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Viscosities of some *n*-alkoxyethanols with ethyl *tert*-butyl ether at $T=(293.15, 298.15 \text{ and } 303.15)$ K

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Abstract

Viscosities at $T=(293.15, 298.15, \text{and } 303.15)$ K in the binary mixtures of ethyl *tert*-butyl ether with 2-methoxyethanol, 2-(2-methoxyethoxy) ethanol and 2-[2-(2-methoxyethoxy)ethoxy]ethanol have been measured as a function of composition. From the experimental data, deviations in the viscosity from a mole fraction average and excess energies of activation for viscous flow have been calculated. The viscosity data were correlated with equations of Grunberg and Nissan, Auslaender, and McAllister. The results for $\Delta \ln \eta$ and ΔG^{*E} are discussed on the basis of intermolecular interactions between the components of the analysed mixtures.

Keywords: Ethyl *tert*-butyl ether; 2-methoxyethanol; 2-(2-methoxyethoxy)ethanol; 2-[2-(2-methoxyethoxy)ethoxy]ethanol; Viscosity; Intermolecular interactions

1. Introduction

In earlier paper [1], we reported the results of our investigations of the excess molar volumes for binary mixtures of ethyl *tert*-butyl ether (ETBE) with 2-methoxyethanol (ME), 2-(2-methoxyethoxy)ethanol (DEM) and 2-[2-(2-methoxyethoxy)ethoxy]ethanol (TEM) at different temperatures. These results suggested the relative importance of the intermolecular interactions between the ethyl *tert*-butyl ether and alkoxyethanol molecules in the studied binary liquid mixtures.

In continuation of these investigations, the present paper reports the viscosity η, deviations in viscosity $\Delta \ln \eta$ and excess energies of activation for viscous flow ΔG^{*E} for binary mixtures containing ETBE with ME, DEM and TEM over the whole concentration range at $T=(293.15, 298.15, \text{and } 303.15)$ K.

2. Experimental section

2.1. Materials

The following materials with mole fraction purity as stated were used: 2-methoxyethanol (Merck–Schuchardt FRG, GC >0.99 mole fraction), 2-(2-methoxyethoxy)ethanol (Merck–Schuchardt FRG, GC >0.98 mole fraction) and 2-{2-(2-methoxyethoxy)ethoxy}ethanol (Fluka, Switzerland, purum, GC ≥0.97 mole fraction). All alkoxyethanols were further purified by the methods described by Pal et al. [2]. Additionally ethyl *tert*-butyl ether (Fluka, Switzerland, purum, GC ≥0.97 mole fraction) was used. It was purified by fractional distillation using a spinning band distillation column after drying it over molecular sieves (type 4A). The purity of this solvent was confirmed by gas chromatography to be 0.999 mol fraction. The mixtures were prepared just before use by mass on a Sartorius balance of the type ING1, operating in a dry box to avoid atmospheric moisture. Conversion to molar quantities was based on the relative atomic mass table published in 1985, next issued by IUPAC in 1986. The uncertainty in the mole fraction ethyl *tert*-butyl ether is estimated to be less than $\pm 1 \cdot 10^{-4}$. Liquids were stored in dry-box over phosphorus pentoxide and degassed

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Table 1
Viscosities of the pure components at T=298.15 K

Solvent	η (mPa s)	η (mPa s)
	Experimental	Literature
2-methoxyethanol	1.544	1.532 [2] 1.5414 [12]
2-(2-methoxyethoxy)ethanol	3.574	3.448 [2] 3.565 [14] 3.480 [13]
2-[2-(2-methoxyethoxy)ethoxy]ethanol	6.254	6.252 [2] 6.240 [13] 6.586 [14] 6.253 [15]
ethyl *tert*-butyl ether	0.504	–

by ultrasound just before the experiment. Experimental viscosities for the pure solvents, at T=298.15 K, are compared with values available in the literature and listed in Table 1. The differences between the measured and literature values can be ascribed to different measurement methods used, and to the different purification procedures employed by other authors [3].

2.2. Measurements

The flow times of the mixtures and the pure liquids were measured in a ViscoClock (made by Schott), equipped with an Ubbelohde capillary viscometer. Double distilled, deionized and degassed water with a specific conductance of $1 \cdot 10^{-9}$ S· m^{-1} was used for the calibration. The time measurement tolerance was ±0.005%, and the display accuracy was ±0.01 s. The uncertainty in the viscosity measurements was ±0.001 mPa s.

Table 2
Viscosity (η) and deviations in viscosity ($\Delta\ln\eta$) for ethyl *tert*-butyl ether (1) + 2-methoxyethanol (2) binary mixtures at T=(293.15, 298.15, and 303.15) K

ETBE (1)+ME (2)						
x_1	η (mPa s)			$\Delta\ln\eta$		
	293.15 K	298.15 K	303.15 K	293.15 K	298.15 K	303.15 K
0.0000	1.708	1.544	1.404	–	–	–
0.0501	1.598	1.452	1.327	−0.0079	−0.0051	−0.0027
0.1000	1.493	1.361	1.246	−0.0182	−0.0142	−0.0114
0.1508	1.386	1.267	1.164	−0.0327	−0.0286	−0.0247
0.2000	1.291	1.183	1.089	−0.0466	−0.0424	−0.0385
0.2512	1.198	1.100	1.015	−0.0616	−0.0579	−0.0538
0.2990	1.118	1.029	0.951	−0.0748	−0.0708	−0.0674
0.3489	1.041	0.961	0.890	−0.0878	−0.0836	−0.0801
0.4000	0.971	0.898	0.834	−0.0984	−0.0942	−0.0898
0.4503	0.909	0.842	0.784	−0.1061	−0.1022	−0.0974
0.4990	0.854	0.793	0.740	−0.1111	−0.1072	−0.1024
0.5500	0.803	0.748	0.700	−0.1127	−0.1090	−0.1040
0.6100	0.750	0.700	0.657	−0.1110	−0.1081	−0.1027
0.6599	0.711	0.665	0.625	−0.1064	−0.1032	−0.0982
0.7000	0.682	0.639	0.602	−0.1008	−0.0978	−0.0931
0.7511	0.649	0.610	0.575	−0.0908	−0.0878	−0.0840
0.8000	0.621	0.584	0.552	−0.0786	−0.0766	−0.0721
0.8489	0.595	0.561	0.532	−0.0650	−0.0620	−0.0558
0.9000	0.571	0.540	0.512	−0.0459	−0.0433	−0.0390
0.9490	0.550	0.521	0.495	−0.0262	−0.0239	−0.0200
1.0000	0.532	0.504	0.478	–	–	–

Table 3
Viscosity (η) and deviations in viscosity ($\Delta\ln\eta$) for ethyl *tert*-butyl ether (1) + 2-(2-methoxyethoxy)ethanol (2) binary mixtures at T=(293.15, 298.15, and 303.15) K

ETBE (1)+DEM (2)						
x_1	η (mPa s)			$\Delta\ln\eta$		
	293.15 K	298.15 K	303.15 K	293.15 K	298.15 K	303.15 K
0.0000	3.906	3.574	3.152	–	–	–
0.0501	3.519	3.231	2.865	−0.0045	−0.0028	−0.0011
0.1000	3.158	2.906	2.589	−0.0132	−0.0111	−0.0083
0.1459	2.847	2.627	2.351	−0.0253	−0.0221	−0.0181
0.1998	2.518	2.328	2.097	−0.0406	−0.0371	−0.0306
0.2556	2.218	2.060	1.862	−0.0563	−0.0504	−0.0445
0.3031	1.991	1.855	1.683	−0.0695	−0.0619	−0.0559
0.3521	1.784	1.669	1.520	−0.0819	−0.0719	−0.0651
0.4004	1.605	1.506	1.377	−0.0913	−0.0796	−0.0729
0.4511	1.438	1.355	1.244	−0.0999	−0.0862	−0.0792
0.4998	1.299	1.227	1.130	−0.1047	−0.0901	−0.0831
0.5628	1.142	1.082	1.001	−0.1075	−0.0921	−0.0858
0.5997	1.062	1.007	0.934	−0.1068	−0.0918	−0.0855
0.6621	0.942	0.894	0.833	−0.1019	−0.0887	−0.0824
0.6997	0.879	0.834	0.779	−0.0963	−0.0846	−0.0783
0.7411	0.816	0.773	0.725	−0.0887	−0.0788	−0.0722
0.7995	0.736	0.697	0.657	−0.0749	−0.0679	−0.0597
0.8401	0.687	0.651	0.616	−0.0625	−0.0573	−0.0478
0.8998	0.623	0.591	0.560	−0.0422	−0.0377	−0.0305
0.9498	0.575	0.545	0.518	−0.0221	−0.0194	−0.0137
1.0000	0.532	0.504	0.478	–	–	–

Table 4
Viscosity (η) and deviations in viscosity ($\Delta\ln\eta$) for ethyl *tert*-butyl ether (1) + 2-[2-(2-methoxyethoxy)ethoxy]ethanol (2) binary mixtures at T=(293.15, 298.15, and 303.15) K

ETBE (1)+TEM (2)						
x_1	η (mPa s)			$\Delta\ln\eta$		
	293.15 K	298.15 K	303.15 K	293.15 K	298.15 K	303.15 K
0.0000	7.211	6.254	5.412	–	–	–
0.0504	6.269	5.479	4.777	−0.0086	−0.0053	−0.0026
0.1000	5.458	4.800	4.209	−0.0179	−0.0128	−0.0088
0.1509	4.734	4.186	3.689	−0.0274	−0.0215	−0.0172
0.2025	4.101	3.643	3.225	−0.0365	−0.0305	−0.0262
0.2489	3.607	3.216	2.859	−0.0439	−0.0382	−0.0341
0.3007	3.129	2.801	2.501	−0.0510	−0.0458	−0.0421
0.3511	2.729	2.453	2.199	−0.0565	−0.0519	−0.0486
0.3999	2.394	2.159	1.944	−0.0604	−0.0565	−0.0535
0.4508	2.091	1.893	1.712	−0.0630	−0.0597	−0.0570
0.5001	1.837	1.669	1.516	−0.0641	−0.0613	−0.0587
0.5493	1.616	1.475	1.345	−0.0638	−0.0613	−0.0589
0.6000	1.418	1.300	1.192	−0.0620	−0.0597	−0.0573
0.6503	1.248	1.149	1.058	−0.0588	−0.0565	−0.0539
0.6998	1.102	1.019	0.943	−0.0544	−0.0519	−0.0489
0.7491	0.974	0.906	0.842	−0.0488	−0.0458	−0.0424
0.7999	0.860	0.803	0.751	−0.0417	−0.0382	−0.0342
0.8509	0.759	0.712	0.669	−0.0332	−0.0294	−0.0250
0.9001	0.674	0.635	0.600	−0.0237	−0.0201	−0.0157
0.9498	0.599	0.566	0.536	−0.0127	−0.0100	−0.0069
1.0000	0.532	0.504	0.478	–	–	–