Studies of Viscosities and Excess Molar Volumes of the Binary Mixtures of 1-Heptanol + 1,2-Dichloroethane, + 1,1,1-Trichloroethane, + 1,1,2,2-Tetrachloroethane, + Trichloroethylene and Tetrachloroethylene at (293.15, 298.15, and 303.15) K for the Liquid Region and at Ambient Pressure

H. Iloukhani*,† and B. Samiey‡

Department of Chemistry, Faculty of Science, University of Bu-Ali Sina, Hamedan, Iran, and Department of Chemistry, Faculty of Science, University of Lorestan, Khoramabad, Iran

Densities (ρ) and viscosities (η) of the binary mixtures of 1-heptanol with 1,2-dichloroethane, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, trichloroethylene, and tetrachloroethylene have been measured at (293.15, 298.15, and 303.15) K for the liquid region and at ambient pressure for the whole composition range. Excess molar volumes (V^E), excess thermal expansivities (α^E), and viscosity deviations ($\delta\eta$) were calculated and correlated by Redlich−Kister type function to determine the fitting parameters and the standard deviations. The results are consistent with the self-association of 1-heptanol and the polar and nonpolar characters of used chloroethanes or chloroethylenes, which produce the dissociation of 1-heptanol. The two-parameter Heric interaction model has also been used to correlate the kinematic viscosities of binary liquid mixtures with mole fractions.

Introduction

Research activities of our laboratory comprise, among others, the systematic measurements of volumetric properties of different groups of organic compounds.[1−4] Measurements of thermodynamic and transport properties can give insight into the nature of molecular interactions in liquid mixtures. Here we report viscosities and excess molar volumes of 1-heptanol binary mixtures with 1,2-dichloroethane, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, trichloroethylene, and tetrachloroethylene at temperatures (293.15, 298.15, and 303.15) K for the liquid region and at ambient pressure. This work will also provide a test of the semi-empirical Heric model to correlate viscosity of abovementioned binary mixtures.

Experimental Section

Materials. The mole fraction purity of the molecules from Merck were as follows: 1-heptanol (≥99 %), 1,2-dichloroethane (>99 %), and 1,1,1-trichloroethane (≥99 %). The molecules from Fluka had the following mole fraction: 1,1,2,2-tetrachloroethane (≥99 %), trichloroethylene (>99 %), and tetrachloroethylene (>99 %). Densities of the pure liquids and their mixtures at (293.15, 298.15, and 303.15) K were measured with an Anton Paar digital densimeter (model DMA 4500) operated in the static mode and capable of a precision of better than ± 10^{-2} kg·m^{-3} and automatically thermostated within ± 0.01 K. Densities and viscosities of the pure reagents were in good agreement with values found in the literature[5−9] (reported in Table 1).

Table 1. Pure Component Properties at 298.15 K[a]

	ρ/kg·m^{-3}		η/mPa·s		
liquid	exptl	lit	exptl	lit	$\alpha^{*\circ}$/kK
1-heptanol	818.48	818.60[b]	5.818	5.810[e]	0.856
1,2-dichloroethane	1245.64	1245.61[c]	0.776	0.779[e]	1.169
1,1,1-trichloroethane	1329.55	1329.63[c]	0.789	0.793[e]	1.250
1,1,2,2-tetrachloroethane	1586.65	1586.83[c]	1.431	1.437[e]	0.979
trichloroethylene	1455.65	1455.72[d]	0.536	0.545[e]	1.153
tetrachloroethylene	1613.20	1613.09[d]	0.839	0.844[e]	1.030

[a] $\alpha^{*\circ}$ values were calculated from the measured densities at different temperatures. [b] Ref 5. [c] Ref 6. [d] Ref 7. [e] Refs 8 and 9.

Apparatus and Procedure. Viscosities at (293.15, 298.15, and 303.15) K were measured with an Ubbleohde viscometer. The equation for viscosity is

$$\eta = \rho v = \rho(kt - c/t) \quad (1)$$

where k and c are the viscometer constants and t, η, and v are the efflux time, dynamic viscosity, and kinematic viscosity, respectively. The dynamic viscosity was reproducible to within ± 2 × 10^{-3} mPa·s. The viscometer was suspended in a thermostated water bath maintained to ± 0.01 K.

Results and Discussion

Densities, Excess Molar Volumes, and Excess Thermal Expansivity. The excess molar volumes of the solutions of molar composition x were calculated from the densities of the pure liquids and their mixtures according to the following equation:

$$V^E/\mathrm{m}^3\cdot\mathrm{mol}^{-1} = [xM_1 + (1-x)M_2]/\rho - [xM_1/\rho_1 + (1-x)M_2/\rho_2] \quad (2)$$

* Corresponding author. E-mail: iloukhani@basu.ac.ir.
† University of Bu-Ali Sina.
‡ University of Lorestan.

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Table 2. Excess Molar Volumes for Binary Mixtures at (293.15, 298.15, and 303.15) K

x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}
						(x) 1-Heptanol + (1 − x) Dichloroethane								
						T = 293.15 K								
0.0502	1213.23	0.171	0.3445	1038.38	0.584	0.5017	970.85	0.610	0.6956	903.77	0.460	0.8548	858.28	0.249
0.1024	1175.90	0.296	0.3896	1017.38	0.624	0.5510	952.41	0.580	0.6602	914.96	0.497	0.8898	849.21	0.194
0.1493	1145.01	0.391	0.4198	1004.18	0.626	0.6036	933.66	0.561	0.7480	887.98	0.399	0.9489	834.67	0.081
0.2511	1085.65	0.520	0.4550	989.42	0.627	0.6481	918.87	0.509	0.7974	873.84	0.333			
						T = 298.15 K								
0.0502	1206.24	0.176	0.3445	1032.88	0.605	0.5017	966.00	0.629	0.6956	899.55	0.475	0.8548	854.47	0.259
0.1024	1169.21	0.305	0.3896	1012.13	0.639	0.5510	947.76	0.595	0.6602	910.61	0.517	0.8898	845.44	0.209
0.1493	1138.62	0.400	0.4198	999.04	0.643	0.6036	929.17	0.577	0.7480	883.88	0.416	0.9489	831.05	0.089
0.2511	1079.74	0.537	0.4550	984.40	0.646	0.6481	914.50	0.527	0.7974	869.91	0.342			
						T = 303.15 K								
0.0502	1199.30	0.180	0.3445	1027.38	0.555	0.5017	961.14	0.651	0.6956	895.28	0.494	0.8548	850.61	0.270
0.1024	1162.55	0.316	0.3896	1006.83	0.662	0.5510	943.04	0.619	0.6602	906.29	0.530	0.8898	841.70	0.212
0.1493	1132.15	0.420	0.4198	993.91	0.630	0.6036	924.63	0.599	0.7480	879.79	0.427	0.9489	827.43	0.090
0.2511	1073.87	0.664	0.4550	979.35	0.671	0.6481	910.13	0.543	0.7974	865.91	0.356			
						(x) 1-Heptanol + (1 −x) 1,1,1-Trichloroethane								
						T = 293.15 K								
0.1030	1252.20	0.106	0.3090	1128.37	0.180	0.5016	1028.73	0.174	0.6573	957.28	0.134	0.7937	900.46	0.071
0.1615	1214.95	0.134	0.3514	1105.21	0.182	0.5509	1005.32	0.161	0.6724	950.85	0.114	0.8459	879.86	0.052
0.2047	1188.54	0.156	0.4022	1078.45	0.182	0.5800	991.84	0.155	0.7421	921.42	0.095	0.9027	858.15	0.037
0.2545	1159.20	0.172												
						T = 298.15 K								
0.1030	1244.75	0.110	0.3090	1122.23	0.182	0.5016	1023.53	0.175	0.6573	952.71	0.136	0.7937	896.37	0.070
0.1615	1207.90	0.138	0.3514	1099.32	0.181	0.5509	1000.35	0.160	0.6724	946.34	0.115	0.8459	875.95	0.050
0.2047	1181.77	0.159	0.4022	1072.77	0.186	0.5800	986.98	0.155	0.7421	917.17	0.093	0.9027	854.41	0.034
0.2545	1152.74	0.175												
						T = 303.15 K								
0.1030	1237.24	0.114	0.3090	1116.01	0.185	0.5016	1018.27	0.178	0.6573	948.09	0.137	0.7937	892.23	0.071
0.1615	1200.80	0.141	0.3514	1093.32	0.185	0.5509	995.29	0.164	0.6724	941.77	0.116	0.8459	871.97	0.051
0.2047	1174.93	0.164	0.4022	1067.06	0.187	0.5800	982.04	0.159	0.7421	912.86	0.093	0.9027	850.61	0.034
0.2545	1146.20	0.179												
						(x) 1-Heptanol + (1 − x) 1,1,2,2-Tetrachloroethane								
						T = 293.15 K								
0.0506	1541.06	0.078	0.2515	1351.89	0.190	0.4464	1191.47	0.154	0.6506	1042.68	0.046	0.8505	912.27	−0.049
0.1031	1488.84	0.132	0.2998	1310.19	0.192	0.5113	1142.28	0.126	0.6959	1011.91	0.017	0.8979	883.17	−0.048
0.1519	1442.21	0.161	0.3499	1268.42	0.184	0.5524	1112.04	0.105	0.7507	975.70	−0.010	0.9513	851.10	−0.034
0.2003	1397.58	0.178	0.4109	1219.27	0.169	0.6013	1077.03	0.073	0.8001	943.88	−0.031			
						T = 298.15 K								
0.0506	1533.58	0.079	0.2515	1345.42	0.202	0.4464	1185.87	0.174	0.6506	1037.91	0.067	0.8505	908.25	−0.036
0.1031	1481.60	0.139	0.2998	1303.92	0.208	0.5113	1136.96	0.145	0.6959	1007.34	0.033	0.8979	879.34	−0.041
0.1519	1435.22	0.171	0.3499	1262.39	0.201	0.5524	1106.90	0.124	0.7507	971.35	0.003	0.9513	847.45	−0.029
0.2003	1390.83	0.190	0.4109	1213.55	0.184	0.6013	1072.05	0.096	0.8001	939.68	−0.016			
						T = 303.15 K								
0.0506	1526.03	0.089	0.2515	1338.90	0.220	0.4464	1180.31	0.188	0.6506	1033.17	0.079	0.8505	904.23	−0.029
0.1031	1474.35	0.150	0.2998	1297.68	0.223	0.5113	1131.65	0.161	0.6959	1002.73	0.050	0.8979	875.45	−0.031
0.1519	1428.22	0.185	0.3499	1256.35	0.220	0.5524	1101.73	0.143	0.7507	966.91	0.023	0.9513	843.75	−0.024
0.2003	1384.07	0.206	0.4109	1207.77	0.205	0.6013	1067.13	0.108	0.8001	935.48	−0.006			
						(x) 1-Heptanol + (1 − x) Trichloroethylene								
						T = 293.15 K								
0.0507	1412.78	0.042	0.2558	1237.46	0.067	0.4300	1115.18	0.030	0.6574	982.15	−0.028	0.8728	877.14	−0.041
0.0992	1367.53	0.063	0.3109	1196.47	0.060	0.5100	1065.33	0.008	0.7071	956.39	−0.040	0.9405	847.47	−0.024
0.1569	1317.05	0.071	0.3618	1160.63	0.046	0.5514	1040.91	−0.002	0.7571	931.38	−0.046			
0.2026	1279.18	0.072	0.3997	1134.97	0.038	0.6149	1005.06	−0.016	0.8016	909.97	−0.047			
						T = 298.15 K								
0.0507	1404.82	0.046	0.2558	1230.87	0.082	0.4300	1109.55	0.046	0.6574	977.54	−0.016	0.8728	873.27	−0.034
0.0992	1359.90	0.072	0.3109	1190.18	0.078	0.5100	1060.09	0.023	0.7071	951.95	−0.027	0.9405	843.79	−0.017
0.1569	1309.82	0.083	0.3618	1154.67	0.059	0.5514	1035.82	0.016	0.7571	927.10	−0.031			
0.2026	1272.23	0.088	0.3997	1129.21	0.052	0.6149	1000.28	−0.004	0.8016	905.84	−0.033			
						T = 303.15 K								
0.0507	1396.73	0.054	0.2558	1224.15	0.102	0.4300	1103.85	0.063	0.6574	972.87	−0.004	0.8728	869.35	−0.027
0.0992	1352.18	0.083	0.3109	1183.85	0.093	0.5100	1054.79	0.038	0.7071	947.47	−0.016	0.9405	840.09	−0.014
0.1569	1302.52	0.095	0.3618	1148.63	0.075	0.5514	1030.70	0.032	0.7571	922.80	−0.022			
0.2026	1265.25	0.100	0.3997	1123.37	0.067	0.6149	995.43	0.010	0.8016	901.69	−0.024			
						(x) 1-Heptanol + (1 − x) Tetrachloroethylene								
						T = 293.15 K								
0.0564	1560.55	0.063	0.2480	1370.53	0.121	0.4484	1198.21	0.104	0.6503	1046.14	0.063	0.8963	884.26	0.014
0.0980	1516.90	0.082	0.2944	1328.47	0.122	0.5051	1153.53	0.090	0.7419	983.09	0.044	0.9453	854.68	0.008
0.1520	1462.26	0.102	0.3527	1277.56	0.118	0.5477	1121.03	0.084	0.8016	943.84	0.032			
0.2001	1415.53	0.113	0.3983	1239.09	0.113	0.6002	1082.09	0.071	0.8533	910.96	0.019			

Table 2 (Continued)

x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}	x	ρ / kg·m^{-3}	$10^6\,V^E$ / m^3·mol^{-1}
						$T = 298.15$ K								
0.0564	1552.56	0.070	0.2480	1363.81	0.139	0.4484	1192.43	0.125	0.6503	1041.30	0.082	0.8963	880.43	0.019
0.0980	1509.20	0.090	0.2944	1321.91	0.139	0.5051	1148.07	0.107	0.7419	978.66	0.057	0.9453	851.01	0.012
0.1520	1454.91	0.111	0.3527	1271.32	0.136	0.5477	1115.76	0.101	0.8016	939.63	0.045			
0.2001	1408.42	0.128	0.3983	1233.07	0.133	0.6002	1077.06	0.087	0.8533	906.93	0.032			
						$T = 303.15$								
0.0564	1544.51	0.080	0.2480	1356.93	0.158	0.4484	1186.64	0.144	0.6503	1036.45	0.097	0.8963	876.54	0.025
0.0980	1501.40	0.104	0.2944	1315.32	0.156	0.5051	1142.54	0.127	0.7419	974.19	0.069	0.9453	847.30	0.014
0.1520	1447.45	0.127	0.3527	1265.06	0.152	0.5477	1110.45	0.118	0.8016	935.38	0.056			
0.2001	1401.24	0.147	0.3983	1227.04	0.150	0.6002	1071.96	0.107	0.8533	902.87	0.042			

where ρ, ρ_1, and ρ_2 are the densities of the solution and pure components 1 and 2, respectively, and M_1 and M_2 are the molar masses of the pure components. The excess molar volumes were reproducible to $\pm\ 3 \times 10^{-9}$ m^3·mol^{-1}.

A possible definition of excess thermal expansivity (α^E), which has been often used, is the following equation:

$$\alpha^E/(K^{-1}) = \alpha - \alpha^{id} = (\partial V_m/\partial T)_p/V_m - \sum_{j=1} \phi_j \alpha_j^* \qquad (3)$$

where V_m is the molar volume of the mixture, φ_j is the volume fraction of component j in the premixing state, and α_j^* is thermal expansivity of the pure component j. Equation 3 proposed by Benson and Kiyohara.[10] The thermal expansivities (α) are calculated from the following equation:

$$\alpha = (\partial V_m/\partial T)_p/V_m \qquad (4)$$

The corresponding V^E values of binary mixtures of [(x) 1-heptanol + (1 − x) chloroethanes or chloroethylenes] measured at (293.15, 298.15, and 303.15) K are presented in Table 2 and are plotted against mole fraction of 1-heptanol in Figure 1. Each set of results were fitted using a Redlich−Kister polynomial,[11] which for binary mixtures is

$$Y = x(1-x)\sum_{k=0}^{N} A_k (1-2x)^k \qquad (5)$$

where $Y = (V^E$ or $\delta\eta)$ and x is the mole fraction of the first component. The coefficients A_k were calculated by the unweighted least-squares method.

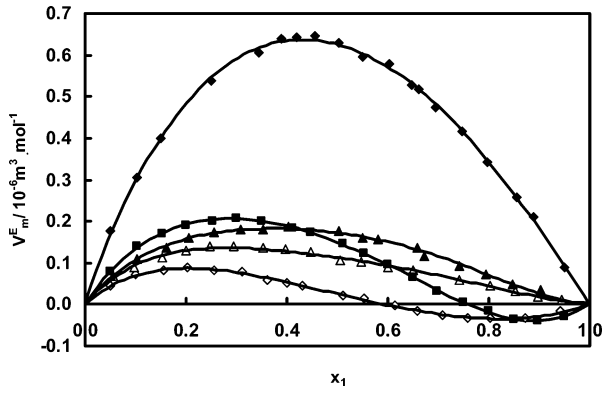

Figure 1. Excess molar volumes vs mole fraction of 1-heptanol for 1-heptanol binary mixtures with ◆, 1,2-dichloroethane; ▲, 1,1,1-trichloroethane; ■, 1,1,2,2-tetrachloroethane; ◇, trichloroethylene; and △, tetrachloroethylene at 298.15 K. The solid curves were calculated from coefficients of eq 5 given in Table 4.

In each case, the optimum number of coefficients was ascertained from an examination of the variation of standard deviation (σ) with

$$\sigma = \left[\sum \left(Y_{exp} - Y_{cal}\right)^2/(n-p)\right]^{1/2} \qquad (6)$$

where Y_{cal} is the calculated values of the property Y, and n and p are the number of experimental points and number of parameters retained in the respective equations, respectively. As seen in Figure 1 and Table 2, at all temperatures, the measured V^E values are positive over the entire range of mole fractions for the binary systems of 1-heptanol + 1,2-dichloroethane, + 1,1,1-trichloroethane, and + tetrachloroethylene, and for the systems 1-heptanol + 1,1,2,2-tetrachloroethane and + trichloroethylene an inversion of sign of V^E is observed over part of the concentration range, as expected from the depolymerization effects of chloroethanes or chloroethylenes (unassociated liquids) on the 1-heptanol (an associated liquid). The values of dipole moments of 1,2-dichloroethane, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, trichloroethylene, and tetrachloroethylene are (1.8, 1.76, 1.32, 0.8, and 0) D, respectively.[12] It seems that with decrease in dipole moments according to latter sentence the polar interactions between unlike molecules decrease. This results in the decrease in V^E values; however, the observed V^E value of tetrachloroethylene with 1-heptanol is mainly due to the van der Waals interactions (Figure 1). The magnitude of this property increases slightly with temperature (Figure 2). The V^E values were fitted to eq 5, and the adjustable parameters and standard deviations are given in Table 4.

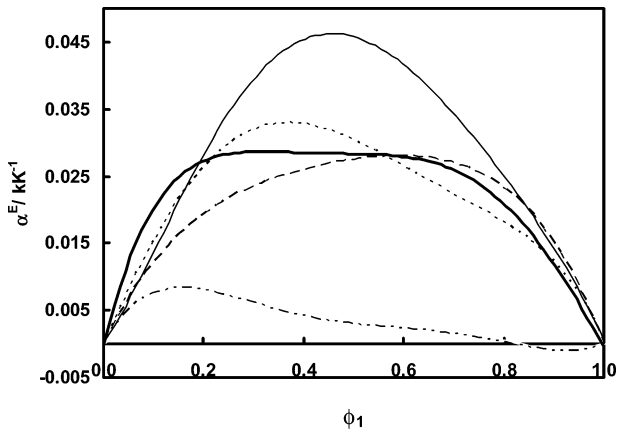

Figure 2. Profiles of excess thermal expansivities vs volume fraction of binary mixtures of 1-heptanol with —, 1,2-dichloroethane; − ·· −, 1,1,1-trichloroethane; - - -, 1,1,2,2-tetrachloroethane; ···, trichloroethylene; and ——, tetrachloroethylene at 298.15 K.

Table 3. Viscosities and Viscosity Deviations for Binary Mixtures at (293.15, 298.15, and 303.15) K

x	η / mPa·s	$\delta\eta$ / mPa·s	x	η / mPa·s	$\delta\eta$ / mPa·s	x	η / mPa·s	$\delta\eta$ / mPa·s	x	η / mPa·s	$\delta\eta$ / mPa·s
(x) 1-Heptanol + (1 − x) 1,2-Dichloroethane											
T = 293.15 K											
0.1023	0.922	−0.557	0.5437	2.355	−1.928	0.3465	1.501	−1.529	0.7475	3.887	−1.689
0.2009	1.104	−1.001	0.5998	2.703	−1.935	0.4616	1.939	−1.822	0.7978	4.397	−1.498
0.2957	1.342	−1.365	0.6972	3.412	−1.845	0.5035	2.139	−1.887	0.8862	5.474	0.983
T = 298.15 K											
0.1023	0.851	−0.464	0.5437	2.079	−1.559	0.3465	1.353	−1.247	0.7475	3.354	−1.356
0.2009	1.006	−0.828	0.5998	2.367	−1.567	0.4616	1.732	−1.474	0.7978	3.773	−1.203
0.2957	1.215	−1.117	0.6972	2.955	−1.491	0.5035	1.901	−1.525	0.8862	4.650	−0.788
T = 303.15 K											
0.1023	0.796	−0.400	0.5437	1.844	−1.406	0.3465	1.227	−1.105	0.7475	2.905	−1.293
0.2009	0.928	−0.727	0.5998	2.089	−1.422	0.4616	1.546	−1.322	0.7978	3.253	−1.179
0.2957	1.105	−0.990	0.6972	2.583	−1.381	0.5035	1.699	v1.364	0.8862	3.979	−0.862
(x) 1-Heptanol + (1 − x) 1,1,1-Trichloroethane											
T = 293.15 K											
0.1048	0.996	−0.519	0.5533	2.729	−1.623	0.3542	1.714	−1.379	0.7416	4.217	−1.326
0.2027	1.224	−0.910	0.5993	3.043	−1.600	0.3980	1.895	−1.475	0.7956	4.783	−1.102
0.3034	1.529	−1.242	0.6811	3.690	−1.471	0.5030	2.426	−1.608	0.9003	5.912	−0.635
T = 298.15 K											
0.1048	0.914	−0.425	0.5533	2.393	−1.302	0.3542	1.539	−1.110	0.7416	3.629	−1.054
0.2027	1.110	−0.744	0.5993	2.664	−1.272	0.3980	1.699	−1.180	0.7956	4.090	−0.877
0.3034	1.379	−1.003	0.6811	3.196	−1.169	0.5030	2.140	−1.291	0.9003	5.018	−0.498
T = 303.15 K											
0.1048	0.858	−0.361	0.5533	2.127	−1.174	0.3542	1.388	−0.989	0.7416	3.141	−1.033
0.2027	1.014	−0.660	0.5993	2.353	−1.160	0.3980	1.526	−1.054	0.7956	3.495	−0.929
0.3034	1.245	−0.896	0.6811	2.791	−1.102	0.5030	1.907	−1.160	0.9003	4.297	−0.613
(x) 1-Heptanol + (1 − x) 1,1,2,2-Tetrachloroethane											
T = 293.15 K											
0.0997	1.852	−0.449	0.5438	3.564	−1.144	0.3445	2.558	−1.070	0.7530	5.166	−0.675
0.2073	2.091	−0.794	0.5988	3.924	−1.083	0.4085	2.833	−1.141	0.8007	5.595	−0.504
0.3054	2.417	−0.999	0.6937	4.654	−0.865	0.5042	3.341	−1.152	0.8971	6.506	−0.116
T = 298.15 K											
0.0997	1.690	−0.364	0.5438	3.101	−0.919	0.3445	2.272	−0.865	0.7530	4.389	−0.558
0.2073	1.907	−0.624	0.5988	3.392	−0.872	0.4085	2.506	−0.915	0.8007	4.737	−0.421
0.3054	2.187	−0.778	0.6937	3.992	−0.692	0.5042	2.908	−0.937	0.8971	5.365	−0.219
T = 303.15 K											
0.0997	1.547	−0.318	0.5438	2.715	−0.881	0.3445	2.027	−0.792	0.7530	3.763	−0.667
0.2073	1.710	−0.575	0.5988	2.962	−0.848	0.4085	2.225	−0.844	0.8007	4.035	−0.578
0.3054	1.927	−0.740	0.6937	3.429	−0.751	0.5042	2.555	−0.886	0.8971	4.627	−0.345
(x) 1-Heptanol + (1 − x) Trichloroethylene											
T = 293.15 K											
0.0927	0.671	−0.496	0.5508	2.307	−1.897	0.3040	1.158	−1.410	0.8020	4.510	−1.358
0.2010	0.883	−1.002	0.6022	2.648	−1.896	0.4057	1.535	−1.707	0.8699	5.313	−1.005
0.2560	1.017	−1.233	0.7077	3.520	−1.723	0.5098	2.050	−1.881	0.8930	5.624	−0.847
T = 298.15 K											
0.0927	0.635	−0.402	0.5508	2.046	−1.517	0.3040	1.073	−1.129	0.8020	3.865	−1.084
0.2010	0.826	−0.808	0.6022	2.342	−1.504	0.4057	1.397	−1.367	0.8699	4.537	−0.785
0.2560	0.949	−0.989	0.7077	3.065	−1.363	0.5098	1.838	−1.499	0.8930	4.804	−0.646
T = 303.15 K											
0.0927	0.600	−0.352	0.5508	1.839	−1.345	0.3040	0.989	−0.992	0.8020	3.333	−1.075
0.2010	0.763	−0.716	0.6022	2.082	−1.352	0.4057	1.280	−1.198	0.8699	3.890	−0.849
0.2560	0.875	−0.872	0.7077	2.672	−1.277	0.5098	1.662	−1.322	0.8930	4.112	−0.740
(x) 1-Heptanol + (1 − x) Tetrachloroethylene											
T = 293.15 K											
0.1052	1.064	−0.483	0.5500	2.827	−1.521	0.4073	2.024	−1.425	0.8034	4.966	−0.977
0.2000	1.285	−0.859	0.5992	3.169	−1.488	0.4612	2.292	−1.496	0.8578	5.520	−0.765
0.2939	1.569	−1.166	0.6926	3.922	−1.323	0.4982	2.509	−1.512	0.8961	5.942	−0.584
T = 298.15 K											
0.1052	0.993	−0.393	0.5500	2.501	−1.199	0.4073	1.830	−1.128	0.8034	4.249	−0.769
0.2000	1.186	−0.693	0.5992	2.798	−1.158	0.4612	2.050	−1.188	0.8578	4.704	−0.596
0.2939	1.441	−0.926	0.6926	3.397	−1.044	0.4982	2.231	−1.199	0.8961	5.052	−0.447
T = 303.15 K											
0.1052	0.961	−0.313	0.5500	2.222	−1.090	0.4073	1.661	−0.997	0.8034	3.631	−0.841
0.2000	1.116	−0.593	0.5992	2.462	−1.075	0.4612	1.851	−1.055	0.8578	4.030	−0.691
0.2939	1.321	−0.818	0.6926	2.958	−1.007	0.4982	2.002	−1.073	0.8961	4.324	−0.573

Thermal expansivity (α) is considered to be the cross fluctuation of volume and enthalpy.[13] Excess thermal expansivities (α^E values) of systems used in this work are given in Figure 2. Positive α^E values of these systems, as seen in Figure 2, suggests that a stronger interaction, like a hydrogen bond, in pure liquid is broken by mixing.[14] On the other hand, negative α^E is due to the formation of new molecular interaction in the mixture. Negative α^E means that fluctuation of the volume causing interaction energy in the mixture is lesser than in random mixing liquids. The α^E values were fitted to eq 5 in terms of ϕ_1, and the adjustable parameters and standard deviations are given in Table 4.

Dynamic and Kinematic Viscosities. The measured η values for binary systems at (293.15, 298.15, and 303.15) K are listed in Table 3.

Table 4. Parameters of Equation 5 and the Standard Deviations for Binary Mixtures at (293.15, 298.15, and 303.15) K

system	A_0	A_1	A_2	A_3	A_4	A_5	σ
			(x) 1-Heptanol + (1 − x) 1,2-Dichloroethane				
			T = 293.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	2.437	0.735	0.039	−0.660	0.259	1.307	0.007
$\delta\eta$/mPa·s	−7.256	2.783	−0.654	−0.670			0.006
			T = 298.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	2.514	0.741	−0.011	−0.652	0.428	1.226	0.007
$\delta\eta$/mPa·s	−6.099	2.160	−0.551	−0.653			0.006
α^E/K^{-1}	1.7×10^{-4}	5.6×10^{-5}	6×10^{-6}	9.5×10^{-5}			3×10^{-6}
			T = 303.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	2.597	0.781	0.120	−0.609	0.212	1.176	0.007
$\delta\eta$/mPa·s	−5.416	1.996	−1.635	1.091			0.013
			(x) 1-Heptanol + (1 − x) 1,1,1-Trichloroethane				
			T = 293.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.667	0.390	0.113	0.100			0.005
$\delta\eta$/mPa·s	−6.398	1.199	0.242	−0.384			0.012
			T = 298.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.689	0.310	0.070	0.396			0.006
$\delta\eta$/mPa·s	−5.124	0.888	0.185	−0.410			0.009
α^E/K^{-1}	9×10^{-6}	6×10^{-6}	2.3×10^{-5}	7.7×10^{-5}			2×10^{-6}
			T = 303.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.699	0.322	0.085	0.411			0.005
$\delta\eta$/mPa·s	−4.562	0.910	−1.123	1.482			0.013
			(x) 1-Heptanol + (1 − x) 1,1,2,2-Tetrachloroethane				
			T = 293.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.527	0.961	−0.267	0.426	0.211		0.002
$\delta\eta$/mPa·s	−4.732	0.296	2.400	−3.209			0.018
			T = 298.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.601	0.963	−0.208	0.382	0.128		0.002
$\delta\eta$/mPa·s	−3.685	−0.562	0.907	0.845			0.021
α^E/K^{-1}	1.1×10^{-4}	-1.2×10^{-5}	6.4×10^{-5}				1×10^{-6}
			T = 303.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.672	0.960	−0.227	0.441	0.269		0.003
$\delta\eta$/mPa·s	−3.509	0.063	−0.178	0.090			0.006
			(x) 1-Heptanol + (1 − x) Trichloroethylene				
			T = 293.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.048	0.541	−0.012	0.230	0.268		0.001
$\delta\eta$/mPa·s	−7.476	2.097	0.111	−0.366			0.005
			T = 298.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.108	0.569	0.048	0.172	0.267		0.003
$\delta\eta$/mPa·s	−5.980	1.678	0.229	−0.614			0.007
α^E/K^{-1}	1.1×10^{-4}	4.1×10^{-5}	8.2×10^{-5}	-5.1×10^{-5}			3×10^{-6}
			T = 303.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.172	0.579	0.046	0.234	0.333		0.003
$\delta\eta$/mPa·s	−5.231	1.638	−1.181	0.949			0.007
			(x) 1-Heptanol + (1 − x) Tetrachloroethylene				
			T = 293.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.384	0.355	0.040	0.242	0.374		0.004
$\delta\eta$/mPa·s	−6.052	0.713	0.610	0.010			0.007
			T = 298.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.461	0.352	0.043	0.280	0.401		0.005
$\delta\eta$/mPa·s	−4.782	0.524	0.469	−0.174			0.007
α^E/K^{-1}	1.14×10^{-4}	-2.9×10^{-5}	7.9×10^{-5}	1.21×10^{-4}			3×10^{-6}
			T = 303.15 K				
$V^E/10^{-6}$ m^3·mol^{-1}	0.532	0.343	0.090	0.390	0.422		0.005
$\delta\eta$/mPa·s	−4.279	0.754	−0.659	1.592			0.007

Table 5. Parameters of Heric's Model and Standard Deviations for Kinematic Viscosities at Various Temperatures

system	T/K	α_{12}	α_{21}	σ
(x) 1-heptanol + (1 − x) 1,2-dichloroethane	293.15	−0.3874	0.4295	1.72×10^{-8}
	298.15	−0.3943	0.4320	1.86×10^{-8}
	303.15	−0.4847	0.2179	3.60×10^{-8}
(x) 1-heptanol + (1 − x) 1,1,1-trichloroethane	293.15	−0.0550	0.4891	1.64×10^{-8}
	298.15	−0.0521	0.4662	1.40×10^{-8}
	303.15	−0.1565	0.2678	4.27×10^{-8}
(x) 1-heptanol + (1 − x) 1,1,2,2-tetrachloroethane	293.15	−0.2332	0.7416	3.88×10^{-8}
	298.15	−0.2450	0.6140	1.59×10^{-8}
	303.15	−0.3797	0.4449	1.85×10^{-8}
(x) 1-heptanol + (1 − x) trichloroethylene	293.15	0.0959	0.4481	1.39×10^{-8}
	298.15	0.1107	0.3862	7.47×10^{-8}
	303.15	2.689×10^{-4}	0.1780	4.11×10^{-8}
(x) 1-heptanol + (1 − x) tetrachloroethylene	293.15	0.0430	0.4518	1.22×10^{-8}
	298.15	0.0332	0.4254	1.00×10^{-8}
	303.15	0.0734	0.1128	2.96×10^{-8}

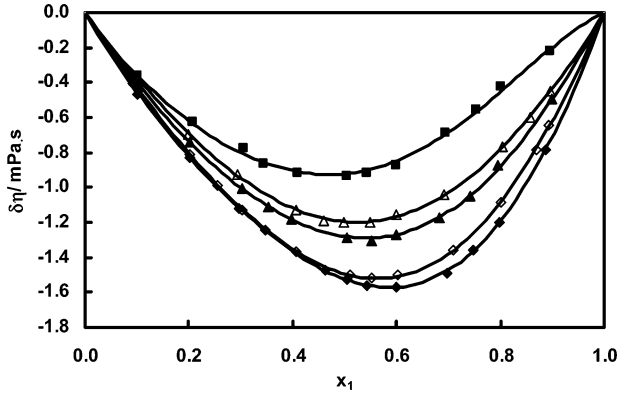

Figure 3. Viscosity deviations vs mole fraction of 1-heptanol for binary mixtures of 1-heptanol with ◆, 1,2-dichloroethane; ▲, 1,1,1-trichloroethane; ■, 1,1,2,2-tetrachloroethane; ◇, trichloroethylene; and △, tetrachloroethylene at 298.15 K.

The viscosity deviations ($\delta\eta$) were calculated by using

$$\delta\eta/\text{mPa·s} = \eta_{\text{mix}} - x_1\eta_1 - x_2\eta_2 \quad (7)$$

where η_{mix} is the viscosity of the binary mixture and η_1 and η_2 are viscosities of components 1 and 2, respectively. The value of $\delta\eta$ for the studied binary mixtures at three different temperatures are also listed in Table 3 and the variation of $\delta\eta$ with the mole fraction of 1-heptanol at 298.15 K is shown in Figure 3. The $\delta\eta$ values were fitted to eq 5 in terms of mole fraction of 1-heptanol, and the adjustable parameters and standard deviations are also given in Table 4. The $\delta\eta$ versus x_1 curves for all the mixtures are almost symmetrical with a minimum around $x_1 \approx 0.6$. The values of $\delta\eta$ at this concentration follow the order:

1,2-dichloroethane < trichloroethylene < 1,1,1-trichloroethane < 1,1,2,2-tetrachloroethane < tetrachloroethylene

The two-parameter Heric interaction model[15] has been used to correlate the kinematic viscosities of binary liquid mixtures. The two-parameter Heric[15] equation is of the form:

$$\ln v = x_1 \ln v_1 + x_2 \ln v_2 + x_1 \ln M_1 + x_2 \ln M_2 - \ln(x_1M_1 + x_2M_2) + x_1x_2[\alpha_{12} + \alpha_{21}(x_1 - x_2)] \quad (8)$$

where α_{12} and α_{21} are adjustable parameters. Table 5 includes the different parameters and standard deviations. From Table 5, it is clear that Heric's two-parameter interaction model is suitable for correlating the kinematic viscosities of the binary mixtures studied.

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