Viscosities and Densities for Heptane + 1-Pentanol, +1-Hexanol, +1-Heptanol, +1-Octanol, +1-Decanol, and +1-Dodecanol at 298.15 K and 308.15 K

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Densities and viscosities for heptane + 1-pentanol, +1-hexanol, +1-heptanol, +1-octanol, +1-decanol, and +1-dodecanol are reported at (298.15 K and 308.15) K. The viscosity deviations were calculated. The mixture viscosity data were fitted to the semiempirical equations of Grunberg−Nissan, Heric, McAllister, and Auslander.

Introduction

As a part of systematic measurements on transport and dielectric properties of 1-alkanol + alkane mixtures, we have recently reported the densities, speeds of sound, viscosities, and dielectric properties for 1-heptanol + hexane and +heptane (at 303.15 and 313.15 K) (Sastry and Raj, 1996) and similar data for heptane + 1-propanol and +1-butanol mixtures at (298.15 and 308.15) K (Sastry and Valand, 1996). To complete our investigations of the effect of the carbon chain length of 1-alkanols on the viscosities of their mixtures with heptane, this paper presents the data on densities and viscosities of a series of mixtures containing heptane + 1-pentanol, +1-hexanol, +1-heptanol, +1-octanol, +1-decanol, and +1-dodecanol at (298.15 and 308.15) K. The viscosity deviations for all the binary mixtures at both temperatures were calculated from the measured viscosities of the pure and mixture components. The experimental mixture viscosities were also fitted to several correlating equations.

Experimental Section

Materials. 1-Pentanol and 1-hexanol were of Riedel make and 1-heptanol and 1-dodecanol were Merck products. 1-Octanol and 1-decanol were Fluka chemicals. The purity of all the chemicals was stated to be more than 99% on a mole basis. All the reagents were used as such without any purifications. Heptane was of SD fine chemicals and purified further by a standard procedure (Riddick et al., 1986). The measured viscosities of all the pure components at both temperatures were compared with the literature values, and such a comparison is presented in Table 1.

Methods. The binary mixtures were prepared in stoppered glass vials by mass on a Mettler balance with a mole fraction accuracy of ±0.0001. The viscosities, η, of the pure and mixture components were calculated from the measured flow times, t, in an Ubbelohde suspended type viscometers by using the following equation:

$$\eta = \rho\{At - B/t\} \qquad (1)$$

where ρ = density and A and B are viscometer calibration constants which were determined from the measured flow times, absolute viscosities, and densities of the triple distilled water and double distilled cyclohexane. Two viscometers (one with $A = 0.005\,442$, $B = 2.7578$ at 298.15 K and $A = 0.005\,304$, $B = 1.3415$ at 308.15 K and another with $A = 0.018\,20$, $B = 2.2058$ at 298.15 K and $A = 0.018\,429$, $B = 4.1936$ at 308.15 K, respectively) were employed to cover the mixtures with all the alkanols. The measured viscosities were found to be accurate up to ±0.0003 mPa·s. The densities of the pure and mixture components were measured by a bicapillary pycnometer accurate up to ±0.0001 g·cm^{-3}.

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Table 1. Viscosities of Pure Components

	298.15 K		308.15 K	
	exp	lit.	exp	lit.
1-pentanol	3.510	3.5128[a]	2.648	2.668[a]
1-hexanol	4.477	4.339[b]	3.413	3.398[b]
		4.590[b]		
1-heptanol	5.770	5.774[c]	4.266	4.263[c]
1-octanol	7.363	7.363[c]	5.250	5.256[c]
1-decanol	11.790	11.798[d]	8.124	7.569[b]
1-dodecanol	16.136		11.315	11.633[b]
heptane	0.3901	0.3906[e]	0.3520	0.3525[e]

[a] TRC Tables (1994). [b] TRC Tables (1996). [c] Rauf et al. (1983). [d] Bravo et al. (1991). [e] TRC Tables (1992).

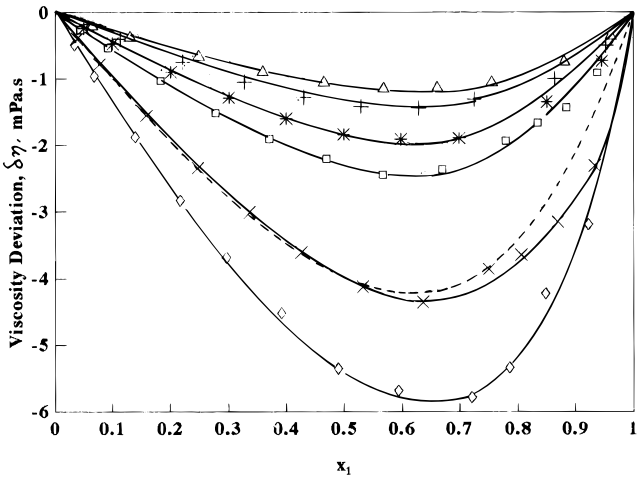

Figure 1. Viscosity deviations of 1-alkanol + heptane mixtures versus the 1-alkanol mole fraction at 298.15 K: (△) 1-pentanol + heptane; (+) 1-hexanol + heptane; (*) 1-heptanol + heptane; (□) 1-octanol + heptane; (×) 1-decanol + heptane; (◇) 1-dodecanol + heptane; (—) published values for the 1-decanol + heptane mixture at 298.15 K (Bravo et al., 1991).

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Table 2. Densities (ρ), Experimental Viscosities (η_{exp}), and Viscosity Deviations ($\delta\eta$) for 1-Alkanol + Heptane Mixtures at 298.15 and 308.15 K

x_1	ρ/g·cm^{-3}	η_{exp}/mPa·s	$\delta\eta$/mPa·s	ρ/g·cm^{-3}	η_{exp}/mPa·s	$\delta\eta$/mPa·s	x_1	ρ/g·cm^{-3}	η_{exp}/mPa·s	$\delta\eta$/mPa·s	ρ/g·cm^{-3}	η_{exp}/mPa·s	$\delta\eta$/mPa·s
1-Pentanol (1) + Heptane (2)													
0.0000	0.6794			0.6709			0.5682	0.7438	1.0414	−1.121	0.7356	0.8410	−0.815
0.0652	0.6854	0.4117	−0.182	0.6769	0.3680	−0.137	0.6617	0.7569	1.3384	−1.116	0.7488	1.0619	−0.809
0.1304	0.6919	0.4449	−0.352	0.6834	0.3956	−0.256	0.7552	0.7707	1.7128	−1.033	0.7629	1.3526	−0.733
0.2489	0.7045	0.5244	−0.642	0.6961	0.4627	−0.461	0.8805	0.7905	2.4183	−0.719	0.7829	1.9315	−0.442
0.3595	0.7172	0.6427	−0.869	0.7088	0.5523	−0.625	0.9606	0.8039	3.0568	−0.330	0.7965	2.3824	−0.175
0.4654	0.7302	0.8116	−1.031	0.7220	0.6821	−0.738	1.0000	0.8107			0.8034		
1-Hexanol (1) + Heptane (2)													
0.0567	0.6857	0.4405	−0.181	0.6771	0.3960	−0.130	0.6292	0.7604	1.5232	−1.439	0.7523	1.2012	−1.077
0.1134	0.6924	0.4541	−0.399	0.6838	0.4021	−0.297	0.7248	0.7743	2.0473	−1.305	0.7663	1.5737	−0.997
0.2217	0.7057	0.5473	−0.749	0.6972	0.4788	−0.552	0.8643	0.7951	2.9304	−0.992	0.7873	2.2993	−0.698
0.3279	0.7192	0.6831	−1.047	0.7108	0.5863	−0.769	0.9526	0.8086	3.7885	−0.495	0.8010	2.9206	−0.347
0.4307	0.7328	0.8745	−1.276	0.7245	0.7378	−0.932	1.0000	0.8160			0.8083		
0.5294	0.7463	1.1416	−1.412	0.7382	0.9541	−1.018							
1-Heptanol (1) + Heptane (2)													
0.0508	0.6830	0.4239	−0.239	0.6774	0.3784	−0.172	0.5981	0.7626	1.7025	−1.905	0.7543	1.3464	−1.347
0.1004	0.6929	0.4638	−0.466	0.6842	0.4111	−0.334	0.6990	0.7768	2.2613	−1.889	0.7685	1.8206	−1.267
0.2012	0.7068	0.5765	−0.896	0.6984	0.5039	−0.639	0.8500	0.7979	3.6162	−1.347	0.7892	2.8060	−0.873
0.3013	0.7210	0.7282	−1.283	0.7127	0.6241	−0.907	0.9456	0.8115	4.7488	−0.729	0.8025	3.6081	−0.445
0.4001	0.7347	0.9460	−1.597	0.7265	0.7914	−1.127	1.0000	0.8189			0.8126		
0.4992	0.7486	1.2426	−1.833	0.7404	1.0228	−1.283							
1-Octanol (1) + Heptane (2)													
0.0448	0.6861	0.4411	−0.261	0.6780	0.3932	−0.178	0.6697	0.7777	2.7002	−2.360	0.7709	2.2134	−1.419
0.0922	0.6934	0.4999	−0.533	0.6854	0.4375	−0.366	0.7784	0.7925	3.8850	−1.933	0.7857	3.0206	−1.144
0.1826	0.7072	0.6375	−1.026	0.6993	0.5457	−0.701	0.8336	0.7998	4.5447	−1.658	0.7930	3.4656	−0.969
0.2780	0.7215	0.8198	−1.509	0.7139	0.6942	−1.019	0.8844	0.8064	5.1239	−1.433	0.7977	3.8848	−0.799
0.3705	0.7352	1.0723	−1.901	0.7277	0.8964	−1.270	0.9381	0.8134	6.0244	−0.907	0.8067	4.3994	−0.547
0.4690	0.7495	1.4637	−2.197	0.7422	1.1492	−1.500	1.0000	0.8212			0.8146		
0.5664	0.7633	1.9021	−2.437	0.7563	1.5937	−1.533							
1-Decanol (1) + Heptane (2)													
0.0386	0.6867	0.4346	−0.396	0.6785	0.3825	−0.270	0.6364	0.7830	3.2902	−4.355	0.7759	2.6996	−2.599
0.0772	0.6941	0.4872	−0.783	0.6859	0.4312	−0.521	0.7498	0.7976	5.0801	−3.858	0.7909	3.9296	−2.250
0.1584	0.7090	0.6420	−1.554	0.7010	0.5562	−1.027	0.8055	0.8044	5.9264	−3.646	0.7977	4.8292	−1.783
0.2472	0.7245	0.8698	−2.338	0.7167	0.7324	−1.541	0.8688	0.8119	7.1453	−3.149	0.8052	5.9384	−1.166
0.3368	0.7392	1.2246	−3.005	0.7316	1.0344	−1.935	0.9331	0.8192	8.7221	−2.305	0.8125	6.7881	−0.816
0.4264	0.7532	1.6470	−3.604	0.7456	1.3311	−2.335	1.0000	0.8265			0.8195		
0.5326	0.7688	2.3378	−4.124	0.7613	1.9030	−2.588							
1-Dodecanol (1) + Heptane (2)													
0.0343	0.6872	0.4411	−0.489	0.6790	0.3932	−0.335	0.5941	0.7839	4.0558	−5.689	0.7772	3.1988	−3.666
0.0687	0.6950	0.5140	−0.958	0.6871	0.4523	−0.653	0.7213	0.7967	5.9583	−5.789	0.7932	4.8576	−3.402
0.1389	0.7098	0.7038	−1.873	0.7021	0.6054	−1.269	0.7853	0.8066	7.4140	−5.341	0.8005	5.8545	−3.107
0.2173	0.7252	0.9825	−2.829	0.7176	0.8279	−1.906	0.8475	0.8132	9.5058	−4.229	0.8071	7.0727	−2.571
0.2965	0.7394	1.3719	−3.687	0.7320	1.1257	−2.477	0.9227	0.8208	11.731	−3.188	0.8146	8.8565	−1.611
0.3920	0.7550	2.0397	−4.523	0.7479	1.6319	−3.018	1.0000	0.8281			0.8217		
0.4898	0.7696	2.7465	−5.356	0.7627	2.2239	−3.498							

Table 3. Coefficients a_i of Eq 3 with Standard Deviation, σ, for the Least Squares Representations of $\delta\eta$ (mPa·s) of 1-Alkanol + Heptane Mixtures at 298.15 K and 308.15 K

	298.15 K				308.15 K				
	a_0	a_1	a_2	σ	a_0	a_1	a_2	a_3	σ
1-pentanol + heptane	−4.1224	−2.6760	−1.8554	0.024	−3.0995	−1.3392	−0.3264		0.001
1-hexanol + heptane	−5.3291	−3.4719	−2.0823	0.001	−3.9660	−2.4264	−1.2378		0.001
1-heptanol + heptane	−7.1286	−4.4795	−2.6705	0.001	−5.0312	−2.5345	−1.1441		0.001
1-octanol + heptane	−8.9312	−4.6724	−2.0451	0.001	−5.7326	−0.8656	−0.9844	−2.4040	0.001
1-decanol + heptane	−15.101	−11.970	−9.2552	0.003	−9.9663	−2.8377	0.3661		0.001
1-dodecanol + heptane	−21.057	−14.913	−9.858	0.001	−13.859	−6.8088	−3.1879		0.001

Results and Discussion

The experimental viscosities (η_{exp}) and the viscosity deviations ($\delta\eta$) for the mixtures at the two temperatures are given in Table 2. The viscosity deviations were calculated from the measured viscosities, η_{12}, of the mixture and η_i of the pure components by using the following relation:

$$\delta\eta = \eta_{12} - (x_1\eta_1 + x_2\eta_2) \tag{2}$$

The values of $\delta\eta$ were further fitted through an equation of the type

$$\delta\eta/\text{mPa·s} = x_1(1 - x_1)\sum_{i=0} a_i\,(2x_1 - 1)^i \tag{3}$$

where x_1 is the 1-alkanol mole fraction and a_i are the coefficients. The values of the a_i were obtained by a multiple regression analysis based on a least squares method and are given in Table 3 along with the standard deviations, σ, between the experimental and fitted $\delta\eta$ values. The σ values were calculated from the following expression:

$$\sigma = \left[\frac{\sum(\delta\eta_{exp} - \delta\eta_{fitt})^2}{n - p}\right]^{1/2} \tag{4}$$

where $\delta\eta_{exp}$ is the viscosity deviation evaluated by eq 2 using the experimental data, $\delta\eta_{fitt}$ is the calculated deviation using eq 3 and coeffcients from Table 3. n is the number of experimental points and p is the number of

Table 4. Adjustable Parameters of Equations and Standard Deviations σ for the Correlation of Mixture Viscosities at 298.15 K and 308.15 K

	G_{12}[a]	σ	He_{12}[b]	σ	M_{12}[c]	M_{21}[c]	σ	A_{21}[d]	B_{21}[d]	B_{12}[d]	σ
					298.15 K						
pentanol + heptane	−1.1451	0.009	0.1889	0.001	1.2844	0.4970	0.002	0.1850	22.1536	−0.0797	0.003
hexanol + heptane	−0.8998	0.001	0.1474	0.001	1.6915	0.5686	0.004	1.2255	3.2895	0.2104	0.016
heptanol + heptane	−0.7398	0.013	0.1222	0.001	2.0401	0.6679	0.004	0.8979	4.4594	0.0758	0.010
octanol + heptane	−0.2258	0.003	0.0295	0.001	2.9999	0.9011	0.003	0.7530	4.6844	0.0350	0.007
decanol + heptane	−0.1390	0.004	0.0162	0.001	3.6390	1.1831	0.003	3.8331	1.3397	1.1104	0.050
dodecanol + heptane	0.5172	0.005	−0.1038	0.003	5.0764	1.5856	0.001	1.1521	3.9110	0.2072	0.014
					308.15 K						
pentanol + heptane	−1.1070	0.004	0.1789	0.001	1.0234	0.4318	0.002	2.7894	1.1066	−0.1327	0.004
hexanol + heptane	−0.9193	0.003	0.1495	0.001	1.2974	0.5028	0.004	1.0707	3.5485	0.1354	0.010
heptanol + heptane	−0.7040	0.001	0.1147	0.001	1.6479	0.5611	0.003	0.8349	4.1273	0.0054	0.004
octanol + heptane	−0.2231	0.014	0.0262	0.001	2.5231	0.6890	0.004	1.4129	2.2013	0.4387	0.040
decanol + heptane	−0.0972	0.004	−0.0299	0.001	3.6002	0.8593	0.004	0.7504	3.6656	−0.1424	0.006
dodecanol + heptane	0.5925	0.004	−0.1179	0.001	4.4406	1.2853	0.003	1.1091	3.0295	0.0289	0.002

[a] Grunberg−Nissan. [b] Heric. [c] McAllister. [d] Auslander.

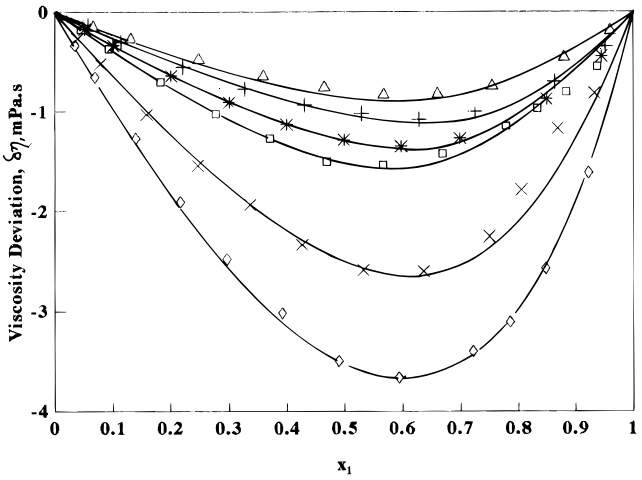

Figure 2. Viscosity deviations of 1-alkanol + heptane mixtures versus the 1-alkanol mole fraction at 308.15 K. Legend: same as Figure 1.

coefficients of eq 3 needed for the mathematical representation of $\delta\eta$ values.

The viscosity deviations, $\delta\eta$, of all the binary mixtures are also graphed as a function of 1-alkanol mole fraction at (298.15 and 308.15) K in Figures 1 and 2, respectively. There are only very few viscosity studies involving the alkanol + alkane mixtures in the literature with which a direct comparison of our values can be made. The published viscosity data for 1-decanol + heptane at 298.15 K (Bravo et al., 1991) are also shown in Figure 1 for a comparison. It is apparent from Figures 1 and 2 that the viscosity deviations of the present mixtures were negative in general and larger in magnitude in the case of mixtures of heptane with higher alcohols. The large negative $\delta\eta$ values in general indicate the presence of weaker dispersing interactions. The mixture viscosity data were further fitted to Grunberg−Nissan, McAllister, Heric, and Auslander equations. The relations for expressing the mixture viscosities by these equations are given in the literature very often (Sastry and Raj, 1996; Bravo et al., 1991; Franjo et al., 1995) and hence will not be repeated here. The adjustable parameters of these equations were estimated by a nonlinear regression analysis employing the Marquardt algorithm from the individual fits of the experimental viscosity data. The values of the parameters together with the estimated standard deviations between the experimental and calculated viscosity values for all the binary mixtures at the two measuring temperatures are given in Table 4. The smaller σ values shown in Table 4 suggest that these semiempirical relations give satisfactory fits for representing the present mixture viscosity data.

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