1778 *J. Chem. Eng. Data* **2006,** *51,* 1778−1782

Density and Surface Tension Variation with Temperature for Heptane + 1-Alkanol

Javier Vijande,* Manuel M. Piñeiro, Josefa García, José Luis Valencia, and José Luis Legido

Departamento de Física Aplicada, Edificio de Ciencias Experimentais, Universidade de Vigo, E-36310 Vigo, Spain

New experimental densities and surface tensions for binary mixtures of {heptane + 1-butanol, + 1-hexanol, and + 1-octanol} in a temperature range of (288.15, 293.15, 298.15, 303.15, and 308.15) K are reported for the whole composition range. Densities were measured with an Anton Paar DMA 4500 densimeter. Surface tensions were measured using a Lauda TVT2 automated tensiometer, which uses the principle of the pending drop volume. The experimental data of pure liquids and mixtures have been used to calculate excess molar volumes and surface tension deviations of the mixtures as a function of mole fractions.

Introduction

The understanding of physical properties such as density or surface tension is of great utility for both fundamental research and industrial engineering applications. Systematic investigations of intermolecular interactions and the internal structures of binary liquid mixtures continue to be an area of interest in physical chemistry. Regarding structural studies, a review of the literature shows that for the analysis of this type of effect in liquid solvent mixtures it is possible to apply a wide range of spectral or thermochemical methods as well as studies on intensive macroscopic properties of solutions (density, viscosity, surface tension, etc.) carried out at different temperatures. Thus, using this last method, the accurate measurement of experimental data of physical properties in mixtures of organic liquids is required for a better understanding of their thermodynamic behavior. Furthermore, in recent years, interest in surface tension and interfacial tension has increased considerably because this property plays an important role in the design of contacting equipment involved in several chemical processes, as for instance gas absorption distillation, extraction, etc.

Over the last years our research group has conducted a systematic study[1−8] of the thermophysical properties of mixtures of hydrogen bonded molecules with alkanes. Recently, new experimental data[9] of densities and surface tension for nonane + 1-hexanol mixture were measured at the temperatures (288.15, 298.15, and 308.15) K. In this work, experimental density and surface tension data of heptane + 1-butanol, + 1-hexanol, and + 1-octanol mixtures at (288.15, 293.15, 298.15, 303.15, and 308.15) K and atmospheric pressure are reported. In addition, excess molar volumes and surface tension deviations were calculated from experimental densities and surface tensions, respectively. The resulting data were correlated using Redlich−Kister[10] type equation, and the obtained fitting parameters are presented.

Experimental Section

The mass purities and the source of chemical employed were as follows: heptane (Fluka, ≥ 99.5 %), 1-butanol (Aldrich, ≥ 99.8 %), 1-hexanol (Fluka, ≥ 99.0 %), and 1-octanol (Fluka, ≥ 99.5 %). All chemicals were degassed and dried over molecular sieves (Union Carbide, type 0.4 nm). Precautions such as cooling chemicals before sample preparation and minimizing empty space in vessels were taken in order to avoid evaporation losses during manipulations and subsequent errors in calculations.

Table 1. Density ρ and Surface Tension σ of the Pure Compounds from T = 288.15 K to 308.15 K

	T	ρ/g·cm^{-3}		σ/mN·m^{-1}	
substance	K	this work	lit.	this work	lit.
heptane	288.15	0.68798	0.68784[14]	20.81	
	293.15	0.68378	0.68375[15]	20.27	20.50[16]
	298.15	0.67955	0.67954[14]	19.68	19.69[17]
	303.15	0.67530	0.67525[14]	19.19	19.47[16]
	308.15	0.67100	0.67101[18]	18.93	
1-butanol	288.15	0.81332	0.81349[19]	24.68	
	293.15	0.80956	0.81034[20]	24.21	24.16[21]
	298.15	0.80572	0.80586[19]	23.79	23.70[21]
	303.15	0.80191	0.80195[20]	23.34	23.26[21]
	308.15	0.79807	0.79804[19]	22.79	22.78[21]
1-hexanol	288.15	0.82228	0.82233[22]	26.08	
	293.15	0.81875	0.81890[23]	25.61	
	298.15	0.81523	0.81515[24]	25.19	25.73[24]
	303.15	0.81160	0.81195[25]	24.74	
	308.15	0.80800	0.80800[22]	24.19	
1-octanol	288.15	0.82855	0.82849[22]	27.41	
	293.15	0.82511	0.82516[23]	26.94	
	298.15	0.82164	0.82163[24]	26.52	27.13[24]
	303.15	0.81819	0.81831[25]	26.07	
	308.15	0.81469	0.81462[22]	25.52	

The samples were prepared by mass using a Mettler AE-240 balance, with a precision of 10^{-4} in mole fraction, covering the whole composition range of the mixture. Densities of the pure liquids and their mixtures were measured with an Anton Paar DMA 4500 vibrating-tube densimeter with an uncertainty of $5 \cdot 10^{-5}$ g·cm^{-3}. The density measuring cell was thermostated with a temperature stability of ± 0.01 K. The apparatus calibration was performed periodically, and water and air were used for calibration.

Surface tension was measured using a Lauda TVT2 automated tensiometer with a precision of 10^{-2} mN·m^{-1}, which is based on the principle of the pending drop volume. This technique consists of measuring the volume of a drop detaching from a capillary with circular cross section. The measuring procedure consists of a precise dosing system which forms drops continu-

---

* Corresponding author. Tel/Fax: +34 986 812 295. E-mail: jvijande@uvigo.es.

10.1021/je060179e CCC: $30.25

Table 2. Experimental Densities ρ and Excess Molar Volumes V^E for Heptane + 1-Alkanol from $T = 288.15$ K to 308.15 K

	T/K = 288.15		T/K = 293.15		T/K = 298.15		T/K = 303.15		T/K = 308.15	
x	ρ/g·cm^{-3}	V^E/cm^3·mol^{-1}	ρ/g·cm^{-3}	V^E/cm^3·mol^{-1}	ρ/g·cm^{-3}	V^E/cm^3·mol^{-1}	ρ/g·cm^{-3}	V^E/cm^3·mol^{-1}	ρ/g·cm^{-3}	V^E/cm^3·mol^{-1}
x Heptane + (1 − x) 1-Butanol										
0.0510	0.80335	0.007	0.79952	0.010	0.79566	0.007	0.79177	0.011	0.78785	0.014
0.0998	0.79433	0.016	0.79046	0.018	0.78655	0.017	0.78261	0.022	0.77863	0.028
0.2067	0.77612	0.046	0.77216	0.051	0.76815	0.054	0.76411	0.062	0.76004	0.070
0.3087	0.76061	0.072	0.75657	0.080	0.75248	0.088	0.74835	0.101	0.74418	0.116
0.4059	0.74714	0.115	0.74300	0.131	0.73885	0.142	0.73465	0.161	0.73042	0.179
0.5052	0.73463	0.157	0.73046	0.174	0.72625	0.190	0.72200	0.213	0.71771	0.235
0.5986	0.72401	0.173	0.71980	0.193	0.71556	0.210	0.71128	0.235	0.70695	0.259
0.7259	0.71089	0.192	0.70665	0.212	0.70238	0.231	0.69807	0.255	0.69371	0.281
0.8066	0.70339	0.181	0.69915	0.198	0.69486	0.218	0.69054	0.242	0.68618	0.265
0.9080	0.69480	0.131	0.69055	0.147	0.68627	0.161	0.68195	0.181	0.67761	0.197
0.9523	0.69135	0.092	0.68711	0.103	0.68283	0.116	0.67852	0.132	0.67417	0.147
x Heptane + (1 − x) 1-Hexanol										
0.0500	0.81476	−0.043	0.81117	−0.042	0.80756	−0.038	0.80392	−0.044	0.80026	−0.044
0.0976	0.80766	−0.076	0.80403	−0.076	0.80037	−0.072	0.79668	−0.078	0.79298	−0.080
0.3197	0.77517	−0.099	0.77133	−0.098	0.76746	−0.092	0.76356	−0.094	0.75964	−0.093
0.3943	0.76462	−0.080	0.76072	−0.077	0.75680	−0.073	0.75284	−0.074	0.74886	−0.072
0.5088	0.74893	−0.054	0.74495	−0.051	0.74094	−0.045	0.73690	−0.043	0.73283	−0.040
0.6171	0.73453	−0.012	0.73047	−0.005	0.72639	0.002	0.72228	0.005	0.71813	0.012
0.7045	0.72324	0.025	0.71914	0.031	0.71501	0.038	0.71084	0.046	0.70664	0.053
0.8080	0.71042	0.040	0.70627	0.046	0.70207	0.057	0.69785	0.067	0.69359	0.076
0.9072	0.69854	0.045	0.69433	0.055	0.69009	0.066	0.68582	0.078	0.68151	0.089
x Heptane + (1 − x) 1-Octanol										
0.0514	0.82218	−0.067	0.81871	−0.070	0.81521	−0.074	0.81170	−0.073	0.80816	−0.076
0.1001	0.81602	−0.116	0.81251	−0.121	0.80898	−0.129	0.80543	−0.130	0.80185	−0.136
0.2015	0.80293	−0.197	0.79933	−0.204	0.79572	−0.215	0.79209	−0.220	0.78843	−0.230
0.3082	0.78860	−0.220	0.78492	−0.229	0.78122	−0.241	0.77749	−0.246	0.77375	−0.260
0.4054	0.77517	−0.207	0.77141	−0.216	0.76763	−0.229	0.76385	−0.241	0.76010	−0.271
0.5170	0.75950	−0.189	0.75565	−0.198	0.75177	−0.208	0.74787	−0.215	0.74394	−0.227
0.6305	0.74328	−0.170	0.73934	−0.178	0.73537	−0.187	0.73138	−0.193	0.72736	−0.204
0.7114	0.73148	−0.142	0.72747	−0.147	0.72344	−0.154	0.71937	−0.156	0.71528	−0.164
0.8136	0.71621	−0.074	0.71211	−0.073	0.70799	−0.075	0.70384	−0.073	0.69965	−0.074
0.9061	0.70220	−0.016	0.69804	−0.014	0.69384	−0.009	0.68961	−0.002	0.68535	0.001
0.9518	0.69528	−0.003	0.69108	0.003	0.68685	0.008	0.68259	0.016	0.67830	0.020

ously at the end of the capillary. The volume of a drop is determined from the time interval of droplet formation, obtained by the precise measurement of the time period that goes from the detaching of a drop from the capillary end to the next one, determined with a light barrier. Detailed instrumentation design and experimental procedure have been described in the literature[11] for the preceding model TVT1, which basically differs only in the control unit, the measuring device being the same for both models. Compared to the ring detachment or Wilhelmy plate methods, the drop volume technique has several advantages: first, its easy handling and small amount of sample necessary to perform the measurement; second, the temperature control can easily be arranged in a wider temperature range than the other methods; and finally, this method is applicable to liquid−gas and liquid−liquid interfaces without any modifications, avoiding the disturbing and wetting effects observed in the ring or plate tensiometry.[12]

The surface tension (σ) can thus be determined as follows:

$$\sigma = \frac{\Delta\rho g V}{2\pi r_{\mathrm{cap}} f} \tag{1}$$

where $\Delta\rho$ stands for the density difference between the liquid and vapor phase, g is the gravitational acceleration, V is the drop volume, $2r_{\mathrm{cap}}$ is the outer diameter of the capillary, and f is a shape correction factor. The factor f is introduced to correct the balance forces equation between the weight of the critical drop ($\Delta\rho g V$) and interfacial tension ($2\pi r_{\mathrm{cap}}\sigma$) just before detaching due to the fact that the drop does not detach directly at the tip of the capillary but at its neck, which has a smaller diameter than the capillary. As Wikinson[13] showed, the correction factor can be expressed as a polynomial function of $r_{\mathrm{cap}}/V^{1/3}$ based on experimental data. From the average drop volume, the TVT2 software determines the correction factor f using this polynomial function.

The total accuracy of the surface tension determination depends directly on the accuracy of the measurements of the drop volume, the capillary diameter, and the density difference between liquid and vapor phases and amounts to less than ± 0.1 mN·m^{-1}. In this particular case, the uncertainty is estimated to be of ± 0.05 mN·m^{-1}.

Results and Discussion

The measured density and surface tension of the pure liquids at the working temperatures are listed in Table 1 together with those values found in the literature.[14−25] The agreement, within the experimental uncertainties for most values, ensures both the purity of the chemicals used and the experimental devices accuracy. Note that the experimental data of surface tension from literature[16,17,21,24] where measured using different techniques: Queimada et al.[16] used the Wilhelmy plate method, Azizian et al.[21] used the ring detachment method, and Penas et al.[17] and Segade et al.[24] used the drop volume technique as in this work.

In Tables 2 and 3, experimental density and surface tension data of the three mixtures at the temperatures cited for the whole composition range are presented together with excess molar volumes (V^E) and the surface tension deviation ($\Delta\sigma$) obtained from experimental densities and surface tensions, respectively.

Excess molar volumes were determined from the density data as follows:

$$V^E = \frac{M}{\rho} - \sum_{i=1}^{2} x_i \frac{M_i}{\rho_i} \tag{2}$$

Table 3. Experimental Surface Tension σ and Surface Tension Deviation $\Delta\sigma$ for Heptane + 1-Alkanol from T = 288.15 K to 308.15 K

T/K = 288.15			T/K = 293.15			T/K = 298.15			T/K = 303.15			T/K = 308.15		
x	σ/mN·m^{-1}	$\Delta\sigma$/mN·m^{-1}	x	σ/mN·m^{-1}	$\Delta\sigma$/mN·m^{-1}	x	σ/mN·m^{-1}	$\Delta\sigma$/mN·m^{-1}	x	σ/mN·m^{-1}	$\Delta\sigma$//mN·m^{-1}	x	σ/mN·m^{-1}	$\Delta\sigma$/mN·m^{-1}
x Heptane + (1 − x) 1-Butanol														
0.0498	24.31	−0.18	0.0503	23.76	−0.25	0.0560	23.17	−0.39	0.0491	22.62	−0.52	0.0507	22.35	−0.24
0.1007	23.81	−0.48	0.1008	23.26	−0.55	0.0937	22.75	−0.65	0.0997	22.16	−0.76	0.1017	21.89	−0.50
0.2005	22.99	−0.91	0.2010	22.44	−0.98	0.2085	21.94	−0.99	0.2052	21.41	−1.08	0.2054	20.98	−1.02
0.3043	22.37	−1.13	0.2986	21.85	−1.18	0.3020	21.35	−1.19	0.3051	20.81	−1.26	0.3025	20.33	−1.29
0.4058	21.88	−1.23	0.4002	21.37	−1.26	0.3975	20.86	−1.29	0.4003	20.30	−1.38	0.4017	19.87	−1.37
0.5054	21.56	−1.16	0.5009	21.01	−1.22	0.5054	20.44	−1.27	0.5040	19.92	−1.33	0.5052	19.53	−1.31
0.5990	21.38	−0.99	0.5998	20.79	−1.05	0.6086	20.17	−1.11	0.5966	19.72	−1.14	0.6007	19.28	−1.19
0.7072	21.17	−0.78	0.7034	20.62	−0.81	0.8060	19.99	−0.48	0.7052	19.48	−0.93	0.7306	19.20	−0.77
0.8008	21.03	−0.55	0.7971	20.51	−0.55	0.9082	19.85	−0.20	0.8014	19.39	−0.62	0.8079	19.10	−0.57
0.8982	20.94	−0.27	0.9020	20.37	−0.28	0.9502	19.81	−0.07	0.9024	19.30	−0.29	0.9086	18.99	−0.29
0.9532	20.87	−0.13	0.9511	20.33	−0.12				0.9507	19.27	−0.12	0.9532	18.90	−0.21
x Heptane + (1 − x) 1-Hexanol														
0.0507	25.60	−0.21	0.0494	25.01	−0.33	0.0497	24.61	−0.30	0.0488	24.10	−0.37	0.0428	23.64	−0.32
0.1018	25.01	−0.53	0.1036	24.45	−0.60	0.0987	24.05	−0.59	0.1027	23.55	−0.62	0.1025	23.03	−0.61
0.2001	24.02	−1.00	0.2010	23.47	−1.06	0.2023	22.92	−1.15	0.1865	22.62	−1.08	0.1986	22.00	−1.14
0.3087	23.22	−1.23	0.3037	22.65	−1.34	0.3096	22.09	−1.39	0.3100	21.59	−1.43	0.3055	21.10	−1.49
0.3949	22.55	−1.45	0.4422	21.75	−1.49	0.4078	21.45	−1.49	0.4122	20.97	−1.48	0.4030	20.52	−1.55
0.5021	22.16	−1.28	0.5056	21.54	−1.37	0.5054	21.04	−1.36	0.5086	20.49	−1.43	0.4980	20.11	−1.46
0.6053	21.80	−1.09	0.5979	21.26	−1.15	0.6099	20.58	−1.25	0.6147	20.00	−1.33	0.6165	19.57	−1.38
0.7097	21.46	−0.88	0.6999	20.80	−1.07	0.7075	20.28	−1.00	0.7097	19.78	−1.02	0.7042	19.35	−1.13
0.8055	21.20	−0.63	0.8091	20.54	−0.75	0.8127	20.04	−0.67	0.8089	19.54	−0.71	0.8118	19.06	−0.86
0.9066	21.05	−0.26	0.9061	20.43	−0.34	0.9050	19.93	−0.27	0.9068	19.26	−0.44	0.9054	18.89	−0.54
0.9517	20.94	−0.13	0.9510	20.29	−0.24	0.9515	19.74	−0.20	0.9519	19.13	−0.33	0.9503	18.77	−0.42
x Heptane + (1 − x) 1-Octanol														
0.0516	26.75	−0.32	0.0564	26.14	−0.42	0.0541	25.64	−0.51	0.0504	25.18	−0.54	0.0562	24.54	−0.61
0.0995	26.18	−0.57	0.1057	25.54	−0.69	0.1083	25.03	−0.75	0.1033	24.57	−0.79	0.1017	24.05	−0.80
0.1845	25.05	−1.14	0.2084	24.34	−1.21	0.2004	23.91	−1.24	0.2052	23.46	−1.20	0.2078	22.86	−1.29
0.3346	23.74	−1.46	0.3112	23.38	−1.48	0.3137	22.82	−1.55	0.3108	22.37	−1.56	0.3065	21.92	−1.58
0.4142	23.12	−1.56	0.4066	22.59	−1.63	0.4050	22.09	−1.66	0.4134	21.56	−1.66	0.4117	21.11	−1.70
0.5034	22.60	−1.49	0.5114	21.96	−1.57	0.5089	21.44	−1.60	0.5153	20.94	−1.58	0.5064	20.53	−1.65
0.6074	22.16	−1.24	0.6092	21.52	−1.35	0.6085	20.94	−1.41	0.6005	20.46	−1.47	0.6065	20.00	−1.52
0.6639	21.90	−1.13	0.7164	20.99	−1.17	0.7107	20.46	−1.20	0.7067	19.98	−1.22	0.7081	19.61	−1.24
0.8325	21.24	−0.68	0.8124	20.62	−0.89	0.8072	20.15	−0.85	0.8043	19.58	−0.95	0.8000	19.27	−0.98
0.9105	20.94	−0.46	0.8965	20.48	−0.48	0.9071	19.82	−0.49	0.9047	19.22	−0.62	0.9028	18.88	−0.69
0.9561	20.87	−0.24	0.9573	20.26	−0.29	0.9536	19.64	−0.35	0.9486	19.14	−0.40	0.9483	18.82	−0.45

Table 4. Parameters A_j in Equation 4 and Standard Deviations (s/cm^3·mol^{-1}) for Heptane + 1-Alkanol

	T/K	A_0	A_1	A_2	A_3	s
Heptane + 1-Butanol						
V^E/cm^3·mol^{-1}	288.15	0.5811	0.6253	0.4052	0.3763	0.008
	293.15	0.6473	0.6763	0.4437	0.4358	0.009
	298.15	0.7059	0.7253	0.4778	0.5593	0.010
	303.15	0.7890	0.7746	0.5590	0.6575	0.012
	308.15	0.8725	0.8372	0.6243	0.7022	0.014
$\Delta\sigma$/mN·m^{-1}	288.15	−4.693	1.783	0.843		0.04
	293.15	−4.785	2.048			0.03
	298.15	−5.041	1.524	0.686	2.441	0.03
	303.15	−5.177	1.496	−0.910	2.885	0.05
	308.15	−5.326	2.782	1.089	−2.422	0.03
Heptane + 1-Hexanol						
V^E/cm^3·mol^{-1}	288.15	−0.2099	0.6636	0.0667	0.2681	0.004
	293.15	−0.1966	0.6802	0.1125	0.3302	0.005
	298.15	−0.1789	0.6921	0.2154	0.3707	0.005
	303.15	−0.1733	0.7201	0.2467	0.5173	0.006
	308.15	−0.1628	0.7495	0.3061	0.5893	0.007
$\Delta\sigma$/mN·m^{-1}	288.15	−5.285	1.908	1.090		0.06
	293.15	−5.553	1.621	−0.204		0.06
	298.15	−5.649	2.104			0.04
	303.15	−5.792	2.342	−0.533	−1.794	0.05
	308.15	−5.996	1.150	−1.329		0.07
Heptane + 1-Octanol						
V^E/cm^3·mol^{-1}	288.15	−0.8175	0.3516	−0.0352	0.5303	0.011
	293.15	−0.8571	0.3553	0.0157	0.6182	0.011
	298.15	−0.9054	0.3651	0.0486	0.7311	0.012
	303.15	−0.9453	0.3814	0.1570	0.7936	0.013
	308.15	−1.0200	0.4465	0.2576	0.7687	0.014
$\Delta\sigma$/mN·m^{-1}	288.15	−5.922	1.764			0.07
	293.15	−6.264	1.423	−0.579		0.05
	298.15	−6.368	1.725	−1.104		0.05
	303.15	−6.335	1.775	−2.142	−1.064	0.06
	308.15	−6.490	1.413	−2.563		0.07

where M and M_i are the molar masses of the mixture and component i, respectively; ρ and ρ_i are the densities of the mixture and component i; and x_i is the mole fraction of the component i.

The surface tension deviations ($\Delta\sigma$) were calculated by

$$\Delta\sigma = \sigma - \sum_{i=1}^{2} x_i\sigma_i \tag{3}$$

where σ and σ_i are the surface tensions of the mixture and the component i, and x_i is the mole fraction of the component i.

Excess molar volumes (V^E) and the surface tension deviations ($\Delta\sigma$) were fitted to a Redlich−Kister[10] type equation:

$$Q = x_1x_2\sum_{k=0}^{N} A_k(2x_1 - 1)^k \tag{4}$$

where Q represents V^E or $\Delta\sigma$, and A_k denotes the polynomial fitting coefficients that they were obtained by the unweighted least-squares method. The degree of the polynomial was optimized by applying the F-test.[26] The computed A_k parameters are shown in Table 4.

Figure 1 shows excess molar volumes obtained from experimental densities of heptane + 1-alcohol mixtures against composition at 298.15 K, being positive in all composition range for heptane + 1-butanol, showing a sigmoidal curve for heptane + 1-hexanol, and being negative for heptane + 1-octanol. The negative region increases when the alcohol chain length increases. The surface tension deviations ($\Delta\sigma$) for heptane +

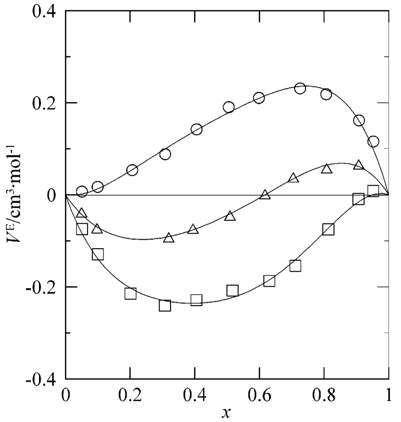

Figure 1. Excess molar volumes obtained from experimental densities against mole fraction of *x* heptane + (1 − *x*) alcohol at 298.15 K: ○, 1-butanol; △, 1-hexanol; □, 1-octanol; —, eq 4.

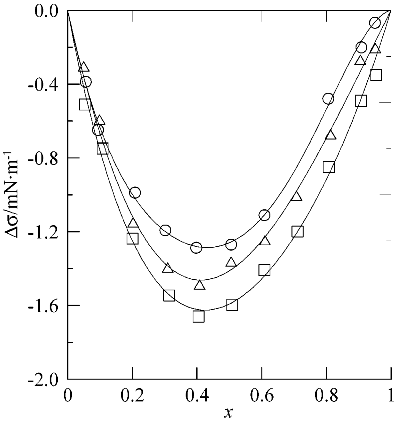

Figure 2. Plot of surface tension deviations against mole fraction of *x* heptane + (1 − *x*) alcohol at 298.15 K: ○, 1-butanol; △, 1-hexanol; □, 1-octanol; —, eq 4.

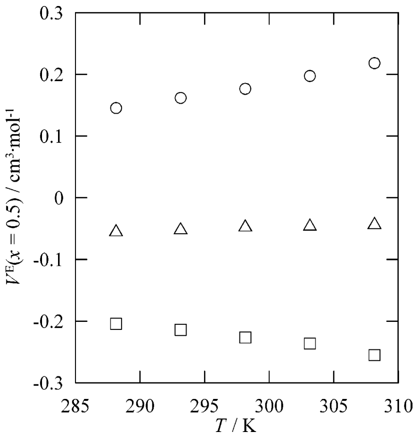

Figure 3. Excess molar volume against temperature for heptane + 1-alcohol mixtures at equimolar composition: ○, 1-butanol; △, 1-hexanol; □, 1-octanol.

1-alcohol systems were negative over the mole fraction range, as shown in Figure 2.

On the other side, Figure 3 shows excess molar volumes at equimolar composition plotted against temperature for the three mixtures, showing an increasing trend for alkanols of smaller chain length while the values decrease for the longer chain ones. The same representation is shown in Figure 4 for surface tension deviation variation with temperature at equimolar composition, showing a decreasing trend with increase temperature for the three mixtures.

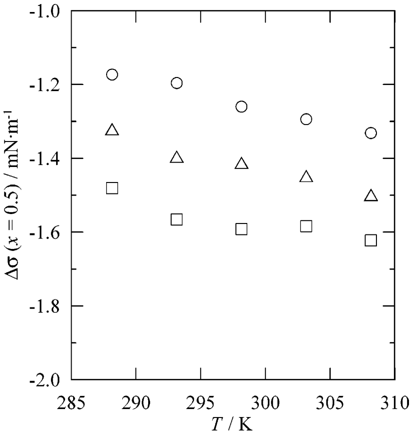

Figure 4. Surface tension deviation, $\Delta\sigma$, against temperature for heptane + 1-alcohol mixtures at equimolar composition: ○, 1-butanol; △, 1-hexanol; □, 1-octanol.

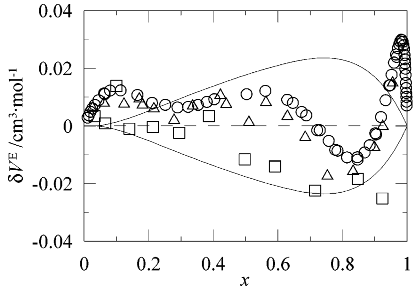

Figure 5. Deviations of excess molar volume δV^E for *x* heptane + (1 − *x*) 1-butanol at 298.15 K: ○, ref 27; △, 28; □, ref 29; —, ± 0.1 × V^E (eq 4).

Volumetric properties of heptane + 1-alcohol at different temperatures have been published by many authors; however, no experimental data of surface tension have been presented so far for these mixtures. For comparison, in Figure 5 the deviations (eq 5) between our correlated data with Redlich−Kister equation (eq 4) and some authors experimental data[27−29] at 298.15 K are shown:

$$\delta V^E = V^E_{\text{lit}} - V^E_{\text{R-K}} \tag{5}$$

V^E_{lit} being the literature excess molar volumes, and $V^E_{\text{R-K}}$ is the value of the excess molar volumes fitted with the Redlich−Kister equation (eq 4), using our correlation parameters, at the same mole fraction. As it can be observed in Figure 5 there is agreement between our results and the previously published data within ∼10 % over most of the mole fraction range. This percentage is also similar to the one obtained by establishing a comparison among different literature references experimental data.[27−29]

Acknowledgment

The authors express their gratitude to Silvia Miramontes for her technical assistance.

Literature Cited

(1) De Cominges, B. E.; Piñeiro, M. M.; Mascato, E.; Mosteiro, L.; Iglesias, T. P.; Legido, J. L. Relative permittivities of binary mixtures of 1-butanol + *n*-alkane at 298.15 K. *J. Therm. Anal. Calorim.* **2003**, *72*, 129−133.

(2) De Cominges, B. E.; Piñeiro, M. M.; Mosteiro, L.; Mascato, E.; Mato, M. M.; Legido, J. L. Temperature dependence of thermophysical properties of octane + 1-butanol system. *J. Therm. Anal. Calorim.* **2002**, *70*, 217−227.

(3) Mascato, E.; Mosteiro, L.; Piñeiro, M. M.; García, J.; Iglesias, T. P.; Legido, J. L. Density, speed of sound and refrantive index of (*n*-heptane + cyclohexane + 1-hexanol) at $T = 298.15$ K. *J. Chem. Thermodyn.* **2001**, *33*, 1081−1096.

(4) Mascato, E.; Mosteiro, L.; Piñeiro, M. M.; García, J.; Iglesias, T. P.; Legido, J. L. Thermodynamic properties of mixing for (1-alkanol + a *n*-alkane + a cyclic alkane) at $T = 298.15$ K. I. (*n*-Hexane + cyclohexane + 1-butanol). *J. Chem. Thermodyn.* **2001**, *33*, 269−286.

(5) De Cominges, B. E.; Piñeiro, M. M.; Mosteiro, L.; Iglesias, T. P.; Legido, J. L.; Paz-Andrade, M. I. Temperature dependence of thermophysical properties of hexane + 1-hexanol. *J. Chem. Eng. Data* **2001**, *46*, 1206−1210.

(6) De Cominges, B. E.; Piñeiro, M. M.; Mascato, E.; Iglesias, T. P.; Legido, J. L. Temperature dependence of the thermophysical properties of binary mixtures of *n*-hexane + 1-butanol. *High Temp.-High Pressures* **2000**, *32*, 653−661.

(7) De Cominges, B. E.; Piñeiro, M. M.; Iglesias; T. P.; Legido, J. L.; Paz Andrade, M. I. Refractive indices and speeds of sound of binary mixtures of *n*-octane with 1-alkanol at the temperature 298.15 K. *Phys. Chem. Liq.* **1999**, *37*, 683−699.

(8) De Cominges, B. E.; Piñeiro, M. M.; Iglesias; T. P.; Legido, J. L.; Paz Andrade, M. I. Refractive indices and speed of sound of binary mixtures of *n*-hexane with 1-alkanols at 298.15 K. *J. Chem. Thermodyn.* **1998**, *30*, 1147−1157.

(9) Piñeiro, M. M.; García, J.; De Cominges, B. E.; Vijande, J.; Valencia, J. L.; Legido, J. L. Density and surface tension variation with temperature for *n*-nonane + 1-hexanol. *Fluid Phase Equilib.* **2006**, *245*, 32−36.

(10) Redlich, O.; Kister, A. Thermodynamics of nonelectrolytic solutions. algebraic representation of thermodynamic properties and the classification of solutions. *J. Ind. Eng. Chem.* **1948**, *40*, 845−848.

(11) Miller, R.; Hofmenn, A.; Hartmann, R.; Schano, K. H.; Halbig, A. Measuring dynamic surface and interfacial tensions. *Adv. Mater. (Weinheim, Ger.)* **1992**, *4*, 370−374.

(12) Lunkenheimer, K.; Wantke, K.-D. Determination of the surface tension of surfactant solutions applying the method of Lecomte du Noüy (ring tensiometer). *Colloid Polym. Sci.* **1981**, *259*, 354−366.

(13) Wilkinson, M. C. Extended use of, and comments on, the drop-weight (drop-volume) technique for the determination of surface and interfacial tensions. *J. Colloid Interface Sci.* **1972**, *40*, 14−26.

(14) Nath, J. Speeds of sound in and isentropic compressibilities of (*n*-butanol + *n*-pentane, or *n*-hexane, or *n*-heptane, or 2,2,4-trimethylpentane) at $T = 288.15$ K, (*n*-hexanol + *n*-pentane or *n*-hexane) at $T = 298.15$ K, and (*n*-hexanol + *n*-heptane or *n*-octane) at $T = 298.15$ K and $T = 303.15$ K. *J. Chem. Thermodyn.* **2002**, *34*, 1857−1872.

(15) Cerdeiriña, C. A.; Tovar, C. A.; González-Salgado, D.; Carballo, E.; Romaní, L. Isobaric thermal expansivity and thermophysical characterization of liquids and liquid mixtures. *Phys. Chem. Chem. Phys.* **2001**, *3*, 5230−5236.

(16) Queimada, J. A.; Silva, F. A. E.; Caço, A. I.; Marrucho, I. M.; Coutinho, J. A. P. Measurement and modeling of surface tensions of asymmetric systems: heptane, eicosane, docosane, tetracosane and their mixtures. *Fluid Phase Equilib.* **2003**, *214*, 211−221.

(17) Penas, A.; Calvo, E.; Pintos, M.; Amigo, A.; Bravo, R. Refractive indices and surface tensión of binary mixtures of 1,4-dioxane + *n*-alkanes at 298.15 K. *J. Chem. Eng. Data* **2000**, *45*, 682−685.

(18) Tovar, C. A.; Carballo, E.; Cerdeiriña, C. A., Paz Andrade, M. I.; Romaní, L. Thermodynamic properties of polyoxyethyleneglycol dimethyl ether + *n*-alkane mixtures. *Fluid Phase Equilib.* **1997**, *136*, 223−234.

(19) Troncoso, J.; Valencia J. L.; Souto-Caride, M.; González-Salgado, D.; Peleteiro, J. Thermodynamic properties of dodecane + 1-butanol and + 2-butanol systems. *J. Chem. Eng. Data* **2004**, *49*, 1789−1793.

(20) Jiménez, E.; Cabanas, M.; Segade, L.; García-Garabal, S.; Casas, H. Excess volume, changes of refractive index and surface tension of binary 1,2-ethanediol + 1-propanol or 1-butanol mixtures at several temperatures. *Fluid Phase Equilib.* **2001**, *180*, 151−164.

(21) Azizian, S.; Bashavard, N. Surface tension of dilute solutions of linear alcohols in benzyl alcohol. *J. Chem. Eng. Data* **2005**, *50*, 1303−1307.

(22) Alonso, V.; Calvo, E.; Bravo, R.; Pintos, M.; Amigo, A. Thermodynamic properties of tetrahydropyran + 1-alkanol mixtures. *J. Chem. Eng. Data* **1994**, *39*, 926−928.

(23) Wagner, D.; Heintz, A. Excess volumes of binary 1-alkanol/nonane mixtures at temperatures between 293.15 and 333.15 K. *J. Chem. Eng. Data* **1986**, *31*, 483−487.

(24) Segade, L.; Jiménez de Llano, J.; Domínguez-Pérez, M.; Cabeza, O.; Cabanas, M.; Jiménez, E. Density, surface tension, and refractive index of octane + 1-alkanol mixtures at $T = 298.15$ K. *J. Chem. Eng. Data* **2003**, *48*, 1251−1255.

(25) Oswal, S. L.; Desai, H. S. Studies of viscosity and excess molar volume of binary mixtures. 2. Butylamine + 1-alkanol mixtures at 303.15 and 313.15 K. *Fluid Phase Equilib.* **1999**, *161*, 191−204.

(26) Bevington, P. R.; Robinson, D. K. *Data Reduction and Error Analysis for the Physical Sciences*, 2nd ed.; McGraw-Hill: Singapore, 1994.

(27) Benson, G. C. Excess volume. 1-Butanol−heptane system. *Int. Data Ser., Sel. Data Mixtures, Ser. A* **1986**, 266.

(28) Berro, C.; Péneloux, A. Excess Gibbs energies and excess volumes of 1-butanol−*n*-heptane and 2-methyl-1-propanol−*n*-heptane binary systems. *J. Chem. Eng. Data* **1984**, *29*, 206−210.

(29) Sastry, N. V.; Valand, M. K. Densities, speeds of sound, viscosities, and relative permittivities for 1-propanol + and 1-butanol + heptane at 298.15 K and 308.15 K. *J. Chem. Eng. Data* **1996**, *41*, 1421−1425.

Received for review April 27, 2006. Accepted July 9, 2006. The authors are grateful to Xunta de Galiza (Galiza, Spain) for financial support, through research project PGIDT99PXI30103B.

JE060179E