Study of thermodynamic properties in binary liquid mixtures through ultrasonic measurements at 298.15K.

Dhirendra Kumar Sharma[1], Suneel Kumar[2], Chandra Pal Prajapati[3] and Sandeep sahu[4]

[1]*Department of Chemistry, Institute of Basic Science, Bundelkhand University, Jhansi (U.P), India.*
[2,3,4]*Research Scholar, Department of Chemistry, Institute of Basic Science, Bundelkhand University, Jhansi (U.P), India.*

Abstract: *The thermodynamic properties of the binary liquid mixture of 1,3-dioxolane + 1-alkanols were studied at at T= 298.15 K and at 1 atm . The thermodynamic properties, viscosity- η, density- ρ, and sound velocity (u) are studied. The 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) we and re estimated from the experimental data. The Redlich-Kister model was employed to correlate the deviations of thermodynamic properties. In this work all the experimental data were correlated and close-fitting with the thermodynamic models. The results obtained were also concluded based on the interactions of the binary mixture.*
Keywords: *Binary mixtures, density, viscosity, enthalpy, free volume, internal pressure, hydrogen bonding, molecular interaction.*

I.   Introduction:

In recent years, many research scholars have discussed thermodynamic and excess thermodynamic properties in liquid mixture and interpreted these properties using the interactions among the molecules [1-7]. Additionally, the study of liquid mixtures involves investigating the acoustic and thermodynamic properties, which provide insights on molecular interactions among different compounds [5]. This study explains

the relationship between thermodynamic parameters and the nature of molecular bonds. Therefore, ultrasonic techniques mainly used to explore and understand the characteristics and dynamics of such molecular interactions. The study of thermo physical properties of fluids are essential to understanding the molecular interactions and it facilitates the design of many industrial chemical processes involving heat, mass and fluid flow . The deviations arising in thermodynamic and transport properties are very complex due to interactions between the solute-solute, solvent-solvent, and solute-solvent2 and the interstitial accommodation due to structural effects. A quantifiable estimation of liquid mixtures is required to design the mass transfer operations. The excess thermodynamic property of binary liquid mixtures of 1,3-dioxolane with 1-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 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, enthalpy (H), free volume (V_f), internal pressure (P_i) and their deviations 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 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 many

industrial processes such as pharmaceutical and cosmetics have greatly stimulated the need for extensive information on the thermodynamic, acoustic and transport properties of 1,3-dioxolane, 1-alcohols and their mixtures. The 1,3-dioxolane and the 1-alcohols have both a proton donor and a proton acceptor group. It is expected that there will be a significant degree of H-bonding leading to self-association in the pure state in addition to mutual association in their binaries.

II.   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.

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. We determined the density 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. The procedure was standardized with the help of deionized water with a density of 992 kg/m^3 at 298.15 K. The specific gravity bottle was placed in the thermostat water bath where the temperature was maintained constant to ± 0.01K for about 15 minutes in order to attain the thermal equilibrium. 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.

III.   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 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), Internal pressure (Pᵢ) and Free Volume (V_f) of binary mixture of 1,3-dioxolane (1) + 1-alkanol (2) at 298.15K

Mole fraction 1,3-Dioxolane (x_1)	Density (ρ) / g.cm⁻³	Sound velocity (u) / ms⁻¹	Viscosity (η) / mPas.	Internal pressure (P_i) × 10⁹/ N m⁻²	Free Volume (V_f) × 10⁻⁷ M³mol⁻¹	Enthalpy (H) × 10⁶
1,3-Dioxolane + Hexanol						
0.0000	0.8124	1198	3.3978	2.9099	1.9568	0.3156
0.0939	0.8276	1284	2.3973	3.2892	3.5817	0.3450
0.1942	0.8436	1290	1.8970	3.3763	4.9996	0.3468
0.2941	0.8640	1296	1.4437	3.4821	9.9265	0.3384
0.3942	0.8836	1300	1.1866	3.5776	11.0374	0.3341
0.4787	0.9068	1304	1.0904	3.6885	10.8499	0.33.8
0.5999	0.9316	1310	0.9311	3.8155	13.4125	0.3262
0.6972	0.9596	1318	0.7717	3.9663	17.4788	0.3236
0.7928	0.9876	1324	0.7171	4.1099	17.4788	0.3201
0.9035	1.0260	1332	0.6489	4.3085	19.1422	0.3166
1.0000	1.0616	1340	0.5885	4.4982	21.7624	0.3135
1,3-Dioxolane + Hexanol						
24.74130	0.8176	1306	4.6091	3.3333	1.7591	0.4163
0.0912	0.8252	1317	3.3826	3.4069	2.7275	0.4112
0.1955	0.8432	1320	2.3306	3.4931	4.5760	0.4003
0.2923	0.8584	1322	1.9839	3.5642	5.5951	0.3899
0.3982	0.8792	1325	1.5720	3.6629	7.5845	0.3787
0.4942	0.8992	1327	1.3059	3.7548	9.5968	0.3683
0.6059	0.9264	1330	1.0343	3.8815	12.9396	0.3567
0.6976	0.9508	1332	0.9131	3.9927	14.9307	0.465
0.8018	0.9836	1335	0.7680	4.1444	18.3980	0.3352
0.8914	1.0168	1337	0.7304	4.2939	18.9465	0.3254
1.0000	1.0616	1340	0.5885	4.4982	24.7413	0.3135
1,3-Dioxolane + Heptanol						
0.0000	0.8196	1325	5.9066	3.4147	1.5030	0.4838
0.0928	0.8304	1334	4.3181	3.4949	2.3075	0.4725
0.1905	0.8412	1334	3.2577	3.5404	3.3296	0.4552
0.2939	0.8592	1335	2.5895	3.6202	4.4224	0.4373
0.3894	0.8740	1335	1.9926	3.6826	6.1746	0.4201
0.4818	0.8916	1336	1.5315	3.7609	8.6425	0.4042
0.6021	0.9184	1337	1.2190	3.8784	11.2315	0.3835
0.6952	0.9420	1337	1.0959	3.9780	12.3322	0.3667
0.7892	0.9756	1338	0.9903	4.1245	13.4017	0.3505
0.9006	1.0156	1339	0.7057	4.2985	20.4381	0.3309
1.0000	1.0616	1340	0.5885	4.4982	24.7413	0.3135
1,3-Dioxolane + Octanol						
0.0000	0.8296	1350	7.1508	3.5546	1.3767	0.5619
0.0885	0.8296	1350	5.6095	3.5585	1.8692	0.5363
0.1967	0.8464	1349	3.9321	3.6225	2.9529	0.5100
0.2998	0.8560	1348	3.2616	3.6596	3.6234	0.4845
0.3902	0.8712	1348	2.4284	3.7245	5.2656	0.4629
0.4963	0.8876	1348	1.9058	3.7947	6.9577	0.4375
0.6008	0.9140	1347	1.3631	3.9032	10.5160	0.4117
0.6925	0.9340	1348	1.1376	3.9930	12.7180	0.3905
0.7975	0.9676	1348	0.9141	4.1367	15.9753	0.3652
0.8940	1.0104	1348	0.7652	4.3197	18.9060	0.3421
1.0000	1.0616	1340	0.5885	4.4982	24.7413	0.3135
1,3-Dioxolane + Nonanol						
0.0000	0.8248	1366	8.9258	3.5970	1.1714	0.6291
0.0876	0.8336	1366	6.8601	3.6354	1.6286	0.6020
0.1913	0.8404	1363	5.8531	3.6530	1.899	0.5684
0.2942	0.8504	1359	4.4022	3.6802	2.6620	0.5347
0.3963	0.8692	1355	3.1558	3.7449	3.9924	0.5014
0.4959	0.8844	1352	2.3340	3.7978	5.7014	0.4697
0.6050	0.9092	1349	1.7321	3.8913	7.9725	0.4354
0.6947	0.9332	1346	1.3334	3.9807	10.6902	0.4072
0.7993	0.9648	1343	0.9642	4.1018	15.3683	0.3744
0.9013	1.0084	1340	0.8031	4.2372	17.3683	0.3402
1.0000	1.0616	1340	0.5885	4.4982	24.7413	0.3135
1,3-Dioxolane + Decanol						

0.0000	0.8292	1378	11.8027	3.6639	0.8971	0.6990
0.0881	0.8364	1374	8.5615	3.6797	1.3454	0.6634
0.191	0.8396	1370	7.8207	3.6977	1.4040	0.6226
0.2921	0.8560	1366	5.5340	3.7331	2.1400	0.5827
0.3937	0.8672	1362	4.2319	3.7654	2.8863	0.5429
0.4956	0.8824	1358	3.4173	3.8145	3.5598	0.5035
0.604	0.9076	1353	2.5370	3.9018	4.8971	0.4615
0.7129	0.9308	1348	1.5262	3.9793	9.1301	0.4198
0.7983	0.9616	1344	1.1637	4.0927	12.1810	0.3871
0.8971	1.0040	1340	0.8623	4.2541	16.4668	0.3505
1.0000	1.0616	1340	0.5885	4.4982	24.7413	0.3135

The excess parameters such as Enthalpy (H^E), internal pressure (p_i^E) and Free Volume (V_f^E) have been calculated using the following equations.

The free volumes of the mixtures have been computed using its relationship with the ultrasonic velocity and viscosity is given below

$$V_f = (M\ U/\ k\ \eta)^{3/2} \qquad\qquad …(1)$$

where k is a constant, independent of temperature and it's value is 4.28×10^9 for all liquids.

On the basis of dimensional analysis, using free volume concept, the following expression can be used for calculating internal pressure

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

here b is packing factor (b = 2), k is a constant, independent of temperature and it's value is 4.28×10^9 for all liquids, R is universal gas constant and T is absolute temperature.

Enthalpy (H) can be calculated by the following equation

$$H = V_m \times P_i \qquad\qquad …(3)$$

The excess values of the above acoustical parameters have been calculated from the following relations.

$$Y^E = Y_{exp} - (X_1 Y_1 + X_2\ Y_2) \qquad\qquad …(4)$$

Y^E refer to (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 1,3-dioxolane 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.

The concept of free volume is an extension of the idea that each molecule is enclosed by its neighbor in a cell. The free volume per molecules may be regarded as the effective volume accessible to the centers of a molecule in a liquid. It is however, evident from the consideration of the liquid state theories that the concept of free volume varies with the specific model chosen for the liquid. A perusal of Figure 1 shows that the value of excess Free Volume(V_f^E), are negative for the all binary liquid system 1,3-dioxolane with 1-alkanols at 298.15 K. In the present investigation the negative excess free volume(V_f^E), for binary mixtures of 1,3-dioxolane with 1-alkanols may be attributed to hydrogen bond formation through dipole-dipole interaction between 1-alkanol and 1,3-dioxolane molecule or to structural contributions arising from the geometrical fitting of 1-alkanol into the 1,3-dioxolane due to difference in the free volume between components. The interactions of alcohols with organic liquids are interesting due to its acetic nature. The O-H bond in alcohols is polar and allows the release of hydrogen atom as proton (H^+). The order of acidity in alcohols is: 1^0-alcohol $>2^0$- alcohol $>3^0$- alcohol. This order is due to +I effect while the interacting ability of alcohols is well established no such opinion is suggested from literature with regards to 1,3-dioxolane with 1-alkanols were selected to study their molecular interactions through their acoustical behavior.
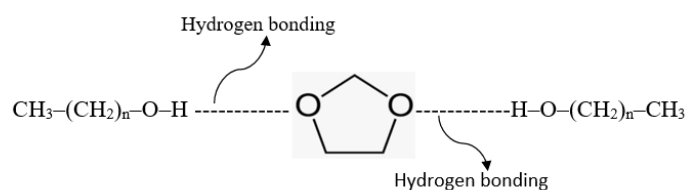

Figure: Hydrogen bonding present in 1,3-dioxolane– n-alkanols.

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.
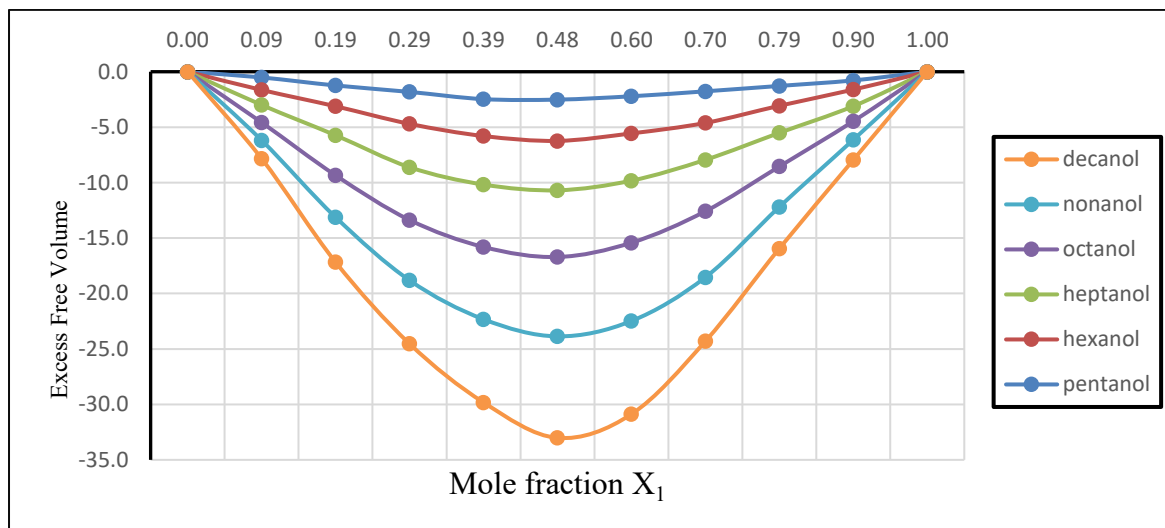

Figure 1. Variation of excess Free Volume(V_f^E), with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

The internal pressure is a cohesive force, which is the result of attractive and repulsive forces between the molecules. The attraction forces mainly consist of hydrogen bonding, dipole-dipole and dispersion interactions. Repulsive forces acting over very small intermolecular distances play a minor role in the cohesion process under normal circumstances. For the binary system 1,3-dioxolane with 1-alkanols , the excess internal pressure 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. Figure 2 shows the variation of excess internal pressure (p_i^E) with mole fraction of 1,3-dioxolane at the temperature 298.15K. This negative trend in excess internal pressure(p_i^E) indicate that only dispersion and dipolar forces operating with complete absence of specific interaction. Fort and Moore, suggested that the liquids having different molecular sizes and shapes mix well there by reducing the volume which causes the values of excess internal pressure(p_i^E) to be negative. It is also suggest that the liquids are less compressible when compared to their ideal mixtures signifying the chemical effects including charge transfer forces, formation of H-bond and other complex forming interactions. It can also be said that the molecular interactions are strong in these binary liquid mixtures that the medium is highly packed. The negative values of excess internal pressure(p_i^E) in these mixtures can be associated with a structure forming tendency.
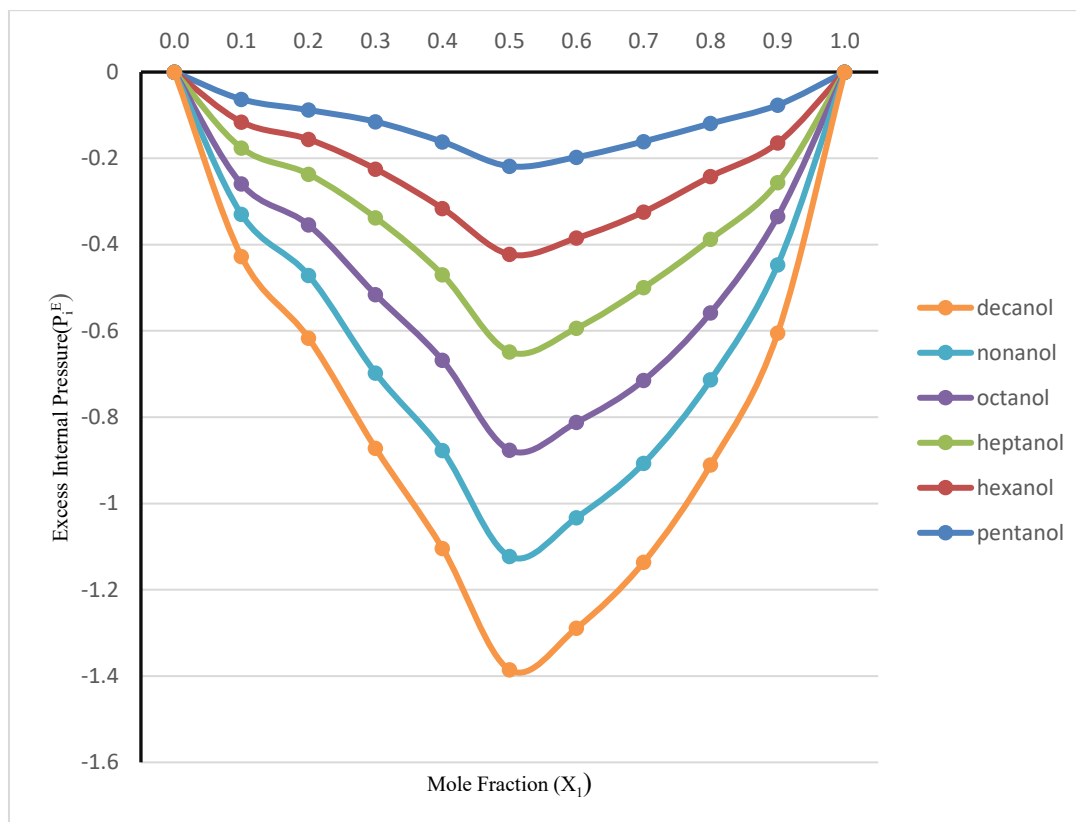
Figure 2. Variation of excess internal pressure (p_i^E) with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

Figure 3 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 3. 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 1-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 [26-29].
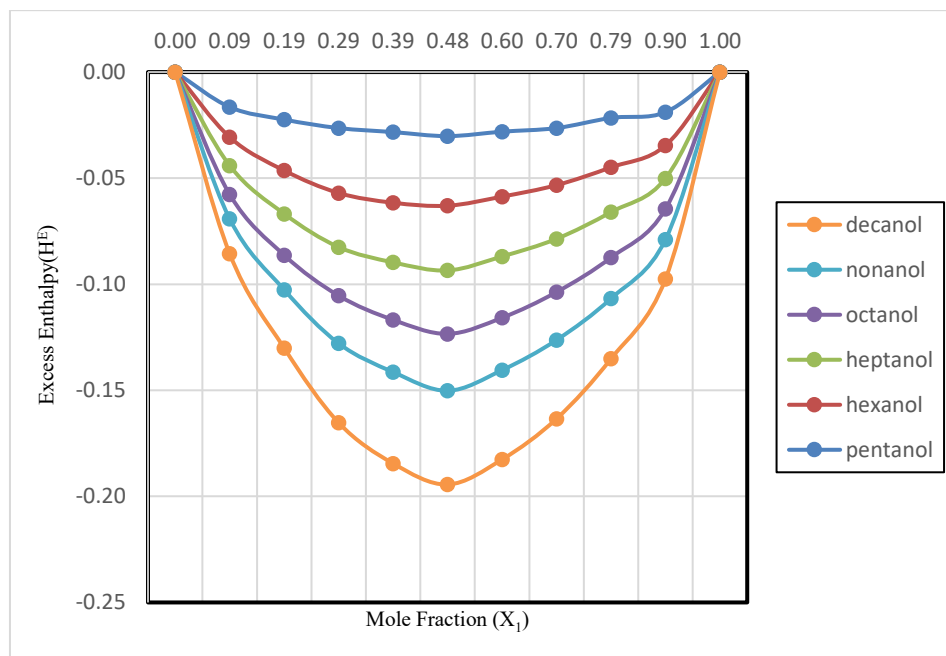
Figure 3- Variation of excess enthalpy (H^E) with mole fraction (x_1) of 1,3-dioxolane with 1-alkanols at 298.15K.

IV.   Conclusion

We measured sound velocity, density and viscosity of 1,3-dioxolane with 1-alkanols experimentally at 298.15K. The calculated 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. After a through study of the behavior of 1-alkanols and 1,3-dioxolane, we get a clear idea about the type and amount of molecular interactions between the components. In addition, molecular interactions are confirmed from the negative values of excess enthalpy (H^E), excess internal pressure (p_i^E) and excess Free Volume (V_f^E). Hence it is concluded that there exist a molecular interaction between 1,3-dioxolane and 1-alkanols due to Hydrogen bonding. It is observed from the study that there is intermolecular contact exists between the components in the binary mixture.

ACKNOWLEDGEMENTS

Nomenclature

ρ, Densities of liquid

u, Ultrasonic velocity

η, Viscosity

X_1, Mole fraction of 1,3-Dioxolane

T, Temperature

(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

References

[1].   G.Nath and R. Paikaray, Ultra science, Role of frequency in studying intermolecular interactions in a binary mixture of industrial importance liquid, Mol. Liq, **21(1)**, 99-104, (2009).

[2].   D.D.Deshpande , Vapour-liquid equilibrium and excess free energies for benzene + dioxane and carbon tetrachloride + dioxane systems, J. Chem. Soc., Farday Trans, **168**, 1059-1064, (1972).

[3].   T.M. Letcher, and U.P. Govende, Excess molar enthalpies of an alkanol + a cyclic ether at 298.15 K, J. Chem. Eng. Data, **40(5)**, 1097-1100 (1995).

[4]. M.K. Gangwar, and A.K. Saxena , Ultrasonic study of molecular interactions in binary mixtures of isopropyl-benzene (cumene) with benzene, toluene and acetone at 303K, Res. J. Chem. Sci., **3(2)**, 27-30, (2013).

[5]. S.L. Oswal and R.P. Phalak, Speed of sound and isentropic compressibility's of non electrolyte liquid mixtures.1. binary mixtures containing p-dioxane, J. Sol. Chem. **22**, 43-58 (1993).

[6]. T.M. Letcher and U. Domaska, The excess enthalpies of (tri butyl amine + an ether) at the temperature 298.15 K", J. Chem. Thermodyn, **26(5)**,553-560, (1994).

[7]. R. Palani , S. Saravanan and R. Kumar, Ultrasonic studies on some ternary organic liquid mixtures at 303, 308 and313K, Rasayan J. Chem., **2(3)**, 622-629, (2009).

[8]. P. Deepali, M.L. Gulwade Narwade and K.N. Wadodkar ,Ultrasonic behavior and study of molecular inter-actions of substituted azole in N, N-dimethylformamide at different temperatures and concentrations, Indian J. Chem. **43A**, 2102-2104, (2004).

[9]. J. Galka, L. Suski, P. Tomczyk and V. Vasilescu, Ultrasonic velocity and compressibility of fused bismuth + bismuth halide solutions, J. Chem. Thermodyn, **9(7)**, 673-681, (1977).

[10]. V. Kannappan, and J. Santhi , Ultrasonic study of induced dipole-dipole interactions in binary liquid mixtures, Indian J. Pure Appl. Phys., **43,**750-754, (2005).

[11]. M.F. Bolotnikov, Y.A. Neruchev, V.N. Melikhov, Verveyko and M.V. Verveyko, Temperature dependence of the speed of sound, densities and isentropic compressibility of hexane + hexadecane in the range of (293.15 to 373.15) K , J. Chem. Eng. Data, **50**, 1095-1098, (2005).

[12]. C. Vallés, E. Pérez , A.M. Mainar , J. Santafé and M. Domínguez , Excess enthalpy, density, speed of sound, and viscosity for 2-methyltetrahydrofuran + 1-butanol at (283.15, 298.15, and, 313.15) K", J. Chem. Eng. Data, **51**, 1105–1109, (2006).

[13]. A.H. Zainab, T.A. Al-Dulaimy, Dhafir, Al-Heetim, Husam Saleem Khalaf and Abbas, Ahmed Mohammed, Excess molar quantities of binary mixture of dipropyl amine with aliphatic alcohols at 298.15 K. *Oriental Journal of Chemistry*, **34(4),** 2074-208, (2018)**.**

[14]. G.P. Dubey and Monika Sharma, Excess volumes, densities, speed of sound and viscosities for the binary systems of 1-Octanol with hexadecane and squalane at (298.15,303.15 and 308.15)K. *Int. J Thermo phys.* **24,** 1361-1375, (2008)**.**

[15]. J.A. Al-Kandary, A.S. Al-Jimaz and A.H.M. Abdul-Latif, Densities, viscosities, speeds of sound and refractive indices of binary mixtures of tetra hydro furan with 1-hexanol, 1-heptanol, 1-octanol, 1-nonanol, 1-decanol at 298.15, 303.15, and 313.15 K. *Physics and Chemistry of Liquids*, **47(2),** 210-224, (2009).

[16]. M. Indumati,G. Meenakshi, V.J. Priyadharshini, R. Kayalvizhi and S. Thiyagaraj, 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(2),** 1332-1384, (2013).

[17]. R. Chanda, A. Banerjee and R.N. Mahendra, Studies of viscous antagonism, excess molar volumes, viscosity deviation and isentropic compressibility of ternary mixtures containing N,N-di methyl formamide, benzene and some ethers at 298.15 K. *Journal of Serbian Chemical Society*, **75(12)**, 1721-1732, (2010).

[18]. I. Giner, M. Haro, I. Gascon and C. Lafuente, Thermodynamic properties of binary mixtures formed by cyclic ethers and chloro alkanes. *Journal of Thermal Analysis and Calorimetry*, **2**, 587-595, (2007).

[19]. A. Kumar and C. Srinivasu, Speeds of Sound and Excess molar volume for binary mixture of 1,4-Dioxane with 1-Heptanol at five Temperatures. *Advance in Chemistry*, 1-7, 2014**.**

[20]. C. Bhatia Subhash, R. Rani, J. Sangwan and R. Bhatia, Densities, viscosities, speed of sound , refractive indices of binary mixtures of 1-Decanol with Isomeric Chloro toluene. *Int J Thermo phys*, **32,** 1163-1174, (2011)**.**

[21]. P.K. Banipal, V. Singh, N. Kaur, R. Sharma, S. Thakur, M. Kaur and T.S. Banipal, Physico-Chemical studies on binary mixtures of 1,4-Dioxane and Alkan-1-ols at 298.15K, *Acad. Sci. India. Sec. A Phys. Sci.* **88(4),** 479-490, (2017)**.**

[22]. V.Venkatalakshmi, M. Gowrisankar, P. Venkateswarlu and K.S. Reddy, Density, Ultrasonic velocity and their excess parameters of the binary mixtures of 2-Methyl-aniline with 1-Alkanols (C$_3$-C$_8$) at different temperatures, *International Journal of Physics and Research*, **3(5)** , 33-44, (2013)**.**

[23]. A.H. Zainab, T.A. Al-Dulaimy, Dhafir, Al-Heetimiand, Husen Saleem Khalaf and A.M. Abbas, Excess molar quantities of binary mixture of Di propyl amine with Aliphatic Alcohols at 298.15K"., *Oriental Journal of Chemistry*, **34 (4),** 2074-2082, (2018)**.**

[24]. N. Santhi and J. Madhumitha, Molecular interaction studies in binary liquid mixture through ultrasonic measurememts at 303.15K, International Journal of Advanced Chemistry, **2(1)** 12-16,(2014)**.**

[25]. J.D. Pandey, R.D. Rai, R.K. Shukla, A.K. Shukla and N. Mishra, Ultrasonic And Thermodynamic Properties Of Quaternary Liquid System At 298.15 K, Indian J. Pure Appl. Phys.**31**, 84-90, (1993).

[26]. O. Nomoto, Empirical Formula for Sound Velocity In Binary Liquid Mixtures, J. Phys. Soc. (Japan.), **13**, 1528-1532, (1958).

[27]. R. Gaba, N. Kaur, A. Pal, D. Sharma, J. Mol. Liq. **380**, 121766, (2023).

[28]. H. Kaur, N. Chakraborty, K.C. Juglan, A. Upmanyu, J. Mol. Liq. **392**, 123403, (2023).

[29]. T. Sharma, R. Rani, A. Kumar, R.K. Bamezai, J. Mol. Liq. **300,** 111985, (2020).