioxolane + Decanol							
0.0000	0.8292	1378	11.8027	1.9794	6.4976	3.6639	0.8971	0.6990
0.0881	0.8364	1374	8.5615	1.9638	6.4289	3.6797	1.3454	0.6634
0.191	0.8396	1370	7.8207	1.9578	6.4051	3.6977	1.4040	0.6226
0.2921	0.8560	1366	5.5340	1.9413	6.3671	3.7331	2.1400	0.5827
0.3937	0.8672	1362	4.2319	1.9374	6.2662	3.7654	2.8863	0.5429
0.4956	0.8824	1358	3.4173	1.9153	6.1859	3.8145	3.5598	0.5035
0.604	0.9076	1353	2.5370	1.8759	6.0439	3.9018	4.8971	0.4615
0.7129	0.9308	1348	1.5262	1.8427	5.9145	3.9793	9.1301	0.4198
0.7983	0.9616	1344	1.1637	1.7943	5.7466	4.0927	12.1810	0.3871
0.8971	1.0040	1340	0.8623	1.7288	5.5228	4.2541	16.4668	0.3505
1.0000	1.0616	1340	0.5885	1.6350	5.246	4.4982	24.7413	0.3135

The excess parameters such as Intermolecular free length (L_f^E), adiabatic compressibility (β_{ad}^E), Enthalpy (H^E), internal pressure (p_i^E) and Free Volume (V_f^E) have been calculated using the following equations.

$$L_f = K\,\beta_s^{1/2} \quad \ldots(1)$$

$$\beta_{ad} = u^{-2}\,\rho^{-1} \quad \ldots(2)$$

$$V_f = (M\,U/\,k\,\eta)^{3/2} \quad \ldots(3)$$

$$p_i = bRT\,(\frac{k\eta}{u})^{\frac{1}{2}}\,\frac{\rho^{2/3}}{M_{eff}^{7/6}} \quad \ldots(4)$$

$$H = V_m \times P_i \quad \ldots(5)$$

$$Y^E = Y_{exp} - (X_1 Y_1 + X_2\,Y_2) \quad \ldots(6)$$

Y^E refer to (L_f^E), (β_{ad}^E), (H^E), (p_i^E) and (V_f^E), whereas Y_{exp} is measured property under question. Y_1, Y_2, X_1 and X_2 refer to the properties and mole fractions of pure components 1 and 2 respectively.

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 [25]. When 1,3-Dioxolane

is added, it likely leads to closer packing of molecules due to molecular interactions, such as dipole-induced dipole forces.

A perusal of table 2 shows that the values of excess intermolecular free length for all the six binary system are negative. These negative values of excess intermolecular free length are shown in figure 1. From figure 1 shows that the excess intermolecular free length (L_f^E) values are negative for all binary systems but the magnitude of the negative values increase with increasing chain length of alcohols, the order are given below-

1-Pentanol < 1-Hexanol < 1-Heptanol < 1-Octanol < 1-Nonanol < 1-Decanol

The above order indicates the strength of interactions between component molecules decreases due to decrease in polarizability of alkanol molecules.

The negative values of excess intermolecular free length (L_f^E) play a very important role in description of molecular interaction in liquid mixtures through dipole-dipole interaction and hydrogen bonding. Due to polar nature of ethyl acetate and alkanols, the dipole-dipole interactions prevail in these mixtures. When the compounds are mixed the changes the occur in association equilibria are evidently rapture of the hydrogen bonds in pure 1,3-dioxolane and alkanols, dipole-dipole interactions and the formation of O − H----O hydrogen bonds between the components. This suggests the existence of strong interaction between the components in all the binary systems. The values of L_f^E suggest that strong specific interaction like the formation of H- bond association through weaker physical forcers of attraction.

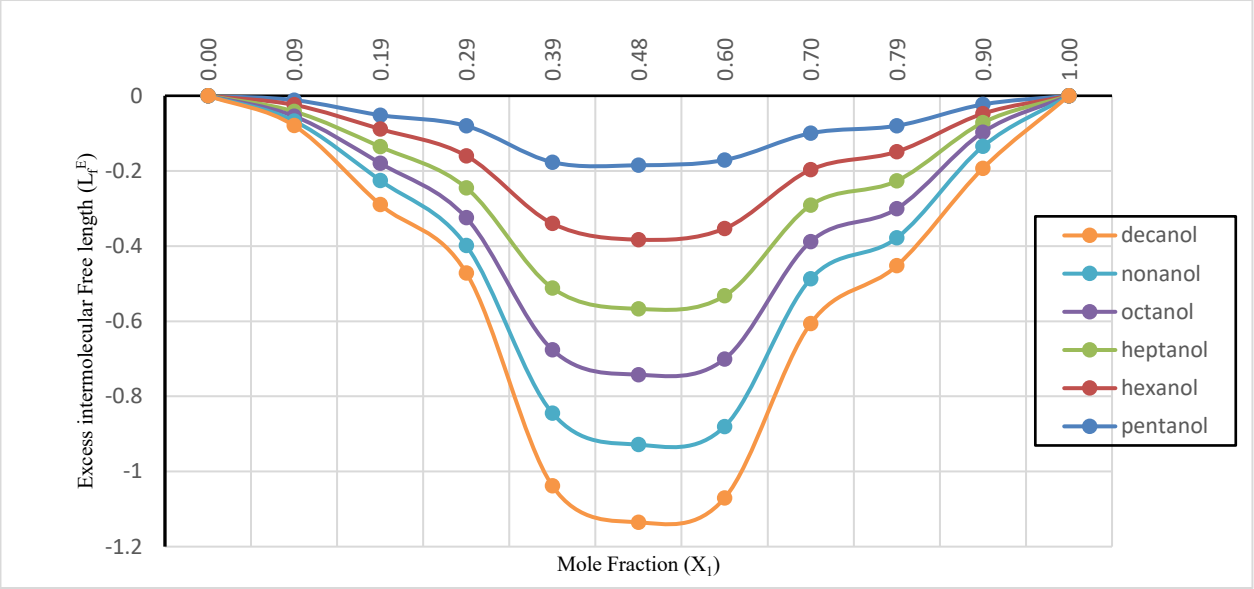

Figure 1- Variation of excess intermolecular free length (L_f^E) with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

A perusal of Table 2 also reveal that the values of excess adiabatic compressibility (β_{ad}^E), are negative over the entire range of concentration in all the six binary system at 303.15 K. The value of excess adiabatic compressibility (β_{ad}^E), are plotted against the mole fraction of ethyl acetate and are shown in Figure 2.

The sign of excess adiabatic compressibility (β_{ad}^E), play a vital role in assessing the compactness due to molecular interaction in liquid mixtures through charge transfer, dipole-dipole interaction and dipole induced dipole interactions interstitial accommodation and orientational ordering leading to more compact structure making, which enhances excess adiabatic compressibility (β_{ad}^E), to have negative values. Fort and Moore [26] suggested that the liquid having different molecular size and shape mix well there by reducing the volume which causes the values of excess adiabatic compressibility (β_{ad}^E), to be negative. It is also suggested that liquids are less compressible when compared to their ideal

mixtures signifying the chemical effects including charge transfer forces, formation of hydrogen bond and other complex forming interactions. It can also be said that the molecular interaction are strong in these binary liquid mixtures and that the medium is highly packed. Similar results were obtained by earlier worker [27]. The negative value of excess adiabatic compressibility (β_{ad}^{E}), in these mixtures can be associated with a structure forming tendency.

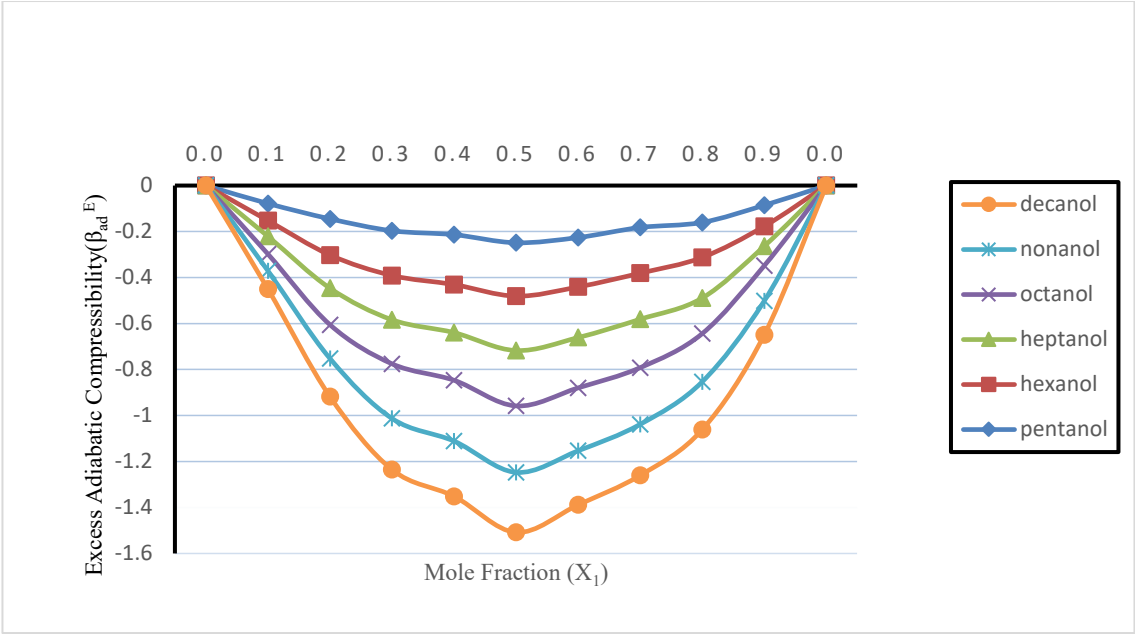

Figure 2. Variation of excess adiabatic compressibility (β_{ad}^{E}) with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

A perusal of Table-2 reveal that value of excess free volume V_f^E are negative in all systems and increase with increase in the concentration of 1,3-dioxolane in its binary mixture at 298.15 K. The value of excess free volume V_f^E are plotted against the mole fraction of 1,3-dioxolane and are shown in Figure 3. Generally excess free volume V_f^E can be considered to arise from two type of interaction between component molecule (i) Physical interaction consisting mainly of dispersion forces or weak dipole-dipole interaction and making a positive contribution (ii) Chemical or Specific interactions, including formation of hydrogen bond, charge transfer and other complex forming interactions, difference in size and shapes of the structure of component molecules which result in negative contribution. When 1,3-dioxolane is mixed with alcohols hydrogen bond of alcohols of alcohols polymers are broken and specific intermolecular interaction leading to the bond formation like (− H----O−) take place causing decrease in excess free volume V_f^E.

A perusal of Table-2 also reveal that the values of excess free volume V_f^E are negative with the increase in concentration of 1,3-dioxolane molecule at 298.15 K. The value of V_f^E are plotted against the mole fraction of 1,3-dioxolane and are shown in Figure 3.

The observed values of V_f^E over whole range of composition suggest the weak interaction between component molecules. A perusal of Table -2 shows that the value of excess free volume of the mixture under investigation are negative for all the binary liquid mixture 1,3-dioxolane + pentanol, 1,3-dioxolane + hexanol , 1,3-dioxolane + heptanol, 1,3-dioxolane + octanol, 1,3-dioxolane + nonanol and 1,3-dioxolane + decanol. A negative excess free volume value is suggestive of the presence of 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.

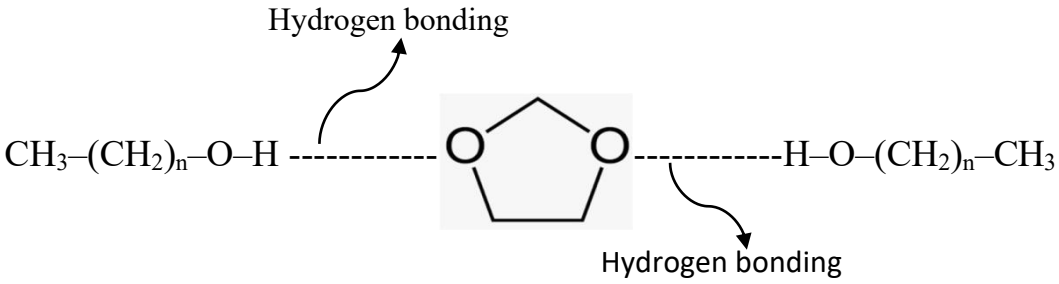

Figure: Hydrogen bonding present in 1,3-dioxolane– n-alkanols**.**

The negative values of excess free volume(V_f^E), indicate the presence of strong molecular interaction. We may conclude that 1-alkanols, is disrupted. It is also concluded that Suryanarayana approach for estimating free volume thermodynamic considerations is very well applicable in the present case.

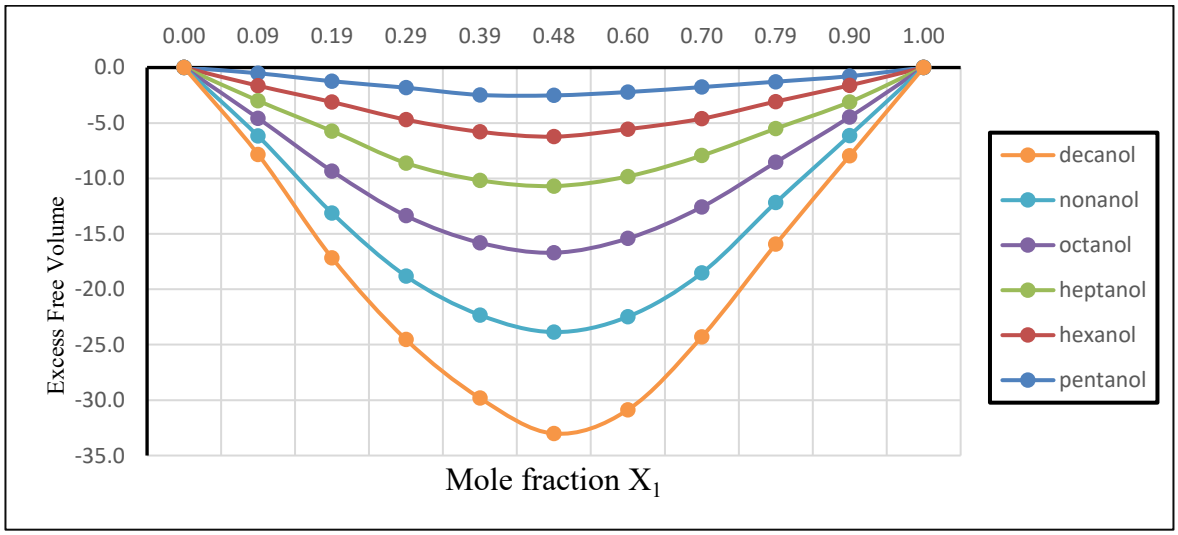

Figure 3. Variation of excess Free Volume(V_f^E), with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

The excess internal pressure (p_i^E) is another important parameter through which molecular interactions can be explained. In the present investigation for the six binary systems it is observed that, as the mole fraction of 1,3-dioxolane increase, the p_i^E values decreases. The values of p_i^E are almost negative and gradually decrease and move towards the positive values by the increase of mole fraction of 1,3-dioxolane. More over the p_i^E decrease with increase in X_1. This situation is observed for all six binary system under study and can be viewed from plots Figure 4.

The negative values of excess internal pressure (p_i^E) indicate the presence of strong molecular interaction. We may conclude that alkanols, which is a self – associating polar organic liquid has a tendency to form complexes with ethyl acetate and the increase in its dilution causes disruption of aromatic C – H bond stretching as the self –

association of alkanols is disrupted. It is also concluded that suryanarayana approach for estimating internal pressure of binary liquid mixtures, based on dimensional analysis using thermodynamic consideration is very well applicable in the present case.

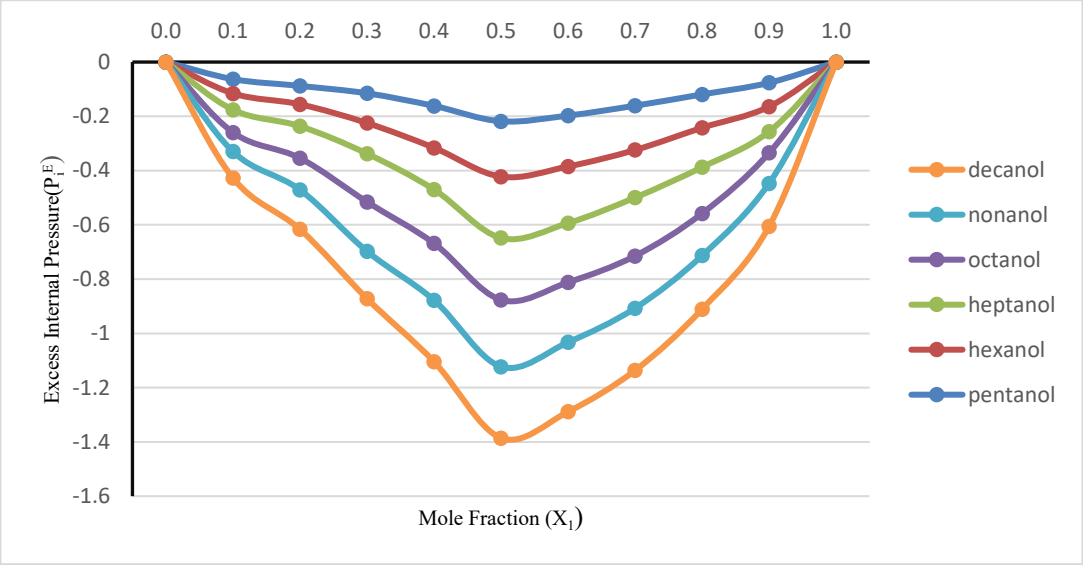

Figure 4. Variation of excess internal pressure (p_i^E) with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

Figure 5 shows the variation of excess enthalpy (H^E) with mole fraction of 1,3-dioxolane at the temperature 298.15K For the binary system 1,3-dioxolane with 1-alkanols , the excess enthalpy (H^E) values are negative and decreasing with the increase in mole fraction of 1,3-dioxolane up to the mole fraction (0.5) and the increase with increase in mole fraction. The excess enthalpy (H^E) is another important parameter through which molecular interactions can be explained. In the present investigation for the six binary systems it is observe that, as the mole fraction of 1,3-dioxolane increase, the excess enthalpy (H^E) values decreases. This situation is observed for all six binary system under study and can be viewed from plots Figure 5. This suggests that dipole and dispersive force are operative in these systems, when the 1,3-dioxolane concentration low. When the concentration of 1,3-dioxolane increased, the corresponding decrease in concentration of 1,3-dioxolane leads to specific interactions i.e., the interactions move from weak to strong which supports the above arguments is case of other parameters. As a result, the free dipoles released from the alkanols in association with 1,3-dioxolane molecules forming strong hydrogen bonds, hence stronger molecular association existing between the 1,3-dioxolane with 1-alkanols molecules through hydrogen bonding [28].

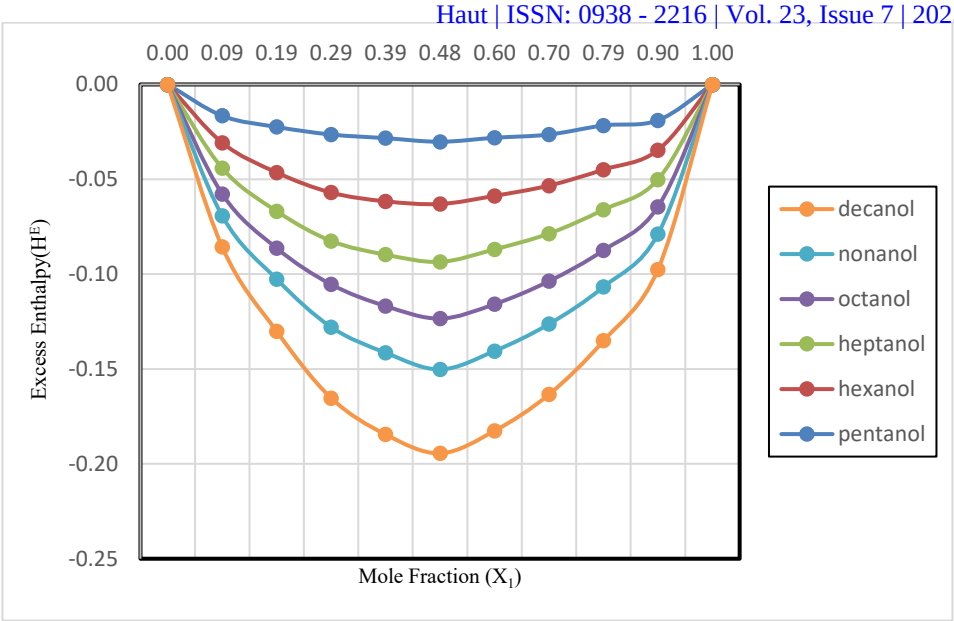

Figure 5- Variation of excess enthalpy (H^E) with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

Conclusion

We have determined the sound velocity, density and viscosity of 1,3-dioxolane with 1-alkanols experimentally at 298.15K. The calculated intermolecular free length (L_f), excess Intermolecular free length (L_f^E), adiabatic compressibility (β_{ad}),excess adiabatic compressibility (β_{ad}^E) , enthalpy (H), excess enthalpy (H^E), internal pressure (P_i), excess internal pressure (p_i^E) , Free Volume (V_f) and excess Free Volume (V_f^E) strongly confirm the presence of strong molecular interactions between the unlike molecules through the hydrogen bonding. In addition, the presence of the molecular interactions is also confirmed from the negative values of excess intermolecular free length (L_f^E), excess adiabatic compressibility (β_{ad}^E), excess enthalpy (H^E), excess internal pressure (p_i^E) and excess Free Volume(V_f^E).

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Nomenclature

ρ, Densities of liquid

u, Ultrasonic velocity

η, Viscosity

X_1, Mole fraction of 1,3-Dioxolane

T, Temperature

(β_{ad}), Adiabatic compressibility

(β_{ad}^E), Excess adiabatic compressibility

(L_f), Inter molecular free length

(L_f^E), Excess inter molecular free length

(H), Enthalpy

(H^E), Excess enthalpy

(V_f), Free volume

(V_f^E), Excess free volume,

(P_i), Internal pressure

(p_i^E), Excess internal pressure

Y^E, Thermodynamic excess function

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