Densities, Viscosities, and Thermodynamic Properties of (*N*,*N*-Dimethylformamide + Benzene + Chlorobenzene) Ternary Mixtures at (298.15, 303.15, 308.15, and 313.15) K

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Densities and viscosities of ternary mixtures of *N*,*N*-dimethylformamide + benzene + chlorobenzene and corresponding binary mixtures of *N*,*N*-dimethylformamide + benzene, *N*,*N*-dimethylformamide + chlorobenzene, and benzene + chlorobenzene have been measured at (298.15, 303.15, 308.15, and 313.15) K. From these data, excess molar volumes (V^E) and deviations in viscosity ($\Delta\eta$) have been calculated. Several empirical equations have been used to predict the excess molar volumes and deviations in viscosity of ternary mixtures. The kinematic viscosities of binary and ternary liquid mixtures have also been correlated with mole fractions by McAllister's equation.

Introduction

A thorough knowledge of thermodynamic and transport properties of multicomponent systems is essential in many industrial applications such as design calculation, heat transfer, mass transfer, fluid flow, and so forth. Thermodynamic and transport properties of ternary mixtures of nonelectrolytes have been studied previously.[1−5] The calculated excess quantities are predicted from the corresponding properties of binary mixtures. In this paper, density and viscosity data for ternary mixtures of *N*,*N*-dimethylformamide + benzene + chlorobenzene and corresponding binary mixtures of *N*,*N*-dimethylformamide + benzene, *N*,*N*-dimethylformamide + chlorobenzene, and benzene + chlorobenzene, of varing composition at the temperatures (298.15, 303.15, 308.15, and 313.15) K, have been reported.

From the experimental values of densities and viscosities, the excess molar volumes and viscosity deviations have been calculated. Several empirical equations (Radojkovic et al., Kohler and Scatchard et al.) have been used to predict the excess molar volumes and deviations in viscosity of ternary mixtures. By using McAllister's three-body interaction model, the kinematic viscosities of binary and ternary mixtures are correlated with mole fractions.

There are few reports[6−11] on thermodynamic and transport properties of binary mixtures of *N*,*N*-dimethylformamide + benzene, *N*,*N*-dimethylformamide + chlorobenzene, and benzene + chlorobenzene. There appear to be no reports on density and viscosity data for ternary mixtures of *N*,*N*-dimethylformamide + benzene + chlorobenzene in the literature.

Experimental Section

Benzene (S. D. Fine Chemicals, purity > 99%) was further purified by means of a simple distillation technique with the first and last 20% of the distillate being discarded. *N*,*N*-Dimethylformamide (S. D. Fine Chemicals, analytical reagent, purity > 99.5%) and chlorobenzene (S. D. Fine Chemicals, analytical reagent, purity > 99.5%) were directly used. The purity of solvents was ascertained by GLC and also by comparing experimental values of densities and viscosities with those reported in the literature (Table 1). Our experimental values of densities and viscosities match very well with those reported in the literature.

Table 1. Comparison of Experimental Densities, ρ, and Viscosities, η, of Pure Liquids with Literature Values at (298.15, 303.15, 308.15, and 313.15) K

		ρ/g·cm^{-3}		η/mPa·s	
liquid	*T*/K	expt	lit.	expt	lit.
N,*N*-dimethyl-	298.15	0.9445	0.9445[21]	0.803	0.802[20]
formamide	303.15	0.9398	0.9397[22]	0.756	0.752[24]
	308.15	0.9351	0.9356[22]	0.710	0.707[24]
	313.15	0.9302	0.9298[23]	0.673	0.664[24]
benzene	298.15	0.8734	0.8735[25]	0.603	0.601[26]
	303.15	0.8682	0.8682[25]	0.568	0.569[26]
	308.15	0.8629	0.8629[25]	0.531	
	313.15	0.8574	0.8576[25]	0.500	0.503[28]
chlorobenzene	298.15	1.1009	1.1011[25]	0.756	0.758[27]
	303.15	1.0958	1.0957[25]	0.714	0.718[27]
	308.15	1.0908	1.0904[25]	0.673	0.678[26]
	313.15	1.0851	1.0848[25]	0.635	0.631[26]

Binary and ternary mixtures were prepared by mixing a known mass of each liquid in an airtight, stoppered glass bottle.The masses were recorded on a Adairdutt balance to an accuracy of $\pm 1 \times 10^{-4}$ g. The estimated error in mole fraction was $< 1 \times 10^{-4}$. Care was taken to avoid contamination during mixing.

The densities of degassed pure liquids and binary and ternary mixtures were measured using a 15 cm^3 double-arm pycnometer, as reported earlier,[12] in a transparent glass-walled water bath having a thermal stability of ±0.01 K. The pycnometer was calibrated using the conductivity water[13] having a conductivity $< 1 \times 10^{-6}$ Ω^{-1} cm^{-1}. Uncertainties in density measurement were within $\pm 1 \times 10^{-4}$ g·cm^{-3}.

Dynamic viscosities were measured using an Ubbelohde suspended-level viscometer,[12] calibrated with conductivity water.[13] An electronic digital stopwatch with accuracy to ±0.01 s was used for flow time measurements. At least

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Table 2. Density, ρ, Viscosity, η, Excess Molar Volume, V^E, and Deviations in Viscosity, $\Delta\eta$, for Binary Mixtures at (298.15, 303.15, 308.15, and 313.15) K

x_1	$10^3\rho^a$	η^b	$V^{E\,c}$	$\Delta\eta^b$	x_1	$10^3\rho^a$	η^b	$V^{E\,c}$	$\Delta\eta^b$	x_1	$10^3\rho^a$	η^b	$V^{E\,c}$	$\Delta\eta^b$	x_1	$10^3\rho^a$	η^b	$V^{E\,c}$	$\Delta\eta^b$
N,*N*-Dimethylformamide (1) + Chlorobenzene (2)																			
298.15 K															308.15 K				
0.0000	1.1009	0.756	0.000	0.000	0.6084	1.0202	0.862	−0.325	0.077	0.0000	1.0908	0.673	0.000	0.000	0.6084	1.0106	0.757	−0.345	0.061
0.1473	1.0835	0.790	−0.062	0.027	0.7009	1.0038	0.856	−0.246	0.067	0.1473	1.0736	0.701	−0.076	0.023	0.7009	0.9945	0.752	−0.284	0.053
0.2093	1.0763	0.804	−0.136	0.038	0.7842	0.9881	0.846	−0.159	0.053	0.2093	1.0665	0.712	−0.157	0.031	0.7842	0.9787	0.744	−0.180	0.042
0.2762	1.0681	0.818	−0.201	0.049	0.9351	0.9577	0.818	−0.005	0.018	0.2762	1.0583	0.723	−0.220	0.040	0.9351	0.9483	0.721	−0.0.011	0.015
0.4032	1.0512	0.838	−0.291	0.063	1.0000	0.9445	0.803	0.000	0.000	0.4032	1.0415	0.739	−0.313	0.051	1.0000	0.9351	0.710	0.000	0.000
0.4661	1.0422	0.847	−0.307	0.069						0.4661	1.0325	0.745	−0.326	0.055					
303.15 K															313.15 K				
0.0000	1.0958	0.714	0.000	0.000	0.6084	1.0154	0.808	−0.336	0.068	0.0000	1.0851	0.635	0.000	0.000	0.6084	1.0054	0.714	−0.354	0.056
0.1473	1.0785	0.745	−0.068	0.025	0.7009	0.9991	0.803	−0.262	0.060	0.1473	1.0681	0.661	−0.086	0.020	0.7009	0.9894	0.709	−0.294	0.047
0.2093	1.0713	0.757	−0.141	0.034	0.7842	0.9834	0.794	−0.170	0.048	0.2093	1.0631	0.671	−0.164	0.028	0.7842	0.9737	0.702	−0.192	0.037
0.2762	1.0632	0.770	−0.213	0.044	0.9351	0.9530	0.769	−0.008	0.016	0.2762	1.0529	0.681	−0.233	0.036	0.9351	0.9434	0.683	−0.017	0.011
0.4032	1.0463	0.788	−0.300	0.057	1.0000	0.9398	0.756	0.000	0.000	0.4032	1.0363	0.696	−0.328	0.046	1.0000	0.9302	0.673	0.000	0.000
0.4661	1.0373	0.795	−0.314	0.061						0.4661	1.0272	0.702	−0.337	0.049					
N,*N*-Dimethylformamide (1) + Benzene (2)																			
298.15 K															308.15 K				
0.0000	0.8734	0.603	0.000	0.000	0.6145	0.9186	0.731	−0.356	0.005	0.0000	0.8629	0.531	0.000	0.000	0.6145	0.9089	0.644	−0.382	0.003
0.1076	0.8811	0.622	−0.098	−0.003	0.7093	0.9250	0.747	−0.293	0.002	0.1076	0.8708	0.547	−0.112	−0.003	0.7093	0.9154	0.659	−0.316	0.001
0.2069	0.8884	0.641	−0.187	−0.003	0.8084	0.9316	0.763	−0.204	−0.002	0.2069	0.8784	0.564	−0.223	−0.004	0.8084	0.9222	0.673	−0.231	−0.003
0.3124	0.8963	0.662	−0.271	−0.004	0.8998	0.9368	0.780	−0.034	−0.003	0.3124	0.8865	0.582	−0.318	−0.005	0.8998	0.9274	0.689	−0.046	−0.003
0.4132	0.9042	0.688	−0.360	0.002	1.0000	0.9445	0.803	0.000	0.000	0.4132	0.8946	0.602	−0.419	−0.003	1.0000	0.9351	0.710	0.000	0.000
0.5148	0.9117	0.712	−0.390	0.006						0.5148	0.9022	0.627	−0.446	0.004					
303.15 K															313.15 K				
0.0000	0.8682	0.568	0.000	0.000	0.6145	0.9137	0.688	−0.362	0.005	0.0000	0.8574	0.500	0.000	0.000	0.6145	0.9040	0.608	−0.411	0.002
0.1076	0.8760	0.585	−0.105	−0.003	0.7093	0.9202	0.703	−0.303	0.002	0.1076	0.8654	0.515	−0.118	−0.004	0.7093	0.9103	0.622	−0.321	−0.001
0.2069	0.8835	0.603	−0.210	−0.004	0.8084	0.9270	0.718	−0.225	−0.002	0.2069	0.8733	0.531	−0.256	−0.005	0.8084	0.9172	0.636	−0.238	−0.004
0.3124	0.8914	0.622	−0.291	−0.005	0.8998	0.9321	0.734	−0.040	−0.003	0.3124	0.8815	0.549	−0.356	−0.005	0.8998	0.9225	0.651	−0.054	−0.005
0.4132	0.8994	0.645	−0.387	−0.001	1.0000	0.9398	0.756	0.000	0.000	0.4132	0.8896	0.567	−0.452	−0.004	1.0000	0.9302	0.673	0.000	0.000
0.5148	0.9069	0.670	−0.410	0.005						0.5148	0.8972	0.592	−0.473	0.003					
Benzene (1) + Chlorobenzene (2)																			
298.15 K															308.15 K				
0.0000	1.1009	0.756	0.000	0.000	0.6074	0.9704	0.683	−0.032	0.020	0.0000	1.0908	0.673	0.000	0.000	0.6074	0.9600	0.598	−0.041	0.011
0.1206	1.0765	0.744	0.003	0.006	0.7069	0.9468	0.665	−0.024	0.017	0.1206	1.0664	0.656	−0.007	0.001	0.7069	0.9364	0.582	−0.036	0.009
0.2642	1.0465	0.727	0.002	0.011	0.8131	0.9209	0.643	−0.016	0.011	0.2642	1.0363	0.639	−0.009	0.004	0.8131	0.9105	0.562	−0.028	0.004
0.3982	1.0175	0.711	0.000	0.016	0.9162	0.8950	0.621	−0.006	0.005	0.3982	1.0073	0.623	−0.019	0.007	0.9162	0.8846	0.545	−0.019	0.002
0.4644	1.0028	0.702	−0.002	0.018	1.0000	0.8734	0.603	0.000	0.000	0.4644	0.9926	0.616	−0.025	0.009	1.0000	0.8629	0.531	0.000	0.000
0.5321	0.9877	0.694	−0.024	0.019						0.5321	0.9773	0.607	−0.031	0.010					
303.15 K															313.15 K				
0.0000	1.0958	0.714	0.000	0.000	0.6074	0.9652	0.640	−0.035	0.015	0.0000	1.0851	0.635	0.000	0.000	0.6074	0.9545	0.561	−0.057	0.008
0.1206	1.0714	0.699	−0.006	0.003	0.7069	0.9416	0.623	−0.027	0.012	0.1206	1.0607	0.618	−0.007	−0.002	0.7069	0.9309	0.545	−0.048	0.005
0.2642	1.0414	0.682	- 0.005	0.007	0.8131	0.9157	0.601	−0.018	0.006	0.2642	1.0307	0.601	−0.018	0.001	0.8131	0.9050	0.527	−0.037	0.002
0.3982	1.0124	0.667	- 0.010	0.011	0.9162	0.8898	0.583	−0.008	0.003	0.3982	1.0017	0.585	−0.028	0.004	0.9162	0.8792	0.512	−0.033	0.001
0.4644	0.9977	0.659	−0.014	0.013	1.0000	0.8682	0.568	0.000	0.000	0.4644	0.9870	0.578	−0.033	0.006	1.0000	0.8574	0.500	0.000	0.000
0.5321	0.9825	0.650	−0.027	0.014						0.5321	0.9717	0.570	−0.038	0.007					

[a] kg·m^{-3}. [b] mPa·s. [c] cm^3·mol^{-1}.

three repetitions of each data point obtained were reproducible to ±0.05 s, and results were averaged. Since all flow times were >300 s, the kinetic energy corrections were not applied. To evaluate the viscometer constant, the length of the capillary of the viscometer (l) term is to be corrected as $l' = l + 0.5r$, with r being the radius of the viscometer capillary. Since l is much larger (50 to 60 mm) as compared to r ($r = 0.5$ mm), $l = l'$ and hence end effects in viscometers are negligible. The dynamic viscosities (η) of the liquids were calculated[12] using

$$\eta/\eta_0 = (\rho t)/(\rho_0 t_0) \quad (1)$$

where ρ, ρ_0, t, t_0, and η, η_0 refer to density, flow time, and viscosity of liquids and water, respectively. The reproducibility in the measurement of viscosity was ±0.003 mPa·s.

Results and Discussion

Excess Molar Volumes and Deviations in Viscosity for Binary Mixtures. Table 2 lists experimental values of densities (ρ) and viscosities (η) of binary mixtures of *N*,*N*-dimethylformamide + benzene, *N*,*N*-dimethylformamide + chlorobenzene, and benzene + chlorobenzene at (298.15, 303.15, 308.15, and 313.15) K. The excess molar volumes (V^E) were calculated by using the following equation

$$V^E = (x_1M_1 + x_2M_2)/\rho_{mix} - x_1M_1/\rho_1 - x_2M_2/\rho_2 \quad (2)$$

where x_1, x_2, M_1, M_2, ρ_1, and ρ_2 are the mole fractions, molecular weights, and densities of pure components 1 and 2, respectively, and ρ_{mix} is the density of the binary mixture.

The viscosity deviations ($\Delta\eta$) were calculated by using the equation

$$(\Delta\eta) = \eta_{mix} - x_1\eta_1 - x_2\eta_2 \quad (3)$$

where η_{mix} is the viscosity of the binary mixture and η_1, η_2 are the viscosities of components 1 and 2, respectively. The excess molar volumes and deviations in viscosity of binary liquid mixtures are included in Table 2. The variations of V^E and $\Delta\eta$ with mole fraction (x_1) of the component 1 for the three binary systems, (x_1)*N*,*N*-dimethylformamide + (1 − x_1)benzene, (x_1)*N*,*N*-dimethylformamide + (1 − x_1)-chlorobenzene, and (x_1)benzene + (1 − x_1)chlorobenzene at (298.15, 303.15, 308.15, and 313.15) K, are represented in Figures 1−6. For the binary systems, *N*,*N*-dimethylformamide + chlorobenzene and *N*,*N*-dimethylformamide + benzene, V^E values are negative over the entire range of composition and at all temperatures. For the benzene + chlorobenzene system, V^E values are positive at lower concentrations of benzene and at 298.15 K only. $\Delta\eta$ values for *N*,*N*-dimethylformamide + chlorobenzene and benzene + chlorobenzene systems are positive over the entire range of composition and at all temperatures. For the *N*,*N*-dimethylformamide + benzene system, $\Delta\eta$ values are negative at the lower and higher composition ranges and at all temperatures. Negative values of V^E and positive values of $\Delta\eta$ indicate strong specific interactions among the components.

The results of V^E and $\Delta\eta$ are fitted in the Redlich−Kister equation[14]

$$Y = x_1x_2\sum a_i(x_1 - x_2)^i \quad (4)$$

where Y refers to V^E or $\Delta\eta$. The coefficients a_i were obtained by fitting eq 4 to the experimental results using a least-squares regression method, and in each case, the optimum number of coefficients is ascertained from the examination of the variation in the standard deviation, (σ).

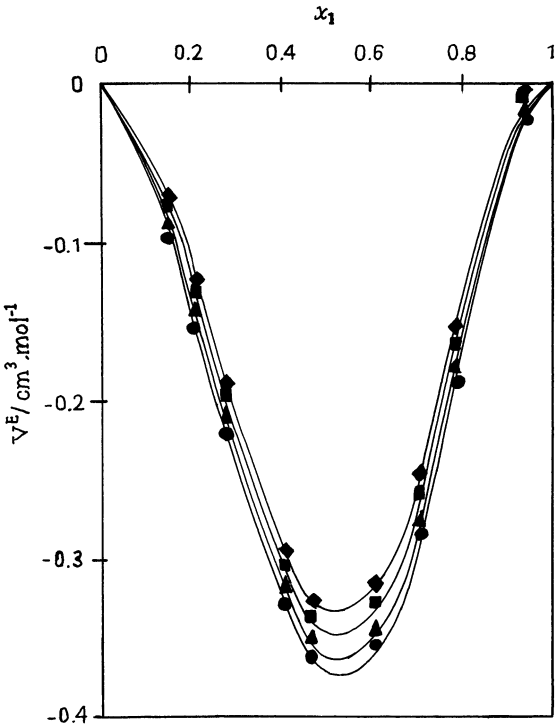

Figure 1. Excess molar volumes (eq 4) (V^E) for (x_1)*N*,*N*-dimethylformamide + (1 − x_1)chlorobenzene at various temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

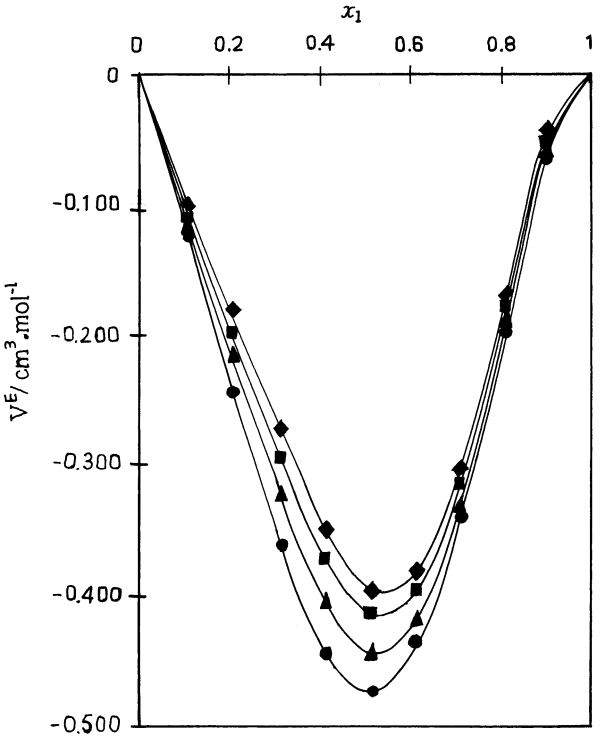

Figure 2. Excess molar volumes (eq 4) (V^E) for (x_1)*N*,*N*-dimethylformamide + (1 − x_1)benzene at various temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

The σ was calculated using

$$\sigma(Y) = \left(\sum(Y_{exptl} - Y_{cal})^2/(n - m)\right)^{1/2} \quad (5)$$

where n is the number of data points and m is the number

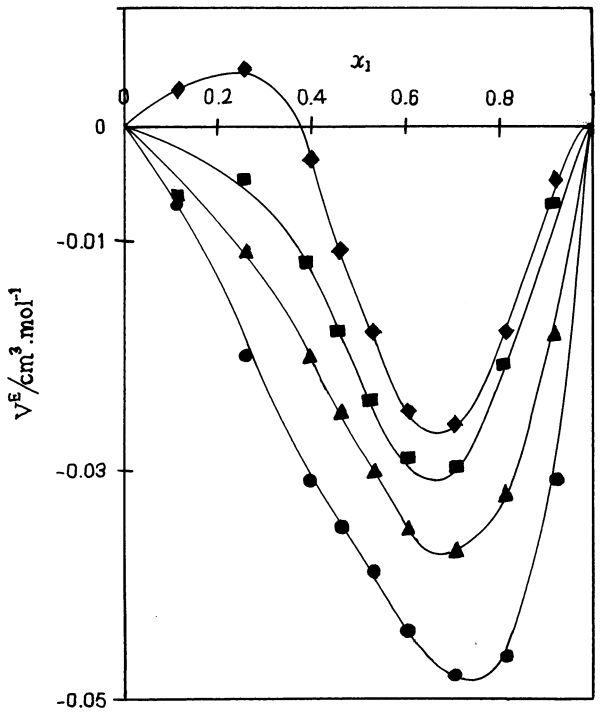

Figure 3. Excess molar volumes (eq 4) (V^E) for (x_1)benzene + (1 − x_1)chlorobenzene at various temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

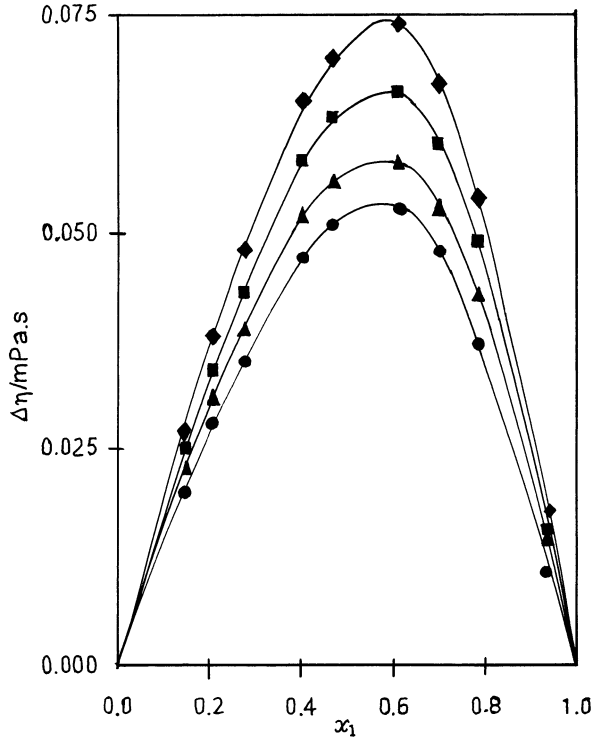

Figure 4. Deviations in viscosity (eq 4) ($\Delta\eta$) for (x_1)*N*,*N*-dimethylformamide + (1 − x_1)chlorobenzene at various temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

of coefficients. The calculated values of a_i along with standard deviations (σ) are given in Table 3.

Excess Molar Volumes and Deviations in Viscosity for Ternary Mixtures. Table 4 lists experimental values of densities (ρ) and viscosities (η) of ternary mixtures of *N*,*N*-dimethylformamide + benzene + chlrobenzene at

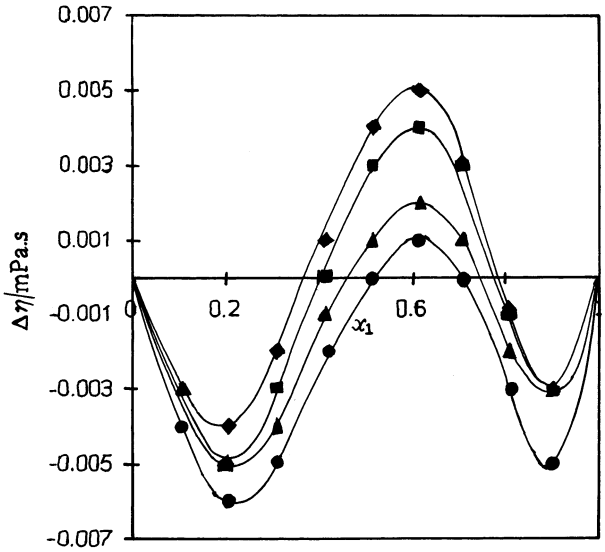

Figure 5. Deviations in viscosity (eq 4) ($\Delta\eta$) for (x_1)*N*,*N*-dimethylformamide + (1 − x_1)benzene at various temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

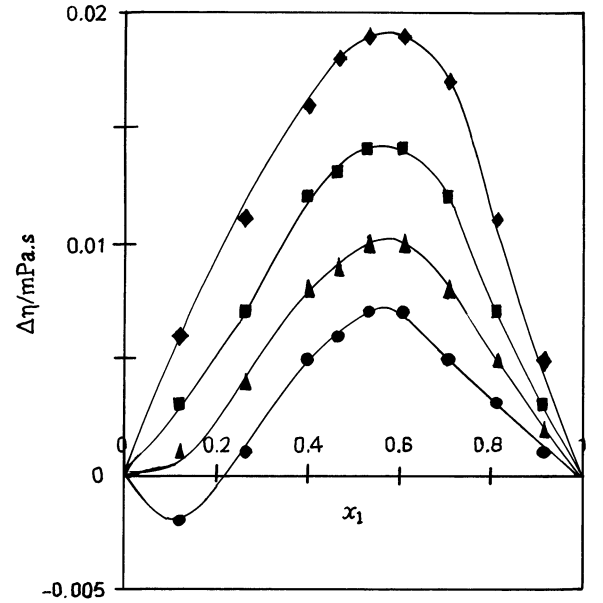

Figure 6. Deviations in viscosity (eq 4) ($\Delta\eta$) for (x_1)benzene + (1 − x_1)chlorobenzene at various temperatures: ◆, 298.15 K; ■, 303.15 K; ▲, 308.15 K; ●, 313.15 K.

(298.15, 303.15, 308.15, and 313.15) K. The excess molar volumes (V^E_{123}) were calculated by using the following equation.

$$V^E_{123} = (x_1M_1 + x_2M_2 + x_3M_3)/\rho_{mix} - x_1M_1/\rho_1 - x_2M_2/\rho_2 - x_3M_3/\rho_3 \quad (6)$$

where x_1, x_2, x_3, M_1, M_2, M_3, ρ_1, ρ_2, and ρ_3 are mole fractions, molecular weights, and densities of pure components 1, 2, and 3, respectively, and ρ_{mix} is the density of the ternary mixture. The excess molar volumes of the ternary mixtures studied in the present work are negative.

The viscosity deviations ($\Delta\eta_{123}$) were calculated by using the equation

$$\Delta\eta_{123} = \eta_{mix} - x_1\eta_1 - x_2\eta_2 - x_3\eta_3 \quad (7)$$

Table 3. Parameters and Standard Deviations (σ) of Eqs 4 and 5 for Binary Systems

property	T/K	a_0	a_1	a_2	a_3	σ
		N,*N*-Dimethylformamide + Chlorobenzene				
V^E/cm^3·mol^{-1}	298.15	−1.3410	−0.2879	1.5311	0.5107	0.010
	303.15	−1.3861	−0.3332	1.5090	0.5852	0.011
	308.15	−1.4399	−0.3747	1.4707	0.6894	0.012
	313.15	−1.4856	−0.3622	1.4154	0.6529	0.012
		N,*N*-Dimethylformamide + Chlorobenzene				
$\Delta\eta$/mPa·s	298.15	0.2904	0.1053	−0.0500	−0.0750	0.001
	303.15	0.2585	0.0969	−0.0361	−0.0800	0.001
	308.15	0.2305	0.0734	−0.0248	−0.0466	0.001
	313.15	0.2106	0.0751	−0.0510	−0.0860	0.001
		N,*N*-Dimethylformamide + Benzene				
V^E/cm^3·mol^{-1}	298.15	−1.5650	−0.5459	1.2482	1.4106	0.016
	303.15	−1.6467	−0.4557	1.2313	1.2584	0.022
	308.15	−1.7629	−0.3640	1.3304	1.1136	0.021
	313.15	−1.8909	−0.1306	1.4062	0.7309	0.020
		N,*N*-Dimethylformamide + Benzene				
$\Delta\eta$/mPa·s	298.15	0.0149	0.0395	−0.0782	−0.0668	0.001
	303.15	0.0095	0.0533	−0.0694	−0.0897	0.001
	308.15	0.0035	0.0448	−0.0602	−0.0772	0.001
	313.15	0.0013	0.0416	−0.0794	−0.0814	0.001
		Benzene + Chlorobenzene				
V^E/cm^3·mol^{-1}	298.15	−0.0595	−0.2230	0.0427	0.2514	0.005
	303.15	−0.0842	−0.1789	−0.0011	0.2420	0.003
	308.15	−0.1114	−0.1556	−0.0554	0.0794	0.003
	313.15	−0.1497	−0.1262	−0.1070	−0.1282	0.006
		Benzene + Chlorobenzene				
$\Delta\eta$/mPa·s	298.15	0.0745	0.0341	−0.0211	−0.0439	0.001
	303.15	0.0541	0.0237	−0.0351	−0.0255	0.001
	308.15	0.0382	0.0246	−0.0348	−0.0211	0.001
	313.15	0.0259	0.0181	−0.0501	0.0066	0.001

where η_{mix} is the viscosity of the ternary mixture and η_1, η_2, and η_3 are the viscosities of components 1, 2, and 3, respectively. The ($\Delta\eta_{123}$) values of the ternary systems investigated in the present work are positive. The excess molar volumes and deviations in viscosity of ternary liquid mixtures are included in Table 4. The excess molar volumes and deviations in viscosity of the ternary systems studied have been predicted from the corresponding properties of their constituent binary subsystems by empirical equations available in the literature. The equations used were as follows.

The equation of Radjkovic et al.[15]

$$\Delta M_{123} = \Delta M_{12} + \Delta M_{13} + \Delta M_{23} \quad (8)$$

where $\Delta M_{ij} = x_i x_j[(a_0)_{ij} + (a_1)_{ij}(x_i - x_j) + (a_2)_{ij}(x_i - x_j)^2 + (a_3)_{ij}(x_i - x_j)^3]$ and x_i and x_j are the mole fractions of the components in a ternary mixture.

The equation of Kohler[16]

$$\Delta M_{123} = (x_1 + x_2)^2 \Delta M_{12}(x_1', x_2') + (x_1 + x_3)^2 \Delta M_{13}(x_1', x_3') + (x_2 + x_3)^2 \Delta M_{23}(x_2', x_3') \quad (9)$$

where $\Delta M_{ij} = x_i' x_j'[(a_0)_{ij} + (a_1)_{ij}(x_i' - x_j') + (a_2)_{ij}(x_i' - x_j')^2 + (a_3)_{ij}(x_i' - x_j')^3]$ and $x_i' = 1 - x_j' = x_i/(x_i + x_j)$.

The equation of Scatchard et al.[17]

$$\Delta M_{123} = (x_2/(1 - x_1))\Delta M_{12}(x_1', x_2') + (x_3/(1 - x_1))\Delta M_{13}(x_1', x_3') + \Delta M_{23}(x_2', x_3') \quad (10)$$

It is observed that all these three equations give the best predictions of excess molar volumes and deviations in viscosity of ternary mixtures.

Kinematic Viscosities of Binary and Ternary Mixtures. The kinematic viscosities (ν) of binary and ternary liquid mixtures are calculated from their densities and dynamic viscosities. The kinematic viscosities of binary

Table 4. Density, ρ, Viscosity, η, Excess Molar Volume, V^E_{123}, and Deviations in Viscosity, $\Delta\eta_{123}$, for Ternary Mixtures at (298.15, 303.15, 308.15, and 313.15) K

x_1	x_2	$10^3\rho$/kg·m^{-3}	η/mPa·s	V^E_{123}/cm^3·mol^{-1}	$\Delta\eta_{123}$/mPa·s	$10^3\rho$/kg·m^{-3}	η/mPa·s	V^E_{123}/cm^3·mol^{-1}	$\Delta\eta_{123}$/mPa·s
		(x_1)*N*,*N*-Dimethylformamide + (x_2)Benzene (1 − x_1− x_2)Chlorobenzene							
		298.15 K				303.15 K			
0.0763	0.3891	1.0092	0.717	−0.094	0.017	1.0041	0.675	−0.103	0.015
0.1565	0.5273	0.9650	0.712	−0.181	0.029	0.9600	0.669	−0.198	0.025
0.2213	0.4764	0.9671	0.724	−0.252	0.030	0.9620	0.683	−0.257	0.029
0.2844	0.1713	1.0293	0.784	−0.262	0.041	1.0243	0.737	−0.271	0.036
0.3520	0.3806	0.9689	0.751	−0.316	0.037	0.9639	0.705	−0.326	0.032
0.5232	0.0933	1.0102	0.828	−0.243	0.062	1.0054	0.776	−0.258	0.054
0.5399	0.2755	0.9622	0.781	−0.322	0.042	0.9573	0.733	−0.331	0.037
0.6282	0.1948	0.9660	0.800	−0.225	0.044	0.9612	0.751	−0.237	0.039
0.7018	0.1964	0.9518	0.792	−0.233	0.033	0.9470	0.744	−0.242	0.029
0.7657	0.1392	0.9542	0.795	−0.162	0.024	0.9496	0.747	−0.184	0.021
0.8092	0.1259	0.9493	0.804	−0.157	0.029	0.9446	0.755	−0.169	0.025
0.8472	0.0724	0.9561	0.805	−0.111	0.020	0.9514	0.757	−0.125	0.018
0.9164	0.0508	0.9479	0.803	−0.070	0.012	0.9432	0.756	−0.075	0.011
		(x_1)*N*,*N*-Dimethylformamide + (x_2)Benzene + (1 − x_1 − x_2)Chlorobenzene							
		308.15 K				313.15 K			
0.0763	0.3891	0.9990	0.632	−0.111	0.011	0.9935	0.594	−0.125	0.009
0.1565	0.5273	0.9549	0.626	−0.209	0.022	0.9494	0.589	−0.215	0.019
0.2213	0.4764	0.9570	0.639	−0.275	0.025	0.9518	0.601	−0.307	0.022
0.2844	0.1713	1.0194	0.692	−0.285	0.033	1.0142	0.652	−0.317	0.029
0.3520	0.3806	0.9589	0.659	−0.337	0.027	0.9536	0.620	−0.352	0.023
0.5232	0.0933	1.0005	0.726	−0.263	0.047	0.9953	0.683	−0.273	0.041
0.5399	0.2755	0.9523	0.685	−0.333	0.031	0.9472	0.644	−0.353	0.026
0.6282	0.1948	0.9563	0.703	−0.242	0.034	0.9513	0.661	−0.264	0.028
0.7018	0.1964	0.9422	0.697	−0.253	0.026	0.9373	0.657	−0.278	0.022
0.7657	0.1392	0.9449	0.700	−0.199	0.018	0.9400	0.660	−0.219	0.015
0.8092	0.1259	0.9399	0.708	−0.181	0.023	0.9350	0.666	−0.198	0.017
0.8472	0.0724	0.9468	0.709	−0.137	0.015	0.9418	0.670	−0.142	0.013
0.9164	0.0508	0.9385	0.708	−0.081	0.008	0.9336	0.668	−0.088	0.005

liquid mixtures are correlated by using McAllister's[18] three -body collision equation of the following type.

$$\ln \nu = x_1^3 \ln \nu_1 + x_2^3 \ln \nu_2 + 3x_1^2x_2 \ln \nu_{12} + 3x_2^2x_1 \ln \nu_{21} - \ln(x_1 + x_2M_2/M_1) + 3x_1^2x_2 \ln(^2/_3 + M_2/3M_1) + 3x_2^2x_1 \ln(^1/_3 + 2M_2/3M_1) + x_2^3 \ln(M_2/M_1) \quad (11)$$

where ν is the kinematic viscosity of the binary mixture and ν_1, ν_2, x_1, and x_2 are the kinematic viscosities and mole fractions of components 1 and 2, respectively. The equation consists of two adjustable parameters ν_{12} and ν_{21} which are determined by a least-squares method.

To correlate the kinematic viscosities of ternary mixtures, McAllister's extended[19] three-body collision equation has been used. The equation consists of seven constants comprising six binary constants and one ternary constant. The six binary constants ν_{12}, ν_{21}, ν_{23}, ν_{32}, ν_{13}, and ν_{31} may be determined from three binary systems of components 1 and 2, 2 and 3, and 3 and 1. The equation contains only one undetermined constant ν_{123} which is determined from least-squares fitting. The kinematic viscosities of binary and ternary liquid mixtures are well correlated.

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