(5). Of the remaining systems, the highly skewed $C_p^E{}_m(x)$ of CDT + benzene is to be noted.

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Registry No. CDT, 706-31-0; n-C_7H_{16}, 142-82-5; n-$C_{12}H_{26}$, 112-40-3; n-$C_{16}H_{34}$, 544-76-3; c-C_6H_{12}, 110-82-7; C_6H_6, 71-43-2; CCl_4, 56-23-5.

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Viscosity and Density of Ternary Mixtures for Toluene, Ethylbenzene, Bromobenzene, and 1-Hexanol

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Mixture viscosities and densities of the ternary mixtures of ethylbenzene, toluene, bromobenzene, and 1-hexanol were measured at 30, 40, 50, and 60 °C. The nonidealities reflected in mixture viscosities were expressed and discussed in terms of excess viscosities which were both positive and negative.

Introduction

In a continuation of our earlier work (*1–9*) on viscosities and dielectric constants of liquid mixtures, the present paper reports the viscosities and the densities for the ternary mixtures of toluene, ethylbenzene, bromobenzene, and 1-hexanol at 30, 40, 50, and 60 °C.

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Experimental Section

Materials. Toluene (BDH), ethylbenzene (E. Merck), and 1-hexanol (BDH) were purified by fractional distillation and drying, whereas bromobenzene (E. Merck) was purified by distillation and then fractional distillation, collecting the portion at 156 ± 0.5 °C before use. The mean of several repeat density, viscosity, and refractive index measurements compared favorably with the corresponding literature values within allowable limits (Table V). Redistilled, deionized, and degassed water that showed electrical conductivity of less than 7.0×10^{-7} mhos cm^{-1} was used for checking the instruments and calibrating the pycnometers for density measurements.

Experimental Measurements. Ternary mixtures were prepared by weight with an accuracy of 0.0001 g. Viscosities were measured with Ostwald viscometers to ascertain that the viscometer limbs coincided with the vertical within 0.5° and that the standard deviation for the time flow in each case did not exceed 0.1%. The densities were measured pycnometrically by using water with 0.997 07 g mL^{-1} as its density at 25 °C for calibration. The experimental procedures adopted for viscosity

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Table I. Experimental Densities, ρ_m, and Viscosities, η_m, for the Ternary Mixture Ethylbenzene (1)–Toluene (2)–Bromobenzene (3) at Different Temperatures

no.	X_1	X_2	t, °C	ρ_m, g mL^{-1}	η_m, cP
1	0.9238	0.0377	30	0.883 24	0.5738
			40	0.877 90	0.5264
			50	0.872 72	0.4843
			60	0.867 74	0.4508
2	0.0292	0.9367	30	0.882 45	0.5770
			40	0.876 19	0.5193
			50	0.870 23	0.4685
			60	0.867 15	0.4225
3	0.0288	0.0329	30	1.446 4	0.9795
			40	1.438 2	0.8781
			50	1.434 4	0.7963
			60	1.430 2	0.7266
4	0.0584	0.6014	30	1.070 6	0.6291
			40	1.063 7	0.5665
			50	1.057 3	0.5136
			60	1.054 4	0.4736
5	0.3008	0.0688	30	1.239 2	0.8640
			40	1.231 5	0.7623
			50	1.225 5	0.6898
			60	1.219 6	0.6358
6	0.5666	0.3600	30	0.902 94	0.6234
			40	0.897 53	0.5634
			50	0.895 00	0.5072
			60	0.892 52	0.4588
7	0.3023	0.3457	30	1.096 1	0.7011
			40	1.089 7	0.6467
			50	1.089 5	0.6019
			60	1.082 5	0.5688
8	0.1177	0.4711	30	1.111 8	0.6836
			40	1.104 9	0.6191
			50	1.099 1	0.5658
			60	1.096 3	0.5183
9	0.1785	0.5444	30	1.029 4	0.6559
			40	1.022 4	0.5889
			50	1.018 7	0.5312
			60	1.016 3	0.4924
10	0.2388	0.2049	30	1.198 2	0.7894
			40	1.190 5	0.7032
			50	1.185 3	0.6361
			60	1.182 7	0.5823
11	0.3650	0.1391	30	1.156 0	0.7538
			40	1.148 6	0.6750
			50	1.145 2	0.6201
			60	1.143 1	0.5753
12	0.4323	0.4238	30	0.944 89	0.6022
			40	0.940 21	0.5450
			50	0.935 26	0.4985
			60	0.930 83	0.4680
13	0.4979	0.2847	30	0.986 88	0.6177
			40	0.981 06	0.5599
			50	0.976 37	0.5138
			60	0.972 98	0.4749

Table II. Experimental Densities, ρ_m, and Viscosities, η_m, for the Ternary Mixture Ethylbenzene (1)–Bromobenzene (2)–1-Hexanol (3) at Different Temperatures

no.	X_1	X_2	t, °C	ρ_m, g mL^{-1}	η_m, cP
1	0.9238	0.0386	30	0.881 25	0.5864
			40	0.875 96	0.5335
			50	0.871 72	0.4892
			60	0.867 73	0.4526
2	0.0289	0.9427	30	1.446 7	0.9728
			40	1.439 0	0.8462
			50	1.436 8	0.7824
			60	1.434 9	0.7422
3	0.0337	0.0393	30	0.840 14	3.254
			40	0.835 35	2.531
			50	0.833 06	2.010
			60	0.831 91	1.628
4	0.0610	0.6395	30	1.224 2	1.219
			40	1.217 5	1.065
			50	1.212 8	0.9280
			60	1.208 3	0.8247
5	0.3334	0.0776	30	0.876 65	1.519
			40	0.871 65	1.257
			50	0.867 75	1.047
			60	0.863 59	0.9006
6	0.5695	0.3684	30	1.068 7	0.7463
			40	1.061 4	0.6695
			50	1.059 0	0.6137
			60	1.057 9	0.5701
7	0.3179	0.3701	30	1.056 2	1.049
			40	1.051 3	0.9244
			50	1.044 1	0.8318
			60	1.040 5	0.7632
8	0.1247	0.5082	30	1.137 9	1.269
			40	1.131 5	1.106
			50	1.126 8	0.9674
			60	1.121 7	0.8475
9	0.1847	0.5736	30	1.185 7	1.026
			40	1.177 1	0.9042
			50	1.175 5	0.8123
			60	1.172 1	0.7398
10	0.2606	0.2276	30	0.964 51	1.448
			40	0.957 48	1.208
			50	0.955 38	1.028
			60	0.951 74	0.8869
11	0.3947	0.1532	30	0.924 12	1.169
			40	0.918 82	1.013
			50	0.917 08	0.8766
			60	0.914 65	0.7674
12	0.4389	0.4380	30	1.106 8	0.8566
			40	1.100 6	0.7541
			50	1.096 6	0.6801
			60	1.090 2	0.6204
13	0.5127	0.2985	30	1.020 2	0.8654
			40	1.013 0	0.7603
			50	1.009 3	0.6796
			60	1.007 9	0.6087

and density measurements were the same as described elsewhere (*10*).

For each measurement, sufficient time was allowed to attain thermal equilibrium in a Toshniwal GL-15 precision thermostat whose bath temperature was monitored to 0.01 °C with a standardized Beckmann thermometer. The fluctuations in bath temperature did not exceed ±0.1 °C, and the evaporations remained insignificant. The measured viscosities and densities were considered significant to four figures.

Results and Discussion

The viscosity and density data for the ternary mixtures ethylbenzene (1)–toluene (2)–bromobenzene (3), ethylbenzene (1)–bromobenzene (2)–1-hexanol (3), ethylbenzene (1)–toluene (2)–1-hexanol (3) and toluene (1)–bromobenzene (2)–1-hexanol (3) at 30, 40, 50, and 60 °C are presented in Tables I–IV. The component mole fractions were chosen in such a way that, in each table, mixtures 1, 2, and 3 represented ternaries located in the extreme corner regions and mixtures 4, 5, and 6 represented ternaries located near the edges while mixture 7 represented the ternary located in the central region of the triangular composition diagrams. The rest of the mixtures represented ternaries with each component mole fraction greater than 0.1.

The experimental measurements of viscosities and densities were made at 30, 40, 50, and 60 °C. The increment in temperature level was kept regular at 10 °C with a view to ensure measurable effects of temperature change on experimental observations. The highest temperature level was restricted to

Table III. Experimental Densities, ρ_m, and Viscosities, η_m, for the Ternary Mixture Ethylbenzene (1)-Toluene (2)-1-Hexanol (3) at Different Temperatures

no.	X_1	X_2	t, °C	ρ_m, g mL^{-1}	η_m, cP
1	0.9294	0.0380	30	0.861 06	0.5657
			40	0.855 23	0.5154
			50	0.850 57	0.4724
			60	0.845 46	0.4345
2	0.0294	0.9417	30	0.860 85	0.5186
			40	0.854 66	0.4778
			50	0.852 15	0.4415
			60	0.848 81	0.4088
3	0.0337	0.0386	30	0.819 73	3.142
			40	0.814 65	2.444
			50	0.812 54	1.959
			60	0.810 34	1.553
4	0.0617	0.6353	30	0.845 90	0.8001
			40	0.840 14	0.6982
			50	0.835 40	0.6179
			60	0.832 45	0.5555
5	0.3338	0.0746	30	0.833 39	1.425
			40	0.828 56	1.179
			50	0.824 24	1.002
			60	0.820 51	0.8681
6	0.5732	0.3642	30	0.859 36	0.5858
			40	0.853 27	0.5298
			50	0.849 88	0.4824
			60	0.846 41	0.4407
7	0.3200	0.3659	30	0.845 59	0.8193
			40	0.839 74	0.7275
			50	0.837 89	0.6584
			60	0.836 12	0.5987
8	0.1258	0.5037	30	0.843 46	0.8825
			40	0.836 79	0.7663
			50	0.832 43	0.6698
			60	0.829 75	0.5930
9	0.1866	0.5691	30	0.849 09	0.6988
			40	0.842 51	0.6199
			50	0.838 73	0.5565
			60	0.836 40	0.5039
10	0.2617	0.2245	30	0.837 39	1.218
			40	0.831 96	1.026
			50	0.829 35	0.8884
			60	0.826 94	0.7635
11	0.3958	0.1509	30	0.839 82	1.033
			40	0.835 15	0.8836
			50	0.833 13	0.7726
			60	0.830 88	0.6732
12	0.4423	0.4336	30	0.855 55	0.6236
			40	0.850 22	0.5587
			50	0.845 65	0.5026
			60	0.841 54	0.4649
13	0.5155	0.2948	30	0.852 65	0.6829
			40	0.846 55	0.6122
			50	0.842 61	0.5489
			60	0.839 82	0.5024

Table IV. Experimental Densities, ρ_m, and Viscosities, η_m, for the Ternary Mixture Toluene (1)-Bromobenzene (2)-1-Hexanol (3) at Different Temperatures

no.	X_1	X_2	t, °C	ρ_m, g mL^{-1}	η_m, cP
1	0.9372	0.0341	30	0.880 95	0.5788
			40	0.870 42	0.5175
			50	0.864 50	0.4753
			60	0.861 69	0.4456
2	0.0329	0.9388	30	1.446 4	0.8713
			40	1.438 5	0.7953
			50	1.435 2	0.7463
			60	1.433 5	0.7012
3	0.0384	0.0391	30	0.842 27	3.229
			40	0.836 49	2.491
			50	0.833 46	1.985
			60	0.831 52	1.614
4	0.0692	0.6339	30	1.222 2	1.156
			40	1.215 0	1.010
			50	1.209 3	0.8946
			60	1.205 0	0.8186
5	0.3638	0.0741	30	0.876 42	1.499
			40	0.870 85	1.239
			50	0.866 96	1.048
			60	0.861 61	0.8967
6	0.6020	0.3045	30	1.068 7	0.7285
			40	1.061 2	0.6589
			50	1.057 3	0.6024
			60	1.053 5	0.5546
7	0.3476	0.3540	30	1.054 9	1.022
			40	1.049 3	0.9090
			50	1.044 7	0.8157
			60	1.042 0	0.7560
8	0.1401	0.4992	30	1.136 5	1.189
			40	1.130 2	1.035
			50	1.124 5	0.9048
			60	1.122 0	0.8060
9	0.2058	0.5587	30	1.183 5	0.9737
			40	1.176 8	0.8653
			50	1.172 6	0.7809
			60	1.170 5	0.7086
10	0.2873	0.2194	30	0.963 48	1.402
			40	0.957 07	1.186
			50	0.953 96	1.022
			60	0.950 37	0.8775
11	0.4272	0.1450	30	0.924 89	1.138
			40	0.918 49	0.9718
			50	0.915 00	0.8489
			60	0.913 37	0.7059
12	0.4721	0.4121	30	1.107 1	0.8069
			40	1.100 5	0.7254
			50	1.095 3	0.6559
			60	1.090 9	0.6016
13	0.5462	0.2780	30	1.020 5	0.8174
			40	1.013 8	0.7304
			50	1.008 9	0.6456
			60	1.002 1	0.5876

60 °C in order to avoid errors due to evaporation losses during the experimental work.

The molecules of one or more of the components forming the ternaries are either polar or associating and accordingly show nonideal behaviors in mixtures. The nonidealities as reflected in mixture viscosities are expressed in terms of excess viscosity η^E given by

$$\eta^E = \eta_m - \sum X_i \eta_i \qquad (1)$$

where η is the viscosity, X is the component mole fraction, superscript E stands for excess, and subscripts i and m stand for pure components and the mixture, respectively. Using η-X_i-T data from Tables I–V and eq 1, the corresponding η^E-X_i-T data were calculated.

Figure 1 shows the plots of η^E vs η_m. Positive values of η^E arise due to the higher viscosity contributions of nonspecific interactions involving highly polar bromobenzene and H-bonding effects of the monomeric and multimeric 1-hexanol species in real mixtures than those in corresponding ideal mixtures while negative values of η^E are the consequence of lower viscosity contributions of similar nonspecific interactions and H-bonding effects of molecular species in real mixtures than those in the corresponding ideal mixtures. For the ternary ethylbenzene (1)–toluene (2)–bromobenzene (3), the η^E values are both positive and negative depending on the contributions of component mole fractions while for the remaining ternaries studied, η^E values are always negative except in a few cases in the temperature range 30–60 °C. However, no regular pattern of

Table V. Experimental Densities and Viscosities for Pure Components of the Ternaries

pure components	t, °C	ρ, g mL^{-1}	η, cP	ref
ethylbenzene	25	0.8666	0.6342	
		(0.86264)	(0.6373)	*11*
	30	0.86454	0.5976	
	40	0.85976	0.5369	
	50	0.85471	0.4852	
	60	0.84975	0.4410	
toluene	25	0.8623	0.5520	
		(0.86231)	(0.5516)	*11*
	30	0.86696	0.5372	
	40	0.85473	0.4851	
	50	0.84969	0.4272	
	60	0.84750	0.3905	
bromobenzene	25	1.496	1.045	
		(1.48820)	(1.0430)	*11*
	30	1.4889	0.9850	
	40	1.4748	0.8744	
	50	1.4610	0.7819	
	60	1.4470	0.7129	
1-hexanol	25	0.8160	4.590	
		(0.81590)	(4.5920)	*11*
	30	0.81353	3.765	
	40	0.81050	2.934	
	50	0.80650	2.169	
	60	0.80340	1.655	

component–concentration combinations capable of predicting the sign of η^E values could be identified.

Acknowledgment

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Glossary

T	temperature, K
t	temperature, °C
X	mole fraction
cP	centipoise

Greek Letters

η	absolute viscosity, cP
ρ	density, g mL^{-1}

Subscripts

i	component in a mixture
m	mixture
1, 2, 3	component number in a mixture

Superscript

E	excess quantity

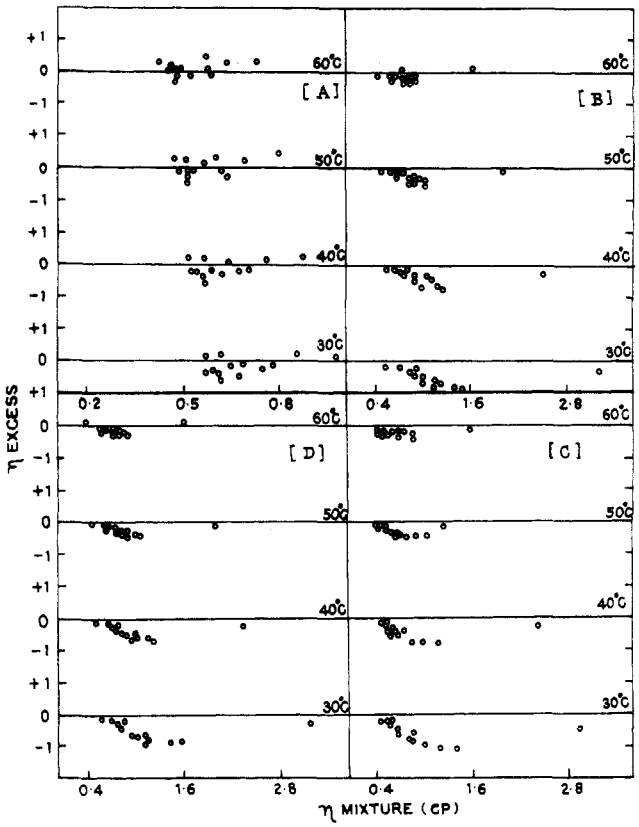

Figure 1. Plot of excess viscosity against corresponding mixture viscosity for the ternaries (A) ethylbenzene (1)–toluene (2)–bromobenzene (3), (B) ethylbenzene (1)–bromobenzene (2)–1-hexanol (3), (C) ethylbenzene (1)–toluene (2)–1-hexanol (3), and (D) toluene (1)–bromobenzene (2)–1-hexanol (3) at 30, 40, 50, and 60 °C.

Registry No. Ethylbenzene, 100-41-4; toluene, 108-88-3; bromobenzene, 108-86-1; 1-hexanol, 111-27-3.

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