# EXCESS PARAMETERS OF ACOUSTICAL AND THERMODYNAMIC STUDIES IN BINARY LIQUID MIXTURES OF TETRACHLOROETHYLENE WITH NITROBENZENE AT FOUR (303.15, 308.15, 313.15 AND 318.15) K DIFFERENT TEMPERATURES

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*Abstract:* The density, viscosity, the speed of sound at Temperatures (303.15, 308.15, 313.15 and 318.15) K, in binary mixtures of Tetrachloroethylene with Nitrobenzene, were measured over the entire mole fraction range of the binary mixtures. Using these data, The Excess Acoustic and Thermodynamic parameters, deviations in Experimental and Theoretical values of Ultrasonic velocity were calculated. The computed quantities were fitted to the Redlich-Kister equation to derive the coefficients and estimate the standard error values. The results are discussed and interpreted in terms of structural and specific interaction predominated by hydrogen bonding.

***IndexTerms* - Ultrasonic velocity, density, binary liquid mixture, excess parameters, tetrachloroethylene, Nitrobenzene.**

## I. INTRODUCTION

Thermodynamic properties of non-electrolyte solutions have proved to be a useful tool in elucidating the structural interactions among component molecules [1]. For example, excess volume and density data can be used to study solvent–solvent specific interactions as a function of temperature, while the composition dependence provides valuable un-substitutable information about the presence and the stoichiometry of complex adducts. The intermolecular interactions influence the structural arrangement along with the shape of the molecules. The sign and magnitude of these properties guide us to understand possible interactions between the component molecules. The knowledge of physicochemical properties of non-aqueous binary liquid mixtures has relevance in theoretical and applied areas of research, and such results are frequently used in the design process (flow, mass transfer or heat transfer calculations) in many chemical and industrial processes. The excess properties derived from these physical property data reflect the physicochemical behaviour of the liquid mixtures with respect to the solution structure and intermolecular interactions between the component molecules of the mixture [2, 3]. In continuation of our studies of acoustic and volumetric properties of non-electrolyte liquid mixtures [4], the present study reports densities and viscosity at, 303.15, 308.15, 313.15,318.15 K and speed of sound data at 303.15 and 308.15 313.15 and318.15 K for binary mixtures of Tetrachloroethylene with Nitrobenzene, over the entire composition range.

From these data, excess molar volumes ($V^E$), excess speed of sound ($u^E$) and excess isentropic compressibility ($i^E$) were calculated. Further, Excess Acoustic and Thermodynamic parameters of Ultrasonic Velocity ($U^E$), Adiabatic Compressibility ($\beta ad^E$), Intermolecular Free Length ($L_f^E$), Acoustical Impedance ($Z^E$), Molar Volume ($V_m^E$), Available Volume ($Va^E$), Viscosity ($\Delta\eta$), Free Volume ($V_f^E$), Internal Pressure ($\pi^E$), Enthalpy ($H^E$), Gibb's Free Energy ($\Delta G^E$) at temperatures (303.15, 308.15,313.15,318.15)K for mole fraction Tetrachloroethylene with Nitrobenzene. The experimental speed of sound data were compared with Schaaff's collision factor theory (CFT) and Jacobson's free length theory (FLT).Liquids that were chosen in the present investigation are of much interest due to their various industrial and consumer applications. The applications of tetrachloroethylene are in dry cleaning, textile processing, degreasing metals, insulating fluid, and cooling gas in electrical transformers. The application of nitrobenzene are used to mask unpleasant odors in shoe and floor polishes, leather dressings, paint solvents, and other materials. Redistilled, as oil of mirbane, nitrobenzene had been used as an inexpensive perfume for soaps. It has been replaced by less toxic chemicals for this purpose. To the best of our knowledge, acoustic and volumetric properties of binary mixtures of Tetrachloroethylene with the nitrobenzene considered in this work are reported in literature.

## II. EXPERIMENTAL SECTION

### 2.1 Chemicals Used:

All the chemicals used in the present work were of analytical reagent grade procured from Merck India and their purities were as follows: Tetrachloroethylene (99.5 %), Nitrobenzene (99.0 %), prior to experimental measurements, all the liquids were purified as described in the literature [5-7].

**2.2 Analysis of Water Content in Chemicals:**

The water content of solvents used in this work was measured using an Analab (Micro Aqua Cal 100) Karl Fischer Titrator and Karl Fisher reagent from Merck. It can detect water content from less than 10 ppm to 100 % by conduct metric titration with dual platinum electrodes.

The water contents are given in Table 1 along with their CAS number, supplier and manufacturer's stated purities. The purities of chemicals, after distillation, were checked by comparing the measured densities and speeds of sound, which are in good agreement with literature values [8 - 14] and these are given in Table 2

Table 1: List of chemicals with details of supplier, CAS number and purity

| Chemical | Supplier | CAS number | Purity in mole fraction(as received from supplier) | Purity in mole fraction(after purification) | Water content |
|---|---|---|---|---|---|
| Tetrachloroethylene | Merck | 127-18-4 | 0.990 | 0.995 | 0.012 |
| Nitrobenzene | Merck | 98-95-3 | 0.989 | 0.990 | 0.046 |

Table 2: Comparison of experimental Ultrasonic Velocity (U), Density (ρ), Viscosity (η), of pure liquid with literature value at 303.15K

| Components | Velocity (U) $m.s^{-1}$ | | Density (ρ) $Kg.m^{-3}$ | | Viscosity (η) $Ns.m^{-2}$ | |
|---|---|---|---|---|---|---|
| | Exp | Lit | Exp | Lit | Exp | Lit |
| Tetrachloroethylene | 1028.70 | 1028.0(8) | 1606.36 | 1606.34(9) | 0.797 | 0.798(10,11) |
| Nitrobenzene | 1413.97 | 1432(12) | 1193.3 | 1193.4(13) | 1.6592 | 1.6595(14) |

**2.3 Measurements:**

All binary liquid mixtures were prepared by weighing appropriate amounts of pure liquids on an electronic balance (Afoset, ER-120A, and India) with a precision of ±0.1 mg, by syringing each component into airtight stopper bottles to minimize evaporation losses. The uncertainty of the mole fraction was ±1 9 $10^{-4}$. After mixing, a bubble free homogenous sample was transferred into the U-tube of the densimeter through a syringe. The density measurements were performed with a Rudolph Research Analytical digital densimeter (Model DDM-2911), equipped with a built-in solid state thermostat and a resident program, with an accuracy of temperature of ±0.03 K. The uncertainty in the density measurements is ±2 9 $10^{-5}$ $g.cm^{-3}$. Calibration of the densimeter, at each temperature, was with doubly distilled, deionized water and with air as standards. The ultrasonic speeds in the pure liquids and in their mixtures were measured by using a multi frequency ultrasonic interferometer (M-82 Model, Mittal Enterprise, New Delhi, India) single-crystal variable-path at (303.15 ,308.15, 313.15 and 318.15) K. The uncertainty in the measurement of ultrasonic sound velocity is ±0.3 %. The temperature stability is maintained within ±0.01 K by a circulating thermostatic water bath around the cell with a circulating pump. The present investigation has been devoted to the study of densities, speed of sounds of binary liquid mixtures at different temperatures at a pressure of 0.1 MPa.

**2.4 Calculations**

Using the measured data, the acoustical parameters have been calculated

- Excess Ultrasonic Velocity

$$U^E = U_{(mix)} - \left[ (1 - x) U_1 + x U_2 \right] \quad (1)$$

- Excess Viscosity

$$\eta^E = \eta_{(mix)} - \left[ (1 - x) \eta_1 + x \eta_2 \right] \quad (2)$$

- Excess Adiabatic Compressibility

$$\beta_{ad}{}^E = \beta_{ad(mix)} - \left[ (1 - x) \beta_{ad1} + x \beta_{ad2} \right] \quad (3)$$

- Excess Intermolecular Free Length

$$L_f^E = L_{f(mix)} - \left[ (1 - x) L_{f1} + x L_{f2} \right] \quad (4)$$

❖ Excess Acoustic Impedance

$$Z^E = Z_{(mix)} - \left[(1-x)Z_1 + xZ_2\right] \quad (5)$$

❖ Excess Molar Volume

$$V_m^E = V_{m(mix)} - \left[(1-x)V_{m1} + xV_{m2}\right] \quad (6)$$

❖ Excess Free Volume

$$V_f^E = V_{f(mix)} - \left[(1-x)V_{f1} + xV_{f2}\right] \quad (7)$$

❖ Excess Internal Pressure

$$\pi_i^E = \pi_{i(mix)} - \left[(1-x)\pi_{i1} + x\pi_{i2}\right] \quad (8)$$

Where, $x$ represents mole fraction of the component and subscript 1 and 2 stands for components 1 & 2.

The excess properties were fitted to a Redlich, Kister-type polynomial equation

$$Y^E = x_1 x_2 \sum_{i=0}^{j} A_i (1-2x_1)^i \quad (9)$$

The optimum number of coefficients, j, was ascertained from an examination of the variation of the standard deviation σ. The values of coefficients, *Ai*, were evaluated by using the method of least squares, with all points weighted equally.

$$\sigma = \left[\left(\Sigma\{Y_{exp} - Y_{cal}\}^2\right)/(N-n)\right]^{1/2} \quad (10)$$

**Table 3**: Values of Ultrasonic Velocity (U), Density (ρ), Adiabatic Compressibility (βad), Intermolecular Free Length (Lf), Acoustical Impedance (Z), Molar Volume (Vm), Rao's Constant (R),Wada's constant (W), Available Volume (Va), Degree of Molecular Interaction (χu) at temperatures ( 303.15,308.15,313.15,318.15)K for molefraction Tetrachloroethylene with Nitrobenzene.

| X1 | U m.s-1 | ρ Kg.m-3 | βad. $10^{-10}$ m2.N-1 | Lf x $10^{-10}$ m | Z x$10^6$ Kg.m$^2$.s$^{-1}$ | R ×$10^{-3}$ m10/3 s-1/3 mol-1 | W ×$10^{-1}$ (m3/mol-1) (N/m2)1/7 | Vm ×$10^{-6}$ m3/mol-1 | Va ×$10^{-6}$ m3/mol-1 | χu ×$10^{-2}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 303.15 K | | | | | | | | | | |
| 0.0000 | 1028.70 | 1606.34 | 5.8828 | 0.5032 | 1.6524 | 3.5910 | 5.9499 | 76.6400 | 2.7365 | 0.0000 |
| 0.0993 | 1110.65 | 1501.84 | 5.3978 | 0.4820 | 1.6680 | 4.0761 | 6.6647 | 84.7985 | 2.5935 | 0.0799 |
| 0.2161 | 1202.64 | 1389.3 | 4.9765 | 0.4628 | 1.6708 | 4.7020 | 7.5743 | 95.2593 | 2.3657 | 0.1615 |
| 0.3554 | 1247.14 | 1337.67 | 4.8064 | 0.4549 | 1.6682 | 5.1653 | 8.2614 | 103.3852 | 2.2800 | 0.1322 |
| 0.5244 | 1318.79 | 1296.8 | 4.4337 | 0.4369 | 1.7102 | 5.7116 | 9.0707 | 112.2116 | 1.9721 | 0.1307 |
| 0.7338 | 1374.39 | 1247.64 | 4.2431 | 0.4274 | 1.7147 | 6.3889 | 10.0706 | 123.8022 | 1.7456 | 0.0765 |
| 1.0000 | 1431.97 | 1193.3 | 4.0867 | 0.4194 | 1.7087 | 7.2703 | 11.3650 | 138.9675 | 1.4594 | 0.0000 |
| 308.15 K | | | | | | | | | | |
| 0.0000 | 1007.80 | 1597.72 | 6.1624 | 0.5200 | 1.6101 | 3.5857 | 5.9425 | 77.0535 | 2.8519 | 0.0000 |
| 0.0993 | 1095.04 | 1494.42 | 5.5804 | 0.4949 | 1.6364 | 4.0771 | 6.6662 | 85.2208 | 2.6895 | 0.0900 |
| 0.2161 | 1186.20 | 1382.01 | 5.1424 | 0.4750 | 1.6393 | 4.7053 | 7.5789 | 95.7644 | 2.4767 | 0.1689 |
| 0.3554 | 1257.23 | 1331.62 | 4.7510 | 0.4566 | 1.6741 | 5.2029 | 8.3130 | 103.8585 | 2.2249 | 0.1855 |
| 0.5244 | 1301.73 | 1291.07 | 4.5709 | 0.4479 | 1.6806 | 5.7123 | 9.0717 | 112.71380 | 2.1011 | 0.1300 |
| 0.7338 | 1357.08 | 1242.28 | 4.37088 | 0.4379 | 1.6858 | 6.3896 | 10.0716 | 124.3398 | 1.8877 | 0.0715 |
| 1.0000 | 1420.89 | 1187.49 | 4.1710 | 0.4278 | 1.6872 | 7.2870 | 11.3874 | 139.6474 | 1.5632 | 0.0000 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 313.15 K | | | | | | | | | | |
| 0.0000 | 993.00 | 1589.35 | 6.3809 | 5.3425 | 1.5782 | 3.5869 | 5.9441 | 77.4593 | 2.9386 | 0.0000 |
| 0.0993 | 1079.51 | 1486.96 | 5.7709 | 5.0808 | 1.6051 | 4.0782 | 6.6678 | 85.6511 | 2.7862 | 0.0903 |
| 0.2161 | 1169.71 | 1374.49 | 5.3174 | 4.8770 | 1.6077 | 4.7093 | 7.5845 | 96.2939 | 2.5896 | 0.1691 |
| 0.3554 | 1240.46 | 1325.57 | 4.9026 | 4.6830 | 1.6443 | 5.2037 | 8.3141 | 104.3404 | 2.3446 | 0.1861 |
| 0.5244 | 1284.69 | 1285.33 | 4.7139 | 4.5920 | 1.6512 | 5.7131 | 9.0729 | 113.2260 | 2.2313 | 0.1303 |
| 0.7338 | 1339.79 | 1236.91 | 4.5038 | 4.4885 | 1.6571 | 6.3904 | 10.0727 | 124.8868 | 2.0310 | 0.0717 |
| 1.0000 | 1403.24 | 1182.53 | 4.2946 | 4.3830 | 1.6593 | 7.2872 | 11.3876 | 140.2332 | 1.7245 | 0.0000 |
| 318.15 K | | | | | | | | | | |
| 0.0000 | 978.26 | 1580.9 | 6.6097 | 5.4889 | 1.5465 | 3.5881 | 5.9459 | 77.8733 | 3.0260 | 0.0000 |
| 0.0993 | 1064.17 | 1479.34 | 5.9691 | 5.2161 | 1.5742 | 4.0798 | 6.6701 | 86.0952 | 2.8832 | 0.0909 |
| 0.2161 | 1153.71 | 1365.96 | 5.5000 | 5.0070 | 1.5759 | 4.7173 | 7.5955 | 96.9011 | 2.7028 | 0.1701 |
| 0.3554 | 1223.74 | 1319.49 | 5.0607 | 4.8029 | 1.6147 | 5.2045 | 8.3153 | 104.8294 | 2.4651 | 0.1867 |
| 0.5244 | 1267.73 | 1279.59 | 4.8626 | 4.7079 | 1.6221 | 5.7139 | 9.0740 | 113.7430 | 2.3620 | 0.1306 |
| 0.7338 | 1322.51 | 1231.54 | 4.6425 | 4.6001 | 1.6287 | 6.3909 | 10.0735 | 125.4388 | 2.1755 | 0.0717 |
| 1.0000 | 1385.72 | 1177.54 | 4.4225 | 4.4898 | 1.6317 | 7.2875 | 11.3880 | 140.8274 | 1.8860 | 0.0000 |

**Table 4**: Values of Viscosity (*η*), Free Volume ($V_f$), Relaxation Time (*τ*), Internal Pressure (*π*), Gibb's Free Energy (*ΔG*), Enthalpy (*H*), Classical Absorption coefficient ($\alpha/f^2$), Ultrasonic Attenuation (*α*) at temperatures( 303.15,308.15,313.15,318.15)K for molefraction Tetrachloroethylene with Nitrobenzene.

| X | $\eta \times 10^{-3}$ $NSm^{-2}$ | $V_f \times 10^{-7}$ $m^3mol^{-1}$ | $\tau$ x $10^{-12}$ sec | $\pi \times 10^6$ $Nm^{-2}$ | $\Delta G$ x $10^{-20}$ K J $mol^{-1}$ | H x $10^{-3}$ J $mol^{-1}$ | $\alpha/f^2$ x $10^{14}$ $m^{-1}s^2$ | α Neper/m |
|---|---|---|---|---|---|---|---|---|
| 303.15 K | | | | | | | | |
| 0.0000 | 0.7972 | 2.2613 | 0.6251 | 458.5863 | 0.1077 | 35.1460 | 3.6709 | 48.0211 |
| 0.0993 | 0.9981 | 1.9048 | 0.7182 | 453.9051 | 0.1082 | 38.4905 | 5.4088 | 51.1038 |
| 0.2161 | 1.1911 | 1.7441 | 0.7902 | 432.5652 | 0.1085 | 41.2058 | 7.5811 | 51.9262 |
| 0.3554 | 1.3540 | 1.6230 | 0.8677 | 419.5296 | 0.1089 | 43.3731 | 9.2540 | 54.9796 |
| 0.5244 | 1.4511 | 1.7171 | 0.8577 | 389.8390 | 0.1088 | 43.7444 | 11.3680 | 51.3979 |
| 0.7338 | 1.5863 | 1.7483 | 0.8972 | 362.9293 | 0.1090 | 44.9314 | 13.5313 | 51.5895 |
| 1.0000 | 1.6194 | 2.0054 | 0.8822 | 320.9983 | 0.1090 | 44.6083 | 14.9422 | 48.6825 |
| 308.15 K | | | | | | | | |
| 0.0000 | 0.7562 | 2.3732 | 0.6211 | 457.0427 | 0.1095 | 35.2167 | 3.2565 | 48.7052 |
| 0.0993 | 0.9433 | 2.0304 | 0.7016 | 450.1863 | 0.1099 | 38.3652 | 4.8740 | 50.6322 |
| 0.2161 | 1.1165 | 1.8836 | 0.7652 | 427.0553 | 0.1103 | 40.8967 | 6.7805 | 50.9750 |
| 0.3554 | 1.2590 | 1.8323 | 0.7975 | 408.3106 | 0.1104 | 42.4065 | 8.7754 | 50.1278 |
| 0.5244 | 1.3484 | 1.8806 | 0.8215 | 383.2902 | 0.1105 | 43.2021 | 10.1116 | 49.8718 |
| 0.7338 | 1.4682 | 1.9263 | 0.8555 | 356.1477 | 0.1107 | 44.2833 | 12.0054 | 49.8159 |
| 1.0000 | 1.6010 | 2.0157 | 0.8903 | 324.6783 | 0.1108 | 45.3405 | 14.3654 | 49.5174 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 313.15 K | | | | | | | | |
| 0.0000 | 0.732 | 2.4365 | 0.6227 | 458.8106 | 0.1113 | 35.5391 | 3.0005 | 49.5589 |
| 0.0993 | 0.894 | 2.1531 | 0.6878 | 447.12810 | 0.1117 | 38.2970 | 4.4048 | 50.3542 |
| 0.2161 | 1.05 | 2.0212 | 0.7444 | 422.3451 | 0.1120 | 40.6692 | 6.0839 | 50.2910 |
| 0.3554 | 1.178 | 1.9843 | 0.7700 | 402.8097 | 0.1122 | 42.0293 | 7.8508 | 49.0537 |
| 0.5244 | 1.257 | 2.0479 | 0.7900 | 377.4612 | 0.1122 | 42.7384 | 9.0232 | 48.5963 |
| 0.7338 | 1.365 | 2.1077 | 0.8197 | 350.2068 | 0.1124 | 43.7362 | 10.6954 | 48.3462 |
| 1.0000 | 1.461 | 2.2693 | 0.8365 | 316.2826 | 0.1125 | 44.3533 | 12.5740 | 47.11076 |
| 318.15 K | | | | | | | | |
| 0.0000 | 0.711 | 2.4888 | 0.6266 | 461.2074 | 0.1132 | 35.9157 | 2.7712 | 50.6151 |
| 0.0993 | 0.85 | 2.2732 | 0.6764 | 444.5859 | 0.1135 | 38.2767 | 3.9915 | 50.2337 |
| 0.2161 | 0.99 | 2.1628 | 0.7260 | 417.7609 | 0.1138 | 40.4815 | 5.4699 | 49.7261 |
| 0.3554 | 1.104 | 2.1433 | 0.7449 | 397.6194 | 0.1139 | 41.6822 | 7.0317 | 48.1031 |
| 0.5244 | 1.176 | 2.2187 | 0.7624 | 372.2519 | 0.1140 | 42.3410 | 8.0756 | 47.5263 |
| 0.7338 | 1.273 | 2.2954 | 0.7879 | 344.8109 | 0.1141 | 43.2526 | 9.5519 | 47.0826 |
| 1.0000 | 1.359 | 2.4823 | 0.8013 | 310.9878 | 0.1142 | 43.7956 | 11.2160 | 45.6978 |

**Table 5**: Excess Acoustic and Thermodynamic parameters of Ultrasonic Velocity ($U^E$), Adiabatic Compressibility ($\beta_{ad}^E$), Intermolecular Free Length ($L_f^E$), Acoustical Impedance ($Z^E$), Molar Volume ($V_m^E$), Available Volume ($V_a^E$), Viscosity ($\Delta\eta$), Free Volume ($V_f^E$), Internal Pressure ($\pi^E$), Enthalpy ($H^E$), Gibb's Free Energy ($\Delta G^E$) at temperatures (303.15, 308.15,313.15,318.15)K for mole fraction Tetrachloroethylene with Nitrobenzene.

| X | $U^E$ m/sec | $\beta_{ad}^E$ X$10^{-10}$ $N^{-1}ms^2$ | $L_f^E$ X$10^{-10}$ m | $Z^E$ X$10^6$ $Kgm^2 s^{-1}$ | $V_m^E$ X$10^{-6}$ $m^3/mol^{-1}$ | $V_a^E$ X$10^{-6}$ $m^3/mol^{-1}$ | $\Delta\eta$ X $10^{-3}$ $NSm^{-2}$ | $V_f^E$ X$10^{-7}$ $m^3/mol^{-1}$ | $\pi^E$ X$10^6$ $N/m^2$ | $H^E$ X$10^{-3}$ J/mol | $\Delta G^E$ X$10^{-20}$ J/mol |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 303.15K | | | | | | | | | | | |
| 0.0000 | 0.0000 | 6.1136 | 0.000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0993 | 46.2365 | 5.9497 | -0.1512 | 0.0199 | 1.9667 | -0.0161 | 0.1234 | -0.3529 | 9.3217 | 2.4044 | 0.0049 |
| 0.2161 | 89.4578 | 5.8439 | -0.2414 | 0.0332 | 5.1473 | -0.0947 | 0.2343 | -0.4759 | 2.9834 | 4.0145 | 0.0085 |
| 0.3554 | 101.0125 | 5.7667 | -0.2944 | 0.0382 | 4.5901 | -0.0025 | 0.2758 | -0.4632 | 2.6243 | 4.8636 | 0.0094 |
| 0.5244 | 83.9636 | 5.6954 | -0.2240 | 0.0328 | 2.8816 | -0.0945 | 0.2254 | -0.3623 | -1.2321 | 3.9624 | 0.0082 |
| 0.7338 | 45.7954 | 5.6448 | -0.1435 | 0.0209 | 1.4222 | -0.0536 | 0.1175 | -0.1945 | -0.1245 | 2.1123 | 0.0049 |
| 1.0000 | 0.0000 | 5.5913 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 308.15K | | | | | | | | | | | |
| -0.0000 | 0.0000 | 6.1979 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0993 | 46.1843 | 6.0365 | -0.1600 | 0.0223 | 1.9463 | -0.0342 | 0.1104 | -0.3075 | 6.2988 | 2.1423 | 0.0048 |
| 0.2161 | 89.0771 | 5.9125 | -0.2504 | 0.0366 | 5.1761 | -0.0965 | 0.2087 | -0.4346 | -1.3660 | 3.6124 | 0.0080 |
| 0.3554 | 102.5453 | 5.8376 | -0.3063 | 0.0408 | 4.5481 | -0.1687 | 0.2514 | -0.4325 | -1.6665 | 4.2369 | 0.0088 |
| 0.5244 | 84.5245 | 5.7701 | -0.2379 | 0.0354 | 2.8227 | -0.0746 | 0.1975 | -0.3321 | -4.3125 | 3.2874 | 0.0076 |
| 0.7338 | 46.0877 | 5.7113 | -0.1440 | 0.0235 | 1.3446 | -0.0183 | 0.1045 | -0.1845 | -2.2432 | 1.7245 | 0.0044 |
| 1.0000 | 0.0000 | 5.6535 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 313.15K | | | | | | | | | | | |
| 0.0000 | 0.0000 | 6.2597 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0993 | 45.6984 | 6.1097 | -0.1663 | 0.0256 | 1.9469 | -0.0315 | 0.0894 | -0.2668 | 2.4964 | 1.8810 | 0.0044 |
| 0.2161 | 87.9292 | 5.9852 | -0.2578 | 0.0405 | 5.2496 | -0.0862 | 0.1602 | -0.3914 | -5.6207 | 3.2226 | 0.0078 |
| 0.3554 | 101.4884 | 5.8982 | -0.3181 | 0.0452 | 4.5449 | -0.1619 | 0.1904 | -0.3927 | -5.2865 | 3.6589 | 0.0082 |
| 0.5244 | 83.5254 | 5.8314 | -0.2468 | 0.0386 | 2.8180 | -0.0700 | 0.1457 | -0.3001 | -6.5396 | 2.8297 | 0.0069 |
| 0.7338 | 45.6040 | 5.7698 | -0.1495 | 0.0263 | 1.3407 | -0.0162 | 0.0804 | -0.1755 | -3.9639 | 1.3654 | 0.0039 |
| 1.0000 | 0.0000 | 5.7188 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 318.15K | | | | | | | | | | | |
| 0.0000 | 0.0000 | 6.3463 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0993 | 45.3347 | 6.1874 | -0.1733 | 0.0296 | 1.9434 | -0.0292 | 0.0744 | -0.2149 | -1.6625 | 1.5762 | 0.0041 |
| 0.2161 | 87.1947 | 6.0664 | -0.2655 | 0.0453 | 5.2345 | -0.0762 | 0.1386 | -0.3458 | -10.9091 | 2.8589 | 0.0072 |
| 0.3554 | 100.3946 | 5.9659 | -0.3303 | 0.0493 | 4.5332 | -0.1549 | 0.1692 | -0.3431 | -10.0989 | 3.1254 | 0.0078 |
| 0.5244 | 83.8987 | 5.8973 | -0.2563 | 0.0423 | 2.8645 | -0.0652 | 0.1313 | -0.2666 | -10.0673 | 2.3123 | 0.0062 |
| 0.7338 | 45.0174 | 5.8359 | -0.1550 | 0.0288 | 1.3123 | -0.0133 | 0.0713 | -0.1725 | -6.0774 | 1.1124 | 0.0033 |
| 1.0000 | 0.0000 | 5.7841 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

**Table 6:** Experimental and Theoretical values of Ultrasonic velocity at temperatures (303.15, 308.15, 313.15, 318.15) K for molefraction Tetrachloroethylene with Nitrobenzene

| Mole Fraction *X* | $U_{EXP}$ $ms^{-1}$ | $U_J$ $ms^{-1}$ | $U_{NOM}$ $ms^{-1}$ | $U_{FLT}$ $ms^{-1}$ | $U_{IDR}$ $ms^{-1}$ | $U_{IMR}$ $ms^{-1}$ | $U_{RAO}$ $ms^{-1}$ |
|---|---|---|---|---|---|---|---|
| 303.15 K | | | | | | | |
| 0.0000 | 1028.70 | 1028.70 | 1.0287 | 102.87 | 1028.70 | 1028.70 | 1028.70 |
| 0.0993 | 1110.65 | 1079.29 | 1.0898 | 100.03 | 1059.24 | 1043.90 | 973.15 |
| 0.2161 | 1202.64 | 1135.14 | 1.1533 | 93.81 | 1097.26 | 1065.75 | 907.07 |
| 0.3554 | 1247.14 | 1197.12 | 1.2192 | 98.11 | 1145.89 | 1098.45 | 973.09 |
| 0.5244 | 1318.79 | 1266.30 | 1.2876 | 107.91 | 1210.31 | 1150.42 | 1092.61 |
| 0.7338 | 1374.39 | 1344.01 | 1.3585 | 121.03 | 1299.68 | 1241.40 | 1237.10 |
| 1.0000 | 1431.97 | 1431.97 | 1.4319 | 143.19 | 1431.97 | 1431.97 | 1431.97 |
| 308.15 K | | | | | | | |
| 0.0000 | 1007.80 | 1007.80 | 1.0078 | 100.78 | 1007.8 | 1007.8 | 1007.8 |
| 0.0993 | 1095.04 | 1058.99 | 1.07018 | 98.45 | 1039.11 | 1023.22 | 956.20 |
| 0.2161 | 1186.2 | 1115.70 | 1.13507 | 92.76 | 1078.09 | 1045.38 | 892.00 |
| 0.3554 | 1257.23 | 1178.90 | 1.2025 | 97.40 | 1127.93 | 1078.54 | 960.78 |
| 0.5244 | 1301.73 | 1249.75 | 1.2726 | 107.29 | 1193.94 | 1131.34 | 1081.21 |
| 0.7338 | 1357.08 | 1329.77 | 1.3454 | 120.60 | 1285.47 | 1224.18 | 1227.10 |
| 1.0000 | 1420.89 | 1420.89 | 1.4208 | 142.08 | 1420.89 | 1420.89 | 1420.89 |
| 313.15 K | | | | | | | |
| 0.0000 | 993.00 | 993.00 | 0.9930 | 99.30 | 993.00 | 993.00 | 993.00 |
| 0.0993 | 1079.51 | 1043.72 | 1.0549 | 97.30 | 1024.15 | 1008.30 | 942.86 |
| 0.2161 | 1169.71 | 1099.94 | 1.1193 | 91.99 | 1062.92 | 1030.28 | 878.35 |
| 0.3554 | 1240.46 | 1162.64 | 1.1863 | 96.97 | 1112.49 | 1063.18 | 948.57 |
| 0.5244 | 1284.69 | 1233.01 | 1.2559 | 106.84 | 1178.07 | 1115.56 | 1067.62 |
| 0.7338 | 1339.79 | 1312.56 | 1.3282 | 119.94 | 1268.94 | 1207.72 | 1211.82 |
| 1.0000 | 1403.24 | 1403.24 | 1.4032 | 140.32 | 1403.24 | 1403.24 | 1403.24 |
| 318.15K | | | | | | | |
| 0.0000 | 978.26 | 978.26 | 0.9782 | 97.82 | 978.26 | 978.26 | 978.26 |
| 0.0993 | 1064.17 | 1028.51 | 1.0285 | 96.13 | 1009.27 | 993.45 | 929.42 |
| 0.2161 | 1153.71 | 1084.26 | 1.0842 | 91.02 | 1047.84 | 1015.25 | 862.98 |
| 0.3554 | 1223.74 | 1146.47 | 1.1464 | 96.47 | 1097.12 | 1047.89 | 936.46 |
| 0.5244 | 1267.73 | 1216.35 | 1.2163 | 106.30 | 1162.30 | 1099.87 | 1054.22 |
| 0.7338 | 1322.51 | 1295.44 | 1.2954 | 119.18 | 1252.53 | 1191.35 | 1196.75 |
| 1.0000 | 1385.72 | 1385.72 | 1.3857 | 138.572 | 1385.72 | 1385.72 | 1385.72 |

**Table 7:** Percentage deviation between Experimental and Theoretical values of Ultrasonic velocity at temperatures (303.15, 308.15, 313.15, 318.15) K for mole fraction Tetrachloroethylene with Nitrobenzene

| Mole Fraction *X* | $\%U_{NOM}$ | $\%U_{J}$ | $\%U_{IDR}$ | $\%U_{FLT}$ | $\%U_{IMR}$ | $\%U_{RAO}$ | $U^2_{exp}/ U^2_{imx}$ |
|---|---|---|---|---|---|---|---|
| 303.15 K | | | | | | | |
| 0.0000 | 0.0000 | -2.2103 | 0.0000 | -90.0000 | 0.0000 | -2.2103 | 1.0000 |
| 0.0993 | 0.2046 | -2.8231 | -4.6287 | -90.9934 | -6.0094 | -12.3798 | 1.1319 |
| 0.2161 | 0.3180 | -5.6120 | -8.7621 | -92.1988 | -11.3818 | -24.5767 | 1.2733 |
| 0.3554 | 0.3557 | -4.0102 | -8.1177 | -92.1327 | -11.9219 | -21.9740 | 1.2890 |
| 0.5244 | 0.3047 | -3.9798 | -8.2251 | -91.8170 | -12.7663 | -17.1500 | 1.3141 |
| 0.7338 | 0.1823 | -2.2097 | -5.4356 | -91.1933 | -9.6756 | -9.9886 | 1.2257 |
| 1.0000 | 0.0000 | -1.5878 | 0.0000 | -90.0000 | 0.0000 | 3.1756 | 1.0000 |
| 308.15 K | | | | | | | |
| 0.0000 | 1.0078 | 0.0000 | 1.1280 | -90.0000 | 0.0000 | 4.5122 | 1.0000 |
| 0.0993 | 1.0701 | -3.2918 | -5.1072 | -91.0093 | -6.5579 | -12.6789 | 1.1452 |
| 0.2161 | 1.1350 | -5.9425 | -9.1139 | -92.1794 | -11.8714 | -24.8013 | 1.2875 |
| 0.3554 | 1.2025 | -6.2302 | -10.2838 | -92.2522 | -14.2128 | -23.5792 | 1.3587 |
| 0.5244 | 1.2726 | -3.9925 | -8.2803 | -91.7573 | -13.0893 | -16.9402 | 1.3238 |
| 0.7338 | 1.3454 | -2.0117 | -5.2765 | -91.1126 | -9.7925 | -9.5775 | 1.2288 |
| 1.0000 | 1.4208 | 0.0000 | 0.0000 | -90.0000 | 0.0000 | -8.0014 | 1.0000 |
| 313.15K | | | | | | | |
| 0.0000 | 0.993 | -2.2897 | 0.0000 | -90.0000 | -1.1448 | -1.1448 | 5.3425 |
| 0.0993 | 1.0549 | -3.3153 | -5.1274 | -90.9868 | -6.5956 | -12.6577 | 5.6365 |
| 0.2161 | 1.1193 | -5.9638 | -9.1287 | -92.1354 | -11.9194 | -24.9083 | 6.2013 |
| 0.3554 | 1.1863 | -6.2727 | -10.3162 | -92.1822 | -14.2911 | -23.5305 | 5.9902 |
| 0.5244 | 1.2559 | -4.0225 | -8.2989 | -91.6831 | -13.1643 | -16.8965 | 5.5213 |
| 0.7338 | 1.3282 | -2.0323 | -5.2874 | -91.0471 | -9.8570 | -9.5513 | 5.0136 |
| 1.0000 | 1.4032 | 1.6203 | 0.0000 | -90.0000 | 1.6203 | -1.6203 | 4.3830 |
| 318.15K | | | | | | | |
| 0.0000 | 0.0785 | 1.1621 | -1.1621 | -90.0000 | -1.1621 | -8.1349 | 1.0000 |
| 0.0993 | 1.0014 | -3.3508 | -5.1588 | -90.9666 | -6.6453 | -12.6622 | 1.1474 |
| 0.2161 | 1.1500 | -6.0195 | -9.1762 | -92.1103 | -12.0006 | -25.1945 | 1.2913 |
| 0.3554 | 1.2000 | -6.3138 | -10.3464 | -92.1167 | -14.3694 | -23.4749 | 1.3637 |
| 0.5244 | 1.2226 | -4.0521 | -8.3162 | -91.6144 | -13.2408 | -16.8418 | 1.3285 |
| 0.7338 | 1.2745 | -2.0462 | -5.2900 | -90.9879 | -9.9172 | -9.5091 | 1.2323 |
| 1.0000 | 1.3208 | 0.0000 | 0.0000 | -90.0000 | 0.0000 | -3.2816 | 1.0000 |

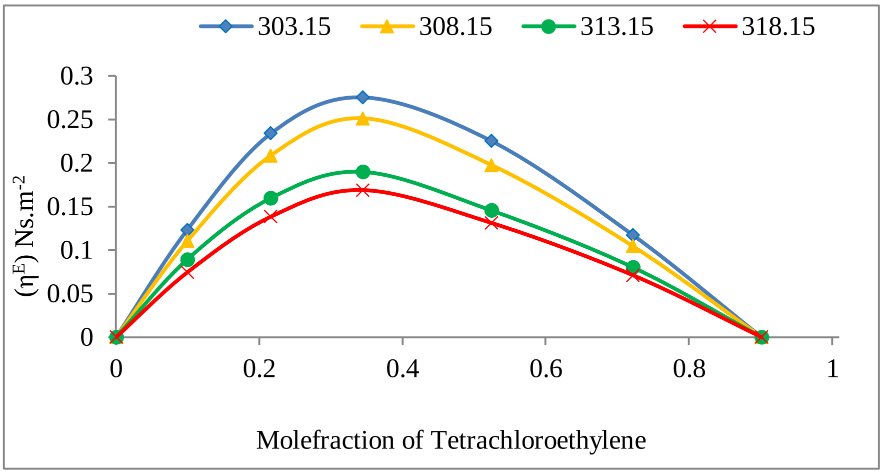


Fig.1. Variation of Excess Viscosity with molefraction of Tetrachloroethylene + Nitrobenzene.

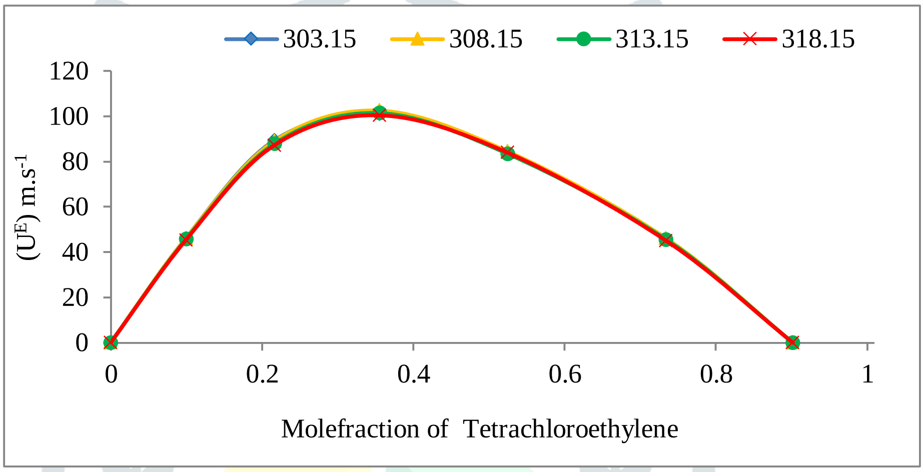


Fig.2. Variation of Excess Velocity with molefraction of Tetrachloroethylene + Nitrobenzene.

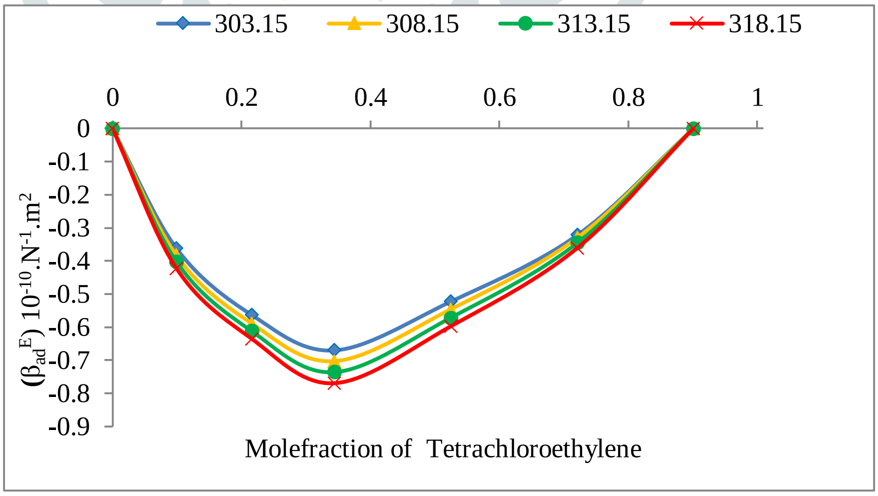


Fig.3. Variation of Excess Adiabatic compressibility with molefraction of Tetrachloroethylene + Nitrobenzene

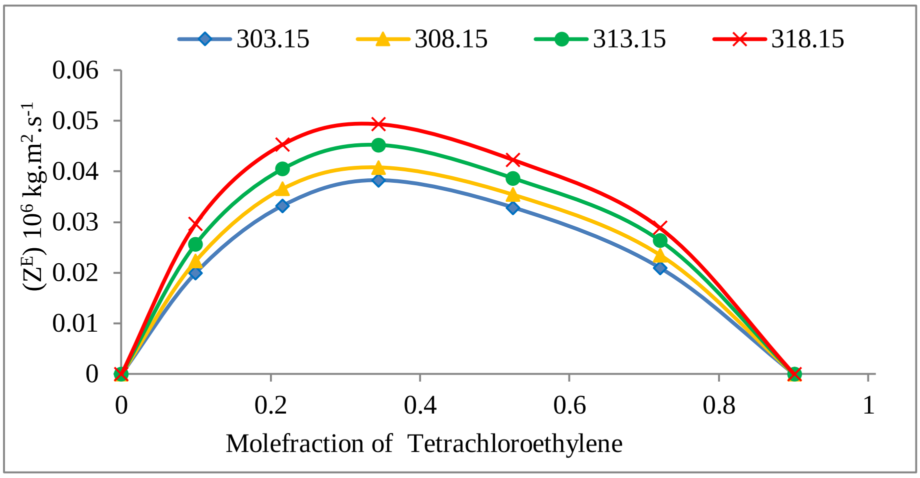


Fig.4. Variation of Excess Acoustic impedance with molefraction of Tetrachloroethylene + Nitrobenzene

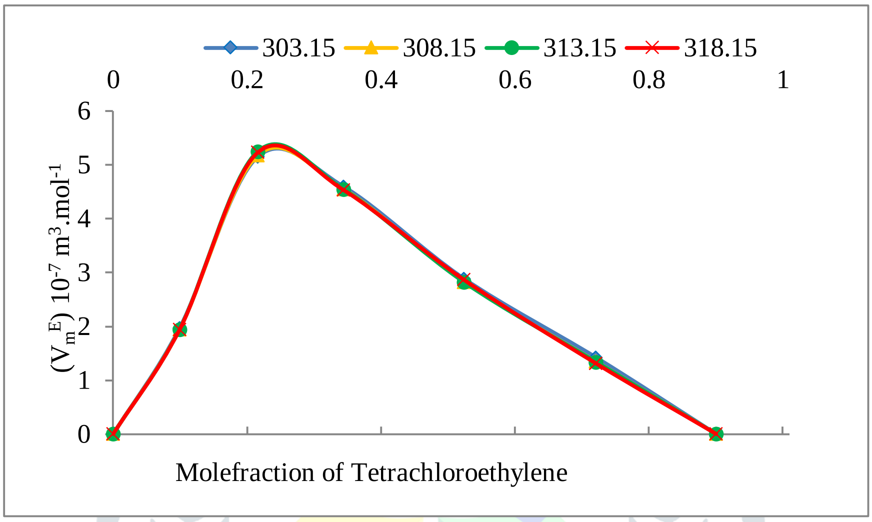


Fig.5. Variation of Excess molar volume with molefraction Tetrachloroethylene +Nitrobenzene

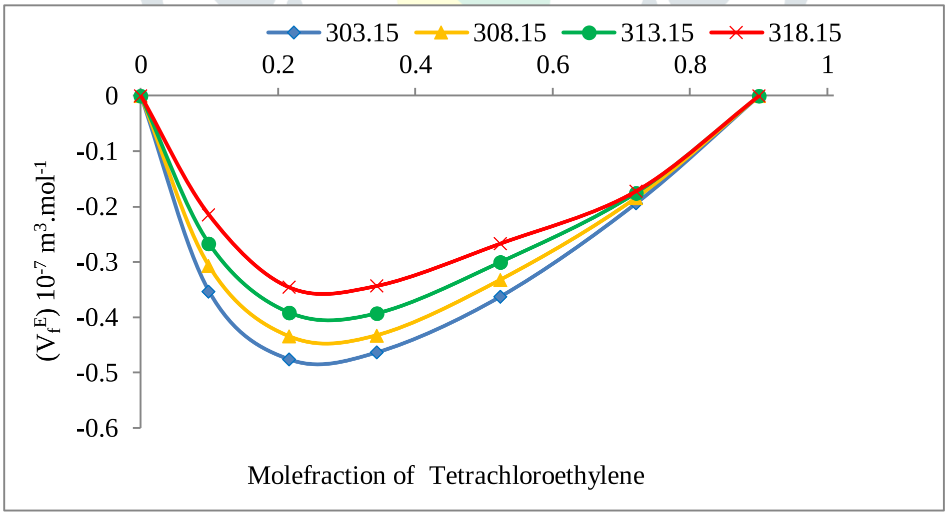


Fig.6. Variation of Excess Acoustic impedance with molefraction of Tetrachloroethylene +Nitrobenzene

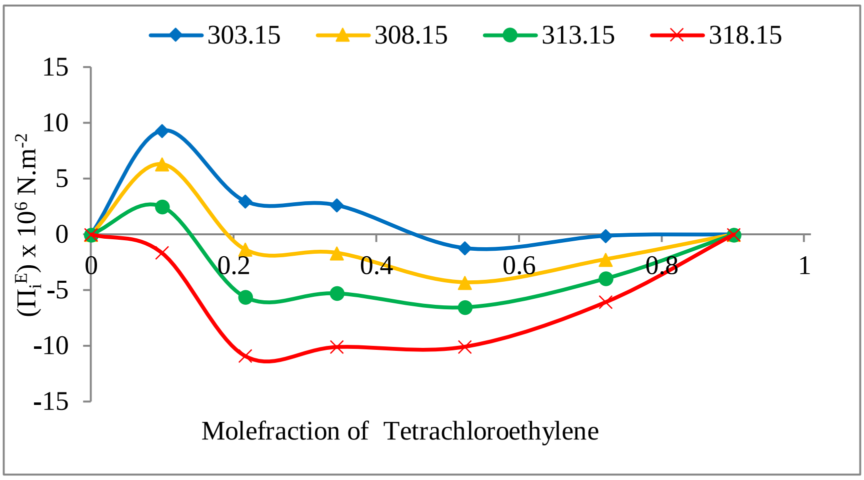


Fig.7. Variation of Excess Internal pressure with molefraction of Tetrachloroethylene +Nitrobenzene

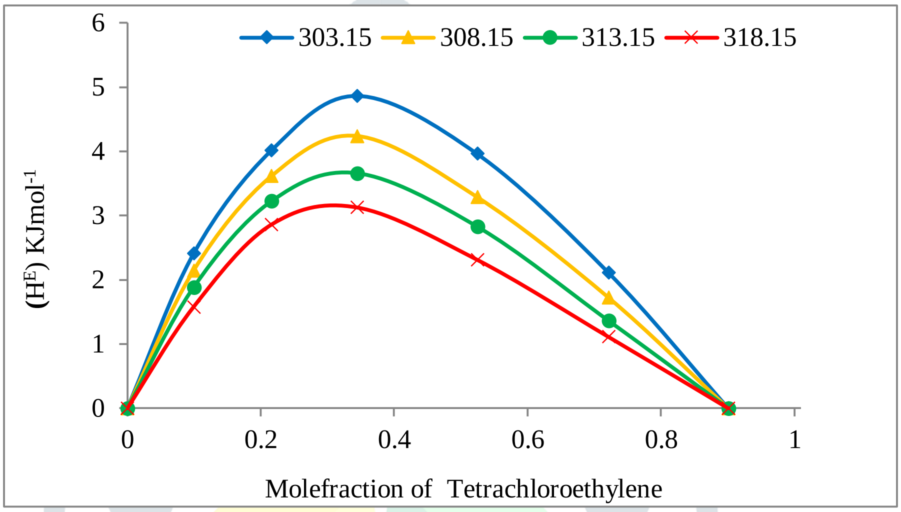


Fig.8. Variation of Excess Enthalpy with molefraction of Tetrachloroethylene +Nitrobenzene.

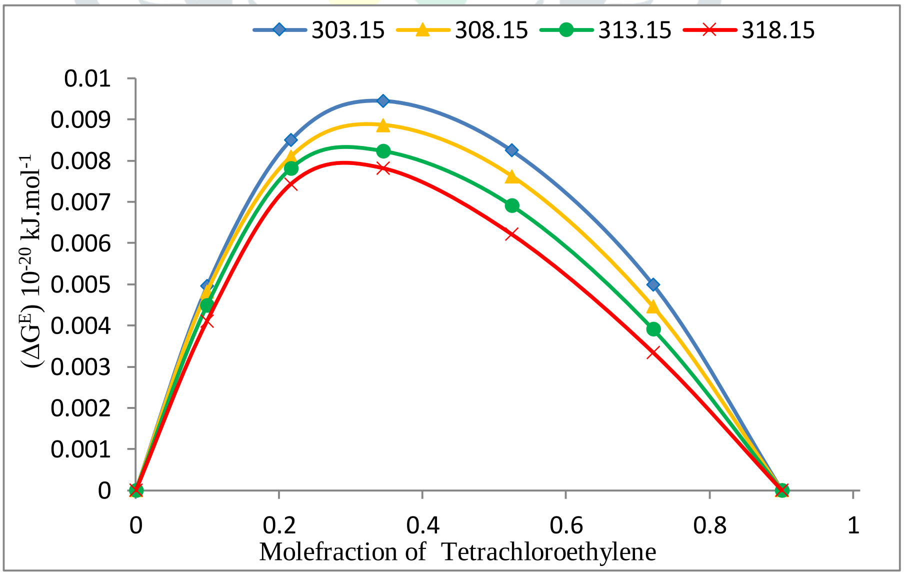


Fig.9. Variation of Excess Gibb's Free Energy with molefraction of Tetrachloroethylene +Nitrobenze

## III. Result and discussions:

The experimentally measured values of Density (ρ), Ultrasonic velocity (U), Viscosity (η) and thermodynamic parameters like adiabatic compressibility (βad), Intermolecular free length ($L_f$), Acoustic impedance (Z), Molar volume ($V_m$), Rao's Constant (R), Wada's constant (W), Internal pressure (π) and Free volume ($V_f$) of with nitrobenzene binary liquid system at different temperatures over the whole concentration of Tetrachloroethylene with Nitrobenzene are presented in table-2 shows us ultrasonic velocity decreases with increase in the concentration of Tetrachloroethylene and decreases with increase in temperature[15-18]. The decrease in velocity is perhaps due to structural changes occurring in the mixtures resulting in weakening of intermolecular forces. Further the ultrasonic velocity decreases with increase in temperature at any concentrations as rise in temperature leads to less disordered structure and more spacing between the molecules. Also Density increases with increasing the concentration tetrachloroethylene of and it decreases with increasing the temperature. It suggests that a solute-solvent interaction exist between Tetachloroethylene and Nitrobenzene system. In other words the decrease in density may be interpreted to the structure maker of the solvent due to H-bonding.

The induced dipole moment that creates induced dipole–induced dipole force of attraction between pair of atoms. This type of interaction is weaker which is given by the least ultrasonic velocity[19]. From the Table-2, the adiabatic compressibility and free length decreases with increasing mole fraction of the Tetrachloroetyhlene and increases with increasing temperature. Which suggest that making and breaking of H- bonding between molecules of the system[20-22]. The intermolecular free length depends upon the intermolecular attractive and repulsive forces. Eyring and Kincaid have proposed that $L_f$ is a predominating factor in determining the variation of ultrasonic velocity of solution. Hence it can be concluded that there is significant interaction between solute and solvent molecules due to which the structural arrangement is also affected. From the above parameters it is clear that there is a strong association between and Nitrobenzene system.

The acoustic impedance (Z) (which is the product of ultrasonic velocity and density of the solution) increases with increase in concentration of Tetrachloroethylene. It represents that there is strong interaction between the Tetrachloroethylene and Nitrobenzene system. In this system, viscosity increases with increasing molefraction of Tetrachloroethylene and decreases with increasing temperature. The decrease in density and viscosity with temperature indicates that decrease in intermolecular forces due to increase in thermal energy of the system, which cause increase in volume expansion and hence increase in free length.

The table-3 parameters investigation of Viscosity increases with concentration of Tetrachloroethylene confirms that increase of cohesive forces because of strong interaction[23-25].The internal pressure decreases with increasing mole fraction of Tetrachloroethylene. The reduction in internal pressure may be due to the loosening of cohesive forces and adhesive force leading to breaking the structure of the solution. This gives the information regarding the nature and strength of forces existing between the molecules. The free volume decreases with increase molefraction of Tetrachloroethylene. The free volume is the space available for the molecules to move in an imaginary unit cell[26-29]. It clearly indicates the existence of intermolecular interaction, due to which the structural arrangement is considerably affected. International Letters of Chemistry, Physics and Astronomy Vol. 52-55.These binary systems exhibit non-linear increase/decrease in U, $V_f$, Z and $\pi_i$ values with composition of T. This indicates the presence of intermolecular interactions between the component molecules of the mixture[30-32]. In order to substantiate the presence of interactions (either adhesive or cohesive forces) between the molecules.

Table-4 the plot of excess molar volume ($V^E$) versus molefraction ($x_1$) of Tetrachloroethylene with Nitrobenzene at T = (303.15, 308.15, 313.15, 318.15) K is represented in Fig. 5, and it is clear that the curves of excess molar volume ($V^E$) for the binary system (Tetrachloroethylene + Nitrobenzene) are positive. The observed positive values of $V^E$ over entire range of mole fraction can be attributed to the presence of specific interactions between similar molecules of the mixtures [33]. Dipole–dipole interactions and molecular complex formation between unlike molecules may be responsible for the specific interactions [34].

Tables (5, 6) shows us the positive values of deviation in ultrasonic speed (from Fig. 1), generally, indicate dispersion forces due to strong interactions [35–37]. The observed negative values of excess acoustic impedance (Fig. 4) and positive excess free length (Fig. 3) values over the entire composition range of the liquid mixtures support the variation of deviation in ultrasonic velocity as well as deviation in isentropic compressibility[38,39]. The excess enthalpies for tetrachloroethylene with nitrobenzene are positive over the entire range of mole fractions. The curves of excess molar enthalpies vs. composition vary almost symmetrically and maximum positive values are excess enthalpy decreases as the size of the tetrachloroethylene increases. The same trend is found in the results of Kiyohara et al. [40]. In general, negative $\Delta\alpha$ values indicate the presence of strong interactions, whereas, positive $\Delta\alpha$values are attributed to the weak interactions between the components in the mixtures [41].

## CONCLUSION

From the data of ultrasonic speed, density and viscosity, various acoustical parameters and their excess values for the binary liquid mixture of Tetrachloroethylene with Nitrobenzene was measured at (303.15, 308.15, 313.15and 318.15) K, it is obvious that there exist strong molecular interactions between Tetrachloroethylene and Nitrobenzene. The existence of type of molecular interactions in solute-solvent is favoured in the system, confirmed from the U, ρ, βad, $L_f$, Z, $V_m$, R, W, η, π and $V_f$ data. Weak dispersive type intermolecular interactions are confirmed in the systems investigated. The observed negative and positive values of deviation/excess properties are attributed to the dispersion forces between the unlike molecules of the mixtures. Further theoretical values of sound velocity in the mixtures have been evaluated using various theories and have been compared with experimental sound velocities to verify the applicability of such theories to the systems studied. All the experimental determinations of acoustic parameters are weakly correlated between Tetrachloroethylene with Nitrobenzene.

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## REFERENCES

[1] Wilhelm, E.: Chemical thermodynamics: a journey of many vistas. J. Solution Chem. 43, 525–576 (2014).
[2] Rowlinson, J.S., Swinton, F.L.: Liquid and Liquid Mixtures. Butterworths, London (1982)
[3] Gardas, R.L., Oswal, and S.L.: J. Solution Chem. 37, 1449–1470 (2008).
[4] Venkatramana, L., Gardas, R.L., Sivakumar, K., Dayananda Reddy, Fluid Phase Equilib. 367, 7–21 (2014)
[5] Riddick, J., Bunger, W.B., Sakano, T.K.: Techniques of Chemistry, Organic Solvents, Physical Properties and Methods of Purifications, 4th edn. Wiley Interscience, New York (1986)
[6] Timmermans, J.: Physico-Chemical Constants of Pure Organic Compounds. Elsevier, Amsterdam (1950)

[7] Ciocirlan, O., Teodorescu, M., Dragoescu, D., Iulian, O., Barhala, A.: Densities and excess molar volumes of the binary mixtures of cyclopentanone with chloroalkanes at T = (288.15, 298.15, 308.15, and 318.15) K. J. Chem. Eng. Data 55, 3891–3895 (2010)
[8] L. Venkatramana , R. L. Gardas ,C. Narasimha Rao ,K. Sivakumar , K. Dayananda Reddy . Study of the Excess Properties of Aliphatic Chlorinated Compounds with Benzyl alcohol at Various Temperatures J Solution Chem (2015) 44:327–359
[9] Hossein Iloukhan, K.Dayanada reddy and M.V Prabhakara rao. Excess volumes of homologous series of aliphatic alcohols with tetrachloroethylene at 303.15K and 313.15K. J Solution Chem (2007) 36: 691–714 DOI 10.1007/s10953-007-9143-4. Chemical Laboratories, Sri Venkateswara University, Tirupati - 517 502, Andhra Pradesh (India)
[10] Dimple Agarwal and Mukhtar Singh*. Densities and Viscosities of Binary Liquid Mixtures of Trichloroethylene and Tetrachloroethylene with Some Polar and Nonpolar Solvents Department of Chemistry, Agra College, Agra 282002, India J. Chem. Eng. Data 2004, 49, 1218-1224
[11]D. Venkatesulu, P. Venkatesu, and M. V. Prabhakara Rao* J. Chem. Eng. Data 1997, 42, 365-367Viscosities and Densities of Trichloroethylene or Tetrachloroethylene with 2-Alkoxyethanols at 303.15 K and 313.15 K. Department of Chemistry, Sri Venkateswara University, Tirupati 517 502, Andhra Pradesh, India J. Chem. Eng. Data 1997, 42, 365-367. .
[12] Thirumaran S. and Savithri S. (2010) Ultrasonic investigation in ternary liquid mixtures of substituted benzenes with acetophenone at different temperature,J. Ind. Chem.Soc, 87, 279-287.
[13] K Manapragada V. Rathnam* and Rajeev Kumar R. Singh B. N. Bandodkar College of Science, Thane 400 601, India Manapragada S. Kumar Zulal Bilajrao Pail College, Dhule 424002, India Excess Volumes of Binary Solutions of Methyl Formate, Ethyl Formate, Propyl Formate, and Benzyl Acetate with Bromo-, Chloro-, and Nitrobenzenes at (303.15, 308.15, and 313.15) J. Chem. Eng. Data 2008, 53, 265–270.
[14] Kannappan A N and Palaniappan L, Ind. J. Phy., 73(B), 531, 1999.International Letters of Chemistry, Physics and Astronomy Vol. 52 61
[15] Sadasiva Rao A, Vijayakumar Naidu B and Chawdoji Rao, J. Acous. Soc. Ind., 28, 303, 2000
[16] Bhatti S S and Singh D P, Ind. J. Pure and Appl. Phy., 21, 506, 1983
[17]D.D. Perrin, W.L.F. Armarego, Purification of Lab. Chem, thirded., Pergamon Press, Oxford, 1980
[18] M. Rastogi, A. Awasthi, M. Guptha and J. P. Shukla. Ind. J. Pure Appl. Phys., 40, 256, 2002
[19] M. Kondaiaha, and D Krishna Raob International Journal of Research in Pure and Applied Physics 2013; 3(4):49
[20] Noothi Raghuram ,Ryshetti Suresh ,Godishala Ramesh , Gangarapu Sowjanya ,Tangeda Savitha Jyostna J Therm Anal Calorim (2015) 119:2107–2117
[21] S. L. Dahire, Y. C. Morey2 and P. S. Agrawal IJETCAS 13-370; 2013
[22] Bangqing Ni, Liyan Su, Haijun Wang, and Haigang Qiu J. Chem. Eng. Data 2010, 55, 4541–4545
[23]HARISH KUMAR, DHEERAJ KUMAR and SUMAN YADAV J. Pure Appl. & Ind. Phys. Vol.2 (3), 248-263 (2012)
[24] S.Thirumaran, R. Mathammal, M.bharathi ARPN Journal of Science and Technology,VOL. 2, NO. 7, August 2012
[25] Harish Kumar and Dheeraj Kumar International Journal of Thermodynamics (IJoT) Vol. 16 (No. 3), pp. 123-131, 2013
[26] Chandra Mohan Saxena Archna Saxena and Harsh Kumar Mishra IOSR Journal of Applied Chemistry (IOSR-JAC) ISSN: 2278-5736.Volume 10, Issue 9 Ver. I (September. 2017), PP 61-64
[27] Chandra Mohan Saxena, Archna Saxena And Naveen Kumar Shukla Chemical Science 2015, 4(4), 955-960
[28] A. Ali, M. Tariq Journal of Molecular Liquids 137 (2008) 64–73
[29] Shahram Ranjbar and Seyyed Hamid Momenian J. Chem. Eng. Data 2011, 56, 3949–3954
[30] Anil Kumar Nain, Rajni Sharma ,Anwar Ali , Swarita Gopal Int J Thermophys (2010) 31:1073–1091
[31] T. E. Vittal Prasad, A. Phanibhushan, and D. H. L. Prasad Journal of Solution Chemistry, Vol. 34, No. 11, November 2005 (C 2005)
[32] M. Vranes, S. AnaPapovic, A. Tot, N. Zec, S. Gadzuric, J.Chem.Thermodyn 76 (2014) 161e171
[33] Reddy DVB, Ramanjaneyulu K, Krishnaiah A. Excess volumes of binary liquid mixtures of acetophenone with some chloroethanes And chloroethanes. Indian J Tech. 1989; 27:303–5
[34] Chansbeng Y, Peisheng MA, Qing Z. Densities, viscosities and related properties for binary mixtures of sulfolane + p-xylene, sulfolane + ethylbenzene in the temperature range from 303.15K to 353.15 K. Chin J Chem Eng. 2004; 12:537–42.
[35] A.K. Nain, Fluid Phase Equilib. 265 (2008) 46–56.
[36] A.K. Nain, J. Mol. Liq. 140 (2008) 108–116.
[37] F. Kawaizumi, M. Ohno, Y. Miyahara, Bull. Chem. Soc. Jpn. 50 (1977) 2229–2233
[38] A.M.E. Raj, L.B. Resmi, V.B. Jothy,M. Jaychandran, C. Sanjeeviraja, Fluid Phase Equilib.281 (2009) 78–86.
[39] S. Thirumaran, R. Murugan, N. Prakash, J. Chem. Pharm. Res. 2 (2010) 53–61.
[40] O. Kiyohara, Y.P. Handa, G.C. Benson, J. Chem. Thermodyn. 11 (1979) 453460
[41] K. Tamura, M. Nakamura, S. Murakami, J. Solut. Chem. 26 (1997) 1199–1207.