Research Article

Volumetric, Viscometric and Excess Properties of Binary Mixtures of 1-Iodobutane with Benzene, Toluene, *o*-Xylene, *m*-Xylene, *p*-Xylene, and Mesitylene at Temperatures from 303.15 to 313.15K

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Densities and viscosities have been determined for binary mixtures of 1-iodobutane with benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene at 303.15, 308.15, and 313.15 K for the entire composition range at atmospheric pressure. The excess molar volumes, V^E , deviations in viscosity, $\Delta\eta$, and excess Gibbs' free energy of activation flow, ΔG^{*E} have been calculated from the experimental values. The experimental data were fitted to Redlich-Kister polynomial equation. The variations of these parameters with composition of the mixtures and temperature have been discussed in terms of molecular interactions occurring in these mixtures. Further, the viscosities of these binary mixtures were calculated theoretically from their corresponding pure component data by using empirical relations like Bingham, Arrhenius and Eyring, Kendall and Munroe, Hind, Katti and Chaudhari, Grunberg and Nissan, and Tamura and Kurata. Comparison of various interaction parameters has been expressed to explain the intermolecular interactions between iodobutane and selected hydrocarbons.

1. Introduction

Densities and viscosities of solution are very important properties especially for the chemical design and for the optimization of chemical processes. The study of these properties plays an important role in many industrially interesting systems such as organic synthesis, ion extraction systems, gas adsorption solvents, and mass transfer phenomena. Furthermore, the study of excess thermodynamics and transport properties for binary mixtures gives an important information concerning the deeper understanding of the molecular liquid structure and intermolecular interactions [1]. 1-iodobutane has vast applications at industrial level because it works as an alkylating agent in organic synthesis. Aromatic hydrocarbons are also important organic solvents in organic synthesis and extraction systems. Aromatic hydrocarbons like xylenes were frequently used as octane enhancer in

vehicles [2]. The excess molar volume and viscosity deviations are properties sensitive to different kinds of association in the pure components and in the mixtures. These properties have been used to investigate the molecular packing, molecular motions, and various types of intermolecular interactions and their strengths, but these properties are influenced by the size, shape, and chemical nature of the component molecules [3–5]. In view of this significance, it was thought worthwhile to study the binary mixtures of 1-iodobutane, benzene, toluene, *o*-, *m*-, and *p*-xylenes in order to understand the interactions between these components. The lack of information has motivated us to undertake the present investigations. Here, densities and viscosities of the binary mixtures of 1-iodobutane with benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene at different temperatures (303.15, 308.15, 313.15) K are studied. To account more for the interactions between these binaries, some viscosity models, namely, Bingham,

Arrhenius and Eyring, Kendall and Munroe, Hind, Katti and Chaudhary, Grunberg and Nissan, and Tamura and Kurata are studied.

2. Experimental

2.1. Chemicals/Materials. 1-iodobutane, benzene, toluene, *o*-xylene, and *p*-xylene were supplied by Sd Fine-Chemicals Ltd., Mumbai, India, with purity 99.5%. *m*-Xylene was supplied by Spectrochem Pvt. Ltd., Mumbai, India, with 99.5% purity. Mesitylene was supplied by CDH Ltd. New Delhi, India, with 99.5% purity.

2.2. Apparatus and Procedure. Airtight stopper bottles were used for the preparation of the mixtures and were placed in the dark place. The losses in the mixtures were kept to minimum, as evidenced by repeated measurements of physical properties over an interval of 2-3 days during in which before use time no change in physical properties was observed. The mixtures were well mixed by shaking before use. Binary mixtures were prepared by mass, using an electronic analytical balance (Reptech RA-2012) supplied by Reptechindia Pvt. Ltd., Gujarat, India, with a precision of ± 0.0001 g. The uncertainty in mole fraction was estimated to be ± 0.0001 .

Accurate densities of $\pm 0.0001 \text{ g} \cdot \text{cm}^{-3}$ were measured by using pycnometer having bulb volume of 10 cm^3 and capillary orifice with internal diameter 1 cm^3 . For each measurement, the pycnometer was filled with required liquid and was kept in water bath with thermal stability which was checked by calibrated thermometer at the equilibrium. An average of triplicate measurements was taken into account and their reproducibility was within the range of $\pm 0.3\%$. The viscosities of pure components and their mixtures have been measured by SV 10, Vibro-viscometer, supplied by A and D instruments Pvt. Ltd., Haryana, India, having measurement range $0.3 \text{ m} \cdot \text{Pa} \cdot \text{s}$ – $10,000 \text{ m} \cdot \text{Pa} \cdot \text{s}$. Its working vibration frequency is 30 Hz, and the temperature measurement range is 0 – 160°C with $\pm 0.1^\circ\text{C}$ accuracy. Accurate viscosity of $\pm 0.001 \text{ m} \cdot \text{Pa} \cdot \text{s}$ was measured by the viscometer. For maintaining the temperature throughout the experiment, NSW 274 water bath supplied by NSW company, India, has been used. The temperature has been measured with accuracy of $\pm 0.01^\circ\text{C}$.

2.3. Calculations. The excess molar volumes, V^E , viscosity deviations, $\Delta\eta$, and excess Gibbs' free energy of activation flow, ΔG^{*E} , for binary mixtures were determined using the following equations (Table 4).

2.3.1. Excess Molar Volumes. Excess molar volume [4] is calculated by using following equation:

$$V^E = V_m - \sum_{i=1}^2 V_i x_i, \quad (1)$$

where V_i represents the molar volume and x_i is the mole fraction of i th component. The quantity V_m refers to the molar volume of the mixture which can be calculated from the

mixture density, ρ_m , and the component molecular weights M_1 and M_2 as

$$V_m = \frac{(M_1 x_1 + M_2 x_2)}{\rho_m}. \quad (2)$$

2.3.2. Viscosity Deviations. The viscosity deviations ($\Delta\eta$) [5] with mole fraction were calculated by the following:

$$\Delta\eta \text{ (m} \cdot \text{Pa} \cdot \text{s)} = \eta_{12} - \sum_{i=1}^2 x_i \eta_i, \quad (3)$$

where x_i , η_i , and η_{12} refer, respectively, to the mole fraction and viscosities of i th pure components and of the binary mixtures.

2.3.3. Excess Gibbs' Free Energy of Activation of Flow. The excess Gibbs' free energy of activation of flow, ΔG^{*E} , for the binary liquid mixture was computed by the following equation:

$$G^{*E} \text{ (J mol}^{-1}\text{)} = RT \{ \ln(\eta V) - x_1 \ln(\eta_1 V_1) - x_2 \ln(\eta_2 V_2) \}, \quad (4)$$

where, V_1 , V_2 , and V are the molar volumes of component 1, component 2, and mixture, respectively. η_1 , η_2 , and η are viscosities of the component 1, component 2, and mixture, respectively. R and T have their usual meaning.

The experimentally determined values of V^E , $\Delta\eta$ and ΔG^{*E} for binary mixtures were fitted to the Redlich-Kister equation (5) [6]:

$$Y_m^E = x_1 (1 - x_1) \sum_{i=0}^n a_i (2x_1 - 1)^i, \quad (5)$$

where Y^E is V^E or $\Delta\eta$ or ΔG^{*E} ; x_1 denoted the mole fraction of the 1st component in the binary mixture. The coefficient a_i was obtained by fitting (5) to experimental results using a least squares regression method. The values of coefficient, a_i , along with the standard deviations, σ , are presented in Table 6.

$$\sigma = \left\{ \frac{\sum (Y_{\text{exp}}^E - Y_{\text{fit}}^E)^2}{(n - p)} \right\}^{1/2}. \quad (6)$$

2.4. Interaction Parameters. Several equations have been put forward to correlate viscosity of binary liquid mixtures in terms of their pure component data. Some of these equations are discussed here.

(i) Bingham [7] proposed the following equation, which gives ideal viscosity of the mixture:

$$\eta = \sum x_i \eta_i, \quad (7)$$

where x_i and η_i are the mole fraction and viscosity of i th component, respectively.

TABLE 1: Comparison of experimental density and viscosity of pure liquid with the literature values.

Component	T/K	$\rho/\text{g}\cdot\text{cm}^{-3}$		$\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	
		exptl	lit.	exptl	lit.
Benzene	303.15	0.8683	0.86292 [24]	0.563	0.561 [25]
	308.15	0.8626	0.85758 [24]	0.538	0.537 [26]
	313.15	0.8574	0.85224 [24]	0.506	0.506 [25]
Toluene	303.15	0.8574	0.85764 [27]	0.526	0.525 [26]
	308.15	0.8531	0.85293 [27]	0.497	0.498 [26]
	313.15	0.8487	0.84821 [27]	0.465	0.4659 [28]
o-Xylene	303.15	0.8709	0.87131 [27]	0.708	0.709 [29]
	308.15	0.8672	0.86705 [27]	0.662	0.665 [30]
	313.15	0.8629	0.86279 [27]	0.621	0.621 [31]
m-Xylene	303.15	0.8556	0.85574 [24]	0.552	0.552 [32]
	308.15	0.8520	0.85145 [24]	0.523	0.524 [32]
	313.15	0.8469	0.84717 [24]	0.497	0.497 [32]
p-xylene	303.15	0.8524	0.85247 [24]	0.571	0.572 [33]
	308.15	0.8481	0.84812 [24]	0.540	0.540 [33]
	313.15	0.8438	0.84377 [27]	0.518	0.517 [31]
Mesitylene	303.15	0.8571	0.85754 [27]	0.623	0.622 [33]
	308.15	0.8534	0.85363 [27]	0.586	0.586 [33]
	313.15	0.8498	0.84971 [27]	0.543	—
1-Iodobutane	303.15	1.5861	—	1.446	—
	308.15	1.5714	—	1.237	—
	313.15	1.5632	—	1.153	—

(ii) Arrhenius' [8] model for the viscosity of pure liquid and mixtures can be modified as

$$\ln \eta v = \sum x_i \ln \eta_i v_i, \quad (8)$$

where x_i , η_i , and v_i are the mole fraction, viscosity, and volume of i th component, respectively.

(iii) Kendall [9] has modified the equation for viscosity of binary liquid system which is given as

$$\ln \eta = \sum x_i \ln \eta_i, \quad (9)$$

where x_i and η_i are the mole fraction and viscosity of i th component, respectively.

(iv) Grunberg and Nissan [10] have formulated (10) to assess the molecular interactions due to viscosity changes:

$$\ln \eta_{12} = x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_1 x_2 G_{12}, \quad (10)$$

where G_{12} is a constant, proportional to interchange energy, x_1 and x_2 are mole fractions of components 1 and 2, respectively, and η_1 , η_2 , and η_{12} are the dynamic viscosities of component 1, component 2, and binary mixtures, respectively.

(v) Hind et al. [11] have suggested the following (11) for the viscosity of binary liquid mixtures as follows:

$$\eta = x_1^2 \eta_1 + x_2^2 \eta_2 + 2x_1 x_2 H_{12}, \quad (11)$$

where H_{12} is the Hind interaction parameter and is attributed to unlike pair interactions, x_1 and x_2 are the mole fractions

TABLE 2: Mole fraction (x_1), density (ρ_{12}), and excess molar volume (V^E) for 1-iodobutane + hydrocarbons binary mixtures at different temperatures.

x_1	$\rho_{12}/\text{gm}\cdot\text{cm}^{-3}$			$V^E/\text{cm}^3\cdot\text{mol}^{-1}$		
	303.15 K	308.15 K	313.15 K	303.15 K	308.15 K	313.15 K
1-Iodobutane + benzene						
0.0000	0.8683	0.8626	0.8574	0.0000	0.0000	0.0000
0.0793	0.9402	0.9338	0.9282	-0.0117	-0.0145	-0.0099
0.1624	1.0121	1.0049	0.9989	-0.0223	-0.0218	-0.0119
0.2494	1.0840	1.0760	1.0697	-0.0320	-0.0320	-0.0253
0.3408	1.1559	1.1470	1.1403	-0.0410	-0.0362	-0.0225
0.4367	1.2277	1.2179	1.2110	-0.0413	-0.0350	-0.0308
0.5377	1.2995	1.2888	1.2816	-0.0416	-0.0371	-0.0326
0.6440	1.3712	1.3595	1.3520	-0.0343	-0.0265	-0.0206
0.7562	1.4429	1.4302	1.4225	-0.0274	-0.0194	-0.0191
0.8747	1.5145	1.5008	1.4928	-0.0134	-0.0081	-0.0045
1.0000	1.5861	1.5714	1.5632	0.0000	0.0000	0.0000
1-Iodobutane + toluene						
0.0000	0.8576	0.8531	0.8487	0.0000	0.0000	0.0000
0.0933	0.9300	0.9249	0.9201	0.0314	0.0362	0.0392
0.1880	1.0028	0.9968	0.9916	0.0370	0.0499	0.0553
0.2842	1.0757	1.0688	1.0632	0.0317	0.0452	0.0525
0.3818	1.1486	1.1408	1.1348	0.0270	0.0351	0.0440
0.4809	1.2216	1.2128	1.2064	0.0137	0.0203	0.0305
0.5815	1.2946	1.2847	1.2780	0.0017	0.0104	0.0129
0.6837	1.3676	1.3566	1.3494	-0.0091	-0.0037	0.0086
0.7875	1.4405	1.4283	1.4208	-0.0111	-0.0055	-0.0003
0.8929	1.5133	1.4998	1.4920	-0.0053	0.0036	0.0023
1.0000	1.5861	1.5714	1.5632	0.0000	0.0000	0.0000
1-Iodobutane + o-xylene						
0.0000	0.8709	0.8672	0.8629	0.0000	0.0000	0.0000
0.1045	0.9418	0.9372	0.9325	0.0798	0.0963	0.1006
0.2080	1.0127	1.0072	1.0019	0.1478	0.1699	0.2016
0.3105	1.0835	1.0770	1.0713	0.2172	0.2476	0.2801
0.4119	1.1545	1.1470	1.1408	0.2566	0.2866	0.3298
0.5123	1.2257	1.2171	1.2104	0.2716	0.3039	0.3559
0.6118	1.2972	1.2874	1.2804	0.2572	0.2938	0.3342
0.7103	1.3690	1.3580	1.3506	0.2184	0.2522	0.2906
0.8078	1.4411	1.4289	1.4212	0.1593	0.1842	0.2118
0.9044	1.5135	1.5001	1.4921	0.0832	0.0941	0.1113
1.0000	1.5861	1.5714	1.5632	0.0000	0.0000	0.0000
1-Iodobutane + m-xylene						
0.0000	0.8556	0.8520	0.8469	0.0000	0.0000	0.0000
0.1062	0.9282	0.9238	0.9182	0.0597	0.0645	0.0822
0.2110	1.0007	0.9954	0.9894	0.1223	0.1367	0.1606
0.3143	1.0732	1.0668	1.0605	0.1755	0.1995	0.2251
0.4162	1.1458	1.1384	1.1317	0.2107	0.2417	0.2685
0.5168	1.2185	1.2100	1.2030	0.2313	0.2572	0.2865
0.6160	1.2916	1.2819	1.2745	0.2121	0.2442	0.2772
0.7139	1.3649	1.3540	1.3463	0.1777	0.2050	0.2410
0.8105	1.4384	1.4264	1.4183	0.1308	0.1451	0.1799
0.9059	1.5122	1.4989	1.4906	0.0656	0.0731	0.0978
1.0000	1.5861	1.5714	1.5632	0.0000	0.0000	0.0000

TABLE 2: Continued.

x_1	$\rho_{12}/\text{gm}\cdot\text{cm}^{-3}$			$V^E/\text{cm}^3\cdot\text{mol}^{-1}$		
	303.15 K	308.15 K	313.15 K	303.15 K	308.15 K	313.15 K
1-Iodobutane + <i>p</i> -xylene						
0.0000	0.8524	0.8481	0.8438	0.0000	0.0000	0.0000
0.1066	0.9254	0.9202	0.9154	0.0494	0.0685	0.0854
0.2116	0.9984	0.9923	0.9870	0.0910	0.1186	0.1493
0.3151	1.0713	1.0643	1.0586	0.1376	0.1655	0.1963
0.4171	1.1444	1.1364	1.1303	0.1565	0.1885	0.2189
0.5177	1.2175	1.2086	1.2021	0.1727	0.1921	0.2218
0.6169	1.2909	1.2808	1.2739	0.1589	0.1894	0.2181
0.7147	1.3644	1.3532	1.3459	0.1380	0.1637	0.1913
0.8111	1.4382	1.4258	1.4180	0.0949	0.1191	0.1536
0.9062	1.5121	1.4985	1.4904	0.0487	0.0666	0.0910
1.0000	1.5861	1.5714	1.5632	0.0000	0.0000	0.0000
1-Iodobutane + mesitylene						
0.0000	0.8571	0.8534	0.8498	0.000	0.000	0.000
0.1190	0.9295	0.9249	0.9207	0.127	0.146	0.178
0.2330	1.0017	0.9961	0.9915	0.247	0.286	0.314
0.3425	1.0738	1.0673	1.0622	0.349	0.383	0.419
0.4476	1.1461	1.1385	1.1329	0.402	0.446	0.488
0.5486	1.2186	1.2099	1.2038	0.416	0.462	0.506
0.6458	1.2914	1.2815	1.2749	0.391	0.441	0.485
0.7393	1.3646	1.3535	1.3463	0.326	0.371	0.423
0.8294	1.4381	1.4257	1.4180	0.237	0.280	0.328
0.9162	1.5119	1.4984	1.4903	0.129	0.149	0.184
1.0000	1.5861	1.5714	1.5632	0.000	0.000	0.000

of components 1 and 2, respectively, and η_1 and η_2 are the viscosities of component 1 and component 2, respectively.

(vi) Tamura-Kurata [12] have developed (12) for the viscosity of binary liquid mixtures as follows:

$$\eta = x_1\phi_1\eta_1 + x_2\phi_2\eta_2 + 2(x_1x_2\phi_1\phi_2)^{0.5}T_{12}, \quad (12)$$

where T_{12} is the interaction parameter which depends on temperature and composition of the mixtures, and x_1 and x_2 are the mole fractions of components 1 and 2, respectively. η_1 and η_2 are the viscosities of component 1 and component 2, respectively, and ϕ_1 and ϕ_2 are the volume fractions of components 1 and 2, respectively.

(vii) Katti et al. [13] have suggested following equation for viscosity of binary liquid system:

$$\ln \eta V = \sum x_i \ln V_i + \left(\frac{W_{\text{vis}}}{RT} \right) x_1 x_2, \quad (13)$$

where W_{vis} is the interaction energy parameter, V is the volume of the mixture, x_1 and x_2 are the mole fractions, and η_1 and η_2 are the viscosities of component 1 and component 2, respectively.

3. Results and Discussion

The experimental values of densities and viscosities of the hydrocarbons are compared with the literature values and are presented in Table 1. It was found that the experimental values

FIGURE 1: Excess molar volume (V^E) with mole fraction (x_1) for 1-iodobutane + benzene (■), 1-iodobutane + toluene (●), 1-iodobutane + *o*-xylene (▲), 1-iodobutane + *m*-xylene (▼), 1-iodobutane + *p*-xylene (◆), and 1-iodobutane + mesitylene (►) at 308.15 K.

FIGURE 2: Viscosity deviations ($\Delta\eta$) with mole fraction (x_1) for 1-iodobutane + benzene (■), 1-iodobutane + toluene (●), 1-iodobutane + *o*-xylene (▲), 1-iodobutane + *m*-xylene (▼), 1-iodobutane + *p*-xylene (◆), and 1-iodobutane + mesitylene (►) at 308.15 K.

are in proximity with the literature values. Insufficient data on densities and viscosities of pure 1-iodobutane is available [14].

The densities, ρ , and viscosities, η , of binary mixtures were measured at 303.15, 308.15, 313.15 $\pm$ 0.01 K as a function of the composition of the corresponding binary mixtures. The results of the study are presented in Tables 2 and 3.

The plots of V^E , $\Delta\eta$, and ΔG^{*E} versus x_i in respective binary mixtures have been given in Figures 1, 2, and 3 at 308.15 K.

It can be seen from Figure 1 that the values of V^E are negative for 1-iodobutane + benzene and positive for 1-iodobutane + *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene mixtures over the whole composition range at three temperatures. The shape of the curve is sigmoid for 1-iodobutane +

TABLE 3: Mole fraction (x_1), experimental and theoretical viscosities (η) for 1-iodobutane + hydrocarbons binary mixtures at 303.15, 308.15, and 313.15 K.

x_1	$\eta_{(\text{Exp})}$			$\eta_{(\text{Big})}$			$\eta_{(\text{Arr})}$			$\eta_{(\text{K-M})}$		
	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15
1-Iodobutan + benzene												
0.0000	0.563	0.538	0.506	0.563	0.538	0.506	0.563	0.538	0.506	0.563	0.538	0.506
0.0793	0.622	0.582	0.541	0.634	0.594	0.558	0.619	0.585	0.550	0.607	0.575	0.540
0.1624	0.686	0.629	0.583	0.707	0.652	0.612	0.681	0.637	0.598	0.656	0.616	0.579
0.2494	0.755	0.681	0.630	0.784	0.713	0.668	0.748	0.692	0.649	0.713	0.663	0.622
0.3408	0.830	0.738	0.683	0.865	0.777	0.728	0.823	0.752	0.705	0.777	0.716	0.671
0.4367	0.912	0.802	0.742	0.950	0.845	0.790	0.904	0.818	0.765	0.851	0.775	0.726
0.5377	1.002	0.873	0.808	1.039	0.915	0.855	0.993	0.889	0.831	0.936	0.843	0.789
0.6440	1.101	0.952	0.881	1.133	0.989	0.924	1.091	0.965	0.902	1.035	0.921	0.861
0.7562	1.207	1.040	0.962	1.232	1.068	0.996	1.199	1.049	0.979	1.150	1.011	0.944
0.8747	1.323	1.135	1.052	1.336	1.150	1.072	1.317	1.139	1.063	1.285	1.115	1.041
1.0000	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153
1-Iodobutane + toluene												
0.0000	0.526	0.497	0.465	0.526	0.497	0.465	0.526	0.497	0.465	0.526	0.497	0.465
0.0933	0.583	0.533	0.492	0.612	0.566	0.529	0.582	0.545	0.510	0.578	0.541	0.506
0.1880	0.649	0.581	0.533	0.699	0.636	0.595	0.644	0.597	0.558	0.636	0.590	0.552
0.2842	0.724	0.638	0.586	0.788	0.708	0.661	0.713	0.654	0.612	0.701	0.644	0.602
0.3818	0.807	0.704	0.647	0.878	0.780	0.728	0.789	0.717	0.670	0.774	0.704	0.658
0.4809	0.896	0.776	0.714	0.969	0.853	0.796	0.872	0.785	0.733	0.855	0.771	0.720
0.5815	0.991	0.854	0.786	1.061	0.928	0.865	0.965	0.860	0.803	0.947	0.845	0.789
0.6837	1.093	0.938	0.864	1.155	1.003	0.936	1.068	0.942	0.879	1.050	0.927	0.865
0.7875	1.202	1.028	0.949	1.251	1.080	1.007	1.182	1.032	0.962	1.166	1.019	0.951
0.8929	1.319	1.126	1.044	1.348	1.158	1.079	1.307	1.130	1.053	1.297	1.122	1.046
1.0000	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153
1-Iodobutane + o-xylene												
0.0000	0.708	0.662	0.621	0.708	0.662	0.621	0.708	0.662	0.621	0.708	0.662	0.621
0.1045	0.726	0.652	0.597	0.786	0.723	0.677	0.761	0.706	0.661	0.763	0.707	0.663
0.2080	0.751	0.655	0.590	0.862	0.782	0.732	0.818	0.752	0.704	0.822	0.755	0.707
0.3105	0.788	0.673	0.602	0.938	0.841	0.787	0.878	0.800	0.750	0.884	0.805	0.753
0.4119	0.840	0.708	0.632	1.013	0.900	0.841	0.943	0.852	0.798	0.951	0.857	0.802
0.5123	0.908	0.761	0.682	1.087	0.958	0.895	1.013	0.907	0.848	1.022	0.913	0.854
0.6118	0.993	0.830	0.749	1.161	1.015	0.947	1.088	0.965	0.902	1.097	0.972	0.908
0.7103	1.092	0.915	0.832	1.233	1.071	1.000	1.168	1.027	0.959	1.177	1.033	0.965
0.8078	1.203	1.013	0.929	1.305	1.127	1.051	1.254	1.093	1.020	1.261	1.098	1.024
0.9044	1.322	1.122	1.037	1.376	1.182	1.102	1.347	1.163	1.084	1.351	1.166	1.087
1.0000	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153
1-Iodobutane + m-xylene												
0.0000	0.552	0.523	0.497	0.552	0.523	0.497	0.552	0.523	0.497	0.552	0.523	0.497
0.1062	0.566	0.511	0.471	0.647	0.599	0.567	0.608	0.571	0.541	0.611	0.573	0.544
0.2110	0.597	0.520	0.470	0.741	0.674	0.636	0.670	0.623	0.589	0.676	0.628	0.594
0.3143	0.644	0.548	0.491	0.834	0.748	0.704	0.738	0.679	0.641	0.747	0.686	0.648
0.4162	0.711	0.595	0.533	0.925	0.821	0.771	0.813	0.740	0.698	0.825	0.749	0.706
0.5168	0.796	0.662	0.593	1.015	0.893	0.837	0.895	0.807	0.759	0.909	0.817	0.769
0.6160	0.899	0.746	0.671	1.104	0.964	0.902	0.985	0.879	0.825	1.000	0.890	0.835
0.7139	1.019	0.847	0.766	1.191	1.033	0.966	1.084	0.957	0.897	1.098	0.968	0.907
0.8105	1.151	0.964	0.878	1.277	1.102	1.029	1.193	1.043	0.976	1.205	1.052	0.984
0.9059	1.295	1.094	1.007	1.362	1.170	1.092	1.314	1.136	1.061	1.321	1.141	1.066
1.0000	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153

TABLE 3: Continued.

x_1	$\eta_{(\text{Exp})}$			$\eta_{(\text{Big})}$			$\eta_{(\text{Arr})}$			$\eta_{(\text{K-M})}$		
	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15
1-Iodobutane + <i>p</i> -xylene												
0.0000	0.571	0.540	0.518	0.571	0.540	0.518	0.571	0.540	0.518	0.571	0.540	0.518
0.1066	0.572	0.507	0.453	0.665	0.615	0.586	0.627	0.587	0.562	0.630	0.590	0.564
0.2116	0.590	0.500	0.434	0.757	0.688	0.653	0.688	0.639	0.609	0.695	0.644	0.614
0.3151	0.627	0.518	0.449	0.848	0.760	0.719	0.756	0.694	0.660	0.766	0.702	0.667
0.4171	0.686	0.559	0.490	0.937	0.832	0.784	0.829	0.754	0.715	0.842	0.764	0.724
0.5177	0.767	0.621	0.552	1.025	0.902	0.848	0.910	0.819	0.775	0.924	0.830	0.785
0.6169	0.869	0.704	0.632	1.112	0.971	0.910	0.998	0.890	0.839	1.014	0.901	0.849
0.7147	0.991	0.807	0.729	1.197	1.039	0.972	1.095	0.966	0.909	1.110	0.977	0.918
0.8111	1.130	0.930	0.846	1.281	1.106	1.034	1.201	1.049	0.984	1.214	1.058	0.992
0.9062	1.283	1.074	0.985	1.364	1.172	1.094	1.318	1.139	1.065	1.325	1.145	1.070
1.0000	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153
1-Iodobutane + mesitylene												
0.0000	0.623	0.586	0.543	0.623	0.586	0.543	0.623	0.586	0.543	0.623	0.586	0.543
0.1190	0.606	0.530	0.460	0.686	0.636	0.590	0.650	0.607	0.561	0.664	0.620	0.575
0.2330	0.609	0.509	0.429	0.752	0.688	0.639	0.685	0.634	0.586	0.711	0.659	0.611
0.3425	0.636	0.518	0.436	0.822	0.743	0.691	0.729	0.669	0.618	0.764	0.702	0.651
0.4476	0.690	0.557	0.474	0.896	0.802	0.745	0.783	0.713	0.658	0.824	0.751	0.697
0.5486	0.769	0.621	0.537	0.974	0.864	0.803	0.849	0.766	0.708	0.892	0.806	0.749
0.6458	0.872	0.708	0.621	1.057	0.929	0.865	0.929	0.830	0.767	0.971	0.869	0.808
0.7393	0.995	0.815	0.724	1.145	0.999	0.930	1.025	0.906	0.839	1.063	0.941	0.876
0.8294	1.134	0.940	0.847	1.239	1.073	1.000	1.140	0.998	0.925	1.170	1.025	0.954
0.9162	1.286	1.082	0.990	1.339	1.152	1.074	1.279	1.107	1.029	1.296	1.123	1.046
1.0000	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153	1.446	1.237	1.153

FIGURE 3: Excess Gibbs' Free energy of activation of flow (ΔG^{*E}) with mole fraction toluene ($\bullet$), 1-iodobutane + *o*-xylene ($\blacktriangle$), 1-iodobutane + *m*-xylene ($\blacktriangledown$), 1-iodobutane + *p*-xylene ($\blacklozenge$), and 1-iodobutane + mesitylene ($\blacktriangleright$) at 308.15 K.

toluene mixtures, where V^E changes sign from positive to negative as the concentration of 1-iodobutane in mixtures has increased.

The observed changes in excess molar volumes are discussed in terms of three types of contributions physical, chemical, and structural in general [15].

- (i) Physical contribution, that is, nonspecific interaction between the real species present in mixtures and this effect contributes positive value to V^E .
- (ii) The chemical or specific interaction results in a volume decrease and these include charge transfer type forces and other complex forming interactions. This effect contributes negative value to V^E .
- (iii) The structural contributions arise from several effects, especially from interstitial accommodation and change in free volume. In other words, structural contribution arises due to geometrical fitting of one component into another because of large difference in the free volume and molar volume of components. This effect contributes negative value to V^E .

V^E values observed are both negative to positive, in case highly polar 1-Iodobutane and non polar hydrocarbons. V^E values are negative for benzene and 1-iodobutane binary mixtures indicating strong interaction between the two components. The observed V^E values are both positive and negative for 1-iodobutane-toluene mixtures and shift from positive to negative values at a mole fraction of $x_1 = 0.6837$ for component 1. For remaining binary mixtures, V^E values are positive and indicate for involvement of dispersion type of force. The plot of V^E versus x_1 shows maxima near the middle

TABLE 4: Mole fraction (x_1), viscosity deviations ($\Delta\eta$), and excess Gibbs' free energy of activation flow (ΔG^{*E}) for 1-iodobutane + hydrocarbons binary mixtures at 303.15, 308.15, and 313.15 K.

x_1	$\Delta\eta$			ΔG^{*E}		
	303.15	308.15	313.15	303.15	308.15	313.15
1-Iodobutane + benzene						
0.0000	0.000	0.000	0.000	0.00	0.00	0.00
0.0793	-0.011	-0.012	-0.016	71.96	36.98	12.70
0.1624	-0.020	-0.023	-0.028	125.76	64.83	30.85
0.2494	-0.028	-0.032	-0.038	164.06	86.04	49.80
0.3408	-0.033	-0.038	-0.044	188.05	100.83	67.50
0.4367	-0.036	-0.042	-0.047	198.35	110.16	80.31
0.5377	-0.035	-0.041	-0.046	194.77	112.66	85.55
0.6440	-0.031	-0.036	-0.042	175.83	106.95	81.69
0.7562	-0.023	-0.027	-0.033	139.36	89.16	66.46
0.8747	-0.012	-0.014	-0.020	82.24	55.42	39.53
1.0000	0.000	0.000	0.000	0.00	0.00	0.00
1-Iodobutane + toluene						
0.0000	0.000	0.000	0.000	0.00	0.00	0.00
0.0933	-0.029	-0.034	-0.037	21.57	-39.67	-73.07
0.1880	-0.049	-0.056	-0.061	53.57	-38.92	-85.11
0.2842	-0.063	-0.069	-0.075	84.30	-19.63	-67.59
0.3818	-0.070	-0.075	-0.081	107.23	3.72	-40.77
0.4809	-0.072	-0.076	-0.082	118.78	22.05	-17.88
0.5815	-0.069	-0.073	-0.079	117.28	31.05	-4.43
0.6837	-0.061	-0.065	-0.071	103.19	30.46	-0.15
0.7875	-0.048	-0.052	-0.058	77.54	22.38	-2.50
0.8929	-0.028	-0.032	-0.035	42.28	10.67	-4.72
1.0000	0.000	0.000	0.000	0.00	0.00	0.00
1-Iodobutane + <i>o</i> -xylene						
0.0000	0.000	0.000	0.000	0.00	0.00	0.00
0.1045	-0.059	-0.070	-0.081	-121.57	-203.82	-270.46
0.2080	-0.110	-0.128	-0.143	-219.58	-356.89	-465.17
0.3105	-0.149	-0.168	-0.185	-281.28	-449.00	-576.84
0.4119	-0.171	-0.191	-0.208	-302.31	-480.32	-609.09
0.5123	-0.178	-0.197	-0.213	-286.12	-457.55	-574.42
0.6118	-0.166	-0.184	-0.198	-241.86	-393.36	-490.65
0.7103	-0.140	-0.155	-0.168	-180.27	-302.37	-376.59
0.8078	-0.101	-0.113	-0.123	-112.82	-199.08	-248.60
0.9044	-0.053	-0.061	-0.066	-50.05	-95.24	-120.09
1.0000	0.000	0.000	0.000	0.00	-0.00	0.00
1-Iodobutane + <i>m</i> -xylene						
0.0000	0.000	0.000	0.000	-0.00	0.00	0.00
0.1062	-0.080	-0.088	-0.096	-189.39	-289.97	-368.25
0.2110	-0.143	-0.155	-0.165	-310.71	-477.93	-601.87
0.3143	-0.188	-0.200	-0.212	-366.01	-569.82	-712.90
0.4162	-0.213	-0.225	-0.238	-364.78	-580.07	-725.48
0.5168	-0.218	-0.231	-0.244	-322.97	-530.53	-667.36
0.6160	-0.203	-0.217	-0.231	-257.54	-442.44	-562.96
0.7139	-0.171	-0.186	-0.200	-182.52	-333.70	-432.70
0.8105	-0.125	-0.139	-0.152	-109.55	-218.16	-289.90
0.9059	-0.066	-0.076	-0.085	-46.85	-104.93	-143.98
1.0000	0.000	0.000	0.000	0.00	0.00	0.00

TABLE 4: Continued.

x_1	$\Delta\eta$			ΔG^{*E}		
	303.15	308.15	313.15	303.15	308.15	313.15
1-Iodobutane + <i>p</i> -xylene						
0.0000	0.000	0.000	0.000	0.00	0.00	0.00
0.1066	-0.092	-0.108	-0.133	-241.39	-387.50	-571.77
0.2116	-0.166	-0.187	-0.219	-409.31	-642.71	-899.93
0.3151	-0.219	-0.243	-0.269	-495.99	-772.16	-1022.85
0.4171	-0.249	-0.273	-0.292	-508.23	-794.32	-1005.69
0.5177	-0.257	-0.281	-0.294	-462.88	-737.24	-905.59
0.6169	-0.241	-0.267	-0.278	-379.97	-626.37	-761.73
0.7147	-0.205	-0.231	-0.243	-278.90	-483.78	-593.63
0.8111	-0.150	-0.175	-0.187	-175.23	-325.48	-409.31
0.9062	-0.080	-0.099	-0.108	-79.59	-162.11	-211.36
1.0000	0.000	0.000	0.000	0.00	0.00	0.00
1-Iodobutane + mesitylene						
0.0000	0.000	0.000	0.000	-0.00	0.00	0.00
0.1190	-0.114	-0.133	-0.155	-315.62	-477.99	-658.56
0.2330	-0.205	-0.229	-0.256	-540.70	-796.46	-1059.79
0.3425	-0.267	-0.290	-0.315	-657.61	-952.89	-1223.63
0.4476	-0.300	-0.320	-0.341	-673.96	-968.85	-1210.05
0.5486	-0.304	-0.322	-0.340	-613.68	-882.66	-1084.90
0.6458	-0.281	-0.298	-0.316	-504.97	-733.83	-897.67
0.7393	-0.236	-0.252	-0.269	-373.81	-553.88	-681.37
0.8294	-0.170	-0.185	-0.201	-238.35	-363.39	-454.10
0.9162	-0.090	-0.100	-0.112	-111.25	-176.46	-225.13
1.0000	0.000	0.000	0.000	0.00	0.00	0.00

point, that is, $x_1 = 0.5$ confirming the maximum interaction at the equimolar composition.

As we move from benzene, toluene, and xylenes to mesitylene, there is an increase in the number of $-\text{CH}_3$ groups. As the number of methyl groups increases, electron donating tendency increases in hydrocarbons but at the same time there may be steric repulsion between methyl groups of 1-iodobutane and hydrocarbons which hinders proper orientation. V^E values for *o*, *m*, *p*-xylene, and 1, 3, 5 tri-methylbenzene are positive over the whole composition range. The increase in V^E values with the increase in number of $-\text{CH}_3$ groups implies that dipole-induced dipole interaction is weaker in higher hydrocarbon owing to its decreased polarizabilities with the increase of $-\text{CH}_3$ groups. A similar type of study was reported by Nain et al. [16] for 1,4-dioxane and hydrocarbons. The observed V^E values are in the order of

$$\text{Benzene} < \text{Toluene} < p\text{-xylene} < m\text{-xylene} < o\text{-xylene} < \text{Mesitylene}$$

Addition of two methyl groups in benzene ring in xylenes further exceeds the electron donating capacity, when compared to toluene, but at the same time steric (hindrance) repulsion between methyl groups of 1-iodobutane which hinders proper orientation that is expected to be more.

The stereo regularity of methyl groups in *o*-xylene is such that steric repulsion is maximum; so V^E values for

TABLE 5: Comparison of interaction parameters (T_{12} , G_{12} , H_{12} , and W_{vis}) for 1-iodoutane + hydrocarbons binary mixtures at 303.15, 308.15, and 313.15 K.

x_1	T_{12}				G_{12}			H_{12}			W_{vis}	
	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15
1-Iodobutane + benzene												
0.0000	—	—	—	—	—	—	—	—	—	—	—	—
0.0793	−0.0189	−0.0219	−0.0295	0.3578	0.1628	0.0315	0.9344	0.8064	0.7205	985.35	506.38	173.94
0.1624	−0.0267	−0.0308	−0.0386	0.3343	0.1527	0.0533	0.9322	0.8041	0.7249	924.68	476.69	226.85
0.2494	−0.0318	−0.0367	−0.0438	0.3157	0.1467	0.0693	0.9310	0.8027	0.7283	876.37	459.58	266.02
0.3408	−0.0350	−0.0405	−0.0464	0.3008	0.1429	0.0827	0.9306	0.8020	0.7316	837.12	448.86	300.47
0.4367	−0.0363	−0.0420	−0.0470	0.2889	0.1428	0.0935	0.9313	0.8028	0.7346	806.31	447.81	326.46
0.5377	−0.0355	−0.0412	−0.0461	0.2804	0.1456	0.1009	0.9333	0.8049	0.7370	783.54	453.22	344.18
0.6440	−0.0324	−0.0377	−0.0434	0.2741	0.1510	0.1057	0.9367	0.8088	0.7388	766.95	466.52	356.32
0.7562	−0.0269	−0.0314	−0.0385	0.2703	0.1581	0.1080	0.9418	0.8144	0.7399	755.87	483.59	360.49
0.8747	−0.0185	−0.0217	−0.0296	0.2683	0.1670	0.1080	0.9488	0.8219	0.7401	750.14	505.51	360.57
1.0000	—	—	—	—	—	—	—	—	—	—	—	—
1-Iodobutane + toluene												
0.0000	—	—	—	—	—	—	—	—	—	—	—	—
0.0933	−0.0501	−0.0577	−0.0643	0.0947	−0.1903	−0.3393	0.8137	0.6687	0.5880	254.91	−468.84	−863.65
0.1880	−0.0636	−0.0712	−0.0781	0.1340	−0.1058	−0.2207	0.8233	0.6848	0.6090	350.91	−254.93	−557.50
0.2842	−0.0700	−0.0764	−0.0828	0.1600	−0.0430	−0.1333	0.8308	0.6977	0.6254	414.41	−96.48	−332.29
0.3818	−0.0726	−0.0775	−0.0833	0.1762	0.0015	−0.0713	0.8366	0.7075	0.6375	454.32	15.76	−172.75
0.4809	−0.0725	−0.0765	−0.0820	0.1853	0.0305	−0.0319	0.8408	0.7139	0.6449	475.82	88.31	−71.61
0.5815	−0.0705	−0.0742	−0.0797	0.1882	0.0462	−0.0107	0.8431	0.7166	0.6474	481.90	127.57	−18.18
0.6837	−0.0662	−0.0703	−0.0763	0.1868	0.0519	−0.0039	0.8436	0.7158	0.6449	477.14	140.83	−0.67
0.7875	−0.0589	−0.0638	−0.0704	0.1815	0.0493	−0.0090	0.8421	0.7110	0.6370	463.27	133.73	−14.97
0.8929	−0.0457	−0.0510	−0.0572	0.1730	0.0400	−0.0224	0.8383	0.7021	0.6239	442.08	111.55	−49.36
1.0000	—	—	—	—	—	—	—	—	—	—	—	—
1-Iodobutane + <i>o</i> -xylene												
0.0000	—	—	—	—	—	—	—	—	—	—	—	—
0.1045	−0.0960	−0.1144	−0.1308	−0.5235	−0.8593	−1.1194	0.7632	0.5756	0.4596	−1298.68	−2177.41	−2889.27
0.2080	−0.1352	−0.1561	−0.1749	−0.5374	−0.8550	−1.0954	0.7440	0.5649	0.4561	−1332.81	−2166.29	−2823.48
0.3105	−0.1603	−0.1809	−0.1996	−0.5310	−0.8292	−1.0466	0.7306	0.5585	0.4557	−1313.92	−2097.34	−2694.49
0.4119	−0.1740	−0.1937	−0.2111	−0.5052	−0.7847	−0.9779	0.7234	0.5560	0.4580	−1247.98	−1982.82	−2514.38
0.5123	−0.1773	−0.1960	−0.2119	−0.4647	−0.7259	−0.8958	0.7224	0.5575	0.4630	−1145.16	−1831.33	−2299.07
0.6118	−0.1706	−0.1885	−0.2028	−0.4144	−0.6578	−0.8062	0.7269	0.5628	0.4708	−1018.34	−1656.26	−2065.89
0.7103	−0.1542	−0.1712	−0.1841	−0.3578	−0.5848	−0.7157	0.7371	0.5721	0.4811	−876.00	−1469.35	−1830.01
0.8078	−0.1277	−0.1437	−0.1549	−0.2983	−0.5115	−0.6274	0.7529	0.5847	0.4940	−726.62	−1282.16	−1601.09
0.9044	−0.0893	−0.1025	−0.1112	−0.2391	−0.4400	−0.5452	0.7734	0.6009	0.5088	−578.65	−1101.16	−1388.47
1.0000	—	—	—	—	—	—	—	—	—	—	—	—
1-Iodobutane + <i>m</i> -xylene												
0.0000	—	—	—	—	—	—	—	—	—	—	—	—
0.1062	−0.1301	−0.1419	−0.1546	−0.7989	−1.1997	−1.4989	0.5768	0.4195	0.3232	−1995.10	−3054.68	−3879.35
0.2110	−0.1759	−0.1886	−0.2023	−0.7488	−1.1293	−1.3985	0.5680	0.4176	0.3291	−1866.60	−2871.25	−3615.80
0.3143	−0.2026	−0.2151	−0.2282	−0.6827	−1.0415	−1.2810	0.5627	0.4167	0.3334	−1698.33	−2644.07	−3307.99
0.4162	−0.2156	−0.2281	−0.2409	−0.6051	−0.9419	−1.1578	0.5615	0.4173	0.3362	−1501.29	−2387.32	−2985.75
0.5168	−0.2173	−0.2304	−0.2436	−0.5231	−0.8397	−1.0379	0.5641	0.4189	0.3374	−1293.33	−2124.52	−2672.44
0.6160	−0.2085	−0.2229	−0.2371	−0.4418	−0.7406	−0.9258	0.5703	0.4217	0.3376	−1088.76	−1870.41	−2379.95
0.7139	−0.1893	−0.2054	−0.2209	−0.3642	−0.6481	−0.8255	0.5801	0.4256	0.3363	−893.65	−1633.85	−2118.52
0.8105	−0.1591	−0.1762	−0.1924	−0.2926	−0.5644	−0.7369	0.5930	0.4303	0.3340	−713.36	−1420.55	−1887.69
0.9059	−0.1138	−0.1296	−0.1445	−0.2269	−0.4896	−0.6603	0.6093	0.4361	0.3303	−549.50	−1230.73	−1688.72
1.0000	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 5: Continued.

x_1	T_{12}				G_{12}			H_{12}			W_{vis}	
	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15	303.15	308.15	313.15
1-Iodobutane + <i>p</i> -xylene												
0.0000	—	—	—	—	—	—	—	—	—	—	—	—
0.1066	-0.1487	-0.1743	-0.2158	-1.0126	-1.5966	-2.3159	0.5267	0.3236	0.1361	-2535.38	-4070.09	-6005.51
0.2116	-0.2031	-0.2294	-0.2678	-0.9804	-1.5117	-2.0814	0.5111	0.3269	0.1798	-2453.68	-3852.82	-5394.80
0.3151	-0.2359	-0.2603	-0.2895	-0.9196	-1.4050	-1.8300	0.5006	0.3282	0.2123	-2298.29	-3577.98	-4739.62
0.4171	-0.2531	-0.2761	-0.2966	-0.8372	-1.2837	-1.5983	0.4952	0.3286	0.2340	-2090.35	-3267.03	-4136.39
0.5177	-0.2570	-0.2803	-0.2946	-0.7438	-1.1610	-1.4025	0.4943	0.3275	0.2459	-1853.86	-2952.65	-3626.92
0.6169	-0.2481	-0.2739	-0.2857	-0.6461	-1.0433	-1.2478	0.4981	0.3252	0.2477	-1607.76	-2650.33	-3223.07
0.7147	-0.2269	-0.2559	-0.2687	-0.5509	-0.9350	-1.1281	0.5060	0.3218	0.2404	-1367.72	-2372.46	-2911.13
0.8111	-0.1920	-0.2236	-0.2393	-0.4616	-0.8379	-1.0367	0.5180	0.3173	0.2241	-1143.67	-2124.32	-2671.45
0.9062	-0.1383	-0.1683	-0.1855	-0.3790	-0.7533	-0.9663	0.5342	0.3113	0.1994	-936.39	-1907.15	-2486.55
1.0000	—	—	—	—	—	—	—	—	—	—	—	—
1-Iodobutane + mesitylene												
0.0000	—	—	—	—	—	—	—	—	—	—	—	—
0.1190	-0.1773	-0.2060	-0.2405	-1.2220	-1.8101	-2.4480	0.4858	0.2740	0.1035	-3023.82	-4579.44	-6309.42
0.2330	-0.2433	-0.2707	-0.3033	-1.2279	-1.7692	-2.3099	0.4583	0.2702	0.1296	-3034.21	-4469.46	-5947.16
0.3425	-0.2825	-0.3057	-0.3321	-1.1865	-1.6806	-2.1177	0.4388	0.2668	0.1475	-2925.39	-4238.94	-5443.32
0.4476	-0.3023	-0.3218	-0.3431	-1.1091	-1.5577	-1.9092	0.4264	0.2642	0.1578	-2727.38	-3920.78	-4896.87
0.5486	-0.3058	-0.3231	-0.3417	-1.0107	-1.4189	-1.7113	0.4201	0.2624	0.1614	-2476.84	-3562.42	-4378.69
0.6458	-0.2944	-0.3114	-0.3296	-0.9032	-1.2795	-1.5355	0.4195	0.2610	0.1594	-2203.99	-3202.85	-3917.94
0.7393	-0.2685	-0.2864	-0.3060	-0.7966	-1.1486	-1.3861	0.4237	0.2600	0.1519	-1934.38	-2866.22	-3525.94
0.8294	-0.2268	-0.2456	-0.2670	-0.6954	-1.0296	-1.2615	0.4326	0.2597	0.1394	-1678.34	-2558.77	-3197.56
0.9162	-0.1635	-0.1810	-0.2012	-0.6026	-0.9243	-1.1561	0.4456	0.2598	0.1233	-1442.92	-2288.59	-2919.88
1.0000	—	—	—	—	—	—	—	—	—	—	—	—

o-xylene are found to be higher than the *m*-xylene and *p*-xylene. Moreover, V^E values are found to be positive indicating existence of weak interactions of dipole-induced dipole because of the large difference in dipole moments of polar iodobutane and nonpolar hydrocarbons. The observed V^E values are due to cumulative effect of (i) the specific interaction of the electron donor acceptor between vacant 2p level of iodine atom of butyl iodide and $n-\pi$ electron cloud of aromatic hydrocarbons and of (ii) disruption in the orientation order of the two components.

The increase in V^E values (positive effect) with increase in temperature suggests for declustering of components at higher temperatures and corresponding increase in kinetic energy.

The values of $\Delta\eta$ are negative for all the selected binary mixtures and regularly decrease with an increase in $-\text{CH}_3$ groups from benzene to mesitylene. The deviations in viscosity of binary mixtures are essentially due to two factors (in general).

- The depolymerization of the associated entities like hydrocarbons and formation of monomeric moieties on mixing make a negative contribution to $\Delta\eta$ values.
- Replacement of like contents in pure components by unlike contents in mixture makes positive contributions to $\Delta\eta$ values.

Negative values of $\Delta\eta$ throughout the whole composition range and at all temperatures suggest that the intermolecular interaction becomes weaker on mixing of components, also indicating that the dispersion type [17] of forces is predominant in these mixtures. The negative $\Delta\eta$ values support the positive V^E values and account for dispersive forces in these binaries. $\Delta\eta$ values are also expected to be negative because of vast difference in viscosities of pure components (see Table 1).

The negative values of $\Delta\eta$ at equimolar concentrations of 1-iodobutane and hydrocarbons mixtures are in the following order:

Theoretical calculations of viscosities are carried out by using Bingham, Arrhenius-Eyring's, Kendall-Munroe, Grunberg and Nissan, Hind, Tamura-Kurata, and Katti and Chaudhari equations. It is evident from Table 3 that amongst all, 1-iodobutane + benzene, + toluene, + *o*-xylene, + *m*-xylene, + *p*-xylene, and + mesitylene systems, Bingham relation gives better results in comparison to other theoretical relations. The differences observed are higher between experimental and theoretical values for other relations studied here. The positive values of G_{12} may be attributed to the presence of strong interactions between the components, while the negative values of G_{12} indicate for the dominance of dispersion forces [18]. The negatives values of interaction parameters

TABLE 6: Estimated parameters of excess functions for the binary mixtures.

T/K	Property	a_0	a_1	a_2	σ
1-Iodobutane + benzene					
303.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	-0.19353	0.056339	0.03151	0.00061
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.14391	0.021268	0.03090	0.00099
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	788.943	-129.204	113.662	0.87574
308.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	-0.16502	0.04078	0.04097	0.00045
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.166734	0.02273	0.03440	0.00106
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	548.980	15.1675	90.1316	0.78438
313.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	-0.13365	0.02870	0.04514	0.00043
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.18658	0.02261	-0.01560	0.00147
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	339.928	98.0700	-36.0700	0.65201
1-Iodobutane + toluene					
303.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.02382	-0.23228	0.12467	0.00054
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.28914	0.02915	-0.04614	0.00173
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	480.4040	95.1956	-201.504	1.77526
308.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.04619	-0.23986	0.16826	0.00077
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.30438	0.039250	-0.09070	0.00136
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	100.9140	322.488	-428.142	3.15995
313.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.07510	-0.25487	0.18761	0.00047
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.32637	0.04103	-0.12316	0.00117
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-53.7875	450.688	-616.998	4.56484
1-Iodobutane + <i>o</i> -xylene					
303.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.07263	0.094710	-0.38669	0.00519
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.70946	0.010234	0.14544	0.00052
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-1158.39	475.112	336.513	3.49245
308.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.20463	0.11318	-0.35657	0.00731
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.78458	0.02994	0.02994	0.00045
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-1849.53	703.595	318.786	4.09992
313.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.35378	0.148064	-0.33833	0.00630
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.84918	0.06067	0.06842	0.00075
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-2326.01	980.469	277.406	5.34433
1-Iodobutane + <i>m</i> -xylene					
303.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.893315	0.0919527	-0.39339	0.00268
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.870867	0.0380843	0.0927006	0.000952
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-1330.55	936.723	69.7958	3.986474775
308.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.02629	0.12081	-0.40535	0.00239
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.92278	0.02020	0.02972	0.00086
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-2171.17	1882.14	17.275	51.30856
313.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.14139	0.18127	-0.21424	0.00026
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-0.97503	0.00949	-0.03237	0.00119
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-2728.59	2416.03	11.677	74.84276
1-Iodobutane + <i>p</i> -xylene					
303.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.65948	0.07493	-0.29170	0.00067
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-1.02855	0.00630	0.11383	0.00078
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-1897.91	1047.69	228.763	6.20047
308.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.76618	0.08259	-0.14702	0.00037
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-1.12118	-0.01445	-0.03117	0.000735
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-3011.98	1405.81	2.22353	6.20501
313.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	0.87229	0.07852	0.10885	0.00044
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-1.18189	0.08514	-0.24129	0.00036
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-3735.78	2268.28	-874.668	6.51020

TABLE 6: Continued.

T/K	Property	a_0	a_1	a_2	σ
1-Iodobutane + mesitylene					
303.15 K	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.62871	0.29016	-0.39479	0.00093
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-1.22421	-0.06006	0.13936	0.00173
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-2590.67	1029.62	505.569	8.39538
	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.8029	0.36073	-0.26269	0.00062
308.15 K	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-1.29645	-0.01910	0.01344	0.00136
	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-3725.94	1500.1	375.06	10.40171
	$V^E/\text{cm}^3\cdot\text{mol}^{-1}$	1.97966	0.426317	-0.04511	0.00063
	$\Delta\eta/\text{m}\cdot\text{Pa}\cdot\text{s}$	-1.37477	0.03507	-0.14984	0.00117
313.15 K	$\Delta G^{*E} (\text{J}\cdot\text{mol}^{-1})$	-4625.33	2242.21	-127.195	12.87715

W_{vis} are also suggesting for weak interactions and positive values for strong interactions [19]. In the present study, G_{12} values are positive for benzene and both positive and negative for toluene mixtures and negative for the remaining hydrocarbons. The values of interaction parameters, T_{12} and H_{12} , do not differ appreciably from each other. This is in agreement with the view put forward by Fort and Moore [20] in regard to the nature of parameters T_{12} and H_{12} .

The ΔG^{*E} values are positive for 1-iodobutane + benzene mixtures, positive to negative for 1-iodobutane + toluene, and negative for 1-iodobutane + *o*-, *m*-, *p*-xylenes, and mesitylene mixtures for the entire composition range selected here (shown in Figure 3). ΔG^{*E} parameter can be considered as a reliable criterion to detect and interpret the presence of interactions between unlike molecules [21, 22]. ΔG^{*E} values at equimolar concentration of 1-iodobutane and hydrocarbon mixtures show the following order

benzene > toluene > *o*-xylene > *m*-xylene > *p*-xylene
> mesitylene.

Nain et al. [23] had made similar observations from their ΔG^{*E} studies of Tetrahydrofuran with Benzene, Toluene, *o*-Xylene, *m*-Xylene, *p*-Xylene, Mesitylene binary mixtures. ΔG^{*E} values for all the selected mixtures decrease with the increase in temperature.

4. Conclusion

The excess molar volumes, V^E , deviations in viscosity, $\Delta\eta$, and excess Gibbs' free energy of activation flow, ΔG^{*E} , have been calculated from the experimental values at three temperatures for iodobutane, benzene, toluene, *o*-, *p*-, *m*-xylenes, and mesitylene binary mixtures. The sign and magnitude of these quantities have been discussed in terms of the molecular interactions between the mixing components. Negative V^E , negative $\Delta\eta$, positive ΔG^{*E} , and positive H_{12} are observed for iodobutane + benzene mixtures; both negative and positive V^E and ΔG^{*E} values and only negative $\Delta\eta$ values are observed for the toluene mixtures. However, positive V^E , negative $\Delta\eta$, and positive ΔG^{*E} values are obtained for xylenes and mesitylene binary mixtures. Interaction parameters H_{12} and W_{vis} also support the V^E and $\Delta\eta$ values in explaining the

molecular interactions (Table 5). The expansion and contraction in volumes cannot be explained on the basis of simply considering V^E and $\Delta\eta$ values. Any observed property is combined effect of interaction part and size effect. The size effect can be due to free volumes and dipole moments of components. The size effect can be compared with interaction part and this may reverse the trend of interaction parameters. So, in iodobutane + benzene mixtures, strong interactions are reported; in toluene binaries, weak to strong interactions are observed; for other binaries of xylenes and mesitylenes, weak dispersion type of interactions is reported here. In all binaries, these interactions become weaker with increase in content of iodobutane and with rise of temperature.

References

- [1] J.-H. Yang, L.-Y. Dai, X.-Z. Wang, and Y.-Q. Chen, "Densities and viscosities of binary mixtures of methyl 4-chlorobutyrate with aromatic hydrocarbons at $T = (298.15 \text{ to } 318.15)\text{K}$," *Journal of Chemical and Engineering Data*, vol. 54, no. 8, pp. 2332–2337, 2009.
- [2] M. V. Rathnam, S. Mohite, and M. S. S. Kumar, "Interaction studies in binary liquid mixtures of methyl formate with *o*-, *m*- and *p*-xylenes using viscosity data at 303.15K," *Indian Journal of Chemical Technology*, vol. 15, no. 4, pp. 409–412, 2008.
- [3] B. B. Gurung and M. N. Roy, "Study of densities, viscosities and ultrasonic speeds of binary mixtures containing 1,2-dimethoxyethane and an alkan-1-ol at 298.15K," *Journal of Solution Chemistry*, vol. 35, no. 12, pp. 1587–1606, 2006.
- [4] M. Domínguez, J. Santafé, M. C. López, F. M. Royo, and J. S. Urieta, "Viscosities of the ternary mixture (1-butanol + *n*-hexane + 1-chlorobutane) at 298.15K and 313.15K," *Fluid Phase Equilibria*, vol. 152, no. 1, pp. 133–148, 1998.
- [5] M. M. Palaiologou, "Densities, viscosities, and refractive indices of some alkyl esters with 4-chlorotoluene systems at (293.15, 298.15, and 303.15)K," *Journal of Chemical and Engineering Data*, vol. 41, no. 5, pp. 1036–1039, 1996.
- [6] O. Redlich and A. T. Kister, "Algebraic representation of thermodynamic properties and the Classifications of solutions," *Journal of Industrial and Engineering Chemistry*, vol. 40, pp. 345–348, 1948.
- [7] E. C. Bingham, *Fluidity and Plasticity*, McGraw-Hill, New York, NY, USA, 1922.
- [8] S. Arrhenius, *Meddelanden Från K. Vetenskapsakademiens Nobelinstitut*, vol. 2, p. 25, 1913.

- [9] J. Kendall, "The viscosity of liquids. II. The viscosity-composition curve for ideal liquid mixtures," *Journal of the American Chemical Society*, vol. 39, no. 9, pp. 1787–1802, 1917.
- [10] L. Grunberg and A. H. Nissan, "Mixture law for viscosity," *Nature*, vol. 164, no. 4175, pp. 799–800, 1949.
- [11] R. K. Hind, E. McLaughlin, and A. R. Ubbelohde, "Structure and viscosity of liquids camphor+pyrene mixtures," *Transactions of the Faraday Society*, vol. 56, pp. 328–330, 1960.
- [12] M. Tamura and M. Kurata, "Viscosity of binary mixtures of liquids," *Bulletin of the Chemical Society of Japan*, vol. 25, pp. 32–37, 1952.
- [13] P. K. Katti, M. M. Chaudhri, and O. Prakash, "Viscosities of binary mixtures involving benzene, carbon tetrachloride, and cyclohexane," *Journal of Chemical and Engineering Data*, vol. 11, no. 4, pp. 593–594, 1966.
- [14] M. F. Bolotnikov, Y. A. Neruchev, and O. S. Ryshkova, "Density of 1-iodopropane and 1-iodobutane within the temperature range from (253.15 to 383.15)K," *Journal of Chemical and Engineering Data*, vol. 52, no. 3, pp. 1146–1147, 2007.
- [15] T. M. Aminabhavi, M. I. Aralaguppi, S. B. Harogoppad, and R. H. Balundgi, "Densities, viscosities, refractive indices, and speeds of sound for methyl acetoacetate + aliphatic alcohols (C1–C8)," *Journal of Chemical and Engineering Data*, vol. 38, no. 1, pp. 31–39, 1993.
- [16] A. K. Nain, P. Chandra, J. D. Pandey, and S. Gopal, "Densities, refractive indices, and excess properties of binary mixtures of 1,4-dioxane with benzene, toluene, o-xylene, m-xylene, p-xylene, and mesitylene at temperatures from (288.15 to 318.15)K," *Journal of Chemical and Engineering Data*, vol. 53, no. 11, pp. 2654–2665, 2008.
- [17] T. M. Aminabhavi and S. S. Joshi, "Excess molar volumes and viscosities of ten binary and four ternary liquid mixtures," *Indian Journal of Technology*, vol. 30, pp. 197–1208, 1992.
- [18] D. Agarwal and M. Singh, "Viscometric studies of molecular interactions in binary liquid mixtures of nitromethane with some polar and non-polar solvents at 298.15K," *Journal of the Indian Chemical Society*, vol. 81, no. 10, pp. 850–859, 2004.
- [19] S. Baluja, A. Solanki, N. Pandya, and N. S. Kachhadia, "Theoretical evaluation of viscosity in binary solutions of acetophenone at 308.15K," *Journal of the Indian Chemical Society*, vol. 84, no. 11, pp. 1130–1134, 2007.
- [20] R. J. Fort and W. R. Moore, "Viscosities of binary liquid mixtures," *Transactions of the Faraday Society*, vol. 62, pp. 1112–1119, 1966.
- [21] T. M. Reed III and T. E. Taylor, "Viscosities of liquid mixtures," *Journal of Physical Chemistry*, vol. 63, no. 1, pp. 58–67, 1959.
- [22] R. Meyer, M. Meyer, J. Metzner, and A. Peneloux, "Thermodynamics and physicochemical properties of binary solvent," *Chemical Physics*, vol. 62, p. 406, 1971.
- [23] A. K. Nain, D. Chand, P. Chandra, and J. D. Pandey, "Excess internal pressures, excess free volumes and excess thermodynamic parameters of some non-aqueous binary mixtures from ultrasonic speed, density and viscosity data," *Physics and Chemistry of Liquids*, vol. 47, no. 2, pp. 195–209, 2009.
- [24] A. K. Nain, "Densities and volumetric properties of binary mixtures of tetrahydrofuran with some aromatic hydrocarbons at temperatures from 278.15 to 318.15K," *Journal of Solution Chemistry*, vol. 35, no. 10, pp. 1417–1439, 2006.
- [25] C. Yang, Z. Liu, H. Lai, and P. Ma, "Thermodynamic properties of binary mixtures of N-methyl-2-pyrrolidinone with cyclohexane, benzene, toluene at (303.15 to 353.15)K and atmospheric pressure," *Journal of Chemical Thermodynamics*, vol. 39, no. 1, pp. 28–38, 2007.
- [26] V. Mutalik, L. S. Manjeshwar, M. Sairam, and T. M. Aminabhavi, "Thermodynamic properties of (tetradecane + benzene, + toluene, + chlorobenzene, + bromobenzene, + anisole) binary mixtures at T = (298.15, 303.15, and 308.15)K," *Journal of Chemical Thermodynamics*, vol. 38, no. 8, pp. 1062–1071, 2006.
- [27] A. K. Nain, P. Chandra, J. D. Pandey, and S. Gopal, "Densities, refractive indices, and excess properties of binary mixtures of 1,4-dioxane with benzene, toluene, o-xylene, m-xylene, p-xylene, and mesitylene at temperatures from (288.15 to 318.15)K," *Journal of Chemical and Engineering Data*, vol. 53, no. 11, pp. 2654–2665, 2008.
- [28] N. C. Exarchos, M. Tasioula-Margari, and I. N. Demetropoulos, "Viscosities and densities of dilute solutions of glycerol trioleate + octane, + p-xylene, + toluene, and + chloroform," *Journal of Chemical and Engineering Data*, vol. 40, no. 3, pp. 567–571, 1995.
- [29] L. Serrano, J. A. Silva, and F. Farello, "Densities and viscosities of binary and ternary liquid systems containing xylenes," *Journal of Chemical and Engineering Data*, vol. 35, no. 3, pp. 288–291, 1990.
- [30] G. Moumouzias, C. Ritzoulis, and G. Ritzoulis, "Study in mixtures of γ -butyrolactone with o-xylene and m-xylene: densities and viscosities," *Journal of Chemical and Engineering Data*, vol. 44, no. 6, pp. 1187–1191, 1999.
- [31] M. V. Rathnam, S. Mohite, and M. S. S. Kumar, "Viscosity, density, and refractive index of some (ester + hydrocarbon) binary mixtures at 303.15K and 313.15K," *Journal of Chemical and Engineering Data*, vol. 50, no. 2, pp. 325–329, 2005.
- [32] M. A. Saleh, M. Habibullah, M. S. Ahmed et al., "Viscosity of the systems m-xylene, +1-propanol, +2-propanol, +1-butanol, +t-butanol," *Physics and Chemistry of Liquids*, vol. 43, no. 5, pp. 485–494, 2005.
- [33] J. G. Baragi and M. I. Aralaguppi, "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," *Journal of Chemical Thermodynamics*, vol. 38, no. 12, pp. 1717–1724, 2006.