JOURNAL OF CHEMICAL & ENGINEERING DATA

SHORT ARTICLE

pubs.acs.org/jced

Densities, Speeds of Sound, and Isentropic Compressibilities of Binary Mixtures of {Alkan-1-ols + 1,2-Dimethylbenzene, or 1,3-Dimethylbenzene, or 1,4-Dimethylbenzene, or Ethylbenzene} at (293.15, 303.15, and 313.15) K

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ABSTRACT: Densities and speeds of sound of binary liquid mixtures of {nonan-1-ol and decan-1-ol + 1,2-dimethylbenzene, or 1,3-dimethylbenzene, or 1,4-dimethylbenzene, or ethylbenzene} were measured over the entire composition range at (293.15, 303.15, and 313.15) K and at a pressure of 0.1 MPa. The experimental densities and speeds of sound were used to obtain the excess molar volumes and the isentropic compressibilities of the binary liquid mixtures. The Redlich−Kister polynomial was fitted to the excess molar volumes to derive the binary coefficients and the standard errors between the experimental and the calculated quantities. The excess molar volumes are positive for the binary liquid mixtures of {nonan-1-ol and decan-1-ol + ethylbenzene} over the entire composition range at (293.15 to 313.15) K. For the binary liquid mixtures of {nonan-1-ol + 1,2-dimethylbenzene, or 1,3-dimethylbenzene, or 1,4-dimethylbenzene}, the excess molar volumes show sigmoid trend, and the values vary from negative to positive over the whole composition range, except for the binary liquid mixtures of (nonan-1-ol + 1,2-dimethylbenzene) at (303.15 and 313.15) K where the excess molar volumes are positive over the whole composition range. For the binary liquid mixtures of {decan-1-ol + 1,2-dimethylbenzene, or 1,3-dimethylbenzene}, the excess molar volumes show slightly s-shaped trend at (293.15 and 303.15) K, but the excess molar volumes are positive over the whole composition range at T = 313.15 K for these binary liquid mixtures. For the binary liquid mixtures of {decan-1-ol + 1,4-dimethylbenzene), the excess molar volumes show sigmoid trend over the whole composition range at (293.15 to 313.15) K. As we go from nonan-1-ol to decan-1-ol and increase the temperature from (293.15 to 313.15) K, the excess molar volumes become more positive for all the binary liquids mixtures which indicate weak intermolecular interactions between (nonan-1-ol and decan-1-ol + aromatic hydrocarbon) at higher temperatures.

INTRODUCTION

The measurements of thermodynamic properties of binary liquid mixtures of alkan-1-ols and aromatic compounds as one of the components have been employed in understanding the nature of molecular systems and physicochemical behavior of binary liquid mixtures,[1−3] but the literature survey on the thermodynamic, acoustic, and optical properties of binary mixtures containing aromatic hydrocarbons and higher alcohols reveals that the databases are limited.[4−7] It is, therefore, quite essential in this area of research to carry out systematic investigations involving the physical properties of the binary mixtures containing aromatic hydrocarbons and higher alcohols. These physicochemical properties are of great significance in the selection of appropriate solvent for (i) gas and liquid chromatography, (ii) dissolution of materials, and (iii) their use in propellants and aerosols. As a part of our ongoing research work to study the behavior and nature of molecular interactions occurring between the mixing components of binary liquid mixtures, the densities, and speeds of sound of binary liquid mixtures of {nonan-1-ol and decan-1-ol + 1,2-dimethylbenzene, or 1,3-dimethylbenzene, or 1,4-dimethylbenzene, or ethylbenzene} were measured over the entire range of composition at (293.15 to 313.15) K and at a pressure of 0.1 MPa. The experimental densities and speeds of sound were used to obtain the excess molar volumes and the isentropic compressibilities of the binary liquid mixtures. The Redlich−Kister polynomial was fitted to the excess molar volumes to derive the binary coefficients and the standard errors between the experimental and the calculated quantities.

EXPERIMENTAL SECTION

Chemicals. The purities, densities, and speeds of sound of the pure liquid components (nonan-1-ol, decan-1-ol, 1,2-dimethylbenzene, 1,3-dimethylbenzene, 1,4-dimethylbenzene, and ethylbenzene) are listed in Table 1. Prior to experimental measurements, all the liquids were used after double-distillation and partially degassed with a vacuum pump under inert atmosphere. The purity of these liquids was ascertained by comparing the measured densities and speeds of sound at (293.15 and 313.15) K with the available literature values[7−16]presented in Table 1.

Measurements. All the liquid mixtures were prepared by weighing appropriate amounts of pure liquids on an electronic balance (Afcoset−ER-120A, India) with a precision of ± 0.1 mg

Special Issue: John M. Prausnitz Festschrift

Received: July 12, 2010
Accepted: January 4, 2011
Published: January 31, 2011

Table 1. Comparison of Experimental Densities ρ and Speeds of Sound u of Pure Components with Available Literature Values at T = (293.15 and 313.15) K

component	supplier	T/K	purity (mass fraction)	$\rho \cdot 10^{-3}$/kg·m^{-3} exp.	$\rho \cdot 10^{-3}$/kg·m^{-3} lit.	u/m·s^{-1} exp.	u/m·s^{-1} lit.
1-nonan-1-ol	SD Fine Chemical	293.15	>0.995	0.82770	0.82766[b]	1381	1381[g]
		313.15		0.81388	0.81387[b]	1314	1313[g]
1-decan-1-ol	SD Fine Chemical	293.15	>0. 995	0.82998	0.82999[c]	1396	1396[c]
		313.15		0.81627	0.8163[a], 0.81626[c]	1329	1332[a], 1328[c]
1,2-dimethylbenzene	SD Fine Chemical	293.15	>0.995	0.87949	0.87908[d]	1369	1369[d]
		313.15		0.86259	0.8628[a], 0.86283[e]	1289	1287[a], 1290[h]
1,3-dimethylbenzene	SD Fine Chemical	293.15	>0.990	0.86418	0.86405[d]	1341	1321[h] (298.15 K)
		313.15		0.84690	0.8468[a], 0.84715[e]	1259	1259[a], 1259[h]
1,4-dimethylbenzene	SD Fine Chemical	293.15	>0.990	0.86096	0.86092[d]	1330	1331[d]
		313.15		0.84351	0.8441[a], 0.84383[e]	1249	1252[a], 1248[h]
ethylbenzene	SD Fine Chemical	293.15	>0.997	0.86681	0.86695[f]	1340	1319[i] (298.15 K)
		313.15		0.84918	0.84940[e]	1257	1256[j]

[a] Ref 7. [b] Ref 8. [c] Ref 9. [d] Ref 10. [e] Ref 11. [f] Ref 12. [g] Ref 13. [h] Ref 14. [i] Ref 15. [j] Ref 16.

using a syringe. Each component was weighed in airtight stoppered bottles to minimize evaporation losses. The accuracy of the mole fraction was $\pm 1 \cdot 10^{-4}$.

Densities, ρ, and speeds of sound, u, of the pure liquids and their mixtures were measured with a density and sound speed analyzer apparatus (Anton Paar DSA 5000, Austria-Europe) with precision in densities and speeds of sound better than $\pm 2 \cdot 10^{-3}$ kg·m^{-3} and $\pm$ 0.01 m·s^{-1}, respectively. The instrument is made up of an oscillating U-tube, which measures density and speed of sound simultaneously, and the temperature in the cell was regulated $\pm$ 0.001 K using the in-built integrated thermostat with cascaded peltier elements and Pt-100 thermometer. Before each series of measurements, the calibration of the apparatus was carried out at working temperatures by measuring densities and speeds of sound of double-distilled water, benzene, and toluene, respectively. The uncertainty in the experimental measurements has been found to be lower than $\pm 10^{-2}$ kg·m^{-3} for the density and $\pm$ 1 m·s^{-1} for the speed of sound.

RESULTS AND DISCUSSION

The experimental densities, ρ, and the excess molar volumes, V_m^E, speeds of sound, u, and the isentropic compressibilities, κ_S, obtained by means of the Laplace equation ($\kappa_S = 1/u^2\rho$) for binary liquid mixtures at (293.15, 303.15, and 313.15) K and at p = 0.1 MPa are listed in Tables 2 and 3, respectively.

The excess molar volumes, V_m^E, of the binary mixtures were obtained from the densities of the pure liquids and their mixtures using the following equation

$$V_m^E = \sum_{i=1}^{2} x_i M_i (\rho^{-1} - \rho_i^{-1}) \quad (1)$$

where ρ is the density of the mixture and x_i, M_i, and ρ_i are the mole fraction, molecular weight, and density of the i^{th} component of the system.

The experimental results of V_m^E were fitted to the Redlich–Kister equation[17] of the type

$$Y(x) = x(1-x)\sum_{k=1}^{n} A_k (1-2x)^{k-1} \quad (2)$$

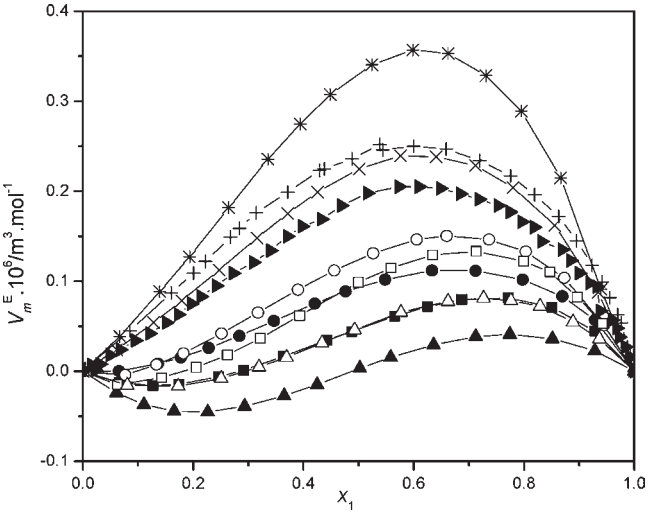

Figure 1. Excess molar volume, V_m^E, plotted against mole fraction, x_1, for [x_1 aromatic hydrocarbon + x_2 alkan-1-ol] systems at T = 303.15 K: ●, 1,2-dimethylbenzene; ■, 1,3-dimethylbenzene; ▲, 1,4-dimethylbenzene; and ×, ethylbenzene for [x_1 aromatic hydrocarbon + x_2 nonan-1-ol] and ○, 1,2-dimethylbenzene; □, 1,3-dimethylbenzene; Δ, 1,4-dimethylbenzene; and *, ethylbenzene for [x_1 aromatic hydrocarbons + x_2 decan-1-ol]. Solid triangle pointing right, for [ethylbenzene + octan-1-ol];[4] + for [ethylbenzene + decan-1-ol].[4]

where k is the number of estimated parameters, and A_k, the polynomial coefficients, were obtained by fitting the equation to the experimental results by the least-squares regression method. The standard deviations, σ, for V_m^E were calculated using the relation

$$\sigma(Y) = \left[\sum_{i}^{n} \{Y(x)_{exp} - Y(x)_{cal}\}^2/(N-n)\right]^{1/2} \quad (3)$$

where $Y(x)_{exp}$, $Y(x)_{cal}$, N, and n are values of the experimental and calculated property, the number of data points, and the number of parameter of the fitting equation, respectively. The polynomial coefficients and the standard deviation between the experimental and the calculated values of V_m^E are given in Table 4.

dx.doi.org/10.1021/je100734t |J. Chem. Eng. Data 2011, 56, 1675–1681

Table 2. Densities ρ and Excess Molar Volumes V_m^E for Binary Liquid Mixtures at T = (293.15 to 313.15) K

	$\rho \cdot 10^{-3}$/kg·m^{-3}			$V_m^E \cdot 10^6$/m^3·mol^{-1}		
x_1	T/K = 293.15	303.15	313.15	T/K = 293.15	303.15	313.15
	x_1 1,2-Dimethylbenzene + x_2 Nonan-1-ol					
0.0000	0.82770	0.82082	0.81388	0.0000	0.0000	0.0000
0.0653	0.83013	0.82315	0.81610	−0.0064	0.0001	0.0060
0.1360	0.83282	0.82573	0.81858	−0.0048	0.0083	0.0201
0.1773	0.83444	0.82729	0.82007	−0.0016	0.0152	0.0301
0.2281	0.83648	0.82925	0.82195	0.0046	0.0259	0.0443
0.2834	0.83877	0.83145	0.82406	0.0137	0.0392	0.0613
0.3463	0.84146	0.83404	0.82655	0.0260	0.0560	0.0819
0.4203	0.84478	0.83724	0.82963	0.0414	0.0753	0.1040
0.4761	0.84741	0.83978	0.83207	0.0524	0.0887	0.1190
0.5478	0.85096	0.84321	0.83538	0.0637	0.1019	0.1331
0.6327	0.85543	0.84754	0.83957	0.0734	0.1118	0.1419
0.7121	0.85993	0.85192	0.84383	0.0749	0.1115	0.1379
0.7974	0.86514	0.85699	0.84877	0.0692	0.1017	0.1213
0.8695	0.86988	0.86163	0.85331	0.0563	0.0833	0.0948
0.9287	0.87408	0.86573	0.85734	0.0357	0.0570	0.0593
1.0000	0.87949	0.87114	0.86259	0.0000	0.0000	0.0000
	x_1 1,3-Dimethylbenzene + x_2 Nonan-1-ol					
0.0000	0.82770	0.82082	0.81388	0.0000	0.0000	0.0000
0.0660	0.82952	0.82253	0.81547	−0.0178	−0.0124	−0.0055
0.1270	0.83123	0.82414	0.81698	−0.0267	−0.0158	−0.0043
0.1739	0.83257	0.82539	0.81816	−0.0305	−0.0146	−0.0004
0.2461	0.83467	0.82736	0.82001	−0.0285	−0.0057	0.0119
0.2913	0.83603	0.82863	0.82121	−0.0249	0.0014	0.0210
0.3635	0.83825	0.83072	0.82317	−0.0139	0.0166	0.0394
0.4422	0.84077	0.83310	0.82542	0.0012	0.0346	0.0605
0.4872	0.84227	0.83452	0.82676	0.0108	0.0443	0.0715
0.5648	0.84495	0.83708	0.82918	0.0301	0.0611	0.0897
0.6251	0.84715	0.83919	0.83118	0.0436	0.0718	0.0994
0.6873	0.84954	0.84147	0.83335	0.0541	0.0796	0.1059
0.7713	0.85300	0.84478	0.83650	0.0594	0.0815	0.1053
0.8507	0.85656	0.84819	0.83976	0.0532	0.0711	0.0913
0.9284	0.86034	0.85184	0.84328	0.0351	0.0445	0.0564
1.0000	0.86418	0.85556	0.84690	0.0000	0.0000	0.0000
	x_1 1,4-Dimethylbenzene + x_2 Nonan-1-ol					
0.0000	0.82770	0.82082	0.81388	0.0000	0.0000	0.0000
0.0611	0.82931	0.82232	0.81527	−0.0289	−0.0239	−0.0179
0.1108	0.83062	0.82355	0.81641	−0.0456	−0.0368	−0.0266
0.1652	0.83208	0.82491	0.81767	−0.0571	−0.0443	−0.0298
0.2260	0.83372	0.82644	0.81910	−0.0618	−0.0452	−0.0263
0.2932	0.83556	0.82816	0.82070	−0.0591	−0.0387	−0.0160
0.3651	0.83759	0.83007	0.82247	−0.0507	−0.0272	−0.0010
0.4248	0.83934	0.83170	0.82400	−0.0401	−0.0148	0.0131
0.5023	0.84169	0.83391	0.82607	−0.0231	0.0034	0.0326
0.5580	0.84346	0.83558	0.82763	−0.0108	0.0155	0.0449
0.6359	0.84606	0.83804	0.82995	0.0046	0.0295	0.0576
0.7123	0.84877	0.84061	0.83239	0.0168	0.0388	0.0643
0.7744	0.85112	0.84284	0.83450	0.0224	0.0411	0.0634
0.8514	0.85423	0.84581	0.83733	0.0226	0.0363	0.0526
0.9286	0.85759	0.84902	0.84041	0.0157	0.0230	0.0316
1.0000	0.86096	0.85225	0.84351	0.0000	0.0000	0.0000

Table 2. Continued

	$\rho \cdot 10^{-3}$/kg·m^{-3}			$V_m^E \cdot 10^6$/m^3·mol^{-1}		
x_1	T/K = 293.15	303.15	313.15	T/K = 293.15	303.15	313.15
	x_1 Ethylbenzene + x_2 Nonan-1-ol					
0.0000	0.82770	0.82082	0.81388	0.0000	0.0000	0.0000
0.0611	0.82932	0.82234	0.81530	0.0203	0.0239	0.0213
0.1285	0.83114	0.82406	0.81691	0.0472	0.0543	0.0580
0.1791	0.83256	0.82540	0.81816	0.0688	0.0782	0.0887
0.2466	0.83450	0.82723	0.81987	0.0999	0.1125	0.1333
0.3151	0.83657	0.82917	0.82169	0.1310	0.1479	0.1788
0.3717	0.83835	0.83085	0.82326	0.1547	0.1753	0.2140
0.4254	0.84012	0.83251	0.82482	0.1747	0.1989	0.2428
0.5007	0.84274	0.83499	0.82714	0.1979	0.2249	0.2749
0.5756	0.84555	0.83765	0.82963	0.2110	0.2393	0.2910
0.6411	0.84819	0.84017	0.83197	0.2134	0.2384	0.2931
0.7122	0.85128	0.84311	0.83474	0.2027	0.2284	0.2758
0.7798	0.85446	0.84614	0.83759	0.1791	0.2041	0.2410
0.8557	0.85837	0.84983	0.84114	0.1316	0.1621	0.1695
0.9341	0.86285	0.85410	0.84528	0.0571	0.0878	0.0673
1.0000	0.86681	0.85809	0.84919	0.0000	0.0000	0.0000
	x_1 1,2-Dimethylbenzene + x_2 Decan-1-ol					
0.0000	0.82998	0.82310	0.81627	0.0000	0.0000	0.0000
0.0766	0.83248	0.82552	0.81851	−0.0066	−0.0041	0.0172
0.1331	0.83438	0.82733	0.82023	−0.0036	0.0073	0.0325
0.1823	0.83610	0.82896	0.82179	0.0010	0.0200	0.0477
0.2509	0.83857	0.83131	0.82405	0.0154	0.0420	0.0713
0.3173	0.84106	0.83371	0.82636	0.0350	0.0652	0.0947
0.3896	0.84395	0.83648	0.82902	0.0551	0.0907	0.1201
0.4556	0.84673	0.83916	0.83161	0.0744	0.1120	0.1408
0.5261	0.84991	0.84223	0.83457	0.0919	0.1311	0.1576
0.6054	0.85377	0.84595	0.83818	0.1052	0.1463	0.1689
0.6597	0.85661	0.84871	0.84085	0.1106	0.1505	0.1704
0.7364	0.86094	0.85291	0.84492	0.1088	0.1462	0.1616
0.8029	0.86503	0.85689	0.84880	0.0970	0.1328	0.1404
0.8730	0.86974	0.86149	0.85327	0.0746	0.1036	0.1059
0.9447	0.87504	0.86672	0.85833	0.0369	0.0512	0.0511
1.0000	0.87949	0.87114	0.86259	0.0000	0.0000	0.0000
	x_1 1,3-Dimethylbenzene + x_2 Decan-1-ol					
0.0000	0.82998	0.82310	0.81627	0.0000	0.0000	0.0000
0.0627	0.83148	0.82451	0.81753	−0.0194	−0.0149	0.0006
0.1424	0.83339	0.82627	0.81918	−0.0234	−0.0072	0.0112
0.2052	0.83493	0.82772	0.82053	−0.0156	0.0044	0.0258
0.2618	0.83635	0.82906	0.82178	−0.0026	0.0183	0.0429
0.3217	0.83790	0.83053	0.82314	0.0181	0.0368	0.0660
0.3934	0.83984	0.83237	0.82485	0.0435	0.0620	0.0934
0.4989	0.84294	0.83528	0.82760	0.0755	0.0987	0.1281
0.5581	0.84481	0.83705	0.82926	0.0922	0.1147	0.1458
0.6343	0.84744	0.83952	0.83160	0.1021	0.1290	0.1561
0.7131	0.85041	0.84231	0.83424	0.1044	0.1331	0.1576
0.7991	0.85399	0.84571	0.83747	0.0947	0.1223	0.1421
0.8465	0.85611	0.84774	0.83940	0.0865	0.1104	0.1280
0.8964	0.85852	0.85009	0.84161	0.0686	0.0823	0.1002
0.9421	0.86090	0.85238	0.84382	0.0447	0.0531	0.0645
1.0000	0.86418	0.85556	0.84690	0.0000	0.0000	0.0000

dx.doi.org/10.1021/je100734t |J. Chem. Eng. Data 2011, 56, 1675–1681

Table 2. Continued

	$\rho \cdot 10^{-3}$/kg·m^{-3}			$V_m^E \cdot 10^6$/m^3·mol^{-1}		
x_1	T/K = 293.15	303.15	313.15	T/K = 293.15	303.15	313.15
	x_1 1,4-Dimethylbenzene + x_2 Decan-1-ol					
0.0000	0.82998	0.82310	0.81627	0.0000	0.0000	0.0000
0.0806	0.83176	0.82474	0.81776	−0.0256	−0.0154	−0.0055
0.1731	0.83382	0.82666	0.81954	−0.0299	−0.0165	−0.0026
0.2506	0.83560	0.82833	0.82108	−0.0232	−0.0079	0.0096
0.3197	0.83725	0.82988	0.82250	−0.0097	0.0048	0.0270
0.3693	0.83849	0.83104	0.82357	0.0010	0.0154	0.0408
0.4336	0.84017	0.83260	0.82502	0.0145	0.0317	0.0572
0.4929	0.84179	0.83412	0.82643	0.0278	0.0462	0.0718
0.5771	0.84426	0.83642	0.82858	0.0449	0.0654	0.0891
0.6620	0.84698	0.83896	0.83098	0.0544	0.0779	0.0962
0.7265	0.84920	0.84106	0.83294	0.0601	0.0812	0.0979
0.7763	0.85104	0.84280	0.83458	0.0601	0.0786	0.0942
0.8293	0.85313	0.84477	0.83644	0.0560	0.0724	0.0835
0.8891	0.85565	0.84720	0.83871	0.0458	0.0547	0.0651
0.9369	0.85784	0.84927	0.84068	0.0297	0.0361	0.0414
1.0000	0.86096	0.85225	0.84351	0.0000	0.0000	0.0000
	x_1 Ethylbenzene + x_2 Decan-1-ol					
0.0000	0.82998	0.82310	0.81627	0.0000	0.0000	0.0000
0.0666	0.83150	0.82447	0.81746	0.0213	0.0388	0.0599
0.1392	0.83318	0.82600	0.81882	0.0580	0.0885	0.1243
0.1932	0.83447	0.82718	0.81988	0.0887	0.1272	0.1732
0.2642	0.83624	0.82880	0.82132	0.1333	0.1819	0.2434
0.3355	0.83811	0.83052	0.82285	0.1788	0.2356	0.3107
0.3936	0.83972	0.83203	0.82421	0.2140	0.2746	0.3573
0.4483	0.84133	0.83352	0.82558	0.2428	0.3075	0.3960
0.5238	0.84373	0.83578	0.82765	0.2749	0.3404	0.4345
0.5980	0.84633	0.83823	0.82991	0.2910	0.3569	0.4545
0.6621	0.84879	0.84059	0.83213	0.2931	0.3530	0.4480
0.7309	0.85172	0.84340	0.83480	0.2758	0.3285	0.4163
0.7953	0.85476	0.84631	0.83756	0.2410	0.2892	0.3716
0.8668	0.85859	0.84996	0.84106	0.1695	0.2149	0.2857
0.9396	0.86299	0.85430	0.84513	0.0673	0.0911	0.1639
1.0000	0.86681	0.85809	0.84919	0.0000	0.0000	0.0000

The variation of V_m^E with mole fraction x_1 is plotted in Figure 1 over the entire composition range at T = 303.15 K for the binary liquid mixtures of {alkan-1-ols + aromatic hydrocarbons}, and a comparison has been made with the values reported by Dewan et al.[4] for the binary liquid mixtures of the {octan-1-ol/decan-1-ol + ethylbenzene} system at T = 303.15 K. The shape and symmetry of the V_m^E curve are in accordance with the literature data.[4] The results shown in Table 2 reveal that for the binary liquid mixtures {nonan-1-ol and decan-1-ol + ethylbenzene}, $V_m^E > 0$ over the whole composition range at (293.15 to 313.15) K. For the binary liquid mixtures of {nonan-1-ol + 1,2-dimethylbenzene, or 1,3-dimethylbenzene, or 1,4-dimethylbenzene), the excess molar volumes show sigmoid trend, and the values vary from negative to positive over the whole composition range, except for the binary liquid mixtures of (nonan-1-ol + 1,2-dimethylbenzene) at (303.15 and 313.15) K where the excess molar volumes are positive over the whole composition range. For the binary liquid mixtures of {decan-1-ol + 1,2-dimethylbenzene, or

Table 3. Speeds of Sound u and Isentropic Compressibilities κ_S for binary mixtures at T = (293.15 to 313.15) K

	u/m·s^{-1}			κ_S/TPa^{-1}		
x_1	T/K = 293.15	303.15	313.15	T/K = 293.15	303.15	313.15
	x_1 1,2-Dimethylbenzene + x_2 Nonan-1-ol					
0.0000	1381	1347	1314	633.77	671.60	711.65
0.0653	1380	1345	1312	632.67	671.47	712.36
0.1360	1378	1343	1309	632.23	671.83	713.47
0.1773	1377	1341	1307	632.17	672.20	714.26
0.2281	1375	1339	1304	632.25	672.78	715.31
0.2834	1373	1336	1301	632.48	673.45	716.50
0.3463	1370	1334	1298	632.75	674.18	717.74
0.4203	1368	1330	1295	632.83	674.75	718.93
0.4761	1366	1328	1292	632.64	675.02	719.72
0.5478	1364	1326	1289	631.97	674.82	720.12
0.6327	1362	1323	1286	630.16	673.62	719.68
0.7121	1361	1322	1285	627.69	671.62	718.23
0.7974	1361	1322	1284	623.63	668.10	715.14
0.8695	1363	1322	1284	619.18	663.68	711.13
0.9287	1365	1324	1285	614.21	658.68	706.55
1.0000	1369	1328	1289	606.87	650.81	697.97
	x_1 1,3-Dimethylbenzene + x_2 Nonan-1-ol					
0.0000	1381	1347	1314	633.77	671.60	711.65
0.0660	1378	1343	1310	634.64	673.64	714.88
0.1270	1375	1340	1306	636.10	676.08	718.10
0.1739	1373	1337	1302	637.50	678.23	720.76
0.2461	1368	1332	1297	639.92	681.70	725.47
0.2913	1365	1328	1293	641.58	683.89	728.38
0.3635	1361	1323	1287	644.43	687.83	733.16
0.4422	1355	1317	1281	647.43	691.89	738.47
0.4872	1353	1314	1277	648.99	694.03	741.23
0.5648	1348	1309	1272	651.34	697.25	745.51
0.6251	1345	1305	1268	652.75	699.25	748.50
0.6873	1342	1302	1264	653.61	700.69	750.89
0.7713	1339	1299	1260	653.54	701.20	752.84
0.8507	1338	1298	1258	651.75	700.15	752.74
0.9284	1339	1298	1257	648.01	697.01	750.09
1.0000	1341	1300	1259	643.57	692.12	745.11
	x_1 1,4-Dimethylbenzene + x_2 Nonan-1-ol					
0.0000	1381	1347	1314	633.77	671.60	711.65
0.0611	1378	1343	1310	634.95	673.99	715.12
0.1108	1375	1340	1306	636.47	676.48	718.42
0.1652	1372	1336	1301	638.60	679.33	722.17
0.2260	1368	1331	1296	641.24	683.05	726.81
0.2932	1363	1326	1290	644.57	687.15	732.07
0.3651	1357	1320	1284	648.00	691.77	737.90
0.4248	1353	1315	1278	651.21	695.68	742.62
0.5023	1347	1308	1272	654.91	700.41	748.63
0.5580	1343	1304	1267	657.34	703.77	752.89
0.6359	1338	1299	1261	660.03	707.58	757.81
0.7123	1334	1294	1256	661.87	710.40	761.73
0.7744	1332	1291	1252	662.51	711.60	764.00
0.8514	1330	1289	1249	662.11	711.70	764.97
0.9286	1329	1288	1248	660.09	710.02	763.99
1.0000	1330	1289	1249	656.36	706.19	760.50

dx.doi.org/10.1021/je100734t |J. Chem. Eng. Data 2011, 56, 1675–1681

Table 3. Continued

	u/m·s^{-1}			κ_S/TPa^{-1}		
x_1	T/K = 293.15	303.15	313.15	T/K = 293.15	303.15	313.15
	x_1 Ethylbenzene + x_2 Nonan-1-ol					
0.0000	1381	1347	1314	633.77	671.60	711.65
0.0611	1378	1343	1309	635.13	674.14	715.30
0.1285	1374	1338	1304	637.24	677.45	719.82
0.1791	1371	1335	1300	638.93	679.94	723.44
0.2466	1366	1330	1294	641.81	683.68	728.42
0.3151	1362	1324	1288	644.50	687.56	733.46
0.3717	1358	1320	1283	646.91	690.67	737.59
0.4254	1354	1316	1279	649.42	693.59	741.40
0.5007	1349	1311	1273	651.99	697.21	746.29
0.5756	1345	1306	1267	654.10	700.33	750.49
0.6411	1341	1302	1263	655.21	702.34	753.44
0.7122	1339	1298	1259	655.40	703.47	755.54
0.7798	1337	1296	1257	654.83	703.56	756.14
0.8557	1336	1295	1255	652.38	701.81	755.32
0.9341	1338	1295	1254	647.80	697.98	751.78
1.0000	1340	1298	1257	642.77	691.71	745.16
	x_1 1,2-Dimethylbenzene + x_2 Decan-1-ol					
0.0000	1396	1362	1329	618.40	655.14	693.99
0.0766	1394	1359	1325	618.52	656.00	695.71
0.1331	1391	1356	1322	618.96	656.95	697.40
0.1823	1389	1354	1319	619.54	657.97	699.08
0.2509	1386	1350	1315	620.61	659.59	701.51
0.3173	1383	1347	1311	621.81	661.25	704.04
0.3896	1379	1343	1307	623.05	663.05	706.59
0.4556	1376	1339	1303	624.09	664.60	708.78
0.5261	1372	1335	1298	624.76	665.99	710.67
0.6054	1369	1332	1294	624.98	666.60	712.26
0.6597	1367	1329	1292	624.67	666.69	712.56
0.7364	1365	1327	1289	623.35	666.06	712.17
0.8029	1364	1325	1287	621.13	664.37	710.92
0.8730	1364	1325	1287	617.61	661.37	708.02
0.9447	1366	1326	1287	612.11	656.62	703.47
1.0000	1369	1328	1289	606.87	650.81	697.97
	x_1 1,3-Dimethylbenzene + x_2 Decan-1-ol					
0.0000	1396	1362	1329	618.40	655.14	693.99
0.0627	1392	1358	1324	620.27	657.88	697.87
0.1424	1388	1352	1318	623.27	661.88	703.09
0.2052	1383	1347	1312	625.99	665.38	707.48
0.2618	1379	1343	1308	628.64	668.71	711.62
0.3217	1375	1338	1302	631.63	672.39	716.22
0.3934	1369	1332	1296	635.22	676.85	721.73
0.4989	1361	1324	1287	639.99	683.05	729.31
0.5581	1357	1319	1282	642.60	686.53	733.66
0.6343	1352	1313	1276	645.35	690.43	738.78
0.7131	1348	1308	1270	647.36	693.59	743.37
0.7991	1344	1304	1265	648.48	695.75	746.67
0.8465	1342	1302	1262	648.27	696.17	747.75
0.8964	1341	1300	1260	647.59	695.75	748.04
0.9421	1341	1300	1259	646.29	694.26	747.13
1.0000	1340	1300	1259	644.24	692.12	745.11

Table 3. Continued

	u/m·s^{-1}			κ_S/TPa^{-1}		
x_1	T/K = 293.15	303.15	313.15	T/K = 293.15	303.15	313.15
	x_1 1,4-Dimethylbenzene + x_2 Decan-1-ol					
0.0000	1396	1362	1329	618.40	655.14	693.99
0.0806	1391	1356	1322	621.23	659.24	699.69
0.1731	1385	1349	1314	625.56	664.85	706.70
0.2506	1378	1342	1307	629.82	670.18	713.09
0.3197	1373	1336	1300	634.00	675.22	719.11
0.3693	1368	1331	1295	637.17	679.02	723.66
0.4336	1362	1325	1289	641.32	683.95	729.52
0.4929	1357	1320	1283	645.03	688.46	735.05
0.5771	1350	1312	1275	649.71	694.53	742.54
0.6620	1344	1305	1267	653.70	699.89	749.51
0.7265	1340	1300	1262	656.03	703.28	754.03
0.7763	1337	1297	1258	657.34	705.29	756.82
0.8293	1335	1294	1255	658.10	706.91	759.34
0.8891	1333	1292	1252	658.14	707.58	760.82
0.9369	1332	1290	1250	657.52	707.22	761.47
1.0000	1330	1289	1249	656.36	706.19	760.50
	x_1 Ethylbenzene + x_2 Decan-1-ol					
0.0000	1396	1362	1329	618.40	655.14	693.99
0.0666	1391	1356	1322	621.66	659.36	699.46
0.1392	1385	1350	1316	625.48	664.22	705.55
0.1932	1381	1345	1310	628.47	668.06	710.31
0.2642	1375	1339	1304	632.42	673.08	716.42
0.3355	1369	1333	1297	636.42	678.12	722.61
0.3936	1364	1327	1291	639.68	682.24	727.56
0.4483	1360	1322	1286	642.70	686.01	732.11
0.5238	1354	1316	1279	646.47	690.77	738.22
0.5980	1349	1310	1273	649.58	694.86	743.59
0.6621	1344	1305	1268	651.75	698.05	747.88
0.7309	1341	1301	1263	653.31	700.48	751.26
0.7953	1338	1298	1259	653.84	701.52	753.28
0.8668	1336	1295	1256	652.60	701.29	753.48
0.9396	1336	1295	1255	648.73	697.91	751.19
1.0000	1340	1298	1257	642.77	691.71	745.16

1,3-dimethylbenzene}, the excess molar volumes show a slightly s-shaped trend at (293.15 and 303.15) K where the excess molar volumes show a positive trend over the whole composition range at T = 313.15 K for these binary liquid mixtures. For the binary liquid mixtures of {decan-1-ol + 1,4-dimethylbenzene}, the excess molar volumes show a sigmoid trend over the whole composition range at (293.15 to 313.15) K. In general, higher molecular packing is obtained for the binary liquid mixtures of the {nonan-1-ol and decan-1-ol + 1,2-dimethylbenzene/1,3-dimethylbenzene/1,4-dimethylbenzene} as compared to that for the binary liquid mixtures of {nonan-1-ol and decan-1-ol + ethylbenzene}. The V_m^E at the maximum of the curves for {nonan-1-ol/decan-1-ol + aromatic hydrocarbons} decrease in the following sequence: ethylbenzene > 1,2-dimethylbenzene > 1,3-dimethylbenzene > 1,4-dimethylbenzene. As we go from nonan-1-ol to decan-1-ol and increase the temperature from T = (293.15 to 313.15) K, the excess molar volumes become more positive for all the binary liquids mixtures which indicate weak intermolecular interactions

dx.doi.org/10.1021/je100734t |J. Chem. Eng. Data 2011, 56, 1675–1681

Table 4. Coefficients of the Redlich−Kister Equation and Standard Deviations for Excess Molar Volume V_m^E for Binary Liquid Mixtures at T = (293.15 to 313.15) K

T/K	A_1	A_2	A_3	σ
	x_1 1,2-Dimethylbenzene + x_2 Nonan-1-ol			
293.15	0.224	0.356	−0.009	0.0010
303.15	0.369	0.432	0.045	0.0028
313.15	0.495	0.442	−0.003	0.0012
	x_1 1,3-Dimethylbenzene + x_2 Nonan-1-ol			
293.15	0.060	0.468	0.081	0.0008
303.15	0.190	0.473	0.057	0.0014
313.15	0.297	0.512	0.097	0.0017
	x_1 1,4-Dimethylbenzene + x_2 Nonan-1-ol			
293.15	−0.095	0.437	−0.055	0.0006
303.15	0.010	0.448	−0.066	0.0006
313.15	0.127	0.465	−0.066	0.0006
	x_1 Ethylbenzene + x_2 Nonan-1-ol			
293.15	0.796	0.459	−0.099	0.0047
303.15	0.890	0.553	0.007	0.0023
313.15	1.109	0.618	−0.303	0.0079
	x_1 1,2-Dimethylbenzene + x_2 Decan-1-ol			
293.15	0.343	0.483	−0.056	0.0009
303.15	0.501	0.562	−0.026	0.0024
313.15	0.608	0.459	0.008	0.0011
	x_1 1,3-Dimethylbenzene + x_2 Decan-1-ol			
293.15	0.300	0.590	−0.118	0.0033
303.15	0.393	0.630	−0.007	0.0023
313.15	0.511	0.622	0.063	0.0028
	x_1 1,4-Dimethylbenzene + x_2 Decan-1-ol			
293.15	0.117	0.451	−0.057	0.0022
303.15	0.193	0.475	0.001	0.0005
313.15	0.291	0.459	−0.005	0.0014
	x_1 Ethylbenzene + x_2 Decan-1-ol			
293.15	1.075	0.727	−0.195	0.0086
303.15	1.331	0.774	−0.114	0.0066
313.15	1.689	0.967	0.112	0.0063

between (nonan-1-ol and decan-1-ol + the aromatic hydrocarbon) molecules at higher temperatures.

CONCLUSIONS

In this work, densities and speeds of sound of binary liquid mixtures of nonan-1-ol and decan-1-ol with 1,2-dimethylbenzene, 1,3-dimethylbenzene, 1,4-dimethylbenzene, and ethylbenzene were measured over the entire range of composition at T = (293.15 to 313.15) K and at a pressure of 0.1 MPa. The observed V_m^E values at the maximum of the curves for nonan-1-ol and decan-1-ol decrease in the following sequence: ethylbenzene > 1,2-dimethylbenzene > 1,3-dimethylbenzene > 1,4-dimethylbenzene. Also, as we go from nonan-1-ol to decan-1-ol and increase the temperature from T = (293.15 to 313.15) K, the excess molar volumes become more positive for all the binary liquid mixtures which indicates weak intermolecular interactions between (nonan-1-ol and decan-1-ol) and the aromatic hydrocarbon molecules at higher temperatures.

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Funding Sources

The authors are grateful for the award of a University Research Fellowship to one of the authors.

ACKNOWLEDGMENT

The authors are grateful to the Kurukshetra University authorities for providing the necessary facilities to carry out the research work.

REFERENCES

(1) Bhatia, S. C.; Bhatia, R.; Dubey, G. P. Studies of Thermodynamic Properties of Binary Mixtures of Hexan-1-ol with Halogenated compounds at 308.15 and 313.15 K. *J. Chem. Thermodyn.* **2009**, *41*, 1132–1144.

(2) Bhatia, S. C.; Bhatia, R.; Dubey, G. P. Studies on Transport and Thermodynamic Properties of Binary Mixtures of Octan-ol with Chloroform, 1,2-Dichloroethane and 1,1,2,2-Tetrachloroethane at 298.15 and 308.15 K. *J. Mol. Liq.* **2009**, *144*, 163–171.

(3) Bhatia, S. C.; Bhatia, R.; Dubey, G. P. Studies on transport and thermodynamic properties of binary mixtures of hexan-1-ol with halogenated compounds at 293.15 K. *J. Chem. Eng. Data* **2009**, *54*, 3303–3306.

(4) Dewan, R. K.; Mehta, S. K. Excess Volume of (Ethylbenzene + an Alkanol). *J. Chem. Thermodyn.* **1987**, *19*, 819–822.

(5) Dewan, R. K.; Gupta, C. M.; Mehta, S. K. Ultrasonic Study of {Ethylbenzene + n-Alkanol}. *Acustica* **1988**, *65*, 245–253.

(6) Garg, S. K.; Ahluwalia, J. C. Excess Volumes of Binary Mixtures of Ethylbenzene with Octanol, Nonanol and Dodecanol from 50 to 100° C and 0.1 to 7.5 MPa. *J. Solution Chem.* **1995**, *24*, 153–170.

(7) Gopal, K.; Rao, N. P. Ultrasonic Studies in Binary Liquid Mixtures n-Decyl Alcohol as a Common Component. *Acustica* **1983**, *54*, 115–119.

(8) Dzida, M. Speeds of Sound, Densities, Isobaric Thermal Expansion, Compressibilities, and Internal Pressures of Heptan-1-ol, Octan-1-ol, Nonan-1-ol, and Decan-1-ol at Temperatures from (293 to 318) K and Pressures up to 100 MPa. *J. Chem. Eng. Data* **2007**, *52*, 521–531.

(9) Bhatia, S. C.; Bhatia, R.; Dubey, G. P. Thermodynamic and Sonochemical Behaviour of Binary Mixtures of Decan-1-ol with Halohydrocarbons at (293.15 and 313.15) K. *J. Chem. Thermodyn.* **2010**, *42*, 114–127.

(10) Al-Kandary, J. A.; Al-Jimaz, A. S.; Abdul-Latif, A.-H. M. Viscosities, Densities, and Speeds of Sound of Binary Mixtures of Benzene, Toluene, o-Xylene, m- Xylene, p-Xylene, and Mesitylene with Anisole at (288.15, 293.15, 298.15, and 303.15) K. *J. Chem. Eng. Data* **2006**, *51*, 2074–2082.

(11) Rao, Y. P.; Suri, S. K. Thermodynamic Properties of Solutions Containing an Aliphatic Amine. 1. Excess Volumes of Binary Systems of Triethylamine with Benzene, Toluene, Ethylbenzene, and Isomeric Xylenes at 313.15 K. *J. Chem. Eng. Data* **1980**, *25*, 388–390.

(12) Al-Jimaz, A. S.; Al-Kandary, J. A.; Abdul-Latif, A.-H. M. Densities, Viscosities, and Refractive Indices of Binary Mixtures of Anisole with Benzene, Methylbenzene, Ethylbenzene, Propylbenzene, and Butylbenzene at (293.15 and 303.15) K. *J. Chem. Eng. Data* **2006**, *51* (1), 99–103.

(13) Zorebski, E.; Lubowiecka-Kostka, B. Thermodynamic and Transport Properties of (1,2-ethanediol + 1-nonanol) at Temperatures from (298.15 to 313.15) K. *J. Chem. Thermodyn.* **2009**, *41*, 197–204.

(14) Gonzalez, B.; Gonzalez, E. J.; Calvar, N.; Domınguez, I.; Canosa, J. Density, Speed of Sound, and Refractive Index for Binary

Mixtures Containing Cycloalkanes with *o*-Xylene, *m*-Xylene, *p*-Xylene, and Mesitylene at *T*) (298.15 and 313.15) K. *J. Chem. Eng. Data* **2010**, *55*, 2294–2305.

(15) Gonzalez, B.; Dominguez, I; Gomez, E.; Gonzalez; Dominguez, A. Density, Speeds of Sound, and Refractive Index of the Binary Systems Cyclohexane (1) or Methylcyclohexane (1) or Cyclo-octane (1) with Benzene (2), Toluene (2), and Ethylbenzene (2) at Two Temperatures. *J. Chem. Eng. Data* **2010**, *55*, 1003–1011.

(16) Calvar, N.; Gomez, E.; Gonzalez, B.; Dominguez, A. Experimental Densities, Refractive Indices, and Speeds of Sound of 12 Binary Mixtures Containing Alkanes and Aromatic Compounds at T = 313.15 K. *J. Chem. Thermodyn.* **2009**, *41*, 939–944.

(17) Redlich, O.; Kister, A. T. Algebric Representation of Thermodynamic Properties and Classification of Solution. *Ind. Eng. Chem.* **1948**, *40*, 345–348.