THERMODYNAMIC AND ACOUSTIC STUDIES ON VARIOUS BINARY LIQUID MIXTURES

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ABSTRACT

Acoustical and excess thermo physical properties of 2methylcyclohexanone with O-chloroaniline, O-toluidine explored at varying temperatures (303.15 - 318.15 K) and close gas pressure by evaluating speed of sound (u), density (ρ) and viscosity (η) over the total vary of composition. The trend in the acoustical and excess thermo acoustic parameters exhibit the existence of hydrogen-bonded and charge transfer complexes between the binary system. The variation of the excess parameters both in sign and magnitude in the full range of composition investigated. These results were fitted to Redlich-Kister polynomial equations to estimate the binary coefficients and standard errors. The partial and excess partial molar volumes for each component at infinite dilution have been appraised and reported.

Keywords: Speed of Sound, Viscosity, Density, R-K polynomial, Partial and Excess Partial Molar Volumes.

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INTRODUCTION

The investigation of atomic connections in blended dissolvable frameworks is of incredible noteworthiness inferable from the reasonable utilization of these frameworks in different advancements, as they furnish a wide selection of arrangements with fitting properties. The abundance thermodynamic properties of parallel fluid blends have been valuable for acquiring data on the intermolecular connections in the frameworks. The negative or positive deviations from the perfect worth rely upon the sort and degree of the cooperation between not at all like particles, just as on the organization and the temperature.^{1,2} Knowledge of the physico-concoction properties of non-watery paired fluid blends has importance in hypothetical and connected regions of research and such outcomes are much of the time utilized in the structure procedure (stream, mass exchange or warmth move counts) in numerous compound and modern procedures. The overabundance properties got from these physical property information mirror the physico-concoction conduct of the fluid blends concerning the arrangement structure and intermolecular collaborations between the segment particles of the mixture.^{3,4}

This work is part of our program to give information/data for the characterization of molecular interactions between solvents in binary systems.⁵ The liquids were chosen for the present study on the basis of their general importance. 2-Methylcyclohexanone (2MCH) is an important compound used in the Dairy products and analogs, oil emulsions, processed fruit and vegetables, Ready-to-eat savories and snacks. It is also used in the Salts, spices, soups, sauces, salads and protein products. On the other hand, the liquids were chosen in the present study on the basis of their industrial importance. O-Chloroaniline (O-CA) is chosen as polar solvent and self associated through hydrogen bonding of their amine group. The amino group in o-chloroaniline is an electron-donor and the hydrogen atom in the NH₂ group can also play the role of proton-acceptor centers. O-Chloroaniline is used as parent substances in the

production of antioxidants, agricultural, pharmaceutical and rubber chemicals. It is also used in the manufacture of intermediate for synthetic dyes, and organic pigments especially for red color.⁶ O-Toluidine (O-TA) may cause rupture or enhance self-association in pyridine or substituted O-Toluidine which in turn would change their respective topology.⁷

In the present study, our focus is on the study of liquid mixtures of substituted O-CA and O-TA with 2-methylcyclohexanone because there have been a few studies on these mixtures.⁸ It is expected that there will be a significant degree of H-bonding in these binary mixtures we report the densities, speeds of sound and viscosities for two binary systems (2MCH with O-CA and O-TA) at $T = 303.15\text{--}318.15\text{ K}$ ambient atmospheric pressure. The experimental data has been used to compute the excess parameters, partial molar volumes and FTIR studies. The results are used to qualitatively discuss specific interactions between unlike molecules.

EXPERIMENTAL

Materials

Chemicals used in the present study are 2-methylcyclohexanone (Sigma–Aldrich), O-Chloroaniline and O-Toluidine (Sigma–Aldrich). These chemicals were purchased from S.D. Fine Chemicals Ltd. These chemicals were further purified by standard methods,^{9, 10} like distillation and fractional distillation under reduced pressure, and only the middle fractions were collected. Before use, the chemicals were stored over 0.4 nm molecular sieves for about 72 h to remove water and gas. The purity of the liquid samples was checked by gas chromatography. The water contents were determined by the Karl–Fischer method.

Method

All liquid mixtures were prepared by weighing a number of pure liquids in an electronic balance with a precision of $\pm 0.1\text{ kg m}^{-3}$. The binary mixtures were prepared just before use. The uncertainty in mole fraction was estimated to be less than ± 0.0001 . The speed of sound was measured with an ultrasonic interferometer (Mittal Enterprises, Delhi, India) working at 2 MHz frequency and 303.15–318.15 K temperature. The uncertainty in the speed of sound was found to be $\pm 0.1\text{ ms}^{-1}$. An electronically digital operated constant temperature water bath has been used to circulate water through the double-walled measuring cell made up of steel containing the experimental solution at the desired temperature.

The viscosities were measured with Ostwald viscometer. The viscometer was calibrated at each temperature using distilled water. The uncertainty in viscosity measurement is up to 0.001 mPa s. The flow time has been measured after the attainment of bath temperature by each mixture. The flow measurements were made with an electronic stopwatch with precision of 0.01 s. For all pure components and mixtures, 3–4 readings were taken, and the average of these values was used in all the calculations.

The densities of the pure compounds and their mixtures were determined accurately using 10 mL specific gravity bottles in digital electronic balance with an uncertainty of $\pm 0.1\text{ kg m}^{-3}$. The average uncertainty in the measured density was $\pm 0.001\text{ kg m}^{-3}$.

Theoretical Details

The values of experimentally determined density, viscosity and speed of sound for the liquid mixtures of 2-methylcyclohexanone with O-Chloroaniline and O-Toluidine at 303.15 K–318.15 K over the entire composition range are given in Table-1. The experimentally determined values of speed of sound, density and viscosity, various thermodynamic parameters like excess isentropic compressibility (K_s^E), excess Enthalpy (H^E), excess molar volume (V^E), excess Gibb's free energy (ΔG^{*E}) and excess free length (L_f^E) were calculated. The excess values of isentropic compressibility, K_s^E were calculated as follows;

Table-1: Comparison of Experimental Densities (ρ), Viscosities (η) and Speed of Sound (U) of Pure Liquids with Literature Values.

Liquid	Temp T (K)	Density(ρ) kg m ³		Viscosity(η) mPa.S		Speed of sound (U)m.s-1	
		expt	Lit	expt	Lit	expt	Lit
2-Methylcyclo hexanone	303.15	0.9196	0.9195 ^a	2.2241	2.2242 ^a	1345.20	1344.6 ^a
	308.15	0.9125	---	2.1739	---	1338.53	---

	313.15	0.9110	---	2.0238	---	1330.27	---
	318.15	0.9086	---	2.0172	---	1320.08	---
O-Chloroaniline	303.15	1.2026	1.2026 ^b	3.8262	3.8256 ^b	1470.20	1469.6 ^b
	308.15	1.1979	1.9802 ^b	3.4219	3.4122 ^b	1454.5	1453.3 ^b
	313.15	1.1928	1.1930 ^b	3.0634	3.0602 ^b	1436.4	1435.2 ^b
	318.15	1.1879	1.1884 ^b	2.7708	2.7621 ^b	1419.8	1418.9 ^b
	303.15	0.9902	0.9902 ^c	3.4521	---	1577.79	1577.82 ^c
O-Toluidine	308.15	0.9860	0.9860 ^c	3.1254	---	1558.38	1588.38 ^c
	313.15	0.9816	---	2.8643	---	1539.62	---
	318.15	0.9746	---	2.4217	---	1518.34	---

a Gowrisankar et al.⁴,

b D. Ubagaramary et al.⁶

c Neeti sainsi et al.^{7,11}

$$K_s^E = K_s - K_s^{id} \quad (1)$$

Where, K_s^E is its excess value, K_s^{id} is the ideal isentropic compressibility value and K_s represents the calculated value of isentropic compressibility for the mixture. K_s^{id} for an ideal mixture was calculated from the relation recommended by Kiyohara and Benson.¹² Benson and Kiyohara.¹³ and Douheret et al.¹⁴

$$K_s^{id} = \sum \phi_i \left\{ K_{s,i}^\circ + \frac{TV_i^\circ (\alpha_i^\circ)^2}{C_{p,i}^\circ} \right\} - T \left(\sum X_i V_i^\circ \right) \left[\frac{\sum \phi_i \alpha_i^{\circ 2}}{\sum X_i C_{p,i}^\circ} \right] \quad (2)$$

In which $K_{s,i}^\circ$, V_i° , α_i° , $C_{p,i}^\circ$ are the isentropic compressibility, molar volume, isobaric thermal expansion coefficient and molar isobaric heat capacity of pure component i , T represents temperature, ϕ_i is the volume fraction and x_i represents the mole fraction of i in the mixture.

Excess enthalpy H^E was calculated from usual relation,

$$H^E = H - (X_1 H_1 + X_2 H_2) \quad (3)$$

Where H represents the calculated value of enthalpy for the mixture and H_1 , H_2 represents enthalpy of pure components 1 and 2, respectively.

The density values have been used to calculate the excess volumes, V^E , using the following equation,

$$V^E = \frac{X_1 M_1 + X_2 M_2}{\rho} - \left(\frac{X_1 M_1}{\rho_1} + \frac{X_2 M_2}{\rho_2} \right) \quad (4)$$

Where, ρ is the density of the mixture and X_1 , M_1 , and X_2 , M_2 , and ρ_1 , ρ_2 are the mole fraction, molar mass, and density of pure components 1 and 2, respectively.

Excess Gibbs free energy of activation ΔG^{*E} was calculated as follows,

$$\Delta G^{*E} = RT \left[\ln \left(\frac{\eta V}{\eta_1 V_1} \right) - X_1 \ln \left(\frac{\eta_1 V_1}{\eta_2 V_2} \right) \right] \quad (5)$$

Where, R represents gas constant, T is absolute temperature, η is the viscosity of the mixture and η_1, η_2 are the viscosities of the pure compounds, V_m is the molar volume of the mixture and V_1, V_2 are the volumes of the R .

The excess values of the free length L_f^E were calculated by using the expression,

$$L_f^E = L_f - K_T (K_s^{id})^{1/2} \quad (6)$$

Where L_f represents the calculated value for the mixture and K_T represents a temperature-dependent constant whose value is $K_T = (91.368 + 0.3565T) \times 10^{-8}$.

The conventional smooth curve fitting strategy for excess properties of binary mixture involves Redlich-Kister.¹⁵ polynomial non-linear regression,

$$Y^E = X_1(1-X_1) \sum_{i=1}^n A_i (2x_1 - 1) \quad (7)$$

Where $Y^E = K_s^E$, V^E , ΔG^{*E} , H^E . The values of coefficient A_i were determined by a regression analysis based on the least-squares method.

The standard deviation (σ) was calculated using the relation,

$$\sigma(Y^E) = \left[\sum (Y_{obs}^E - Y_{cal}^E)^2 / n-m \right]^{1/2} \quad (8)$$

Where n, m represents the number of experimental points and adjustable parameters.

RESULTS AND DISCUSSION

The experimental values of density, viscosity and speed of sound in case of all the liquid mixtures under study over the entire range of composition and at 303.15 - 318.15 K are given in Table-1. From this available data of speed of sound, density and viscosity, values of excess isentropic compressibility (K_s^E), excess molar volume (V^E), excess free length (L_f^E), excess Gibbs free energy of activation (ΔG^{*E}) and excess Enthalpy (H^E), were calculated. These excess parameters were plotted against mole fraction of 2MCH with O-CA and O-TA over the entire mole fraction range and at 303.15 -318.15 K. The plots are shown in Figs.-1 to 5. The excess parameters of isentropic compressibility (K_s^E), molar volume (V^E), free length (L_f^E), Gibbs free energy of activation (ΔG^{*E}) and Enthalpy (H^E), are fitted to the Redlich-Kister type polynomial equation and the coefficients A_i evaluated by the method of least squares, along with standard deviation (σ) are given in Table-2.¹⁶ The deviations observed in the excess parameters indicate the strength of interactions present between the component molecules of the binary mixtures under study. The variations in these excess parameters may be the result of contributions from several effects such as (a) The Specific forces that exist between the molecules, like the charge transfer complexes and existence of hydrogen bonds result in the negative excess values. (b) Physical interatomic forces. (c) The structural contribution arising from the geometrical fitting of one component into the other because of the differences in the size and shape of the component molecules.¹⁷ Figures-1a and 1b shows the excess isentropic compressibility K_s^E for the binary liquid mixtures of 2MCH with O-CA, O-TA respectively, over the entire mole fraction range and at different temperatures $T = (303.15-318.15)$ K. The excess isentropic compressibility (K_s^E) for the liquid mixtures under study is as shown in Fig.-1a and b. It can be observed that the K_s^E values are positive in case of 2MCH+ O-TA over the entire mole fraction range indicating the presence of weak interactions in these mixtures and also that the molecules are loosely packed in the mixtures due to their shape and size.¹⁸ K_s^E values are negative in case of 2MCH+O-CA over the entire mole fraction range. The negative values of K_s^E are of the sign of excess isentropic compressibility plays a vital role in assessing the compactness due to molecular interaction in liquid mixtures through charge transfer, dipole-dipole interactions, and dipole induced dipole interactions interstitial accommodation and orientation ordering which leads to more compact structure making, which enhances excess isentropic compressibility to have negative values as suggested by Fort and Moore.¹⁹

The variation of excess molar volume (V^E), with respect to mole fraction, x_1 , is given in Fig.-2a, and b over the entire composition range and at different $T = (303.15-318.15)$ K. The strength of the intermolecular interactions in binary liquid mixtures can be explained using the sign and magnitude of the V^E values. The negative values of V^E are due to strong specific interactions like the formation of H-bond, association through weaker physical forces and accommodation of one component molecules into the voids in the network of the other component molecules. So in the present study we observed that the behavior of V^E can be ascribed to the formation of H-bond, disruption of alcohol self-associations and the structural characteristics like geometrical fitting of one component into the other as a result of the increase in difference of size and shape of the component molecules. It is clear from Fig.-2 that the negative values of V^E are in 2MCH+O-CA. The expansion in molar volume can be attributed to the presence of weak intermolecular forces of attraction.²⁰ Similar results were reported by Garcí'a *et al.*²¹

The negative values of V^E indicate that there is more compact packing of the molecules which implies that the molecular interactions are strong, whereas in 2MCH+O-TA, the positive values indicate a loose packing of molecules in the binary mixture compared to those in the pure component. Similar results were observed by earlier works.^{22, 23}

Figure-3a and b show the L_f^E values have negative suggest that existence of strong intermolecular interaction through hydrogen bonding between the component molecules in 2MCH+O-CA. The positive values indicate the specific interactions are present between unlike molecules between the component molecules of the 2MCH+O-TA liquid mixtures under study.²⁴

Figures-4a and b represent the excess Gibb's free energy of activation (ΔG^{*E}) with respect to mole fraction x_1 , over the entire composition range and at $T = (303.15-318.15)$ K. The ΔG^{*E} are in 2MCH+O-CA, O-TA having negative values. The expansion in molar volume can be attributed to the presence of

weak intermolecular forces of attraction. Similar results were observed by earlier workers.²⁵ From Fig.-5a and b it is clear that the excess values of Enthalpy (H^E) are positive with respect to the mole fraction x_1 , over the entire composition range and at $T = 303.15$ - 318.15 K. The positive values of H^E insist the fact that there are strong specific interactions between unlike molecules in these liquid mixtures. The positive H^E values also suggest the existence of intermolecular hydrogen bond and the breaking of associated structures in case of 2MCH with O-CA, O-TA.²⁶

Fig.-1: Variation of Excess Isentropic Compressibility (K_s^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2MCH with O-CA, O-TA at Various Temperatures.

Fig.-2: Variation of Excess Molar Volume (V^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2MCH with O-CA, O-TA at Various Temperatures.

Fig.-3: Variation of Excess Free Length (L_f^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2MCH with O-CA, O-TA at Various Temperatures.

Fig.-4: Variation of Excess Gibbs's Function (ΔG^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2MCH with O-CA, O-TA at Various Temperatures.

Fig.-5: Variation of Excess Enthalpy (H^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2MCH with O-CA, O-TA at Various Temperatures.

The variations in these above excess parameters with mole fraction and temperature predict the presence of hydrogen bonding between the compounds in 2MCH+O-CA. The excess parameters calculated in the present study correlate with one another and at the same time, each parameter supports the formation of hydrogen bonding in these binary liquid mixtures. But in case of 2MCH + O-TA presence of weak intermolecular forces of attraction.

The existing molecular interactions in the systems are well reflected in the properties of partial molar volumes. The partial molar volumes $V_{m,1}$ of component 1 and $V_{m,2}$ of component 2 in the mixtures over the entire composition range have been calculated by using the following relations:

$$V_{m,1} = V_m^E + V_1^* + x_2 \left(\frac{\partial V_m^E}{\partial x} \right)_{T,P}, \quad (9)$$

$$V_{m,2} = V_m^E + V_2^* + x_1 \left(\frac{\partial V_m^E}{\partial x} \right)_{T,P},$$

Where V_1^* and V_2^* are the molar volumes of the pure components of (2MCH with O-CA, O-TA) respectively. The derivatives in the above equations are obtained by differentiating Redlich-Kister equation (7) which leads to the following equations for $V_{m,1}$ and $V_{m,2}$:

$$V_{m,1} = V_1^* + x_2^2 \sum_{i=0}^j A_i (x_2 - x_1)^i - 2x_1 x_2^2 \sum_{i=1}^j A_i (x_2 - x_1)^{i-1}, \quad (10)$$

$$V_{m,2} = V_2^* + x_1^2 \sum_{i=0}^j A_i (x_2 - x_1)^i - 2x_1 x_2^2 \sum_{i=1}^j A_i (x_2 - x_1)^{i-1}, \quad (11)$$

Using the above equations, $V_{m,1}^E$, $V_{m,2}^E$ have been calculated using,

$$\begin{aligned} V_{m,1}^E &= V_{m,1} - V_1^*, \\ V_{m,2}^E &= V_{m,2} - V_2^*, \end{aligned} \quad (12)$$

The values of $V_{m,1}$ and $V_{m,2}$ for both the components in the mixtures are less than their respective molar volumes in the pure state; that is, an expansion of volume takes place on mixing 2MCH with O-CA, O-TA. These results also support the observed negative values of V_m^E in O-CA and positive in O-TA.

Table-2: Coefficients of Redlich-Kister equation and Standard Deviations (σ) for 2MCH with O-CA and O-TA at T=303.15 -318.15K.

Parameter	Temperature (K)	A0	A1	A2	A3	σ
2MCH + O-Chloroaniline						
$10^{12} K_S^E / (\text{m}^2 \cdot \text{N}^{-1})$	303.15	-0.4853	0.0605	-0.0054	-0.0143	0.0013
	308.15	-0.4665	0.0513	0.0025	-0.0222	0.0010
	313.15	-0.4535	0.0419	0.0094	-0.0134	0.0002
	318.15	-0.4425	0.0356	0.0041	0.0047	0.0001
$10^6 V^E / (\text{m}^3 \cdot \text{mol}^{-1})$	303.15	-10.3307	-0.1509	-0.4226	0.1629	0.0414
	308.15	-9.9633	0.2012	0.1085	-0.4949	0.0507
	313.15	-9.5355	0.2000	0.2215	-0.6389	0.0477
	318.15	-9.1378	0.4085	0.2222	-0.8609	0.0472
$10^{13} L_r^E / (\text{m})$	303.15	-2.6965	0.1293	0.0479	0.1339	0.0060
	308.15	-2.6374	0.0825	0.1263	0.1471	0.0057
	313.15	-2.5636	0.1965	0.1787	-0.1372	0.0030
	318.15	-2.4674	0.1375	0.1220	0.0597	0.0021
$\Delta G^E / (\text{J} \cdot \text{mol}^{-1})$	303.15	-18.7391	-2.7516	-7.0665	10.1421	0.3853
	308.15	-21.2560	3.1104	-5.1565	-1.0211	0.1040
	313.15	-20.3096	4.7459	-3.3951	-7.7833	0.0677
	318.15	-19.3548	2.4926	-6.0194	0.3575	0.0920
$H^E / (\text{J} \cdot \text{mol}^{-1})$	303.15	0.0020	-0.0002	0.0000	0.0000	0.0000
	308.15	0.0013	-0.0001	0.0001	0.0001	0.0000
	313.15	0.0010	-0.0001	0.0001	0.0000	0.0000
	318.15	0.0004	0.0000	0.0001	0.0000	0.0000
2MCH + O-Toluidine						
$10^{12} K_S^E / (\text{m}^2 \cdot \text{N}^{-1})$	303.15	0.0031	-0.0117	0.0079	0.0013	0.0001
	308.15	0.0200	-0.0098	0.0068	-0.0011	0.0002
	313.15	0.0390	-0.0098	0.0081	0.0018	0.0001
	318.15	0.0586	-0.0074	0.0052	0.0004	0.0000
$10^6 V^E / (\text{m}^3 \cdot \text{mol}^{-1})$	303.15	1.3179	0.1557	0.0923	-0.1358	0.0025
	308.15	1.2756	0.1308	0.0799	-0.0555	0.0060
	313.15	1.2476	0.1011	0.0076	-0.0418	0.0067
	318.15	1.2157	0.1107	-0.0368	-0.1242	0.0066
$10^{13} L_r^E / (\text{m})$	303.15	2.1870	0.0740	0.1514	0.0349	0.0018
	308.15	2.2986	0.0993	0.1406	0.0077	0.0027
	313.15	2.3950	0.1000	0.1582	0.0413	0.0019
	318.15	2.4540	0.1238	0.1266	0.0217	0.0011
$\Delta G^E / (\text{J} \cdot \text{mol}^{-1})$	303.15	-0.3235	-0.0425	-0.0506	0.0330	0.0008
	308.15	-0.3073	-0.0424	-0.0398	0.0511	0.0012

$H^E/(J.mol^{-1})$	313.15	-0.2956	-0.0355	-0.0301	0.0450	0.0008
	318.15	-2.8930	1.5517	-1.0190	0.8137	0.0024
	303.15	0.0000	0.0000	0.0000	0.0000	0.0000
	308.15	0.0000	0.0000	0.0001	0.0000	0.0000
	313.15	0.0000	0.0000	0.0001	0.0000	0.0000
	318.15	0.0000	0.0000	0.0001	0.0000	0.0000

Fig.-6: Variation of Excess Partial Molar Volume (V_1^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2MCH with O-CA 6(a), O-TA 6(b) at Various Temperatures.

Fig.-7: Variation of Excess Partial Molar Volume (V_2^E) with Mole Fraction (x_1) in the Binary Liquid Mixtures of 2-Methylcyclohexanone with O-Chloroaniline 7(a), O-Toluidine 7(b)

Figures-6a and b represent the variation of excess partial molar volumes of $V_{m,1}$ (2MCH), $V_{m,2}$ (amines) in the binary mixtures. Examination of these figures reveals that attractive and weak forces exist between the unlike molecules. These figures support the conclusions drawn from V_m^E . The partial molar volumes and excess partial molar volumes of 2MCH and amines in all the binary liquid mixtures at infinite dilution, $V_{m,1}^\infty$, $V_{m,2}^\infty$, $V_{m,1}^{E,\infty}$, and $V_{m,2}^{E,\infty}$, respectively, were obtained by putting $x = 0$ in (10) and $x = 1$ in (11). Consider,

$$V_{m,1}^{E,\infty} = A_0 + A_1 + A_2 + A_3 + \dots = V_{m,1}^\infty - V_1^*, \quad (13)$$

$$V_{m,2}^{E,\infty} = A_0 + A_1 + A_2 + A_3 + \dots = V_{m,2}^\infty - V_2^*,$$

The pertinent values of $V_{m,1}^\infty$, $V_{m,2}^\infty$, $V_{m,1}^{E,\infty}$ and $V_{m,2}^{E,\infty}$ are reported in Table-2. From this table, it is seen that these values are negative, from which we conclude that strong interactions exist among the unlike molecules of the liquid mixtures.²⁷

CONCLUSION

Ultrasonic speeds u , viscosity, η and densities ρ , of mixtures of (2-methylcyclohexanone with O-CA, O-TA) over the entire composition range have been measured at $T = 303.15$ - 318.15 K. The values of K_s^E , V^E , L_f^E , H^E and ΔG^{*E} are calculated from this data. The excess and deviation properties have been fitted to Redlich-Kister type polynomial and corresponding standard deviations have been evaluated. The observed negative values of K_s^E , V^E , L_f^E , H^E and positive values for all the liquid mixtures studied clearly indicate. The calculated values of partial molar volumes have also been examined. The observed low partial molar volumes in the liquid mixture, when compared to the respective molar volumes of pure components, indicate strong and weak interactions present in the systems.

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