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# Study on volumetric and acoustic properties of binary mixtures of p-Cymene with fluorobenzene, chlorobenzene and bromobenzene at various temperatures

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Volumetric and acoustic properties of p-cymene with fluorobenzene, chlorobenzene and bromobenzene have been investigated using density, ($\rho$), and speed of sound, ($U$) measurements over the entire composition range at T= (303.15, 308.15 and 313.15) K. From the experimentally measured density, ($\rho$); Excess molar volumes, ($V_m^E$), infinite dilution partial molar volume, ($\bar{V}_{m,i}^o$), excess partial molar volume,($\bar{V}_{m,i}^{o,E}$), apparent molar volume, ($V_{m,\phi,i}$), infinite dilution apparent molar volume, ($V_{m,\phi,1}^o$), with empirical parameters, $S_v$, $B_v$ and limiting apparent molar expansibility, ($E_\phi^o$) have been calculated. Deviation in speed of sound, ($\Delta U$), deviation in isentropic compressibility, ($\Delta\kappa_s$), deviation in acoustic impedance, ($\Delta z$), infinite dilution partial molar isentropic compressibility, ($\bar{K}_{s,m,i}^o$), excess partial molar isentropic compressibility, ($\bar{K}_{s,m,i}^{o,E}$), apparent molar isentropic compressibility, ($K_{s,m,\phi,i}$), infinite dilution apparent molar isentropic compressibility, ($K_{s,m,\phi,1}^o$) with empirical parameters $S_k$ and$B_k$ and intermolecular free length ($L_f$) have been calculated using experimentally measured speed of sound, ($U$).To derive fitting coefficients, ($A_i$) with standard deviation, ($\sigma$), excess properties were fitted to the Redlich-Kister type polynomial equation. Various theoretical speed of sound and average deviations have been calculated using well established equation like Nomoto, ($U_{nmt}$), Ideal Mixing Rule, ($U_{imr}$), Junji, ($U_{junji}$)and Jacobson's Free Length Theory, ($U_{flt}$). The variation of these properties with composition and temperature has been discussed in terms of molecular interaction on mixing and their interacting abilities have also been compared.

**Keywords:** Density, Speed of sound, Excess molar volume, Isentropic compressibility, Acoustic impedance

## 1 Introduction

A study on spectral, thermodynamic and transport properties such as FT-IR, density, viscosity, refractive index and speed of sound for binary and multicomponent liquid mixtures are reported by many research groups in recent years[1–7]. Thermodynamic and transport properties are essential for a process design as well as understanding a structure orientation in liquid mixtures. The excess thermodynamic properties of binary liquid mixtures have been extremely helpful to get data on the intermolecular interactions and geometrical impacts in the frameworks[8,9].

The knowledge of physicochemical properties of binary liquid mixtures have significance importance in theoretical and applied areas of research, and such outcomes are frequently used in designing processes (flow, mass transfer or heat transfer calculations) in many chemical and industrial units. The excess property values obtained from these physical property data reveal the physicochemical behaviour of the liquid mixtures regarding the arrangement of structure and intermolecular interactions between the component molecules in the mixture[10]. p-Cymene (1-methyl-4-(propan-2-yl) benzene) is a naturally obtained from oils of cypress and essential oils in various plant species. The study of volumetric and acoustic properties of p-cymene with organic solvents help us to understand the nature and behavior in binary mixture. The study of these parameters helps us in various separation techniques, mass transfer phenomena as well as in various analytical techniques[11,12].

In present study, the density, sound velocity and its related properties such as excess molar volumes and deviation in sound velocities were studies. Some theoretical sound velocities of binary mixture were calculated by using well known relations and were compared with experimental values. The results were interpreted in terms of intermolecular interaction between the components of binary mixture.

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## 2 Experimental

### 2.1 Chemicals

p-Cymene(with >95% purity, Tokyo chemical industry Co. Ltd., Tokyo, Japan), fluorobenzene (with 99% purity, S. D. Fine Chem. Ltd., India), chlorobenzene (with 99% purity, S. D. Fine Chem. Ltd., India), bromobenzene (with 99% purity, S. D. Fine Chem. Ltd., India) were used in this study as received. List of chemicals with details like CAS number, molar mass, chemical formula, supplier, purity and comparison of experimental values of densities ($\rho$) in gcm$^{-3}$and speed of sound($U$)in m·s$^{-1}$- with literature values were reported in Table 1.

### 2.2 Apparatus and procedure

Binary mixtures were freshly prepared by gravimetrically with an electronic balance Reptech RA-2012 (supplied by Reptech India) with an accuracy of ±0.0001 g. The uncertainty in the mole fraction of the mixtures was estimated to less than ± 0.0001. Densities and sound velocity were measured by using automatic density and sound velocity meter (Anton Paar, DSA 5000 M, Anton Paar India Pvt. Ltd., Gurgaon, India). The instrument was calibrated by using highly pure deionized water provided by manufacturer. Temperature compensation in the instrument is achieved with inbuilt integrated Pt 1000 temperature sensor having measuring scale 0 °C to 70 °C (32 °F to 158 °F) with accuracy of 0.001 °C (0.002 °F) during the measurement of density. The accuracy in densities and sound velocities were ±0.000001 gcm$^{-3}$ and ±0.01 ms$^{-1}$, respectively.

## 3 Calculations

### 3.1 Mathematical representation of excess or deviation functions

All the excess and deviation in properties have been fitting with the Redlich-Kister[21] polynomial equation for representing excess or deviation functions for binary mixtures.

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

where, $Y^E$ = excess/ deviation properties. $x_i$ represents mole fraction of i$^{th}$ component. $A_i$is fitting coefficient. The fourth-order form of equation of the Redlich-Kister equation gives the minimum standard deviation in $Y^E$. The standard deviation ($\sigma$) has been calculated using following relation.

$$\sigma(Y) = \left[\frac{\sum(Y^E_{exp}-Y^E_{cal})}{N-P}\right]^{\frac{1}{2}} \quad \ldots (2)$$

where, $Y^E_{exp}$, $Y^E_{cal}$ represent experimental and calculated values of excess properties, respectively. $N$ is the number of experimental points and $P$ is the number of parameters of the Redlich-Kister equation. The values of Fitting coefficients ($A_0$, $A_1$, $A_2$, $A_3$, $A_4$) with standard deviation ($\sigma$) in least square representation of $V^E_m$, $\Delta U$, $\Delta\kappa_s$, $K^E_{s,m}$, $\Delta z$ for studied binary mixtures were reported in Table 2.

Table 1 — List of chemicals with details of CAS number, molar mass, chemical formula, supplier, purity and comparison of experimental values of Densities ($\rho$) in g·cm$^3$and Speed of sound ($U$) in m·s$^{-1}$ with literature values

| Compound Name | CAS number | Molar mass | Chemical Formula | Supplier | Initial mass-fraction purity | Temp. in K | Densities ($\rho$) in g·cm$^3$ | | Speed of sound ($U$)in m·s$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Exp. | Lit | Exp. | Lit |
| p-Cymene | 99-87-6 | 134.21 g/mol | $C_{10}H_{14}$ | TCI Co. Ltd. Tokyo, Japan | 95% | 303.15 | 0.847195 | ----- | 1293.28 | ----- |
| | | | | | | 308.15 | 0.843178 | ----- | 1273.89 | ----- |
| | | | | | | 313.15 | 0.839156 | ----- | 1254.90 | ----- |
| Fluorobenzene | 462-06-6 | 96.103 g/mol | $C_6H_5F$ | S.D. Fine Chemicals Ltd. India | 99% | 303.15 | 1.013097 | 1.01316[34] | 1145.29 | 1171[34] |
| | | | | | | 308.15 | 1.007057 | ----- | 1125.26 | ----- |
| | | | | | | 313.15 | 1.000977 | ----- | 1105.04 | ----- |
| Chlorobenzene | 108-90-7 | 112.55 g/mol | $C_6H_5Cl$ | S.D. Fine Chemicals Ltd. India | 99.5% | 303.15 | 1.095771 | 1.09547[35] | 1249.33 | 1249[35] |
| | | | | | | 308.15 | 1.090368 | 1.09006[35] | 1231.22 | 1235[35] |
| | | | | | | 313.15 | 1.084941 | 1.08366[36] | 1212.98 | 1212.63 [38] |
| Bromobenzene | 108-86-1 | 157.02 g/mol | $C_6H_5Br$ | S.D. Fine Chemicals Ltd. India | 98% | 303.15 | 1.481918 | 1.48148[35] | 1138.27 | 1131[39] |
| | | | | | | 308.15 | 1.475155 | 1.47481[35] | 1122.88 | 1122[40] |
| | | | | | | 313.15 | 1.468378 | 1.4670[37] | 1107.62 | 1109[41] |

Table 2 — Fitting coefficients ($A_0$, $A_1$, $A_2$, $A_3$, $A_4$) with Standard deviation ($\sigma$) for Least square representation of $V_m^E$, $\Delta U$, $\Delta\kappa_s$, $K_{s,m}^E$, $\Delta z$ of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| | $T$ (K) | $A_0$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $\sigma$ |
|---|---|---|---|---|---|---|---|
| | p-Cymene (1) + Fluorobenzene (2) | | | | | | |
| $V_m^E$ | 303.15 | -0.699533 | 0.271621 | 0.513154 | -0.183438 | -0.395109 | 0.00097 |
| | 308.15 | -0.703608 | 0.284997 | 0.525753 | -0.210058 | -0.432421 | 0.00097 |
| | 313.15 | -0.709128 | 0.283548 | 0.533262 | -0.202750 | -0.444715 | 0.00113 |
| $\Delta U$ | 303.15 | 43.629 | -6.419 | -11.475 | 6.795 | 25.010 | 0.179 |
| | 308.15 | 42.765 | -5.739 | -7.753 | 4.872 | 19.361 | 0.258 |
| | 313.15 | 42.611 | -4.027 | -5.415 | -1.740 | 10.351 | 0.186 |
| $\Delta\kappa_s$ | 303.15 | -13.90570 | 2.42337 | 18.43250 | -9.41566 | -32.86830 | 0.2193 |
| | 308.15 | -15.46650 | 2.14497 | 14.27310 | -7.54989 | -27.01330 | 0.3276 |
| | 313.15 | -18.36290 | 0.47332 | 11.94380 | 0.89897 | -16.96790 | 0.2512 |
| $K_{s,m}^E$ | 303.15 | 0.00072 | 0.00017 | 0.00254 | -0.00146 | -0.00424 | 0.000027 |
| | 308.15 | 0.00091 | 0.00011 | 0.00218 | -0.00132 | -0.00376 | 0.000038 |
| | 313.15 | 0.00102 | -0.00021 | 0.00192 | -0.00012 | -0.00239 | 0.000030 |
| $\Delta z$ | 303.15 | -0.03106 | 0.00628 | -0.01733 | 0.00860 | 0.02494 | 0.00017 |
| | 308.15 | -0.02927 | 0.00630 | -0.01454 | 0.00600 | 0.02140 | 0.00023 |
| | 313.15 | -0.02694 | 0.00688 | -0.01123 | 0.00160 | 0.01180 | 0.00017 |
| | p-Cymene (1) + Chlorobenzene (2) | | | | | | |
| $V_m^E$ | 303.15 | -0.577382 | 0.261057 | 0.554597 | -0.294344 | -0.455024 | 0.00160 |
| | 308.15 | -0.569972 | 0.260869 | 0.581361 | -0.304482 | -0.496203 | 0.00191 |
| | 313.15 | -0.564252 | 0.263156 | 0.582485 | -0.305820 | -0.496699 | 0.00204 |
| $\Delta U$ | 303.15 | 9.309 | -0.852 | 1.089 | 1.137 | -2.190 | 0.070 |
| | 308.15 | 8.653 | -2.052 | -0.357 | 3.173 | 0.299 | 0.077 |
| | 313.15 | 8.159 | -0.568 | -1.359 | 1.429 | 1.455 | 0.032 |
| $\Delta\kappa_s$ | 303.15 | 25.76250 | -1.95625 | 2.08067 | -2.92608 | -0.12849 | 0.0718 |
| | 308.15 | 27.15960 | -0.71835 | 3.73242 | -5.17225 | -2.94719 | 0.0891 |
| | 313.15 | 28.50980 | -2.42830 | 4.87536 | -3.21915 | -4.25777 | 0.0474 |
| $K_{s,m}^E$ | 303.15 | -0.00375 | 0.00060 | 0.00061 | -0.00050 | -0.00042 | 0.000008 |
| | 308.15 | -0.00386 | 0.00080 | 0.00084 | -0.00079 | -0.00079 | 0.000012 |
| | 313.15 | -0.00395 | 0.00064 | 0.00096 | -0.00057 | -0.00093 | 0.000007 |
| $\Delta z$ | 303.15 | -0.10982 | 0.02077 | -0.00770 | 0.00561 | 0.00046 | 0.00008 |
| | 308.15 | -0.10795 | 0.01906 | -0.01248 | 0.00763 | 0.00815 | 0.00010 |
| | 313.15 | -0.10621 | 0.02024 | -0.01153 | 0.00517 | 0.00567 | 0.00005 |
| | p-Cymene (1) + Bromobenzene (2) | | | | | | |
| $V_m^E$ | 303.15 | -0.453247 | 0.176241 | 0.720204 | -0.310766 | -0.689489 | 0.00237 |
| | 308.15 | -0.452467 | 0.175941 | 0.722299 | -0.309228 | -0.710914 | 0.00230 |
| | 313.15 | -0.452334 | 0.180101 | 0.729574 | -0.311519 | -0.731033 | 0.00238 |
| $\Delta U$ | 303.15 | -20.939 | 1.832 | 0.599 | -0.336 | 3.105 | 0.030 |
| | 308.15 | -21.116 | 1.019 | 4.349 | -2.100 | 0.835 | 0.053 |
| | 313.15 | -21.162 | -0.495 | -1.809 | -1.483 | 7.095 | 0.056 |
| $\Delta\kappa_s$ | 303.15 | 22.72340 | -2.24533 | 2.42901 | -1.42972 | -6.34960 | 0.033 |
| | 308.15 | 23.70300 | -1.37115 | -1.37991 | 0.13539 | -4.44265 | 0.052 |
| | 313.15 | 24.62380 | 0.37348 | 5.25418 | -0.16174 | -11.07170 | 0.071 |
| $K_{s,m}^E$ | 303.15 | -0.00697 | 0.00039 | 0.00064 | -0.00041 | -0.00118 | 0.000004 |
| | 308.15 | -0.00733 | 0.00052 | 0.00018 | -0.00026 | -0.00091 | 0.000005 |
| | 313.15 | -0.00769 | 0.00081 | 0.00107 | -0.00026 | -0.00174 | 0.000010 |
| $\Delta z$ | 303.15 | -0.22634 | 0.04637 | -0.01721 | 0.00440 | 0.01236 | 0.00006 |
| | 308.15 | -0.22384 | 0.04530 | -0.01336 | 0.00162 | 0.01156 | 0.00008 |
| | 313.15 | -0.22116 | 0.04290 | -0.02044 | 0.00315 | 0.01989 | 0.00009 |

### 3.2 Molar volume $(V_m)$

Molar volumes have been calculated form experimental measured density data. The following equation has been used to determine molar volumes of for pure components and for mixtures, respectively:

$$V_i(cm^3.mol^{-1}) = M_i/\rho_i \quad \ldots (3)$$

$$V_m(cm^3.mol^{-1}) = M_1x_1 + M_2x_2/\rho_m \quad \ldots (4)$$

where,$x_1$and $x_2$, $M_1$and $M_2$ and $\rho_i$ and $\rho_m$ are the mole fraction, molar mass and density of the components, respectively.

### 3.3 Excess molar volume$(V_m^E)$

Excess molar volume ($V_m^E$) has been calculated using following standard equation:

$$V_m^E(cm^3.mol^{-1}) = V_m - V_1x_1 - V_2x_2 \quad \ldots (5)$$

$$V_m^E(cm^3.mol^{-1}) = \left(\frac{x_1M_1+x_2M_2}{\rho_m}\right) - \left(\frac{x_1M_1}{\rho_1}\right) - \left(\frac{x_2M_2}{\rho_2}\right) \quad \ldots (6)$$

where, $V_m$, $V_1$and $V_2$, are the molar volumes of mixture and component 1 and 2, respectively. $x_1$, $x_2$& $M_1$, $M_2$represents the mole fraction and molar masses of component 1 and 2, respectively. $\rho_m$, $\rho_1$ and $\rho_2$ represents densities of a binary liquid mixture, component 1 and 2, respectively.

### 3.4 Partial molar volume$(\bar{V}_{m,i}^o)$and excess partial molar volume, $(\bar{V}_{m,i}^{o,E})$

The partial molar volume ($\bar{V}_{m,i}^o$) and excess partial molar volume, $(\bar{V}_{m,i}^{o,E})$ of components in their binary mixtures have been calculated using following equations[13]:

$$\bar{V}_{m,1}^o = V_m^E + V_{m,1}^* + x_2\left(\frac{\partial V_m^E}{\partial x_1}\right)_{T,P} \quad \ldots (7)$$

$$\bar{V}_{m,2}^o = V_m^E + V_{m,2}^* - x_1\left(\frac{\partial V_m^E}{\partial x_1}\right)_{T,P} \quad \ldots (8)$$

where,$V_{m,1}^*$, $V_{m,2}^*$ and $\bar{V}_{m,1}^o$, $\bar{V}_{m,2}^o$ represent the molar volume and partial molar volume of component 1 and 2, respectively. Taking differentiation of $\left(\frac{\partial V_m^E}{\partial x_1}\right)_{T,P}$ derivative, the following relations were obtained.

$$\bar{V}_{m,1}^o = V_{m,1}^* + x_2^2\sum_{i=0}^{n}A_i(1-2x_1)^i - 2x_1x_2^2\sum_{i=1}^{n}A_i(1-2x_1)^{i-1} \quad \ldots (9)$$

$$\bar{V}_{m,2}^o = V_{m,2}^* + x_1^2\sum_{i=0}^{n}A_i(1-2x_1)^i + 2x_1^2x_2\sum_{i=1}^{n}A_i(1-2x_1)^{i-1} \quad \ldots (10)$$

The excess partial molar volume of binary mixtures has been calculated by following equations.

$$\bar{V}_{m,1}^{o,E}(cm^3.mol^{-1}) = \bar{V}_{m,1}^o - V_{m,1}^* \quad \ldots (11)$$

$$\bar{V}_{m,2}^{o,E}(cm^3.mol^{-1}) = \bar{V}_{m,2}^o - V_{m,2}^* \quad \ldots (12)$$

where, $\bar{V}_{m,1}^o$, $\bar{V}_{m,2}^o$ represent the partial molar volume of component 1 and 2, respectively.

### 3.5 Apparent molar volume$(V_{m,\Phi,i})$

Using two different relations, apparent molar volumes for all binary mixtures over the entire composition range have been calculated as under.

**Relation 1**[14]**.**

$$V_{m,\phi,i}(cm^3.mol^{-1}) = \frac{M}{\rho} - \frac{(\rho-\rho_o)}{m\rho\rho_o} \quad \ldots (13)$$

where, $M$ and $m$ represents the molar mass and molality of solute molecules. $\rho$ and $\rho_o$ represents the density of solution and solute molecules, respectively.

**Relation 2**

$$V'_{m,\phi,1}(cm^3.mol^{-1}) = \left(\frac{V_m-(1-x_1)\bar{V}_{m,2}^o}{x_1}\right) \quad \ldots (14)$$

$$V'_{m,\phi,2}(cm^3.mol^{-1}) = \left(\frac{V_m-x_1\bar{V}_{m,1}^o}{(1-x_1)}\right) \quad \ldots (15)$$

Using the equation of $V_m^E$ in above equations, we get:

$$V'_{m,\phi,1}(cm^3.mol^{-1}) = \bar{V}_{m,1}^o + \left(\frac{V_m^E}{x_1}\right) \quad \ldots (16)$$

$$V'_{m,\phi,2}(cm^3.mol^{-1}) = \bar{V}_{m,2}^o + \left(\frac{V_m^E}{x_2}\right) \quad \ldots (17)$$

where, $V'_{m,\phi,1}$, $V'_{m,\phi,2}$ represents the apparent molar volume of component 1 and 2, respectively.

### 3.6 Infinite dilution apparent molar volume$(V_{m,\Phi,1}^o)$and empirical parameters $S_v$, $B_v$using the redlich-rosenberg-mayer equation

The infinite dilution apparent molar volume $V_{m,\Phi,1}^o$ for all binary mixtures have been calculated using the Redlich-Rosenberg-Mayer relation[14].

$$V_{m,\phi,1} = V_{m,\phi,1}^o + S_vm^{1/2} + B_vm \quad \ldots (18)$$

where, $S_v$ and $B_v$ are empirical parameters.

### 3.7 Limiting apparent molar expansibility($E_\Phi^o$)

The limiting apparent molar expansibility ($E_\Phi^o$) for all binary mixtures has been calculated using following relations[14].

Temperature dependence for $V_{m,\phi,i}^o$ can be calculated using following relation.

$$V_{m,\phi,i}^o = A + BT + CT^2 \quad \ldots (19)$$

The limiting apparent molar expansibility ($E_\Phi^o$) can be calculated by differentiation of the above equation with respect to temperature ($T$).

$$E_\phi^o = \left(\frac{\partial V_\phi^o}{\partial T}\right) = B + 2CT \quad \ldots (20)$$

where, $A$, $B$ and $C$ are temperature dependence constants of $V_{m,\phi,i}^o$.

### 3.8 Deviation in speed of Sound ($\Delta U$)

Deviation in the speed of sound ($\Delta U$)has been calculated using the following relations.

$$\Delta U\ (m \cdot s^{-1}) = U_{exp} - (x_1U_1 + x_2U_2) \quad \ldots (21)$$

$$\Delta U\ (m \cdot s^{-1}) = U_{exp} - (x_1U_1 + x_2U_2 + x_3U_3) \quad \ldots (22)$$

where, $U_{exp}$ represents speed of sound of mixture. $x_1, x_2$ and $U_1, U_2$ represents mole fraction and speed of sound of pure component 1 and 2, respectively.

### 3.9 Isentropic compressibility($k_s$), deviation in isentropic compressibility($\Delta k_s$), acoustical impedance($z$), deviation in acoustical impedance($\Delta z$)and intermolecular free length($L_f$)

These properties have been calculated using following relations[15].

$$k_s(T\ Pa^{-1}) = \frac{1}{U_i^2\rho_i} \quad \ldots (23)$$

$$Z\ (g \cdot m^{-2} \cdot s^{-1}) = U_i\rho_i \quad \ldots (24)$$

$$L_f = Kk_s^{1/2} \quad \ldots (25)$$

$$\Delta k_s = k_{s_{exp}} - (x_1k_{s_1} + x_2k_{s_2}) \quad \ldots (26)$$

$$\Delta z = z_{exp} - (x_1z_1 + x_2z_2) \quad \ldots (27)$$

where, $x_1, x_2, \phi_1, \phi_2$, $k_{s_1}, k_{s_2}$ and $z_1, z_2$ represent mole fraction, volume fraction, isentropic compressibility and acoustical impedance of component 1 and 2, respectively, $k_{s_{exp}}$ and $z_{exp}$ represents isentropic compressibility and acoustical impedance of binary mixtures. $U_i$ and $\rho_i$ represent speed of sound and density of i[th] component respectively. $K$ is the temperature dependent Jacobson constant.

### 3.10 Partial molar isentropic compressibility($K_{s,m,\Phi,i}$)and excess partial molar isentropic compressibility($\bar{K}_{s,m,i}^{o,E}$)

These properties have been calculated using the following relations[15].

$$\bar{K}_{s,m,1}^o = K_{s,m}^E + K_{s,m,1}^* + x_2\left(\frac{\partial K_{s,m}^E}{\partial x_1}\right)_{T,P} \quad \ldots (28)$$

$$\bar{K}_{s,m,2}^o = K_{s,m}^E + K_{s,m,2}^* - x_1\left(\frac{\partial K_{s,m}^E}{\partial x_1}\right)_{T,P} \quad \ldots (29)$$

Taking differentiation of $\left(\frac{\partial K_{s,m}^E}{\partial x_1}\right)_{T,P}$ derivative, we get following relations.

$$\bar{K}_{s,m,1}^o = K_{s,m,1}^* + x_2^2\sum_{i=0}^n A_i(1-2x_1)^i - 2x_1x_2^2\sum_{i=1}^n A_i(1-2x_1)^{i-1} \quad \ldots (30)$$

$$\bar{K}_{s,m,2}^o = K_{s,m,2}^* + x_1^2\sum_{i=0}^n A_i(1-2x_1)^i + 2x_1^2x_2\sum_{i=1}^n A_i(1-2x_1)^{i-1} \quad \ldots (31)$$

$$\bar{K}_{s,m,1}^{o,E}\ ((TPa)^{-1} \cdot m^3 \cdot mol^{-1}) = \bar{K}_{s,m,1}^o - K_{s,m,1}^* \quad \ldots (32)$$

$$\bar{K}_{s,m,2}^{o,E}\ ((TPa)^{-1} \cdot m^3 \cdot mol^{-1}) = \bar{K}_{s,m,2}^o - K_{s,m,2}^* \quad \ldots (33)$$

where, $K_{s,m}^E$ represents excess molar isentropic copmpressibiity of mixture.$K_{s,m,1}^*$, $K_{s,m,2}^*$ and $\bar{K}_{s,m,1}^o$, $\bar{K}_{s,m,2}^o$ represents molar isentropic compressibility and partial molar isentropic compressibility of component 1 and 2, respectively.

### 3.11 Apparent molar isentropic compressibility($K_{s,m,\phi,i}$)& redlich-rosenberg-mayer equation

Apparent molar isentropic compressibility ($K_{s,m,\phi,i}$) has been calculated using following two methods[14,15].

**Relation 1**

$$K_{s,m,\phi,i} = \frac{K_sM}{\rho} - \frac{1000(K_{s_o}\rho - K_s\rho_0)}{m\rho\rho_0} \quad \ldots (34)$$

**Relation 2**

$$K'_{s,m,\phi,1} = \bar{K}_{s,m,1}^0 + \left(\frac{K_{s,m}^E}{x_1}\right) \quad \ldots (35)$$

$$K'_{s,m,\phi,2} = \bar{K}_{s,m,2}^0 + \left(\frac{K_{s,m}^E}{x_2}\right) \quad \ldots (36)$$

where, $K'_{s,m,\phi,1}$ and $K'_{s,m,\phi,2}$ represents apparent molar isentropic compressibility of component 1 and

2, respectively. $K_s$, $K_{s_o}$, $\rho$, $\rho_0$ represents isentropic compressibility of mixture, isentropic compressibility of solvent, density of mixture and solvent, respectively.

### 3.12 Limiting apparent molar isentropic compressibility $(K^0_{s.m.\phi,i})$ and redlich-rosenberg-mayer equation

The limiting apparent molar isentropic compressibility $(K^0_{s.m.\phi,i})$ has been calculated using the following Redlich-Rosenberg-Mayer equation[14,15].

$$K_{s,m,\phi,i}\ ((TPa)^{-1}\cdot m^3\cdot mol^{-1}) = K^0_{s.m.\phi,i} + S_k m^{\frac{1}{2}} + B_k m \quad \ldots (37)$$

where, $K^0_{s.m.\phi,i}$ represents limiting apparent molar isentropic compressibility of i[th] component. $S_k$ and $B_k$ are the empirical parameters.

### 3.13 Theoretical models of speed of sound

Following models are used in the present study to calculate theoretical speed of sound.

#### *(i) Junjie equation*

Experimental values of speed of sound are generally compared with those obtained from the Junjie's equation[16], which has the following form

$$U_{junji} = \left\{\left(\frac{x_1M_1}{\rho_1}\right)+\left(\frac{x_2M_2}{\rho_2}\right)\right\} / \left\{(x_1M_1+x_2M_2)^{\frac{1}{2}}\left[\left(\frac{x_1M_1}{\rho_1U_1^2}\right)+\left(\frac{x_2M_2}{\rho_2U_2^2}\right)^{1/2}\right]\right\} \quad \ldots (38)$$

where, $x_i$, $M_i$, $\rho_i$ and $U_i$ are the mole fraction, molecular weight, density and speed of sound for component 1 and component 2, respectively.

#### *(ii) Nomoto equation*

Theoretical values of speed of sound were also obtained using Nomoto equation[17]

$$U_{nom} = \left\{\frac{x_1R_1+x_2R_2}{x_1V_1+x_2V_2}\right\} \quad \ldots (39)$$

where, $V_i$ is the molar volume of component 1 and component 2 and $R_i$ is Wada's constant and is calculated as:

$$R_i = U_i^{1/3}V_i \quad \ldots (40)$$

where, $U_i$is the speed of sound of i[th] component.

#### *(iii) Ideal mixture relation*

Van deal and Van Geel[18] proposed the following expression for the estimation of sound velocity $u_{imr}$ in an ideal mixture using sound velocities in the pure components:

$$U_{imr} = \left[\frac{1}{\left(x_1M_1+x_2M_2\right)^{\frac{1}{2}}}\right] \left\{1/\ \left[\left(\frac{x_1}{M_1U_1^2}\right)+\left(\frac{x_2}{M_2U_2^2}\right)\right]^{1/2}\right\} \quad \ldots (41)$$

where $M_1$,$M_2$ and $U_1$, $U_2$are the molar masses and sound velocities of first and second components, and $U_{imr}$ is the ultrasonic velocity of ideal mixture.

#### *(iv) Free length theory*

According to Jacobson's theory [19] of free length, the ultrasonic velocity is given by:

$$U\ = K/(L_f\rho^{\frac{1}{2}}) = KY/(2V_a\rho^{\frac{1}{2}}) \quad \ldots (42)$$

For the Binary liquid mixture Eq. 42 is

$$U\ = K(x_1Y_1+x_2Y_2)/2[V_M-(x_1V_{0.1}+x_2V_{0.2})]\rho^{1/2} \quad \ldots (43)$$

$Y$ is an adjustable parameter in the evaluation of velocity in liquid mixtures. $Y$ can be obtained from velocity of pure liquids using equation 42

$$Y = 2V_aU\rho^{1/2}/K \quad \ldots (44)$$

where $K$ is the temperature dependent Jacobson's constant[20], $V_a$ is the available molar volume, which is the difference between the molar volumes at T(K) and 0(K), is a direct measure of the compactness and the strength of bonding between the molecules of a liquid in mixture. $V_a$ is given by

$$V_a = V_M - V_0 \quad \ldots (45)$$

when $Y$ in equation 43 is replaced according to equation 44and when the resulting expression is rearranged, we gets

$$U_{flt} = \left\{\left[x_1(V_{M1}-V_{0.1})U_1\rho_1^{1/2}\right]+\left[x_2(V_{M2}-V_{0.2})U_2\rho_2^{1/2}\right]\right\} / [V_M-(x_1V_{0.1}+x_2V_{0.2})]\rho^{1/2} \quad \ldots (46)$$

Equation 44 says that according to the free length theory the square root of the inverse of the adiabatic compressibility of liquid mixture $(U\rho^{1/2})$is the sum of the available volume fraction average of the square root of the inverse of adiabatic compressibilities of the individual components.

## 4 Results and Discussion

### 4.1 Densities, $(\rho)$ and excess molar volumes, $(V_m^E)$

The experimental values of densities, $(\rho)$ and calculated excess molar volumes, $(V_m^E)$ of p-cymene

+ fluoro-, chloro-, and bromobenzene binary mixtures with mole fraction, $(x_1)$ of p-cymene at 303.15, 308.15 and 313.15 K are reported in Table 3. It can be seen form Fig. 1, the $V_m^E$ values have negative deviation for all three binary mixtures over the whole composition range at all three temperatures. When mixtures changes from fluorobenzene to bromobenzene; the negative values of $V_m^E$ become less negative (i.e. increases). In general, the negative $V_m^E$ values indicate for volume contraction on mixing and also means that the mixtures are more compressible than the corresponding ideal mixtures and it comes from specific intermolecular interactions[22]. These interactions may be due to charge transfer and the structural contributions due to geometrical fitting of one component into another due to differences in

Table 3 — Density ($\rho$) and Excess molar volume ($V_m^E$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | $\rho$ (gm·cm$^3$) | | | $V_m^E$ (cm$^3$·mol$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 303.15 K | 308.15 K | 313.15 K | 303.15 K | 308.15 K | 313.15 K |
| p-Cymene (1) + Fluorobenzene (2) | | | | | | |
| 0.0000 | 1.013097 | 1.007057 | 1.000977 | 0.0000 | 0.0000 | 0.0000 |
| 0.0624 | 0.996890 | 0.991074 | 0.985219 | -0.0380 | -0.0388 | -0.0394 |
| 0.1302 | 0.980639 | 0.975029 | 0.969391 | -0.0760 | -0.0761 | -0.0768 |
| 0.2042 | 0.964331 | 0.958933 | 0.953515 | -0.1123 | -0.1128 | -0.1143 |
| 0.2853 | 0.947958 | 0.942796 | 0.937577 | -0.1456 | -0.1497 | -0.1500 |
| 0.3745 | 0.931492 | 0.926502 | 0.921492 | -0.1715 | -0.1718 | -0.1724 |
| 0.4732 | 0.914869 | 0.910079 | 0.905283 | -0.1793 | -0.1796 | -0.1815 |
| 0.5828 | 0.898026 | 0.893438 | 0.888842 | -0.1558 | -0.1564 | -0.1581 |
| 0.7055 | 0.881061 | 0.876666 | 0.872262 | -0.1087 | -0.1089 | -0.1095 |
| 0.8435 | 0.864107 | 0.859907 | 0.855697 | -0.0553 | -0.0560 | -0.0565 |
| 1.0000 | 0.847195 | 0.843178 | 0.839156 | 0.0000 | 0.0000 | 0.0000 |
| p-Cymene (1) + Chlorobenzene (2) | | | | | | |
| 0.0000 | 1.095771 | 1.090368 | 1.084941 | 0.0000 | 0.0000 | 0.0000 |
| 0.0672 | 1.071199 | 1.065930 | 1.060642 | -0.0284 | -0.0278 | -0.0274 |
| 0.1395 | 1.046614 | 1.041469 | 1.036324 | -0.0589 | -0.0567 | -0.0565 |
| 0.2175 | 1.022012 | 1.017011 | 1.011998 | -0.0914 | -0.0897 | -0.0885 |
| 0.3018 | 0.997369 | 0.992499 | 0.987625 | -0.1233 | -0.1205 | -0.1191 |
| 0.3934 | 0.972627 | 0.967907 | 0.963177 | -0.1466 | -0.1452 | -0.1443 |
| 0.4931 | 0.947684 | 0.943097 | 0.938506 | -0.1454 | -0.1431 | -0.1418 |
| 0.6021 | 0.922567 | 0.918121 | 0.913670 | -0.1180 | -0.1157 | -0.1141 |
| 0.7217 | 0.897420 | 0.893118 | 0.888810 | -0.0812 | -0.0795 | -0.0781 |
| 0.8537 | 0.872293 | 0.868134 | 0.863969 | -0.0414 | -0.0405 | -0.0396 |
| 1.0000 | 0.847195 | 0.843178 | 0.839156 | 0.0000 | 0.0000 | 0.0000 |
| p-Cymene (1) + Bromobenzene (2) | | | | | | |
| 0.0000 | 1.481918 | 1.475155 | 1.468378 | 0.0000 | 0.0000 | 0.0000 |
| 0.0692 | 1.418655 | 1.412164 | 1.405657 | -0.0162 | -0.0169 | -0.0174 |
| 0.1432 | 1.355386 | 1.349154 | 1.342911 | -0.0345 | -0.0348 | -0.0352 |
| 0.2228 | 1.292143 | 1.286176 | 1.280199 | -0.0584 | -0.0586 | -0.0589 |
| 0.3084 | 1.228901 | 1.223202 | 1.217494 | -0.0867 | -0.0868 | -0.0869 |
| 0.4008 | 1.165595 | 1.160165 | 1.154729 | -0.1131 | -0.1129 | -0.1130 |
| 0.5008 | 1.102034 | 1.096879 | 1.091720 | -0.1140 | -0.1135 | -0.1136 |
| 0.6095 | 1.038271 | 1.033400 | 1.028518 | -0.0876 | -0.0875 | -0.0870 |
| 0.7279 | 0.974533 | 0.969945 | 0.965348 | -0.0582 | -0.0582 | -0.0578 |
| 0.8575 | 0.910852 | 0.906551 | 0.902241 | -0.0306 | -0.0310 | -0.0309 |
| 1.0000 | 0.847195 | 0.843178 | 0.839156 | 0.0000 | 0.0000 | 0.0000 |

Standard uncertainties u, u($T$)= ±0.001 K, u($\rho$) = ±0.000001 g·cm$^{-3}$, u($x$) = ±0.0001. All physical quantities are measured at atmospheric pressure

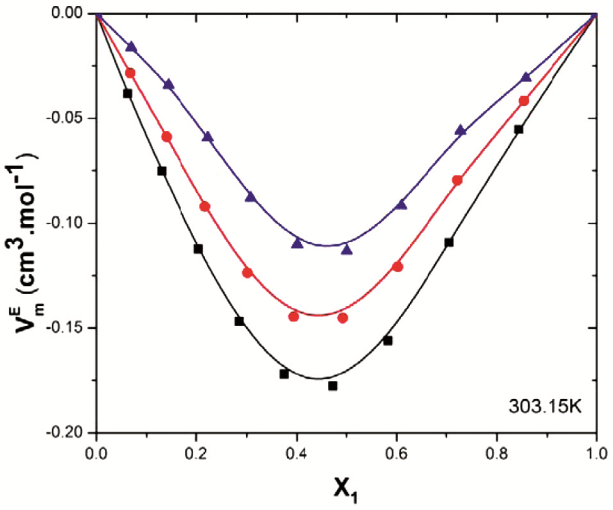


Fig. 1 — Excess molar volume ($V_m^E$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

molar volume of pure components[23]. The negative contributions also come from changes of free volume in the real mixtures due to physical, chemical, and structural characteristics of liquids[24]. In present case, negative $V_m^E$ values indicate that there is a volume contraction on mixing which may result from physical and non-specific interactions between p-cymene and selected halo benzenes.

$V_m^E$ values are negative and these values become less negative as the mixture changes from p-cymene + fluorobenzene to p-cymene + bromobenzene, suggesting that intermolecular interactions are strong in fluorobenzene binary mixture as compared to chloro- and bromobenzene binary mixtures. There are four possibilities for the interaction between these molecules; (i) due to high electronegativity of fluorine atom; fluorobenzene molecules are attracted by the hydrogen atom of p-cymene molecules which are hydrogen rich molecules, and bonding is possible between fluorine and hydrogen atom (ii) $\pi$-$\pi$ interaction like benzene dimer and may be slipped parallel, T-shaped or sandwich between two molecules (iii) CH/ $\pi$ interaction; the methyl group of p-Cymene is the potential electron donating group to the aromatic ring[25] causes the attraction between a C-H bond and $\pi$ system of the aromatic ring of halo benzenes (iv) geometrical fitting of the halo benzene molecules in the void of the p-cymene molecules.

This may be due to fact that the size of the haloatom increases from fluorine to bromine atom and also electronegativity decreases. The H-bond formation between the halo atom and hydrogen strongly depend on the electronegativity of the halo atoms. This interactions become weaker in chloro- and bromobenzene binary mixtures when compared to fluorobenzene binary mixtures. In case of $\pi$-$\pi$ interactions and CH/$\pi$ interactions, size of the atom is more important; when moving from fluorine to bromine atom, the size of atom increases and results weakening in intermolecular attractions. The increment in size is also affect the geometrical fitting of one molecule into another. The order of interaction of p-cymene with halobenzenes is as under

fluorobenzene > chlorobenzene > bromobenzene

### 4.2 Infinite dilution partial molar volume, ($\bar{V}_{m,i}^{o}$), excess partial molar volume, ($\bar{V}_{m,i}^{o,E}$), apparent molar volume, ($V_{m,\phi,i}$),

Infinite dilution partial molar volume, ($\bar{V}_{m,i}^{o}$), excess partial molar volume, ($\bar{V}_{m,i}^{o,E}$) and apparent molar volume, ($V_{m,\phi,i}$) are calculated for both components present in the binary mixtures (e.g. for p-cymene and halo benzenes) and the values are presented in the Table 4. The graphical variation of these properties is also given in Figs 2 to 9.The values of excess partial molar volume, ($\bar{V}_{m,i}^{o,E}$) are negative for p-cymene for all fluoro-, chloro- and bromobenzene containing binary mixtures and positive for the halobenzenes. The negative values of excess partial molar volume, ($\bar{V}_{m,i}^{o,E}$) indicate that there is a strong interaction present between unlike molecules. When p-cymeneis introduced into the halo benzene, the molar volume changes and the resultant excess partial molar volume, ($\bar{V}_{m,i}^{o,E}$) become negative. The negative values of $\bar{V}_{m,i}^{o,E}$ become less negative for p-Cymene with binary mixture changes from fluoro- to bromobenzene. It can be said that the interaction become weaker when binary mixture changes from fluoro- to bromobenzene.

Apparent molar volumes, ($V_{m,\phi,i}$) are calculated by two different methods and both results are shown in Table 5. Using Redlich-Rosenberg-Mayer equation, the infinite dilution apparent molar volume, ($V_{m,\phi,1}^{o}$) has been calculated and also the values of empirical parameters $S_v$, $B_v$ and limiting apparent molar expansibility, ($E_\phi^o$) are also calculated and the values are presented in Table 5.

Infinite dilution apparent molar volume, ($V_{m,\phi,1}^{o}$) are positive for all three binary mixtures and increase

Table 4 — Infinite dilution partial molar volume ($\bar{V}^{o}_{m,i}$), Excess partial molar volume ($\bar{V}^{o,E}_{m,i}$), Apparent molar volume ($V_{m,\phi,i}$) and Apparent molar volume ($V'_{m,\phi,i}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | Molality $m_1$ (mol·Kg$^{-1}$) | Molality $m_2$ (mol·Kg$^{-1}$) | $\bar{V}^{o}_{m,1}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o}_{m,2}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o,E}_{m,1}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o,E}_{m,2}$ (cm$^3$·mol$^{-1}$) | $V_{m,\phi,1}$ (cm$^3$·mol$^{-1}$) | $V_{m,\phi,2}$ (cm$^3$·mol$^{-1}$) | $V'_{m,\phi,1}$ (cm$^3$·mol$^{-1}$) | $V'_{m,\phi,2}$ (cm$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| p-Cymene (1) + Fluorobenzene (2) at 303.15 K | | | | | | | | | | |
| 0.0000 | - | - | 157.747 | 94.861 | -0.6697 | 0.0000 | - | - | - | - |
| 0.0624 | 0.6923 | 111.9884 | 157.849 | 94.863 | -0.5683 | 0.0023 | 157.8079 | 94.8201 | 157.7727 | 94.8579 |
| 0.1302 | 1.5577 | 49.7726 | 157.924 | 94.871 | -0.4926 | 0.0105 | 157.8334 | 94.7733 | 157.7630 | 94.8470 |
| 0.2042 | 2.6704 | 29.0340 | 157.983 | 94.889 | -0.4339 | 0.0283 | 157.8668 | 94.7194 | 157.7563 | 94.8308 |
| 0.2853 | 4.1539 | 18.6647 | 158.035 | 94.922 | -0.3822 | 0.0615 | 157.9064 | 94.6568 | 157.7524 | 94.8094 |
| 0.3745 | 6.2309 | 12.4432 | 158.089 | 94.976 | -0.3275 | 0.1150 | 157.9591 | 94.5865 | 157.7670 | 94.7826 |
| 0.4732 | 9.3463 | 8.2954 | 158.155 | 95.049 | -0.2618 | 0.1883 | 158.0379 | 94.5202 | 157.8283 | 94.7553 |
| 0.5828 | 14.5387 | 5.3328 | 158.234 | 95.128 | -0.1826 | 0.2675 | 158.1497 | 94.4872 | 157.9582 | 94.7424 |
| 0.7055 | 24.9234 | 3.1108 | 158.319 | 95.184 | -0.0975 | 0.3236 | 158.2628 | 94.4915 | 158.1277 | 94.7250 |
| 0.8435 | 56.0777 | 1.3826 | 158.390 | 95.204 | -0.0272 | 0.3432 | 158.3513 | 94.5073 | 158.2877 | 94.6538 |
| 1.0000 | - | - | 158.417 | 95.354 | 0.0000 | 0.4933 | - | - | - | - |
| p-Cymene (1) + Fluorobenzene (2) at 308.15 K | | | | | | | | | | |
| 0.0000 | - | - | 158.486 | 95.430 | -0.6852 | 0.0000 | - | - | - | - |
| 0.0624 | 0.6932 | 111.8511 | 158.594 | 95.432 | -0.5780 | 0.0024 | 158.5213 | 95.3862 | 158.5134 | 95.4266 |
| 0.1302 | 1.5596 | 49.7116 | 158.672 | 95.440 | -0.4992 | 0.0107 | 158.5612 | 95.3381 | 158.5152 | 95.4167 |
| 0.2042 | 2.6736 | 28.9984 | 158.732 | 95.458 | -0.4392 | 0.0288 | 158.5964 | 95.2817 | 158.5071 | 95.4005 |
| 0.2853 | 4.1590 | 18.6419 | 158.784 | 95.492 | -0.3874 | 0.0624 | 158.6269 | 95.2118 | 158.4906 | 95.3747 |
| 0.3745 | 6.2385 | 12.4279 | 158.839 | 95.546 | -0.3326 | 0.1167 | 158.6959 | 95.1443 | 158.5180 | 95.3541 |
| 0.4732 | 9.3578 | 8.2853 | 158.905 | 95.620 | -0.2664 | 0.1908 | 158.7783 | 95.0758 | 158.5797 | 95.3280 |
| 0.5828 | 14.5565 | 5.3262 | 158.986 | 95.700 | -0.1858 | 0.2702 | 158.8926 | 95.0392 | 158.7099 | 95.3143 |
| 0.7055 | 24.9540 | 3.1070 | 159.073 | 95.754 | -0.0988 | 0.3249 | 159.0100 | 95.0419 | 158.8816 | 95.2965 |
| 0.8435 | 56.1465 | 1.3809 | 159.144 | 95.777 | -0.0272 | 0.3470 | 159.1015 | 95.0510 | 159.0408 | 95.2181 |
| 1.0000 | - | - | 159.172 | 95.965 | 0.0000 | 0.5353 | - | - | - | - |
| p-Cymene (1) + Fluorobenzene (2) at 313.15 K | | | | | | | | | | |
| 0.0000 | - | - | 159.233 | 96.009 | -0.7014 | 0.0000 | - | - | - | - |
| 0.0624 | 0.6941 | 111.7087 | 159.347 | 96.012 | -0.5880 | 0.0025 | 159.2460 | 95.9633 | 159.2665 | 96.0063 |
| 0.1302 | 1.5616 | 49.6483 | 159.430 | 96.020 | -0.5048 | 0.0109 | 159.2926 | 95.9129 | 159.2721 | 95.9965 |
| 0.2042 | 2.6771 | 28.9615 | 159.492 | 96.038 | -0.4422 | 0.0290 | 159.3283 | 95.8532 | 159.2620 | 95.9790 |
| 0.2853 | 4.1643 | 18.6181 | 159.546 | 96.072 | -0.3890 | 0.0626 | 159.3680 | 95.7825 | 159.2518 | 95.9545 |
| 0.3745 | 6.2465 | 12.4121 | 159.601 | 96.126 | -0.3337 | 0.1172 | 159.4397 | 95.7122 | 159.2786 | 95.9334 |
| 0.4732 | 9.3697 | 8.2747 | 159.667 | 96.201 | -0.2674 | 0.1918 | 159.5227 | 95.6384 | 159.3373 | 95.9049 |
| 0.5828 | 14.5751 | 5.3195 | 159.748 | 96.281 | -0.1868 | 0.2720 | 159.6415 | 95.5988 | 159.4685 | 95.8911 |
| 0.7055 | 24.9858 | 3.1030 | 159.835 | 96.337 | -0.0995 | 0.3276 | 159.7645 | 95.6010 | 159.6425 | 95.8756 |
| 0.8435 | 56.2181 | 1.3791 | 159.907 | 96.359 | -0.0274 | 0.3498 | 159.8600 | 95.6065 | 159.8026 | 95.7960 |
| 1.0000 | - | - | 159.935 | 96.549 | 0.0000 | 0.5398 | - | - | - | - |
| p-Cymene (1) + Chlorobenzene (2) at 303.15 K | | | | | | | | | | |
| 0.0000 | - | - | 157.972 | 102.722 | -0.4445 | 0.0000 | - | - | - | - |
| 0.0672 | 0.6401 | 103.4177 | 158.040 | 102.724 | -0.3767 | 0.0014 | 157.9945 | 102.6918 | 157.9746 | 102.7189 |
| 0.1395 | 1.4402 | 45.9634 | 158.079 | 102.730 | -0.3377 | 0.0075 | 157.9944 | 102.6537 | 157.9482 | 102.7085 |
| 0.2175 | 2.4689 | 26.8120 | 158.103 | 102.745 | -0.3142 | 0.0232 | 157.9964 | 102.6053 | 157.9129 | 102.6927 |
| 0.3018 | 3.8405 | 17.2363 | 158.124 | 102.777 | -0.2928 | 0.0549 | 158.0085 | 102.5457 | 157.8815 | 102.6722 |

(*Contd.*)

Table 4 — Infinite dilution partial molar volume ($\bar{V}^{o}_{m,i}$), Excess partial molar volume ($\bar{V}^{o,E}_{m,i}$), Apparent molar volume ($V_{m,\phi,i}$) and Apparent molar volume ($V'_{m,\phi,i}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures (*Contd*.)

| $x_1$ | Molality $m_1$ (mol·Kg$^{-1}$) | Molality $m_2$ (mol·Kg$^{-1}$) | $\bar{V}^{o}_{m,1}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o}_{m,2}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o,E}_{m,1}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o,E}_{m,2}$ (cm$^3$·mol$^{-1}$) | $V_{m,\phi,1}$ (cm$^3$·mol$^{-1}$) | $V_{m,\phi,2}$ (cm$^3$·mol$^{-1}$) | $V'_{m,\phi,1}$ (cm$^3$·mol$^{-1}$) | $V'_{m,\phi,2}$ (cm$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| p-Cymene (1) + Chlorobenzene (2) at 303.15 K | | | | | | | | | | |
| 0.3934 | 5.7607 | 11.4909 | 158.155 | 102.829 | -0.2617 | 0.1063 | 158.0442 | 102.4805 | 157.8803 | 102.6503 |
| 0.4931 | 8.6411 | 7.6606 | 158.203 | 102.895 | -0.2135 | 0.1724 | 158.1220 | 102.4353 | 157.9447 | 102.6430 |
| 0.6021 | 13.4417 | 4.9247 | 158.269 | 102.957 | -0.1481 | 0.2345 | 158.2208 | 102.4256 | 158.0659 | 102.6497 |
| 0.7217 | 23.0430 | 2.8727 | 158.340 | 102.988 | -0.0764 | 0.2655 | 158.3044 | 102.4304 | 158.2020 | 102.6286 |
| 0.8537 | 51.8467 | 1.2768 | 158.397 | 103.002 | -0.0197 | 0.2797 | 158.3684 | 102.4391 | 158.3205 | 102.5543 |
| 1.0000 | - | - | 158.417 | 103.233 | 0.0000 | 0.5111 | - | - | - | - |
| p-Cymene (1) + Chlorobenzene (2) at 308.15 K | | | | | | | | | | |
| 0.0000 | - | - | 158.730 | 103.231 | -0.4412 | 0.0000 | - | - | - | - |
| 0.0672 | 0.6402 | 103.3980 | 158.805 | 103.233 | -0.3666 | 0.0014 | 158.7520 | 103.2010 | 158.7393 | 103.2278 |
| 0.1395 | 1.4405 | 45.9547 | 158.846 | 103.238 | -0.3253 | 0.0071 | 158.7597 | 103.1644 | 158.7218 | 103.2181 |
| 0.2175 | 2.4694 | 26.8069 | 158.869 | 103.253 | -0.3029 | 0.0222 | 158.7543 | 103.1152 | 158.6796 | 103.2008 |
| 0.3018 | 3.8412 | 17.2330 | 158.887 | 103.284 | -0.2844 | 0.0533 | 158.7679 | 103.0566 | 158.6491 | 103.1816 |
| 0.3934 | 5.7618 | 11.4887 | 158.915 | 103.336 | -0.2568 | 0.1044 | 158.7986 | 102.9893 | 158.6414 | 103.1584 |
| 0.4931 | 8.6428 | 7.6591 | 158.960 | 103.402 | -0.2114 | 0.1706 | 158.8782 | 102.9458 | 158.7060 | 103.1545 |
| 0.6021 | 13.4443 | 4.9237 | 159.024 | 103.463 | -0.1477 | 0.2321 | 158.9769 | 102.9366 | 158.8260 | 103.1638 |
| 0.7217 | 23.0474 | 2.8722 | 159.095 | 103.492 | -0.0763 | 0.2611 | 159.0598 | 102.9411 | 158.9608 | 103.1434 |
| 0.8537 | 51.8566 | 1.2765 | 159.152 | 103.506 | -0.0196 | 0.2747 | 159.1233 | 102.9494 | 159.0771 | 103.0686 |
| 1.0000 | - | - | 159.172 | 103.760 | 0.0000 | 0.5284 | - | - | - | - |
| p-Cymene (1) + Chlorobenzene (2) at 313.15 K | | | | | | | | | | |
| 0.0000 | - | - | 159.499 | 103.748 | -0.4358 | 0.0000 | - | - | - | - |
| 0.0672 | 0.6403 | 103.3765 | 159.572 | 103.749 | -0.3621 | 0.0013 | 159.5130 | 103.7172 | 159.5075 | 103.7443 |
| 0.1395 | 1.4408 | 45.9451 | 159.613 | 103.755 | -0.3218 | 0.0070 | 159.5178 | 103.6800 | 159.4867 | 103.7341 |
| 0.2175 | 2.4699 | 26.8013 | 159.634 | 103.770 | -0.3002 | 0.0220 | 159.5170 | 103.6315 | 159.4487 | 103.7180 |
| 0.3018 | 3.8420 | 17.2294 | 159.652 | 103.800 | -0.2824 | 0.0529 | 159.5305 | 103.5728 | 159.4175 | 103.6991 |
| 0.3934 | 5.7630 | 11.4863 | 159.679 | 103.851 | -0.2554 | 0.1038 | 159.5597 | 103.5045 | 159.4077 | 103.6754 |
| 0.4931 | 8.6446 | 7.6575 | 159.724 | 103.917 | -0.2105 | 0.1695 | 159.6403 | 103.4613 | 159.4727 | 103.6726 |
| 0.6021 | 13.4471 | 4.9227 | 159.787 | 103.978 | -0.1472 | 0.2302 | 159.7398 | 103.4529 | 159.5928 | 103.6834 |
| 0.7217 | 23.0522 | 2.8716 | 159.858 | 104.006 | -0.0761 | 0.2579 | 159.8227 | 103.4575 | 159.7268 | 103.6640 |
| 0.8537 | 51.8674 | 1.2763 | 159.915 | 104.017 | -0.0195 | 0.2696 | 159.8863 | 103.4660 | 159.8419 | 103.5904 |
| 1.0000 | - | - | 159.935 | 104.269 | 0.0000 | 0.5211 | - | - | - | - |
| p-Cymene (1) + Bromobenzene (2) at 303.15 K | | | | | | | | | | |
| 0.0000 | - | - | 158.129 | 105.949 | -0.2880 | 0.0000 | - | - | - | - |
| 0.0692 | 0.4733 | 100.2679 | 158.227 | 105.949 | -0.1900 | 0.0002 | 158.1832 | 105.9317 | 158.1810 | 105.9459 |
| 0.1432 | 1.0649 | 44.5635 | 158.264 | 105.951 | -0.1526 | 0.0014 | 158.1758 | 105.9088 | 158.1674 | 105.9343 |
| 0.2228 | 1.8256 | 25.9954 | 158.265 | 105.958 | -0.1523 | 0.0092 | 158.1546 | 105.8739 | 158.1225 | 105.9176 |
| 0.3084 | 2.8398 | 16.7113 | 158.251 | 105.981 | -0.1658 | 0.0322 | 158.1358 | 105.8238 | 158.0636 | 105.8977 |
| 0.4008 | 4.2597 | 11.1409 | 158.245 | 106.025 | -0.1723 | 0.0762 | 158.1346 | 105.7603 | 158.0207 | 105.8755 |
| 0.5008 | 6.3895 | 7.4272 | 158.260 | 106.085 | -0.1572 | 0.1358 | 158.1893 | 105.7208 | 158.0540 | 105.8785 |
| 0.6095 | 9.9392 | 4.7747 | 158.300 | 106.137 | -0.1167 | 0.1882 | 158.2732 | 105.7249 | 158.1526 | 105.9070 |
| 0.7279 | 17.0386 | 2.7852 | 158.356 | 106.153 | -0.0613 | 0.2037 | 158.3370 | 105.7353 | 158.2608 | 105.8992 |

(*Contd*.)

Table 4 — Infinite dilution partial molar volume ($\bar{V}^{o}_{m,i}$), Excess partial molar volume ($\bar{V}^{o,E}_{m,i}$), Apparent molar volume ($V_{m,\phi,i}$) and Apparent molar volume ($V'_{m,\phi,i}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures (*Contd*.)

| $x_1$ | Molality $m_1$ (mol·Kg$^{-1}$) | Molality $m_2$ (mol·Kg$^{-1}$) | $\bar{V}^{o}_{m,1}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o}_{m,2}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o,E}_{m,1}$ (cm$^3$·mol$^{-1}$) | $\bar{V}^{o,E}_{m,2}$ (cm$^3$·mol$^{-1}$) | $V_{m,\phi,1}$ (cm$^3$·mol$^{-1}$) | $V_{m,\phi,2}$ (cm$^3$·mol$^{-1}$) | $V'_{m,\phi,1}$ (cm$^3$·mol$^{-1}$) | $V'_{m,\phi,2}$ (cm$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| p-Cymene (1) + Bromobenzene (2) at 303.15 K | | | | | | | | | | |
| 0.8575 | 38.3369 | 1.2379 | 158.402 | 106.164 | -0.0149 | 0.2153 | 158.3812 | 105.7343 | 158.3454 | 105.8239 |
| 1.0000 | - | - | 158.417 | 106.506 | 0.0000 | 0.5571 | - | - | - | - |
| p-Cymene (1) + Bromobenzene (2) at 308.15 K | | | | | | | | | | |
| 0.0000 | - | - | 158.864 | 106.435 | -0.3078 | 0.0000 | - | - | - | - |
| 0.0692 | 0.4732 | 100.2858 | 158.971 | 106.435 | -0.2004 | 0.0003 | 158.9386 | 106.4175 | 158.9236 | 106.4316 |
| 0.1432 | 1.0647 | 44.5715 | 159.015 | 106.436 | -0.1570 | 0.0016 | 158.9390 | 106.3960 | 158.9188 | 106.4204 |
| 0.2228 | 1.8252 | 26.0000 | 159.018 | 106.444 | -0.1535 | 0.0093 | 158.9183 | 106.3623 | 158.8759 | 106.4034 |
| 0.3084 | 2.8393 | 16.7143 | 159.006 | 106.467 | -0.1656 | 0.0322 | 158.8991 | 106.3133 | 158.8181 | 106.3832 |
| 0.4008 | 4.2589 | 11.1429 | 159.000 | 106.511 | -0.1718 | 0.0760 | 158.8976 | 106.2516 | 158.7763 | 106.3613 |
| 0.5008 | 6.3883 | 7.4286 | 159.015 | 106.570 | -0.1569 | 0.1356 | 158.9515 | 106.2140 | 158.8098 | 106.3648 |
| 0.6095 | 9.9374 | 4.7755 | 159.055 | 106.623 | -0.1166 | 0.1879 | 159.0332 | 106.2189 | 158.9076 | 106.3927 |
| 0.7279 | 17.0356 | 2.7857 | 159.110 | 106.638 | -0.0612 | 0.2034 | 159.0954 | 106.2310 | 159.0157 | 106.3846 |
| 0.8575 | 38.3300 | 1.2381 | 159.157 | 106.652 | -0.0148 | 0.2172 | 159.1374 | 106.2290 | 159.0993 | 106.3059 |
| 1.0000 | - | - | 159.172 | 107.009 | 0.0000 | 0.5744 | - | - | - | - |
| p-Cymene (1) + Bromobenzene (2) at 313.15 K | | | | | | | | | | |
| 0.0000 | - | - | 159.612 | 106.926 | -0.3224 | 0.0000 | - | - | - | - |
| 0.0692 | 0.4731 | 100.3035 | 159.726 | 106.926 | -0.2081 | 0.0003 | 159.7056 | 106.9091 | 159.6781 | 106.9228 |
| 0.1432 | 1.0645 | 44.5793 | 159.774 | 106.928 | -0.1606 | 0.0018 | 159.7098 | 106.8885 | 159.6780 | 106.9118 |
| 0.2228 | 1.8249 | 26.0046 | 159.779 | 106.936 | -0.1551 | 0.0095 | 159.6898 | 106.8560 | 159.6371 | 106.8948 |
| 0.3084 | 2.8388 | 16.7173 | 159.768 | 106.958 | -0.1666 | 0.0324 | 159.6702 | 106.8083 | 159.5800 | 106.8747 |
| 0.4008 | 4.2581 | 11.1448 | 159.762 | 107.002 | -0.1727 | 0.0763 | 159.6680 | 106.7479 | 159.5384 | 106.8531 |
| 0.5008 | 6.3872 | 7.4299 | 159.777 | 107.062 | -0.1579 | 0.1361 | 159.7208 | 106.7118 | 159.5721 | 106.8570 |
| 0.6095 | 9.9357 | 4.7764 | 159.817 | 107.114 | -0.1174 | 0.1882 | 159.8022 | 106.7197 | 159.6712 | 106.8866 |
| 0.7279 | 17.0326 | 2.7862 | 159.873 | 107.129 | -0.0615 | 0.2028 | 159.8625 | 106.7336 | 159.7793 | 106.8783 |
| 0.8575 | 38.3233 | 1.2383 | 159.920 | 107.143 | -0.0148 | 0.2167 | 159.9024 | 106.7331 | 159.8625 | 106.7981 |
| 1.0000 | - | - | 159.935 | 107.511 | 0.0000 | 0.5852 | - | - | - | - |

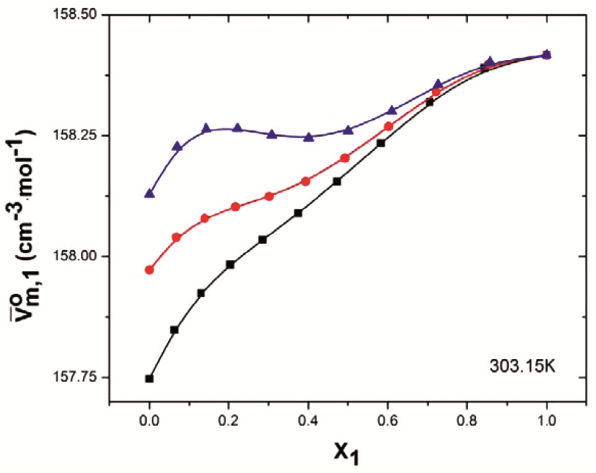


Fig. 2 — Infinite dilution partial molar volume ($\bar{V}^{o}_{m,1}$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

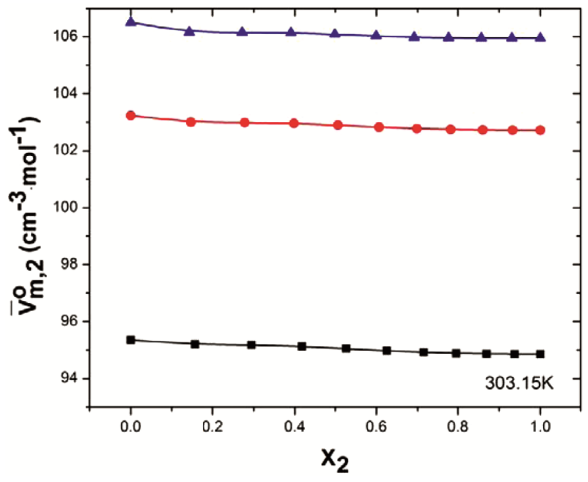


Fig. 3 — Infinite dilution partial molar volume ($\bar{V}^{o}_{m,2}$) as a function of mole fraction ($X_2$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

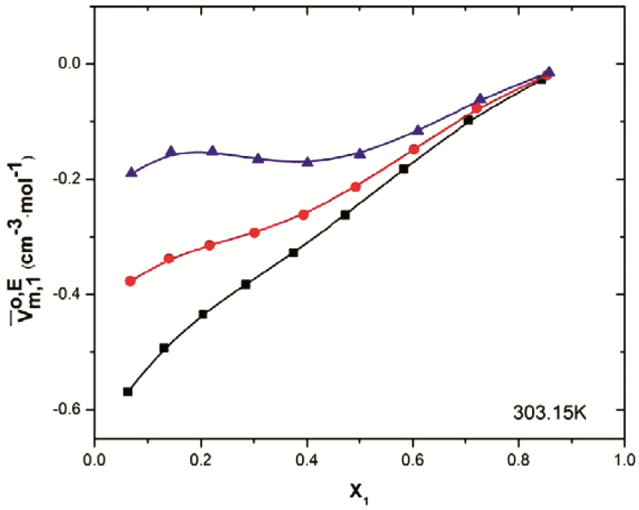


Fig. 4 — Infinite dilution excess partial molar volume ($\bar{V}^{o,E}_{m,1}$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

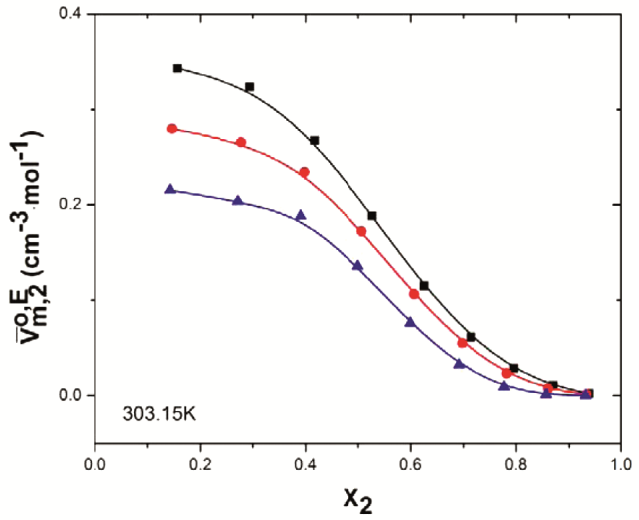


Fig. 5 — Infinite dilution excess partial molar volume ($\bar{V}^{o,E}_{m,2}$) as a function of mole fraction ($X_2$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

with rise in temperature. The increasing trend in $V^{o}_{m,\phi,1}$ suggest that attraction between the solvent and solute molecules become weaker at higher temperatures. The values of limiting apparent molar expansibility, ($E^{o}_{\phi}$) also increases with temperature supports the view that at higher temperature solute molecules show expansion and the attraction towards the solvent molecules

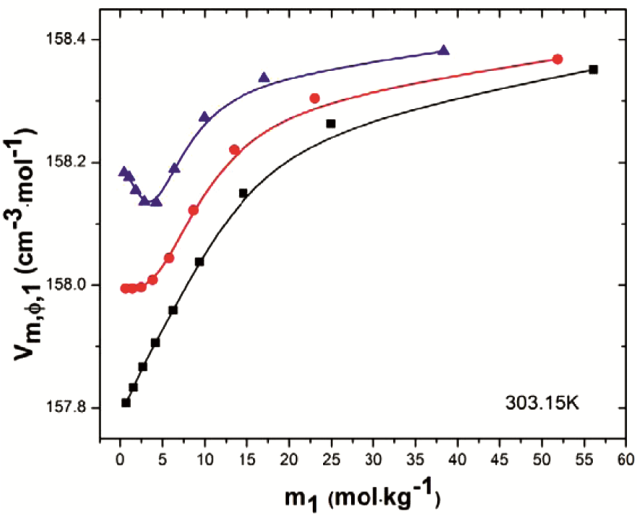


Fig. 6 — Apparent molar volume ($V_{m,\phi,1}$) as a function of molality, ($m_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

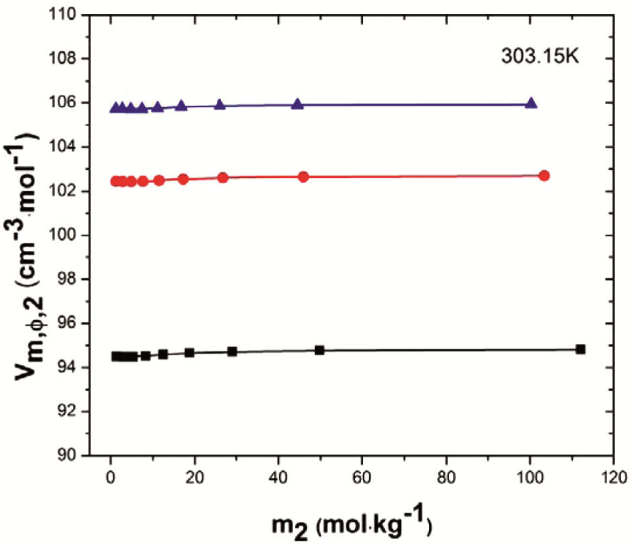


Fig. 7 — Apparent molar volume ($V_{m,\phi,2}$) as a function of molality ($m_2$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

become weaker. Empirical parameter $S_v$ have negative and $B_v$ have positive values for all binary mixtures. When there is a presence of strong electrostatic type interaction between the charged atoms, the empirical parameters $S_v$ and $B_v$ have large positive values[26].

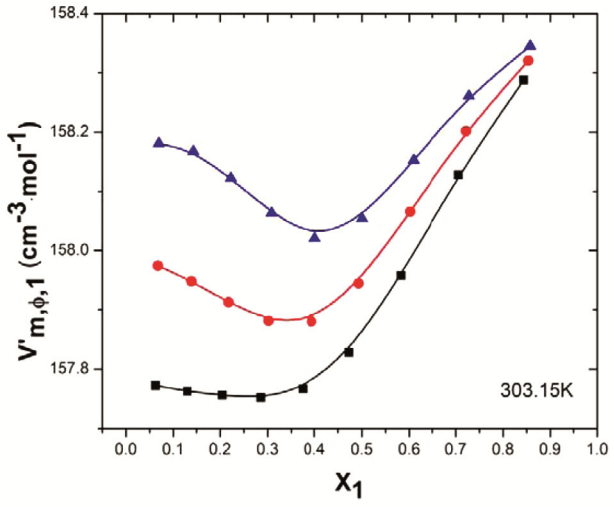


Fig. 8 — Apparent molar volume ($V'_{m,\phi,1}$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

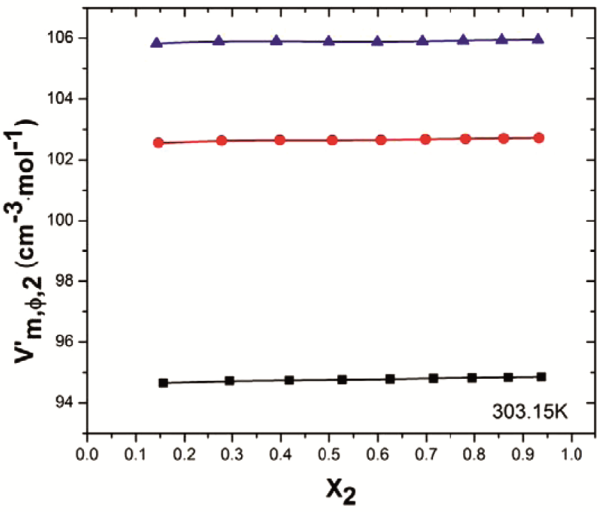


Fig. 9 — Apparent molar volume ($V'_{m,\phi,2}$) as a function of mole fraction ($X_2$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

Table 5 — Infinite dilution apparent molar volume ($V^o_{m,\phi,1}$), Empirical parameters $S_v$ and $B_v$ of Redlich-Rosenberg-Mayer equation with Standard deviation ($\sigma$)and The limiting apparent molar expansibility ($E^o_\phi$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $T$ (K) | $V^o_{m,\phi,1}$ ($cm^3.mol^{-1}$) | $S_v$ ($cm^3.mol^{-(3/2)}.kg^{(1/2)}$) | $B_v$ ($cm^3.mol^{-2}.kg$) | $\sigma$ | $E^o_\phi$ ($cm^3.mol^{-1}.K^{-1}$) |
|---|---|---|---|---|---|
| p-Cymene (1) + Fluorobenzene (2) | | | | | |
| 303.15 | 157.887 | -0.0400821 | 0.0299590 | 0.097732 | 0.1445 |
| 308.15 | 158.614 | -0.0395755 | 0.0302123 | 0.105355 | 0.1463 |
| 313.15 | 159.350 | -0.0390766 | 0.0304617 | 0.111912 | 0.1481 |
| p-Cymene (1) + Chlorobenzene (2) | | | | | |
| 303.15 | 158.018 | -0.0419436 | 0.0290282 | 0.071438 | 0.1513 |
| 308.15 | 158.776 | -0.0420395 | 0.0289803 | 0.070304 | 0.1519 |
| 313.15 | 159.537 | -0.0419970 | 0.0290015 | 0.070842 | 0.1525 |
| p-Cymene (1) + Bromobenzene (2) | | | | | |
| 303.15 | 158.919 | -0.0433418 | 0.0283291 | 0.933800 | 0.1512 |
| 308.15 | 158.919 | -0.0434911 | 0.0282544 | 0.045245 | 0.1532 |
| 313.15 | 159.690 | -0.0436318 | 0.0281841 | 0.044550 | 0.1552 |

### 4.3 Speed of sound, $(U)$ and deviation in speed of sound, $(\Delta U)$

Deviation in the speed of sound, $(\Delta U)$are calculated from the experimentally measured speed of sound, $(U)$ over the whole composition range and at all studied temperatures. The values of $U$ and $(\Delta U)$are given in Table 6. The graphical variation of $\Delta U$ values as function of mole fraction, $(x_1)$ of p-cymene is shown in Fig. 10 at 303.15 K. $\Delta U$ values are positive for p-cymene + fluorobenzene and + chlorobenzene binary mixtures and negative for p-cymene + bromobenzene binary mixtures. Highest $\Delta U$ values are obtained for p-cymene + fluorobenzene binary mixtures. With increase in temperature, $\Delta U$values systematically decrease.

In general, positive deviation in $\Delta u$ values indicate the presence of strong interaction and negative deviation in $\Delta U$ indicate the presence of weak interactions between the unlike molecules[27,28]. The positive $\Delta U$ values support that there is a strong

Table 6 — Speed of sound ($\boldsymbol{U}$) and Deviation in speed of sound ($\boldsymbol{\Delta U}$)of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | $U$ (m·s$^{-1}$) | | | $\Delta U$ (m·s$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 303.15 K | 308.15 K | 313.15 K | 303.15 K | 308.15 K | 313.15 K |
| p-Cymene (1) + Fluorobenzene (2) | | | | | | |
| 0.0000 | 1145.29 | 1125.26 | 1105.04 | 0.00 | 0.00 | 0.00 |
| 0.0624 | 1157.47 | 1137.43 | 1117.26 | 2.95 | 2.90 | 2.87 |
| 0.1302 | 1169.85 | 1149.91 | 1129.79 | 5.29 | 5.30 | 5.24 |
| 0.2042 | 1183.06 | 1163.18 | 1143.15 | 7.55 | 7.57 | 7.51 |
| 0.2853 | 1196.27 | 1176.18 | 1156.45 | 8.76 | 8.51 | 8.65 |
| 0.3745 | 1211.15 | 1191.14 | 1171.21 | 10.43 | 10.21 | 10.04 |
| 0.4732 | 1226.44 | 1206.61 | 1186.83 | 11.12 | 11.02 | 10.88 |
| 0.5828 | 1241.84 | 1222.03 | 1202.62 | 10.29 | 10.14 | 10.23 |
| 0.7055 | 1257.99 | 1238.31 | 1219.01 | 8.30 | 8.20 | 8.25 |
| 0.8435 | 1275.62 | 1256.07 | 1236.61 | 5.50 | 5.44 | 5.17 |
| 1.0000 | 1293.28 | 1273.89 | 1254.90 | 0.00 | 0.00 | 0.00 |
| p-Cymene (1) + Chlorobenzene (2) | | | | | | |
| 0.0000 | 1249.33 | 1231.22 | 1212.98 | 0.00 | 0.00 | 0.00 |
| 0.0672 | 1252.82 | 1234.61 | 1216.27 | 0.54 | 0.52 | 0.47 |
| 0.1395 | 1256.70 | 1238.24 | 1219.77 | 1.24 | 1.07 | 0.94 |
| 0.2175 | 1260.41 | 1242.01 | 1223.43 | 1.52 | 1.51 | 1.33 |
| 0.3018 | 1264.64 | 1246.04 | 1227.32 | 2.05 | 1.94 | 1.69 |
| 0.3934 | 1268.93 | 1250.30 | 1231.49 | 2.31 | 2.30 | 2.02 |
| 0.4931 | 1273.35 | 1254.32 | 1235.67 | 2.35 | 2.06 | 2.02 |
| 0.6021 | 1277.98 | 1258.86 | 1240.11 | 2.19 | 1.95 | 1.89 |
| 0.7217 | 1282.88 | 1263.66 | 1244.83 | 1.83 | 1.64 | 1.59 |
| 0.8537 | 1287.99 | 1268.67 | 1249.76 | 1.14 | 1.02 | 0.99 |
| 1.0000 | 1293.28 | 1273.89 | 1254.90 | 0.00 | 0.00 | 0.00 |
| p-Cymene (1) + Bromobenzene (2) | | | | | | |
| 0.0000 | 1138.27 | 1122.88 | 1107.62 | 0.00 | 0.00 | 0.00 |
| 0.0692 | 1147.70 | 1132.25 | 1116.71 | -1.29 | -1.08 | -1.10 |
| 0.1432 | 1157.85 | 1142.16 | 1126.30 | -2.62 | -2.35 | -2.42 |
| 0.2228 | 1169.14 | 1153.11 | 1136.92 | -3.66 | -3.41 | -3.51 |
| 0.3084 | 1181.48 | 1165.11 | 1148.56 | -4.59 | -4.34 | -4.48 |
| 0.4008 | 1195.30 | 1178.26 | 1161.57 | -5.09 | -5.14 | -5.07 |
| 0.5008 | 1210.64 | 1193.21 | 1176.13 | -5.26 | -5.30 | -5.25 |
| 0.6095 | 1227.85 | 1209.99 | 1192.20 | -4.89 | -4.92 | -5.18 |
| 0.7279 | 1247.18 | 1228.87 | 1210.61 | -3.92 | -3.93 | -4.22 |
| 0.8575 | 1268.92 | 1250.09 | 1231.33 | -2.28 | -2.29 | -2.59 |
| 1.0000 | 1293.28 | 1273.89 | 1254.90 | 0.00 | 0.00 | 0.00 |

Standard uncertainties u, u($T$)= ±0.001 K, u($x$)= ±0.0001, u($U$)= ±0.1 m·s$^{-1}$. All physical quantities are measured at atmospheric pressure

interaction between p-cymene + fluorobenzene molecules. Dueto close packing of molecules in the binary mixture, sound waves can easily pass through the molecules and deviation in speed of sound, ($\Delta U$) values become positive.

#### 4.4 Theoretical relations of speed of sound

Various theoretical speed of sound and average deviations were calculated using well established equation like Nomoto,($U_{nmt}$), Ideal Mixing Rule, ($U_{imr}$), Junji, ($U_{junji}$), and Jacobson's Free Length Theory, ($U_{flt}$)and their average deviation ($\sigma$) are listed in Table 7.

It can be observed from data that

(i) Ideal mixture relation ($U_{imr}$) have highest values for p-cymene + fluorobenzene and + chlorobenzene binary mixtures. For bromobenzene containing binary mixture, highest $\sigma$ values are obtained for free length theory, ($U_{flt}$).

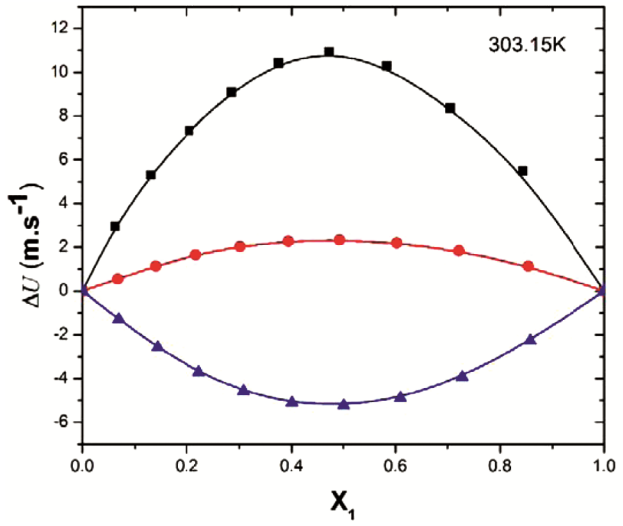


Fig. 10 — Deviation in speed of sound ($\Delta U$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

(ii) Lowest $\sigma$ values are obtained for $U_{junji}$, $U_{nmt}$ and $U_{imr}$ for p-cymene + fluorobenzene, + chlorobenzene and + bromobenzene binary mixtures respectively at all studied temperatures.

### 4.5 Isentropic compressibility, $(\kappa_s)$, acoustical impedances, $(z)$ and intermolecular free length, $(L_f)$

From the experimentally measured speed of sound, $(U)$; isentropic compressibility, $(\kappa_s)$, acoustical impedances, $(z)$ and intermolecular free length, $(L_f)$ are calculated and their values are listed in Table 8, 9 and 10 respectively.

Values of $\kappa_s$ and $L_f$ increase with increase in temperature for all three binary mixtures. The volume expansion of the mixture leads to increase in $\kappa_s$and $L_f$values with rise in temperature. The value of $z$ decrease with increase in temperature which results due to less close packing of molecules with increase in temperature[29].

### 4.6 Deviation in isentropic compressibility, $(\Delta\kappa_s)$ and deviation in acoustical impedance, $(\Delta z)$

The calculated values of deviation in isentropic compressibility, $(\Delta\kappa_s)$ and deviation in acoustical impedance, $(\Delta z)$ for all binary mixtures over the whole composition range are reported in Tables 8 and 9, respectively. The graph of $\Delta\kappa_s$ and $\Delta z$ vs $x_1$ of p-cymene are given in Figs 11 and 12

Table 7 — Average deviation ($\sigma$) in the Speed of sound from various theoretical relations of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| Parameters | $T$ (K) | | |
|---|---|---|---|
| | 303.15 | 308.15 | 313.15 |
| p-Cymene (1) + Fluorobenzene (2) | | | |
| $U_{nmt}$ | 0.403 | 0.419 | 0.432 |
| $U_{imr}$ | 2.690 | 2.722 | 2.766 |
| $U_{junji}$ | 0.193 | 0.205 | 0.213 |
| $U_{flt}$ | 0.362 | 0.348 | 0.330 |
| p-Cymene (1) + Chlorobenzene (2) | | | |
| $U_{nmt}$ | 0.132 | 0.136 | 0.143 |
| $U_{imr}$ | 0.550 | 0.539 | 0.532 |
| $U_{junji}$ | 0.333 | 0.330 | 0.323 |
| $U_{flt}$ | 0.472 | 0.432 | 0.403 |
| p-Cymene (1) + Bromobenzene (2) | | | |
| $U_{nmt}$ | 0.154 | 0.144 | 0.149 |
| $U_{imr}$ | 0.019 | 0.020 | 0.033 |
| $U_{junji}$ | 0.739 | 0.759 | 0.762 |
| $U_{flt}$ | 1.224 | 1.140 | 1.078 |

nmt = Nomoto, imr = Ideal mixture relation, junji= Junji , flt = Free length Theory

respectively. $\Delta\kappa_s$values are negative for p-cymene + fluorobenzene binary mixture and positive for p-cymene + chlorobenzene and + bromobenzene binary mixtures. The values of $\Delta\kappa_s$change from negative to positive when binary mixture changes from fluorobenzene to bromobenzene .$\Delta z$ values are negative for all binary mixture at all studied temperature.$\Delta z$ values become negative to more negative when binary mixtures change from fluorobenzene to bromobenzene.

In general, negative $\Delta\kappa_s$values indicate for strong interaction and positive $\Delta\kappa_s$ values indicate for weak interaction present between mixed components[30]. Negative $\Delta z$ values indicate for weak intermolecular interaction in binary mixture[31].The trend and magnitude of $\Delta\kappa_s$ values show that there is strong interaction present between p-cymene + fluorobenzene binary mixture when compared to chlorobenzene and bromobenzene containing binary mixtures. When there is a strong interaction, the molecules in binary mixture are close to each other and resultant isentropic compressibility, $(\kappa_s)$ are less than its pure value. $\Delta z$ values also support the view that interaction become weaker when binary mixture changes from fluorobenzene to bromobenzene.

Table 8 — Isentropic compressibility ($\kappa_s$) and Deviation in isentropic compressibility ($\Delta\kappa_s$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | $\kappa_s$ (TPa$^{-1}$) | | | $\Delta\kappa_s$ (TPa$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 303.15 K | 308.15 K | 313.15 K | 303.15 K | 308.15 K | 313.15 K |
| p-Cymene (1) + Fluorobenzene (2) | | | | | | |
| 0.0000 | 752.52 | 784.22 | 818.13 | 0.00 | 0.00 | 0.00 |
| 0.0624 | 748.74 | 779.91 | 813.13 | -0.86 | -0.98 | -1.17 |
| 0.1302 | 745.13 | 775.63 | 808.18 | -1.30 | -1.64 | -1.96 |
| 0.2042 | 740.90 | 770.76 | 802.54 | -2.06 | -2.56 | -3.05 |
| 0.2853 | 737.14 | 766.72 | 797.52 | -2.02 | -2.27 | -3.09 |
| 0.3745 | 731.85 | 760.73 | 791.11 | -3.14 | -3.50 | -4.02 |
| 0.4732 | 726.69 | 754.72 | 784.22 | -3.69 | -4.24 | -4.85 |
| 0.5828 | 722.07 | 749.50 | 777.89 | -3.17 | -3.60 | -4.45 |
| 0.7055 | 717.20 | 743.89 | 771.50 | -2.30 | -2.67 | -3.31 |
| 0.8435 | 711.20 | 737.09 | 764.21 | -1.85 | -2.10 | -2.12 |
| 1.0000 | 705.72 | 730.83 | 756.73 | 0.00 | 0.00 | 0.00 |
| p-Cymene (1) + Chlorobenzene (2) | | | | | | |
| 0.0000 | 584.69 | 605.00 | 626.45 | 0.00 | 0.00 | 0.00 |
| 0.0672 | 594.77 | 615.48 | 637.34 | 1.95 | 2.02 | 2.13 |
| 0.1395 | 604.99 | 626.24 | 648.56 | 3.42 | 3.69 | 3.93 |
| 0.2175 | 615.91 | 637.42 | 660.18 | 4.90 | 5.05 | 5.40 |
| 0.3018 | 626.92 | 648.94 | 672.19 | 5.70 | 5.96 | 6.42 |
| 0.3934 | 638.53 | 660.90 | 684.59 | 6.23 | 6.41 | 6.90 |
| 0.4931 | 650.79 | 673.95 | 697.84 | 6.42 | 6.91 | 7.16 |
| 0.6021 | 663.67 | 687.30 | 711.69 | 6.12 | 6.54 | 6.80 |
| 0.7217 | 677.07 | 701.18 | 726.06 | 5.03 | 5.37 | 5.58 |
| 0.8537 | 691.06 | 715.68 | 741.05 | 3.04 | 3.25 | 3.38 |
| 1.0000 | 705.72 | 730.83 | 756.73 | 0.00 | 0.00 | 0.00 |
| p-Cymene (1) + Bromobenzene (2) | | | | | | |
| 0.0000 | 520.82 | 537.65 | 555.11 | 0.00 | 0.00 | 0.00 |
| 0.0692 | 535.14 | 552.37 | 570.48 | 1.53 | 1.36 | 1.42 |
| 0.1432 | 550.34 | 568.18 | 587.01 | 3.04 | 2.86 | 3.02 |
| 0.2228 | 566.18 | 584.73 | 604.31 | 4.17 | 4.05 | 4.29 |
| 0.3084 | 582.95 | 602.24 | 622.62 | 5.11 | 5.02 | 5.34 |
| 0.4008 | 600.48 | 620.87 | 641.84 | 5.56 | 5.80 | 5.93 |
| 0.5008 | 619.12 | 640.34 | 662.18 | 5.70 | 5.94 | 6.10 |
| 0.6095 | 638.85 | 660.95 | 684.05 | 5.34 | 5.57 | 6.07 |
| 0.7279 | 659.70 | 682.72 | 706.82 | 4.29 | 4.45 | 4.95 |
| 0.8575 | 681.84 | 705.87 | 731.02 | 2.47 | 2.56 | 3.02 |
| 1.0000 | 705.72 | 730.83 | 756.73 | 0.00 | 0.00 | 0.00 |

**4.7 Infinite dilution partial molar isentropic compressibility, $\bar{K}^{o}_{s,m,i}$, Excess partial molar isentropic compressibility, $\bar{K}^{o,E}_{s,m,i}$ and Apparent molar isentropic compressibility, $K_{s,m,\phi,i}$**

$\bar{K}^{o}_{s,m,i}$, $\bar{K}^{o,E}_{s,m,i}$, and $K_{s,m,\phi,i}$ are calculated for both components of all binary mixtures and their value are presented in Table 11. The graphical variation of $\bar{K}^{o,E}_{s,m,i}$ and $K_{s,m,\phi,i}$ is shown in Fig. 13 to 16. $\bar{K}^{o}_{s,m,1}$ and $\bar{K}^{o}_{s,m,2}$ values are positive for al binary mixtures at all studied temperatures. With increase in temperature, these values become more positive. When binary mixture changes from fluorobenzene to bromobenzene the value of $\bar{K}^{o}_{s,m,1}$ and $\bar{K}^{o}_{s,m,2}$ become less positive i.e. decreases. For

Table 9 — Acoustical impedance ($\boldsymbol{z}$) and Deviation in acoustical impedance ($\boldsymbol{\Delta z}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | $z$ (km·m$^{-2}$·s$^{-1}$) × 10$^{-3}$ | | | $\Delta z$ (gm·m$^{-2}$·s$^{-1}$) × 10$^{-3}$ | | |
|---|---|---|---|---|---|---|
| | 303.15 K | 308.15 K | 313.15 K | 303.15 K | 308.15 K | 313.15 K |
| p-Cymene (1) + Fluorobenzene (2) | | | | | | |
| 0.0000 | 1.1603 | 1.1332 | 1.1061 | 0.0000 | 0.0000 | 0.0000 |
| 0.0624 | 1.1539 | 1.1273 | 1.1007 | -0.0024 | -0.0022 | -0.0021 |
| 0.1302 | 1.1472 | 1.1212 | 1.0952 | -0.0047 | -0.0043 | -0.0040 |
| 0.2042 | 1.1409 | 1.1154 | 1.0900 | -0.0062 | -0.0057 | -0.0053 |
| 0.2853 | 1.1340 | 1.1089 | 1.0843 | -0.0078 | -0.0074 | -0.0067 |
| 0.3745 | 1.1282 | 1.1036 | 1.0793 | -0.0079 | -0.0075 | -0.0070 |
| 0.4732 | 1.1220 | 1.0981 | 1.0744 | -0.0077 | -0.0071 | -0.0066 |
| 0.5828 | 1.1152 | 1.0918 | 1.0689 | -0.0074 | -0.0070 | -0.0063 |
| 0.7055 | 1.1084 | 1.0856 | 1.0633 | -0.0063 | -0.0059 | -0.0054 |
| 0.8435 | 1.1023 | 1.0801 | 1.0582 | -0.0035 | -0.0033 | -0.0032 |
| 1.0000 | 1.0957 | 1.0741 | 1.0531 | 0.0000 | 0.0000 | 0.0000 |
| p-Cymene (1) + Chlorobenzene (2) | | | | | | |
| 0.0000 | 1.3690 | 1.3425 | 1.3160 | 0.0000 | 0.0000 | 0.0000 |
| 0.0672 | 1.3420 | 1.3160 | 1.2900 | -0.0086 | -0.0084 | -0.0083 |
| 0.1395 | 1.3153 | 1.2896 | 1.2641 | -0.0156 | -0.0155 | -0.0153 |
| 0.2175 | 1.2882 | 1.2631 | 1.2381 | -0.0214 | -0.0210 | -0.0207 |
| 0.3018 | 1.2613 | 1.2367 | 1.2121 | -0.0252 | -0.0248 | -0.0245 |
| 0.3934 | 1.2342 | 1.2102 | 1.1861 | -0.0273 | -0.0267 | -0.0264 |
| 0.4931 | 1.2067 | 1.1829 | 1.1597 | -0.0275 | -0.0272 | -0.0267 |
| 0.6021 | 1.1790 | 1.1558 | 1.1331 | -0.0254 | -0.0251 | -0.0246 |
| 0.7217 | 1.1513 | 1.1286 | 1.1064 | -0.0204 | -0.0202 | -0.0198 |
| 0.8537 | 1.1235 | 1.1014 | 1.0798 | -0.0121 | -0.0120 | -0.0118 |
| 1.0000 | 1.0957 | 1.0741 | 1.0531 | 0.0000 | 0.0000 | 0.0000 |
| p-Cymene (1) + Bromobenzene (2) | | | | | | |
| 0.0000 | 1.6868 | 1.6564 | 1.6264 | 0.0000 | 0.0000 | 0.0000 |
| 0.0692 | 1.6282 | 1.5989 | 1.5697 | -0.0177 | -0.0172 | -0.0170 |
| 0.1432 | 1.5693 | 1.5409 | 1.5125 | -0.0328 | -0.0321 | -0.0318 |
| 0.2228 | 1.5107 | 1.4831 | 1.4555 | -0.0444 | -0.0436 | -0.0432 |
| 0.3084 | 1.4519 | 1.4252 | 1.3984 | -0.0526 | -0.0517 | -0.0512 |
| 0.4008 | 1.3932 | 1.3670 | 1.3413 | -0.0567 | -0.0561 | -0.0553 |
| 0.5008 | 1.3342 | 1.3088 | 1.2840 | -0.0566 | -0.0560 | -0.0553 |
| 0.6095 | 1.2748 | 1.2504 | 1.2262 | -0.0517 | -0.0511 | -0.0508 |
| 0.7279 | 1.2154 | 1.1919 | 1.1687 | -0.0411 | -0.0406 | -0.0404 |
| 0.8575 | 1.1558 | 1.1333 | 1.1110 | -0.0241 | -0.0238 | -0.0238 |
| 1.0000 | 1.0957 | 1.0741 | 1.0531 | 0.0000 | 0.0000 | 0.0000 |

p-cymene + fluorobenzene binary mixture $\overline{K}^{o}_{s,m,1}$ and $\overline{K}^{o}_{s,m,2}$ values are higher than chlorobenzene and bromobenzene binary mixture which suggest that p-cymene molecules are highly attracted by fluorobenzene molecules and resultant infinite dilution partial molar isentropic compressibility, ($\overline{K}^{o}_{s,m,i}$ ) are higher.

Apparent molar isentropic compressibility, $K_{s,m,\phi,i}$ are calculated by two different equations and calculated values are very close to each other. The values of infinite dilution apparent molar isentropic compressibility, $K^{o}_{s,m,\phi,1}$ with empirical parameters $S_k$ and$B_k$ of Redlich-Rosenberg-Mayer equation are given in Table 12 with standard deviation, ($\sigma$). The

Table 10 — Intermolecular free length ($L_f$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | $L_f$ (A$^0$) | | |
|---|---|---|---|
| | 303.15 K | 308.15 K | 313.15 K |
| p-Cymene (1) + Fluorobenzene (2) | | | |
| 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0624 | -0.0003 | -0.0003 | -0.0004 |
| 0.1302 | -0.0005 | -0.0006 | -0.0007 |
| 0.2042 | -0.0007 | -0.0009 | -0.0011 |
| 0.2853 | -0.0007 | -0.0008 | -0.0011 |
| 0.3745 | -0.0011 | -0.0012 | -0.0014 |
| 0.4732 | -0.0013 | -0.0015 | -0.0017 |
| 0.5828 | -0.0012 | -0.0013 | -0.0016 |
| 0.7055 | -0.0008 | -0.0009 | -0.0012 |
| 0.8435 | -0.0007 | -0.0008 | -0.0008 |
| 1.0000 | 0.0000 | 0.0000 | 0.0000 |
| p-Cymene (1) + Chlorobenzene (2) | | | |
| 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0672 | 0.0010 | 0.0010 | 0.0011 |
| 0.1395 | 0.0017 | 0.0018 | 0.0019 |
| 0.2175 | 0.0025 | 0.0025 | 0.0027 |
| 0.3018 | 0.0029 | 0.0030 | 0.0032 |
| 0.3934 | 0.0031 | 0.0032 | 0.0034 |
| 0.4931 | 0.0032 | 0.0034 | 0.0035 |
| 0.6021 | 0.0030 | 0.0032 | 0.0033 |
| 0.7217 | 0.0025 | 0.0026 | 0.0027 |
| 0.8537 | 0.0015 | 0.0016 | 0.0016 |
| 1.0000 | 0.0000 | 0.0000 | 0.0000 |
| p-Cymene (1) + Bromobenzene (2) | | | |
| 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0692 | 0.0011 | 0.0010 | 0.0011 |
| 0.1432 | 0.0021 | 0.0021 | 0.0022 |
| 0.2228 | 0.0029 | 0.0029 | 0.0030 |
| 0.3084 | 0.0035 | 0.0035 | 0.0037 |
| 0.4008 | 0.0038 | 0.0039 | 0.0040 |
| 0.5008 | 0.0039 | 0.0040 | 0.0041 |
| 0.6095 | 0.0036 | 0.0037 | 0.0040 |
| 0.7279 | 0.0029 | 0.0030 | 0.0032 |
| 0.8575 | 0.0017 | 0.0017 | 0.0019 |
| 1.0000 | 0.0000 | 0.0000 | 0.0000 |

value of $K^o_{s,m,\phi,1}$ are affected by two factors, such as (i) Presence of intermolecular free space gives more compressibility and gives positive effect due to solvent intrinsic compressibility of large sized organic

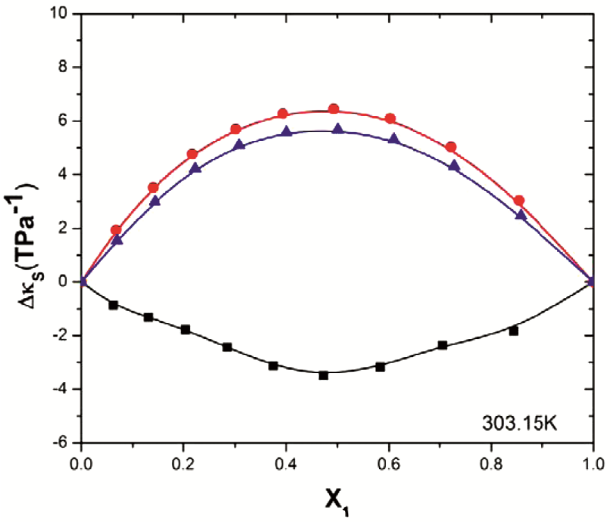


Fig. 11 — Deviation in isentropic compressibility ($\Delta\kappa_s$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

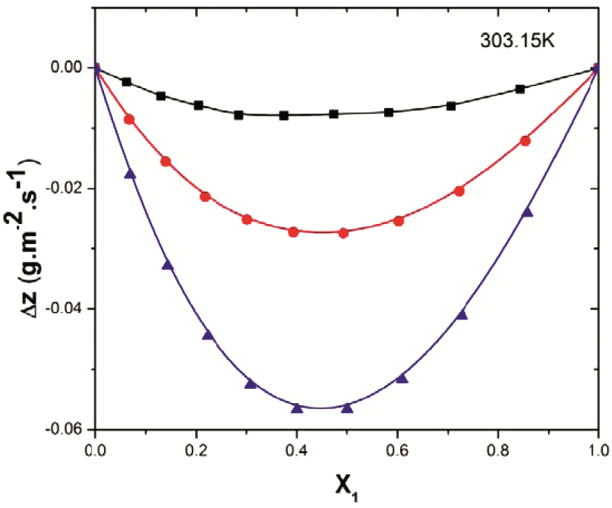


Fig. 12 — Deviation in acoustic impedance ($\Delta z$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

group and (ii) Negative effect due to the more compressibility to the solution because of solvent molecules can penetrate into intra-group free space[32,33]. Positive values of $K^o_{s,m,\phi,1}$ indicate that there is a higher solvent intrinsic compressibility than penetration effect in studied binary mixtures. From the above discussion the interaction trend of the mixtures is as under

Table 11 — Excess molar isentropic compressibility ($K_{s,m}^{E}$), Infinite dilution partial molar isentropic compressibility ($\bar{K}_{s,m,i}^{o}$), Excess partial molar isentropic compressibility ($\bar{K}_{s,m,i}^{o,E}$), Apparent molar isentropic compressibility ($K_{s,m,\phi,i}$) and Apparent molar isentropic compressibility ($K'_{s,m,\phi,i}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $x_1$ | Molality $m_1$ (mol·Kg$^{-1}$) | Molality $m_2$ (mol·Kg$^{-1}$) | $K_{s,m}^{E}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,1}^{o}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,2}^{o}$ ((TPa)$^{-}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,1}^{o,E}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,2}^{o,E}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K_{s,m,\phi,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K_{s,m,\phi,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K'_{s,m,\phi,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K'_{s,m,\phi,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| p-Cymene (1) + Fluorobenzene (2) at 303.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1095 | 0.0714 | - | - | - | - | - | - |
| 0.0624 | 0.6923 | 111.9884 | 0.000061 | 0.1114 | 0.0714 | -0.00040 | 0.00000 | 0.112774 | 0.071449 | 0.112371 | 0.071446 |
| 0.1302 | 1.5577 | 49.7726 | 0.000146 | 0.1122 | 0.0714 | 0.00037 | -0.00001 | 0.112921 | 0.071553 | 0.113296 | 0.071540 |
| 0.2042 | 2.6704 | 29.0340 | 0.000178 | 0.1123 | 0.0714 | 0.00049 | -0.00003 | 0.112669 | 0.071608 | 0.113156 | 0.071581 |
| 0.2853 | 4.1539 | 18.6647 | 0.000271 | 0.1121 | 0.0713 | 0.00032 | -0.00004 | 0.112746 | 0.071763 | 0.113065 | 0.071720 |
| 0.3745 | 6.2309 | 12.4432 | 0.000199 | 0.1120 | 0.0713 | 0.00015 | -0.00007 | 0.112329 | 0.071703 | 0.112483 | 0.071636 |
| 0.4732 | 9.3463 | 8.2954 | 0.000151 | 0.1119 | 0.0713 | 0.00012 | -0.00013 | 0.112116 | 0.071671 | 0.112240 | 0.071542 |
| 0.5828 | 14.5387 | 5.3328 | 0.000192 | 0.1120 | 0.0711 | 0.00019 | -0.00030 | 0.112128 | 0.071846 | 0.112315 | 0.071549 |
| 0.7055 | 24.9234 | 3.1108 | 0.000218 | 0.1120 | 0.0707 | 0.00019 | -0.00065 | 0.112107 | 0.072125 | 0.112300 | 0.071479 |
| 0.8435 | 56.0777 | 1.3826 | 0.000079 | 0.1119 | 0.0703 | 0.00007 | -0.00104 | 0.111892 | 0.071890 | 0.111961 | 0.070847 |
| 1.0000 | - | - | 0.000000 | 0.1118 | 0.0711 | - | - | - | - | - | - |
| p-Cymene (1) + Fluorobenzene (2) at 308.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1144 | 0.0748 | - | - | - | - | - | - |
| 0.0624 | 0.6932 | 111.8511 | 0.000071 | 0.1161 | 0.0748 | -0.00020 | 0.00000 | 0.117452 | 0.074913 | 0.117265 | 0.074910 |
| 0.1302 | 1.5596 | 49.7116 | 0.000156 | 0.1168 | 0.0748 | 0.00050 | -0.00002 | 0.117513 | 0.075016 | 0.118024 | 0.075001 |
| 0.2042 | 2.6736 | 28.9984 | 0.000188 | 0.1169 | 0.0748 | 0.00059 | -0.00004 | 0.117238 | 0.075072 | 0.117842 | 0.075038 |
| 0.2853 | 4.1590 | 18.6419 | 0.000321 | 0.1168 | 0.0748 | 0.00043 | -0.00006 | 0.117442 | 0.075283 | 0.117879 | 0.075225 |
| 0.3745 | 6.2385 | 12.4279 | 0.000249 | 0.1166 | 0.0747 | 0.00025 | -0.00010 | 0.116984 | 0.075232 | 0.117246 | 0.075136 |
| 0.4732 | 9.3578 | 8.2853 | 0.000181 | 0.1165 | 0.0747 | 0.00020 | -0.00018 | 0.116703 | 0.075176 | 0.116905 | 0.075002 |
| 0.5828 | 14.5565 | 5.3262 | 0.000232 | 0.1165 | 0.0745 | 0.00022 | -0.00036 | 0.116721 | 0.075389 | 0.116946 | 0.075035 |
| 0.7055 | 24.9540 | 3.1070 | 0.000251 | 0.1165 | 0.0741 | 0.00020 | -0.00071 | 0.116680 | 0.075684 | 0.116880 | 0.074979 |
| 0.8435 | 56.1465 | 1.3809 | 0.000095 | 0.1164 | 0.0737 | 0.00007 | -0.00112 | 0.116439 | 0.075437 | 0.116508 | 0.074329 |
| 1.0000 | - | - | 0.000000 | 0.1163 | 0.0743 | - | - | - | - | - | - |
| p-Cymene (1) + Fluorobenzene (2) at 313.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1212 | 0.0785 | - | - | - | - | - | - |
| 0.0624 | 0.6941 | 111.7087 | 0.000081 | 0.1218 | 0.0785 | 0.00075 | 0.00000 | 0.122293 | 0.078632 | 0.123070 | 0.078630 |
| 0.1302 | 1.5616 | 49.6483 | 0.000178 | 0.1219 | 0.0785 | 0.00084 | -0.00002 | 0.122371 | 0.078749 | 0.123233 | 0.078736 |
| 0.2042 | 2.6771 | 28.9615 | 0.000214 | 0.1217 | 0.0785 | 0.00069 | -0.00004 | 0.122050 | 0.078811 | 0.122765 | 0.078777 |
| 0.2853 | 4.1643 | 18.6181 | 0.000327 | 0.1215 | 0.0785 | 0.00049 | -0.00007 | 0.122154 | 0.078999 | 0.122667 | 0.078932 |
| 0.3745 | 6.2465 | 12.4121 | 0.000301 | 0.1214 | 0.0784 | 0.00036 | -0.00013 | 0.121815 | 0.079021 | 0.122187 | 0.078898 |
| 0.4732 | 9.3697 | 8.2747 | 0.000224 | 0.1213 | 0.0783 | 0.00031 | -0.00024 | 0.121486 | 0.078961 | 0.121809 | 0.078732 |
| 0.5828 | 14.5751 | 5.3195 | 0.000238 | 0.1213 | 0.0781 | 0.00030 | -0.00045 | 0.121426 | 0.079107 | 0.121734 | 0.078669 |
| 0.7055 | 24.9858 | 3.1030 | 0.000265 | 0.1212 | 0.0777 | 0.00022 | -0.00081 | 0.121395 | 0.079432 | 0.121625 | 0.078639 |
| 0.8435 | 56.2181 | 1.3791 | 0.000157 | 0.1211 | 0.0773 | 0.00007 | -0.00121 | 0.121209 | 0.079533 | 0.121284 | 0.078337 |
| 1.0000 | - | - | 0.000000 | 0.1210 | 0.0777 | - | - | - | - | - | - |
| p-Cymene (1) + Chlorobenzene (2) at 303.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1083 | 0.0601 | - | - | - | - | - | - |
| 0.0672 | 0.6401 | 103.4177 | -0.000232 | 0.1088 | 0.0601 | -0.00296 | 0.00002 | 0.108349 | 0.059812 | 0.105385 | 0.059829 |
| 0.1395 | 1.4402 | 45.9634 | -0.000467 | 0.1092 | 0.0601 | -0.00258 | 0.00007 | 0.108451 | 0.059518 | 0.105873 | 0.059593 |
| 0.2175 | 2.4689 | 26.8120 | -0.000640 | 0.1096 | 0.0602 | -0.00224 | 0.00018 | 0.108854 | 0.059243 | 0.106611 | 0.059427 |
| 0.3018 | 3.8405 | 17.2363 | -0.000816 | 0.1099 | 0.0604 | -0.00190 | 0.00036 | 0.109093 | 0.058891 | 0.107188 | 0.059253 |
| 0.3934 | 5.7607 | 11.4909 | -0.000926 | 0.1103 | 0.0607 | -0.00153 | 0.00062 | 0.109444 | 0.058534 | 0.107914 | 0.059158 |

(*Contd.*)

Table 11 — Excess molar isentropic compressibility ($K_{s,m}^{E}$), Infinite dilution partial molar isentropic compressibility ($\bar{K}_{s,m,i}^{o}$), Excess partial molar isentropic compressibility ($\bar{K}_{s,m,i}^{o,E}$), Apparent molar isentropic compressibility ($K_{s,m,\phi,i}$) and Apparent molar isentropic compressibility ($K'_{s,m,\phi,i}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures (*Contd*.)

| $x_1$ | Molality $m_1$ (mol·Kg$^{-1}$) | Molality $m_2$ (mol·Kg$^{-1}$) | $K_{s,m}^{E}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,1}^{o}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,2}^{o}$ ((TPa)$^{-}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,1}^{o,E}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}_{s,m,2}^{o,E}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K_{s,m,\phi,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K_{s,m,\phi,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K'_{s,m,\phi,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K'_{s,m,\phi,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| p-Cymene (1) + Chlorobenzene (2) at 303.15 K | | | | | | | | | | | |
| 0.4931 | 8.6411 | 7.6606 | -0.000943 | 0.1107 | 0.0610 | -0.00112 | 0.00099 | 0.109885 | 0.058200 | 0.108769 | 0.059186 |
| 0.6021 | 13.4417 | 4.9247 | -0.000860 | 0.1111 | 0.0615 | -0.00070 | 0.00146 | 0.110369 | 0.057899 | 0.109673 | 0.059360 |
| 0.7217 | 23.0430 | 2.8727 | -0.000690 | 0.1115 | 0.0621 | -0.00033 | 0.00206 | 0.110841 | 0.057580 | 0.110512 | 0.059636 |
| 0.8537 | 51.8467 | 1.2768 | -0.000413 | 0.1117 | 0.0628 | -0.00008 | 0.00278 | 0.111313 | 0.057235 | 0.111230 | 0.060012 |
| 1.0000 | - | - | 0.000000 | 0.1118 | 0.0637 | - | - | - | - | - | - |
| p-Cymene (1) + Chlorobenzene (2) at 308.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1125 | 0.0625 | - | - | - | - | - | - |
| 0.0672 | 0.6402 | 103.3980 | -0.000242 | 0.1132 | 0.0625 | -0.00309 | 0.00002 | 0.112716 | 0.062195 | 0.109633 | 0.062213 |
| 0.1395 | 1.4405 | 45.9547 | -0.000471 | 0.1137 | 0.0625 | -0.00263 | 0.00008 | 0.112948 | 0.061907 | 0.110326 | 0.061985 |
| 0.2175 | 2.4694 | 26.8069 | -0.000672 | 0.1140 | 0.0626 | -0.00229 | 0.00019 | 0.113233 | 0.061595 | 0.110945 | 0.061788 |
| 0.3018 | 3.8412 | 17.2330 | -0.000845 | 0.1143 | 0.0628 | -0.00198 | 0.00038 | 0.113523 | 0.061242 | 0.111549 | 0.061622 |
| 0.3934 | 5.7618 | 11.4887 | -0.000973 | 0.1147 | 0.0631 | -0.00162 | 0.00065 | 0.113849 | 0.060847 | 0.112235 | 0.061505 |
| 0.4931 | 8.6428 | 7.6591 | -0.000952 | 0.1151 | 0.0635 | -0.00120 | 0.00104 | 0.114392 | 0.060572 | 0.113200 | 0.061612 |
| 0.6021 | 13.4443 | 4.9237 | -0.000871 | 0.1156 | 0.0640 | -0.00075 | 0.00153 | 0.114879 | 0.060262 | 0.114135 | 0.061798 |
| 0.7217 | 23.0474 | 2.8722 | -0.000699 | 0.1160 | 0.0646 | -0.00035 | 0.00214 | 0.115357 | 0.059938 | 0.115010 | 0.062083 |
| 0.8537 | 51.8566 | 1.2765 | -0.000417 | 0.1162 | 0.0653 | -0.00009 | 0.00287 | 0.115838 | 0.059597 | 0.115752 | 0.062474 |
| 1.0000 | - | - | 0.000000 | 0.1163 | 0.0663 | - | - | - | - | - | - |
| p-Cymene (1) + Chlorobenzene (2) at 313.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1172 | 0.0650 | - | - | - | - | - | - |
| 0.0672 | 0.6403 | 103.3765 | -0.000247 | 0.1179 | 0.0650 | -0.00316 | 0.00002 | 0.117339 | 0.064727 | 0.114197 | 0.064746 |
| 0.1395 | 1.4408 | 45.9451 | -0.000476 | 0.1183 | 0.0651 | -0.00270 | 0.00008 | 0.117599 | 0.064437 | 0.114912 | 0.064518 |
| 0.2175 | 2.4699 | 26.8013 | -0.000678 | 0.1187 | 0.0652 | -0.00235 | 0.00020 | 0.117897 | 0.064123 | 0.115555 | 0.064322 |
| 0.3018 | 3.8420 | 17.2294 | -0.000848 | 0.1190 | 0.0654 | -0.00202 | 0.00038 | 0.118208 | 0.063774 | 0.116203 | 0.064163 |
| 0.3934 | 5.7630 | 11.4863 | -0.000978 | 0.1194 | 0.0657 | -0.00163 | 0.00066 | 0.118532 | 0.063375 | 0.116915 | 0.064043 |
| 0.4931 | 8.6446 | 7.6575 | -0.000988 | 0.1198 | 0.0660 | -0.00118 | 0.00104 | 0.119016 | 0.063036 | 0.117843 | 0.064084 |
| 0.6021 | 13.4471 | 4.9227 | -0.000899 | 0.1203 | 0.0665 | -0.00072 | 0.00153 | 0.119528 | 0.062724 | 0.118811 | 0.064261 |
| 0.7217 | 23.0522 | 2.8716 | -0.000721 | 0.1207 | 0.0671 | -0.00033 | 0.00213 | 0.120023 | 0.062389 | 0.119694 | 0.064529 |
| 0.8537 | 51.8674 | 1.2763 | -0.000430 | 0.1209 | 0.0679 | -0.00008 | 0.00288 | 0.120521 | 0.062038 | 0.120438 | 0.064936 |
| 1.0000 | - | - | 0.000000 | 0.1210 | 0.0690 | - | - | - | - | - | - |
| p-Cymene (1) + Bromobenzene (2) at 303.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1043 | 0.0552 | - | - | - | - | - | - |
| 0.0692 | 0.4733 | 100.2679 | -0.000465 | 0.1057 | 0.0552 | -0.00612 | 0.00003 | 0.105069 | 0.054680 | 0.098950 | 0.054713 |
| 0.1432 | 1.0649 | 44.5635 | -0.000865 | 0.1067 | 0.0553 | -0.00505 | 0.00014 | 0.105759 | 0.054171 | 0.100705 | 0.054314 |
| 0.2228 | 1.8256 | 25.9954 | -0.001222 | 0.1076 | 0.0555 | -0.00418 | 0.00035 | 0.106313 | 0.053608 | 0.102129 | 0.053959 |
| 0.3084 | 2.8398 | 16.7113 | -0.001495 | 0.1084 | 0.0559 | -0.00339 | 0.00068 | 0.106949 | 0.053018 | 0.103558 | 0.053696 |
| 0.4008 | 4.2597 | 11.1409 | -0.001692 | 0.1092 | 0.0563 | -0.00261 | 0.00115 | 0.107577 | 0.052357 | 0.104968 | 0.053508 |
| 0.5008 | 6.3895 | 7.4272 | -0.001742 | 0.1100 | 0.0570 | -0.00183 | 0.00180 | 0.108320 | 0.051691 | 0.106487 | 0.053488 |
| 0.6095 | 9.9392 | 4.7747 | -0.001628 | 0.1107 | 0.0578 | -0.00112 | 0.00264 | 0.109126 | 0.051011 | 0.108011 | 0.053655 |
| 0.7279 | 17.0386 | 2.7852 | -0.001341 | 0.1113 | 0.0589 | -0.00053 | 0.00374 | 0.109955 | 0.050250 | 0.109421 | 0.053991 |
| 0.8575 | 38.3369 | 1.2379 | -0.000834 | 0.1116 | 0.0604 | -0.00015 | 0.00522 | 0.110825 | 0.049327 | 0.110676 | 0.054548 |
| 1.0000 | - | - | 0.000000 | 0.1118 | 0.0627 | - | - | - | - | - | - |

(*Contd*.)

Table 11 — Excess molar isentropic compressibility ($K^E_{s,m}$), Infinite dilution partial molar isentropic compressibility ($\bar{K}^o_{s,m,i}$), Excess partial molar isentropic compressibility ($\bar{K}^{o,E}_{s,m,i}$), Apparent molar isentropic compressibility ($K_{s,m,\phi,i}$) and Apparent molar isentropic compressibility ($K'_{s,m,\phi,i}$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures (*Contd.*)

| $x_1$ | Molality $m_1$ (mol·Kg$^{-1}$) | Molality $m_2$ (mol·Kg$^{-1}$) | $K^E_{s,m}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}^o_{s,m,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}^o_{s,m,2}$ ((TPa)$^{-}$ ·m$^3$·mol$^{-1}$) | $\bar{K}^{o,E}_{s,m,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $\bar{K}^{o,E}_{s,m,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K_{s,m,\phi,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K_{s,m,\phi,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K'_{s,m,\phi,1}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) | $K'_{s,m,\phi,2}$ ((TPa)$^{-1}$ ·m$^3$·mol$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| p-Cymene (1) + Bromobenzene (2) at 308.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1085 | 0.0572 | - | - | - | - | - | - |
| 0.0692 | 0.4732 | 100.2858 | -0.000515 | 0.1099 | 0.0573 | -0.00641 | 0.00004 | 0.108887 | 0.056671 | 0.102472 | 0.056706 |
| 0.1432 | 1.0647 | 44.5715 | -0.000944 | 0.1110 | 0.0574 | -0.00532 | 0.00015 | 0.109746 | 0.056124 | 0.104419 | 0.056273 |
| 0.2228 | 1.8252 | 26.0000 | -0.001319 | 0.1119 | 0.0576 | -0.00440 | 0.00037 | 0.110414 | 0.055529 | 0.106005 | 0.055894 |
| 0.3084 | 2.8393 | 16.7143 | -0.001609 | 0.1128 | 0.0579 | -0.00356 | 0.00071 | 0.111117 | 0.054901 | 0.107549 | 0.055609 |
| 0.4008 | 4.2589 | 11.1429 | -0.001777 | 0.1136 | 0.0584 | -0.00275 | 0.00121 | 0.111901 | 0.054264 | 0.109146 | 0.055470 |
| 0.5008 | 6.3883 | 7.4286 | -0.001830 | 0.1144 | 0.0591 | -0.00196 | 0.00190 | 0.112679 | 0.053565 | 0.110717 | 0.055461 |
| 0.6095 | 9.9374 | 4.7755 | -0.001712 | 0.1151 | 0.0601 | -0.00122 | 0.00283 | 0.113524 | 0.052850 | 0.112297 | 0.055671 |
| 0.7279 | 17.0356 | 2.7857 | -0.001413 | 0.1157 | 0.0613 | -0.00061 | 0.00406 | 0.114390 | 0.052042 | 0.113777 | 0.056096 |
| 0.8575 | 38.3300 | 1.2381 | -0.000878 | 0.1161 | 0.0630 | -0.00018 | 0.00576 | 0.115306 | 0.051074 | 0.115126 | 0.056824 |
| 1.0000 | - | - | 0.000000 | 0.1163 | 0.0655 | - | - | - | - | - | - |
| p-Cymene (1) + Bromobenzene (2) at 313.15 K | | | | | | | | | | | |
| 0.0000 | - | - | 0.000000 | 0.1132 | 0.0594 | - | - | - | - | - | - |
| 0.0692 | 0.4731 | 100.3035 | -0.000541 | 0.1146 | 0.0594 | -0.00640 | 0.00004 | 0.113229 | 0.058777 | 0.106804 | 0.058812 |
| 0.1432 | 1.0645 | 44.5793 | -0.000987 | 0.1156 | 0.0595 | -0.00540 | 0.00016 | 0.114157 | 0.058208 | 0.108742 | 0.058364 |
| 0.2228 | 1.8249 | 26.0046 | -0.001377 | 0.1164 | 0.0597 | -0.00458 | 0.00039 | 0.114864 | 0.057590 | 0.110266 | 0.057977 |
| 0.3084 | 2.8388 | 16.7173 | -0.001675 | 0.1172 | 0.0601 | -0.00380 | 0.00076 | 0.115611 | 0.056942 | 0.111794 | 0.057697 |
| 0.4008 | 4.2581 | 11.1448 | -0.001879 | 0.1180 | 0.0607 | -0.00298 | 0.00130 | 0.116353 | 0.056231 | 0.113361 | 0.057520 |
| 0.5008 | 6.3872 | 7.4299 | -0.001932 | 0.1189 | 0.0614 | -0.00212 | 0.00203 | 0.117181 | 0.055499 | 0.115050 | 0.057515 |
| 0.6095 | 9.9357 | 4.7764 | -0.001759 | 0.1197 | 0.0623 | -0.00130 | 0.00299 | 0.118151 | 0.054870 | 0.116841 | 0.057841 |
| 0.7279 | 17.0326 | 2.7862 | -0.001437 | 0.1204 | 0.0636 | -0.00063 | 0.00424 | 0.119059 | 0.054095 | 0.118422 | 0.058314 |
| 0.8575 | 38.3233 | 1.2383 | -0.000869 | 0.1208 | 0.0654 | -0.00018 | 0.00600 | 0.120018 | 0.053284 | 0.119831 | 0.059256 |
| 1.0000 | - | - | 0.000000 | 0.1210 | 0.0683 | - | - | - | - | - | - |

Table 12 — Infinite dilution apparent molar isentropic compressibility ($K^o_{s,m,\phi,1}$), Empirical parameters $S_k$ and $B_k$ of Redlich-Rosenberg-Mayer equation with Standard deviation, ($\sigma$) of p-cymene (1) + fluoro-, chloro- and bromobenzene (2) binary mixtures

| $T$ (K) | $K^o_{s,m,\phi,1}$ (m$^3$·(TPa)$^{-1}$· mol$^{-1}$) | $S_k$ (m$^{-3}$·(TPa)$^{-1}$· mol$^{-(3/2)}$·kg$^{(1/2)}$) | $B_k$ (m$^{-3}$·(TPa)$^{-1}$· mol$^{-2}$·kg) | $\sigma$ |
|---|---|---|---|---|
| p-Cymene (1) + Fluorobenzene (2) | | | | |
| 303.15 | 0.112625 | -0.05002 | 0.024992 | 0.00027 |
| 308.15 | 0.117258 | -0.05002 | 0.024991 | 0.00028 |
| 313.15 | 0.122055 | -0.05002 | 0.024991 | 0.00031 |
| p-Cymene (1) + Chlorobenzene (2) | | | | |
| 303.15 | 0.108932 | -0.04994 | 0.025028 | 0.00059 |
| 308.15 | 0.113362 | -0.04994 | 0.025029 | 0.00062 |
| 313.15 | 0.118014 | -0.04994 | 0.025029 | 0.00059 |
| p-Cymene (1) + Bromobenzene (2) | | | | |
| 303.15 | 0.106510 | -0.04986 | 0.025069 | 0.00115 |
| 308.15 | 0.110622 | -0.04985 | 0.025075 | 0.00134 |
| 313.15 | 0.115060 | -0.04984 | 0.025080 | 0.00140 |

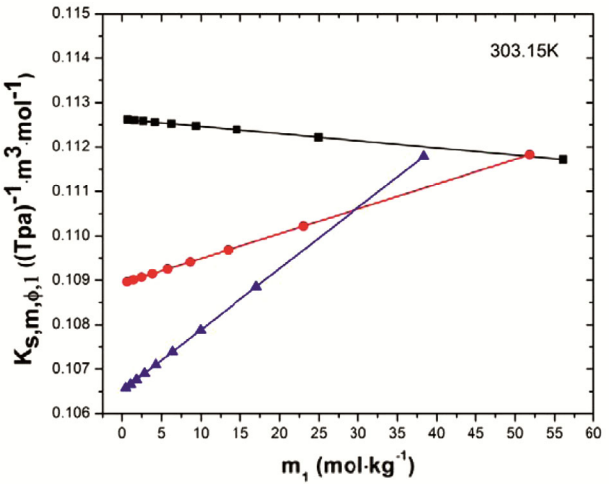


Fig. 13 — Apparent molar isentropic compressibility ($K_{s,m,\phi,1}$) as a function of molality ($m_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

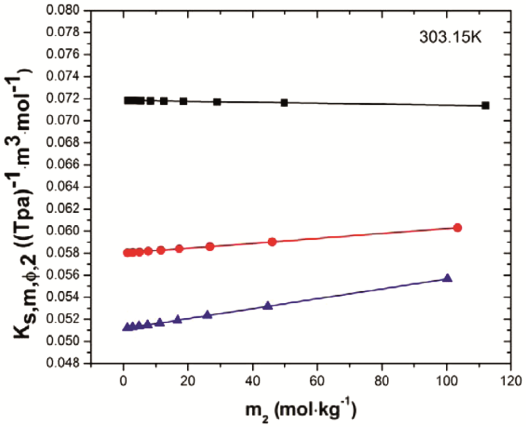


Fig. 14 — Apparent molar isentropic compressibility ($K_{s,m,\phi,2}$) as a function of molality ($m_2$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

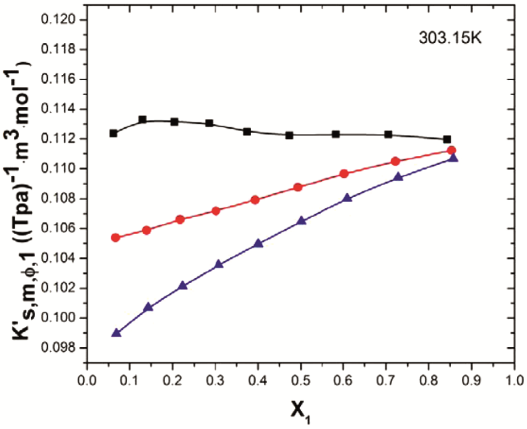


Fig. 15 — Apparent molar isentropic compressibility ($K'_{s,m,\phi,1}$) as a function of mole fraction ($X_1$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

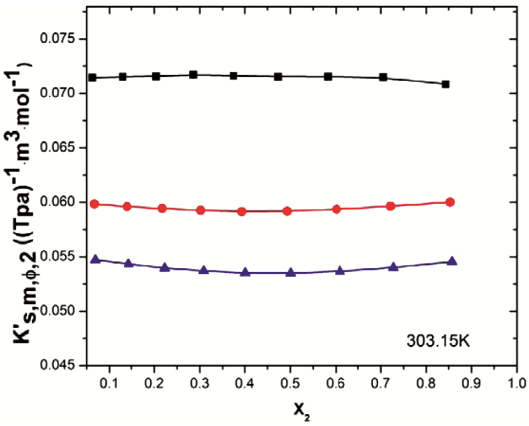


Fig. 16 — Apparent molar isentropic compressibility ($K'_{s,m,\phi,2}$) as a function of mole fraction ($X_2$) for p-Cymene (1) + Fluorobenzene (2) (■), p-Cymene (1) + Chlorobenzene (2) (●), p-Cymene (1) + Bromobenzene (2) (▲) at T= 303.15K.

fluorobenzene > chlorobenzene > bromobenzene

## 5 Conclusions

The density, ($\rho$), and excess molar volumes, ($V_m^E$), of $p-cymene$with halobenzenes (fluorobenzene, chlorobenzene and bromobenzene)are reported at temperatures 303.15, 308.15 K and 313.15 K. Negative deviations are observed in$V_m^E$values for all binary mixtures indicate for presence of strong interaction in binary mixtures.The negative values of excess partial molar volume, ($\bar{V}_{m,i}^{o,E}$) support the conclusion derived from excess molar volume. The positive values of $\Delta U$, negative values of $\Delta\kappa_s$, and $\Delta z$ suggest that there is a strong interaction between present between the molecules of binary mixtures. Interaction trend of the mixtures is fluorobenzene > chlorobenzene > bromobenzene. Theoretical relations of speed of sound were in good agreement with experimental values. From the result, it is anticipated that there is possibility of hydrogen bonding type of interaction between the p-cymene and halobenzene molecules. The interactions become weaker when binary mixture changes form fluorobenzene to bromobenzene and temperature changes from 303.15 to 313.15.

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