Densities and Viscosities of Diethyl Carbonate + Toluene, + Methanol, and + 2-Propanol from (293.15 to 363.15) K

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Densities and viscosities for diethyl carbonate (DEC) with toluene, methanol, and 2-propanol were determined over several temperatures and at atmospheric pressure. The measurements were carried out over the whole mole fraction, using a vibrating-tube densimeter and an Ubbelohde viscometer. Density and viscosity measurements were used to compute the excess molar volumes, V^E, and viscosity deviations, $\Delta\eta$. The excess molar volumes, V^E, and viscosity deviations, $\Delta\eta$, have been fitted to Redlich−Kister equation.

Introduction

Studies on viscosity and density of binary mixtures along with other thermodynamic properties are being increasingly used as tools for the investigation of the properties of pure components and the nature of intermolecular interactions between the liquid mixture constituents. The organic carbonates are attracting an increasing interest due to these chemicals having an extensive variety of applications in the lithium battery technology; for the synthesis of polycarbonates, pharmaceuticals, and agrochemicals; as extractive solvents and solvents for natural and synthetic resins and polymers; and as fuel additives[1]. Also, organic carbonates have been proposed as lubricants of new refrigerants for stationary air conditioners because of their thermal stability, miscibility with HFCs, and lubricity.

This paper is part of our systematic program of research on the measurement of physical and transport properties of binary liquid mixtures containing organic carbonates. In this work, we present density and viscosity data for the binary systems diethyl carbonate + toluene, + methanol, and + 2-propanol from (293.15 to 363.15) K. From the densities and viscosities, excess molar volumes and viscosity deviations are calculated. The Redlich−Kister equation was used to correlate the experimental excess molar volumes and viscosity deviations.

A survey of the literature shows that Lopez et al.[4] measured densities for diethyl carbonate + toluene at (278.15 to 323.15) K. Francesconi et al.[2] measured excess molar enthalpies and densities of DEC in binary mixtures with seven *n*-alkanols at 298.15 K, while Rodriguez et al.[3,5] determined densities and viscosities of DEC with alcohols at 293.15 K, 298.15 K, 303.15 K, and 313.15 K.

Experimental Section

Materials. All chemicals used in this study were supplied by Tianjin Reagent Co. except DEC, which was supplied by Shanghai Chemical Reagent Co. DEC was purified by distillation. Other liquids were subjected to no further purification. All were dried over 0.4 nm molecular sieves and particularly degassed by ultrasound prior to their experimental use. The mass fraction purities tested by gas chromatography were as follows: DEC (> 0.995), toluene (> 0.998), methanol (> 0.998), and 2-propanol (> 0.993). In Table 1, we compare the densities and viscosities determined in this study and the literature data.

Apparatus and Procedure. The densities of the pure components and their mixtures were measured with a high precision vibrating-tube digital density meter (Density/Specific Gravity Meter DA 505, KEM, Japan) whose measurement cell temperature was controlled automatically within ± 0.01 K of the selected value. Before each series of measurements, the instrument was calibrated at atmospheric pressure with double-distilled water and dry air. Densities of both water and dry air at the various working temperatures were given by the manufacturer in the instruction manual. The uncertainty in density measurements was $\pm 5 \times 10^{-5}$ g·cm^{-3}. Density measurements were reproducible to $\pm 3 \times 10^{-5}$ g·cm^{-3}.

The liquid mixtures were prepared by mass using a BP210s balance accurate to within ± 0.01 mg. The average uncertainty in the mole fraction of the mixtures was estimated to be less than ± 0.0001. The molar excess volumes were calculated from composition−density data with an uncertainty better than ± 0.002 cm^3·mol^{-1}. All molar quantities were based on the IUPAC relative atomic mass table.

The viscosities of pure liquids and the mixtures were measured at atmospheric pressure and at different temperatures using several Ubbelohde suspended-level viscometers. The viscometer was immersed in a well-stirred water bath (Lauda, Germany) with temperature control to within ± 0.01 K. An electronic digital stopwatch with a readability of ± 0.01 s was used for flow time measurement. Experiments are repeated a minimum of four times at each temperature for all compositions, and the results were averaged. The viscosity η of the liquid was then calculated from the following relationship:

$$\nu = \frac{\eta}{\rho} = k(t - \theta) \tag{1}$$

where t is the flow time; ν is the kinematic viscosity; and k and θ are the viscometer constant and the Hagenbach correction factor, respectively.

The calibration of the viscometer was carried out with double-distilled water and twice-distilled benzene. During the heating, to minimize the evaporation losses, the viscometer's limbs are closed with Teflon caps. During the measurements of flow time,

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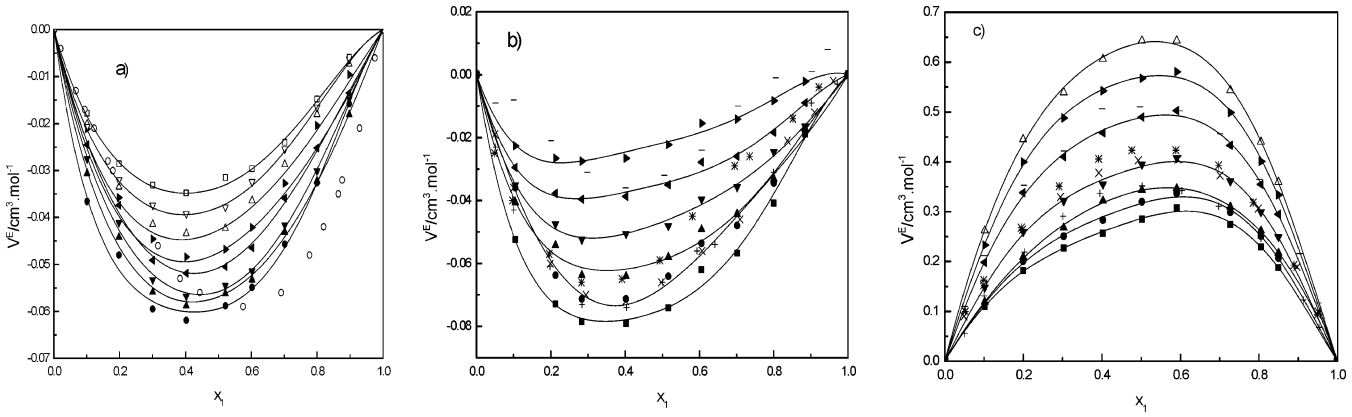

Figure 1. Excess molar volume variation with mole fraction to systems (a) DEC (1) + toluene (2); (b) DEC (1) + methanol (2); (c) DEC (1) + 2-propanol (2) for experimental values: ■, 293.15 K; ●, 298.15 K; ▲, 303.15 K; ▼, 313.15 K; left-facing solid triangle, 323.15 K; right-facing solid triangle, 333.15 K; △, 343.15 K; ▽, 353.15 K; □, 363.15 K. Literature data: Wankhede et al.[4] to DEC (1) + toluene (2) at ○, 298.15 K; Rodriguez et al.[5] to DEC (1) + methanol (2) and DEC (1) + 2-propanol (2) at +, 293.15 K; × , 298.15 K; *, 303.15 K; —, 313.15 K; solid curves, calculated with Redlich−Kister equations; symbols, experimental values.

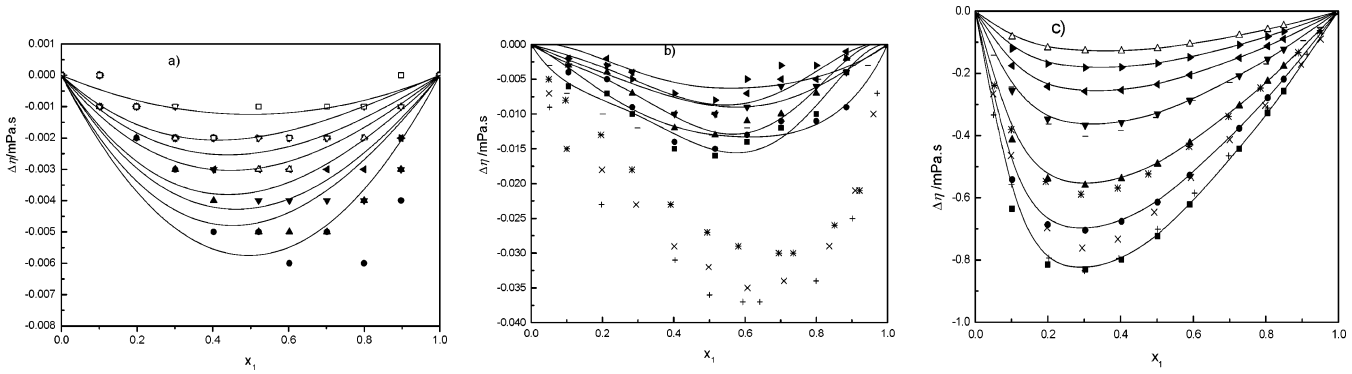

Figure 2. Viscosity deviation variation with mole fraction to systems (a) DEC (1) + toluene (2); (b) DEC (1) + methanol (2); (c) DEC (1) + 2-propanol (2) for experimental values: ■, 293.15 K; ●, 298.15 K; ▲, 303.15 K; ▼, 313.15 K; left-facing solid traingle, 323.15 K; right-facing solid triangle, 333.15 K; △, 343.15 K; ▽, 353.15 K; □, 363.15 K. Literature data: Rodriguez et al.[3] to DEC (1) + methanol (2) and DEC (1) + 2-propanol (2) at +, 293.15 K; × , 298.15 K; *, 303.15 K; —, 313.15 K; solid curves, calculated with Redlich−Kister equations; symbols, experimental values.

Table 1. Comparison of Experimental and Literature Values of Densities ρ, and Viscosities η, for Pure Compounds

		ρ/g·cm^{-3}		η/mPa·s				ρ/g·cm^{-3}		η/mPa·s	
liquid	T/K	exptl	lit	exptl	lit	liquid	T/K	exptl	lit	exptl	lit
diethyl carbonate	293.15	0.97500	0.9747[5]	0.800	0.795[3]	toluene	333.15	0.82993	0.8292[7]	0.385	0.3824[7]
	298.15	0.96897	0.9691[5]	0.746	0.749[3]		343.15	0.82030	0.8197[7]	0.350	0.3491[7]
			0.96916[4]				353.15	0.81054	0.8094[7]	0.310	0.3176[7]
	303.15	0.96239	0.9634[5]	0.695	0.699[3]		363.15	0.79768		0.286	
	313.15	0.95232	0.9522[5]	0.610	0.623[3]	methanol	293.15	0.79154	0.7912[12]	0.582	0.591[3]
			0.95243[6]						0.79106[15]		0.577[15]
	323.15	0.93978	0.94077[4]	0.541			298.15	0.78683	0.7866[12]	0.550	0.553[3]
	333.15	0.92869		0.483							0.538[13]
	343.15	0.91633		0.435			303.15	0.78212	0.7818[12]	0.512	0.514[3]
	353.15	0.90502		0.393					0.7821[14]		0.497[14]
	363.15	0.89371		0.358					0.78195[15]		0.512[15]
toluene	298.15	0.86201	0.86217[8]	0.554	0.5541[10]		313.15	0.77260	0.7726[12]	0.448	0.450[3]
			0.8609[9]		0.5542[9]				0.77201[15]		0.447[15]
			0.8623[11]				323.15	0.76297		0.395	
	303.15	0.85832	0.8565[7]	0.525	0.5171[7]		333.15	0.74969		0.351	
			0.8576[10]		0.5226[10]	2-propanol	293.15	0.78528	0.7894[5]	2.382	2.386[3]
			0.8578[11]		0.5227[11]		298.15	0.78069	0.7809[5]	2.069	2.098[3]
	313.15	0.84892	0.8479[7]	0.470	0.4669[7]		303.15	0.77615	0.7766[5]	1.743	1.763[3]
			0.8482[10]		0.4659[10]		313.15	0.76634	0.7678[5]	1.288	1.325[3]
	323.15	0.83875	0.8385[7]	0.423	0.4219[7]		323.15	0.75566		1.002	
			0.8387[9]		0.4216[9]		333.15	0.74551		0.789	
			0.8390[11]		0.4216[11]		343.15	0.73502		0.626	

the caps of the limps were removed. The overall uncertainty of the viscosity measurements is dependent on the temperature control of the viscometer, the time of the flow, and the concentration, which are of the order of 1×10^{-2}, 1×10^{-2}, and 3×10^{-4}, respectively. The uncertainty of viscosity was within $\pm$ 0.003 mPa·s.

In the experiments, the density and viscosity for one composition sample were measured at different temperatures. Densities and viscosities of pure compounds are reported in Table 1 together with the corresponding literature values. For the densities, good agreement was found between the measured and literature values for all these pure substances. There is an

Table 2. Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for the Binary Mixtures at Different Temperatures

x	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s
(x) Diethyl Carbonate + (1 − x) Toluene																				
				T = 298.15 K										T = 333.15 K						
0.0000	0.86201	0.554	0.0000	0.000	0.6022	0.93018	0.664	−0.0549	−0.006	0.0000	0.82993	0.385	0.0000	0.000	0.6022	0.89288	0.442	−0.0421	−0.002
0.1014	0.87450	0.573	−0.0366	−0.001	0.7016	0.94028	0.684	−0.0457	−0.005	0.1014	0.84139	0.394	−0.0211	−0.001	0.7016	0.90220	0.452	−0.0327	−0.002
0.1984	0.88594	0.590	−0.0480	−0.002	0.7995	0.94995	0.702	−0.0326	−0.006	0.1984	0.85201	0.403	−0.0358	−0.001	0.7995	0.91111	0.461	−0.0204	−0.002
0.3006	0.89767	0.608	−0.0595	−0.003	0.8975	0.95936	0.722	−0.0158	−0.004	0.3006	0.86285	0.413	−0.0446	−0.002	0.8975	0.91981	0.471	−0.0096	−0.002
0.4024	0.90897	0.627	−0.0619	−0.005	1.0000	0.96897	0.746	0.0000	0.000	0.4024	0.87330	0.422	−0.0484	−0.002	1.0000	0.92869	0.483	0.0000	0.000
0.5212	0.92172	0.649	−0.0588	−0.005						0.5212	0.88509	0.434	−0.0468	−0.002					
				T = 303.15 K										T = 343.15 K						
0.0000	0.85832	0.525	0.0000	0.000	0.6022	0.92471	0.622	−0.0533	−0.005	0.0000	0.82030	0.350	0.0000	0.0000	0.6022	0.88151	0.398	−0.0364	−0.003
0.1014	0.87046	0.542	−0.0306	−0.001	0.7016	0.93452	0.639	−0.0431	−0.005	0.1014	0.83146	0.358	−0.0201	−0.0003	0.7016	0.89057	0.407	−0.0287	−0.002
0.1984	0.88162	0.557	−0.0442	−0.002	0.7995	0.94393	0.657	−0.0322	−0.004	0.1984	0.84179	0.365	−0.0335	−0.0012	0.7995	0.89924	0.415	−0.0181	−0.002
0.3006	0.89306	0.573	−0.0559	−0.003	0.8975	0.95308	0.674	−0.0181	−0.003	0.3006	0.85232	0.373	−0.0414	−0.0020	0.8975	0.90769	0.425	−0.0073	−0.001
0.4024	0.90406	0.590	−0.0588	−0.004	1.0000	0.96239	0.695	0.0000	0.000	0.4024	0.86248	0.382	−0.0434	−0.0021	1.0000	0.91633	0.435	0.0000	0.000
0.5212	0.91647	0.609	−0.0562							0.5212	0.87394	0.391	−0.0423	−0.0028					
				T = 313.15 K										T = 353.15 K						
0.0000	0.84892	0.470	0.0000	0.000	0.6022	0.91485	0.550	−0.0514	−0.004	0.0000	0.81054	0.310	0.0000	0.000	0.6022	0.87074	0.358	−0.0324	−0.002
0.1014	0.86095	0.484	−0.0275	−0.000	0.7016	0.92460	0.564	−0.0416	−0.004	0.1014	0.82153	0.318	−0.0207	−0.001	0.7016	0.87966	0.367	−0.0254	−0.002
0.1984	0.87204	0.497	−0.0411	−0.002	0.7995	0.93395	0.579	−0.0301	−0.004	0.1984	0.83167	0.326	−0.0320	−0.001	0.7995	0.88820	0.375	−0.0165	−0.002
0.3006	0.88339	0.510	−0.0533	−0.003	0.8975	0.94304	0.593	−0.0148	−0.003	0.3006	0.84202	0.334	−0.0374	−0.002	0.8975	0.89652	0.384	−0.0063	−0.001
0.4024	0.89433	0.523	−0.0568	−0.003	1.0000	0.95232	0.610	0.0000	0.000	0.4024	0.85202	0.342	−0.0392	−0.002	1.0000	0.90502	0.393	0.0000	0.000
0.5212	0.90666	0.539	−0.0545	−0.004						0.5212	0.86329	0.352	−0.0378	−0.002					
				T = 323.15 K										T = 363.15 K						
0.0000	0.83875	0.423	0.0000	0.000	0.6022	0.90316	0.491	−0.0465	−0.003	0.0000	0.79768	0.286	0.0000	0.000	0.6022	0.85877	0.328	−0.0296	−0.002
0.1014	0.85049	0.434	−0.0245	−0.001	0.7016	0.91268	0.503	−0.0359	−0.003	0.1014	0.80879	0.293	−0.0178	−0.000	0.7016	0.86785	0.336	−0.0240	−0.001
0.1984	0.86133	0.445	−0.0374	−0.001	0.7995	0.92181	0.515	−0.0252	−0.003	0.1984	0.81907	0.300	−0.0286	−0.001	0.7995	0.87655	0.343	−0.0148	−0.001
0.3006	0.87243	0.457	−0.0491	−0.002	0.8975	0.93072	0.527	−0.0135	−0.002	0.3006	0.82957	0.306	−0.0331	−0.001	0.8975	0.88504	0.351	−0.0059	−0.000
0.4024	0.88311	0.468	−0.0519	−0.003	1.0000	0.93978	0.541	0.0000	0.000	0.4024	0.83971	0.313	−0.0348	−0.002	1.0000	0.89371	0.358	0.0000	0.000
0.5212	0.89517	0.481	−0.0505	−0.003						0.5212	0.85116	0.322	−0.0315	−0.002					
(x) Diethyl Carbonate + (1 − x) Methanol																				
				T = 293.15 K										T = 313.15 K						
0.0000	0.79154	0.582	0.0000	0.000	0.6057	0.94283	0.700	−0.0620	−0.014	0.0000	0.77260	0.448	0.0000	0.000	0.6057	0.92059	0.5371	−0.0396	−0.009
0.1045	0.83993	0.599	−0.0524	−0.006	0.7015	0.95267	0.723	−0.0568	−0.012	0.1045	0.81968	0.462	−0.0351	−0.003	0.7015	0.93026	0.5557	−0.0357	−0.006
0.2128	0.87469	0.622	−0.0729	−0.007	0.8000	0.96118	0.747	−0.0409	−0.010	0.2128	0.85364	0.480	−0.0475	−0.003	0.8000	0.93867	0.5716	−0.0245	−0.006
0.2835	0.89208	0.634	−0.0785	−0.010	0.8845	0.96744	0.772	−0.0189	−0.004	0.2835	0.87071	0.490	−0.0524	−0.004	0.8845	0.94493	0.5874	−0.0164	−0.004
0.4025	0.91512	0.655	−0.0791	−0.015	1.0000	0.97500	0.801	0.0000	0.000	0.4025	0.89330	0.503	−0.0506	−0.010	1.0000	0.95232	0.6101	0.0000	0.000
0.5161	0.93204	0.679	−0.0741	−0.016						0.5161	0.90994	0.521	−0.0481	−0.010					
				T = 298.15 K										T = 323.15 K						
0.0000	0.78683	0.550	0.0000	0.000	0.6057	0.93711	0.656	−0.0536	−0.013	0.0000	0.76297	0.395	0.0000	0.000	0.6057	0.90928	0.477	−0.0278	−0.008
0.1045	0.83464	0.567	−0.0359	−0.004	0.7015	0.94689	0.677	−0.0480	−0.011	0.1045	0.80945	0.408	−0.0295	−0.002	0.7015	0.91888	0.493	−0.0260	−0.005
0.2128	0.86933	0.588	−0.0638	−0.005	0.8000	0.95537	0.696	−0.0345	−0.011	0.2128	0.84300	0.424	−0.0378	−0.002	0.8000	0.92724	0.507	−0.0183	−0.005
0.2835	0.88665	0.598	−0.0713	−0.009	0.8845	0.96165	0.715	−0.0183	−0.009	0.2835	0.85986	0.432	−0.0396	−0.004	0.8845	0.93343	0.523	−0.0089	−0.001
0.4025	0.90956	0.616	−0.0713	−0.014	1.0000	0.96897	0.746	0.0000	0.000	0.4025	0.88225	0.444	−0.0387	−0.010	1.0000	0.93978	0.541	0.0000	0.000
0.5161	0.92635	0.637	−0.0641	−0.015						0.5161	0.89872	0.461	−0.0350	−0.010					
				T = 303.15 K										T = 333.15 K						
0.0000	0.78212	0.512	0.0000	0.000	0.6057	0.93174	0.611	−0.0492	−0.011	0.0000	0.74969	0.351	0.0000	0.000	0.6057	0.89715	0.426	−0.0154	−0.005
0.1045	0.82980	0.527	−0.0407	−0.003	0.7015	0.94149	0.630	−0.0444	−0.010	0.1045	0.79631	0.363	−0.0227	−0.002	0.7015	0.90690	0.441	−0.0142	−0.003
0.2128	0.86412	0.546	−0.0542	−0.004	0.8000	0.94997	0.651	−0.0331	−0.007	0.2128	0.83009	0.376	−0.0266	−0.003	0.8000	0.91539	0.454	−0.0083	−0.003
0.2835	0.88142	0.556	−0.0638	−0.007	0.8845	0.95623	0.671	−0.0171	−0.002	0.2835	0.84711	0.384	−0.0275	−0.005	0.8845	0.92171	0.466	−0.0022	−0.002
0.4025	0.90425	0.573	−0.0641	−0.012	1.0000	0.96239	0.695	0.0000	0.000	0.4025	0.86976	0.397	−0.0266	−0.007	1.0000	0.92869	0.483	0.0000	0.000
0.5161	0.92100	0.593	−0.0580	−0.013						0.5161	0.88644	0.410	−0.0223	−0.008					

(*x*) Diethyl Carbonate + (1 − *x*) 2-Propanol

				T = 293.15 K					
0.0000	0.78528	2.382	0.0000	0.000	0.5905	0.91448	0.827	0.3075	−0.621
0.1015	0.81295	1.586	0.1100	−0.635	0.7267	0.93622	0.791	0.2745	−0.442
0.1993	0.83712	1.252	0.1816	−0.814	0.8053	0.94793	0.781	0.2292	−0.328
0.3027	0.86152	1.073	0.2269	−0.830	0.8494	0.95432	0.782	0.1880	−0.25
0.4029	0.88088	0.946	0.2566	−0.799	1.0000	0.97500	0.800	0.0000	0.000
0.5018	0.90157	0.865	0.2851	−0.724					
				T = 298.15 K					
0.0000	0.78069	2.069	0.0000	0.000	0.5905	0.90868	0.760	0.3365	−0.527
0.1015	0.80812	1.393	0.1151	−0.542	0.7267	0.93030	0.731	0.2988	−0.377
0.1993	0.83198	1.119	0.2006	−0.687	0.8053	0.94194	0.726	0.2509	−0.278
0.3027	0.85503	0.964	0.2506	−0.705	0.8494	0.94831	0.726	0.2067	−0.219
0.4029	0.87534	0.860	0.2831	−0.676	1.0000	0.96897	0.746	0.0000	0.000
0.5018	0.89355	0.791	0.3196	−0.614					
				T = 303.15 K					
0.0000	0.77615	1.743	0.0000	0.000	0.5905	0.90271	0.700	0.3465	−0.424
0.1015	0.80327	1.223	0.1190	−0.414	0.7267	0.92409	0.677	0.3094	−0.304
0.1993	0.82684	0.996	0.2091	−0.539	0.8053	0.93560	0.674	0.2616	−0.225
0.3027	0.84957	0.867	0.2679	−0.559	0.8494	0.94189	0.676	0.2172	−0.177
0.4029	0.86948	0.782	0.3217	−0.538	1.0000	0.96239	0.695	0.0000	0.000
0.5018	0.88762	0.726	0.3433	−0.492					
				T = 313.15 K					
0.0000	0.76634	1.288	0.0000	0.000	0.5905	0.89218	0.601	0.4083	−0.287
0.1015	0.79312	0.964	0.1481	−0.256	0.7267	0.91363	0.588	0.3614	−0.207
0.1993	0.81646	0.806	0.2595	−0.347	0.8053	0.92525	0.588	0.2995	−0.154
0.3027	0.83913	0.716	0.3217	−0.367	0.8494	0.93159	0.590	0.2493	−0.122
0.4029	0.85920	0.657	0.3553	−0.358	1.0000	0.95232	0.610	0.0000	0.000
0.5018	0.87718	0.618	0.3950	−0.330					
				T = 323.15 K					
0.0000	0.75566	1.002	0.0000	0.000	0.5905	0.87949	0.524	0.5025	−0.206
0.1015	0.78171	0.780	0.1982	−0.175	0.7267	0.90094	0.517	0.4328	−0.150
0.1993	0.80458	0.668	0.3379	−0.242	0.8053	0.91258	0.519	0.3547	−0.112
0.3027	0.82695	0.604	0.4101	−0.258	0.8494	0.91893	0.521	0.2948	−0.090
0.4029	0.84673	0.562	0.4581	−0.254	1.0000	0.93978	0.541	0.0000	0.000
0.5018	0.86462	0.535	0.4898	−0.236					
				T = 333.15 K					
0.0000	0.74551	0.789	0.0000	0.000	0.5905	0.86810	0.460	0.5805	−0.148
0.1015	0.77112	0.637	0.2330	−0.121	0.7267	0.88956	0.458	0.4987	−0.108
0.1993	0.79364	0.559	0.3996	−0.169	0.8053	0.90129	0.461	0.4006	−0.081
0.3027	0.81577	0.515	0.4877	−0.181	0.8494	0.90767	0.464	0.3335	−0.065
0.4029	0.83541	0.485	0.5424	−0.181	1.0000	0.92869	0.483	0.0000	0.000
0.5018	0.85329	0.467	0.5674	−0.168					
				T = 343.15 K					
0.0000	0.73502	0.626	0.0000	0.000	0.5905	0.85592	0.407	0.6428	−0.106
0.1015	0.76013	0.523	0.2620	−0.083	0.7267	0.87730	0.409	0.5434	−0.078
0.1993	0.78230	0.470	0.4452	−0.118	0.8053	0.88896	0.413	0.4401	−0.050
0.3027	0.80417	0.440	0.5393	−0.128	0.8494	0.89536	0.417	0.3595	−0.047
0.4029	0.82353	0.421	0.6062	−0.128	1.0000	0.91633	0.435	0.0000	0.000
0.5018	0.84114	0.410	0.6428	−0.120					

appreciable difference for the viscosity data among the literatures for methanol. The viscosity values of methanol obtained in this study are in good agreement with those of Rodriguez et al.[3]

Results and Discussion

The experimental values of density and viscosity for binary mixture at different temperatures and at atmospheric pressure are listed in Table 2. Excess molar volumes were calculated from our measurements according to the following equation:[16]

$$V^{E} = \frac{x_1M_1 + x_2M_2}{\rho} - \frac{x_1M_1}{\rho_1} - \frac{x_2M_2}{\rho_2} \tag{2}$$

where x_1 and x_2 are mole fractions; M_1 and M_2 are the molar masses; and ρ_1 and ρ_2 are the densities of pure components 1 and 2, respectively. Quantities without subscripts refer to the mixture.

The viscosity derivations were calculated from the following relation:

$$\Delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \tag{3}$$

where η is the viscosity of mixtures and η_1 and η_2 are the viscosity of components 1 and 2, respectively. The values of V^E and $\Delta\eta$ for each mixture were fitted to the Redlich−Kister polynominal equation:[17]

$$Y = x_1(1 - x_1)\sum_{i=0}^{n} A_i(2x_1 - 1)^i \tag{4}$$

where $Y = V^E$ or $\Delta\eta$, A_i are adjustable parameters, and x_1 is the mole fraction of component 1.

In each case, the optimum number of coefficients A_i was determined from an examination of the variation of the standard derivations:

$$\sigma(Y) = [\sum(Y_{cal} - Y_{exp})^2/(n - m)\ ]^{(1/2)} \tag{5}$$

where n is the total number of experimental values and m is the number of parameters.

The excess molar volume data and the viscosity derivations are presented in Table 2, they are shown graphically in Figures 1 and 2, and comparison is made with literature data. Our values are in disagreement with those reported by Rodriguez et al. for the binary mixtures of DEC + toluene and + methanol. It may be that the values of V^E and $\Delta\eta$ for these two binary mixtures are very small and only larger one order quantitatively than their uncertainties. Table 3 lists the values of the parameters A_i together with the standard deviations.

It can be seen from the Figure 1 that V^E values for DEC + toluene and methanol over the whole composition range are negative. The absolute values of V^E are small and decrease with temperature rising. However, for diethyl carbonate + 2-propanol, the excess molar volumes are positive and large, increasing with temperature. It can be summarized from our series of work[16−18] that V^E values may be affected by three factors. The first factor is the specific forces between molecules, such as hydrogen bonds, and charge−transfer complexes, breaking of hydrogen bonds and complexes giving positive excess molar volumes, and forming of hydrogen bonds and complexes bringing negative values of V^E. The second factor is the physical intermolecular forces, including electrostatic forces between charged particles and between permanent dipoles and so on, induction forces between a permanent dipole and an

Table 3. Coefficients of the Redlich−Kister Equation and Standard Deviation for Excess Molar Volumes and Viscosity Deviations of Mixtures

T/K	property	A_0	A_1	A_2	A_3	A_4	σ
			(x) Diethyl Carbonate + (1 − x) Toluene				
298.15	V^E/cm^3·mol^{-1}	−0.2377	0.0427	−0.0681	0.1531		0.011
	$\Delta\eta$/mPa·s	−0.0222	−0.0178				0.001
303.15	V^E/cm^3·mol^{-1}	−0.2276	0.0558	−0.0535	0.0459		0.008
	$\Delta\eta$/mPa·s	−0.0185	−0.0165				0.001
313.15	V^E/cm^3·mol^{-1}	−0.2232	0.0474	−0.0100	0.0603		0.006
	$\Delta\eta$/mPa·s	−0.0147	−0.0142				0.002
323.15	V^E/cm^3·mol^{-1}	−0.2029	0.0635	0.0004	0.0187		0.007
	$\Delta\eta$/mPa·s	−0.0101	−0.0132				0.001
333.15	V^E/cm^3·mol^{-1}	−0.1901	0.0712	0.0365	0.0159		0.003
	$\Delta\eta$/mPa·s	−0.0060	−0.0103				0.001
343.15	V^E/cm^3·mol^{-1}	−0.1708	0.0702	0.0314	0.0299		0.003
	$\Delta\eta$/mPa·s	−0.0029	−0.0068				0.001
353.15	V^E/cm^3·mol^{-1}	−0.1514	0.0606	0.0050	0.0617		0.002
	$\Delta\eta$/mPa·s	−0.0078	−0.0103				0.001
363.15	V^E/cm^3·mol^{-1}	−0.1345	0.0512	0.0042	0.0496		0.004
	$\Delta\eta$/mPa·s	−0.0082	−0.0123				0.002
			(x) Diethyl Carbonate + (1 − x) Methanol				
293.15	V^E/cm^3·mol^{-1}	−0.2987	0.0970	−0.1222	0.2219		0.015
	$\Delta\eta$/mPa·s	−0.0598	−0.0313	0.0210	0.0753		0.008
298.15	V^E/cm^3·mol^{-1}	−0.2711	0.1632	−0.0350	−0.0577		0.017
	$\Delta\eta$/mPa·s	−0.0516	−0.0150	−0.0151	−0.0271		0.010
303.15	V^E/cm^3·mol^{-1}	−0.2358	0.0842	−0.1022	0.1277		0.014
	$\Delta\eta$/mPa·s	−0.0496	−0.0279	0.0411	0.0542		0.006
313.15	V^E/cm^3·mol^{-1}	−0.1872	0.0902	−0.1218	0.0726		0.008
	$\Delta\eta$/mPa·s	−0.0348	−0.0150	0.0082	0.0115		0.009
323.15	V^E/cm^3·mol^{-1}	−0.1385	0.0612	−0.0985	0.1305		0.007
	$\Delta\eta$/mPa·s	−0.0341	−0.0129	0.0330	0.0270		0.009
333.15	V^E/cm^3·mol^{-1}	−0.0871	0.0588	−0.0664	0.1281		0.008
	$\Delta\eta$/mPa·s	−0.0247	0.0081	0.0099	−0.0150		0.006
			(x) Diethyl Carbonate + (1 − x) 2-Propanol				
293.15	V^E/cm^3·mol^{-1}	1.1451	0.4496	0.5721	−0.4826	−0.4546	0.021
	$\Delta\eta$/mPa·s	−2.8924	1.7721	−1.1319	2.0741	−2.2033	0.025
298.15	V^E/cm^3·mol^{-1}	1.2657	0.4377	0.6069	−0.3733	−0.5468	0.029
	$\Delta\eta$/mPa·s	−2.4565	1.4708	−0.8682	1.8120	−2.0670	0.023
303.15	V^E/cm^3·mol^{-1}	1.3695	0.3111	0.3136	−0.0444	−0.0872	0.020
	$\Delta\eta$/mPa·s	−1.9632	1.1626	−0.7662	1.2768	−1.2678	0.015
313.15	V^E/cm^3·mol^{-1}	1.5610	0.3955	0.8115	−0.3491	−0.7504	0.035
	$\Delta\eta$/mPa·s	−1.3147	0.7518	−0.5132	0.6514	−0.5844	0.007
323.15	V^E/cm^3·mol^{-1}	1.9546	0.3160	0.8410	−0.4189	−0.6476	0.039
	$\Delta\eta$/mPa·s	−0.9374	0.5158	−0.3611	0.4027	−0.3561	0.007
333.15	V^E/cm^3·mol^{-1}	2.2789	0.2620	1.0084	−0.4483	−0.9150	0.040
	$\Delta\eta$/mPa·s	−0.6701	0.3481	−0.2403	0.2669	−0.2274	0.006
343.15	V^E/cm^3·mol^{-1}	2.5538	0.2621	0.8519	−0.5554	−0.6880	0.045
	$\Delta\eta$/mPa·s	−0.4776	0.2332	−0.1712	0.1765	−0.1191	0.005

induced dipole, and forces of attraction (dispersion forces) and repulsion between nonpolar molecules. Physical intermolecular forces are weak usually, and the sign of V^E values may be positive or negative. The third factor is the structural characteristics of component, arising from geometrical fitting of one component into the other's structure, due to the differences in shape and size of components and free volume. Because of the interaction between the polarity of DEC and π electron in aromatic ring, the values of excess molar volumes are negative for the DEC + toluene mixture. For DEC + alcohols systems, the main contributions to V^E are chemical. DEC is a small polar liquid with dipole−dipole interactions in pure liquid. In contrast, alcohols are self-associated through hydrogen bonding. When these two components are mixed, the hydrogen bonding in alcohols is broken, and dipole−dipole interactions between DEC with alcohol are formed. Because the interaction strength of the hydrogen is stronger than the dipole interaction, the V^E values are positive for DEC with 2-propanol, whereas the sign of excess molar volumes is negative for the DEC + methanol mixture. The steric effect caused by the two additional methylene groups in 2-propanol had to greatly reduced its hydrogen bonding pattern as compared to methanol. Also, the larger size of 2-propanol hindered the molecular packing between the two components.

Figure 2 shows viscosity deviations for these three binary mixtures, plotted against mole fraction together with the fitted curve, obtained from the Redlich−Kister equation. The viscosity deviations for these systems at selected temperatures are negative over the entire composition. For the DEC + toluene and methanol mixtures, the absolute viscosity deviations are very small.

As shown in Figures 1 and 2, there are large difference between the experimental values with literature values[3,5] to the excess molar volumes and the viscosity deviation for DEC + methanol mixture. The reason is the values of these two properties are very small. The little difference in the values of densities and viscosities will result in the larger changes in the excess volumes and deviations of viscosity.

Conclusion

Densities and viscosities of the binary systems of DEC + toluene, + methanol, and + 2-propanol have been measured at several temperatures and for the whole composition range. The excess molar volumes and viscosity deviations were computed. The computed quantities have been fitted to the Redlich−Kister equation. Excess molar volumes and viscosity deviation show a systematic change with increasing temperature. V^E values are negatives for DEC + toluene and methanol; however, V^E values

are positive over the entire composition range for DEC + 2-propanol. The deviations of viscosity, $\Delta\eta$, are negative for all the mixtures over the entire composition range and become less negative with increasing temperature. The effect of interactions of components on excess molar volumes and viscosity deviation is discussed.

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