

DENSITIES, REFRACTIVE INDICES AND DERIVED PROPERTIES OF *n*-HEPTANE WITH SOME AROMATIC HYDROCARBONS AT 298.15 K

M. ABDUR RAHAMAN^{*1}, M. SHAHADAT HOSSAIN², M. KAMRUL HOSSAIN³, SHAMIM AKHTAR⁴ and NISHAT AKTHER⁵

¹Department of Chemistry, Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh;

²Department of Chemistry, Comilla University, Comilla-3506, Bangladesh;

³Department of Basic Science, World University of Bangladesh, Dhaka-1205, Bangladesh;

⁴Department of Chemistry, University of Chittagong, Chittagong-4331, Bangladesh;

⁵Department of Biochemistry and Molecular Biology, Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh

Abstract

Densities (ρ) and refractive indices (n_D) of pure components *n*-heptane, toluene, *o*-xylene, mesitylene and the binary mixtures of *n*-Heptane + toluene, + *o*-xylene and + mesitylene have been measured in the whole range of composition at 298.15K. Excess molar volumes, V_m^E , deviations in refractive index, Δn_D and deviations in molar refraction, ΔR , have also been calculated from the density (ρ) and refractive indices (n_D) data. The excess and deviation functions have been fitted to the Redlich–Kister equations. For mixtures of *n*-heptane with toluene the V_m^E and ΔR is positive and for the remaining two systems is negative. The Δn_D values show the negative for the binary mixtures with toluene, whereas, the positive values have been observed for the remaining binary mixtures. All the results reveal that in *n*-heptane + toluene, dispersive forces are suggested to dominate and in the other two favorable geometrical fitting seem to be overpower due to increasing number of $-CH_3$ as substituent in the aromatic hydrocarbons.

Keywords: Density, excess molar volume, refractive index, aromatic hydrocarbon

Introduction

The physical properties of binary mixtures are studied for many reasons, the most important of which is to provide information about molecular interactions present in the liquid state (Ali *et al.*, 1999). Experimental data of physical properties such of densities, viscosities, or refractive indices are required for a full understanding of the thermodynamic properties of liquid mixtures, as well as for practical chemical engineering work (Francesconi *et al.*, 2000). The studies of excess thermodynamic properties are of considerable interest in understanding the intermolecular interactions in binary liquid mixtures (Dominguez *et al.*, 1996). Knowledge of these properties is very important in many practical problems concerning mass transport and fluid flow. Our present interest is on some aromatic hydrocarbons such as toluene, *o*-xylene and mesitylene and their binary mixtures with aliphatic hydrocarbon such as *n*-heptane.

* Corresponding author: md.ar_ch@yahoo.com

A number of literature survey shows that some paper reported on the co-relation of refractive index with density (Fucaloro, 2002), excess molar volume (Giner *et al.*, 2007 and Pineiro *et al.*, 2000). Some researchers studied on the binary systems of a particular aromatic hydrocarbon with the series of aliphatic hydrocarbons (Iloukhani *et al.*, 2006; Aminabhavi *et al.*, 1997; Lal *et al.*, 2000), on the other hand, some of them reported on a particular aliphatic hydrocarbon with the series of aromatic hydrocarbons (Diaz *et al.*, 2001; Moravkova *et al.*, 2008; Mutalik *et al.*, 2006; Baylaucq *et al.*, 1997; Diaz *et al.*, 2002). Survey of the literatures further indicate that reports are very rare on the physical data of the binary mixtures of n-heptane with + toluene, o-xylene and mesitylene, where different numbers of $-CH_3$ groups present at different positions in the aromatic rings. These will enable us to achieve the following goals: The effect of relative position and number of $-CH_3$ groups in the aromatic hydrocarbons on their volumetric as well as optical properties of all these binary mixtures. And hence, using these results more about the interaction as well as types of forces acting between aliphatic and aromatic hydrocarbons can be understood. Thus the present investigation reports on the density (ρ), refractive index (n_D) and some of their related properties for the binary mixtures of n-heptane + toluene, + o-xylene and + mesitylene in the whole range of composition at 298.15 K.

Materials and Methods

The experiment was conducted in the Professor Dr. Muhammad Abu Saleh Laboratory of the department of chemistry under the faculty of science, University of Chittagong, Chittagong, Bangladesh.

Materials

Liquids used to prepare binary mixtures with quoted purities n-heptane (NHP): 99.6%, o-xylene (OXN): 99.0% and mesitylene (MSN): 99% were procured from Aldrich Chemical Co. Ltd. and toluene (TN): >99% was from Merck.

Density and refractive index measurements of pure and binary mixtures

Each sample mixture was prepared, on mass basis, by mixing the calculated volumes of liquid components. The mass measurements were done with the help of an electronic balance (College B 204-S, METTLER TOLEDO) accurate up to ± 0.0001 g. A set of eleven compositions was prepared for each system. Densities of the pure components and their compositions were measured with a 10 cm³ bi-capillary pycnometer which was previously calibrated with twice distilled water. The mixtures were prepared by mixing known masses of pure liquids in air tight, narrow-mouth ground stopper bottles taking due precautions to minimize evaporation losses. The mole fraction was accurate up to 10^{-4} , while the uncertainty in the measured density was estimated as $\pm 1 \times 10^{-4}$ g.cm⁻³.

The refractive indices were measured with thermostated Abbe refractometer (Bellingham & Stanley Ltd) using sodium D-light at 589 nm with reproducibility in the refractive

index data of 10^{-4} . The experimental densities ($\rho / \text{g.cm}^{-3}$) and refractive index (n_D) along with reported data are tabulated in Table 1 and are found to be in good agreement with literature values.

Results and Discussion

Density

Measured densities (ρ) of n-heptane (NHP) + toluene (TN), NHP + o-xylene (OXN) and NHP + mesitylene (MSN) in the whole range of composition at 298.15 K are summarized in Table 2. Fig. 1 indicates the comparative diagram for ρ against the mole fraction of aromatic hydrocarbons, x_2 at 298.15 K. ρ values are fitted by a five-degree polynomial equation of the form:

$$\rho / \text{g.cm}^{-3} = \sum_{i=0}^n a_i x_2^i \quad (1)$$

Table 1. Comparison of experimental density ($\rho / \text{g.cm}^{-3}$) and refractive index (n_D) of pure liquids with literature values at 298.15 K

Sample	$\rho / \text{g.cm}^{-3}$		n_D	
	This work	Literature	This work	Literature
n-heptane	0.6794	0.6794 ^a	1.38485	1.38512 ^a
Toluene	0.8623	0.86220 ^b	1.49396	1.4939 ^c
o-Xylene	0.8758	0.87553 ^d	1.50226	1.5028 ^e
Mesitylene	0.8616	0.86120 ^f	1.49628	1.4961 ^f

^aRef-[Rodriguez *et al.*, 2003], ^bRef-[Al-Kandary *et al.*, 2006], ^cRef-[Aminabhavi *et al.*, 1999], ^dRef-[Al-Kandary *et al.*, 2006], ^eRef-[Bhatia *et al.*, 2011], ^fRef-[Baragi *et al.*, 2006]

Table 2. Densities, ρ (g.cm^{-3}) and excess molar volumes, V_m^E ($\text{cm}^3 \cdot \text{mol}^{-1}$) of the systems of NHP (x_1) + TN (x_2), + OXN (x_2) and + MSN (x_2) for different molar ratios at 298.15 K

x_2	ρ	V_m^E	x_2	ρ	V_m^E	x_2	ρ	V_m^E
NHP (x_1) + TN (x_2)			NHP (x_1) + OXN (x_2)			NHP (x_1) + MSN (x_2)		
0.0000	0.6794	0.0000						
0.1001	0.6927	0.0703	0.1001	0.6960	-0.0310	0.1000	0.6969	-0.0364
0.1991	0.7067	0.1208	0.2000	0.7133	-0.0845	0.1993	0.7146	-0.0980
0.3002	0.7220	0.1431	0.3005	0.7313	-0.1242	0.3000	0.7327	-0.1479
0.3996	0.7380	0.1599	0.3999	0.7498	-0.1641	0.4000	0.7508	-0.1809
0.5000	0.7552	0.1746	0.5000	0.7690	-0.1748	0.5000	0.7690	-0.1933
0.6000	0.7736	0.1668	0.6002	0.7890	-0.1869	0.5998	0.7872	-0.1750
0.6999	0.7934	0.1345	0.7001	0.8095	-0.1581	0.6992	0.8054	-0.1345
0.8001	0.8147	0.0984	0.8001	0.8308	-0.1195	0.7990	0.8239	-0.0992
0.9001	0.8376	0.0532	0.9000	0.8530	-0.0856	0.9000	0.8428	-0.0589
1.0000	0.8623	0.0000	1.0000	0.8758	0.0000	1.0000	0.8616	0.0000

All the coefficients a_i and the relevant R^2 are expressed in Table 3. ρ of the pure liquids varies in the order: OXN > MSN \geq TN > NHP. For the binary systems, ρ increases systematically as the concentration of the aromatic hydrocarbon increases and the increasing order follows: NHP + OXN > + MSN > + TN.

Excess molar volumes

The excess molar volumes, V_m^E of the binary mixtures were calculated from the densities of the pure liquids and their mixtures using the equation (Tejraj, 1999):

$$V_m^E = \left[\frac{x_1 M_1 + x_2 M_2}{\rho} \right] - \left[\frac{x_1 M_1}{\rho_1} + \frac{x_2 M_2}{\rho_2} \right] \quad (2)$$

where, M_1 and M_2 represent the molar masses, ρ_1 and ρ_2 are the densities and x_1 and x_2 are the mole fraction of components 1 and 2, respectively and ρ is the density of the mixture. All the V_m^E values for the systems of NHP + TN, + OXN and + MSN are listed in Table 2. Fig. 2 represents the comparative diagram for V_m^E of the three systems against x_2 at 298.15 K. Each set of results were fitted by the Redlich-Kister equation (Redlich *et al.*, 1948):

$$Y^E = x_2 (1 - x_2) \sum_{i=0}^n A_i (2x_2 - 1)^i \quad (3)$$

where, $Y^E \equiv (V_m^E \text{ or } \Delta n_D \text{ or } \Delta R)$ and A_i is the polynomial fitting coefficient. The standard deviation, σ , followed the equation:

$$\sigma = \left[\frac{\sum (Y_{\text{exp}} - Y_{\text{cal}})^2}{n - p - 2} \right]^{\frac{1}{2}} \quad (4)$$

where, Y_{exp} and Y_{cal} are the experimental and calculated values of the property, n the total number of compositions for a particular system and p is the number of coefficients. In the whole range of composition V_m^E are found to be positive for NHP + TN, whereas, they are negative for NHP + OXN and NHP + MSN systems.

Table 3. Coefficients, a_i of polynomial equation for density, ρ ($\text{g}\cdot\text{cm}^{-3}$) and Fitting coefficients, A_i & standard deviation, σ for excess molar volumes, V_m^E ($\text{cm}^3\cdot\text{mol}^{-1}$) of the systems of NHP (x_1) + TN (x_2), + OXN (x_2) and + MSN (x_2)

a_0	a_1	a_2	a_3	a_4	a_5	R^2
NHP (x_1) + TN (x_2)						
0.679	0.128	0.046	-0.010	0.027	-0.008	1.000
NHP (x_1) + OXN (x_2)						
0.679	0.161	0.043	-0.029	0.033	-0.011	1.000
NHP (x_1) + MSN (x_2)						
0.679	0.172	0.029	-0.052	0.049	-0.016	1.000

The above behavior can be explained as follows. From the structural point of view, all the molecules in NHP being non-polar as well as linear are bonded by only weak van der Waals forces. The molecules of TN, OXN and MSN all being methyl substituted benzenes, on the other hand, are termed as very weakly polar as envelopes of electron clouds exist above and below their disc/plate-shaped structures. So, unlike NHP, these aromatic hydrocarbons (TN, OXN and MSN) are considered as weakly associative with their weak π - π and dipole-dipole interactions in addition to simple van der Waals forces. Therefore, when a small amount of these aromatic hydrocarbons is added to NHP separately, at the initial stage the liquid structures of TN/ OXN/ MSN are destroyed and they disperse within NHP. As the concentration of TN/ OXN/ MSN in NHP increases further, both the components disperse in each other in greater proportions. At this stage, as there is little scope for specific interaction between the aliphatic and aromatic hydrocarbons, gradual increment of V_m^E continues until it reaches the composition of maximum. But this is found to be true only for the system of NHP + TN. Afterwards, V_m^E starts to decrease following the continuous restructuring of the monomeric TN's into their dimeric / segregated structures, so that, a single positive lobe is formed in the NHP + TN system with the maximum at $x_2=0.5$.

It is generally expected that, in all the systems of NHP + TN, NHP + OXN and NHP + MSN, there should be a volume expansion at all compositions. However, it is striking to note that although the excess molar volumes (V_m^E) are all positive in the first system, these are all negative in the latter two [Fig. 2]. Similar results of positive V_m^E for NHP + TN and negative for NHP + OXN system are also observed by Illukhani *et al.* (2006) and Diaz *et al.* (2001) respectively at 298.15 K.

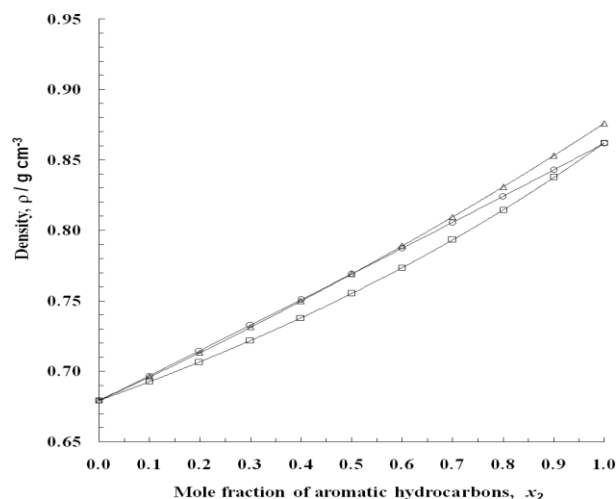


Fig. 1. Comparison of densities, ρ , for the systems of NHP (x_1) + TN (x_2) (□), + OXN (x_2) (Δ) and + MSN (x_2) (○) at 298.15 K.

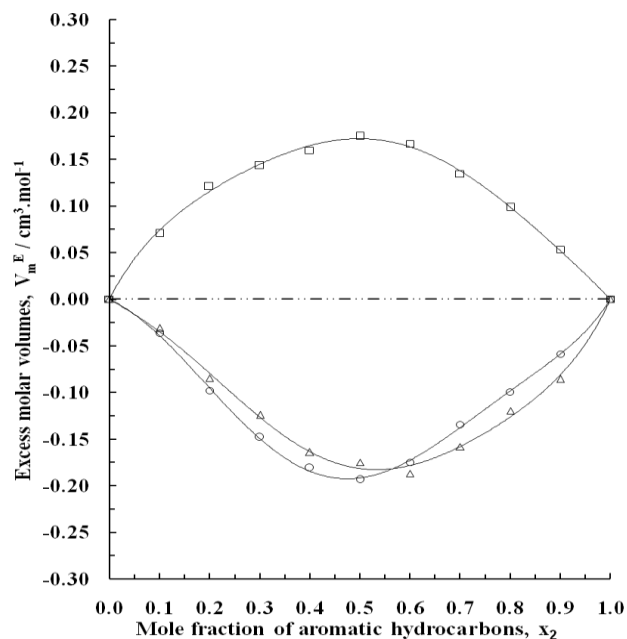


Fig. 2. Comparison of excess molar volumes, V_m^E , for the systems of NHP (x_1) + TN (x_2) (\square), + OXN (x_2) (Δ) and + MSN (x_2) (\circ) at 298.15 K.

As any disruption in ordered structures of pure components during the formation of the mixture leads to positive contribution, while, an order formation leads to negative contribution to V_m^E , in NHP + OXN and NHP + MSN systems the so called ‘ordering’ possibly arises from favourable geometrical fitting/packing of the component molecules. The ordering seems to outweigh the molecular ‘disordering’ associated with dispersive forces explicitly, leading to overall volume contraction. Hence the resultant V_m^E ’s are observed to be negative at all compositions in both the systems.

Refractive Indices

Refractive indices (n_D) of the three binary systems are measured at 298.15 K in the whole range of composition and the results are placed in Table 4. Any system with higher density hinders passage the light should have higher n_D values. This accounts for the observed n_D to follow the same trend and same order as ρ follows for all the pure liquids as well as their mixtures at all compositions. That means, n_D increases as: OXN > MSN > TN > NHP and NHP + OXN > NHP + MSN > NHP + TN.

Deviations in Refractive Index

For each system, deviation in refractive index (Δn_D) of a particular composition is estimated by following equation (Brocos *et al.*, 2003):

$$\Delta n_D = n_D - \sum \phi_i n_{D_i} \quad (5)$$

where, φ_i and n_{Di} represents the volume fraction and the refractive index of the i^{th} component, respectively and n_D represents the observed refractive index of the mixture and the values are listed in Table 4. Fig.3 compares the variation of Δn_D of the three systems against x_2 at 298.15 K. For each system, Δn_D 's are fitted to the Redlich–Kister equation (3). In the whole range of composition the values of Δn_D are found to be negative for NHP + TN, whereas, they are positive for NHP + OXN and NHP + MSN.

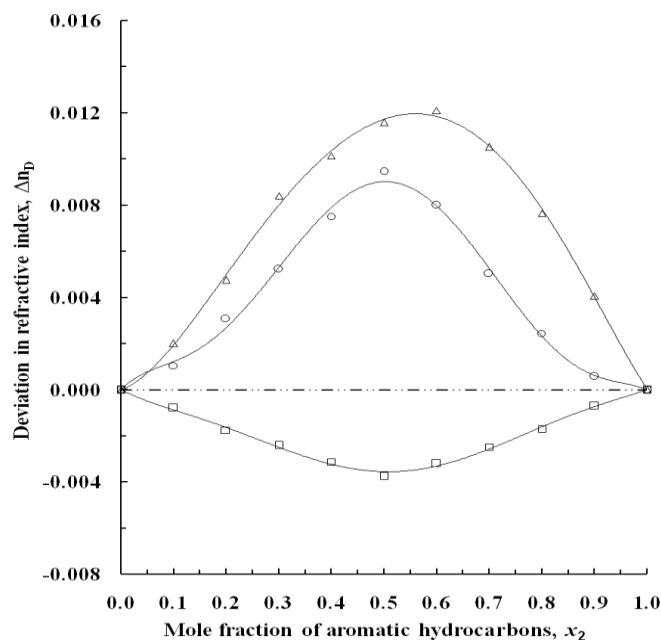


Fig. 3. Comparison of deviation in refractive index, Δn_D as a function of x_2 for the systems of NHP (x_1) + TN (x_2) (\square), + OXN (x_2) (Δ) and + MSN (x_2) (\circ) at 298.15 K.

A qualitative interpretation of the above results may be put forward as follows. The results reflect that on mixing up of the aliphatic hydrocarbon with the aromatic ones, there is decrement in density in NHP + TN, but increment of ρ occurs in NHP + OXN and NHP + MSN systems at all compositions. This is just in accordance with volumetric studies of the present systems. Such results are also observed in other systems (Diaz *et al.*, 2001; Fermeglia *et al.*, 1999; Aznarez *et al.*, 1998; Jimenez *et al.*, 2000; Yanes *et al.*, 1989; Nain, 2008). Pineiro *et al.* (2000) and Brocos *et al.* (2003) shows that the negative deviations in Δn_D values are considered due to the presence of weak interactions and positive deviations in Δn_D values indicate significant interaction between the components of the mixtures. Hence, the negative values of Δn_D for NHP + TN system indicates there are weak interactions and the positive values of Δn_D for the latter two indicates there are significant interactions but their low values indicates such interactions are considered to be negligible.

Table 4. Refractive Index (n_D), deviations in refractive index (Δn_D) and deviations in molar refraction (ΔR) of the systems of NHP (x_1) + TN (x_2), + OXN (x_2) and + MSN (x_2) for different molar ratios at 298.15 K

x_2	n_D	Δn_D	ΔR	x_2	n_D	Δn_D	ΔR	x_2	n_D	Δn_D	ΔR
NHP (x_1) + TN (x_2)				NHP (x_1) + OXN (x_2)				NHP (x_1) + MSN (x_2)			
0.0000	1.38485	0.0000	0.0000								
0.1001	1.39220	-0.0008	0.0167	0.1001	1.39670	0.0020	-0.0074	0.1000	1.39649	0.0010	-0.0088
0.1991	1.39975	-0.0018	0.0293	0.2000	1.40962	0.0048	-0.0209	0.1993	1.40916	0.0031	-0.0242
0.3002	1.40831	-0.0024	0.0353	0.3005	1.42390	0.0084	-0.0317	0.3000	1.42223	0.0052	-0.0376
0.3996	1.41722	-0.0031	0.0402	0.3999	1.43655	0.0101	-0.0430	0.4000	1.43546	0.0075	-0.0472
0.5000	1.42693	-0.0038	0.0448	0.5000	1.44941	0.0116	-0.0469	0.5000	1.44848	0.0095	-0.0518
0.6000	1.43848	-0.0032	0.0438	0.6002	1.46181	0.0121	-0.0514	0.5998	1.45820	0.0080	-0.0478
0.6999	1.45092	-0.0025	0.0362	0.7001	1.47256	0.0105	-0.0443	0.6992	1.46648	0.0050	-0.0373
0.8001	1.46428	-0.0017	0.0272	0.8001	1.48255	0.0077	-0.0341	0.7990	1.47532	0.0025	-0.0279
0.9001	1.47877	-0.0007	0.0151	0.9000	1.49235	0.0041	-0.0248	0.9000	1.48516	0.0006	-0.0169
1.0000	1.49396	0.0000	0.0000	1.0000	1.50226	0.0000	0.0000	1.0000	1.49628	0.0000	0.0000

Deviations in molar refraction

The molar refraction deviations, ΔR , have been calculated from the following expressions (Baraldi *et al.*, 2002):

$$\Delta R = R_m - (x_1 R_1 + x_2 R_2) \quad (6)$$

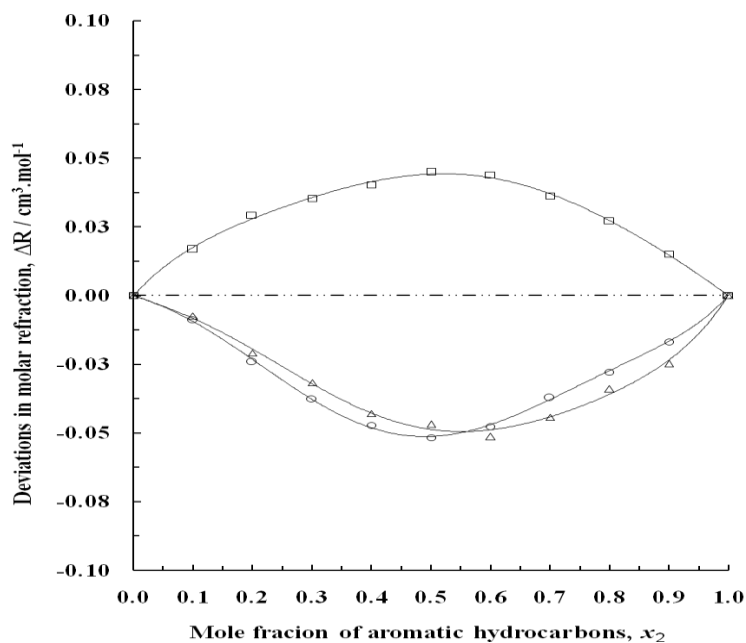
where, $R_m = \left[\frac{n_D^2 - 1}{n_D^2 + 2} \right] \frac{x_1 M_1 + x_2 M_2}{\rho}$, where, R_1 and R_2 represent the molar refractions of

components 1 and 2, respectively of the mixture. All the values are listed in Table 4 and Fig. 4 compares the ΔR of the three systems against x_2 at 298.15K. Concentration dependence of ΔR of each of the mixtures is fitted to the Redlich–Kister equation (3).

In Fig. 4 all the ΔR values like V_m^E are positive in NHP + TN system with maximum at $x_2 \sim 0.5$, exactly coinciding with the composition of maximum in its V_m^E vs. x_2 curves. On the other hand, as there is volume contraction, following the V_m^E 's all the ΔR values are negative for NHP + OXN and NHP + MSN systems with minima $x_2 \sim 0.6$ and $x_2 \sim 0.5$, respectively. The correlation between ΔR and V_m^E is further clarified by Fig. 5. The linear relationship between ΔR and V_m^E for all the systems are as given below: $y = 0.255x$, $R^2 = 0.993$; $y = 0.272x$, $R^2 = 0.994$ and $y = 0.266x + 2 \times 10^{-5}$, $R^2 = 0.995$, respectively.

Table 5. Polynomial fitting coefficients of equation (3) and standard deviations, σ in equation (4) for the systems of NHP (x_1) + TN (x_2), + OXN (x_2) and + MSN (x_2) at 298.15 K

Property	A_0	A_1	A_2	A_3	A_4	ρ
NHP (x_1) + TN (x_2)						
$V_m^E / \text{cm}^3 \text{mol}^{-1}$	0.6882	-0.0037	-0.1383	-0.2301	0.2418	0.00497
Δn_D	-0.0142	-0.0009	0.0152	0.0030	-0.0109	0.00019
$\Delta R / \text{cm}^3 \text{mol}^{-1}$	0.1767	0.0176	-0.0317	-0.0578	0.0571	0.00128
NHP (x_1) + OXN (x_2)						
$V_m^E / \text{cm}^3 \text{mol}^{-1}$	-0.7261	-0.1442	0.3686	-0.2807	-0.3717	0.00759
Δn_D	0.0469	0.0154	-0.0153	-0.0018	-0.0098	0.00030
$\Delta R / \text{cm}^3 \text{mol}^{-1}$	-0.1952	-0.0609	0.1019	-0.0697	-0.1150	0.00211
NHP (x_1) + MSN (x_2)						
$V_m^E / \text{cm}^3 \text{mol}^{-1}$	-0.7653	0.1382	0.5802	-0.4322	-0.3563	0.00354
Δn_D	0.0361	0.0009	-0.0776	-0.0080	0.0581	0.00043
$\Delta R / \text{cm}^3 \text{mol}^{-1}$	-0.2052	0.0158	0.1773	-0.1029	-0.1302	0.00097

**Fig. 4.** Comparison of deviations in molar refraction, ΔR as a function of x_2 for the systems of NHP (x_1) + TN (x_2) (\square), + OXN (x_2) (Δ) and + MSN (x_2) (o) at 298.15 K.

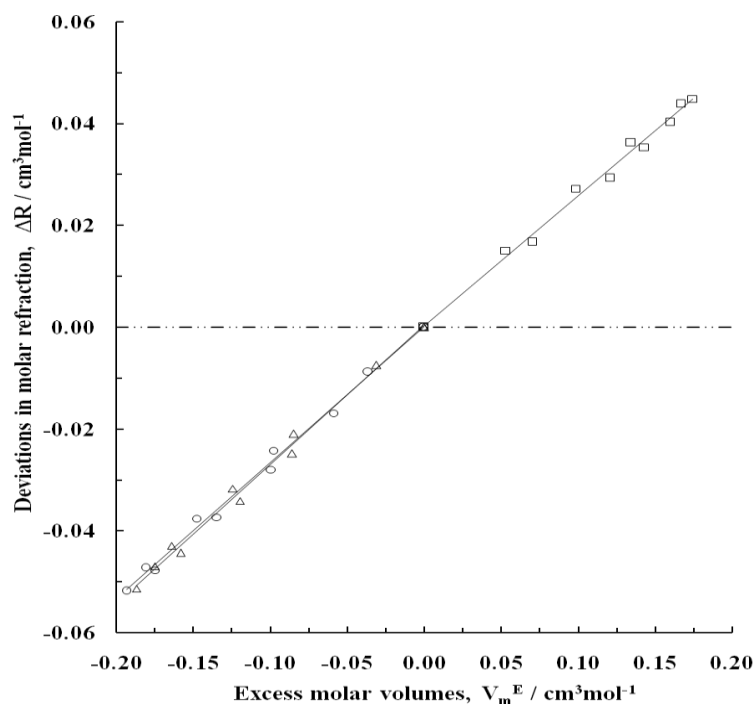


Fig. 5. Comparative study of ΔR vs. V_m^E for the systems of NHP (x_1) + TN (x_2) (\square), + OXN (x_2) (Δ) and +MSN (x_2) (\circ) at 298.15 K.

Thus, irrespective of the aromatic hydrocarbons all the systems show very close slope values. This indicates that whether there is volume expansion or volume contraction, overall interaction follows an equal order.

Conclusion

In NHP + TN system volume expansion takes place in the whole range of composition due to dominating dispersive forces V_m^E positive. On the other hand, in NHP + OXN and NHP + MSN systems, it is suggested that some ‘favourable geometrical fitting’ of the component molecules suppresses the dispersive forces to such an extent, so that, some negative contribution prevails in V_m^E . As a result, instead of expansion, contraction occurs in considerable amount due to their suitable molecular packings.

Acknowledgement

The authors gratefully acknowledge the financial grant from the Ministry of Science, Information and Communication Technology, Government of the People’s Republic of Bangladesh, for the project “Physical Properties and Molecular Interactions in Liquid Systems”.

References

- Ali, A., S. Hyder, and A.K. Nain, (1999). Studies on molecular interactions in binary liquid mixtures by viscosity and ultrasonic velocity measurements at 303.15 K. *J. Mol. Liq.*, **79**: 89-99.
- Al-Kandary, J.A., A.S. Al-Jimaz and A.M. Abdul-Latif, (2006). Excess molar volumes and refractive indices of (methoxybenzene + benzene, or toluene, or o-xylene, or m-xylene, or p-xylene, or mesitylene) binary mixtures between T = (288.15 to 303.15) K. *J. Chem. Thermodyn.*, **38**: 1351-1361.
- Al-Kandary, J.A., A.S. Al-Jimaz and A.M. Abdul-Latif, (2006). Viscosities, Densities, and Speeds of Sound of Binary Mixtures of Benzene, Toluene, o-Xylene, m-Xylene, p-Xylene, and Mesitylene with Anisole at (288.15, 293.15, 298.15, and 303.15) K. *J. Chem. Eng. Data*, **51**: 2074-2082.
- Aminabhavi, T.M. and K. Banerjee, (1999). Density, Viscosity, Refractive Index, and Speed of Sound in Binary Mixtures of 1-Chloronaphthalene with Benzene, Methylbenzene, 1,4-Dimethylbenzene, 1,3,5-Trimethylbenzene, and Methoxybenzene at (298.15, 303.15, and 308.15) K. *J. Chem. Eng. Data*, **44**: 547-552.
- Aminabhavi, T.M. and V.B. Patil, (1997). Density, Refractive Index, Viscosity, and Speed of Sound in Binary Mixtures of Ethenylbenzene with Hexane, Heptane, Octane, Nonane, Decane, and Dodecane. *J. Chem. Eng. Data*, **42**(3): 641-646.
- Aznarez, S., M.A. Postigo, G.C. Pedrosa, I.L. Acevedo and M. Katz, (1998). Densities, Refractive Indexes, and Excess Properties of Mixing of the n-Hexanol + Ethanenitrile + Dichloromethane Ternary System at 25°C. *J. Sol. Chem.*, **27**: 949-964.
- Baragi, J.G. and M.I. Aralaguppi, (2006). Excess and deviation properties for the binary mixtures of methylcyclohexane with benzene, toluene, p-xylene, mesitylene, and anisole at T = (298.15, 303.15, and 308.15) K. *J. Chem. Thermodyn.*, **38**: 1717-1724.
- Baraldi, P., M.G. Giorgini, D. Manzini, A. Marchetti and L. Tassi, (2002). Density, refractive index, and related properties for butanone/n-hexane binary mixtures at various temperatures. *J. Sol. Chem.*, **31**: 873-893.
- Baylaucq, A., C. Boned, P. Dauge and B. Lagourette, (1997). Measurements of the viscosity and density of three hydrocarbons and the three associated binary mixtures versus pressure and temperature. *Int. J. Thermophysics*, **18**(1): 3-23.
- Bhatia, S.C., R. Rani and R. Bhatia, (2011). Viscosities, densities, speeds of sound and refractive indices of binary mixtures of o-xylene, m-xylene, p-xylene, ethylbenzene and mesitylene with 1 decanol at 298.15 and 308.15 K. *J. Mol. Liq.*, **159**: 132-141.
- Brocos, P., A. Pineiro, R. Bravo and A. Amigo, (2003). Refractive indices, molar volumes and molar refractions of binary liquid mixtures: concepts and correlations. *Phys. Chem. Chem. Phys.*, **5**: 550-557.
- Diaz, C., B. Ortega, G. Marino and J. Tojo, (2001). Densities, refractive indices, and derived properties of (cyclohexane, or n-heptane + an aromatic hydrocarbon) at T = 298.15 K. *J. Chem. Thermodyn.*, **33**(9): 1015-1026.
- Díaz, C., A. Dominguez and J. Tojo, (2002). Phase Equilibria of the Binary Systems 1-Hexene with o-Xylene, m-Xylene, p-Xylene, Toluene, and Ethylbenzene at 101.3 kPa. *J. Chem. Eng. Data*, **47**(4): 867-871.
- Dominguez, M., J. Pardo, M.C. Lopez, F.M. Royo and J.S. Urieta, (1996). Viscosities of the ternary mixture (1-butanol + n-hexane + 1-butylamine) at the temperatures 298.15 and 313.15 K. *Fluid Phase Equilib.*, **124**: 147-159.
- Fermeglia, M. and G. Torriano, (1999). Density, Viscosity, and Refractive Index for Binary Systems of n-C16 and Four Nonlinear Alkanes at 298.15 K. *J. Chem. Eng. Data*, **44**: 965-969.

- Francesconi, R., F. Comelli and C. Castellari, (2000). Excess Molar Enthalpies and Excess Molar Volumes of Binary Mixtures Containing Dialkyl Carbonates + Anisole or Phenetole at (288.15 and 313.15) K. *J. Chem. Eng. Data*, **45**(4): 544-548
- Fucaloro, A.F., (2002). Partial molar volumes from refractive index measurements. *J. Chem. Educ.*, **79**: 865-873.
- Giner, B., C. Lafuente, A. Villares, M. Haro and M.C. Lopez, (2007). Volumetric and refractive properties of binary mixtures containing 1,4-dioxane and chloroalkanes. *J. Chem. Thermodyn.*, **39**: 148-157.
- Ilokhani, H., M. Rezaei-Sameti and J. Basiri-Parsa, (2006). Excess molar volumes and dynamic viscosities for binary mixtures of toluene + n-alkanes (C₅-C₁₀) at T = 298.15 K – Comparison with Prigogine–Flory–Patterson theory. *J. Chem. Thermodyn.*, **38**(8): 975-982
- Jimenez, E., H. Casas, L. Segade and C. Franjo, (2000). Surface Tensions, Refractive Indexes and Excess Molar Volumes of Hexane + 1-Alkanol Mixtures at 298.15 K. *J. Chem. Eng. Data*, **45**: 862–866.
- Lal, K., N. Tripathi and G.P. Dubey, (2000). Densities, Viscosities, and Refractive Indices of Binary Liquid Mixtures of Hexane, Decane, Hexadecane, and Squalane with Benzene at 298.15 K. *J. Chem. Eng. Data*, **45**(5): 961-964.
- Morávková, L. and J. Linek, (2008). Excess molar volumes of (octane + benzene, or toluene, or 1,3-xylene, or 1,3,5-trimethylbenzene) at temperatures between (298.15 and 328.15) K. *J. Chem. Thermodyn.*, **40**(4): 671-676.
- Mutalik, V., L.S. Manjeshwar, M. Sairamand and T.M. Aminabhavi, (2006). Thermodynamic properties of (tetradecane + benzene, + toluene, + chlorobenzene, + bromobenzene, + anisole) binary mixtures at T = (298.15, 303.15, and 308.15) K. *J. Chem. Thermodyn.*, **38**(8): 1062-1071.
- Nain, A.K., (2008). Refractive Indices and Deviations in Refractive Indices for Binary Mixtures of Formamide + 1-Butanol, + 2-Butanol, + 1,3-Butanediol, and + 1,4-Butanediol at Temperatures from (293.15 to 318.15) K. *J. Chem. Eng. Data*, **53**(5): 1208-1210.
- Pineiro, A., P. Brocos, A. Amigo, M. Pintos and R. Bravo, (2000). Prediction of excess volumes and excess surface tensions from refractive indices. *Phys. Chem. Liq.*, **38**: 251-260.
- Redlich, O.J. and A.T. Kister, (1948). Algebraic Representation of Thermodynamic Properties and the Classification of Solutions. *Ind. Eng. Chem.*, **40**: 345-348.
- Rodriguez, A., J. Canosa and J. Tojo, (2003). Physical properties of the binary mixtures (diethyl carbonate + hexane, heptane, octane and cyclohexane) from T=293.15K to T=313.15K. *J. Chem. Thermodyn.*, **35**: 1321-1333.
- Tejraj, M.A., (1999). Thermodynamic interactions in binary mixtures of ethenylbenzene with methanol, ethanol, butan-1-ol, pentan-1-ol, and hexan-1-ol in the temperature range 298. 15-308.15 K. *J. Chem. Eng. Data*, **44**: 1291-1297.
- Yanes, C., P. Perez-Tejeda and A. Maestre, (1989). Excess molar volumes and excess refractive indices of (*cis*-9-octadecenoic acid + *n*-hexane or cyclohexane or benzene or trichloroethene or tetrachloroethene) at 298.15 K. *J. Chem. Thermodyn.*, **21**: 1217-1222.