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Densities and Viscosities of Four Binary Diethyl Carbonate + 1-Alcohol Systems from (288.15 to 313.15) K

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ABSTRACT: Densities and viscosities of the binary mixtures of diethyl carbonate (DEC) with ethanol, 1-propanol, 1-pentanol, and 1-octanol were measured over the entire mole fraction at (288.15, 293.15, 303.15, and 313.15) K and normal atmospheric pressure. Moreover, the excess molar enthalpies for the present binary mixtures were determined at 303.15 K. Other mixing properties such as the excess molar volumes have been also obtained for each of the systems and temperatures. The composition−viscosity data were correlated with several specific equations to evaluate their suitability for these systems.

INTRODUCTION

The organic carbonates have an extensive variety of applications. Some of these chemicals have shown to be very useful in the lithium battery technology, for the synthesis of polycarbonates, pharmaceuticals, and agrochemicals, as fuel additives, as lubricants of the new refrigerants (HFCs), and much more. In spite of their importance, the thermodynamic and transport properties for systems of the type carbonate + alcohol are scarce in the literature. This work is aimed to increase the amount of data available from physicochemical properties of the dialkyl carbonates and 1-alkanols and their mixtures in the whole composition range at different temperatures to help better understand the types of interactions involved in the solutions. These data are also very useful for practical chemical engineering purposes.

In a previous work[1] we determined densities, viscosities, and excess molar enthalpies for the binary systems dimethyl carbonate (DMC) + (ethanol, 1-propanol, 1-pentanol, 1-octanol). The two first mentioned properties were determined at 288.15, 293.15, 303.15, and 313.15 K and excess molar enthalpies at 303.15 K. The results were used to calculate the excess molar volumes and the deviation in viscosities. Continuing our research, in this paper we report the same kind of study but using the binary mixtures of diethyl carbonate (DEC) instead of DMC with the same alcohols. The kinematic or dynamic viscosity data were used to test the applicability to these systems of several specific models proposed by McAllister[2] (for three and four interactions), by Grunberg and Nissan,[3] by Heric,[4] and by Hind et al.[5]

EXPERIMENTAL SECTION

Materials. The liquids used in this study were from Fluka and Panreac. Once received, the liquids were dried over molecular sieves (Union Carbide type 4 nm from Fluka), and thereafter, the bottles were sealed with parafilm M and stored in places protected from light. Before any type of measurement, those portions of each liquid required for the test were previously degassed by an ultrasonic bath from SELECTA.

The actual degree of purity of the liquids was evaluated by using gas chromatography analysis. The values obtained by this test were: 0.999 for diethyl carbonate (Fluka), 0.9998 for ethanol (Panreac), 0.997 for 1-propanol (Panreac), 0.996 for 1-pentanol (Fluka), and 0.997 for 1-octanol (Fluka). Table 1 shows the physical properties of the pure liquids together with those available in the literature,[6−33] for comparison. In Table 1 we also included values at 298.15 K, because it is the most commonly investigated temperature.

Apparatus and Methods. The mixtures were prepared by weighing amounts of the pure liquids, covering the whole composition range of the mixture, using a Mettler AE240 semimicro-balance (± 0.01 mg). The average uncertainty in the compositions (mole fraction) of the mixtures was estimated to be less than ± 0.00004. The molar excess volumes were calculated from composition-density data with an average uncertainty of ± 0.003 $\text{cm}^3 \cdot \text{mol}^{-1}$.

The densities of the pure liquids and their mixtures were measured by a DMA-60/602 vibrating-tube densimeter from Anton-Paar using water (Panreac Hiperpur-plus) and *n*-heptane (Fluka > 0.995 mass fraction) as the standard calibration fluids. The temperature of the densimeter measurement cell was checked with several thermometers (DT100-10, 20, 30, and 40) from Anton Paar. The calibrations were verified with *n*-dodecane whose densities, obtained by the National Physical Laboratory of the UK and certified by the National Measurement Accreditation Service (NAMAS), were known with an uncertainty of ± 0.00001 $\text{g} \cdot \text{cm}^{-3}$ in the range between (283.15 and 323.15) K (each 5 K), within the 95 % confidence intervals. The average uncertainty of the density was estimated to be lower than ± 0.00002 $\text{g} \cdot \text{cm}^{-3}$.

The kinematic viscosities (ν) were determined using an automatic viscosimeter Schott-Gerätte and several Ubbelohde viscosimeters with capillaries of different diameters. A stop-watch which measures, through two optoelectronic sensors, the flow time of a liquid between two given positions in the viscosimeter with an uncertainty of ± 0.01 s, was used. The viscosimeter was kept in a CT1450/2 thermostat controlled to ± 0.01 K. The kinematic viscosities were obtained through the equation $\nu = K(t - \vartheta)$ where ϑ is the Hagenbach correction, t is the flow time, and K is the

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Table 1. Densities, ρ ($\mathrm{g \cdot cm^{-3}}$), and Dynamic Viscosities, η (mPa·s), of the Pure Liquids at Several Temperatures

liquid	T	ρ		η	
	K	exp.	lit.	exp.	lit.
diethyl carbonate	288.15	0.98039	0.98043[6]	0.864	0.868[33]
	293.15	0.97483	0.9747[7] 0.97500[8]	0.803	0.800[8]
	298.15	0.96915	0.96916[9]	0.757	0.750[10]
	303.15	0.96339	0.9634[7]	0.700	0.702[10]
	313.15	0.95210	0.9522[7]	0.616	0.618[10]
ethanol	288.15	0.79365[1]	0.79360[6]	1.313[1]	1.3096[11]
	293.15	0.78934[1]	0.7893[7]	1.216[1]	1.192[12]
	298.15	0.78507[1]	0.78509[13]	1.132[1]	1.099[14]
	303.15	0.78072[1]	0.78075[15]	1.010[1]	1.003[16]
	313.15	0.77197[1]	0.77203[15]	0.824[1]	0.823[12]
1-propanol	288.15	0.80755[1]	0.80760[17]	2.507[1]	2.492[6]
	293.15	0.80352[1]	0.80350[18]	2.202[1]	2.203[19]
	298.15	0.79945[1]	0.7995[7]	1.973[1]	1.977[20]
	303.15	0.79547[1]	0.79548[21]	1.733[1]	1.725[6]
	313.15	0.78728[1]	0.78729[13]	1.381[1]	1.372[25]
1-pentanol	288.15	0.81832[1]	0.81468[22]	4.682[1]	4.719[6]
	293.15	0.81463[1]	0.81468[22]	4.025[1]	4.030[22]
	298.15	0.81096[1]	0.81093[23]	3.497[1]	3.497[19]
	303.15	0.80726[1]	0.8072[24]	3.022[1]	2.973[25] 3.056[24]
	313.15	0.79978[1]	0.79978[26]	2.312[1]	2.299[26]
1-octanol	288.15	0.82863[1]	0.8292[27]	11.070[1]	10.662[6]
	293.15	0.82520[1]	0.8253[19]	9.161[1]	9.223[19]
	298.15	0.82174[1]	0.82164[28] 0.8218[19]	7.688[1]	7.663[19]
	303.15	0.81823[1]	0.8182[18]	6.404[1]	6.298[29] 6.4945[30]
	313.15	0.81122[1]	0.8112[31] 0.8113[27]	4.620[1]	4.577[29] 4.646[32]

viscosimeter constant that is supplied by the company. The experimental viscosities were obtained by averaging six measures of flow times. The average uncertainty of the kinematic viscosity values was lower than 0.4 %.

The excess molar enthalpies were determined using a Calvet microcalorimeter equipped with a device allowing operation in the absence of vapor phase. The calorimetric cells had a volume about 10 $\mathrm{cm^3}$ and were thermostatted to (303.15 ± 0.01) K. A Philips PM2535 voltmeter and a data acquisition system were linked to the calorimeter. For the electric calibration, a Setaram EJP30 stabilized current source and a resistance of 957.45 Ω were used. Other details relative to the experimental method have been published elsewhere.[34,35] The average uncertainty in the excess molar enthalpies values was estimated to be lower than 1 %.

RESULTS AND CORRELATIONS

The experimental results for binary mixtures are shown in Table 2. The excess molar volumes V^E have been determined by:

$$V^{\mathrm{E}} = \sum_{i=1}^{2} \frac{x_i M_i}{\rho} - \sum_{i=1}^{2} x_i \frac{M_i}{\rho_i} \tag{1}$$

Table 2. Densities, ρ ($\mathrm{g \cdot cm^{-3}}$), Dynamic Viscosities, η (mPa·s), and Excess Molar Volumes, V^E ($\mathrm{cm^3 \cdot mol^{-1}}$), for the Binary Mixtures at Several Temperatures

x	ρ	η	V^E
x Diethyl Carbonate + $(1 - x)$ Ethanol			
288.15 K			
0.05544	0.81388	1.181	0.004
0.10004	0.82853	1.111	0.010
0.19696	0.85633	0.996	0.026
0.29981	0.88102	0.917	0.044
0.40616	0.90255	0.864	0.062
0.50391	0.91948	0.838	0.081
0.61305	0.93591	0.821	0.097
0.69394	0.94673	0.815	0.100
0.79421	0.95883	0.819	0.094
0.89920	0.97029	0.834	0.063
0.97442	0.97789	0.856	0.020
293.15 K			
0.05208	0.80820	1.115	0.010
0.09645	0.82276	1.045	0.018
0.19831	0.85180	0.930	0.040
0.29306	0.87446	0.867	0.060
0.40891	0.89778	0.818	0.086
0.49447	0.91258	0.794	0.103
0.61114	0.93021	0.777	0.115
0.67868	0.93926	0.771	0.121
0.76920	0.95039	0.770	0.114
0.87673	0.96234	0.779	0.086
0.94443	0.96933	0.791	0.047
303.15 K			
0.04589	0.79714	0.937	0.014
0.09693	0.81363	0.880	0.032
0.19432	0.84098	0.799	0.062
0.28434	0.86232	0.747	0.090
0.40976	0.88733	0.703	0.122
0.51281	0.90470	0.686	0.140
0.61756	0.92001	0.678	0.154
0.69066	0.92962	0.675	0.153
0.78961	0.94146	0.675	0.136
0.88630	0.95196	0.681	0.098
0.96759	0.96023	0.694	0.033
313.15 K			
0.04956	0.78932	0.761	0.021
0.09649	0.80416	0.715	0.044
0.20702	0.83428	0.647	0.093
0.28474	0.85221	0.618	0.122
0.39819	0.87466	0.591	0.158
0.50486	0.89256	0.578	0.186
0.60789	0.90766	0.574	0.195
0.62272	0.90967	0.573	0.196
0.68952	0.91830	0.575	0.196
0.78264	0.92940	0.580	0.175
0.89238	0.94130	0.594	0.115
0.95634	0.94779	0.606	0.056

Table 2. Continued

x	ρ	η	V^E
x Diethyl Carbonate + $(1 - x)$ 1-Propanol			
288.15 K			
0.05124	0.82117	2.135	0.026
0.07262	0.82661	2.007	0.037
0.10630	0.83489	1.833	0.054
0.15107	0.84543	1.638	0.075
0.21218	0.85898	1.459	0.103
0.26378	0.86976	1.330	0.124
0.30997	0.87892	1.248	0.142
0.40161	0.89592	1.115	0.170
0.51471	0.91501	1.000	0.190
0.59163	0.92696	0.947	0.194
0.59935	0.92813	0.937	0.193
0.69064	0.94132	0.905	0.182
0.78869	0.95453	0.871	0.153
0.86945	0.96481	0.859	0.108
0.94284	0.97371	0.865	0.054
293.15 K			
0.04957	0.81657	1.906	0.028
0.10011	0.82910	1.657	0.056
0.21012	0.85396	1.315	0.115
0.30742	0.87357	1.132	0.165
0.40382	0.89134	1.010	0.191
0.50972	0.90909	0.920	0.209
0.60023	0.92304	0.868	0.210
0.69628	0.93676	0.829	0.198
0.80588	0.95125	0.804	0.166
0.88171	0.96076	0.796	0.117
0.94334	0.96814	0.796	0.069
303.15 K			
0.05148	0.80869	1.495	0.036
0.10081	0.82063	1.329	0.068
0.20436	0.84353	1.087	0.136
0.31609	0.86557	0.930	0.196
0.40483	0.88145	0.847	0.229
0.44592	0.88841	0.818	0.236
0.59996	0.91235	0.743	0.244
0.68922	0.92491	0.715	0.230
0.79204	0.93839	0.697	0.195
0.88086	0.94935	0.692	0.138
0.93635	0.95595	0.692	0.086
313.15 K			
0.04668	0.79889	1.214	0.053
0.10085	0.81163	1.071	0.106
0.21187	0.83552	0.885	0.194
0.30748	0.85404	0.783	0.248
0.41325	0.87266	0.710	0.286
0.50186	0.88695	0.668	0.301
0.59979	0.90156	0.637	0.299
0.69131	0.91421	0.618	0.283
0.79018	0.92698	0.607	0.243
0.84555	0.93382	0.608	0.204
0.86990	0.93673	0.606	0.187

Table 2. Continued

x	ρ	η	V^E
0.89033	0.93921	0.607	0.162
0.94879	0.94612	0.610	0.088
x Diethyl Carbonate + $(1 - x)$ 1-Pentanol			
288.15 K			
0.05026	0.82690	3.879	0.063
0.10602	0.83640	3.215	0.118
0.18806	0.85028	2.529	0.180
0.28794	0.86692	1.972	0.241
0.39597	0.88469	1.595	0.280
0.49047	0.90003	1.355	0.294
0.59171	0.91628	1.182	0.287
0.71042	0.93509	1.030	0.252
0.80674	0.95023	0.948	0.195
0.89601	0.96417	0.898	0.122
0.96065	0.97425	0.871	0.051
293.15 K			
0.04854	0.82280	3.391	0.065
0.05720	0.82425	3.292	0.076
0.10709	0.83260	2.796	0.132
0.19882	0.84785	2.138	0.212
0.29002	0.86287	1.725	0.265
0.39801	0.88041	1.402	0.306
0.49386	0.89579	1.202	0.319
0.59983	0.91255	1.049	0.314
0.69683	0.92770	0.947	0.292
0.80091	0.94391	0.869	0.229
0.89019	0.95776	0.826	0.147
0.96040	0.96866	0.808	0.060
303.15 K			
0.06248	0.81746	2.453	0.090
0.09976	0.82353	2.195	0.135
0.20172	0.83999	1.686	0.237
0.28975	0.85409	1.395	0.294
0.39688	0.87100	1.159	0.343
0.49223	0.88591	1.013	0.356
0.59412	0.90164	0.893	0.350
0.69875	0.91765	0.808	0.314
0.80394	0.93363	0.750	0.245
0.89966	0.94813	0.715	0.148
0.96081	0.95742	0.703	0.063
313.15 K			
0.05411	0.80837	1.951	0.086
0.10416	0.81628	1.705	0.155
0.19393	0.83039	1.373	0.252
0.28998	0.84534	1.139	0.326
0.40599	0.86319	0.950	0.379
0.49650	0.87696	0.847	0.394
0.59569	0.89190	0.763	0.386
0.74744	0.91456	0.675	0.313
0.80299	0.92281	0.653	0.267
0.89971	0.93715	0.628	0.161
0.95818	0.94586	0.620	0.072

Table 2. Continued

x	ρ	η	V^E
x Diethyl Carbonate + $(1 - x)$ 1-Octanol			
288.15 K			
0.05879	0.83494	8.723	0.116
0.09178	0.83860	7.678	0.173
0.18398	0.84927	5.521	0.306
0.28395	0.86163	3.992	0.406
0.40005	0.87704	2.876	0.476
0.51087	0.89289	2.157	0.500
0.59796	0.90621	1.773	0.489
0.69268	0.92166	1.441	0.443
0.80731	0.94189	1.157	0.335
0.92747	0.96514	0.953	0.154
0.95308	0.97042	0.921	0.102
293.15 K			
0.05259	0.83075	7.441	0.106
0.10474	0.83645	6.062	0.200
0.19672	0.84703	4.538	0.330
0.29555	0.85915	3.308	0.429
0.39636	0.87238	2.544	0.489
0.50311	0.88737	1.951	0.515
0.60400	0.90257	1.573	0.503
0.69951	0.91801	1.285	0.452
0.81749	0.93867	1.039	0.334
0.91237	0.95676	0.900	0.187
0.95307	0.96498	0.853	0.106
303.15 K			
0.05353	0.82370	5.282	0.113
0.10032	0.82865	4.522	0.200
0.19024	0.83863	3.432	0.335
0.30019	0.85169	2.536	0.452
0.41121	0.86589	1.928	0.520
0.50384	0.87858	1.584	0.539
0.59342	0.89162	1.320	0.531
0.69811	0.90798	1.075	0.475
0.81508	0.92785	0.884	0.351
0.91376	0.94610	0.773	0.193
0.95476	0.95416	0.740	0.107
313.15 K			
0.05666	0.81683	3.842	0.124
0.11088	0.82242	3.267	0.225
0.19564	0.83159	2.590	0.355
0.28933	0.84235	2.054	0.461
0.40054	0.85605	1.585	0.536
0.50674	0.87012	1.273	0.564
0.60440	0.88401	1.059	0.547
0.70378	0.89918	0.893	0.487
0.80411	0.91566	0.766	0.384
0.90916	0.93443	0.672	0.210
0.95396	0.94296	0.643	0.115

Table 3. Excess Molar Enthalpies, H^E ($J \cdot mol^{-1}$), of Diethyl Carbonate + Alkanols at 303.15 K

x	H^E	x	H^E	x	H^E
x Diethyl Carbonate + $(1 - x)$ Ethanol					
0.06432	394.5	0.37386	1488.0	0.71338	1529.3
0.11131	637.3	0.42582	1580.6	0.76628	1403.1
0.18330	943.8	0.50663	1653.6	0.82433	1193.9
0.24389	1154.7	0.54449	1651.9	0.89981	790.5
0.30342	1325.2	0.64000	1629.9	0.95569	395.7
x Diethyl Carbonate + $(1 - x)$ 1-Propanol					
0.05945	432.8	0.37618	1757.8	0.74535	1591.1
0.12274	819.6	0.45692	1844.2	0.82396	1305.7
0.19561	1174.9	0.49061	1868.0	0.87197	1037.6
0.24982	1373.5	0.56418	1885.1	0.91679	726.9
0.26772	1437.6	0.61817	1849.1	—	—
0.30176	1553.1	0.69316	1744.0	—	—
x Diethyl Carbonate + $(1 - x)$ 1-Pentanol					
0.04842	383.1	0.35923	1845.1	0.74154	1703.2
0.08500	654.5	0.43987	1994.2	0.79932	1494.9
0.15206	1051.5	0.45808	1998.1	0.85191	1219.5
0.21215	1362.9	0.54443	2055.3	0.91385	798.4
0.26304	1562.0	0.64003	1965.4	—	—
0.31537	1747.3	0.69253	1820.3	—	—
x Diethyl Carbonate + $(1 - x)$ 1-Octanol					
0.09134	735.6	0.37403	2093.5	0.68952	2089.9
0.12764	986.1	0.43040	2208.7	0.74918	1902.8
0.17644	1295.9	0.49098	2277.2	0.81111	1620.5
0.24837	1648.3	0.56994	2268.1	0.87047	1245.4
0.31555	1923.5	0.62683	2214.1	0.93567	698.1

In this equation, ρ is the density of the mixture, and ρ_i is the corresponding property of the pure components; M_i and x_i are the molecular weight and the mole fraction of the i-th pure component, respectively. The dependence on composition and temperature of the V^E data is shown in Figure 1. The excess molar enthalpies H^E at 303.15 K for the four systems herein considered are listed in Table 3, and their variation with composition is displayed in Figure 2.

V^E and H^E values were correlated to composition, at each of the temperatures, using the Redlich and Kister equation

$$Y = x(1 - x) \sum_{i=0}^{p} A_i(2x - 1)^i \tag{2}$$

where $Y \equiv (V^E \text{ or } H^E)$ and x is the mole fraction of the first component. The coefficients A_i were obtained by fitting the equations to the experimental values with a least-squares method. The optimum number of coefficients p was determined using the F-test[36] as statistical criteria. The computed values and standard deviations are shown in Table 4.

As it has been stated in the Introduction, different specific equations were selected to correlate $\nu(x)$ or $\eta(x)$ data for the current binary systems. These equations are widely known, and we do not show them herein; nevertheless, they have been described in an earlier paper.[37] Table 5 lists the values of the adjustable parameters obtained for each of the models together with the corresponding standard deviation and average percent deviation for each of the systems and temperatures.

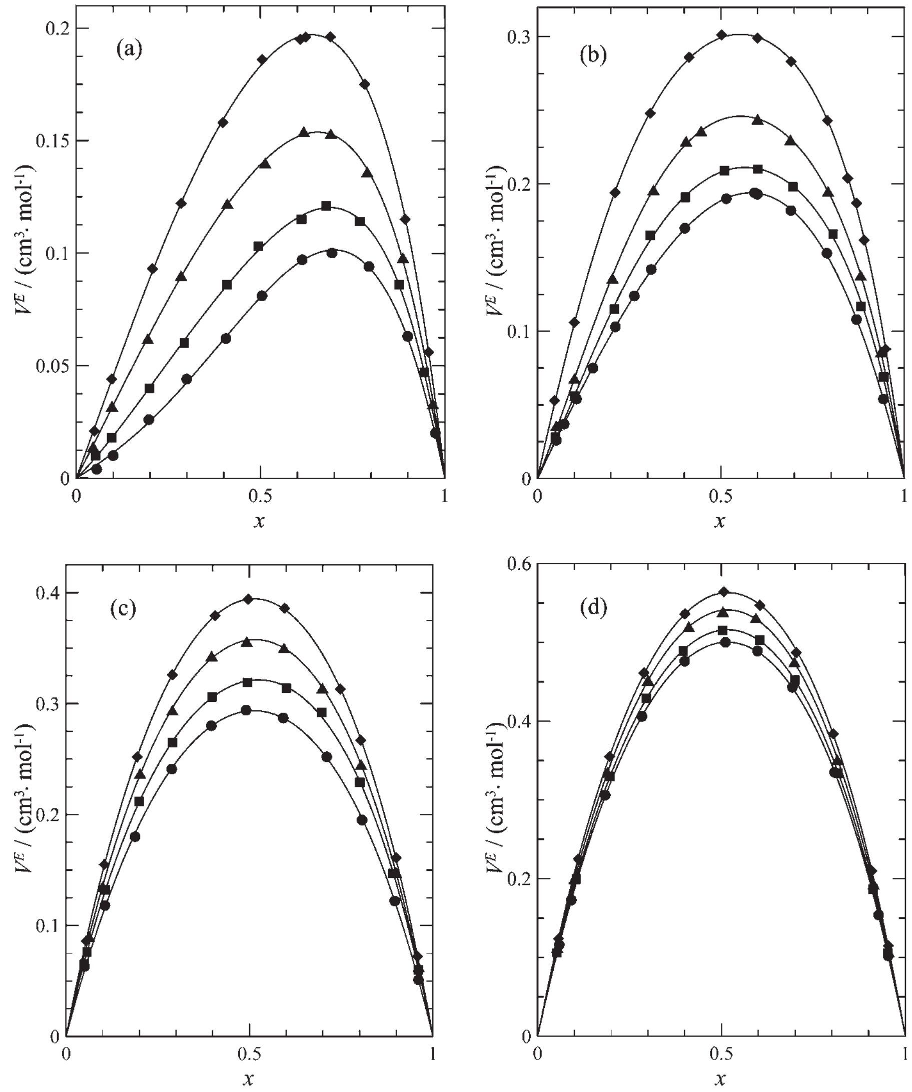

Figure 1. Excess molar volumes, V^{E} ($cm^{3} \cdot mol^{-1}$), for the systems (a) DEC + ethanol, (b) DEC + 1-propanol, (c) DEC + 1-pentanol, and (d) DEC + 1-octanol at ●, 288.15 K; ■, 293.15 K; ▲, 303.15 K; ♦, 313.15 K. Solid lines have been calculated from eq 2 using coefficients given in Table 4.

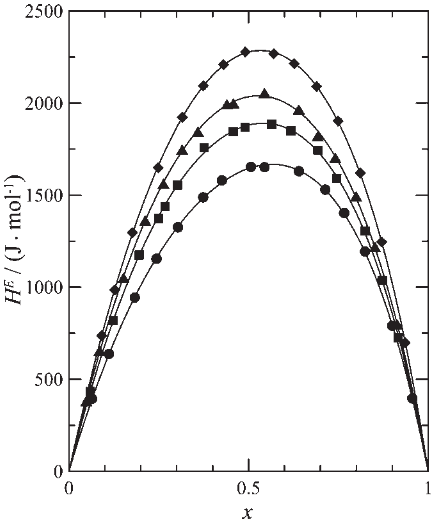

Figure 2. Excess molar enthalpies, H^{E} ($J \cdot mol^{-1}$), of ●, diethyl carbonate + ethanol; ■, diethyl carbonate + 1-propanol; ▲, diethyl carbonate + 1-pentanol; ♦, diethyl carbonate + 1-octanol at 303.15 K. Solid curves are calculated from eq 2 with coefficients from Table 4.

■ DISCUSSION

Figure 1 shows the graphical variation of V^{E} for binary mixtures DEC with ethanol, 1-propanol, 1-pentanol, and 1-octanol all being positive over the entire range of mole fractions and for all temperatures. The excess molar enthalpies obtained in this study are also positive (Figure 2). Positive values of both magnitudes are in agreement with breaking of hydrogen bonding of alkanols during mixing and the consequent loosening of intermolecular interactions. One should also take into account that the number of van der Waals interactions decreases as a result of the increase in the intermolecular distance that causes the appearance of empty spaces among molecules in the mixture. The dilation effects are increasing with the increase of the chain length of the alcohols, as was demonstrated in the paper published by Fracesconi[28] where we can note that with systems containing methanol the excess molar volumes are negative. That could be that the shorter the chain of alkanol, the better the result of the packing effect and that the distances among molecules descend equally due to the increase of the van der Waals interactions. Moreover, the rise of the H^{E} values with the molecular size of alcohol is directly connected with the increasing

Table 4. Coefficients A_i of eq 2 and Standard Deviations, σ, for Excess Molar Volumes, V^E (cm$^3\cdot$mol^{-1}), and Excess Molar Enthalpies, H^E (J$\cdot$mol^{-1}), of the Binary Systems

T/K	prop.	A_0	A_1	A_2	A_3	σ
		Diethyl Carbonate + Ethanol				
288.15	V^E	0.3216	0.3505	0.1314	—	0.001
293.15	V^E	0.4090	0.3271	0.1663	0.0907	0.001
303.15	V^E	0.5577	0.3331	0.1753	0.0860	0.001
	H^E	6581	1352	1646	237	7
313.15	V^E	0.7329	0.3713	0.2000	0.1188	0.001
		Diethyl Carbonate + 1-Propanol				
288.15	V^E	0.7546	0.2553	0.0232	—	0.0006
293.15	V^E	0.8322	0.1904	0.1071	0.2498	0.002
303.15	V^E	0.9743	0.1805	0.1218	0.3069	0.001
	H^E	7522	983	1619	313	11
313.15	V^E	1.1970	0.1769	0.3612	0.2390	0.002
		Diethyl Carbonate + 1-Pentanol				
288.15	V^E	1.1738	0.0508	0.1474	—	0.002
293.15	V^E	1.2836	0.0956	0.2703	—	0.002
303.15	V^E	1.4295	0.0733	0.2207	—	0.001
	H^E	8138	712	1575	599	12
313.15	V^E	1.5772	0.0680	0.2082	—	0.001
		Diethyl Carbonate + 1-Octanol				
288.15	V^E	1.9991	0.1086	0.2509	—	0.0009
293.15	V^E	2.0622	0.1188	0.2565	—	0.001
303.15	V^E	2.1622	0.1288	0.2416	—	0.001
	H^E	9101	1029	1546	802	6
313.15	V^E	2.2497	0.1404	0.2546	—	0.001

difficulty to produce heteromolecular interactions when the aliphatic chain of alcohol is increased. On the other hand, with the increases of the chain carbonate, the polarity lessens, and the intermolecular attraction decreases; dilution process is less endothermic, and the excess molar volumes with the lower value are those of the mixtures containing DEC. This consideration is due to the comparison of the data obtained in our previous work with DMC[1] and the new data obtained in this paper with DEC.

For some of the systems and temperatures addressed in this study excess molar volume data were available in the literature. Rodríguez et al.[7] reported V^E values for the binary systems DEC + (ethanol, 1-propanol, 1-pentanol) at (293.15, 303.15, and 313.15) K. Yang et al.[8] have also reported excess volume values at the same temperatures but only for the two last systems. The results reported by Rodríguez et al. are in reasonable agreement with our values, being the mean deviation of 0.021 cm$^3\cdot$mol^{-1} (15.2 %). On the other hand, the values reported by Yang et al. showed a mean deviation of 12.8 % (0.019 cm$^3\cdot$mol^{-1}) in relation to those obtained in this study.

The results shown in Table 5 reveal that almost all of the equations selected are efficient to describe the viscometric behavior of the mixtures herein studied. Except for the case of the equation proposed by Hind et al., the global differences between both the experimental and the computed values were lower than 3 %. The equation with the highest number of parameters, the three-parameter correlative model[38] proposed by McAllister, provides the best mathematical description, with global mean

Table 5. Values of Parameters, Standard Deviations, σ, and Average Percent Deviations, ε, Obtained for the Binary Systems at Different Temperatures Using Several Specific Equations

		T/K			
equation		288.15	293.15	303.15	313.15
		Diethyl Carbonate + Ethanol			
McAllister (for three-body interactions)	ν_{12}	0.8646	0.8252	0.7336	0.6343
	ν_{21}	0.8545	0.8236	0.7258	0.6029
	σ	0.010	0.007	0.006	0.006
	ε (%)	0.736	0.610	0.487	0.656
McAllister (for four-body interactions)	ν_{1112}	0.8090	0.7812	0.6985	0.5972
	ν_{1122}	0.9427	0.8819	0.7721	0.6734
	ν_{1222}	0.9482	0.9153	0.8019	0.6550
	σ	0.004	0.001	0.003	0.002
	ε (%)	0.228	0.096	0.184	0.169
Grunberg and Nissan	d	−1.0209	−0.9327	−0.8456	−0.8715
	σ	0.025	0.022	0.018	0.017
	ε (%)	2.190	2.169	2.118	2.230
Heric	α_{12}	−0.7596	−0.6720	−0.5834	−0.6055
	σ	0.024	0.021	0.017	0.016
	ε (%)	1.851	1.824	1.732	1.838
Heric	β_{12}	−0.7306	−0.6487	−0.5634	−0.5964
	β'_{12}	0.3039	0.2872	0.2740	0.2969
	σ	0.010	0.007	0.006	0.006
	ε (%)	0.735	0.610	0.472	0.652
Hind et al.	η_{12}	0.5581	0.5543	0.5055	0.4256
	σ	0.041	0.036	0.028	0.023
	ε (%)	3.65	3.50	3.16	3.07
		Diethyl Carbonate + 1-Propanol			
McAllister (for three-body interactions)	ν_{12}	0.9761	0.8882	0.7791	0.6800
	ν_{21}	0.9843	0.9260	0.7897	0.6742
	σ	0.014	0.012	0.012	0.010
	ε (%)	0.886	0.883	0.979	0.967
McAllister (for four-body interactions)	ν_{1112}	0.8663	0.8102	0.7040	0.6237
	ν_{1122}	1.0966	0.9970	0.8789	0.7637
	ν_{1222}	1.2511	1.1585	0.9611	0.8036
	σ	0.006	0.005	0.002	0.003
	ε (%)	0.3053	0.138	0.105	0.286
Grunberg and Nissan	d	−1.6916	−1.5748	−1.4755	−1.3759
	σ	0.055	0.043	0.035	0.029
	ε (%)	4.129	3.450	3.276	3.280
Heric	α_{12}	−1.5835	−1.4656	−1.3627	−1.2615
	σ	0.060	0.047	0.039	0.033
	ε (%)	4.071	3.418	3.250	3.283
Heric	β_{12}	−1.4186	−1.3644	−1.2677	−1.2077
	β'_{12}	0.6062	0.5274	0.5173	0.4994
	σ	0.014	0.012	0.012	0.010
	ε (%)	0.886	0.883	0.980	0.965
Hind et al.	η_{12}	0.1951	0.2779	0.2923	0.3158
	σ	0.158	0.120	0.088	0.064
	ε (%)	11.55	9.56	8.10	7.22
		Diethyl Carbonate + 1-Pentanol			

Table 5. Continued

		T/K			
equation		288.15	293.15	303.15	313.15
McAllister (for three-body interactions)	ν_{12}	1.1019	0.9760	0.8661	0.7590
	ν_{21}	1.5016	1.3543	1.1217	0.9481
	σ	0.016	0.010	0.012	0.010
	ε (%)	0.858	0.590	0.866	0.813
McAllister (for four-body interactions)	ν_{1112}	0.9637	0.9054	0.7641	0.6806
	ν_{1122}	1.4072	1.1916	1.0871	0.9273
	ν_{1222}	2.0363	1.8497	1.4650	1.2123
	σ	0.004	0.009	0.002	0.002
	ε (%)	0.148	0.386	0.107	0.102
Grunberg and Nissan	d	−1.8024	−1.8017	−1.6482	−1.5235
	σ	0.055	0.042	0.038	0.030
	ε (%)	3.053	2.683	2.755	2.671
Heric	α_{12}	−1.7977	−1.7965	−1.6421	−1.5146
	σ	0.062	0.048	0.043	0.035
	ε (%)	3.134	2.730	2.794	2.732
Heric	β_{12}	−1.6422	−1.6589	−1.5165	−1.4043
	β'_{12}	0.4702	0.4032	0.4306	0.4139
	σ	0.016	0.010	0.012	0.010
	ε (%)	0.858	0.590	0.866	0.813
Hind et al.	η_{12}	−0.3256	−0.2292	0.0057	0.1329
	σ	0.320	0.264	0.183	0.127
	ε (%)	17.62	15.89	13.46	11.21
Diethyl Carbonate + 1-Octanol					
McAllister (for three-body interactions)	ν_{12}	1.5588	1.4563	1.2098	0.9959
	ν_{21}	3.1950	2.7421	2.2344	1.8482
	σ	0.014	0.040	0.016	0.015
	ε (%)	0.548	1.015	0.810	0.795
McAllister (for four-body interactions)	ν_{1112}	1.2913	1.1446	0.9881	0.8217
	ν_{1122}	2.3267	2.1947	1.7709	1.4841
	ν_{1222}	4.5205	3.7909	2.9931	2.3834
	σ	0.007	0.035	0.007	0.005
	ε (%)	0.208	0.472	0.305	0.202
Grunberg and Nissan	d	−1.4530	−1.4249	−1.2548	−1.1384
	σ	0.056	0.066	0.037	0.023
	ε (%)	1.844	2.101	1.551	0.840
Heric	α_{12}	−1.4103	−1.3845	−1.2135	−1.0944
	σ	0.065	0.078	0.044	0.025
	ε (%)	1.940	2.201	1.640	0.901
Heric	β_{12}	−1.2869	−1.2402	1.1133	−1.0377
	β'_{12}	0.2831	0.3512	0.2681	0.1597
	σ	0.0137	0.040	0.016	0.014
	ε (%)	0.548	1.015	0.810	0.794
Hind et al.	η_{12}	−2.0405	−1.4784	−0.6102	−0.1853
	σ	0.8189	0.6541	0.3893	0.2456
	ε (%)	30.65	28.04	20.23	15.74

errors of <0.3 %. As expected,[39] the two-parameter equations by Heric and McAllister provide the same result, with a mean error of 0.78 %. Moreover, the predictive model by Grunberg and Nissan and the equation by Heric (one-parameter) produce less useful results with global mean errors around 2.5 %. The largest deviations were obtained with the Hind et al. equation.

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