Viscosities and Densities of Binary Mixtures of (*N*-Acetylmorpholine + Alkanols) from (293.15 to 323.15) K

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The experimental densities and viscosities of *N*-acetylmorpholine + ethanol, + 1-propanol, + 2-propanol, + 1-butanol, and + 2-butanol systems have been measured at temperatures from (293.15 to 323.15) K over the whole mole fraction range. From these data, excess molar volumes V^E and viscosity deviations $\Delta\eta$ have been calculated. The excess molar volumes and viscosity deviations have been fitted to the Redlich−Kister polynomial equation to derive the coefficients and estimate the standard deviation values. V^E values are negative, while viscosity deviations $\Delta\eta$ are positive over the whole mole fraction range and at all temperatures.

Introduction

The physicochemical properties of liquid mixtures have attracted much attention from both theoretical and engineering application points of view. Many engineering applications require quantitative data on the density and viscosity of liquid mixtures. It also provides information about the nature and molecular interactions between the components of the mixture.

As part of our experimental investigation of the thermophysical properties of liquid mixtures with morpholine derivatives as one of the components, recently we have reported similar studies with *N*-methylmorpholine[1,2] and *N*-(2-hydroxyethyl-)morpholine.[3] A survey of the literature shows that Henni et al.[4] have measured the densities and viscosities of aqueous solutions of *N*-acetylmorpholine (NAM) at temperatures from (298.15 to 343.15) K. In the present study, the densities and viscosities were measured at temperatures from (293.15 to 323.15) K and atmospheric pressure for *N*-acetylmorpholine + ethanol, + 1-propanol, + 2-propanol, + 1-butanol, and + 2-butanol systems over the whole composition range. The excess molar volumes V^E and viscosity deviations $\Delta\eta$ were fitted to the Redlich−Kister polynomial equation.

Experimental Section

Materials. Ethanol (stated mass fraction purity 0.998), 1-propanol (stated mass fraction purity 0.998), 2-propanol (stated mass fraction purity 0.995), 1-butanol (stated mass fraction purity 0.998), 2-butanol (stated mass fraction purity 0.995), and *N*-acetylmorpholine (stated mass fraction purity 0.98) were obtained from Fluka AG and used without further purification. All liquids were kept over activated molecular sieves of type 4A (Union Carbide) and filtered before use. The purity of the liquids was confirmed by gas−liquid chromatographic analysis. The measured densities and viscosities of the pure solvents at temperatures from (293.15 to 323.15) K are given in Table 1 together with literature data.[4–11] Binary mixtures were prepared by mass using a Mettler balance (model AE-240) with a precision of ± 0.01 mg.

Table 1. Experimental Densities, ρ, and Viscosities, η, of the Pure Component Liquids from (293.15 to 323.15) K Together with Literature Data

		ρ/g·cm^{-3}		η/mPa·s	
solvent	*T*/K	exptl	lit.	exptl	lit.
ethanol	293.15	0.78962	0.78975[a]	1.188	1.187[a]
	303.15	0.78112	0.78115[a]	0.989	0.987[a]
	313.15	0.77258	0.77460[d]	0.845	0.859[d]
	323.15	0.76411	0.76610[d]	0.749	0.749[d]
1-propanol	293.15	0.80356	0.80359[a]	2.205	2.159[a]
	303.15	0.79558	0.79555[a]	1.714	1.713[a]
	313.15	0.78779	0.78777[c]	1.382	1.391[c]
	323.15	0.77892	0.77990[d]	1.105	1.100[d]
2-propanol	293.15	0.78518	0.78507[b]	2.384	2.382[b]
	303.15	0.77666	0.77660[b]	1.762	1.763[b]
	313.15	0.76783	0.76860[d]	1.335	1.352[c]
	323.15	0.75871	0.75880[d]	1.038	1.041[d]
1-butanol	293.15	0.80952	0.80950[a]	2.942	2.941[a]
	303.15	0.80191	0.80180[a]	2.275	2.275[f]
	313.15	0.79613		1.684	1.774[f]
	323.15	0.78613		1.098	
2-butanol	293.15	0.80556	0.80684[b]	3.625	3.623[b]
	303.15	0.79866	0.79851[b]	2.489	2.493[b]
	313.15	0.79011		2.006	1.784[f]
	323.15	0.78492		1.717	
NAM	293.15	1.11378		8.534	
	303.15	1.10594	1.10600[e]	7.052	7.10[e]
	313.15	1.09731	1.09735[e]	5.122	5.18[e]
	323.15	1.08868	1.08874[e]	3.848	3.96[e]

[a] González et al. (2007). [b] González et al. (2006). [c] Ontreras (2001). [d] Bhuiyan et al. (2007). [e] Henni et al. (2005). [f] Nain (2008).

Apparatus and Procedure. The densities of the pure liquids and their binary mixtures were measured with a digital densimeter DMA 60/602 (Anton Paar) whose cell temperature was controlled within ± 0.01 K of the selected value. Before each series of measurements, the densimeter was calibrated at atmospheric pressure with double-distilled water and dry air. Densities, both water and dry air at the various working temperatures, were given by the manufacturer in the instruction manual. The density obtained for pure toluene and 1,2-

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Table 2. Density and Excess Molar Volumes of Alkanol (1) + *N*-Acetylmorpholine (2) from (293.15 to 323.15) K

	T/K							
x_2	293.15	303.15	313.15	323.15	293.15	303.15	313.15	323.15
	ρ/g·cm^{-3}				V^E/cm^3·mol^{-1}			
	ethanol (1) + *N*-acetylmorpholine (2)							
0.0563	0.82441	0.78071	0.77258	0.76411	−0.0347	−0.0569	−0.0634	−0.0977
0.1288	0.86428	0.85584	0.84785	0.83985	−0.0844	−0.1267	−0.1569	−0.2158
0.2164	0.90609	0.89815	0.89035	0.88259	−0.1314	−0.2137	−0.2674	−0.3564
0.2843	0.93458	0.92693	0.91934	0.91170	−0.1634	−0.2673	−0.3427	−0.4478
0.3147	0.94640	0.93880	0.93130	0.92361	−0.1769	−0.2843	−0.3702	−0.4732
0.3944	0.97479	0.96737	0.96005	0.95245	−0.1985	−0.3185	−0.4231	−0.5388
0.4512	0.99302	0.98563	0.97841	0.97079	−0.2032	−0.3232	−0.4389	−0.5548
0.4957	1.00631	0.99895	0.99171	0.98408	−0.2043	−0.3243	−0.4397	−0.5568
0.5253	1.01469	1.00734	1.00003	0.99242	−0.2015	−0.3215	−0.4312	−0.5502
0.5832	1.03013	1.02267	1.01537	1.00774	−0.1928	−0.2986	−0.4099	−0.5289
0.6341	1.04274	1.03523	1.02770	1.02007	−0.1789	−0.2762	−0.3675	−0.4865
0.6813	1.05371	1.04598	1.03845	1.03083	−0.1622	−0.2359	−0.3263	−0.4453
0.7348	1.06537	1.05759	1.04981	1.04212	−0.1378	−0.2021	−0.2679	−0.3803
0.7921	1.07706	1.06904	1.06114	1.05325	−0.1095	−0.1452	−0.1974	−0.2887
0.8452	1.08726	1.07910	1.07113	1.06299	−0.0844	−0.1004	−0.1439	−0.2095
0.9127	1.09933	1.09120	1.08296	1.07460	−0.0453	−0.0563	−0.0701	−0.1095
0.9734	1.10950	1.10140	1.09309	1.08454	−0.0126	−0.0198	−0.0228	−0.0398
	1-propanol (1) + *N*-acetylmorpholine (2)							
0.0542	0.82908	0.82108	0.81319	0.80486	−0.0211	−0.0276	−0.0543	−0.0874
0.1279	0.86158	0.85365	0.84584	0.83752	−0.0556	−0.0763	−0.1204	−0.1631
0.2156	0.89724	0.88939	0.88160	0.87331	−0.0977	−0.1335	−0.1875	−0.2423
0.2811	0.92189	0.91415	0.90630	0.89798	−0.1234	−0.1743	−0.2267	−0.2816
0.3166	0.93462	0.92686	0.91901	0.91067	−0.1369	−0.1873	−0.2413	−0.2964
0.3902	0.95964	0.95191	0.94400	0.93563	−0.1566	−0.2134	−0.2644	−0.3192
0.4533	0.97969	0.97196	0.96405	0.95567	−0.1632	−0.2213	−0.2733	−0.3282
0.5022	0.99444	0.98669	0.97880	0.97042	−0.1643	−0.2216	−0.2756	−0.3304
0.5437	1.00644	0.99868	0.99079	0.98241	−0.1615	−0.2183	−0.2721	−0.3267
0.5983	1.02151	1.01377	1.00587	0.99750	−0.1489	−0.2069	−0.2607	−0.3155
0.6341	1.03101	1.02323	1.01534	1.00698	−0.1389	−0.1933	−0.2473	−0.3022
0.6883	1.04485	1.03703	1.02915	1.02081	−0.1222	−0.1721	−0.2259	−0.2807
0.7442	1.05843	1.05059	1.04272	1.03440	−0.0978	−0.1436	−0.1973	−0.2521
0.7912	1.06941	1.06146	1.05361	1.04531	−0.0785	−0.1127	−0.1666	−0.2214
0.8542	1.08348	1.07548	1.06757	1.05918	−0.0487	−0.0763	−0.1211	−0.1634
0.9165	1.09679	1.08874	1.08069	1.07216	−0.0238	−0.0432	−0.0712	−0.0953
0.9776	1.10932	1.10111	1.09286	1.08417	−0.0045	−0.0054	−0.0098	−0.0121
	2-propanol (1) + *N*-acetylmorpholine (2)							
0.0522	0.81061	0.80223	0.79347	0.78446	−0.0143	−0.0346	−0.0476	−0.0652
0.1274	0.84507	0.83683	0.82815	0.81927	−0.0403	−0.0803	−0.1065	−0.1455
0.2153	0.88236	0.87408	0.86550	0.85659	−0.0734	−0.1134	−0.1514	−0.1904
0.2813	0.90841	0.90012	0.89154	0.88262	−0.0945	−0.1345	−0.1725	−0.2115
0.3169	0.92181	0.91353	0.90496	0.89604	−0.1045	−0.1445	−0.1825	−0.2215
0.3909	0.94834	0.94001	0.93148	0.92258	−0.1204	−0.1556	−0.1936	−0.2326
0.4569	0.97055	0.96222	0.95373	0.94486	−0.1276	−0.1601	−0.1981	−0.2371
0.4999	0.98433	0.97603	0.96756	0.95872	−0.1278	−0.1608	−0.1988	−0.2378
0.5444	0.99807	0.98979	0.98136	0.97255	−0.1266	−0.1588	−0.1968	−0.2358
0.6113	1.01775	1.00955	1.00118	0.99243	−0.1163	−0.1523	−0.1903	−0.2293
0.6342	1.02424	1.01609	1.00775	0.99901	−0.1112	−0.1512	−0.1892	−0.2282
0.6888	1.03923	1.03112	1.02283	1.01414	−0.0976	−0.1376	−0.1756	−0.2146
0.7522	1.05583	1.04780	1.03958	1.03095	−0.0778	−0.1203	−0.1583	−0.1973
0.7976	1.06721	1.05928	1.05106	1.04248	−0.0612	−0.1097	−0.1423	−0.1813
0.8555	1.08119	1.07323	1.06509	1.05657	−0.0398	−0.0798	−0.1134	−0.1524
0.9231	1.09684	1.08886	1.08063	1.07194	−0.0197	−0.0512	−0.0673	−0.0783
0.9812	1.10973	1.10150	1.09325	1.08458	−0.0039	−0.0043	−0.0089	−0.0157
	1-butanol (1) + *N*-acetylmorpholine (2)							
0.0555	0.83066	0.82307	0.81721	0.80784	−0.0093	−0.0126	−0.0321	−0.0458
0.1321	0.85890	0.85141	0.84534	0.83614	−0.0278	−0.0542	−0.0745	−0.1115
0.2165	0.88887	0.88136	0.87504	0.86584	−0.0589	−0.0944	−0.1126	−0.1496
0.2844	0.91199	0.90441	0.89810	0.88892	−0.0725	−0.1085	−0.1475	−0.1845
0.3126	0.92141	0.91380	0.90741	0.89824	−0.0825	−0.1185	−0.1575	−0.1945
0.4042	0.95097	0.94330	0.93667	0.92756	−0.0984	−0.1344	−0.1734	−0.2104
0.4673	0.97056	0.96285	0.95607	0.94700	−0.1056	−0.1416	−0.1806	−0.2176
0.5033	0.98145	0.97371	0.96685	0.95781	−0.1058	−0.1418	−0.1808	−0.2178
0.5562	0.99710	0.98933	0.98234	0.97336	−0.1046	−0.1406	−0.1796	−0.2166
0.6237	1.01644	1.00864	1.00150	0.99259	−0.0943	−0.1303	−0.1693	−0.2063
0.6431	1.02186	1.01406	1.00688	0.99799	−0.0892	−0.1252	−0.1642	−0.2012
0.6903	1.03486	1.02704	1.01975	1.01093	−0.0756	−0.1116	−0.1506	−0.1876
0.7439	1.04933	1.04150	1.03410	1.02534	−0.0658	−0.1018	−0.1408	−0.1778
0.7911	1.06173	1.05388	1.04638	1.03769	−0.0498	−0.0858	−0.1248	−0.1618
0.8624	1.08002	1.07217	1.06439	1.05580	−0.0321	−0.0681	−0.0923	−0.1293
0.9222	1.09491	1.08695	1.07897	1.07040	−0.0145	−0.0403	−0.0562	−0.0844
0.9785	1.10862	1.10043	1.09225	1.08356	−0.0022	−0.0038	−0.0096	−0.0153

Table 2 Continued

	T/K							
x_2	293.15	303.15	313.15	323.15	293.15	303.15	313.15	323.15
	2-butanol (1) + *N*-acetylmorpholine (2)							
0.0516	0.82538	0.81752	0.80981	0.80444	−0.0065	−0.0078	−0.0104	−0.0133
0.1322	0.85535	0.84754	0.83973	0.83419	−0.0211	−0.0391	−0.0433	−0.0623
0.2217	0.88731	0.87942	0.87154	0.86566	−0.0437	−0.0617	−0.0702	−0.0892
0.2879	0.91003	0.90208	0.89415	0.88803	−0.0552	−0.0732	−0.0832	−0.1022
0.3188	0.92040	0.91244	0.90449	0.89825	−0.0621	−0.0801	−0.0911	−0.1101
0.3996	0.94676	0.93875	0.93077	0.92425	−0.0731	−0.0911	−0.1067	−0.1257
0.4597	0.96569	0.95765	0.94964	0.94289	−0.0775	−0.0955	−0.1105	−0.1295
0.5094	0.98092	0.97286	0.96483	0.95791	−0.0772	−0.0952	−0.1111	−0.1301
0.5496	0.99298	0.98491	0.97687	0.96982	−0.0763	−0.0943	−0.1122	−0.1312
0.6127	1.01142	1.00334	0.99530	0.98803	−0.0701	−0.0881	−0.1081	−0.1271
0.6444	1.02047	1.01239	1.00434	0.99696	−0.0649	−0.0829	−0.1029	−0.1219
0.6915	1.03369	1.02561	1.01754	1.01011	−0.0578	−0.0758	−0.0958	−0.1148
0.7516	1.05014	1.04206	1.03398	1.02624	−0.0458	−0.0638	−0.0838	−0.1028
0.7984	1.06263	1.05455	1.04647	1.03857	−0.0346	−0.0526	−0.0726	−0.0916
0.8599	1.07870	1.07063	1.06246	1.05437	−0.0235	−0.0415	−0.0527	−0.0717
0.9127	1.09214	1.08408	1.07584	1.06751	−0.0112	−0.0292	−0.0341	−0.0452
0.9843	1.10996	1.10176	1.09349	1.08484	−0.0016	−0.0034	−0.0046	−0.0053

ethanoldiol was found to be in good agreement with values published in the literature. The uncertainties in the density measurements are about $\pm 3 \cdot 10^{-5}$ g·cm^{-3}.

Kinematic viscosities of the binary mixtures of alkanol (1) + *N*-acetylmorpholine (2) systems were measured with a Schott-Gerate measuring system (AVA 300) consisting of a basic control unit, a measuring stand, a constant-temperature bath, and a calibrated Ubbelhode suspended level viscometer. Temperature fluctuations were limited to ± 0.01 K. The temperature was measured by a Hewlett-Packerd 2810-A Quartz thermometer. The flow time measurements were made automatically using two light barriers across the viscometer and an electronic timer with a precision of ± 0.01 s. Experiments were repeated a minimum of three times at each temperature for all compositions. The kinetic energy correction was considered not necessary on account of a long flow time obtained by a proper selection of the capillary. The uncertainty in viscosity measurements was ± 0.003 mPa·s.

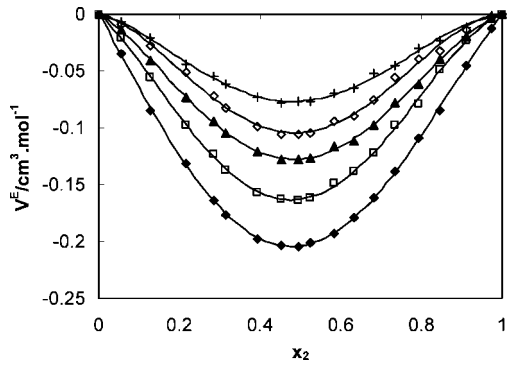

Figure 1. Excess molar volumes of the alkanol (1) + *N*-acetylmorpholine (2) systems at 293.15 K: ◆, ethanol (1) + NAM (2); □, 1-propanol (1) + NAM (2); ▲, 2-propanol (1) + NAM (2); ◇, 1-butanol (1) + NAM (2); +, 2-butanol (1) + NAM (2).

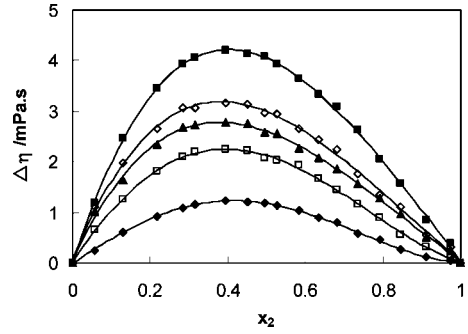

Figure 2. Viscosity deviations of the alkanol (1) + *N*-acetylmorpholine (2) systems at 293.15 K: ◆, ethanol (1) + NAM (2); □, 1-propanol(1) + NAM (2); ▲, 2-propanol (1) + NAM (2); ◇, 1-butanol (1) + NAM (2); ■, 2-butanol (1) + NAM (2).

Results and Discussion

The experimental values of density ρ and viscosity η of the binary mixtures of alkanol (1) + *n*-acetylmorpholine (2) at temperatures from (293.15 to 323.15) K over the whole mole fraction range are listed in Tables 2 and 3. The excess molar volumes V^E for these binary mixtures were obtained from the following relation

$$V^E = \frac{x_1M_1 + x_2M_2}{\rho} - \frac{x_1M_1}{\rho_1} - \frac{x_2M_2}{\rho_2} \quad (1)$$

where x_1 and x_2 are the mole fractions; M_1 and M_2 are molar mass; and ρ_1 and ρ_2 are the densities of the pure component liquids 1 and 2. ρ is the density of binary mixtures.

Deviations in viscosity $\Delta\eta$ were calculated from the following relation

$$\Delta\eta = \eta - x_1\eta_1 - x_2\eta_2 \quad (2)$$

where η is the viscosity of the binary mixtures and η_1 and η_2 are the viscosities of the pure component liquids 1 and 2, respectively.

The values of V^E and $\Delta\eta$ for each mixture were fitted to the Redlich−Kister polynomial equiation[12]

$$Y = x_1x_2\sum_{i=0}^{n} A_i(x_1 - x_2)^i \quad (3)$$

where $Y = V^E$ or $\Delta\eta$. A_i are adjustable parameters.

In each case, the optimum number of coefficients A_i was determined from an examination of the variation of the standard deviation

$$\sigma(Y) = \left[\sum \frac{(Y_{calcd} - Y_{exptl})}{n - m}\right]^{1/2} \quad (4)$$

where n is the total number of experimental points and m is the number of parameters. The fitting coefficients and the standard

deviations values σ for binary mixtures of alkanol (1) + *n*-acetylmorpholine (2) from (293.15 to 323.15) K are given in Table 4.

It can be observed from the experimental results in Table 2 and Figure 1 that V^E values are negative over the whole mole fraction range at temperatures from (293.15 to 323.15) K for binary mixtures of *N*-acetylmorpholine + ethanol, + 1-propanol, + 2-propanol, + 1-butanol, and + 2-butanol. The negative V^E values indicate that there is a volume contraction on mixing. The magnitude of V^E increases at each temperature with an increase of alkyl chain length in the molecule of alkanols, and this becomes more negative with the rise of temperature. Such behavior results from several opposing effects. Disruption of the alkanol and *N*-acetylmorpholine structures and new complex formation are due to hydrogen bonding between alkanol and NAM, the different molecular sizes and shapes of the two component liquids, and the interstitial accommodation effect. V^E becomes less negative for 2-alkanol + NAM mixtures than the corresponding 1-alkanol + NAM mixtures. The binary mixtures of 2-butanol + NAM have the smallest negative V^E values.

The negative V^E values at equimolar concentrations of the binary mixtures follow the order: ethanol > 1-propanol > 2-propanol > 1-butanol > 2-butanol.

Viscosity deviations $\Delta\eta$ versus the mole fraction x_2 at 293.15 K are given in Figure 2. It is observed that viscosity deviations $\Delta\eta$ are positive over the entire composition range and increase with increasing chain length of alkanol. Furthermore, the graphs of viscosity deviation $\Delta\eta$ against mole fraction x_2 present a maximum around the mole fraction $x_2 \approx 0.4$ as observed in Figure 2.

Conclusions

This paper reports new experimental data for the densities and viscosities of binary mixtures of *N*-acetylmorpholine +

Table 3. Viscosities, η, and Viscosity Deviationsa, $\Delta\eta$, for Alkanol (1) + *N*-Acetylmorpholine (2) from (293.15 to 323.15) K

	T/K									*T*/K							
x_2	293.15	303.15	313.15	323.15	293.15	303.15	313.15	323.15	x_2	293.15	303.15	313.15	323.15	293.15	303.15	313.15	323.15
	η/mPa·s				$\Delta\eta$/mPa·s					η/mPa·s				$\Delta\eta$/mPa·s			
ethanol (1) + *N*-acetylmorpholine (2)																	
0.0563	1.847	1.495	1.153	0.928	0.245	0.165	0.086	0.005	0.5832	6.499	5.472	4.199	3.343	1.027	0.947	0.868	0.787
0.1288	2.747	2.302	1.832	1.518	0.613	0.532	0.454	0.372	0.6341	6.728	5.638	4.275	3.358	0.884	0.804	0.725	0.644
0.2164	3.689	3.134	2.511	2.096	0.912	0.833	0.755	0.676	0.6813	6.984	5.832	4.387	3.413	0.791	0.712	0.634	0.553
0.2843	4.374	3.728	2.983	2.484	1.098	1.017	0.936	0.854	0.7348	7.169	5.948	4.407	3.369	0.584	0.504	0.425	0.344
0.3147	4.656	3.974	3.174	2.639	1.156	1.077	0.997	0.915	0.7921	7.459	6.164	4.522	3.417	0.452	0.372	0.293	0.213
0.3944	5.318	4.533	3.594	2.966	1.233	1.153	1.074	0.995	0.8452	7.653	6.289	4.554	3.434	0.256	0.176	0.097	0.066
0.4512	5.718	4.858	3.819	3.122	1.215	1.135	1.056	0.975	0.9127	8.019	6.569	4.788	3.615	0.126	0.046	0.041	0.038
0.4957	6.016	5.101	3.983	3.232	1.187	1.107	1.028	0.947	0.9734	8.395	6.932	5.046	3.797	0.056	0.041	0.038	0.031
0.5253	6.179	5.227	4.056	3.269	1.133	1.053	0.974	0.893									
1-propanol (1) + *N*-acetylmorpholine (2)																	
0.0542	3.211	2.607	2.089	1.678	0.663	0.585	0.505	0.424	0.5983	7.857	6.703	5.329	4.375	1.865	1.787	1.709	1.629
0.1279	4.268	3.591	2.958	2.472	1.254	1.177	1.098	1.016	0.6341	7.889	6.699	5.267	4.277	1.672	1.594	1.513	1.433
0.2156	5.382	4.614	3.842	3.268	1.812	1.733	1.654	1.572	0.6883	8.018	6.776	5.259	4.214	1.459	1.382	1.303	1.221
0.2811	6.079	5.246	4.369	3.728	2.095	2.017	1.936	1.854	0.7442	8.069	6.769	5.161	4.062	1.154	1.077	0.996	0.916
0.3166	6.397	5.529	4.598	3.925	2.188	2.111	2.032	1.952	0.7912	8.099	6.748	5.069	3.922	0.886	0.808	0.728	0.647
0.3902	6.922	5.978	4.928	4.183	2.247	2.169	2.089	2.008	0.8542	8.178	6.766	4.986	3.776	0.567	0.489	0.409	0.328
0.4533	7.294	6.294	5.142	4.331	2.226	2.149	2.065	1.983	0.9165	8.328	6.851	4.972	3.702	0.322	0.243	0.162	0.083
0.5022	7.478	6.414	5.189	4.331	2.087	2.009	1.929	1.848	0.9776	8.508	7.001	5.093	3.823	0.116	0.067	0.055	0.036
0.5437	7.679	6.578	5.289	4.388	2.033	1.955	1.875	1.794									
2-propanol (1) + *N*-acetylmorpholine (2)																	
0.0522	3.709	2.981	2.398	2.058	1.004	0.924	0.847	0.865	0.6113	8.421	7.202	5.778	4.799	2.278	2.198	2.121	2.040
0.1274	4.822	4.027	3.330	2.819	1.654	1.574	1.496	1.415	0.6342	8.356	7.116	5.658	4.656	2.072	1.992	1.914	1.833
0.2153	6.051	5.180	4.350	3.754	2.343	2.263	2.185	2.104	0.6888	8.479	7.191	5.651	4.597	1.859	1.779	1.702	1.621
0.2813	6.792	5.862	4.934	4.274	2.678	2.598	2.520	2.439	0.7522	8.573	7.229	5.593	4.478	1.563	1.483	1.405	1.324
0.3169	7.055	6.094	5.112	4.418	2.722	2.642	2.564	2.483	0.7976	8.575	7.191	5.487	4.328	1.286	1.206	1.128	1.047
0.3909	7.575	6.548	5.454	4.686	2.787	2.706	2.627	2.544	0.8555	8.612	7.176	5.389	4.174	0.967	0.886	0.811	0.731
0.4569	7.956	6.872	5.680	4.850	2.762	2.682	2.604	2.523	0.9231	8.559	7.065	5.172	3.892	0.498	0.418	0.340	0.259
0.4999	8.044	6.922	5.666	4.794	2.586	2.506	2.428	2.347	0.9812	8.649	7.104	5.163	3.893	0.231	0.151	0.112	0.098
0.5444	8.301	7.140	5.816	4.903	2.569	2.489	2.411	2.331									
1-butanol (1) + *N*-acetylmorpholine (2)																	
0.0555	4.367	3.576	2.739	1.957	1.115	1.036	0.955	0.875	0.6237	9.088	7.833	6.290	5.164	2.658	2.579	2.498	2.418
0.1321	5.668	4.813	3.879	3.051	1.987	1.907	1.824	1.745	0.6431	8.989	7.719	6.152	5.014	2.451	2.372	2.291	2.211
0.2165	6.805	5.881	5.042	4.160	2.652	2.572	2.689	2.607	0.6903	9.041	7.732	6.105	4.937	2.239	2.159	2.077	1.996
0.2844	7.590	6.613	5.581	4.657	3.058	2.979	2.988	2.905	0.7439	8.864	7.512	5.819	4.620	1.762	1.683	1.602	1.522
0.3126	7.757	6.756	5.600	4.662	3.067	2.988	2.907	2.827	0.7911	8.713	7.322	5.569	4.342	1.347	1.268	1.185	1.106
0.4042	8.369	7.294	6.023	5.030	3.167	3.088	3.007	2.927	0.8624	8.880	7.431	5.591	4.320	1.115	1.036	0.955	0.875
0.4673	8.697	7.570	6.220	5.191	3.142	3.063	2.981	2.903	0.9222	8.663	7.164	5.249	3.943	0.564	0.484	0.402	0.323
0.5033	8.878	7.734	6.310	5.257	3.122	3.055	2.943	2.864	0.9785	8.737	7.193	5.209	3.868	0.323	0.244	0.163	0.083
0.5562	9.001	7.801	6.341	5.256	2.949	2.869	2.787	2.708									
2-butanol (1) + *N*-acetylmorpholine (2)																	
0.0516	5.054	4.116	3.093	2.101	1.176	1.056	0.926	0.786	0.6127	10.291	8.960	7.323	6.082	3.658	3.538	3.408	3.268
0.1322	6.732	5.737	4.626	3.598	2.458	2.338	2.208	2.068	0.6444	10.110	8.757	7.086	5.830	3.322	3.202	3.072	2.932
0.2217	8.167	7.110	5.901	4.833	3.454	3.334	3.204	3.064	0.6915	10.114	8.728	7.005	5.728	3.094	2.974	2.844	2.704
0.2879	8.981	7.878	6.596	5.499	3.943	3.823	3.693	3.553	0.7516	9.956	8.527	6.739	5.436	2.641	2.521	2.391	2.251
0.3188	9.257	8.132	6.816	5.706	4.067	3.947	3.817	3.677	0.7984	9.588	8.127	6.288	4.964	2.044	1.924	1.794	1.654
0.3996	9.785	8.603	7.199	6.052	4.198	4.078	3.948	3.808	0.8599	9.409	7.905	5.998	4.647	1.563	1.443	1.313	1.173
0.4597	10.024	8.800	7.330	6.157	4.142	4.022	3.892	3.752	0.9127	8.959	7.419	5.454	4.079	0.854	0.734	0.604	0.464
0.5094	10.203	8.944	7.420	6.225	4.077	3.957	3.827	3.687	0.9843	8.843	7.252	5.209	3.918	0.386	0.266	0.136	0.112
0.5496	10.272	8.985	7.418	6.204	3.949	3.829	3.699	3.559									

Table 4. Coefficients of the Redlich−Kister Equation and Standard Deviation for V^E and $\Delta\eta$ of the Alkonal (1) + NAM (2) System

T/K	property	A_0	A_1	A_2	A_3	σ
	ethanol (10) + *N*-acetylmorpholine (2)					
293.15	V^E/cm^3·mol^{-1}	−0.918	−0.101	0.278	0.030	0.0014
	$\Delta\eta$/maP·s	4.664	3.074	−1.772	−1.886	0.046
303.15	V^E/cm^3·mol^{-1}	−1.279	−0.390	0.520	0.275	0.0013
	$\Delta\eta$/maP·s	4.406	3.319	−2.746	−2.649	0.043
313.15	V^E/cm^3·mol^{-1}	−1.732	−0.395	0.907	0.296	0.0012
	$\Delta\eta$/maP·s	4.111	3.659	−3.370	3.931	0.031
323.15	V^E/cm^3·mol^{-1}	−2.214	−0.344	0.755	0.205	0.0017
	$\Delta\eta$/maP·s	3.823	3.866	−3.943	−5.041	0.034
	1-propanol (1) + *N*-acetylmorpholine (2)					
293.15	V^E/cm^3·mol^{-1}	−0.666	−0.086	0.401	0.001	0.0018
	$\Delta\eta$/maP·s	8.541	4.915	0.163	−0.736	0.044
303.15	V^E/cm^3·mol^{-1}	−0.906	−0.055	0.530	−0.044	0.0014
	$\Delta\eta$/maP·s	8.189	4.679	−1.349	−0.197	0.032
313.15	V^E/cm^3·mol^{-1}	−1.104	−0.082	0.146	−0.001	0.0011
	$\Delta\eta$/maP·s	7.936	4.951	−2.348	−1.011	0.035
323.15	V^E/cm^3·mol^{-1}	−1.318	0.007	−0.169	−0.303	0.0012
	$\Delta\eta$/maP·s	7.694	5.126	−3.456	−1.593	0.033
	2-propanol (1) + *N*-acetylmorpholine (2)					
293.15	V^E/cm^3·mol^{-1}	−0.512	−0.044	0.306	0.026	0.0016
	$\Delta\eta$/maP·s	10.303	3.971	3.079	3.889	0.023
303.15	V^E/cm^3·mol^{-1}	−0.643	−0.039	−0.088	0.055	0.0013
	$\Delta\eta$/maP·s	9.754	4.875	1.421	1.306	0.022
313.15	V^E/cm^3·mol^{-1}	−0.801	−0.037	−0.228	0.050	0.0015
	$\Delta\eta$/maP·s	9.863	4.205	0.716	3.068	0.018
323.15	V^E/cm^3·mol^{-1}	−0.945	−0.065	−0.552	0.134	0.0014
	$\Delta\eta$/maP·s	9.365	4.653	1.337	2.213	0.037
	1-butanol (1) + *N*-acetylmorpholine (2)					
293.15	V^E/cm^3·mol^{-1}	−0.423	−0.009	0.319	0.002	0.0021
	$\Delta\eta$/maP·s	12.068	4.788	2.335	3.335	0.046
303.15	V^E/cm^3·mol^{-1}	−0.557	−0.096	−0.032	0.333	0.0019
	$\Delta\eta$/maP·s	11.851	4.899	1.171	2.959	0.031
313.15	V^E/cm^3·mol^{-1}	−0.723	−0.006	0.0221	0.151	0.0023
	$\Delta\eta$/maP·s	11.715	5.676	0.039	1.697	0.022
323.15	V^E/cm^3·mol^{-1}	−0.865	−0.052	−0.249	0.304	0.0024
	$\Delta\eta$/maP·s	11.489	5.783	−1.129	1.325	0.028
	2-butanol (1) + *N*-acetylmorpholine (2)					
293.15	V^E/cm^3·mol^{-1}	−0.292	−0.121	0.096	−0.131	0.0023
	$\Delta\eta$/maP·s	16.433	4.998	0.911	3.079	0.022
303.15	V^E/cm^3·mol^{-1}	−0.391	−0.025	0.118	0.088	0.0016
	$\Delta\eta$/maP·s	16.089	5.254	−0.809	2.213	0.046
313.15	V^E/cm^3·mol^{-1}	−0.456	0.002	0.136	0.104	0.0034
	$\Delta\eta$/maP·s	15.531	5.531	−2.696	1.274	0.044
323.15	V^E/cm^3·mol^{-1}	−0.515	0.058	−0.069	−0.062	0.0033
	$\Delta\eta$/maP·s	15.318	5.829	−0.4715	0.264	0.032

ethanol, + 1-propanol, + 2-propanol, + 1-butanol, and + 2-butanol over the whole mole fraction range at temperatures of (293.15 to 323.15) K and atmospheric pressure. The excess molar volumes V^E and viscosity deviations $\Delta\eta$ were determined from the experimental results of the density and viscosity and fitted to the Redlich−Kister polynomial equation. The excess molar volumes for all the binary mixtures of alkanol + NAM are negative over the whole mole fraction range. On the contrary, the viscosity deviations for these systems at selected temperatures are all positive over the whole mole fraction range.

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