Densities and Viscosities of Binary Mixtures of Isoamyl Acetate, Ethyl Caproate, Ethyl Benzoate, Isoamyl Butyrate, Ethyl Phenylacetate, and Ethyl Caprylate with Ethanol at T = (288.15, 298.15, 308.15, and 318.15) K

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Densities and viscosities for binary mixtures of six flavor esters (isoamyl acetate, ethyl caproate, ethyl benzoate, isoamyl butyrate, ethyl phenylacetate, and ethyl caprylate) with ethanol over the whole composition range were measured at four different temperatures (288.15, 298.15, 308.15, and 318.15) K and atmospheric pressure. Densities were determined using a vibrating-tube density meter. Viscosities were measured with an automatic Ubbelohde capillary viscometer. Excess molar volumes (V^E) and deviations in the viscosity from mole fraction average ($\Delta\eta$) were derived from experimental data. The binary data of V^E and $\Delta\eta$ were correlated as a function of the mole fraction by using the Redlich−Kister equation.

Introduction

The thermophysical study of esters is of increasing interest due to their wide usage in flavoring, perfumery, artificial essences, and cosmetics. Esters are also important solvents in the pharmaceutical, paint, and plastic industries. Among different type of esters, isoamyl acetate, ethyl caproate, ethyl benzoate, isoamyl butyrate, ethyl phenylacetate, and ethyl caprylate are important flavor compounds used in the flavor and fragrance industries; ethanol is the most common alcohol component. On the other hand, ethanol is a versatile solvent with protic and self-associated properties, which is often used to study the hydrophobic effect. Several studies for the binary mixtures of the thermophysical properties containing the above esters have been conducted recently.[1−3] However, no studies on the properties such as density and viscosity for the binary systems formed by the above esters with ethanol have been reported in the literature.

Therefore, in the present paper, we undertake to obtain reliable density and viscosity data for the binary mixtures of isoamyl acetate, ethyl caproate, ethyl benzoate, isoamyl butyrate, ethyl phenylacetate, and ethyl caprylate with ethanol at temperatures of 288.15 K, 298.15 K, 308.15 K, and 318.15 K and atmospheric pressure. The experimental results are used to calculate excess molar volumes and deviations in the viscosity from mole fraction average. The calculated binary data have been fitted to the Redlich−Kister equation to determine the coefficients.

Experimental Section

Materials. The chemicals used were of analytical grade and were used without further purification. The purity of these chemicals was analyzed by gas chromatography (Perkin-Elmer Autosystem). The mass percent purities as determined by the major peak areas on gas chromatography together with the sources and CAS Registry Numbers (CASRN) of the chemicals are given in Table 1. The purity of solvents was further ascertained by comparing their densities, viscosities, and refractive indices at a temperature of 298.15 K, and the results are generally in agreement with the corresponding values reported in the literature as shown in Table 2. Experimental refractive indices in Table 2 were measured with a digital Abbe refractometer RX-5000 (ATAGO, Tokyo, Japan), which works at the wavelength (589 nm) corresponding to the D-line of sodium.

Apparatus and Procedure. Samples were prepared by mass in a 50 cm^3 Erlenmeyer flask provided with a ground glass joint stopper, using a Precisa 262SMA balance with an uncertainty of $\pm 3 \times 10^{-5}$ g. Densities were measured with an Anton Paar DMA-5000 vibrating-tube density meter (Anton-Paar, Graz, Austria) with a stated accuracy of 5×10^{-6} g·cm^{-3} in the range (0 to 3) g·cm^{-3}, which was thermostatically controlled to within $\pm$ 0.01 K in the range (273.15 to 363.15) K. Calibration was performed periodically at atmospheric pressure, in accordance with specifications, using double-distilled water and dry air. The uncertainty of the density measurements was estimated to be less than $\pm 3 \times 10^{-5}$ g·cm^{-3}.

The kinematic viscosities were determined with the commercial Ubbelohde capillary viscometers (Cannon Instrument Co., State College, PA) of (0.36, 0.47, 0.53, and 0.83) mm in diameter. The viscometer was kept in a Lauda D20 KP thermostat controlled to $\pm$ 0.01 K with a proportional integral differential regulator. A computer-controlled measuring system (Lauda, Lauda-Königshofen, Germany) with an uncertainty of $\pm$ 0.01 s was used for flow-time measurement. The range of the flow time for the liquids investigated varied from 200 s to 880 s. The kinematic viscosities (ν) were determined according to

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

where k is the viscometer constant, t is the flow time, and θ is the Hagenbach correction. The absolute viscosity (η) was then calculated from the density by the relation $\eta = \nu\rho$. The values of k were determined by calibrating with pure water at working temperatures. The value θ, which is dependent on the flow time and the size of capillary, was taken from the tables supplied by the manufacturer. Triplicate measurements of flow times were reproducible within $\pm$ 0.02 s. The uncertainty of the viscosity measurement was estimated to be less than $\pm$ 0.006 mPa·s.

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Table 1. Sources and Mass Fraction (W) Purities of the Esters Used in This Study

compounds	molecular formula	sources	CASRN	100 W
isoamyl acetate	$C_7H_{14}O_2$	Tedia (USA)	123-92-2	99.3
ethyl caproate	$C_8H_{16}O_2$	Acros (USA)	123-66-0	99.7
ethyl benzoate	$C_9H_{10}O_2$	Acros (USA)	93-89-0	99.8
isoamyl butyrate	$C_9H_{18}O_2$	Acros (USA)	106-27-4	99.4
ethyl phenylacetate	$C_{10}H_{12}O_2$	Acros (USA)	101-97-3	99.4
ethyl caprylate	$C_{10}H_{20}O_2$	Acros (USA)	106-32-1	99.5
ethanol	C_2H_6O	Merck (Germany)	64-17-5	99.9

Table 2. Comparison of Measured Densities, Viscosities, and Refractive Indices of Pure Components with Literature Values at 298.15 K

	ρ/g·cm^{-3}		η/mPa·s		n_D	
compound	exptl	lit.	exptl	lit.	exptl	lit.
isoamyl acetate	0.86791	0.86621[1]	0.804	0.781[1]	1.39836	
		0.87601[4]		0.827[4]		
		0.8664[5]		0.7895[5]		
ethyl caproate	0.86629		0.940		1.40504	
ethyl benzoate	1.04142	1.041[2]	1.971	1.945[6]	1.50328	1.5046[7]
		1.0421[7]		1.936[7]		
isoamyl butyrate	0.85869	0.86204[4]	1.111	0.967[4]	1.40815	
ethyl phenylacetate	1.02696		2.384		1.49513	
ethyl caprylate	0.86215		1.411		1.41560	
ethanol	0.78500	0.7850[8]	1.105	1.105[8]	1.35941	1.3593[9]
		0.78493[9]		1.0826[9]		1.3595[11]
		0.78515[10]		1.1120[12]		
		0.78506[11]				

Table 3. Experimental Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for System Isoamyl Acetate (1) + Ethanol (2)

	ρ	η	V^E	$\Delta\eta$		ρ	η	V^E	$\Delta\eta$		ρ	η	V^E	$\Delta\eta$
x_1	g·cm^{-3}	mPa·s	cm^3·mol^{-1}	mPa·s	x_1	g·cm^{-3}	mPa·s	cm^3·mol^{-1}	mPa·s	x_1	g·cm^{-3}	mPa·s	cm^3·mol^{-1}	mPa·s
							288.15 K							
0.0000	0.79360	1.337	0.000	0.000	0.3500	0.84158	0.948	0.078	−0.250	0.7000	0.86500	0.911	0.089	−0.148
0.0500	0.80341	1.220	0.013	−0.097	0.4000	0.84581	0.934	0.088	−0.244	0.7500	0.86744	0.912	0.083	−0.127
0.1000	0.81189	1.133	0.026	−0.164	0.4500	0.84970	0.924	0.093	−0.234	0.8000	0.86973	0.916	0.074	−0.103
0.1500	0.81925	1.072	0.043	−0.205	0.5000	0.85326	0.916	0.097	−0.223	0.8500	0.87189	0.926	0.061	−0.074
0.2000	0.82581	1.031	0.053	−0.227	0.5500	0.85653	0.910	0.099	−0.209	0.9000	0.87395	0.937	0.042	−0.043
0.2500	0.83166	0.996	0.061	−0.242	0.6000	0.85957	0.907	0.097	−0.192	0.9500	0.87587	0.939	0.025	−0.021
0.3000	0.83685	0.968	0.073	−0.250	0.6500	0.86236	0.908	0.097	−0.171	1.0000	0.87772	0.940	0.000	0.000
							298.15 K							
0.0000	0.78500	1.105	0.000	0.000	0.3500	0.83208	0.805	0.102	−0.195	0.7000	0.85521	0.775	0.114	−0.119
0.0500	0.79464	1.011	0.015	−0.079	0.4000	0.83624	0.793	0.115	−0.192	0.7500	0.85764	0.780	0.104	−0.099
0.1000	0.80292	0.946	0.035	−0.129	0.4500	0.84007	0.786	0.121	−0.184	0.8000	0.85993	0.782	0.091	−0.082
0.1500	0.81013	0.902	0.057	−0.158	0.5000	0.84359	0.779	0.124	−0.176	0.8500	0.86208	0.791	0.075	−0.058
0.2000	0.81658	0.866	0.070	−0.179	0.5500	0.84682	0.776	0.127	−0.163	0.9000	0.86414	0.799	0.052	−0.035
0.2500	0.82231	0.841	0.082	−0.189	0.6000	0.84983	0.773	0.124	−0.151	0.9500	0.86609	0.804	0.025	−0.015
0.3000	0.82742	0.821	0.096	−0.194	0.6500	0.85258	0.773	0.125	−0.136	1.0000	0.86791	0.804	0.000	0.000
							308.15 K							
0.0000	0.77631	0.921	0.000	0.000	0.3500	0.82244	0.689	0.137	−0.156	0.7000	0.84533	0.670	0.147	−0.099
0.0500	0.78574	0.847	0.022	−0.063	0.4000	0.82653	0.680	0.152	−0.154	0.7500	0.84775	0.675	0.135	−0.083
0.1000	0.79384	0.799	0.048	−0.100	0.4500	0.83032	0.675	0.159	−0.148	0.8000	0.85004	0.680	0.117	−0.067
0.1500	0.80090	0.762	0.076	−0.126	0.5000	0.83379	0.671	0.164	−0.142	0.8500	0.85220	0.688	0.096	−0.049
0.2000	0.80721	0.735	0.095	−0.143	0.5500	0.83699	0.668	0.166	−0.134	0.9000	0.85428	0.697	0.064	−0.029
0.2500	0.81285	0.716	0.109	−0.151	0.6000	0.83997	0.667	0.163	−0.124	0.9500	0.85625	0.703	0.029	−0.012
0.3000	0.81786	0.701	0.127	−0.155	0.6500	0.84271	0.667	0.161	−0.113	1.0000	0.85807	0.704	0.000	0.000
							318.15 K							
0.0000	0.76744	0.771	0.000	0.000	0.3500	0.81265	0.596	0.177	−0.125	0.7000	0.83533	0.588	0.188	−0.082
0.0500	0.77669	0.716	0.027	−0.048	0.4000	0.81669	0.590	0.195	−0.123	0.7500	0.83775	0.594	0.172	−0.069
0.1000	0.78460	0.680	0.062	−0.077	0.4500	0.82042	0.586	0.204	−0.120	0.8000	0.84005	0.601	0.149	−0.055
0.1500	0.79150	0.651	0.097	−0.098	0.5000	0.82386	0.583	0.209	−0.116	0.8500	0.84222	0.609	0.122	−0.040
0.2000	0.79769	0.630	0.122	−0.112	0.5500	0.82703	0.582	0.212	−0.110	0.9000	0.84434	0.618	0.080	−0.023
0.2500	0.80322	0.615	0.142	−0.120	0.6000	0.82999	0.582	0.208	−0.103	0.9500	0.84632	0.625	0.039	−0.009
0.3000	0.80815	0.605	0.164	−0.123	0.6500	0.83272	0.584	0.204	−0.093	1.0000	0.84817	0.627	0.000	0.000

The densities and viscosities of six binary systems isoamyl acetate, ethyl caproate, ethyl benzoate, isoamyl butyrate, ethyl phenylacetate, or ethyl caprylate + ethanol were measured at T = (288.15, 298.15, 308.15, and 318.15) K. A set with the compositions varying from 0.05 to 0.95 mole fractions of alcohol was prepared for each binary system. The uncertainty in the liquid composition was estimated to be $\pm$ 1 $\times$ 10^{-4}. All measurements described above were performed at least three times at atmospheric pressure (100.5 $\pm$ 0.3) kPa, and an average of at least three measurements was calculated for each.

Results and Discussion

Tables 3 to 8 list the experimental densities, viscosities, excess molar volumes, and deviations in the viscosities for six binary systems isoamyl acetate, ethyl caproate, ethyl benzoate, isoamyl butyrate, ethyl phenylacetate, or ethyl caprylate + ethanol at

Table 4. Experimental Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for System Ethyl Caproate (1) + Ethanol (2)

x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s
							288.15 K							
0.0000	0.79360	1.337	0.000	0.000	0.3500	0.84247	1.051	0.081	−0.204	0.7000	0.86422	1.048	0.100	−0.125
0.0500	0.80418	1.241	0.006	−0.084	0.4000	0.84650	1.045	0.091	−0.198	0.7500	0.86643	1.054	0.093	−0.107
0.1000	0.81299	1.182	0.023	−0.132	0.4500	0.85015	1.039	0.098	−0.192	0.8000	0.86848	1.064	0.085	−0.085
0.1500	0.82054	1.139	0.039	−0.163	0.5000	0.85347	1.037	0.103	−0.183	0.8500	0.87041	1.073	0.073	−0.064
0.2000	0.82714	1.106	0.048	−0.184	0.5500	0.85651	1.038	0.104	−0.170	0.9000	0.87222	1.086	0.058	−0.040
0.2500	0.83289	1.082	0.059	−0.196	0.6000	0.85928	1.039	0.106	−0.157	0.9500	0.87399	1.100	0.028	−0.014
0.3000	0.83794	1.062	0.073	−0.204	0.6500	0.86184	1.045	0.105	−0.139	1.0000	0.87564	1.102	0.000	0.000
							298.15 K							
0.0000	0.78500	1.105	0.000	0.000	0.3500	0.83320	0.889	0.107	−0.158	0.7000	0.85482	0.896	0.126	−0.094
0.0500	0.79544	1.031	0.010	−0.066	0.4000	0.83718	0.883	0.121	−0.156	0.7500	0.85702	0.902	0.118	−0.079
0.1000	0.80411	0.982	0.032	−0.107	0.4500	0.84082	0.880	0.126	−0.151	0.8000	0.85909	0.910	0.104	−0.063
0.1500	0.81153	0.948	0.054	−0.132	0.5000	0.84411	0.880	0.132	−0.143	0.8500	0.86104	0.919	0.085	−0.046
0.2000	0.81805	0.926	0.066	−0.146	0.5500	0.84712	0.882	0.135	−0.132	0.9000	0.86286	0.929	0.066	−0.028
0.2500	0.82372	0.909	0.082	−0.155	0.6000	0.84988	0.888	0.136	−0.118	0.9500	0.86466	0.940	0.028	−0.008
0.3000	0.82872	0.897	0.097	−0.158	0.6500	0.85243	0.892	0.134	−0.106	1.0000	0.86629	0.940	0.000	0.000
							308.15 K							
0.0000	0.77631	0.921	0.000	0.000	0.3500	0.82382	0.763	0.141	−0.121	0.7000	0.84533	0.773	0.160	−0.073
0.0500	0.78659	0.866	0.015	−0.050	0.4000	0.82776	0.759	0.157	−0.119	0.7500	0.84754	0.779	0.149	−0.062
0.1000	0.79512	0.829	0.044	−0.081	0.4500	0.83137	0.758	0.165	−0.115	0.8000	0.84963	0.786	0.129	−0.049
0.1500	0.80242	0.806	0.073	−0.099	0.5000	0.83463	0.759	0.173	−0.109	0.8500	0.85159	0.794	0.107	−0.036
0.2000	0.80885	0.789	0.090	−0.111	0.5500	0.83764	0.761	0.174	−0.101	0.9000	0.85345	0.803	0.078	−0.022
0.2500	0.81444	0.777	0.110	−0.117	0.6000	0.84039	0.765	0.175	−0.092	0.9500	0.85527	0.815	0.033	−0.004
0.3000	0.81938	0.769	0.129	−0.120	0.6500	0.84294	0.767	0.171	−0.084	1.0000	0.85691	0.814	0.000	0.000
							318.15 K							
0.0000	0.76744	0.771	0.000	0.000	0.3500	0.81429	0.659	0.184	−0.091	0.7000	0.83575	0.674	0.203	−0.055
0.0500	0.77758	0.732	0.021	−0.036	0.4000	0.81820	0.657	0.203	−0.090	0.7500	0.83797	0.680	0.188	−0.046
0.1000	0.78596	0.710	0.059	−0.055	0.4500	0.82180	0.657	0.211	−0.087	0.8000	0.84008	0.686	0.164	−0.037
0.1500	0.79314	0.691	0.096	−0.071	0.5000	0.82505	0.658	0.219	−0.083	0.8500	0.84207	0.694	0.135	−0.026
0.2000	0.79948	0.676	0.119	−0.083	0.5500	0.82805	0.662	0.221	−0.076	0.9000	0.84397	0.703	0.096	−0.014
0.2500	0.80501	0.667	0.144	−0.089	0.6000	0.83079	0.665	0.222	−0.070	0.9500	0.84583	0.712	0.041	−0.002
0.3000	0.80989	0.662	0.168	−0.091	0.6500	0.83334	0.668	0.218	−0.064	1.0000	0.84750	0.711	0.000	0.000

Table 5. Experimental Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for System Ethyl Benzoate (1) + Ethanol (2)

x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s
							288.15 K							
0.0000	0.79360	1.337	0.000	0.000	0.3500	0.94279	1.557	−0.241	−0.167	0.7000	1.01367	1.959	−0.118	−0.153
0.0500	0.82459	1.342	−0.112	−0.050	0.4000	0.95585	1.607	−0.235	−0.173	0.7500	1.02094	2.028	−0.098	−0.139
0.1000	0.85102	1.360	−0.170	−0.088	0.4500	0.96771	1.661	−0.224	−0.174	0.8000	1.02763	2.099	−0.068	−0.124
0.1500	0.87407	1.388	−0.209	−0.115	0.5000	0.97851	1.715	−0.207	−0.176	0.8500	1.03399	2.178	−0.052	−0.100
0.2000	0.89437	1.425	−0.234	−0.133	0.5500	0.98843	1.773	−0.191	−0.173	0.9000	1.03987	2.267	−0.025	−0.066
0.2500	0.91235	1.465	−0.246	−0.149	0.6000	0.99748	1.833	−0.164	−0.168	0.9500	1.04545	2.373	−0.007	−0.016
0.3000	0.92837	1.510	−0.246	−0.159	0.6500	1.00591	1.895	−0.144	−0.162	1.0000	1.05078	2.444	0.000	0.000
							298.15 K							
0.0000	0.78500	1.105	0.000	0.000	0.3500	0.93345	1.282	−0.229	−0.126	0.7000	1.00422	1.595	−0.104	−0.116
0.0500	0.81581	1.108	−0.112	−0.040	0.4000	0.94647	1.321	−0.221	−0.130	0.7500	1.01150	1.649	−0.086	−0.106
0.1000	0.84208	1.123	−0.167	−0.069	0.4500	0.95830	1.363	−0.208	−0.132	0.8000	1.01820	1.705	−0.057	−0.093
0.1500	0.86501	1.148	−0.203	−0.087	0.5000	0.96907	1.405	−0.191	−0.133	0.8500	1.02457	1.767	−0.043	−0.074
0.2000	0.88522	1.176	−0.226	−0.102	0.5500	0.97897	1.449	−0.173	−0.132	0.9000	1.03048	1.836	−0.020	−0.048
0.2500	0.90311	1.208	−0.235	−0.113	0.6000	0.98807	1.496	−0.153	−0.129	0.9500	1.03609	1.917	−0.006	−0.011
0.3000	0.91907	1.244	−0.234	−0.121	0.6500	0.99646	1.544	−0.130	−0.124	1.0000	1.04142	1.971	0.000	0.000
							308.15 K							
0.0000	0.77631	0.921	0.000	0.000	0.3500	0.92402	1.072	−0.211	−0.095	0.7000	0.99470	1.326	−0.082	−0.087
0.0500	0.80692	0.926	−0.109	−0.030	0.4000	0.93700	1.105	−0.201	−0.097	0.7500	1.00201	1.370	−0.067	−0.078
0.1000	0.83303	0.938	−0.160	−0.053	0.4500	0.94881	1.138	−0.188	−0.099	0.8000	1.00872	1.416	−0.040	−0.067
0.1500	0.85584	0.959	−0.193	−0.067	0.5000	0.95957	1.173	−0.170	−0.100	0.8500	1.01513	1.465	−0.030	−0.054
0.2000	0.87595	0.984	−0.214	−0.078	0.5500	0.96946	1.209	−0.152	−0.099	0.9000	1.02106	1.521	−0.010	−0.033
0.2500	0.89377	1.012	−0.220	−0.085	0.6000	0.97854	1.247	−0.130	−0.096	0.9500	1.02672	1.582	−0.003	−0.007
0.3000	0.90968	1.042	−0.217	−0.090	0.6500	0.98694	1.286	−0.108	−0.092	1.0000	1.03207	1.624	0.000	0.000
							318.15 K							
0.0000	0.76744	0.771	0.000	0.000	0.3500	0.91445	0.908	−0.187	−0.072	0.7000	0.98512	1.124	−0.055	−0.065
0.0500	0.79788	0.778	−0.107	−0.023	0.4000	0.92741	0.935	−0.176	−0.075	0.7500	0.99245	1.159	−0.042	−0.060
0.1000	0.82384	0.793	−0.154	−0.038	0.4500	0.93920	0.964	−0.161	−0.076	0.8000	0.99919	1.198	−0.017	−0.051
0.1500	0.84652	0.812	−0.182	−0.049	0.5000	0.94995	0.993	−0.142	−0.077	0.8500	1.00564	1.241	−0.012	−0.037
0.2000	0.86654	0.833	−0.199	−0.057	0.5500	0.95984	1.024	−0.123	−0.075	0.9000	1.01162	1.288	0.002	−0.020
0.2500	0.88429	0.857	−0.202	−0.063	0.6000	0.96893	1.055	−0.101	−0.074	0.9500	1.01733	1.335	0.003	−0.003
0.3000	0.90015	0.881	−0.196	−0.069	0.6500	0.97735	1.089	−0.081	−0.070	1.0000	1.02273	1.368	0.000	0.000

Table 6. Experimental Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for System Isoamyl Butyrate (1) + Ethanol (2)

x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s
							288.15 K							
0.0000	0.79360	1.337	0.000	0.000	0.3500	0.83937	1.168	0.098	−0.162	0.7000	0.85818	1.224	0.108	−0.099
0.0500	0.80406	1.270	0.004	−0.066	0.4000	0.84296	1.170	0.103	−0.159	0.7500	0.86004	1.237	0.100	−0.085
0.1000	0.81238	1.231	0.034	−0.104	0.4500	0.84614	1.176	0.110	−0.152	0.8000	0.86176	1.253	0.091	−0.068
0.1500	0.81951	1.201	0.049	−0.133	0.5000	0.84903	1.183	0.112	−0.144	0.8500	0.86335	1.268	0.081	−0.052
0.2000	0.82558	1.181	0.063	−0.152	0.5500	0.85161	1.191	0.118	−0.135	0.9000	0.86486	1.284	0.064	−0.035
0.2500	0.83083	1.171	0.073	−0.161	0.6000	0.85401	1.202	0.114	−0.123	0.9500	0.86630	1.302	0.040	−0.016
0.3000	0.83541	1.167	0.082	−0.164	0.6500	0.85619	1.213	0.111	−0.111	1.0000	0.86772	1.317	0.000	0.000
							298.15 K							
0.0000	0.78500	1.105	0.000	0.000	0.3500	0.83031	0.980	0.123	−0.127	0.7000	0.84904	1.031	0.138	−0.078
0.0500	0.79535	1.057	0.008	−0.048	0.4000	0.83385	0.984	0.133	−0.123	0.7500	0.85092	1.043	0.125	−0.066
0.1000	0.80357	1.025	0.043	−0.081	0.4500	0.83702	0.989	0.141	−0.119	0.8000	0.85265	1.056	0.113	−0.054
0.1500	0.81061	1.004	0.063	−0.102	0.5000	0.83990	0.994	0.143	−0.114	0.8500	0.85428	1.071	0.095	−0.039
0.2000	0.81661	0.993	0.082	−0.113	0.5500	0.84246	1.001	0.151	−0.107	0.9000	0.85581	1.086	0.072	−0.024
0.2500	0.82180	0.985	0.097	−0.121	0.6000	0.84486	1.010	0.147	−0.099	0.9500	0.85728	1.099	0.040	−0.012
0.3000	0.82634	0.980	0.109	−0.127	0.6500	0.84705	1.021	0.141	−0.088	1.0000	0.85869	1.111	0.000	0.000
							308.15 K							
0.0000	0.77631	0.921	0.000	0.000	0.3500	0.82111	0.833	0.159	−0.099	0.7000	0.83985	0.882	0.170	−0.061
0.0500	0.78652	0.887	0.015	−0.036	0.4000	0.82464	0.835	0.170	−0.098	0.7500	0.84174	0.891	0.154	−0.053
0.1000	0.79463	0.858	0.057	−0.066	0.4500	0.82779	0.840	0.180	−0.095	0.8000	0.84350	0.903	0.136	−0.043
0.1500	0.80158	0.844	0.084	−0.082	0.5000	0.83066	0.846	0.184	−0.091	0.8500	0.84515	0.915	0.112	−0.032
0.2000	0.80752	0.838	0.107	−0.089	0.5500	0.83324	0.853	0.189	−0.085	0.9000	0.84671	0.929	0.083	−0.020
0.2500	0.81266	0.834	0.127	−0.095	0.6000	0.83564	0.862	0.184	−0.078	0.9500	0.84822	0.941	0.040	−0.009
0.3000	0.81717	0.832	0.141	−0.098	0.6500	0.83784	0.872	0.177	−0.069	1.0000	0.84962	0.952	0.000	0.000
							318.15 K							
0.0000	0.76744	0.771	0.000	0.000	0.3500	0.81178	0.714	0.204	−0.077	0.7000	0.83057	0.760	0.214	−0.050
0.0500	0.77754	0.744	0.022	−0.030	0.4000	0.81530	0.717	0.218	−0.076	0.7500	0.83249	0.770	0.194	−0.043
0.1000	0.78554	0.723	0.073	−0.054	0.4500	0.81844	0.723	0.231	−0.073	0.8000	0.83428	0.781	0.170	−0.035
0.1500	0.79240	0.715	0.109	−0.064	0.5000	0.82132	0.729	0.235	−0.070	0.8500	0.83596	0.792	0.141	−0.027
0.2000	0.79828	0.711	0.138	−0.071	0.5500	0.82390	0.735	0.241	−0.067	0.9000	0.83756	0.806	0.102	−0.015
0.2500	0.80338	0.710	0.163	−0.075	0.6000	0.82633	0.743	0.232	−0.062	0.9500	0.83912	0.817	0.048	−0.007
0.3000	0.80786	0.710	0.183	−0.078	0.6500	0.82854	0.751	0.224	−0.056	1.0000	0.84055	0.827	0.000	0.000

Table 7. Experimental Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for System Ethyl Phenylacetate (1) + Ethanol (2)

x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s
							288.15 K							
0.0000	0.79360	1.337	0.000	0.000	0.3500	0.94014	1.742	−0.207	−0.178	0.7000	1.00413	2.348	−0.093	−0.154
0.0500	0.82534	1.366	−0.095	−0.054	0.4000	0.95217	1.822	−0.198	−0.181	0.7500	1.01049	2.446	−0.074	−0.140
0.1000	0.85200	1.393	−0.153	−0.110	0.4500	0.96302	1.904	−0.188	−0.182	0.8000	1.01636	2.555	−0.052	−0.114
0.1500	0.87472	1.447	−0.185	−0.140	0.5000	0.97279	1.989	−0.170	−0.180	0.8500	1.02184	2.672	−0.033	−0.080
0.2000	0.89442	1.513	−0.207	−0.157	0.5500	0.98167	2.076	−0.151	−0.177	0.9000	1.02695	2.790	−0.015	−0.045
0.2500	0.91160	1.584	−0.215	−0.169	0.6000	0.98981	2.164	−0.133	−0.172	0.9500	1.03175	2.919	0.001	0.000
0.3000	0.92672	1.663	−0.214	−0.173	0.6500	0.99727	2.255	−0.114	−0.164	1.0000	1.03635	3.002	0.000	0.000
							298.15 K							
0.0000	0.78500	1.105	0.000	0.000	0.3500	0.93079	1.418	−0.193	−0.135	0.7000	0.99468	1.895	−0.079	−0.105
0.0500	0.81654	1.127	−0.093	−0.042	0.4000	0.94279	1.479	−0.184	−0.138	0.7500	1.00103	1.974	−0.060	−0.090
0.1000	0.84305	1.151	−0.149	−0.082	0.4500	0.95361	1.543	−0.173	−0.138	0.8000	1.00693	2.053	−0.043	−0.075
0.1500	0.86565	1.195	−0.178	−0.102	0.5000	0.96335	1.610	−0.154	−0.134	0.8500	1.01241	2.140	−0.024	−0.052
0.2000	0.88525	1.244	−0.198	−0.117	0.5500	0.97224	1.677	−0.137	−0.131	0.9000	1.01755	2.230	−0.010	−0.026
0.2500	0.90237	1.298	−0.206	−0.127	0.6000	0.98037	1.747	−0.119	−0.125	0.9500	1.02236	2.330	0.002	0.010
0.3000	0.91742	1.357	−0.202	−0.132	0.6500	0.98781	1.821	−0.098	−0.115	1.0000	1.02696	2.384	0.000	0.000
							308.15 K							
0.0000	0.77631	0.921	0.000	0.000	0.3500	0.92136	1.188	−0.174	−0.092	0.7000	0.98519	1.571	−0.059	−0.069
0.0500	0.80765	0.947	−0.090	−0.025	0.4000	0.93333	1.239	−0.163	−0.093	0.7500	0.99156	1.635	−0.042	−0.056
0.1000	0.83400	0.967	−0.142	−0.057	0.4500	0.94413	1.292	−0.151	−0.091	0.8000	0.99748	1.702	−0.028	−0.041
0.1500	0.85649	1.003	−0.169	−0.072	0.5000	0.95386	1.344	−0.132	−0.090	0.8500	1.00297	1.772	−0.011	−0.022
0.2000	0.87599	1.044	−0.185	−0.082	0.5500	0.96273	1.399	−0.113	−0.087	0.9000	1.00814	1.847	−0.002	0.002
0.2500	0.89303	1.089	−0.190	−0.089	0.6000	0.97086	1.455	−0.096	−0.082	0.9500	1.01299	1.914	0.004	0.017
0.3000	0.90803	1.138	−0.185	−0.091	0.6500	0.97831	1.513	−0.076	−0.076	1.0000	1.01760	1.948	0.000	0.000
							318.15 K							
0.0000	0.76744	0.771	0.000	0.000	0.3500	0.91182	1.012	−0.150	−0.058	0.7000	0.97565	1.336	−0.033	−0.032
0.0500	0.79861	0.798	−0.088	−0.016	0.4000	0.92377	1.055	−0.137	−0.057	0.7500	0.98204	1.387	−0.018	−0.024
0.1000	0.82482	0.823	−0.137	−0.033	0.4500	0.93456	1.099	−0.125	−0.056	0.8000	0.98798	1.441	−0.006	−0.012
0.1500	0.84717	0.855	−0.157	−0.044	0.5000	0.94428	1.145	−0.104	−0.052	0.8500	0.99353	1.498	0.003	0.002
0.2000	0.86660	0.891	−0.171	−0.051	0.5500	0.95316	1.191	−0.086	−0.049	0.9000	0.99873	1.558	0.008	0.019
0.2500	0.88357	0.930	−0.172	−0.054	0.6000	0.96129	1.238	−0.068	−0.045	0.9500	1.00361	1.605	0.010	0.024
0.3000	0.89852	0.971	−0.164	−0.056	0.6500	0.96875	1.286	−0.049	−0.039	1.0000	1.00826	1.624	0.000	0.000

Table 8. Experimental Densities ρ, Viscosities η, Excess Molar Volumes V^E, and Viscosity Deviations $\Delta\eta$ for System Ethyl Caprylate (1) + Ethanol (2)

x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s	x_1	ρ / g·cm^{-3}	η / mPa·s	V^E / cm^3·mol^{-1}	$\Delta\eta$ / mPa·s
							288.15 K							
0.0000	0.79360	1.337	0.000	0.000	0.3500	0.84277	1.375	0.101	−0.088	0.7000	0.86152	1.542	0.117	−0.047
0.0500	0.80514	1.322	0.016	−0.033	0.4000	0.84639	1.398	0.109	−0.083	0.7500	0.86340	1.568	0.097	−0.039
0.1000	0.81437	1.299	0.038	−0.074	0.4500	0.84959	1.420	0.117	−0.079	0.8000	0.86513	1.595	0.076	−0.030
0.1500	0.82204	1.306	0.053	−0.085	0.5000	0.85245	1.443	0.124	−0.074	0.8500	0.86672	1.623	0.055	−0.020
0.2000	0.82852	1.320	0.061	−0.089	0.5500	0.85504	1.468	0.127	−0.067	0.9000	0.86819	1.649	0.034	−0.012
0.2500	0.83398	1.337	0.075	−0.090	0.6000	0.85740	1.492	0.126	−0.061	0.9500	0.86960	1.673	0.004	−0.006
0.3000	0.83869	1.356	0.087	−0.089	0.6500	0.85954	1.517	0.124	−0.054	1.0000	0.87079	1.697	0.000	0.000
							298.15 K							
0.0000	0.78500	1.105	0.000	0.000	0.3500	0.83394	1.145	0.127	−0.067	0.7000	0.85276	1.284	0.141	−0.035
0.0500	0.79650	1.094	0.019	−0.026	0.4000	0.83755	1.164	0.138	−0.063	0.7500	0.85468	1.306	0.114	−0.029
0.1000	0.80566	1.081	0.047	−0.055	0.4500	0.84077	1.183	0.145	−0.060	0.8000	0.85641	1.327	0.093	−0.023
0.1500	0.81327	1.087	0.067	−0.064	0.5000	0.84363	1.202	0.154	−0.056	0.8500	0.85800	1.350	0.073	−0.015
0.2000	0.81974	1.098	0.078	−0.068	0.5500	0.84623	1.222	0.157	−0.051	0.9000	0.85950	1.371	0.046	−0.009
0.2500	0.82517	1.112	0.096	−0.069	0.6000	0.84860	1.242	0.155	−0.047	0.9500	0.86093	1.391	0.010	−0.005
0.3000	0.82987	1.129	0.110	−0.068	0.6500	0.85077	1.262	0.149	−0.042	1.0000	0.86215	1.411	0.000	0.000
							308.15 K							
0.0000	0.77631	0.921	0.000	0.000	0.3500	0.82502	0.969	0.163	−0.047	0.7000	0.84394	1.085	0.177	−0.026
0.0500	0.78773	0.915	0.026	−0.020	0.4000	0.82863	0.984	0.177	−0.046	0.7500	0.84588	1.103	0.147	−0.022
0.1000	0.79682	0.907	0.061	−0.041	0.4500	0.83186	1.000	0.185	−0.043	0.8000	0.84764	1.121	0.121	−0.018
0.1500	0.80439	0.915	0.088	−0.047	0.5000	0.83472	1.016	0.000	0.000	0.8500	0.84925	1.140	0.098	−0.012
0.2000	0.81084	0.926	0.103	−0.049	0.5500	0.83734	1.033	0.199	−0.038	0.9000	0.85078	1.159	0.066	−0.007
0.2500	0.81625	0.940	0.126	−0.049	0.6000	0.83972	1.050	0.198	−0.034	0.9500	0.85226	1.177	0.019	−0.002
0.3000	0.82094	0.953	0.145	−0.050	0.6500	0.84192	1.068	0.189	−0.030	1.0000	0.85352	1.193	0.199	−0.038
							318.15 K							
0.0000	0.76744	0.771	0.000	0.000	0.3500	0.81596	0.831	0.208	−0.030	0.7000	0.83505	0.933	0.220	−0.017
0.0500	0.77881	0.772	0.032	−0.012	0.4000	0.81958	0.844	0.225	−0.029	0.7500	0.83701	0.948	0.189	−0.015
0.1000	0.78783	0.773	0.078	−0.024	0.4500	0.82283	0.859	0.235	−0.027	0.8000	0.83881	0.964	0.157	−0.012
0.1500	0.79536	0.780	0.113	−0.029	0.5000	0.82571	0.873	0.247	−0.026	0.8500	0.84047	0.979	0.125	−0.010
0.2000	0.80179	0.791	0.134	−0.031	0.5500	0.82836	0.888	0.248	−0.024	0.9000	0.84205	0.996	0.083	−0.005
0.2500	0.80719	0.804	0.162	−0.031	0.6000	0.83077	0.903	0.246	−0.022	0.9500	0.84357	1.013	0.028	−0.001
0.3000	0.81188	0.817	0.185	−0.031	0.6500	0.83299	0.917	0.237	−0.020	1.0000	0.84487	1.027	0.000	0.000

temperatures of 288.15 K, 298.15 K, 308.15 K, and 318.15 K. The values of densities and viscosities decrease systematically from 288.15 K to 318.15 K through the whole range of mole fractions. The molar excess volumes (V^E) were calculated from density data according to

$$V^E = \sum_{i=1}^{2} x_i M_i \left(\frac{1}{\rho} - \frac{1}{\rho_i}\right) \quad (2)$$

where x_i, M_i, and ρ_i are the mole fraction, molar mass, and density of the pure component i, respectively. ρ is the density of mixture. The deviation of the viscosity from the mole fraction average ($\Delta\eta$) is given by

$$\Delta\eta = \eta - \sum_{i=1}^{2} x_i \eta_i \quad (3)$$

where η is the absolute viscosities of the mixtures and η_i is the absolute viscosities of pure component i.

In the system studied, excess molar volumes are positive for the systems isoamyl acetate + ethanol, ethyl caproate + ethanol, isoamyl butyrate + ethanol, and ethyl caprylate + ethanol, while the negative values of V^E were observed for systems ethyl benzoate + ethanol and ethyl phenylacetate + ethanol over the whole composition range. The values of V^E increase systematically from 288.15 K to 318.15 K. The values of V^E ($x = 0.5$) vary from −0.207 cm^3·mol^{-1} to 0.247 cm^3·mol^{-1}. Figure 1 shows the excess molar volumes for these six binary systems at $T = 298.15$ K. The excess molar volume V^E ($x = 0.5$) at $T = 298.15$ K increases in the sequence: ethyl benzoate + ethanol < ethyl phenylacetate + ethanol < isoamyl acetate + ethanol < ethyl caproate + ethanol < isoamyl butyrate + ethanol < ethyl caprylate + ethanol.

The dependence of V^E on both composition and temperature for the present mixtures may be explained as a balance between positive contributions (hydrogen bond rupture, dispersive interactions between unlike molecules) and negative contributions (intermolecular dipolar interactions and geometrical fitting between components). In the present investigation, ethanol is

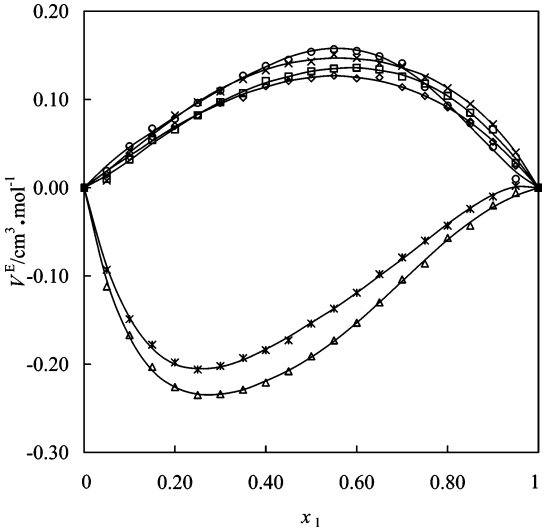

Figure 1. Change of excess molar volume V^E with mole fraction x_1 at $T = 298.15$ K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol. Solid curves were calculated from Redlich−Kister equation.

Table 9. Coefficients and Standard Deviations σ of V^E and $\Delta\eta$ for the Binary Mixtures from $T = 288.15$ K to $T = 318.15$ K

Y	T/K	a_0	a_1	a_2	a_3	a_4	$\sigma\cdot10^4$	Y	T/K	a_0	a_1	a_2	a_3	a_4	$\sigma\cdot10^4$
Isoamyl Acetate (1) + Ethanol (2)															
V^E/cm^3·mol^{-1}	288.15	0.3854	0.1110	0.0163			14	$\Delta\eta$/mPa·s	288.15	−0.8891	0.5135	−0.4036	0.4574		19
	298.15	0.4999	0.1155	−0.0064			21		298.15	−0.6985	0.3828	−0.3158	0.3952		17
	308.15	0.6579	0.1240	−0.0220			27		308.15	−0.5678	0.2792	−0.2412	0.3365		10
	318.15	0.8421	0.1484	−0.0293			31		318.15	−0.4641	0.2000	−0.1559	0.2767		7.2
Ethyl Caproate (1) + Ethanol (2)															
V^E/cm^3·mol^{-1}	288.15	0.4077	0.1476	0.0299	0.1248		19	$\Delta\eta$/mPa·s	288.15	−0.7264	0.3999	−0.3392	0.3721		25
	298.15	0.5315	0.1915	−0.0035			27		298.15	−0.5626	0.3321	−0.2642	0.3320		21
	308.15	0.6911	0.2037	−0.0256			32		308.15	−0.4327	0.2336	−0.1921	0.2778		17
	318.15	0.8834	0.2297	−0.0208			41		318.15	−0.3308	0.1829	−0.1025	0.1751		15
Ethyl Benzoate (1) + Ethanol (2)															
V^E/cm^3·mol^{-1}	288.15	−0.8181	0.6629	−0.4004	0.5428		39	$\Delta\eta$/mPa·s	288.15	−0.7037	0.7653	−0.2359			63
	298.15	−0.7556	0.6678	−0.4197	0.5612		40		298.15	−0.5346	0.0634	−0.1755			54
	308.15	−0.6687	0.6995	−0.4108	0.5353		46		308.15	−0.4005	0.0609	−0.1233			45
	318.15	−0.5551	0.7314	−0.4156	0.5532		51		318.15	−0.3093	0.0486	−0.0460			40
Isoamyl Butyrate (1) + Ethanol (2)															
V^E/cm^3·mol^{-1}	288.15	0.4495	0.0858	0.0928	0.2333		35	$\Delta\eta$/mPa·s	288.15	−0.5750	0.3511	−0.3157	0.2262		12
	298.15	0.5813	0.1206	0.0550	0.1580		34		298.15	−0.4544	0.2484	−0.1972	0.2100		10
	308.15	0.7405	0.1609	0.0230			38		308.15	−0.3558	0.1912	−0.1579	0.1772		13
	318.15	0.9452	0.1778	0.0144			45		318.15	−0.2803	0.1306	−0.1487	0.1803		9.6
Ethyl Phenylacetate (1) + Ethanol (2)															
V^E/cm^3·mol^{-1}	288.15	−0.6758	0.6339	−0.3761	0.5008		21	$\Delta\eta$/mPa·s	288.15	−0.7104	0.0093	−0.6509	0.6749	0.7765	44
	298.15	−0.6138	0.6494	−0.3865	0.4842		22		298.15	−0.5319	0.0767	−0.3503	0.4836	0.4991	45
	308.15	−0.5218	0.6717	−0.4022	0.4607		22		308.15	−0.3524	0.0533	−0.3267	0.5051	0.6775	27
	318.15	−0.4092	0.6978	−0.4214	0.4699		29		318.15	−0.2061	0.0740	−0.1674	0.4137	0.5796	23
Ethyl Caprylate (1) + Ethanol (2)															
V^E/cm^3·mol^{-1}	288.15	0.5023	0.2213	−0.1857	−0.4109		31	$\Delta\eta$/mPa·s	288.15	−0.2909	0.2180	−0.2342	0.2619		28
	298.15	0.6187	0.2079	−0.2005	−0.3585		35		298.15	−0.2218	0.1678	−0.1749	0.1937		17
	308.15	0.7861	0.2241	−0.1862	−0.3426		40		308.15	−0.1605	0.1097	−0.1356	0.1663		13
	318.15	0.9879	0.2455	−0.1881	−0.3505		41		318.15	−0.1025	0.0661	−0.0862	0.8927		7.8

Table 10. Parameters of McAllister's Three-Body and Four-Body Interaction Model and Standard Deviations for Kinematic Viscosities

	three-body			four-body			
T/K	ν_{12}/mm^2·s^{-1}	ν_{21}/mm^2·s^{-1}	$10^3\sigma$/mm^2·s^{-1}	ν_{1112}/mm^2·s^{-1}	ν_{1122}/mm^2·s^{-1}	ν_{2221}/mm^2·s^{-1}	$10^3\sigma$/mm^2·s^{-1}
Isoamyl Acetate (1) + Ethanol (2)							
288.15	1.1113	0.9798	8.8	1.0554	1.0995	1.0608	5.4
298.15	0.9554	0.8531	8.0	0.9081	0.9524	0.9136	5.2
308.15	0.8307	0.7474	6.6	0.7958	0.8264	0.7954	4.7
318.15	0.7299	0.6655	4.5	0.7136	0.7129	0.7092	3.8
Ethyl Caproate (1) + Ethanol (2)							
288.15	1.2607	1.1754	12	1.2218	1.2635	1.2052	5.2
298.15	1.1085	0.9909	6.8	1.0631	1.0890	1.0244	4.6
308.15	0.9594	0.8780	5.5	0.9271	0.9457	0.9007	4.2
318.15	0.8421	0.7822	3.0	0.8284	0.8124	0.8053	2.9
Ethyl Benzoate (1) + Ethanol (2)							
288.15	1.9550	1.6478	9.9	1.9658	1.8672	1.5638	7.0
298.15	1.6063	1.3760	7.9	1.6166	1.5376	1.3103	6.1
308.15	1.3534	1.1679	6.4	1.3616	1.2934	1.1136	5.2
318.15	1.1573	1.0090	4.2	1.1773	1.0873	0.9693	4.1
Isoamyl Butyrate (1) + Ethanol (2)							
288.15	1.4864	1.3710	6.7	1.4411	1.4780	1.3610	2.7
298.15	1.2587	1.1797	3.9	1.2376	1.2340	1.1771	2.6
308.15	1.0857	1.0206	3.4	1.0690	1.0651	1.0123	2.4
318.15	0.9450	0.8921	3.6	0.9289	0.9355	0.8743	2.5
Ethyl Phenylacetate (1) + Ethanol (2)							
288.15	2.4384	1.8817	15	2.4367	2.2448	1.7094	14
298.15	1.9942	1.5456	9.9	2.0124	1.7917	1.4314	9.9
308.15	1.6816	1.3202	8.7	1.7152	1.4774	1.2385	9.2
318.15	1.4486	1.1583	8.3	1.5012	1.2357	1.1006	7.3
Ethyl Caprylate (1) + Ethanol (2)							
288.15	1.8612	1.7426	5.6	1.8419	1.8125	1.6447	4.7
298.15	1.5599	1.4782	3.4	1.5511	1.5167	1.3959	3.0
308.15	1.3259	1.2774	2.9	1.3218	1.2968	1.2005	2.7
318.15	1.1420	1.1321	1.3	1.1532	1.1118	1.0631	1.3

strongly self-associated through hydrogen bonding. The ester molecules studied here do not exhibit this property because they have no groups having that ability. The interactions between ethanol and ethyl benzoate or ethyl phenylacetate lead to

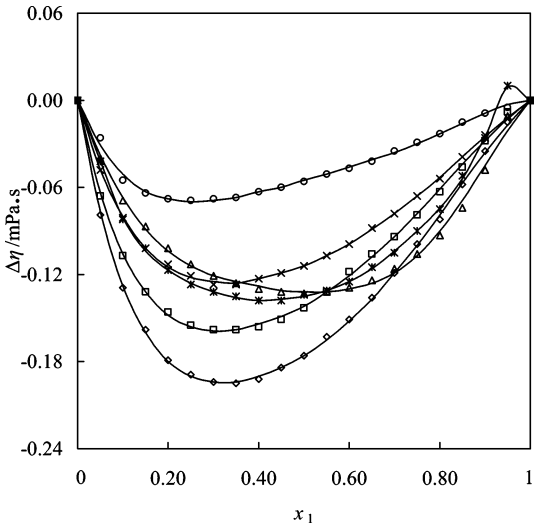

Figure 2. Change of viscosity $\Delta\eta$ with mole fraction x_1 at $T = 298.15$ K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol. Solid curves were calculated from Redlich−Kister equation.

hydrogen bond effects and/or weak dispersion type, giving a negative contribution to V^E. However, the interactions of ethanol with other esters molecules involve mainly dispersion force giving a positive contribution to V^E.

The values of viscosity deviation $\Delta\eta$ increase with a rise in temperature for all of the mixtures. The values of $\Delta\eta$ ($x = 0.5$) vary from −0.223 mPa·s to −0.026 mPa·s. The $\Delta\eta$ values are also graphically represented as a function of mole fraction at $T = 298.15$ K in Figure 2. It is observed that the $\Delta\eta$ values are negative for systems isoamyl acetate + ethanol, ethyl caproate + ethanol, ethyl benzoate + ethanol, isoamyl butyrate + ethanol, and ethyl caprylate + ethanol over the whole composition range. For the ethyl phenylacetate + ethanol system, the values of $\Delta\eta$ are also negative except that some positive values were observed in the low composition region of ethanol. The smallest values of $\Delta\eta$ at $x = 0.5$ were found for the system isoamyl acetate + ethanol.

The mixing functions V^E and $\Delta\eta$ were represented mathematically by the Redlich−Kister equation for correlating the experimental data:[13]

$$Y = x_1(1 - x_1)\sum_{k=0}^{m} a_k(2x_1 - 1)^k \qquad (4)$$

where Y refers to V^E/cm^3·mol^{-1} or $\Delta\eta$/mPa·s, x_1 is the mole fraction of component 1, and a_k are the coefficients. The values of coefficients a_k were determined by a multiple regression analysis based on the least-squares method and are summarized along with the standard deviations between the experimental and fitted values of the respective functions in Table 9. The standard deviation (σ) is defined by

$$\sigma = \left[\sum_{i=1}^{n} \frac{(Y_i^{\text{exptl}} - Y_i^{\text{calcd}})^2}{n - p}\right]^{1/2} \qquad (5)$$

where n is the number of experimental points and p is the number of adjustable parameters. The σ values lie between 0.0014 cm^3·mol^{-1} and 0.0051 cm^3·mol^{-1} and between 0.00072 mPa·s and 0.0045 mPa·s for V^E and $\Delta\eta$, respectively.

McAllister's multibody interaction model[14] is widely used for correlating the kinematic viscosity of binary mixtures with mole fraction. The three-body model is defined as

$$\ln \nu = x_1^3 \ln \nu_1 + 3x_1^2x_2 \ln \nu_{12} + 3x_1x_2^2 \ln \nu_{21} + x_2^3 \ln \nu_2 - \ln\left(x_1 + \frac{x_2M_2}{M_1}\right) + 3x_1^2x_2 \ln\left(\frac{2 + M_2/M_1}{3}\right) + 3x_1x_2^2 \ln\left(\frac{1 + 2M_2/M_1}{3}\right) + x_2^3 \ln\left(\frac{M_2}{M_1}\right) \qquad (6)$$

and the four-body model is given by

$$\ln \nu = x_1^4 \ln \nu_1 + 4x_1^3x_2 \ln \nu_{1112} + 6x_1^2x_2^2 \ln \nu_{1122} + 4x_1x_2^3 \ln \nu_{2221} + x_2^4 \ln \nu_2 - \ln\left(x_1 + \frac{x_2M_2}{M_1}\right) + 4x_1^3x_2 \ln\left(\frac{3 + M_2/M_1}{4}\right) + 6x_1^2x_2^2 \ln\left(\frac{1 + M_2/M_1}{2}\right) + 4x_1x_2^3 \ln\left(\frac{1 + 3M_2/M_1}{4}\right) + x_2^4 \ln\left(\frac{M_2}{M_1}\right) \qquad (7)$$

where ν, ν_1, and ν_2 are the kinematic viscosities of the mixture and the viscosities of pure components 1 and 2, respectively. The ν_{12}, ν_{21}, ν_{1112}, ν_{1122}, and ν_{2221} are the model parameters. Table 10 records the calculated results with the standard deviation (σ) defined as eq 5. It is shown that McAllister's four-body equation generally gave a better result for those three systems. The σ/mm^2·s^{-1} values for the four-body model lie between 0.0024 and 0.014, and the largest value corresponds to ethyl phenylacetate + ethanol system at $T = 288.15$ K.

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