Physical Properties of Binary Mixtures of Ethyl Formate with Benzene, Isopropyl Benzene, Isobutyl Benzene, and Butylbenzene at (303.15, 308.15, and 313.15) K

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Densities, viscosities, and speeds of sound of binary mixtures of ethyl formate with benzene, isopropyl benzene, isobutyl benzene, and butylbenzene have been measured over the entire range of composition, at (303.15, 308.15, and 313.15) K and at atmospheric pressure. The excess volume, V^E, deviation in viscosity, $\Delta\eta$, and deviation in isentropic compressibility, ΔK_s, have been calculated from the experimental values of density, viscosity, and ultrasonic velocity. The excess volumes are positive, while the deviations in viscosities are negative for all of the studied binary systems over the whole composition range. The deviation in isentropic compressibility shows both positive and negative deviations for ethyl formate with benzene and isopropyl benzene, and for the remaining systems they are positive. The ability of some of the empirical models to calculate mixing viscosities was also tested.

Introduction

Acoustic and viscosity data of liquid mixtures of esters find extensive applications as they provide better insight into molecular environments. The interactions in terms of these parameters are of interest to a wide range of disciplines, ranging from medicine to oceanography, geology, mechanical engineering, and to fundamental chemistry and physics. Ethyl formate is used in the lacquer industry as a solvent for cellulose nitrate, oils, and greases. It is used as a fumigant and larvacide for tobacco.

Because of its characteristic smell of rum, it is also used as a synthetic flavor especially in lemonade and rum.

Ortega and Matos[1] reported excess volumes for the binary mixture ethyl formate + 1-chloroalkane. Hu et al.[2] studied excess enthalpies, excess isobaric heat capacities, and speeds of sound of mixtures of ethyl formate with benzene, ethanol, and 2,2,2-trifluoroethan-1-ol. Emmerling et al.[3] reported kinematic viscosities of benzene + ethyl formate. Lu et al.[4] studied excess molar volumes and viscosities of binary mixtures of γ-butyrolactone with methyl formate and ethyl formate. In our earlier work,[5,6] we have reported the excess volumes and viscosities of binary mixtures of ethyl formate in hydrocarbons. This paper is part of a program in our laboratory at providing reliable acoustic and viscosity data of binary liquid mixtures of esters in hydrocarbons. In continuation of our previous work,[7,8] we report data for density, viscosity, and speeds of sound and the values of excess molar volumes V^E and isentropic compressibility K_s for the binary mixtures of ethyl formate with benzene, isopropyl benzene, isobutyl benzene, or butylbenzene at (303.15, 308.15, and 313.15) K. The excess or deviation properties were fitted by the Redlich−Kister[9] equation. The experimental viscosities were correlated by equations of Hind, Heric, and McAllister (four-body interaction).

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Experimental Section

Materials. Ethyl formate, benzene, isopropyl benzene, isobutyl benzene, and butylbenzene, all Fluka with mass fraction purities greater than 99 %, were used without further purification. The purity of these pure liquids was ascertained by measuring their density and viscosity at 303.15 K. Table 1 shows a comparison of densities and viscosities with the available literature data.[10−15] There is a fairly good agreement between our data and the previously reported values.

Methods. Binary mixtures were prepared by mass in airtight stoppered glass bottles. The masses were recorded on a digital electronic balance (Mettler AE 240, Switzerland) to an uncertainty of ± 0.0001 g. Care was taken to avoid evaporation and contamination during mixing. The uncertainty in mole fraction was thus estimated to be less than ± 0.0001. A set of nine compositions was prepared to each mixture, and their physical properties were measured at the respective composition of the mole fraction varying from 0.1 to 0.9 in steps of 0.1.

Densities of pure liquids and their mixtures were measured using a DMA 35 Anton Paar digital density meter with an uncertainty of ± 0.1 %. Viscosities were determined with a modified Ubbelohde viscometer. The time of efflux of a constant volume of liquid through the capillary was measured with the help of a precalibrated RACER stopwatch corrected to ± 0.1 s. The viscometer was always kept in a vertical position in a water thermostat at the required temperature. Viscosity was calculated from the measured efflux time t, using the following relation.

$$\eta = \rho(At - B/t) \quad (1)$$

where ρ is the density and A and B are the characteristic constants of the viscometer, which were determined by taking water and benzene as the calibrating liquids. The uncertainty in viscometer thus estimated was found to be ± 0.5 %. The speed of sound of pure liquids and liquid mixtures was measured with a single-crystal variable path interferometer (Mittal Enterprises, New Delhi, India) operating at a frequency of 2 MHz that had been calibrated with water and benzene. The uncertainty in speed of sound was found to be ± 0.2 %. In all property

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Table 1. Comparison of Experimental Densities, ρ, Viscosities, η, and Speed of Sound, u, of Pure Components with Available Literature Values at 303.15 K

	T	ρ/(g·cm^{-3})		η/(mPa·s)		u/(m·s^{-1})	
liquid	K	exptl	lit.	exptl	lit.	exptl	lit.
ethyl formate						1116[a]	1117.7[a]
	303.15	0.9078	0.9085[b]	0.373	0.371[3]	1092	
	308.15	0.9026	0.9015[c]	0.345	0.345[14]	1072	
	313.15	0.8971		0.324	0.329[14]	1052	
benzene	303.15	0.8676	0.8683[10]	0.569	0.562[10]	1276	1276.37[13]
	308.15	0.8632		0.534	0.533[15]	1252	
	313.15	0.8589	0.8581[3]	0.497		1228	
isopropyl benzene	303.15	0.8527	0.8532[b]	0.690	0.687[b]	1280	
	308.15	0.8490		0.651		1264	1264[12]
	313.15	0.8454		0.611		1248	
isobutyl benzene	303.15	0.8444	0.8450[b]	0.905		1268	
	308.15	0.8411		0.848		1252	
	313.15	0.8376		0.784		1236	
butyl benzene	303.15	0.8513	0.8522[11]	0.901	0.893[11]	1308	
	308.15	0.8480		0.844		1292	
	313.15	0.8446		0.787		1276	

[a] Measured and compared at 298.15 K from ref 2. [b] Extrapolated value from ref 10. [c] Ref 6.

measurements, the temperature was controlled within ± 0.01 K using a constant temperature bath (INSREF model IRI O16C, India) by circulating water from the thermostat.

Results and Discussion

Experimental values of density (ρ), viscosity (η), and speed of sound (u), of all binary mixtures are given in Table 2. Excess volumes (V^E) and the viscosity deviation ($\Delta\eta$) were calculated using the following relation.

$$V^E = (x_1M_1 + x_2M_2)/\rho - (x_1M_1/\rho_1 + x_2M_2/\rho_2) \quad (2)$$

where ρ is the density of the mixture and (x_1, M_1, and ρ_1) and (x_2, M_2, and ρ_2) are the mole fraction, molar mass, and density of pure components 1 and 2, respectively.

The deviations in the viscosity, $\Delta\eta$, are given by

$$\Delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \quad (3)$$

where η is the absolute viscosity of the mixture and η_1 and η_2 are the viscosities of the pure components.

From the experimental speed of sound u and density ρ, the isentropic compressibility K_s was computed by the following expression.

$$K_s = u^{-2}\rho^{-1} \quad (4)$$

The deviation in isentropic compressibility ΔK_s, was obtained from the relation

$$\Delta K_s(m^2\cdot N^{-1}) = K_s - (\Phi_1K_{s1} + \Phi_2K_{s2}) \quad (5)$$

where K_{s1}, K_{s2}, and K_s are the isentropic compressibility of pure liquids 1 and 2 and the liquid mixture, respectively, and Φ_i is the volume fraction and is calculated from the individual pure molar volume V_i with the relation

$$\Phi_i = x_iV_i/(\sum x_iV_i) \quad (6)$$

The excess or deviation values, δA were fitted by the method of nonlinear least-squares to a Redlich−Kister type polynomial.[9]

$$\delta A = x_1x_2\sum A_i(x_1 - x_2)^i \quad (7)$$

The values of coefficient A_i were determined by a regression analysis based on the least-squares method and were reported along with the corresponding standard deviations between the experimental and the calculated values of the respective functions in Table 3.

Figure 1 displays dependence of V^E on x_1 at 303.15 K. It is observed that the V^E values of ethyl formate + butylbenzene exhibit large volume contractions, while for ethyl formate + benzene they are low and follow the order butyl benzene > isobutyl benzene > isopropyl benzene > benzene.

Further, it is observed that the values of V^E at equimolar composition show an increasing trend with an increase in temperature. These positive values of V^E were attributed to dipole-induced dipole interactions proportional to the polarizability of aromatic molecules. Comparison of our V^E at x_1 = 0.5 (0.284 cm^3·mol^{-1}) of ethyl formate + benzene at 303.15 K with those of Hu et al.[2] (0.280 cm^3·mol^{-1}) shows a satisfactory agreement.

The plots of $\Delta\eta$ versus x_1 at 303.15 K are displayed in Figure 2 for the binary mixtures of this study. The $\Delta\eta$ values for all of the mixtures are negative over the whole range of mixture composition and at all of the studied temperatures. These values exhibit dependencies on temperature, and their magnitude decreases systematically with an increase in temperature. An analysis of Figure 2 shows that in the case of ethyl formate + isopropyl benzene and isobutyl benzene the plots shows a minimum at x_1 = 0.5, while for ethyl formate + benzene and butylbenzene, the minima are slightly shifted to x_1 = 0.4 and 0.35, respectively. A comparison of changes in viscosity deviation values of equimolar composition shows that the effect of temperature and $\Delta\eta$ is not the same for all mixtures. These values of $\Delta\eta$ decreases slightly with an increase in temperature for ethyl formate + benzene. However, for the remaining mixtures the magnitude of $\Delta\eta$ values tends to increase in temperature. The increase in $\Delta\eta$ values for the temperature interval of this study is higher (i.e., 0.017 mPa·s) for the ethyl formate + butylbenzene mixture than for ethyl formate + isopropyl benzene (0.012 mPa·s) and ethyl formate + isopropyl benzene (0.006 mPa·s). A comparison of our results of the viscosity of equimolar composition for ethyl formate + benzene at 303.15 K (0.422 mPa·s) with those of Emmerling et al.[3] shows a very close agreement between the two values.

Figure 3 displays the deviation of ΔK_s on volume fraction Φ_1. It is observed that the values of ΔK_s are both positive and negative for the binary mixtures of benzene, isopropyl benzene, and butylbenzene, while for isobutyl benzene these values are completely positive at all of the studied temperatures. The effect

Table 2. Values of Density, ρ, Excess Volume, V^E, Viscosity, η, Speed of Sound, u, and Isentropic Compressibility, K_s, for the Binary Liquid Mixtures

x_1	ρ / g·cm^{-3}	V^E / cm^3·mol^{-1}	η / mPa·s	u / m·s^{-1}	K_s / TPa^{-1}
Ethyl Formate (1) + Benzene (2)					
$T = 303.15$ K					
0.0000	0.8676		0.569	1276	708
0.1089	0.8704	0.124	0.529	1252	733
0.2169	0.8735	0.219	0.493	1228	759
0.3189	0.8769	0.267	0.462	1208	782
0.4239	0.8808	0.283	0.439	1188	804
0.5253	0.8849	0.274	0.422	1172	823
0.6233	0.8891	0.250	0.410	1156	842
0.7211	0.8936	0.205	0.399	1140	861
0.8148	0.8981	0.152	0.389	1124	881
0.9088	0.9030	0.072	0.379	1108	902
1.0000	0.9078		0.373	1092	924
$T = 308.15$ K					
0.0000	0.8632		0.534	1252	739
0.1089	0.8658	0.138	0.499	1228	766
0.2169	0.8689	0.226	0.460	1208	789
0.3189	0.8722	0.276	0.431	1188	812
0.4239	0.8760	0.295	0.408	1168	837
0.5253	0.8801	0.277	0.392	1152	856
0.6233	0.8842	0.255	0.380	1136	876
0.7211	0.8886	0.211	0.370	1120	897
0.8148	0.8930	0.159	0.364	1104	919
0.9088	0.8978	0.081	0.355	1088	941
1.0000	0.9026		0.345	1072	964
$T = 313.15$ K					
0.0000	0.8589		0.497	1228	772
0.1089	0.8613	0.148	0.468	1208	796
0.2169	0.8643	0.235	0.428	1188	820
0.3189	0.8675	0.284	0.401	1168	845
0.4239	0.8712	0.301	0.380	1148	871
0.5253	0.8752	0.281	0.364	1132	892
0.6233	0.8792	0.257	0.354	1116	913
0.7211	0.8834	0.220	0.348	1100	936
0.8148	0.8877	0.166	0.338	1084	959
0.9088	0.8923	0.093	0.329	1068	983
1.0000	0.8971		0.324	1052	1007
Ethyl Formate (1) + Isopropyl Benzene (2)					
$T = 303.15$ K					
0.0000	0.8527		0.690	1280	716
0.1603	0.8570	0.188	0.630	1252	744
0.3007	0.8617	0.286	0.577	1228	770
0.4234	0.8665	0.349	0.534	1204	796
0.5352	0.8719	0.357	0.500	1180	824
0.6330	0.8774	0.334	0.468	1160	847
0.7203	0.8828	0.319	0.444	1144	866
0.8010	0.8889	0.250	0.424	1128	884
0.8724	0.8948	0.191	0.407	1116	897
0.9399	0.9013	0.096	0.390	1104	910
1.0000	0.9078		0.373	1092	924
$T = 308.15$ K					
0.0000	0.8490		0.651	1264	737
0.1603	0.8532	0.175	0.585	1240	762
0.3007	0.8577	0.289	0.537	1216	788
0.4234	0.8624	0.352	0.497	1192	816
0.5352	0.8677	0.351	0.463	1168	845
0.6330	0.8729	0.345	0.437	1148	869
0.7203	0.8782	0.320	0.414	1132	889
0.8010	0.8842	0.250	0.394	1116	908
0.8724	0.8900	0.181	0.382	1100	929
0.9399	0.8964	0.084	0.362	1088	942
1.0000	0.9026		0.345	1072	964
$T = 313.15$ K					
0.0000	0.8454		0.611	1248	760
0.1603	0.8494	0.174	0.544	1228	781
0.3007	0.8537	0.298	0.499	1200	813
0.4234	0.8583	0.346	0.460	1176	842
0.5352	0.8633	0.358	0.431	1152	873
0.6330	0.8684	0.345	0.409	1132	899
0.7203	0.8737	0.309	0.386	1116	919
0.8010	0.8793	0.244	0.367	1100	940
0.8724	0.8849	0.183	0.359	1084	962
0.9399	0.8911	0.084	0.340	1068	984
1.0000	0.8971		0.324	1052	1007

Table 2. Continued

x_1	ρ / g·cm^{-3}	V^E / cm^3·mol^{-1}	η / mPa·s	u / m·s^{-1}	K_s / TPa^{-1}
Ethyl Formate (1) + Isobutyl Benzene (2)					
$T = 303.15$ K					
0.0000	0.8444		0.905	1268	737
0.1772	0.8495	0.209	0.788	1248	756
0.3217	0.8549	0.300	0.699	1224	781
0.4514	0.8608	0.350	0.625	1200	807
0.5631	0.8668	0.379	0.569	1180	829
0.6604	0.8733	0.343	0.520	1164	845
0.7444	0.8797	0.310	0.481	1148	863
0.8191	0.8863	0.262	0.450	1132	881
0.8852	0.8931	0.193	0.418	1120	893
0.9461	0.9005	0.092	0.394	1104	911
1.0000	0.9078		0.373	1092	924
$T = 308.15$ K					
0.0000	0.8411		0.848	1252	759
0.1772	0.8458	0.240	0.726	1228	784
0.3217	0.8510	0.341	0.641	1204	811
0.4514	0.8568	0.376	0.573	1180	838
0.5631	0.8627	0.392	0.522	1160	861
0.6604	0.8688	0.384	0.479	1144	880
0.7444	0.8750	0.342	0.445	1128	898
0.8191	0.8815	0.286	0.415	1112	917
0.8852	0.8880	0.226	0.388	1100	931
0.9461	0.8953	0.114	0.369	1084	951
1.0000	0.9026		0.345	1072	964
$T = 313.15$ K					
0.0000	0.8376		0.784	1236	782
0.1772	0.8421	0.251	0.666	1208	814
0.3217	0.8470	0.360	0.591	1184	842
0.4514	0.8526	0.399	0.529	1160	872
0.5631	0.8583	0.414	0.480	1140	897
0.6604	0.8643	0.389	0.442	1124	916
0.7444	0.8703	0.354	0.413	1108	936
0.8191	0.8766	0.292	0.384	1092	957
0.8852	0.8830	0.218	0.362	1080	971
0.9461	0.8900	0.117	0.347	1064	993
1.0000	0.8971		0.324	1052	1007
Ethyl Formate (1) + Butylbenzene (2)					
$T = 303.15$ K					
0.0000	0.8513		0.901	1308	687
0.1738	0.8554	0.251	0.782	1284	709
0.3241	0.8603	0.339	0.692	1252	742
0.4533	0.8654	0.413	0.625	1220	776
0.5630	0.8707	0.424	0.571	1196	803
0.6587	0.8763	0.396	0.525	1176	825
0.7440	0.8822	0.347	0.482	1156	848
0.8189	0.8884	0.265	0.451	1140	866
0.8855	0.8945	0.200	0.419	1124	885
0.9459	0.9012	0.093	0.398	1108	904
1.0000	0.9078		0.373	1092	924
$T = 308.15$ K					
0.0000	0.8480		0.844	1292	706
0.1738	0.8519	0.245	0.713	1264	735
0.3241	0.8566	0.357	0.627	1232	769
0.4533	0.8615	0.421	0.569	1200	806
0.5630	0.8666	0.439	0.521	1176	834
0.6587	0.8720	0.409	0.480	1156	858
0.7440	0.8776	0.378	0.443	1136	883
0.8189	0.8836	0.290	0.412	1120	902
0.8855	0.8896	0.219	0.385	1104	922
0.9459	0.8960	0.113	0.366	1088	943
1.0000	0.9026		0.345	1072	964
$T = 313.15$ K					
0.0000	0.8446		0.787	1276	727
0.1738	0.8484	0.240	0.650	1244	762
0.3241	0.8529	0.348	0.571	1212	798
0.4533	0.8575	0.427	0.518	1180	838
0.5630	0.8624	0.444	0.476	1156	868
0.6587	0.8676	0.405	0.440	1136	893
0.7440	0.8731	0.356	0.407	1116	920
0.8189	0.8788	0.290	0.381	1100	940
0.8855	0.8846	0.206	0.355	1084	962
0.9459	0.8908	0.102	0.336	1068	984
1.0000	0.8971		0.324	1052	1007

Table 3. Fitting Parameters and Standard Deviations (σ) of Equation 7 for Binary Mixtures

function	T/K	A_0	A_1	A_2	σ
		Ethyl Formate + Benzene			
V^E/(cm^3·mol^{-1})	303.15	1.1347	−0.2450	−0.0513	0.005
	308.15	1.1515	−0.2679	0.0955	0.004
	313.15	1.1599	−0.2647	0.2652	0.004
$\Delta\eta$/(mPa·s)	303.15	−0.1785	0.0440	0.0221	0.002
	308.15	−0.1797	0.0505	0.0900	0.002
	313.15	−0.1722	0.0190	0.0839	0.004
ΔK_s/(TPa^{-1})	303.15	31.40	−29.57	−20.27	1.06
	308.15	18.96	−31.10	−5.01	1.04
	313.15	9.11	−11.92	−28.40	1.23
		Ethyl Formate + Isopropyl Benzene			
V^E/(cm^3·mol^{-1})	303.15	1.4225	0.1819	0.1966	0.007
	308.15	1.4648	0.1915	−0.0924	0.010
	313.15	1.4590	0.1764	−0.0710	0.007
$\Delta\eta$/(mPa·s)	303.15	−0.0938	0.0036	0.0649	0.001
	308.15	−0.1015	0.0499	0.0407	0.002
	313.15	−0.1146	0.0687	0.0380	0.003
ΔK_s/(TPa^{-1})	303.15	96.16	62.66	−11.94	1.95
	308.15	68.54	43.08	−74.35	2.67
	313.15	52.93	49.75	−97.04	0.99
		Ethyl Formate + Isobutyl Benzene			
V^E/(cm^3·mol^{-1})	303.15	1.4617	0.2511	0.2548	0.009
	308.15	1.5498	0.2529	0.6428	0.006
	313.15	1.6246	0.2050	0.5943	0.004
$\Delta\eta$/(mPa·s)	303.15	−0.1522	0.0094	−0.0067	0.001
	308.15	−0.1918	0.0723	0.0422	0.002
	313.15	−0.1987	0.0801	0.0447	0.003
ΔK_s/(TPa^{-1})	303.15	55.38	59.10	−17.71	1.93
	308.15	70.48	47.68	−0.87	1.95
	313.15	87.15	33.52	12.06	2.03
		Ethyl Formate + Butylbenzene			
V^E/(cm^3·mol^{-1})	303.15	1.6873	0.1158	0.1530	0.013
	308.15	1.7216	0.2682	0.3230	0.008
	313.15	1.7323	0.2357	0.1279	0.009
$\Delta\eta$/(mPa·s)	303.15	−0.1499	0.0546	−0.0004	0.002
	308.15	−0.1920	0.1242	−0.0835	0.002
	313.15	−0.2161	0.1515	−0.1971	0.002
ΔK_s/(TPa^{-1})	303.15	79.14	74.89	−90.14	0.95
	308.15	94.93	63.31	−79.191	1.13
	313.15	108.64	53.07	−75.57	1.35

of temperature on ΔK_s is quite significant as shown in Figure 3, where it is found that the magnitude of ΔK_s at equimolar compositions decreases with an increase in temperature for benzene and isopropyl benzene, while for isobutyl benzene and butylbenzene these values increase with an increase in temperature.

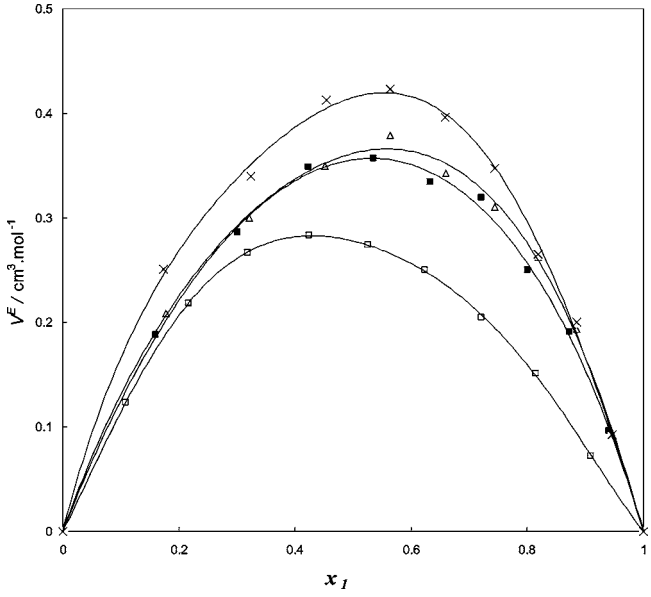

Figure 1. Excess volume V^E vs mole fraction at 303.15 K for ethyl formate with □, benzene; ■, isopropyl benzene; △, isobutyl benzene; and ×, butylbenzene.

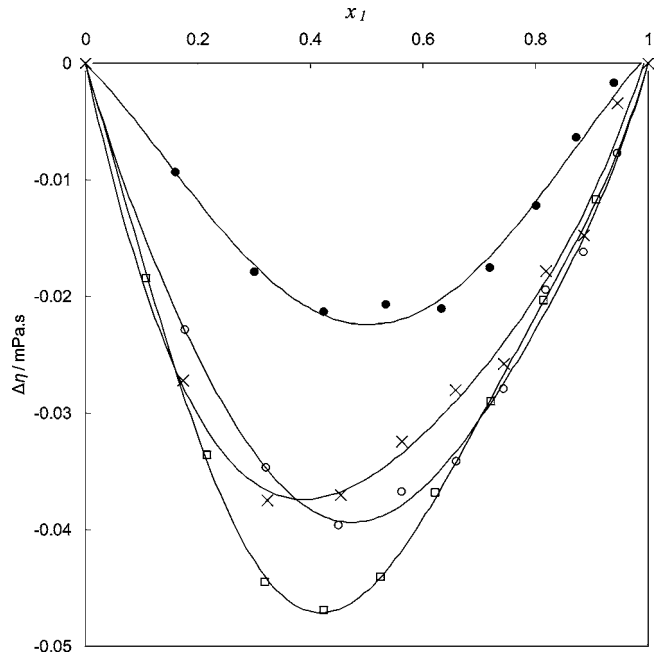

Figure 2. Deviation in viscosity $\Delta\eta$ vs mole fraction at 303.15 K for ethyl formate with □, benzene; ●, isopropyl benzene; ○, isobutyl benzene; and ×, butylbenzene.

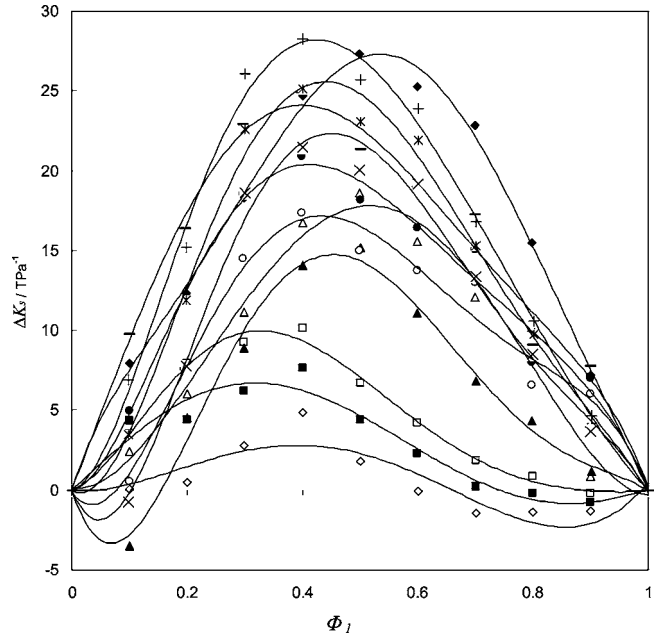

Figure 3. Deviation in isentropic compressibility ΔK_s vs volume fraction for the binary mixtures of ethyl formate + benzene at (□, 303.15; ■, 308.15; ◇, 313.15) K, ethyl formate + isopropylbenzene at (◆, 303.15; △, 308.15; ▲, 313.15) K, ethyl formate + isobutylbenzene at (○, 303.15; ●, 308.15; —, 313.15) K, and ethyl formate + butylbenzene at (×, 303.15, ∗, 308.15, +, 313.15) K.

It may be noted that in all plots points represent the quantities calculated from eqs 2, 3, and 5, while the smooth curves are drawn from the best fitted values calculated from eq 7. The viscosity−mole fraction data pairs of the studied mixtures were used to test the ability of one-parameter model proposed by Hind et al.,[16] the two-parameter model by Heric,[17] and three-parameter model of McAllister[18] (four-body interaction).

Table 4. Adjustable Parameters and Average Relative Deviation (σ) of Equations 8, 9, and 10, Respectively, for the Viscosities of Binary Liquid Mixtures

T	Hind		Heric			McAllister four-body interaction			
K	η_{12}	100 σ	γ_{12}	γ_{21}	100 σ	ν_{1112}	ν_{1122}	ν_{2221}	100 σ
				Ethyl Formate + Benzene					
303.15	0.3837	0.94	−0.2972	0.0597	0.38	−0.8109	−0.7800	−0.6068	0.27
308.15	0.3565	1.23	−0.2976	0.0897	0.65	−0.8394	−0.9063	−0.6411	0.21
313.15	0.3306	1.24	−0.3150	0.0579	0.69	−0.9141	−0.9675	−0.7053	0.48
				Ethyl Formate + Isopropyl Benzene					
303.15	0.4898	0.33	0.1416	0.0205	0.31	−0.6699	−0.5555	−0.3390	0.21
308.15	0.4523	0.73	0.1239	0.0977	0.42	−0.7192	−0.6298	−0.4187	0.37
313.15	0.4160	1.06	0.0809	0.1383	0.51	−0.7765	−0.7057	−0.4967	0.44
				Ethyl Formate + Isobutyl Benzene					
303.15	0.5629	0.23	0.3072	0.0581	0.17	−0.5685	−0.3443	−0.1209	0.17
308.15	0.5076	0.94	0.2517	0.1463	0.26	−0.6196	−0.4516	−0.2051	0.20
313.15	0.4628	1.01	0.2031	0.1327	0.35	−0.7003	−0.5248	−0.2906	0.38
				Ethyl Formate + Butylbenzene					
303.15	0.5650	0.58	0.3163	0.1223	0.28	−0.5655	−0.3268	−0.1578	0.29
308.15	0.4984	1.31	0.2182	0.1908	0.43	−0.6606	−0.3884	−0.2897	0.22
313.15	0.4391	1.69	0.1037	0.1990	0.77	−0.7723	−0.4357	−0.4195	0.35

Hind et al.[16] proposed the following one-parameter equation.

$$\eta = x_1^2\eta_1 + x_2^2\eta_2 + 2x_1x_2\eta_{12} \quad (8)$$

where η_{12} is a parameter independent of the composition and can be attributed to unlike-pair interactions.

The two-parameter Heric equation[17] is of the following form.

$$\ln(\eta) = x_1 \ln(\eta_1) + x_2 \ln(\eta_2) + x_1 \ln(M_1) + x_2 \ln(M_2) - \ln(x_1M_1 + x_2M_2) + x_1x_2[\gamma_{12} + \gamma_{21}(x_1 - x_2)] \quad (9)$$

where γ_{12} and γ_{21} are the adjustable parameters.

The three-parameter McAllister four-body interaction model[18] for kinematic viscosities is of the following form.

$$\ln \nu = x_1^4 \ln \nu_1 + 4x_1^3x_2 \ln \nu_{1112} + 6x_1^2x_2^2 \ln \nu_{1122} + 4x_1x_2^3 \ln \nu_{2221} + x_2^4 \ln \nu_2 - \ln[x_1 + (x_2M_2/M_1)] + 4x_1^3x_2 \ln[\{3 + (M_2/M_1)\}/4] + 6x_1^2x_2^2 \ln[\{1 + (M_2/M_1)\}/2] + 4x_1x_2^3 \ln[\{1 + (3M_2/M_1)\}/4] + x_2^4 \ln(M_2/M_1) \quad (10)$$

where ν, ν_1, and ν_2 are the kinematic viscosities of the mixture and pure components 1 and 2, respectively. ν_{1112}, ν_{1122}, and ν_{2221} are the adjustable parameters. The correlating ability of these equations was tested by calculating the average relative deviation σ (ARD) between the experimental and the calculated viscosity as the following.

$$\mathrm{ARD} = 1/N \sum \frac{|(\mathrm{X} - \mathrm{X_{cal}})|}{\mathrm{X}} \quad (11)$$

where N represents the number of data points. X represents any property.

Table 4 summarizes the results obtained. A comparison of these values indicates that the McAllister equation correlates mixtures of viscosity excellently.

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