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Density, Viscosity, and Speed of Sound in Binary Mixtures of 1-Chloronaphthalene with Methanol, Ethanol, Propan-1-ol, Butan-1-ol, Pentan-1-ol, and Hexan-1-ol in the Temperature Range (298.15−308.15) K

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Density and viscosity data at 298.15, 303.15, and 308.15 K and speed of sound at 298.15 K in the binary mixtures of 1-chloronaphthalene with methanol, ethanol, propan-1-ol, butan-1-ol, pentan-1-ol, and hexan-1-ol are presented over the whole of the mixture composition. From these results, excess molar volume, V^E, deviations in viscosity, $\Delta\eta$, speed of sound, Δu, and isentropic compressiblity, Δk_S have been calculated. These quantities are fitted to Redlich−Kister type equation to derive the binary coefficients and estimate the standard errors between the experimental and fitted quantities.

Introduction

In the literature of solution chemistry, binary mixtures containing 1-chloronaphthalene have attracted considerable interest in view of their widely varying molecular interactions with liquids such as alkanes and ketones (Bendiab et al., 1995; Grolier et al., 1981; Wilhelm et al., 1986; Costas et al., 1988; Comelli and Francesconi, 1992; Aminabhavi and Banerjee, 1997). In continuation of this research, we now present the experimental data of density, ρ, and viscosity, η, at 298.15, 303.15, and 308.15 K and speed of sound, u, at 298.15 K for the binary mixtures of 1-chloronaphthalene with methanol, ethanol, propan-1-ol, butan-1-ol, pentan-1-ol, and hexan-1-ol. From these data, excess volume, V^E, deviations in viscosity, $\Delta\eta$, speed of sound, Δu, and isentropic compressibility, Δk_S, have been calculated. These results are fitted to Redlich−Kister type equation (1948) to derive the binary coefficients and estimate the standard errors between the experimentally calculated and computed values.

Experimental Section

Materials and Methods. High-purity spectroscopic grade samples of 1-chloronaphthalene, pentan-1-ol, and hexan-1-ol were purchased from Fluka (Germany), but ethanol was procured from E. Merck (Germany). Methanol, propan-1-ol, and butan-1-ol were purchased from s.d. fine Chemicals Ltd., Mumbai, India. The GLC analyses of these liquids indicated a mol % purity of 90.06, 99.70, 99.65, 99.60, 99.70, 99.75, and 99.50, respectively. These analyses were performed on a gas chromatograph, HP Series 6890, using a flame ionization detector with fused silica columns, having a sensitivity better than 10^{-8} g of fatty acid/μL of the solvent. All the samples were used without further purification. Experimental values of ρ and refractive indices, n_D, at the sodium D line for the pure liquids are compared with the published results at 298.15 K in Table 1.

Experimental details about the preparations of binary mixtures and measurements of mass, density, speed of sound, and viscosity of pure liquids and binary mixtures are the same as described previously (Aralaguppi et al., 1991). The mass measurements (±0.01 mg) were made using an electronic balance (Mettler AE 240, Switzerland). The reproducibility in mole fraction was within ±0.0001 units. Densities of pure liquids and their mixtures were measured using a pycnometer having a bulb volume of 15 cm^3 and a capillary bore with an internal diameter of 1 mm. Density values are accurate to ±0.0002 $g\cdot cm^{-3}$.

Table 1. Comparison of Experimental Densities (ρ) and Refractive Indices (n_D) of Pure Liquids with Literature Values at 298.15 K

	ρ/g·cm^{-3}		n_D	
liquid (mol % purity)	exptl	lit.	exptl	lit.
1-chloronaphthalene (90.06)	1.1891	1.1881[e]		
methanol (99.7)	0.7866	0.7866[a]	1.3273	1.3274[b]
ethanol (99.6)	0.7855	0.7861[c]	1.3603	1.3595[b]
propan-1-ol (99.75)	0.7998	0.7994[c]	1.3835	1.3833[b]
butan-1-ol (99.5)	0.8059	0.8056[c]	1.3974	1.3974[b]
pentan-1-ol (99.7)	0.8110	0.8109[d]	1.4085	1.4077[b]
hexan-1-ol (99.65)	0.8153	0.8152[b]	1.4164	1.4160[b]

[a] Won et al., 1981. [b] Ortega et al., 1986. [c] Rauf et al., 1983. [d] Garcia et al., 1991. [e] Comelli, 1992.

Viscosities were measured using a Cannon Fenske Viscometer (size 75, Industrial Research Glassware Ltd., Roselle, NJ). An electronic digital stopwatch with a readability of ±0.01 s was used for the flow time measurements. The measured viscosity values are accurate to ±0.001 mPa·s. Calibrations of the pycnometer and viscometer are the same as described earlier (Aminabhavi and Bindu, 1995; Aminabhavi et al., 1994).

The speed of sound values were measured using a variable-path single-crystal interferometer (Mittal Enterprises, model M-84, New Delhi). The interferometer was used at a frequency of 1 kHz and was calibrated using water and benzene. The speed of sound values are accurate to ±2 $m\cdot s^{-1}$. In all the property measurements, an INSREF, model 016 AP thermostat was used at a constant digital temperature display accurate to ± 0.01 K. The results of ρ, η, and u compiled in Table 2 represent the

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Table 2. Experimental Densities (ρ), Viscosities (η), and Speeds of Sound (u) of Binary Mixtures of 1-Chloronaphthalene with Alkanols

x_1	density/(g·cm^{-3})	viscosity/(mPa·s)	speed of sound/(m·s^{-1})	x_1	density/(g·cm^{-3})	viscosity/(mPa·s)	speed of sound/(m·s^{-1})	x_1	density/(g·cm^{-3})	viscosity/(mPa·s)	speed of sound/(m·s^{-1})
1-Chloronaphthalene (1) + Methanol (2)											
298.15 K											
0.0000	0.7866	0.538	1118	0.4003	1.0704	1.617	1323	0.8010	1.1629	2.454	1426
0.0998	0.9004	0.814	1194	0.4961	1.1004	1.847	1354	0.8922	1.1758	2.670	1450
0.1992	0.9757	1.096	1244	0.5978	1.1254	2.064	1378	1.0000	1.1891	3.020	1462
0.3020	1.0310	1.372	1290	0.6961	1.1452	2.237	1402				
303.15 K											
0.0000	0.7817	0.503		0.4003	1.0659	1.468		0.8010	1.1586	2.197	
0.0998	0.8957	0.750		0.4961	1.0957	1.672		0.8922	1.1715	2.385	
0.1992	0.9711	1.002		0.5978	1.1209	1.863		1.0000	1.1849	2.707	
0.3020	1.0265	1.249		0.6961	1.1408	2.012					
308.15 K											
0.0000	0.7769	0.470		0.4003	1.0614	1.336		0.8010	1.1543	1.984	
0.0998	0.8912	0.689		0.4961	1.0913	1.516		0.8922	1.1674	2.157	
0.1992	0.9664	0.918		0.5978	1.1165	1.683		1.0000	1.1807	2.437	
0.3020	1.0219	1.142		0.6961	1.1364	1.818					
1-Chloronaphthalene (1) + Ethanol (2)											
298.15 K											
0.0000	0.7855	1.084	1162	0.3989	1.0374	1.779	1330	0.8011	1.1518	2.470	1419
0.0773	0.8558	1.238	1207	0.5008	1.0739	1.953	1354	0.9009	1.1715	2.655	1438
0.2002	0.9411	1.455	1262	0.5979	1.1027	2.110	1376	1.0000	1.1891	3.020	1462
0.3006	0.9950.	1.630	1302	0.7026	1.1297	2.298	1398				
303.15 K											
0.0000	0.7811	0.986		0.3989	1.0330	1.606		0.8011	1.1476	2.214	
0.0773	0.8515	1.119		0.5008	1.0694	1.757		0.9009	1.1673	2.389	
0.2002	0.9366	1.314		0.5979	1.0983	1.890		1.0000	1.1849	2.707	
0.3006	0.9905	1.471		0.7026	1.1254	2.045					
308.15 K											
0.0000	0.7767	0.898		0.3989	1.0285	1.456		0.8011	1.1433	2.006	
0.0773	0.8472	1.016		0.5008	1.0650	1.588		0.9009	1.1630	2.158	
0.2002	0.9321	1.192		0.5979	1.0940	1.714		1.0000	1.1807	2.437	
0.3006	0.9860	1.334		0.7026	1.1211	1.865					
1-Chloronaphthalene (1) + Propan-1-ol (2)											
298.15 K											
0.0000	0.7998	1.927	1216	0.3950	1.0171	2.172	1350	0.7991	1.1439	2.567	1428
0.1004	0.8698	1.968	1268	0.5003	1.0563	2.255	1372	0.9003	1.1680	2.716	1444
0.2017	0.9286	2.039	1300	0.6002	1.0888	2.349	1393	1.0000	1.1891	3.020	1462
0.2983	0.9761	2.091	1328	0.6993	1.1177	2.448	1413				
303.15 K											
0.0000	0.7956	1.708		0.3950	1.0128	1.918		0.7991	1.1397	2.275	
0.1004	0.8656	1.745		0.5003	1.0518	1.999		0.9003	1.1635	2.417	
0.2017	0.9242	1.805		0.6002	1.0845	2.077		1.0000	1.1849	2.707	
0.2983	0.9716	1.854		0.6993	1.1134	2.166					
308.15 K											
0.0000	0.7914	1.520		0.3950	1.0084	1.714		0.7991	1.1354	2.043	
0.1004	0.8613	1.570		0.5003	1.0474	1.789		0.9003	1.1596	2.178	
0.2017	0.9199	1.620		0.6002	1.0801	1.860		1.0000	1.1807	2.437	
0.2983	0.9671	1.672		0.6993	1.1091	1.943					
1-Chloronaphthalene (1) + Butan-1-ol (2)											
298.15 K											
0.0000	0.8059	2.540	1248	0.4016	1.0019	2.376	1362	0.8006	1.1355	2.591	1428
0.1002	0.8639	2.486	1276	0.5004	1.0392	2.379	1382	0.8969	1.1621	2.697	1444
0.1997	0.9138	2.447	1308	0.5990	1.0732	2.430	1397	1.0000	1.1891	3.020	1462
0.2969	0.9584	2.383	1336	0.6949	1.1041	2.491	1412				
303.15 K											
0.0000	0.8018	2.324		0.4016	0.9977	2.102		0.8006	1.1313	2.301	
0.1002	0.8598	2.176		0.5004	1.0350	2.109		0.8969	1.1578	2.414	
0.1997	0.9097	2.149		0.5990	1.0690	2.153		1.0000	1.1849	2.707	
0.2969	0.9543	2.110		0.6949	1.0998	2.207					
308.15 K											
0.0000	0.7978	1.968		0.4016	0.9935	1.854		0.8006	1.1271	2.059	
0.1002	0.8558	1.927		0.5004	1.0307	1.864		0.8969	1.1536	2.173	
0.1997	0.9056	1.894		0.5990	1.0647	1.914		1.0000	1.1807	2.437	
0.2969	0.9500	1.865		0.6949	1.0956	1.977					
1-Chloronaphthalene (1) + Pentan-1-ol (2)											
298.15 K											
0.0000	0.8110	3.421	1280	0.3710	0.9759	2.833	1356	0.7909	1.1249	2.702	1429
0.1019	0.8603	3.204	1302	0.4944	1.0233	2.708	1379	0.9013	1.1595	2.761	1446
0.1914	0.9009	3.078	1320	0.6006	1.0616	2.669	1398	1.0000	1.1819	3.020	1462
0.3014	0.9477	2.928	1342	0.6961	1.0939	2.659	1414				
303.15 K											
0.0000	0.8074	3.007		0.3710	0.9717	2.473		0.7909	1.1205	2.393	
0.1019	0.8564	2.830		0.4944	1.0191	2.388		0.9013	1.1550	2.464	
0.1914	0.8968	2.704		0.6006	1.0573	2.364		1.0000	1.1849	2.707	
0.3014	0.9436	2.555		0.6961	1.0869	2.358					
308.15 K											
0.0000	0.8037	2.607		0.3710	0.9675	2.179		0.7909	1.1162	2.134	
0.1019	0.8526	2.469		0.4944	1.0148	2.115		0.9013	1.1508	2.217	
0.1914	0.8928	2.370		0.6006	1.0530	2.107		1.0000	1.1807	2.437	
0.3014	0.9394	2.232		0.6961	1.0853	2.107					
1-Chloronaphthalene (1) + Hexan-1-ol (2)											
298.15 K											
0.0000	0.8153	4.216	1328	0.3992	0.9757	3.133	1370	0.8002	1.1211	2.638	1430
0.1047	0.8589	3.951	1336	0.5019	1.0144	2.903	1384	0.9013	1.1559	2.647	1446
0.2004	0.8979	3.680	1347	0.6012	1.0507	2.781	1398	1.0000	1.1891	2.822	1462
0.3023	0.9384	3.366	1358	0.6993	1.0859	2.706	1413				
303.15 K											
0.0000	0.8117	3.567		0.3992	0.9717	2.670		0.8002	1.1169	2.304	
0.1047	0.8553	3.335		0.5019	1.0104	2.506		0.9013	1.1516	2.337	
0.2004	0.8940	3.105		0.6012	1.0466	2.455		1.0000	1.1849	2.497	
0.3023	0.9345	2.858		0.6993	1.0817	2.440					

Table 2 (Continued)

x_1	density/(g·cm^{-3})	viscosity/(mPa·s)	speed of sound/(m·s^{-1})	x_1	density/(g·cm^{-3})	viscosity/(mPa·s)	speed of sound/(m·s^{-1})	x_1	density/(g·cm^{-3})	viscosity/(mPa·s)	speed of sound/(m·s^{-1})
					308.15 K						
0.0000	0.8081	2.766		0.3992	0.9678	2.084		0.8002	1.1127	1.969	
0.1047	0.8515	2.608		0.5019	1.0063	1.971		0.9013	1.1473	2.066	
0.2004	0.8902	2.423		0.6012	1.0425	1.951		1.0000	1.1807	2.225	
0.3023	0.9305	2.248		0.6993	1.0775	1.942					

Table 3. Estimated Parameters of Excess Funtions for Mixtures

function	temp/K	A_0	A_1	A_2	σ
		1-Chloronaphthalene (1) + Methanol (2)			
$V^E/10^{-6}$(m^3·mol^{-1})	298.15	−1.472	−1.168	−0.374	0.012
	303.15	−1.497	−1.255	−0.525	0.013
	308.15	−1.523	−1.317	−0.724	0.015
$\Delta\eta$/(mPa·s)	298.15	0.295	0.686	−0.929	0.008
	303.15	0.294	0.663	−0.939	0.008
	308.15	0.270	0.597	−0.808	0.005
Δu/(m·s^{-1})	298.15	249.4	133.1	131.1	2.503
Δk_S/(TPa^{-1})	298.15	−282.5	116.9	−44.8	1.989
		1-Chloronaphthalene (1) + Ethanol (2)			
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−1.985	−2.118	−0.685	0.015
	303.15	−2.000	−2.103	−0.802	0.016
	308.15	−2.039	−2.161	−0.917	0.020
$\Delta\eta$/(mPa·s)	298.15	−0.386	0.830	−0.667	0.022
	303.15	−0.359	0.755	−0.585	0.014
	308.15	−0.299	0.615	−0.484	0.015
Δu/(m·s^{-1})	298.15	171.5	135.4	19.8	1.282
Δk_S/(TPa^{1-})	298.15	−294.8	124.5	33.7	1.382
		1-Chloronaphthalene (1) + Propan-1-ol (2)			
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−1.998	−1.838	−1.424	0.006
	303.15	−2.025	−1.878	−1.331	0.012
	308.15	−2.001	−1.803	−1.614	0.011
$\Delta\eta$/(mPa·s)	298.15	−0.847	0.637	−0.780	0.016
	303.15	−0.824	0.649	−0.757	0.014
	308.15	−0.754	0.655	−0.503	0.013
Δu/(m·s^{-1})	298.15	134.6	101.1	75.0	2.314
Δk_S/(TPa^{-1})	298.15	−254.7	134.9	−71.0	1.355
		1-Chloronaphthalene (1) + Butan-1-ol (2)			
$V^E/10^{-6}$(m^3·mol^{-1})	298.15	−1.734	−1.831	−0.910	0.032
	303.15	−1.770	−1.848	−0.983	0.037
	308.15	−1.783	−1.847	−0.993	0.039
$\Delta\eta$/(mPa·s)	298.15	−1.555	0.730	−0.507	0.027
	303.15	−1.568	0.370	−0.982	0.017
	308.15	−1.307	0.587	−0.400	0.018
Δu/(m·s^{-1})	298.15	105.8	45.9	−71.6	1.558
Δk_S/(TPa^{-1})	298.15	−227.8	58.4	60.8	0.618
		1-Chloronaphthalene (1) + Pentan-1-ol (2)			
$V^E/10^{-6}$(m^3·mol^{-1})	298.15	−1.749	−1.225	−0.025	0.017
	303.15	−1.674	−1.219	0.217	0.018
	308.15	−1.593	−1.222	0.231	0.019
$\Delta\eta$/(mPa·s)	298.15	−1.983	0.678	−0.611	0.023
	303.15	−1.847	0.578	−0.495	0.022
	308.15	−1.606	0.539	−0.432	0.021
Δu/(m·s^{-1})	298.15	36.4	3.0	−11.5	0.355
Δk_S/(TPa^{-1})	298.15	−167	37.5	−1.2	0.384
		1-Chloronaphthalene (1) + Hexan-1-ol (2)			
$V^E/10^{-6}$(m^3·mol^{-1})	298.15	−1.708	−0.711	0.245	0.008
	303.15	−1.713	−0.727	0.345	0.009
	308.15	−1.686	−0.724	0.442	0.007
$\Delta\eta$/(mPa·s)	298.15	−2.363	0.989	0.211	0.029
	303.15	−1.954	0.547	−0.097	0.049
	308.15	−2.027	0.636	0.514	0.017
Δu/(m·s^{-1})	298.15	−45.6	−14.0	3.6	0.552
Δk_S/(TPa^{-1})	298.15	−91.0	8.0	−1.6	0.467

averages of three independent measurements for each composition of the mixture.

Results and Discussion

Experimental values of ρ, η, and u are used to calculate the mixing functions using the general type equation (Aminabhavi and Bindu, 1995; Aminabhavi et al., 1994)

$$V^E \text{ (or } \Delta Y) = V_m \text{ (or } Y_m) - V_1 \text{ (or } Y_1)x_1 - V_2 \text{ (or } Y_2)x_2 \tag{1}$$

where V_m refers to molar volume of the mixture, which is calculated as

$$V_m = (M_1x_1 + M_2x_2)/\rho_m \tag{2}$$

Here, M_1 and M_2 are molecular weights of the components 1 and 2; V_i ($=M_i/\rho_i$) represent the molar volumes of pure components; Y_m refers to the mixture properties, viz., η, u, and k_S, and Y_i refers to the properties of pure components (i = 1, 2). The quantity ΔY refers to $\Delta\eta$, Δu, and Δk_S. For the calculation of Δk_S, the volume fraction, ϕ_i, was used (Aminabhavi and Bindu, 1995; Aminabhavi et al., 1994)

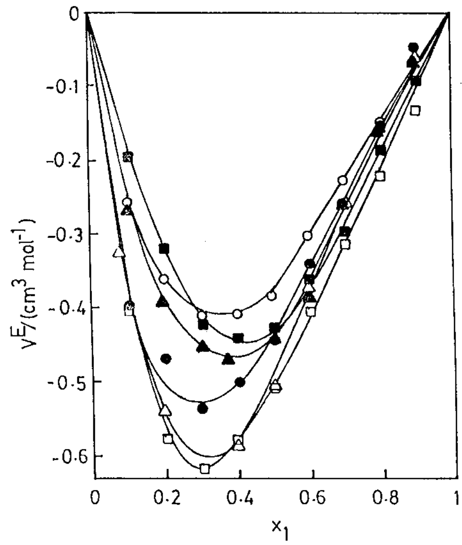

Figure 1. Excess molar volume vs mole fraction of 1-Chloronaphthalene with (O) methanol, (Δ) ethanol, (□) propan-1-ol, (●) butan-1-ol, (▲) pentan-1-ol, and (■) hexan-1-ol at 298.15 K.

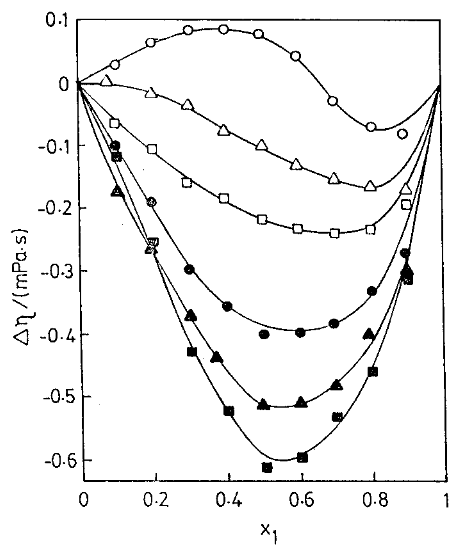

Figure 2. Deviation in viscosity vs mole fraction of 1-chloronaphthalene at 298.15 K. Symbols are the same as given in Figure 1.

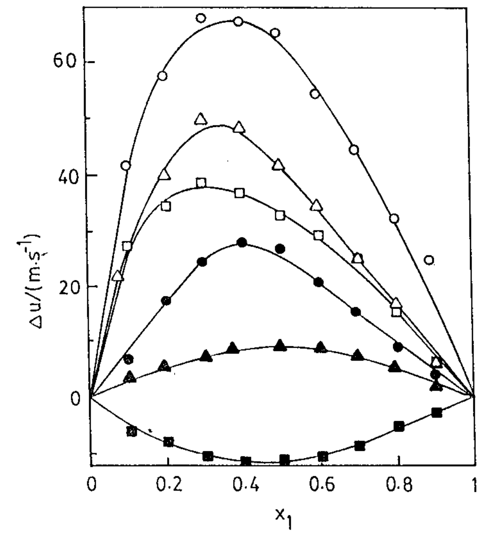

Figure 3. Deviation in speed of sound vs mole fraction of 1-chloronaphthalene at 298.15 K. Symbols are the same as given in Figure 1.

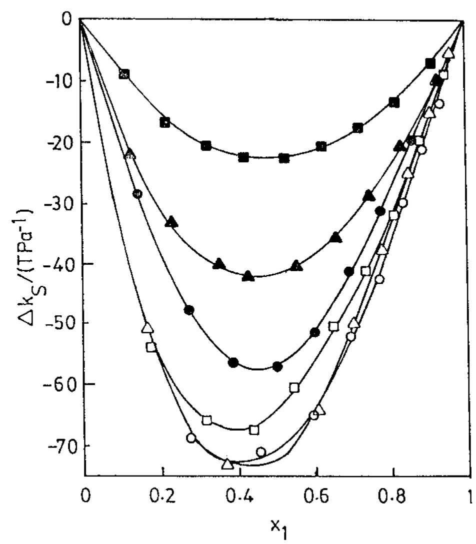

Figure 4. Deviation in isentropic compressibility vs volume fraction of 1-chloronaphthalene at 298.15 K. Symbols are the same as given in Figure 1.

instead of the mole fraction, x_i. The ϕ_i was calculated as

$$\phi_i = \left(\frac{x_i V_i}{\sum_i x_i V_i}\right) \tag{3}$$

The mixing functions V^E, $\Delta\eta$, Δu, and Δk_S have been fitted to Redlich−Kister type equation (1948)

$$V^E \text{ (or } \Delta Y) = x_1 x_2 \sum_{i=1}^{2} A_i (x_2 - x_1)^{i-1} \tag{4}$$

where the coefficients A_i ($i = 0$ to 2) were obtained by the method of least-squares using the Marquardt algorithm (1963). In solving eq 4 for Δk_S, ϕ_i is used in place of x_i. The values of standard error, σ, are computed for each of the functions (V^E, $\Delta\eta$, Δu, and Δk_S). The calculated values of A_0, A_1, and A_2 along with σ are given in Table 3. While minimizing the function, we found that the best fits were obtained by solving eq 4 up to third degree, i.e., $A_i = 0$ to 2.

Figure 1 displays the plots of V^E vs x_1 (referring to 1-chloronaphthalene) at 298.15 K for all the binary mixtures. For all the mixtures, the V^E values are negative, but these values do not show any systematic variation with an increasing size of *n*-alkanols. For mixtures of 1-chloronaphthalene with methanol or hexan-1-ol, the negative V^E values are higher than all the remaining mixtures. For the mixtures of 1-chloronaphthalene + ethanol, or + propan-1-ol, the V^E vs x_1 curves vary almost identically throughout the mixture composition. Compared to 1-chloronaphthalene + butan-1-ol, the 1-chloronaphthalene + pentan-1-ol mixture exhibits higher values of V^E. The effect of temperature on V^E is not the same in all cases; i.e., with 1-chloronaphthalene + methanol, + ethanol, + propan-1-ol, or + butan-1-ol mixtures, the negative values of V^E increase with increasing temperature, whereas with 1-chloronaphthalene + pentan-1-ol, or + hexan-1-ol, the negative V^E values decrease with increasing temperature. In view of the limited temperature range studied, the temperature dependencies of V^E vs x_1 curves are not displayed.

Figure 2 shows the plots of $\Delta\eta$ vs x_1 for 1-chloronaphthalene + *n*-alkanol mixtures at 298.15 K. For 1-chloronaphthalene + methanol mixture, $\Delta\eta$ vs x_1 curve is sigmoidal (varying from positive to negative with increasing concentration of 1-chloronaphthalene in the mixture). However, such a sigmoidal tendency is minimized for the mixtures of 1-chloronaphthalene with ethanol, and also for this mixture, the $\Delta\eta$ values are negative throughout the mixture composition. Similarly, for 1-chloronaphthalene + propan-1-ol mixture, no sharp minimum is observed. On the other hand, with increasing size of alkanols, the curves show sharper minima. Similar effects are also observed at 303.15 and 308.15 K, but these curves are not displayed to avoid redundancy. With increasing temperature, the $\Delta\eta$ values also increase for all the mixtures except 1-chloronaphthalene + methanol.

Figure 3 displays the plots of Δu vs x_1 at 298.1.5 K for all the binary mixtures. The Δu values are negative for 1-chloronaphthalene + hexan-1-ol mixtures. For the remaining mixtures, the Δu values are positive and increase with decreasing size of *n*-alkanols. On the other hand, the results of Δk_S displayed in Figure 4 are negative for all the mixtures, and these values decrease with decreasing size of *n*-alkanols. Thus, the Δk_S values for 1-chloronaphthalene + hexan-1-ol mixtures are higher than those observed for 1-chloronaphthalene + methanol mixtures. Also, the Δk_S values for the mixtures of 1-chloronaphthalene + methanol, or + ethanol, are somewhat identical.

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