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Ultrasonic Studies in Binary Liquid Mixtures of Trichloroethylene with Three Alcohols at 303.15 K

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ABSTRACT

Density (ρ), ultrasonic velocities (u) and dynamic viscosity (η) for three binary mixtures of Trichloroethylene with 1-pentanol, 1-hexanol and 1-heptanol are presented at ambient temperature 303.15 K at atmospheric pressure over the entire composition range. The density and viscosity are measured using Specific gravity bottle and Ostwald's glass capillary viscometer respectively. The velocity is measured using ultrasonic interferometer. Molar volume, adiabatic compressibility, Intermolecular free length, and Wada's Constant are calculated using the above measured values. The excess parameters viz., excess molar volume, Excess adiabatic compressibility, Excess Intermolecular free length, viscosity deviation are also deduced from experimental values. Intermolecular interactions, and structural interactions present in various mixture are discussed in detail.

Keywords: Ultrasonic velocity, Molecular viscosity, Molecular interactions, Binary liquids, Trichloroethylene

INTRODUCTION

The physical and chemical properties of mixture liquids are influenced by the intermolecular forces [1-5]. Knowledge of density and viscosity is essential in the design of processes involving chemical separations, equipment design, solution theory, heat transfer, fluid flow and molecular dynamics. The research findings of Grunberg and Nissan [6], Tamura and Kurata [7] Hind et al. [8], Katti and Chaudhri [9] and Heric [10] proved that the data on viscosity are useful for testing the theories and empirical relations of liquid mixtures. The study of the ultrasonic velocity in liquids and liquid mixtures and its influence on the molecular structure had been studied by several researchers [11-22].

Ultrasonic studies in binary mixtures of hydrocarbon liquids with several alcohols were carried out by Danusso [23]. Willard [24] observed that ultrasonic velocity has a parabolic variation with the composition of the mixture in several aqueous mixtures of alcohols. In the studies carried out by Al-Hayam et al. [25], it was noted that the negative excess molar volume can be attributed to the strong interaction between unlike molecules through hydrogen bonding for the binary mixtures of 1,1,2,2-tetrabromoethane with 1-pentanol, 1-hexanol, 1-heptanol, 1-octanol and 1-decanol at the temperatures of 298.15 and 303.15 K and they concluded that such a behaviour is the result of several opposing effects including as suggested by Treszczanowicz et al. [26]. The variation of excess molar volume, deviation in viscosity and excess Gibb's free energy of binary mixtures of bromoform with anisole, acetophenone, ethyl benzoate, 1,2-dichloroethane and 1,2,2-tetrachloroethane was studied by Srikanth et al. [27]. The authors discussed compound values in terms of thermodynamic interactions involved between the mixing components. In another study carried out by Aminabhavi et al. [28] in aqueous solutions of alcohols and amines, excess thermodynamic properties such as excess enthalpy and excess Gibb's free energy of flow were calculated and it was shown that these liquids also exhibit strong peaks at intermediate concentrations [29].

Prasad and Ray [30] determined the ultrasonic velocity, density, viscosity experimentally and free volume. Internal pressure was computed for the binary mixtures of n-butanol with aniline, N-methylaniline and N-dimethyl aniline. Excess free volume and internal pressures were deduced for these systems. The results were discussed in the light of existing theories of molecular interaction involved and the chemical constitution of the liquid components.

The literature survey on the ultrasonic studies as mentioned above indicates that though investigations on various properties of binary liquid mixtures have been carried out, not much work has been done on Trichloroethylene with alcohols.

Therefore, detailed investigations on three binary liquid mixture, systems viz., 1. Trichloroethylene+1-pentanol, system 2. Trichloroethylene+1-heptanol and system 3. Trichloroethylene+1-hexanol was undertaken to obtain reliable velocity, density and viscosity data at 303.15 K over the entire range of compositions. From these data, molar volume (V), excess molar volume (V^E), adiabatic compressibility (β_{ad}), acoustic impedance (Z), deviation in adiabatic compressibility ($\Delta\beta_{ad}$), intermolecular free length (L_f) excess intermolecular free length (ΔL_f^E), deviation in viscosity ($\Delta\eta$), excess acoustic impedance (Z^E) Rao's Constant (R) Wada's Constant (W) are also calculated. The data obtained was used to understand intermolecular interactions between the unlike molecules and to test the theories of solutions.

MATERIALS AND METHODS

High purity and AR grade samples used in the present study were obtained from Merck Co. Inc., Germany. The liquids are distilled before use, and are mixed in the desired proportions using burette and are allowed to stay for 5 or 6 h to attain thermal equilibrium before taking the experimental observations. Dissolved gases in the organic liquids are often a source of bubble formation, which introduces error in density measurements. In order to overcome this difficulty, all the liquids were degassed.

Variable path ultrasonic interferometer having a gold plated x-cut quartz crystal with a natural frequency of 2 MHz with an accuracy of $\pm 0.1 \text{ ms}^{-1}$ supplied by M/s Mittal enterprises (model-05 F), New Delhi (India), was used in the present investigation. A digitally operated constant temperature bath to circulate water through the double walled measuring cell made up of steel with a thermostat fixed with accuracy of $\pm 0.05\%$ was used to control the temperature. The densities of all the liquids and liquid mixtures have been measured using a 10 ml specific gravity bottle. The weight of the solution was measured correct to 0.1 mg. by means of chemical balance. The viscosities have been determined by means of Ostwald's viscometer with accuracy $0.001 \text{ Nm}^{-2} \text{ s}$. The Viscometer was calibrated before use. The measurement of densities, viscosities and velocities for all the mixtures has been made at 303.15 K. The time of flow of water and time of flow of solution were measured using digital stopwatch. In the entire experimental work, measurements have been made five times and the average values have been taken into consideration to reduce the possible experimental error. The variation in the measurements is with in an error of 0.1%.

THEORY

Excess volume (V^E): If V is the mean molar volume of a binary liquid mixture. Excess molar volume is calculated using the relation $V^E = V - (V_1 X_1 + V_2 X_2)$. Where V_1 , V_2 and X_1 , X_2 are the molar volumes and the mole fractions of binary liquid mixture respectively.

- **Adiabatic compressibility (β_{ad}):** Assuming that ultrasonic absorption is negligible, adiabatic compressibility can be obtained from the density and velocity of ultrasonic sound using the relation $\beta_{ad} = 1/\rho U^2$.
- **Acoustic impedance (Za):** The specific acoustic impedance is given by $Za = \rho U$.
- **Deviation in adiabatic compressibility ($\Delta\beta_{ad}$):** At a given mole fraction is given by: $\Delta\beta_{ad} = \beta_{ad} - (\beta_{ad1} X_1 + \beta_{ad2} X_2)$, where β_{ad1} and β_{ad2} are the individual adiabatic compressibility values of pure liquids in the binary mixtures at that temperature.
- **Intermolecular free length (L_f):** Is obtained from the formula: $L_f = K (\beta_{ad})^{1/2}$, where K is Jacobson's constant.
- **Excess intermolecular free length (L_f^E):** Has been determined as $L_f^E = L_f - (L_{f1} X_1 + L_{f2} X_2)$. where L_{f1} and L_{f2} are the individual intermolecular free length values of pure liquids in the binary mixtures.
- **Deviation in viscosity ($\Delta\eta$):** Calculated by: $\Delta\eta = \eta_{mix} - (X_1 \eta_1 + X_2 \eta_2)$, where η_{mix} , η_1 and η_2 are the viscosities of the liquid mixture and the individual values of pure liquids respectively.
- **Molar sound velocity or Rao's constant (R)** has been calculated using the following relation: $R = VU^{1/3}$.
- **Molar compressibility or Wada's constant (W)** has been calculated using formula: $W = M/\rho X \beta_{ad}^{-1/7}$.

Comparison of experimental values of density (ρ), viscosity (η) and ultrasonic velocity (U) values of pure liquids with literature values

Component	Density (g/cc)		Viscosity (centipoise)		Velocity (m/s)	
	Literature	Experimental	Literature	Experimental	Literature	Experimental
Trichloroethylene (HCIC=CCICI)	1.4556	1.4559	0.5362	0.5365	1015	1016
1-Pentanol	0.8086	0.8087	3.73	3.7309	1264	1264.5
1-Hexanol	0.81165	0.8117	4.683	4.6834	1273	1275.5
1-Heptanol	0.8149	0.8088	6.188	6.1778	1312	1316

RESULTS AND DISCUSSION

The measured values of ultrasonic velocity (U), density (ρ), viscosity (η) and computed values of deviation in viscosity ($\Delta\eta$), molar volume (V), excess molar volume (V^E), adiabatic compressibility (β_{ad}), acoustic impedance (Z), deviation in adiabatic compressibility ($\Delta\beta_{ad}$), intermolecular free length (L_f), excess intermolecular free length (L_f^E), excess velocity (U^E), excess acoustic impedance (Z^E), Rao's constant (R) and Wada's constant (W) for the three binary liquid systems are presented in Tables 1-7 respectively.

Table 1: System-1 trichloroethylene+1-pentanol, temperature–303.15 K

Mole fraction (X)	U (m/s)	$\rho \xi 10^{-3}$ (kg/m ³)	η (Cp)	V_m (cm ³ mol ⁻¹)	$\beta_{\infty} 10^{12}$ (m ² N ⁻²)	L_r (10 ⁻¹⁰ m)	R	W	Z
0	1264.5	0.8087	3.7309	109.002	77.3348	0.5514	5471	3034	1022.6
0.1183	1235.2	0.8762	3.3869	106.444	74.8034	0.5423	5301	2976	1082.28
0.2319	1206.06	0.9435	3.0494	104.052	72.8611	0.5352	5141	2921	1137.98
0.3411	1178.31	1.0104	2.7161	101.838	71.2828	0.5294	4993	2867	1190.58
0.446	1152	1.0774	2.3886	99.7162	69.9369	0.5243	4852	2815	1241.2
0.5471	1127.35	1.144	2.0684	97.7316	68.7792	0.52	4721	2766	1289.69
0.6443	1104	1.2088	1.7516	95.969	67.8721	0.5166	4604	2721	1334.56
0.7381	1082.28	1.2726	1.4384	94.3487	67.0869	0.5136	4496	2680	1377.28
0.8285	1061.74	1.3357	1.1303	92.8129	66.4109	0.511	4395	2640	1418.22
0.9158	1041.09	1.3969	0.8292	91.4526	66.0491	0.5096	4302	2603	1454.27
1	1016	1.4559	0.5365	90.2466	66.5397	0.5115	4211	2566	1479.19

Table 2: System-1, trichloroethylene+1-pentanol, temperature–303.15 K

Mole fraction (X)	V_m^E (Cm ³ mol ⁻¹)	$\beta_{\infty}^E 10^{10}$ (m ² N ⁻¹)	h^E (Cp)	L_r^E (10 ⁻¹⁰ m)	U^E	Z^E
0	0	0	0	0	0	0
0.1183	-0.339	-1.2541	0.034	-0.0044	0.1034	5.659
0.2319	-0.6	-1.97	0.0594	-0.0069	-0.8046	9.4847
0.3411	-0.767	-2.37	0.0748	-0.0084	-1.4349	12.2415
0.446	-0.92	-2.5828	0.0826	-0.0093	-1.6566	14.937
0.5471	-1.01	-2.65	0.085	-0.0096	-1.2056	17.3038
0.6443	-0.948	-2.5069	0.079	-0.0091	-0.3795	17.7612
0.7381	-0.81	-2.28	0.0653	-0.0084	1.1985	17.6707
0.8285	-0.65	-1.98	0.046	-0.0074	3.124	17.3269
0.9158	-0.374	-1.4	0.0236	-0.0053	4.1565	13.5422
1	0	0	0	0	0	0

Table 3: System-2 trichloroethylene+1-hexanol, temperature–303.15 K

Mole fraction (X)	U (m/s)	$\rho \xi 10^{-3}$ (kg/m ³)	η (Cp)	V_m (Cm ³ mol ⁻¹)	$\beta_{\infty} 10^{12}$ (m ² N ⁻²)	L_r (10 ⁻¹⁰ m)	R	W	Z
0	1275.5	0.8117	4.6834	125.884	75.7257	0.5456	6337	3514	1035.32
0.1342	1248.31	0.8792	4.1688	120.682	72.993	0.5357	6031	3386	1097.48
0.2586	1219.4	0.9464	3.6798	115.946	71.0606	0.5285	5750	3266	1154.05
0.3741	1190.4	1.0135	3.2179	111.602	69.6288	0.5232	5490	3153	1206.47
0.4818	1163.12	1.0801	2.7812	107.638	68.4395	0.5187	5254	3048	1256.23
0.5824	1137.27	1.146	2.3671	104.007	67.4654	0.515	5039	2952	1303.33
0.6766	1112.52	1.2111	1.9695	100.686	66.7103	0.5121	4843	2862	1347.41
0.765	1089.06	1.2752	1.59	97.6525	66.1187	0.5098	4663	2779	1388.75
0.848	1066.64	1.3379	1.2258	94.888	65.6958	0.5082	4500	2703	1427.06
0.9262	1044.25	1.3988	0.8755	92.3869	65.5574	0.5077	4351	2633	1460.74
1	1016	1.4559	0.5365	90.2466	66.5397	0.5115	4211	2566	1479.19

Table 4: System-2 trichloroethylene+1-hexanol, temperature–303.15 K

Mole fraction (X)	V_m^E (Cm ³ mol ⁻¹)	$\beta_{\infty}^E 10^{10}$ (m ² N ⁻¹)	h^E (Cp)	L_r^E (10 ⁻¹⁰ m)	U^E	Z^E
0	0	0	0	0	0	0.0033
0.1342	-0.42	-1.5	0.0419	-0.0053	7.6339	2.5945
0.2586	-0.724	-2.29	0.0686	-0.0082	10.9928	3.9678
0.3741	-0.948	-2.66	0.086	-0.0096	11.9939	5.0795
0.4818	-1.074	-2.86	0.096	-0.0105	12.6593	7.0319
0.5824	-1.12	-2.91	0.099	-0.0107	12.9191	9.4783
0.6766	-1.085	-2.8	0.092	-0.0104	12.6029	11.7578
0.765	-0.97	-2.58	0.0788	-0.0097	12.0691	13.8832
0.848	-0.775	-2.24	0.059	-0.0085	11.2035	15.3334
0.9262	-0.489	-1.66	0.033	-0.0063	9.1038	14.3012
1	0	0	0	0	0	0.0044

Table 5: System-3 trichloroethylene+1-heptanol, temperature–303.15 K

Mole fraction (X)	U (m/s)	$\rho \xi 10^{-3}$ (kg/m ³)	η (Cp)	V_m (Cm ⁻³ mol ⁻¹)	$\beta_{\infty} 10^{12}$ (m ² N ⁻²)	L_r (10 ⁻¹⁰ m)	R	W	Z
0	1316	0.8088	6.1778	143.67	71.3916	0.5298	7308	4044	1064.38
0.1503	1286.74	0.8771	5.3849	135.088	68.8624	0.5203	6820	3822	1128.57
0.2847	1253.53	0.9451	4.6593	127.532	67.3403	0.5145	6383	3620	1184.65
0.4056	1220.44	1.0127	3.9962	120.823	66.2938	0.5105	5993	3437	1235.97
0.5149	1188.66	1.0798	3.3889	114.852	65.5435	0.5076	5647	3273	1283.55
0.6142	1158.64	1.1465	2.8318	109.488	64.9716	0.5054	5338	3124	1328.4
0.7048	1129.77	1.2124	2.3116	104.675	64.6218	0.504	5060	2989	1369.72
0.7879	1101.67	1.2772	1.8287	100.347	64.5088	0.5036	4810	2866	1407.11
0.8643	1074.68	1.3408	1.3761	96.4574	64.5782	0.5039	4586	2754	1440.91
0.9348	1048.29	1.4014	0.947	93.052	64.9362	0.5053	4388	2655	1469.03
1	1016	1.4559	0.5365	90.2466	66.5397	0.5115	4211	2566	1479.19

Table 6: System-3 trichloroethylene+1-heptanol, temperature–308.15 K

Mole fraction (X)	V_m^E (Cm ³ mol ⁻¹)	$\beta_{\infty}^E 10^{10}$ (m ² N ⁻¹)	h^E (Cp)	L_r^E (10 ⁻¹⁰ m)	U^E	Z^E
0	0	0	0	0	0	0.0008
0.1503	-0.552	-1.8	0.055	-0.007	15.826	1.8443
0.2847	-0.929	-2.67	0.0875	-0.01	22.934	2.1806
0.4056	-1.18	-3.13	0.1063	-0.012	26.113	3.3609
0.5149	-1.312	-3.35	0.1156	-0.013	27.118	5.6
0.614	-1.37	-3.44	0.1188	-0.013	26.895	9.2466
0.7048	-1.34	-3.35	0.11	-0.013	25.222	12.963
0.7879	-1.231	-3.06	0.0956	-0.012	22.041	15.905
0.8643	-1.04	-2.62	0.0739	-0.01	17.96	18.017
0.9348	-0.68	-1.92	0.0425	-0.007	12.719	16.903
1	0	0	0	0	0	0.0044

The variation of ultrasonic velocity with the mole fraction of trichloroethylene for the three systems indicates that there is a non-linear decrease in velocity without having any minimum as shown in Figure 1. The non-existence of maxima or dips at any intermediate concentration of trichloroethylene with 1-pentanol, 1-hexanol and 1-heptanol indicates that there is no complex formation between the components. These observations are in agreement with the general trends of the ultrasonic velocity variations in binary liquids [31-37].

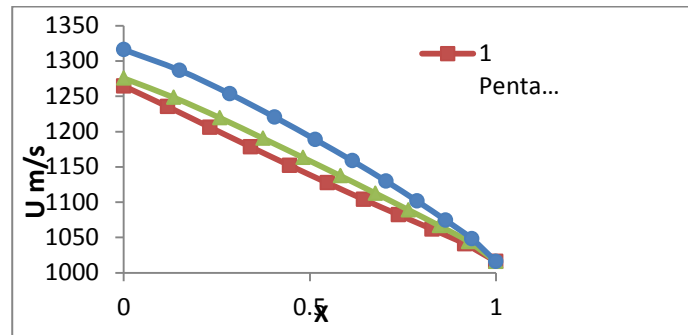


Figure 1: Variation of velocity with mole fraction

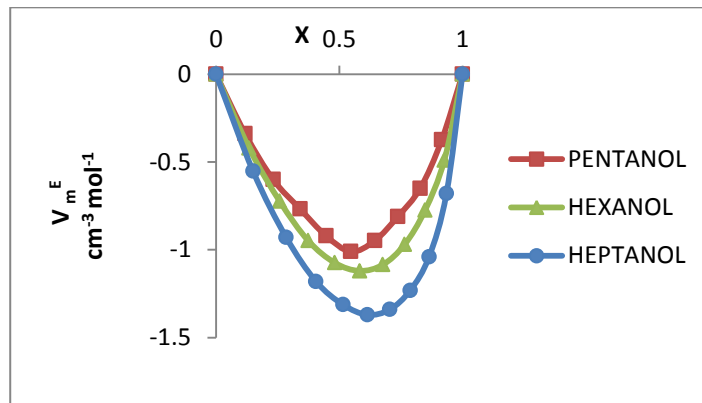


Figure 2: Variation of excess molar volume with mole fraction

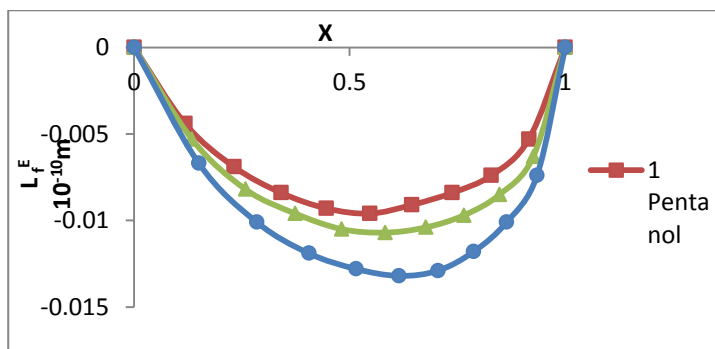


Figure 3: Variation of deviation in excess intermolecular free length with mole fraction

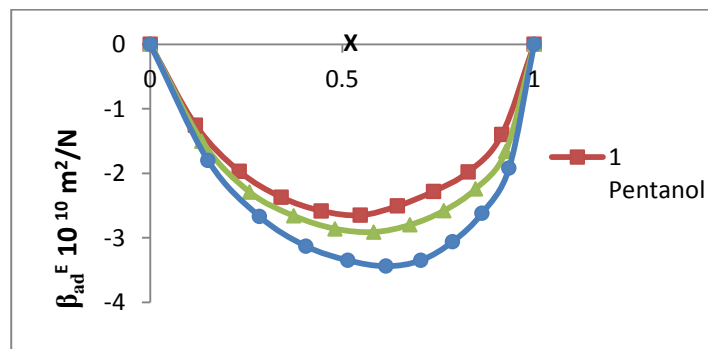


Figure 4: Variation of deviation in adiabatic compressibility with mole fraction

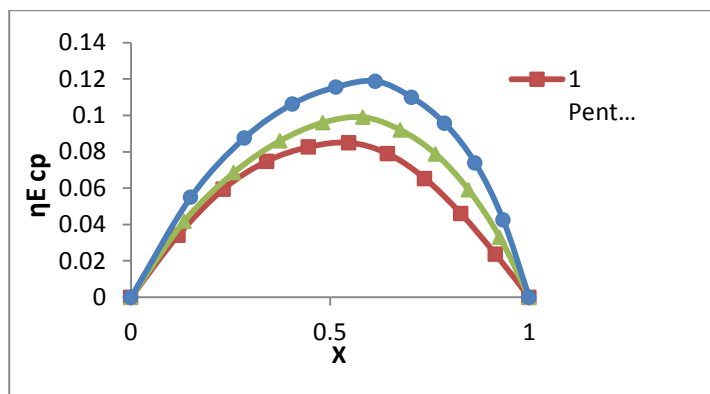


Figure 5: Variation of deviation in viscosity with mole fraction

The existence of structurally different species in solution is bound to have its effect reflected in the other physical parameters. In order to examine such possibilities, excess volumes of mixing in solution were calculated as a function of composition. The excess volumes for all the three systems are negative in the entire range of composition at the temperature of 303.15 K, as shown in Figure 2.

The data indicates that there exists a volume contraction in mixing and the negative excess volumes reach a minimum value at about 0.5 mole fraction of trichloroethylene. These three results indicate the closer approach of unlike molecules due to strong interaction [38]. The sign of excess volume (V^E) of a system depends on the relative magnitude of expansion/contraction on mixing of two liquids. If the factors causing expansion dominate the factors causing contraction, then V^E becomes positive. On the other hand, if the contractive factors dominate the expansive factors, then V^E becomes negative. The factors responsible for expansion in volume are as follows [39,40]: 1. Loss of dipolar association (i.e., rupturing of H-bonding of component by the other or breaking up of associates held by weaker forces, namely, dipole-dipole or dipole-induced dipole interactions or by Van der Waals forces). 2. The geometry of molecular structure, which does not allow fitting of one component in to other component. 3. Steric hindrance, opposes the proximity of the constituent molecules.

The negative V^E values arise due to the dominance of the following factors: (i) Chemical interaction between constituent molecules, such as hetero molecular associations through the formation of H-bond is known as strong specific interaction. (ii) Accommodation of molecules of one component into the other interstitials of molecules with each other component. (iii) Geometry of the molecular structure that favours fitting of the component molecules with each other.

The excess volumes of all the three systems are negative at the temperature studied indicating the existence of strong dipole-dipole interactions between the components. This is due to the dominance of the above mentioned that are factors that are responsible for contraction in volume.

Several workers [41-44] observed the similar trends. This behaviour is being attributed mainly to the specific interactions between unlike molecules of the systems.

Another important parameter to understand the structural adjustment in solution due to molecular interactions is the intermolecular free length. Both intermolecular free length (L_f) and adiabatic compressibility (β_{ad}) have an inverse relationship with ultrasonic velocity (U) shown in Figures 3 and 4. Occurrence of maxima U and minima β_{ad} and L_f at the same concentrations indicates the strong interaction through the formation of hydrogen-bonding and dipole-dipole interactions between the components [45].

The linear free length increases with mole fraction of trichloroethylene for all the three systems. The variation of excess free length with mole fraction; Figure 3 indicates that there exists a broad minimum in excess free length at an intermediate composition for all three systems. In the case of all the three systems studied, a minimum value is obtained at about 0.5 mol fraction of trichloroethylene. The existence of minimum in L_f^E at a particular composition in the three systems is attributed to an indication of molecular species with far away packing than either constituent liquid. The negative excess mean free length for all the three in the entire range of compositions also indicates the existence of strong interaction between the components [46].

Deviations in adiabatic compressibility can be explained in terms of contributions made by the following factors: (a) Increase in free length due to loss of dipolar association, difference in size and shape of the component molecule which leads to decrease in sound velocity and increase in adiabatic compressibility and (b) Decrease in free lengths as a result of dipole-dipole interactions or hydrogen bonded complex formation between unlike molecules which leads to decrease of sound velocity and increase of compressibility. The experimental values of deviations in compressibility in all the three systems are negative. Figure 4, it is reported that negative deviations in compressibility indicates strong molecular interactions in liquid mixtures while positive sign is an indication of weak interactions due to dispersion forces. The negative deviation in compressibility for all the three systems studied indicate the existence of strong interaction between the unlike molecules [47,48].

The deviation in viscosity ($\Delta\eta$) gives a quantitative estimation of intermolecular interactions. The $\Delta\eta$ at each composition is obtained from the relation suggested by Fort and Moore [49]. The deviation in viscosity becomes positive as the strength of interaction increases. The $\Delta\eta$ values may be generally explained by considering the following factors [50-53]. The differences in the size and shape of the component molecules and the loss in dipolar interactions in pure components may contribute to a decrease in viscosity and the specific interactions between unlike molecules such as hydrogen bond formation and charge transfer complexes may lead to increase in viscosity in mixtures than in pure components.

The former effect produces negative deviation in viscosity while the later effect introduces positive deviation. The net deviation in viscosity is generally considered as a result of the two major effects. The deviations in viscosity for the three systems at the temperature (303.15 K) are negative indicating the dominance of non-specific interactions between unlike molecules.

The experimental viscosities as a function of mole fraction of trichloroethylene for three systems are shown in Figure 5. The three systems exhibit a positive deviation of excess viscosity over entire mole fraction range with a maximum corresponding to a mole fraction of about 0.5 at the temperature studied. These deviations indicate specific molecular interactions between different molecules. This is also supported by the excess molar volume studies.

The difference in size of the molecules will have influence on the intermolecular forces and hence the excess thermodynamic properties will be effected [54,55]. An increase in the values of Z with the mole fraction of trichloroethylene for all the mixtures shows the presence of specific interactions between unlike molecules [56-59].

The negative or positive deviations in the Z^E and U^E from rectilinear dependence on composition of the mixtures indicate the extent of association or dissociation between unlike molecules and these are represented in Tables 3, 5 and 7 respectively for all the three systems studied over the entire composition range at the temperature 303.15 K. Positive deviations indicate the increasing strength of interaction between component molecules of the liquid mixtures [57-60]. The above trends are in support of the findings for the variations of β_{ad}^E and L_f^E with compositions.

The positive deviations in ultrasonic velocity may be interpreted in terms of two opposing effects [60]. Components exert a mutual structure-breaking effect on mixing, hydrogen bond interactions between unlike molecules.

The former effect contributes to an increase in the free length, leading to a negative deviation in the speed of sound. However, the latter effect contributes to a positive deviation in the speed of sound [58]. The sign and magnitude of the actual deviation depend on the relative strengths of the two effects. The experimental values of U^E point out that the latter effect dominates in all the three systems.

From the above consideration, it is clear that there is a strong association between unlike molecules in the liquid mixtures and this interaction may be accompanied by the disruption of the structure of the components.

Strong interactions arise among the components of a liquid mixture leading to formation of molecular aggregates and more compact structures leading to the sound waves to travel faster through the mixture and hence the speed of sound deviations will be positive. On the other hand, if the predominant effect in the mixture is structure-breaking resulting in expansion, the speed of sound through the mixture will be slower and the deviation will be negative [61]. In the present study the excess ultrasonic velocity of all binary mixtures are positive which indicates that structure making effect is predominant [62,63].

CONCLUSION

In this work, we have measured density, viscosity and speed of sound in binary methods of trichloroethylene in with 1-pentanol, 1-hexanol and 1-heptanol at the temperature 303.15 K.

Deviations in speed of sound, excess molar volume, viscosity, adiabatic compressibility, excess free length and acoustic impedance have been calculated. The deviation in viscosity, and acoustic impedance showed positive behaviour, while excess molar volume, deviation in adiabatic compressibility and excess free length showed negative behaviour for the systems under investigation indicating strong interactions between the components. However, in the case of deviation in speed of sound in 1-pentanol 1-hexanol and 1-heptanol systems showed a positive trend.

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