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Excess volumes and viscosities of the ternary system water–trifluoroethanol–tetraethylene glycol dimethyl ether at 303.15 K[☆]

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Abstract

Densities and kinematic viscosities of the ternary mixture water–trifluoroethanol–tetraethylene glycol dimethyl ether have been measured at 303.15 K and atmospheric pressure over the entire range of compositions. Excess molar volumes and excess viscosities were obtained from the experimental results. The excess volumes were negative and excess viscosities were positive, indicating the asymmetric composition dependence of the two thermodynamic properties. The excess volumes have been correlated by the Redlich–Kister equation and the kinematic viscosity data have been fitted using the Stephan and Heckenberger correlation.

Keywords: Density; Excess properties; Viscosity

1. Introduction

A knowledge of the densities and viscosities of new working fluids and fluid mixtures is essential to understand the molecular interactions between the molecules and to develop new theoretical models, and also in the engineering applications of absorption heat pumps and heat transformers. The variation of these properties with temperature and composition of the mixtures containing polar and hydrogen-bonded complexes is due to an increase or decrease in hydrogen-bonding interaction.

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Until now, most absorption refrigeration processes have been run with ammonia–water or water–lithium bromide pairs. But these have important disadvantages because of the higher pressure at high temperature in the ammonia–water pair and because the temperature increase is limited due to incomplete miscibility in the water–lithium bromide pair. Therefore, organic mixtures as the absorbent, such as dimethyl ether polyethylene glycol with other polar organic molecules (working fluids), have been suggested by Stephan and Seher [1].

The thermal stability, vapor–liquid equilibrium, enthalpy, density and viscosity were measured for the ternary system trifluoroethanol (TFE)–water–tetraethylene glycol dimethyl ether (TEGDME) by Stephan and Hengerer [2]. In their study, the liquid density was measured with an aerometer, and the viscosity with a falling-ball viscometer. The estimated error was ± 1% for density and ± 10% for the viscosity. They also presented the density and viscosity at 25°C in triangular 3-D plots.

Densities, viscosities, excess molar volumes, dynamic viscosities and Gibbs activation energies at 303.15 K of the binary mixtures TFE–H_2O, TEGDME–H_2O and TFE–TEGDME were published by Olivé et al. [3].

This work reports the precise measurement of density and kinematic viscosity for the system H_2O–TFE–TEGDME at 303.15 K by other techniques. The excess molar volume and excess viscosities were calculated from the density and kinematic viscosity results. The excess volumes were fitted by the Redlich–Kister equation and the viscosity data were correlated by the Stephan and Heckenberger equation [4]. The excess volume and excess viscosity isolines are presented graphically.

2. Experimental

Densities of the pure liquids and liquid mixtures were measured using a densimeter (Anton Paar DMA602H-DMA60) at 303.15 K. The temperature of the vibrating tube was regulated to better than ± 0.005 K using a Julabo F20 thermostat. Temperatures were read from a calibrated precision thermometer (Anton Paar MKT100). Density calibration was carried out with air and double-distilled water and the precision of the measured densities is estimated to higher than $\pm 2 \times 10^{-5}$ g cm^{-3}. All weighings were made on a Mettler AE260 balance. The possible error in the mole fractions is estimated to be less than ± 0.0001.

Kinematic viscosities of the pure liquids and their mixtures were measured with an (AVS300) Schott viscosimeter, consisting of a basic control unit, a measuring stand, a thermostat and a calibrated Ubbelöhde suspended level viscometer. The viscosimeter was recalibrated using benzene and *n*-heptane. The Hagenbach correction was applied for the Ubbelöhde viscometer supplied by Schott-Geräte. Time measurements were made automatically between two measuring levels due to the change in light intensity, converted to a digital electrical signal to start the internal crystal-controlled clock with readout display. The electronic timer can measure time to ± 0.01 s. The temperature was kept constant to ± 0.005 K. The estimated error in the kinematic viscosity was $\pm 5 \times 10^{-4}$ mm^2 s^{-1}.

2.1. Materials and solutions

Trifluoroethanol (Fluka > 99%) was purified by refluxing a large volume for several days and by fractional distillation. TEGDME (Fluka > 98%) was used without further purification. H_2O was deionized, distilled once from alkaline potassium permanganate and twice from itself. TFE and TEGDME were carefully dried with molecular sieve type 4A (Fluka). All chemicals were partially degassed before use. The purity of the chemicals was verified by measuring the density and viscosity at 298.15 and 303.15 K which were in agreement with literature values [5, 6].

3. Results and discussion

The experimental results for the pure components at 303.15 K are reported in Table 1.

The experimental values of densities and viscosities of the ternary system are obtained by adding the third component to a constant relationship of the other two. Molar excess volumes were calculated using the equation

$$V^{E}_{123} = x_1 M_1(\rho^{-1} - \rho_1^{-1}) + x_2 M_2(\rho^{-1} - \rho_2^{-1}) + x_3 M_3(\rho^{-1} - \rho_3^{-1}) \tag{1}$$

where M_1, M_2 and M_3 are the molecular weights of the components, ρ_1, ρ_2 and ρ_3 are the densities of the pure components and ρ is the density of the solution. The experimental densities and excess molar volumes for the ternary system are shown in Table 2.

Excess molar properties presenting asymmetrical composition dependences are difficult to fit. Different smoothing equations have been proposed for V^E of aqueous mixtures, mainly for alcohol–water. We found that the best fits were obtained with the equation of Ott et al. [7] which includes an exponential switching factor

$$V^E = x_1 x_2 [\exp(-\alpha x_1) \sum_{i=0}^{1} A_i (1 - 2x_1)^i + (1 - \exp(-\alpha x_1)) \sum_{i=0}^{3} B_i (1 - 2x_1)^i] \tag{2}$$

Different combinations with the binary systems give different results. The parameters A_i, B_i and α calculated by unweighted least-squares using a Marquard algorithm are shown in Table 3, together with the standard deviation s. Comparison with the experiments of Svejda et al. [8] for the V^E of the binary TFE(1)–TEGDME(2) and of

Table 1
Properties of the pure components at 303.15 K

Substance	ρ/(g cm^{-3})	η/(mPas)
Trifluoroethanol	1.37382	1.5521
Tetraethylene glycol dimethyl ether	1.00185	2.9478
Water	0.99564	0.7987

Table 2
Densities and excess volumes for water(1)–trifluoroethanol(2)–tetra-ethylene glycol dimethyl ether(3) at 303.15 K

x_2	x_3	$\rho/(\mathrm{g\,cm^{-3}})$	$V^{\mathrm{E}}_{123}/(\mathrm{cm^3\,mol^{-1}})$
0.0531	0.4792	1.02260	−1.0531
0.0476	0.5326	1.01910	−0.9676
0.0679	0.7283	1.01528	−0.4630
0.0995	0.6013	1.02464	−0.6514
0.1232	0.5062	1.03379	−0.7666
0.1315	0.4732	1.03753	−0.7956
0.2061	0.1744	1.10331	−0.9727
0.0488	0.9076	1.00876	−0.1036
0.0389	0.8597	1.00840	−0.2357
0.0777	0.8261	1.01401	−0.2218
0.1194	0.8071	1.01973	−0.1522
0.1208	0.7864	1.02055	−0.1931
0.0533	0.7519	1.01264	−0.4524
0.2243	0.7109	1.03715	−0.1133
0.1322	0.6219	1.02864	−0.5059
0.1812	0.4817	1.04581	−0.6466
0.2056	0.4120	1.05704	−0.6879
0.2384	0.3182	1.07685	−0.7347
0.2574	0.2638	1.09211	−0.7678
0.2768	0.2083	1.11162	−0.7816
0.2987	0.1457	1.14069	−0.7678
0.3142	0.6286	1.05448	−0.0898
0.1763	0.6543	1.03344	−0.3213
0.2759	0.5752	1.05314	−0.2448
0.3404	0.5594	1.06403	−0.1527
0.4346	0.5181	1.08215	−0.0685
0.1202	0.7339	1.02222	−0.3028
0.1005	0.6550	1.02239	−0.5198
0.2222	0.5901	1.04405	−0.3388
0.9803	0.0044	1.36784	−0.0245
0.9250	0.0123	1.35539	−0.0971
0.8943	0.0330	1.33267	−0.1394
0.5706	0.0260	1.29526	−0.4753
0.4452	0.0395	1.25407	−0.5886
0.3750	0.0445	1.23052	−0.6599
0.3147	0.6298	1.05446	−0.0872
0.3568	0.5802	1.06452	−0.1031
0.5054	0.4054	1.10933	−0.1055
0.6895	0.1889	1.20171	−0.1568
0.7590	0.1071	1.25709	−0.1948
0.7803	0.0820	1.27775	−0.2065
0.0367	0.6402	1.01339	−0.7694
0.6467	0.0763	1.26143	−0.3456
0.6316	0.0979	1.24285	−0.3381
0.5941	0.1515	1.20372	−0.3196
0.5759	0.1775	1.18769	−0.3117
0.5483	0.2169	1.16617	−0.2929

Table 2 *(continued)*

x_2	x_3	ρ/(g cm^{-3})	V^E_{123}/(cm^3 mol^{-1})
0.5112	0.2699	1.14175	−0.2781
0.4668	0.3334	1.11758	−0.2609
0.4404	0.3710	1.10521	−0.2423
0.3577	0.4891	1.07412	−0.2362
0.3331	0.5243	1.06638	−0.2174
0.3568	0.4904	1.07374	−0.2247
0.2308	0.6704	1.04024	−0.1765
0.3240	0.0748	1.18958	−0.7378
0.1010	0.7116	1.02038	−0.4018
0.0954	0.7274	1.01907	−0.3825
0.1966	0.5225	1.04501	−0.5235
0.3654	0.3315	1.09982	−0.4424
0.4460	0.2894	1.12455	−0.3558
0.5094	0.2562	1.14557	−0.2957
0.4183	0.4983	1.08216	−0.1159
0.2411	0.4966	1.05455	−0.4560
0.2793	0.4032	1.07187	−0.5231
0.5205	0.0536	1.25739	−0.5117
0.5030	0.0854	1.22716	−0.5061
0.4703	0.1450	1.18273	−0.4882
0.4462	0.1887	1.15742	−0.4769
0.4254	0.2265	1.13916	−0.4700
0.4016	0.2698	1.12128	−0.4558
0.3034	0.4484	1.07025	−0.4047
0.2829	0.4856	1.06251	−0.3787
0.2164	0.6065	1.04209	−0.3227
0.1788	0.6751	1.03276	−0.2783
0.4238	0.0586	1.23045	−0.6072
0.4086	0.0925	1.19995	−0.6141
0.3983	0.1154	1.18274	−0.6223
0.3842	0.1467	1.16244	−0.6273
0.3642	0.1911	1.13845	−0.6139
0.3490	0.2249	1.12326	−0.6006
0.3090	0.3137	1.09239	−0.5765
0.2915	0.3525	1.08183	−0.5661
0.7198	0.0496	1.29545	−0.2890
0.5512	0.1007	1.22613	−0.4363
0.0698	0.8453	1.01255	−0.1940
0.3762	0.1644	1.15217	−0.6183
0.2522	0.4400	1.06239	−0.5295
0.5848	0.3120	1.14220	−0.1101
0.1158	0.8638	1.01768	−0.0382
0.2243	0.7362	1.03589	−0.0670
0.1885	0.7782	1.02939	−0.0462
0.4788	0.3163	1.12356	−0.2582
0.0804	0.1951	1.05838	−1.3443
0.0737	0.2626	1.04546	−1.3171
0.0703	0.2964	1.04037	−1.2869
0.0717	0.2825	1.04242	−1.3040

Table 2 *(continued)*

x_2	x_3	$\rho/(\mathrm{g\,cm^{-3}})$	$V^E_{123}/(\mathrm{cm^3\,mol^{-1}})$
0.0610	0.3895	1.02973	−1.1847
0.0096	0.9041	1.00406	−0.1972
0.0721	0.2783	1.04305	−1.3083
0.0661	0.3383	1.03504	−1.2417
0.2263	0.0983	1.14245	−0.9175
0.1864	0.2529	1.07720	−0.9556
0.1520	0.3909	1.04882	−0.8737
0.1298	0.4798	1.03678	−0.7942
0.0913	0.6340	1.02196	−0.6070
0.7170	0.1568	1.22156	−0.1718
0.5845	0.3122	1.14212	−0.1123
0.6092	0.2836	1.15409	−0.1216
0.2446	0.7123	1.03977	−0.0743
0.0801	0.2301	1.05222	−1.3324
0.1528	0.2119	1.07732	−1.1029
0.2760	0.1811	1.12049	−0.8052
0.2936	0.1767	1.12664	−0.7664
0.3151	0.1713	1.13424	−0.7253
0.3371	0.1658	1.14209	−0.6900
0.4120	0.1471	1.16869	−0.5748
0.2431	0.1893	1.10875	−0.8652
0.7388	0.1831	1.21218	−0.1275
0.6817	0.1689	1.20977	−0.1876
0.6576	0.1630	1.20867	−0.2175
0.6243	0.1547	1.20718	−0.2635
0.6001	0.1487	1.20603	−0.2990
0.3920	0.0975	1.19230	−0.6334
0.0456	0.0113	1.07138	−0.4319
0.1756	0.2961	1.06667	−0.9468
0.0966	0.3213	1.04421	−1.1618
0.0485	0.1405	1.05617	−1.3832
0.0676	0.1182	1.06968	−1.2859
0.0995	0.0743	1.09932	−1.0617
0.1162	0.0923	1.10093	−1.1152
0.1378	0.0920	1.11094	−1.0754
0.8241	0.1156	1.26123	−0.1496
0.8483	0.0641	1.30069	−0.1661
0.8248	0.0331	1.32465	−0.1967

McGee et al. [9] for H_2O(1)–TEGDME(2) agree well with our results. The binary parameters for TFE(1)–H_2O(2), TFE(1)–TEGDME(2) and H_2O(1)–TEGDME(2) were presented in our earlier communication [3].

Excess volume data for the ternary system were fitted with a Redlich–Kister-type equation

$$V^E_{123} = V^E_{12} + V^E_{13} + V^E_{23} + x_1x_2x_3[A_0 + A_1(x_2 - x_1) + A_2(x_3 - x_1) + A_3(x_3 - x_2)] \quad (3)$$

Table 3
Parameters and standard deviation of Eq. (2) for different combination of the binary systems at 303.15 K

System	α	A_0	A_1	B_0	B_1	B_2	B_3	s
TFE–H_2O	21.3881	−27.1699	20.8985	−2.1885	−1.4213	−1.0442	−0.8360	0.0044
H_2O–TFE	0.10499	−1.44005	0.30289	−16.1270	5.4771	−13.6359	19.3490	0.0066
TEGDME–H_2O	17.8222	−70.9822	54.9607	−4.8272	−4.2349	−3.6788	−2.2086	0.0059
H_2O–TEGDME	−0.17714	−1.55112	−0.79636	33.8085	−16.6145	25.1916	−23.5627	0.0115
TFE–TEGDME	−0.03003	−0.2582	−0.4254	−13.9467	−28.2255	−51.5140	−171.751	0.0072
TEGDME–TFE	4.65575	−1.44715	−3.0963	0.11078	0.76959	1.50457	1.09670	0.0032

where x_i is the mole fraction of component i in the ternary mixture, and V_{ij}^E are calculated by Eq. (2).

The designation of the compounds 1, 2 and 3 in the mixture is important due to the assymetrical nature of the binaries. Of all the combinations considered, H_2O(1)–TFE(2)–TEGDME(3) gives the lowest standard deviation. The values of the coeffi-

Table 4
Parameters and standard deviation s of Eq. (3) for the ternary system H_2O(1)–TFE(2)–TEGDME(3) at 303.15 K

A_0	A_1	A_2	A_3	s
4.01418	−3.80316	−1.39047	−1.35607	0.0092

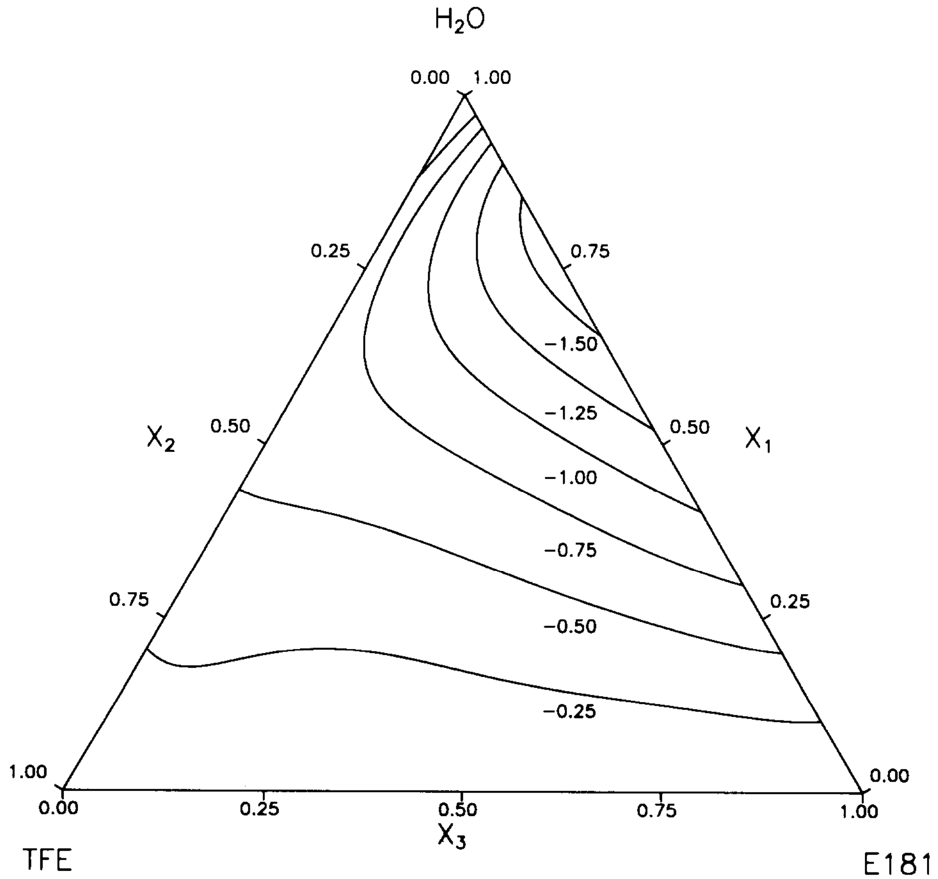

Fig. 1. Excess volume isolines for the mixture water(1)–trifluoroethanol(2)–tetraethylene glycol dimethyl ether(3) at 303.15 K.

cients and standard deviation of Eq. (3) for the suggested order are listed in Table 4. All the binary mixtures, TFE–TEGDME, TFE–H_2O and TEGDME–H_2O, exhibit negative V^E values with a minimum of -0.1509, -0.6327 and -1.6011 cm^{-3} mol^{-1} respectively. This shows that the two binaries exhibiting the largest absolute values in their minima are TEGDME–H_2O and TFE–H_2O, with water being the compound designated as 1 in both binary systems. Fig. 1 shows the excess molar volume isolines for the ternary mixture at 303.15 K.

Table 5 shows the experimental kinematic viscosity, and calculated density and dynamic viscosity data at 303.15 K. The kinematic viscoity data have been correlated

Table 5
Densities, kinematic viscosities and dynamic viscosities for water(1)–TFE(2)–TEGDME(3) at 303.15 K

x_2	x_3	$\rho/(g\ cm^3)$	$\nu/(mm^2\ s^{-1})$	$\eta/(mPas)$
0.0912	0.1052	1.07765	3.9334	4.2388
0.0872	0.1437	1.06751	4.3055	4.5962
0.0796	0.2185	1.05457	4.1936	4.4224
0.0772	0.2426	1.05055	4.1065	4.3141
0.0668	0.3445	1.03563	3.8521	3.9894
0.0640	0.3712	1.03238	3.7574	3.8791
0.0531	0.4792	1.02260	3.4745	3.5530
0.0476	0.5327	1.01910	3.3460	3.4099
0.0679	0.7283	1.01528	3.0727	3.1197
0.0995	0.6013	1.02464	3.1369	3.2142
0.1232	0.5062	1.03389	3.2156	3.3246
0.1315	0.4732	1.03753	3.2666	3.3892
0.1715	0.3129	1.06354	3.5550	3.7809
0.1855	0.2565	1.07670	3.5970	3.8729
0.1531	0.3863	1.04989	3.3893	3.5584
0.1944	0.2240	1.08630	3.5847	3.8941
0.2161	0.1744	1.10294	3.4995	3.8597
0.2166	0.1320	1.12105	3.3132	3.7143
0.0488	0.9076	1.00876	2.9778	3.0039
0.0420	0.9276	1.00751	2.9364	2.9585
0.0389	0.8597	1.00840	2.9847	3.0098
0.0777	0.8261	1.01401	2.9814	3.0232
0.1194	0.8071	1.01964	2.9262	2.9837
0.1308	0.7986	1.02136	2.8707	2.9320
0.1208	0.7864	1.02055	2.9350	2.9953
0.0533	0.7519	1.01264	3.0608	3.0995
0.1837	0.7408	1.03027	2.8521	2.9384
0.2243	0.7109	1.03715	2.8339	2.9392
0.1322	0.6219	1.02864	3.0506	3.1380
0.1812	0.4817	1.04581	3.1296	3.2730
0.2056	0.4120	1.05704	3.2052	3.3880
0.2384	0.3182	1.07685	3.2627	3.5134
0.2574	0.2638	1.09211	3.2752	3.5769
0.2768	0.2083	1.11162	3.2344	3.5954
0.2987	0.1457	1.14069	2.9468	3.3614

Table 5 *(continued)*

x_2	x_3	ρ/(g cm^3)	ν/(mm^2 s^{-1})	η/(mPas)
0.3142	0.6286	1.05448	2.6940	2.8408
0.1763	0.6543	1.03344	2.9568	3.0557
0.2759	0.5752	1.05314	2.8714	3.0240
0.3404	0.5594	1.06403	2.7048	2.8780
0.4346	0.5181	1.08215	2.5890	2.8017
0.1202	0.7339	1.02222	2.9324	2.9976
0.1005	0.6550	1.02239	3.0815	3.1505
0.2222	0.5901	1.04405	2.8900	3.0173
0.9803	0.0044	1.36784	1.1763	1.6090
0.9250	0.0123	1.35539	1.2649	1.7144
0.8943	0.0330	1.33267	1.4463	1.9274
0.2080	0.7553	1.03259	2.7883	2.8792
0.3147	0.6298	1.05446	2.6950	2.8418
0.3568	0.5802	1.06452	2.6530	2.8242
0.4426	0.4793	1.08763	2.5505	2.7740
0.5054	0.4054	1.10933	2.4620	2.7312
0.5547	0.3474	1.12854	2.3762	2.6816
0.5751	0.3234	1.13723	2.3361	2.6567
0.6093	0.2832	1.15359	2.2673	2.6155
0.6612	0.2221	1.18287	2.1544	2.5484
0.6895	0.1889	1.20171	2.0758	2.4945
0.7382	0.1315	1.23912	1.9426	2.4071
0.7590	0.1071	1.25709	1.8307	2.3014
0.7803	0.0820	1.27775	1.7071	2.1812
0.1232	0.8551	1.01868	2.8506	2.9038
0.0367	0.6402	1.01339	3.1817	3.2243
0.6617	0.0549	1.28264	1.6474	2.1130
0.6467	0.0763	1.26143	1.8157	2.2904
0.6316	0.0979	1.24285	1.9753	2.4550
0.5941	0.1515	1.20372	2.1756	2.6188
0.5759	0.1775	1.18769	2.2600	2.6842
0.5483	0.2169	1.16617	2.3443	2.7339
0.5112	0.2699	1.14175	2.4526	2.8002
0.4668	0.3334	1.11758	2.5529	2.8531
0.4404	0.3710	1.10521	2.5964	2.8696
0.3577	0.4891	1.07412	2.6955	2.8953
0.3331	0.5243	1.06638	2.7205	2.9011
0.3568	0.4904	1.07374	2.7001	2.8992
0.2308	0.6704	1.04024	2.7987	2.9113
0.1010	0.7116	1.02038	3.0051	3.0663
0.0954	0.7274	1.01907	2.9974	3.0544
0.1966	0.5225	1.04501	3.0284	3.0662
0.3654	0.3315	1.09982	2.8480	3.1323
0.4460	0.2894	1.12455	2.6296	2.9571
0.5094	0.2562	1.14557	2.4921	2.8549
0.4183	0.4983	1.08216	2.6056	2.8197
0.2411	0.4966	1.05455	2.9930	3.1563
0.2793	0.4032	1.07187	3.0128	3.2293
0.4676	0.1474	1.18094	2.4313	2.8712

Table 5 *(continued)*

x_2	x_3	$\rho/(\mathrm{g\ cm^3})$	$\nu/(\mathrm{mm^2\ s^{-1}})$	$\eta/(\mathrm{mPas})$
0.2132	0.3078	1.07367	3.3551	3.6023
0.5030	0.0854	1.22716	2.1021	2.5796
0.4937	0.1024	1.21300	2.2163	2.6884
0.4703	0.1450	1.18273	2.4242	2.8672
0.4462	0.1887	1.15742	2.5716	2.9764
0.4254	0.2265	1.13916	2.6681	3.0394
0.4016	0.2698	1.12128	2.7489	3.0823
0.3624	0.3410	1.09746	2.8183	3.0930
0.3034	0.4484	1.07025	2.8532	3.0536
0.2829	0.4856	1.06251	2.8610	3.0398
0.2362	0.5706	1.04742	2.8797	3.0163
0.2164	0.6065	1.04209	2.8934	3.0152
0.1788	0.6751	1.03276	2.8992	2.9942
0.4086	0.0925	1.19995	2.3365	2.8037
0.3983	0.1154	1.18274	2.4792	2.9322
0.3842	0.1467	1.16244	2.6870	3.1235
0.3642	0.1911	1.13845	2.8390	3.2321
0.3490	0.2249	1.12326	2.9099	3.2686
0.3090	0.3137	1.09239	3.0010	3.2783
0.2581	0.4267	1.06534	3.0197	3.2170
0.2915	0.3525	1.08183	3.0138	3.2604
0.2360	0.4757	1.05598	2.9781	3.1448
0.2003	0.5551	1.04334	2.9781	3.1072
0.2153	0.1317	1.12048	3.2932	3.6900
0.7198	0.0496	1.29545	1.5562	2.0160
0.8097	0.1251	1.25252	1.8150	2.2733
0.5512	0.1007	1.22613	2.1003	2.5752
0.6513	0.1496	1.21477	2.0942	2.5440

by the equation

$$\ln\nu = x_1\ln\nu_1 + x_2\ln\nu_2 + x_3\ln\nu_3 + \ln\nu_{12} + \ln\nu_{13} + \ln\nu_{23} + \ln\Delta\nu_{123} \qquad (4)$$

$$\begin{aligned}\Delta\nu_{123} = 1 + x_1x_2x_3[&A_0 + A_1x_{12} + A_2x_{13} + A_3x_{23} + A_4x_{12}^2 \\ &+ A_5x_{13}^2 + A_6x_{23}^2 + A_7x_{12}^3 + A_8x_{13}^3 + A_9x_{23}^3]\end{aligned}$$

where $x_{ij} = x_j - x_i$, and ν_{ij} is the kinematic viscosity of the binaries calculated from the Stephan and Heckenberger correlation

$$\ln\nu_{ij} = x_i\ln\nu_i + x_j\ln\nu_j + \ln\left[1 + \frac{x_ix_j}{C + Dx_i^2}\right] \qquad (5)$$

where C and D are adjustable parameters. The coefficients A_i of Eq. (4) and the standard deviation s shown in Table 6 have been obtained by using the binary parameters reported in our earlier communication [3]. Fig. 2 shows the kinematic viscosity isolines for the water–TFE–TEGDME system.

Table 6
Parameters and standard deviation s of Eq. (4) for the kinematic viscosity of the ternary system H_2O(1)–TFE(2)–TEGDME(3) at 303.15 K

A_0	−7.778327	A_5	−31.6474
A_1	3.586707	A_6	−21.4893
A_2	−6.034354	A_7	28.1802
A_3	−6.716702	A_8	−19.5871
A_4	−1.192476	A_9	−31.0600

$s = 0.0054$

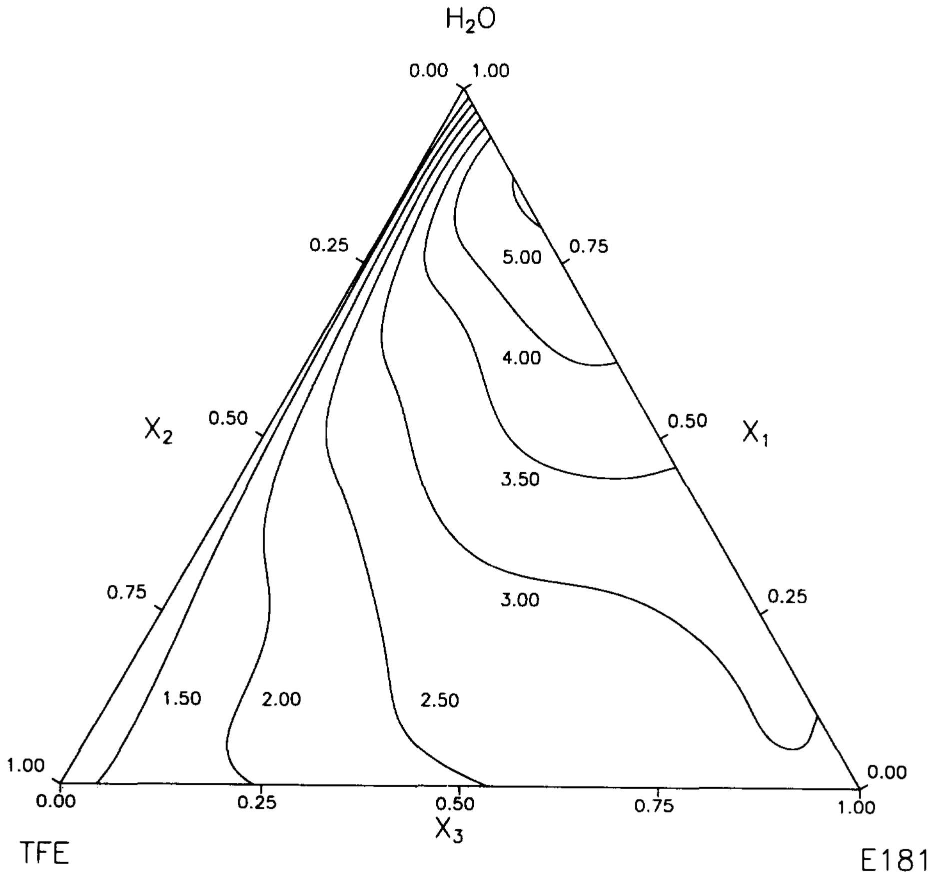

Fig. 2. Kinematic viscosity isolines for the mixture water(1)–trifluoroethanol(2)–tetraethylene glycol dimethyl ether(3) at 303.15 K.

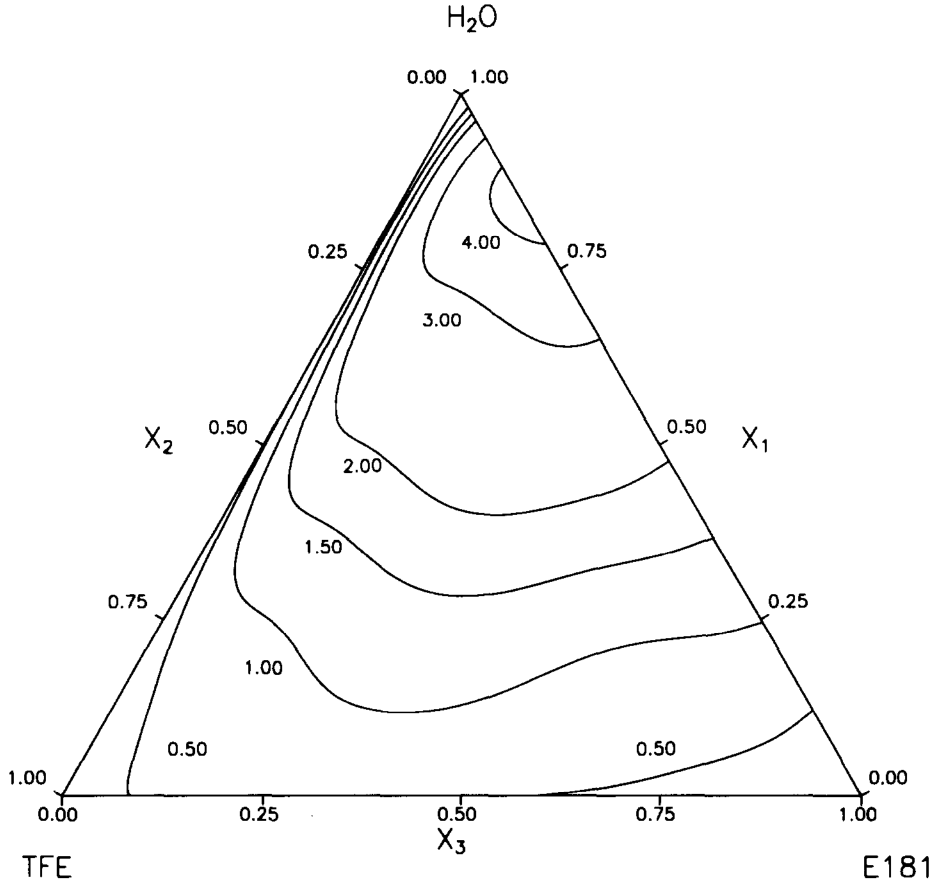

Fig. 3. Excess kinematic viscosity isolines for the mixture water(1)–trifluoroethanol(2)–tetraethylene glycol dimethyl ether(3) at 303.15 K.

The excess viscosity is defined by the equation

$$\eta^E = \eta - \exp(x_1 \ln \eta_1 + x_2 \ln \eta_2 + x_3 \ln \eta_3) \tag{6}$$

where η, η_1, η_2 and η_3 are the viscosities of the mixture and the pure components respectively. The excess viscosity data have been calculated by using Eqs. (1)–(3). Isolines of excess viscosities are shown in Fig. 3.

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References

[1] K. Stephan and D. Seher, Klima, Kalte, Heiz, 7 (1983) 295.

[2] K. Stephan and R. Hengerer, Int. J. Refrig., 16 (1993) 120.

[3] F. Olive, K.R. Patil, A. Coronas and J. Fernandez, Int. J. Thermophys., 15 (1994) 661.

[4] K. Stephan and T. Heckenberger, Dechema Chemistry Data Series, Vol. X, 1989.

[5] TRC Thermodynamic Tables–Hydrocarbons, Thermodynamic Research Center, Texas A & M University System, Colege Station, TX, 1986.

[6] J.A. Riddick, W.B. Bunger and T. Sakano, Organic Solvents. Techniques of Chemistry, Vo. 2, 4th edn., Wiley-Interscience, New York, 1986.

[7] J.B. Ott, C.E. Stouffer, G.V. Cornett, B.F. Woodfield, R.C. Wirthlin, J.J. Christensen and J.A. Dieters, J. Chem. Thermodyn., 18 (1986) 1.

[8] P. Svejda, M.A. Siddiqi, G. Hahn and N. Christoph, J. Chem. Eng. Data, 35 (1990) 47.

[9] R.L. McGee, W.J. Wallace and R.D. Ratalczak, J. Chem. Eng. Data, 28 (1983) 305.