Kinematic Viscosity–Composition Data for Eight Binary Systems Containing Toluene or Ethylbenzene and C_8–C_{16} *n*-Alkanes at 293.15 and 298.15 K

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Kinematic viscosity–composition data for eight binary mixtures, viz., toluene–*n*-octane, toluene–*n*-decane, toluene–*n*-dodecane, toluene–*n*-tetradecane, toluene–*n*-hexadecane, ethylbenzene–*n*-octane, ethylbenzene–*n*-tetradecane, and ethylbenzene–*n*-hexadecane, have been determined at 293.15 and 298.15 K over the entire composition range and fitted by polynomial expressions.

Introduction

Viscometric measurements in liquid mixtures are essential in providing insights into the structure and transport properties of such systems. They also aid in correlating mixture properties with those of the pure components.

The present work represents a continuation of a program (*1–6*) aiming at providing such data. The results provide information on interactions between nonassociating components with significant differences in shape and structure, i.e., toluene and ethylbenzene versus *n*-alkanes. To the best of our knowledge, similar data for the systems considered in this study have not been reported before.

Experimental Section

Equipment. The instruments employed in this study were as follows: (1) a Mettler Model HK 160 electronic balance with a stated precision of 2×10^{-7} kg; (2) a set of five Cannon-Ubbelohde viscometers with a stated precision of ±0.2%, comprising two viscometers of size 25A (range 0.5–2.0 cSt), two of size 50B (range 0.8–4.0 cSt), and one of size 75J (range 1.6–8.0 cSt).

Materials. Reagents with a stated purity of 99+ mole % (99 mol % for *n*-tetradecane) obtained from Aldrich Chemical Co. were used. Reagent purities were checked chromatographically and were found to exceed stated values in all cases. They are reported in the preceding paper in this issue.

Procedure. Solution compositions were determined gravimetrically. Kinematic viscosities were obtained from the measured efflux time, t, and the equation

$$\nu = Ct - E/t^n \qquad (1)$$

where C and E are calibration constants and $n = 2$ for the type of viscometers employed in this investigation. The calibration constants C and E were determined by using calibration standards N.4 (0.4596 cSt at 298.15 K), N.8 (0.7844 cSt at 293.15 K and 0.7416 cSt at 298.15 K), N1.0 (1.3280 cSt at 293.15 K and 1.235 cSt at 298.15 K), and S3 (4.2780 cSt at 293.15 K and 3.781 cSt at 298.15 K) obtained from Cannon Instruments Co. The viscometers were placed in a Model M1-18M constant-temperature bath supplied by Cannon. The bath temperature was controlled within ±0.01 K with water as a bath medium. The bath temperature was measured by a calibrated thermometer (IPTS-68). An electronic stopwatch accurate within ±0.01 s was used for measuring efflux times.

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Table I. Comparison of Pure Component Experimental and Reported Kinematic Viscosities

	293.15 K		298.15 K	
compound	exptl value × 10^6, m^2/s	lit. value[a] × 10^6, m^2/s	exptl value × 10^6, m^2/s	lit. value[a] × 10^6, m^2/s
n-octane	0.7697	0.7758	0.7298	0.7352
n-decane	1.2543	1.268	1.1722	1.182
n-dodecane	1.9743	2.008	1.8248	1.843
n-tetradecane	3.0189	3.061	2.7373	2.771
n-hexadecane	4.4614	4.492	3.9762	4.008
toluene	0.6777	0.6747	0.6413	0.6378
ethylbenzene	0.7701	0.7800	0.7299	0.7367

[a] Reference 7.

Results and Discussion

Table I shows the measured pure-component kinematic viscosities. Available TRC Table (*7*) values are also shown for comparison. As it can be seen from this table, experimental and literature values are in close agreement in all cases.

The experimental kinematic viscosities are listed in Table II. The maximum expected error is 2.73×10^{-10} m^2/s. The experimental ν_m values were correlated by the expression

$$\nu_m = \sum_{i=0}^{n} A_i x_A^i \qquad \text{(cSt)} \qquad (2)$$

The degree of the correlating polynomial that minimizes the standard deviation of the fit was chosen. The resulting values of the adjustable parameters and corresponding standard deviations are given in Table III. As it can be seen from the standard deviations listed in Table III, the correlating equation (2) fits the experimental data very well.

The experimental kinematic viscosity–composition data obtained at 293.15 K are shown plotted in Figures 1 and 2. It follows from these figures that binary mixture kinematic viscosities vary monotonically with composition. In addition, the viscosity–composition behavior is virtually linear for the systems toluene–*n*-octane (Figure 1) and ethylbenzene–*n*-octane (Figure 2). However, as the chain length of the *n*-alkane component

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Table II. Experimental Kinematic Viscosities for Binary Mixtures of Toluene and Ethylbenzene with *n*-Alkanes at 293.15 and 298.15 K

293.15 K			298.15 K			293.15 K			298.15 K		
ω_A	x_A	$\nu_m \times 10^6$, m^2/s	ω_A	x_A	$\nu_m \times 10^6$, m^2/s	ω_A	x_A	$\nu_m \times 10^6$, m^2/s	ω_A	x_A	$\nu_m \times 10^6$, m^2/s
					Toluene–*n*-Octane						
0.0000	0.0000	0.7697	0.0000	0.0000	0.7298	0.4492	0.5027	0.6771	0.3924	0.4447	0.6489
0.0477	0.0584	0.7577	0.0477	0.0499	0.7182	0.5419	0.5946	0.6686	0.4901	0.5437	0.6389
0.0840	0.1021	0.7463	0.0747	0.0910	0.7099	0.6507	0.6979	0.6615	0.5899	0.6408	0.6321
0.1735	0.2065	0.7242	0.1288	0.1548	0.6967	0.7665	0.8028	0.6603	0.7200	0.7612	0.6259
0.2609	0.3044	0.7074	0.2179	0.2566	0.6775	0.8778	0.8990	0.6647	0.8492	0.8747	0.6283
0.3438	0.3937	0.6914	0.3002	0.3472	0.6637	1.0000	1.0000	0.6777	1.0000	1.0000	0.6413
					Toluene–*n*-Decane						
0.0000	0.0000	1.2543	0.0000	0.0000	1.1722	0.3899	0.4968	0.9074	0.4039	0.5113	0.8430
0.0383	0.0579	1.2189	0.0342	0.0519	1.1304	0.4919	0.5992	0.8488	0.5038	0.6106	0.7936
0.0733	0.1088	1.1689	0.0675	0.1005	1.0976	0.6013	0.6996	0.7992	0.6075	0.7050	0.7496
0.1452	0.2078	1.0955	0.1408	0.2019	1.0264	0.7208	0.7994	0.7489	0.7241	0.8021	0.7072
0.2209	0.3046	1.0264	0.2202	0.3037	0.9614	0.8579	0.9031	0.7072	0.8476	0.8957	0.6716
0.3056	0.4047	0.9618	0.3068	0.4060	0.9045	1.0000	1.0000	0.6777	1.0000	1.0000	0.6413
					Toluene–*n*-Dodecane						
0.0000	0.0000	1.9743	0.0000	0.0000	1.8248	0.3512	0.5002	1.2021	0.3242	0.4701	1.1622
0.0359	0.0645	1.8657	0.0306	0.0551	1.7356	0.4484	0.6005	1.0789	0.4183	0.5707	1.0429
0.0600	0.1056	1.7937	0.0500	0.0887	1.6828	0.5597	0.7015	0.9629	0.5410	0.6854	0.9195
0.1245	0.2082	1.6264	0.1165	0.1959	1.5219	0.6870	0.8023	0.8532	0.6579	0.7805	0.8244
0.1885	0.3004	1.4802	0.1730	0.2789	1.4067	0.8311	0.9009	0.7597	0.8133	0.8895	0.7261
0.2681	0.4037	1.3409	0.2491	0.3802	1.2730	1.0000	1.0000	0.6777	1.0000	1.0000	0.6413
					Toluene-*n*-Tetradecane						
0.0000	0.0000	3.0189	0.0000	0.0000	2.7373	0.3201	0.5034	1.5879	0.3100	0.4918	1.4924
0.0318	0.0661	2.8050	0.0223	0.0469	2.6039	0.3927	0.5820	1.4090	0.4049	0.5944	1.2805
0.0537	0.1089	2.6683	0.0528	0.1072	2.4350	0.5232	0.7026	1.1624	0.4984	0.6815	1.1229
0.1082	0.2072	2.3681	0.1022	0.1969	2.1863	0.6569	0.8048	0.9765	0.6400	0.7929	0.9370
0.1678	0.3028	2.0909	0.1565	0.2854	1.9666	0.8100	0.9018	0.8177	0.7978	0.8947	0.7807
0.2360	0.3994	1.8389	0.2259	0.3858	1.7245	1.0000	1.0000	0.6777	1.0000	1.0000	0.6413
					Toluene–*n*-Hexadecane						
0.0000	0.0000	4.4614	0.0000	0.0000	3.9762	0.2866	0.4969	2.1052	0.2914	0.5026	1.9329
0.0186	0.0444	4.2085	0.0284	0.0669	3.6575	0.3794	0.6004	1.7368	0.3763	0.5973	1.6303
0.0414	0.0959	3.9156	0.0578	0.1309	3.3766	0.4843	0.6977	1.4248	0.4890	0.7017	1.3218
0.0941	0.2033	3.3916	0.0886	0.1927	3.0863	0.6163	0.7978	1.1435	0.6170	0.7984	1.0661
0.1373	0.2811	2.9897	0.1313	0.2708	2.7794	0.7863	0.9004	0.8881	0.7818	0.8979	0.8436
0.2057	0.3889	2.5301	0.2373	0.4333	2.1678	1.0000	1.0000	0.6777	1.0000	1.0000	0.6413
					Ethylbenzene–*n*-Octane						
0.0000	0.0000	0.7697	0.0000	0.0000	0.7298	0.4929	0.5113	0.7243	0.5720	0.5898	0.6871
0.0508	0.0544	0.7623	0.0525	0.0562	0.7221	0.6019	0.6193	0.7246	0.6851	0.7007	0.6909
0.0962	0.1028	0.7558	0.0943	0.1008	0.7158	0.6961	0.7113	0.7276	0.7851	0.7972	0.6976
0.1936	0.2053	0.7454	0.18695	0.1983	0.7042	0.7955	0.8071	0.7367	0.8894	0.8964	0.7091
0.2899	0.3052	0.7329	0.2768	0.2917	0.6971	0.8945	0.9012	0.7509	1.0000	1.0000	0.7299
0.3924	0.4099	0.7273	0.3805	0.3979	0.6899	1.0000	1.0000	0.7701			
					Ethylbenzene–*n*-Tetradecane						
0.0000	0.0000	3.0189	0.0000	0.0000	2.7373	0.3452	0.4963	1.6376	0.3492	0.5007	1.5153
0.0286	0.0521	2.8486	0.0347	0.0629	2.5554	0.4428	0.5976	1.4239	0.4459	0.6007	1.3254
0.0651	0.1152	2.6375	0.0595	0.1057	2.4305	0.5526	0.6977	1.2344	0.5555	0.7002	1.1538
0.1246	0.2101	2.3591	0.1251	0.2109	2.1575	0.6798	0.7987	1.0614	0.6783	0.7976	1.0014
0.1817	0.2932	2.1257	0.1889	0.3033	1.9316	0.8279	0.8999	0.9068	0.8242	0.8976	0.8581
0.2664	0.4042	1.8467	0.2586	0.3946	1.7277	1.0000	1.0000	0.7701	1.0000	1.0000	0.7299
					Ethylbenzene–*n*-Hexadecane						
0.0000	0.0000	4.4614	0.0000	0.0000	3.9762	0.3129	0.4927	2.1298	0.3215	0.5027	1.9396
0.0260	0.0539	4.1464	0.0337	0.0692	3.6403	0.4082	0.5953	1.7969	0.4229	0.6099	1.6215
0.0510	0.1029	3.8769	0.0570	0.1142	3.4305	0.5199	0.6978	1.5009	0.5201	0.6979	1.3839
0.1039	0.1983	3.3965	0.1083	0.2058	3.0287	0.6511	0.7992	1.2139	0.6564	0.8029	1.1272
0.1687	0.3022	2.8961	0.1729	0.3084	2.6157	0.8087	0.9002	0.9753	0.8098	0.9008	0.9154
0.2402	0.4028	2.4811	0.2421	0.4053	2.2621	1.0000	1.0000	0.7701	1.0000	1.0000	0.7299

increases, progressively pronounced departures from linearity can be observed. The same qualitative viscosity–composition behavior was also observed at 298.15 K. Thus, the systems containing *n*-octane continued to display a nearly linear viscosity relationship whereas the remaining systems displayed deviations from linearity that increased with increasing chain length of the *n*-alkane component. For both of the temperatures studied, there was no appreciable change in the curvature of the individual viscosity–composition curves with temperature.

Conclusions

Kinematic viscosities for eight binary mixtures were determined at 293.15 and 298.15 K with a maximum error of 2.73 $\times 10^{-10}$ m^2/s.

The experimental values were correlated by polynomial expressions that fitted the data well. For all systems and temperatures studied, kinematic viscosity changed monotonically with composition. Individual viscosity–composition curves were

Table III. Least-Squares Constants for Equation 2

system	A_0	A_1	A_2	A_3	A_4	std dev, 10^{-6} m²/s
			293.15 K			
toluene–*n*-octane	0.7703	−0.2441	0.1232	−0.0501	0.0781	7.64×10^{-4}
toluene–*n*-decane	1.25895	−0.8368	0.2524			3.51×10^{-3}
toluene–*n*-dodecane	1.9754	−1.7651	0.4295	−0.0371		3.09×10^{-3}
toluene–*n*-tetradecane	3.0206	−3.3640	1.0220			2.16×10^{-3}
toluene–*n*-hexadecane	4.4597	−5.7796	2.1767	−0.1797		8.88×10^{-3}
ethylbenzene–*n*-octane	0.7697	−0.1383	0.0480	0.0908		8.59×10^{-4}
ethylbenzene–*n*-tetradecane	3.0199	−3.4457	1.4462	−0.2511		2.54×10^{-3}
ethylbenzene–*n*-hexadecane	4.4627	−5.98096	2.8633	−0.5760		8.08×10^{-3}
			298.15 K			
toluene–*n*-octane	0.7291	−0.2139	0.0391	0.0863		3.06×10^{-3}
toluene–*n*-decane	1.1703	−0.7449	0.1971	0.0173		1.93×10^{-3}
toluene–*n*-dodecane	1.8232	−1.6095	0.4194	0.0066		1.64×10^{-3}
toluene–*n*-tetradecane	2.7396	−2.9624	0.8637	0.00098		2.65×10^{-3}
toluene–*n*-hexadecane	3.9744	−4.8176	1.4848	−0.0028		7.01×10^{-3}
ethylbenzene–*n*-octane	0.7295	−0.1389	0.0725	0.0659		2.87×10^{-3}
ethylbenzene–*n*-tetradecane	2.7368	−2.9906	1.1873	−0.2054		2.46×10^{-3}
ethylbenzene–*n*-hexadecane	3.9772	−5.0289	2.10496	−0.3247		1.70×10^{-3}

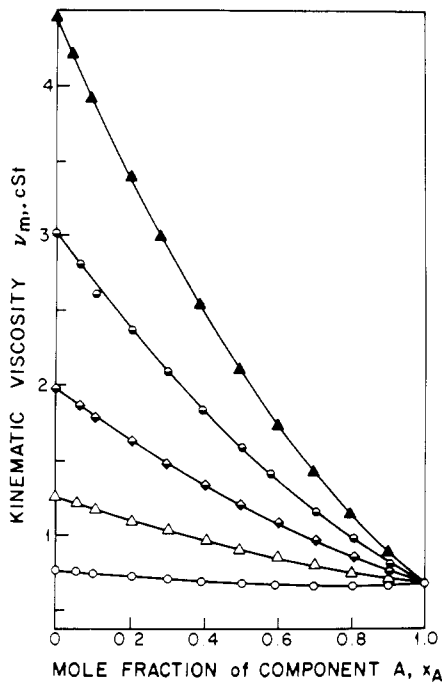

Figure 1. Variation of kinematic viscosity with composition for systems containing toluene at 293.15 K. Key: (O) toluene (A)–*n*-octane (B); (△) toluene (A)–*n*-decane (B); (◆) toluene (A)–*n*-dodecane (B); (◒) toluene (A)–*n*-tetradecane (B); (▲) toluene (A)–*n*-hexadecane (B).

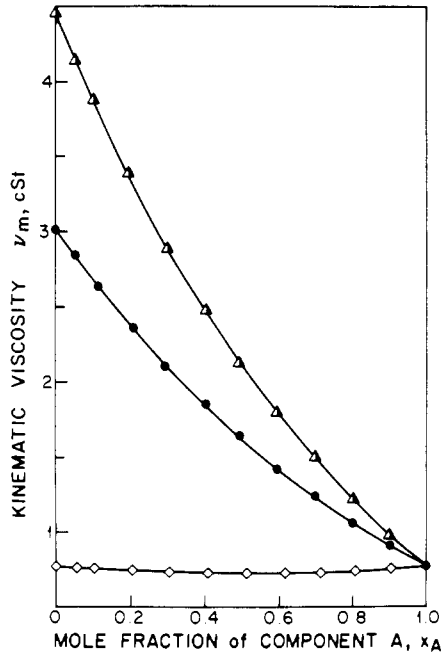

Figure 2. Variation of kinematic viscosity with composition for systems containing ethylbenzene at 293.15 K. Key: (◇) ethylbenzene (A)–*n*-octane (B); (●) ethylbenzene (A)–*n*-tetradecane (B); (▲) ethylbenzene (A)–*n*-hexadecane (B).

nearly linear for the systems containing *n*-octane and displayed progressively more pronounced curvature as the chain length of the *n*-alkane component increased.

Nomenclature

A = adjustable parameter

C = calibration constant

E = calibration constant

x = mole fraction

ν = kinematic viscosity

ω = mass fraction

Subscripts

A = first-named component in a binary mixture

m = mixture

Registry No. Toluene, 108-88-3; ethylbenzene, 100-41-4; octane, 111-65-9; decane, 124-18-5; dodecane, 112-40-3; tetradecane, 629-59-4; hexadecane, 544-76-3.

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