Refractive Indices and Surface Tensions of Binary Mixtures of Isoamyl Acetate, Ethyl Caproate, Ethyl Benzoate, Isoamyl Butyrate, Ethyl Phenylacetate, and Ethyl Caprylate with Ethanol at (288.15, 298.15, 308.15, and 318.15) K

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Refractive indices and surface tensions for six binary mixtures formed by the 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. Refractive indices were measured using a digital Abbe-type refractometer. Surface tensions were determined using the Wilhelmy-plate method. From experimental data, deviations in the refractive index Δn were calculated both on a mole fraction basis and on a volume fraction basis. The deviations in the molar refraction ΔR and the deviations in the surface tension $\Delta\sigma$ were calculated on a mole fraction basis. The binary data of these deviations were correlated as a function of the mole fraction using the Redlich−Kister equation.

Introduction

The thermophysical properties involving flavor esters are of increasing interest due to their wide usage in flavoring, perfumery, artificial essences, and cosmetics. Among these properties, surface tension is a basic property, related to vapor−liquid interfacial effects that must be known to analyze heat and mass transfer of working fluids. Several studies for binary or ternary mixtures on surface tension have been conducted recently, but there are few data in the literature for the mixtures involving such ester compounds.[1,2]

In continuation of our previous work,[3] we report in this paper the measurements of surface tension and refractive index data for the binary mixtures of six flavor esters: isoamyl acetate, ethyl caproate, ethyl benzoate, isoamyl butyrate, ethyl phenylacetate, and ethyl caprylate, respectively, with ethanol at temperatures of (288.15, 298.15, 308.15, and 318.15) K and at atmospheric pressure. From the experimental results, the deviations in the refractive index from the mole fraction average $\Delta_x n_D$ and from the volume fraction average $\Delta_\phi n_D$ have been calculated. The molar refraction deviations ΔR on a mole fraction basis were derived. The deviations in the surface tension from the mole fraction average $\Delta\sigma$ were calculated. To our knowledge, no such data in the literature are available for the binary systems studied here.

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 fraction purities as determined by the major peak areas on gas chromatography together with the sources and Chemical Abstract Service registration numbers (CASRN) of the chemicals are given in Table 1. The purity of solvents was further ascertained by comparing their densities, refractive indices, and surface tensions at a temperature of 298.15 K with the corresponding values reported in the literature as shown in Table 2. Experimental densities were measured with an Anton Paar DMA-5000 vibrating-tube density meter (Anton-Paar, Graz, Austria) with uncertainties of $5\cdot10^{-6}$ g·cm^{-3}, which was thermostatically controlled to within ±0.01 K in all measured variables included.

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 ρ, Refractive Indices n_D, and Surface Tensions σ of Pure Components with Literature Values at 298.15 K

	ρ / g·cm^{-3}		n_D		σ / mN·m^{-1}	
compounds	exptl	lit	exptl	lit	exptl	lit
isoamyl acetate	0.86791	0.86621[4] 0.87601[5] 0.8664[6]	1.39836	1.3981[6]	24.3	24.24[7] [a]
ethyl caproate	0.86629	0.86664[8]	1.40504	1.4077[9] [b]	25.4	25.32[7] [a]
ethyl benzoate	1.04142	1.041[10] 1.0421[11]	1.50328	1.5046[11]	34.6	34.8[12]
isoamyl butyrate	0.85869	0.86204[5]	1.40815	0.8600[7] [a]	24.7	24.92[7] [a]
ethyl phenylacetate	1.02696		1.49513		34.6	
ethyl caprylate	0.86215	0.86219[13]	1.41560	1.4150[13]	26.4	27.03[7] [a]
ethanol	0.78500	0.78493[6] 0.78515[14] 0.78506[15]	1.35941	1.3593[14] 1.3595[15]	22.3	21.68[6] 21.74[14] 21.8[16]

[a] Data obtained from linear interpolation. [b] Data at 20 °C.

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 $\pm3\cdot10^{-5}$ g. Refractive indices (n_D) were measured with a digital Abbe refractometer RX-5000 (ATAGO, Tokyo, Japan),

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10.1021/je0601208 CCC: $30.25
Published on Web 07/29/2006

Table 3. Refractive Indices n_D, Molar Refractions R, and Surface Tensions σ for the System Isoamyl Acetate (1) + Ethanol (2)

		R	σ			R	σ
x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$	x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$
			$T = 288.15$ K				
0.0000	1.36333	12.9183	23.0	0.5500	1.39319	25.7397	24.5
0.0500	1.36803	14.0868	23.2	0.6000	1.39462	26.9034	24.6
0.1000	1.37207	15.2542	23.4	0.6500	1.39595	28.0682	24.7
0.1500	1.37559	16.4217	23.6	0.7000	1.39717	29.2302	24.8
0.2000	1.37870	17.5877	23.7	0.7500	1.39829	30.3917	24.9
0.2500	1.38146	18.7528	23.8	0.8000	1.39933	31.5523	25.0
0.3000	1.38393	19.9188	24.0	0.8500	1.40031	32.7126	25.1
0.3500	1.38614	21.0825	24.1	0.9000	1.40122	33.8709	25.2
0.4000	1.38814	22.2474	24.2	0.9500	1.40207	35.0294	25.3
0.4500	1.38996	23.4110	24.3	1.0000	1.40288	36.1868	25.4
0.5000	1.39164	24.5752	24.4				
			$T = 298.15$ K				
0.0000	1.35941	12.9332	22.3	0.5500	1.38871	25.7716	23.4
0.0500	1.36393	14.1001	22.4	0.6000	1.39013	26.9371	23.5
0.1000	1.36787	15.2687	22.5	0.6500	1.39144	28.1034	23.6
0.1500	1.37133	16.4382	22.7	0.7000	1.39265	29.2666	23.7
0.2000	1.37440	17.6062	22.8	0.7500	1.39378	30.4306	23.8
0.2500	1.37712	18.7736	22.9	0.8000	1.39482	31.5927	23.9
0.3000	1.37954	19.9406	22.0	0.8500	1.39580	32.7550	24.0
0.3500	1.38172	21.1059	23.0	0.9000	1.39670	33.9140	24.1
0.4000	1.38370	22.2730	23.1	0.9500	1.39755	35.0727	24.2
0.4500	1.38550	23.4386	23.2	1.0000	1.39836	36.2328	24.3
0.5000	1.38717	24.6049	23.3				
			$T = 308.15$ K				
0.0000	1.35531	12.9438	21.5	0.5500	1.38404	25.7956	22.5
0.0500	1.35964	14.1088	21.6	0.6000	1.38545	26.9627	22.6
0.1000	1.36349	15.2785	21.6	0.6500	1.38675	28.1299	22.7
0.1500	1.36690	16.4500	21.7	0.7000	1.38795	29.2940	22.8
0.2000	1.36992	17.6199	21.8	0.7500	1.38907	30.4588	22.9
0.2500	1.37260	18.7887	21.9	0.8000	1.39011	31.6221	23.0
0.3000	1.37499	19.9578	22.0	0.8500	1.39109	32.7850	23.1
0.3500	1.37714	21.1248	22.1	0.9000	1.39199	33.9443	23.2
0.4000	1.37909	22.2934	22.2	0.9500	1.39284	35.1033	23.3
0.4500	1.38087	23.4602	22.3	1.0000	1.39365	36.2644	23.4
0.5000	1.38251	24.6275	22.4				
			$T = 318.15$ K				
0.0000	1.35148	12.9662	20.6	0.5500	1.37944	25.8277	21.5
0.0500	1.35556	14.1276	20.6	0.6000	1.38082	26.9950	21.6
0.1000	1.35930	15.2983	20.6	0.6500	1.38211	28.1634	21.7
0.1500	1.36263	16.4716	20.7	0.7000	1.38330	29.3286	21.8
0.2000	1.36558	17.6428	20.8	0.7500	1.38440	30.4934	21.9
0.2500	1.36821	18.8135	20.9	0.8000	1.38543	31.6569	22.0
0.3000	1.37056	19.9842	21.0	0.8500	1.38640	32.8201	22.1
0.3500	1.37268	21.1534	21.1	0.9000	1.38730	33.9790	22.2
0.4000	1.37460	22.3234	21.2	0.9500	1.38814	35.1379	22.3
0.4500	1.37634	23.4914	21.3	1.0000	1.38895	36.2989	22.4
0.5000	1.37795	24.6594	21.4				

Table 4. Refractive Indices n_D, Molar Refractions R, and Surface Tensions σ for the System Ethyl Caproate (1) + Ethanol (2)

		R	σ			R	σ
x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$	x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$
			$T = 288.15$ K				
0.0000	1.36333	12.9183	23.0	0.5500	1.39910	28.2622	25.5
0.0500	1.36942	14.3180	23.4	0.60000	1.40066	29.6550	25.6
0.1000	1.37451	15.7173	23.8	0.6500	1.40210	31.0476	25.7
0.1500	1.37883	17.1144	24.1	0.7000	1.40343	32.4395	25.8
0.2000	1.38253	18.5080	24.3	0.7500	1.40466	33.8310	25.9
0.2500	1.38577	19.9019	24.5	0.8000	1.40579	35.2216	26.0
0.3000	1.38864	21.2967	24.7	0.8500	1.40684	36.6111	26.1
0.3500	1.39119	22.6900	24.9	0.9000	1.40780	37.9985	26.2
0.4000	1.39347	24.0838	25.1	0.9500	1.40868	39.3809	26.3
0.4500	1.39553	25.4771	25.2	1.0000	1.40950	40.7632	26.4
0.5000	1.39740	26.8701	25.4				
			$T = 298.15$ K				
0.0000	1.35941	12.9332	22.3	0.5500	1.39465	28.2934	24.5
0.0500	1.36535	14.3324	22.7	0.6000	1.39620	29.6876	24.6
0.1000	1.37034	15.7327	23.0	0.6500	1.39763	31.0817	24.7
0.1500	1.37461	17.1324	23.2	0.7000	1.39895	32.4743	24.9
0.2000	1.37826	18.5274	23.5	0.7500	1.40019	33.8687	25.0
0.2500	1.38146	19.9233	23.7	0.8000	1.40133	35.2610	25.1
0.3000	1.38429	21.3193	23.9	0.8500	1.40238	36.6514	25.1
0.3500	1.38681	22.7143	24.0	0.9000	1.40334	38.0400	25.2
0.4000	1.38907	24.1102	24.2	0.9500	1.40422	39.4226	25.3
0.4500	1.39111	25.5045	24.3	1.0000	1.40504	40.8075	25.4
0.5000	1.39296	26.8991	24.4				
			$T = 308.15$ K				
0.0000	1.35531	12.9438	21.5	0.5500	1.39016	28.3248	23.6
0.0500	1.36109	14.3419	21.8	0.6000	1.39170	29.7205	23.7
0.1000	1.36602	15.7443	22.1	0.6500	1.39312	31.1157	23.8
0.1500	1.37024	17.1461	22.4	0.7000	1.39444	32.5101	23.9
0.2000	1.37388	18.5444	22.6	0.7500	1.39568	33.9059	24.0
0.2500	1.37706	19.9430	22.8	0.8000	1.39682	35.2991	24.1
0.3000	1.37986	21.3408	23.0	0.8500	1.39787	36.6908	24.2
0.3500	1.38236	22.7377	23.1	0.9000	1.39882	38.0784	24.3
0.4000	1.38460	24.1355	23.3	0.9500	1.39972	39.4634	24.4
0.4500	1.38663	25.5319	23.4	1.0000	1.40055	40.8502	24.5
0.5000	1.38847	26.9286	23.5				
			$T = 318.15$ K				
0.0000	1.35148	12.9662	20.6	0.5500	1.38564	28.3578	22.7
0.0500	1.35703	14.3615	20.9	0.6000	1.38716	29.7545	22.8
0.1000	1.36185	15.7649	21.2	0.6500	1.38857	31.1508	22.9
0.1500	1.36601	17.1692	21.5	0.7000	1.38988	32.5454	23.0
0.2000	1.36960	18.5696	21.7	0.7500	1.39111	33.9418	23.1
0.2500	1.37274	19.9701	21.9	0.8000	1.39225	35.3359	23.2
0.3000	1.37550	21.3697	22.0	0.8500	1.39330	36.7279	23.3
0.3500	1.37795	22.7672	22.2	0.9000	1.39426	38.1162	23.4
0.4000	1.38016	24.1664	22.3	0.9500	1.39515	39.4999	23.5
0.4500	1.38216	25.5635	22.5	1.0000	1.39597	40.8857	23.6
0.5000	1.38398	26.9613	22.6				

which works at the wavelength (589 nm) corresponding to the D-line of sodium. The temperature was controlled to ±0.05 K with circulating thermostat water to a jacketed sample vessel. Calibration was performed periodically under atmospheric pressure using double-distilled water. The uncertainty of the refractive index measurement was estimated to be less than ±0.00002 units.

Surface tensions (σ) were measured with an automatic surface tension meter Model CBVP-A3 (Kyowa, Japan), which works with the Wilhelmy-plate method. The platinum plate was thoroughly cleaned and flame-dried before each measurement. Calibration was performed periodically under atmospheric pressure, in accordance with specifications, using two 200 mg calibration masses. All liquids were thermostatically controlled to within ±0.05 K with circulating thermostat water to a jacketed sample vessel. The uncertainty of the surface tension measurement was estimated to be within ±0.2 $mN \cdot m^{-1}$.

The refractive indexes and surface tensions of the binary mixtures were measured at temperatures of (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 ester was prepared for each binary system. The uncertainty in the liquid composition was estimated to be $\pm 1 \cdot 10^{-4}$. All measurements described above were performed at least three times at atmospheric pressure (100.5 ± 0.3) kPa, and an average of at least three measurements was calculated for each temperature.

Results and Discussion

Tables 3 to 8 list the experimental results at T = (288.15, 298.15, 308.15, and 318.15) K for refractive indices n_D, molar fractions R, and surface tensions σ for the six binary systems in terms of the ester mole fraction. The equation of the molar refraction is defined as

$$R = V\left(\frac{n_D^2 - 1}{n_D^2 + 1}\right) \quad (1)$$

Table 5. Refractive Indices n_D, Molar Refractions R, and Surface Tensions σ for the System Ethyl Benzoate (1) + Ethanol (2)

		R	σ			R	σ
x_1	n_D	cm^3·mol^{-1}	mN·m^{-1}	x_1	n_D	cm^3·mol^{-1}	mN·m^{-1}
			$T = 288.15$ K				
0.0000	1.36333	12.9183	23.0	0.5500	1.47305	29.3291	30.2
0.0500	1.38111	14.4413	23.9	0.6000	1.47816	30.8093	30.7
0.1000	1.39597	15.9459	24.7	0.6500	1.48283	32.2833	31.2
0.1500	1.40895	17.4461	25.5	0.7000	1.48715	33.7577	31.8
0.2000	1.42035	18.9410	26.2	0.7500	1.49115	35.2285	32.3
0.2500	1.43037	20.4292	26.9	0.8000	1.49488	36.7018	32.9
0.3000	1.43936	21.9174	27.5	0.8500	1.49840	38.1727	33.6
0.3500	1.44743	23.4024	28.1	0.9000	1.50170	39.6462	34.3
0.4000	1.45479	24.8877	28.7	0.9500	1.50477	41.1148	35.0
0.4500	1.46145	26.3702	29.2	1.0000	1.50760	42.5757	35.7
0.5000	1.46750	27.8505	29.7				
			$T = 298.15$ K				
0.0000	1.35941	12.9332	22.3	0.5500	1.46865	29.3761	29.2
0.0500	1.37682	14.4502	23.1	0.6000	1.47372	30.8553	29.7
0.1000	1.39165	15.9593	23.9	0.6500	1.47840	32.3338	30.2
0.1500	1.40452	17.4604	24.6	0.7000	1.48273	33.8116	30.8
0.2000	1.41593	18.9601	25.3	0.7500	1.48675	35.2859	31.3
0.2500	1.42598	20.4542	26.0	0.8000	1.49047	36.7610	31.9
0.3000	1.43498	21.9470	26.6	0.8500	1.49401	38.2355	32.5
0.3500	1.44303	23.4348	27.2	0.9000	1.49731	39.7106	33.2
0.4000	1.45038	24.9235	27.7	0.9500	1.50037	41.1801	33.9
0.4500	1.45702	26.4086	28.3	1.0000	1.50328	42.6492	34.6
0.5000	1.46309	27.8935	28.7				
			$T = 308.15$ K				
0.0000	1.35531	12.9438	21.5	0.5500	1.46393	29.4073	28.1
0.0500	1.37237	14.4552	22.2	0.6000	1.46901	30.8899	28.6
0.1000	1.38717	15.9688	23.0	0.6500	1.47368	32.3698	29.1
0.1500	1.39997	17.4721	23.7	0.7000	1.47801	33.8498	29.6
0.2000	1.41131	18.9736	24.4	0.7500	1.48203	35.3253	30.1
0.2500	1.42135	20.4712	25.0	0.8000	1.48578	36.8041	30.6
0.3000	1.43033	21.9667	25.6	0.8500	1.48929	38.2774	31.2
0.3500	1.43840	23.4588	26.1	0.9000	1.49257	39.7525	31.9
0.4000	1.44571	24.9491	26.7	0.9500	1.49565	41.2233	32.6
0.4500	1.45236	26.4377	27.2	1.0000	1.49863	42.6987	33.3
0.5000	1.45841	27.9242	27.7				
			$T = 318.15$ K				
0.0000	1.35148	12.9662	20.6	0.5500	1.45918	29.4399	27.3
0.0500	1.36815	14.4707	21.3	0.6000	1.46424	30.9234	27.8
0.1000	1.38279	15.9844	22.1	0.6500	1.46890	32.4043	28.3
0.1500	1.39551	17.4901	22.8	0.7000	1.47321	33.8850	28.8
0.2000	1.40679	18.9939	23.5	0.7500	1.47724	35.3625	29.3
0.2500	1.41678	20.4938	24.1	0.8000	1.48098	36.8417	29.8
0.3000	1.42576	21.9932	24.7	0.8500	1.48449	38.3155	30.4
0.3500	1.43378	23.4867	25.3	0.9000	1.48776	39.7899	31.0
0.4000	1.44105	24.9782	25.8	0.9500	1.49086	41.2620	31.8
0.4500	1.44765	26.4673	26.3	1.0000	1.49391	42.7423	32.5
0.5000	1.45369	27.9561	26.8				

Table 6. Refractive Indices n_D, Molar Refractions R, and Surface Tensions σ for the System Isoamyl Butyrate (1) + Ethanol (2)

		R	σ			R	σ
x_1	n_D	cm^3·mol^{-1}	mN·m^{-1}	x_1	n_D	cm^3·mol^{-1}	mN·m^{-1}
			$T = 288.15$ K				
0.0000	1.36333	12.9183	23.0	0.5500	1.40240	30.8376	24.8
0.0500	1.37030	14.5478	23.3	0.6000	1.40399	32.4641	24.9
0.1000	1.37602	16.1815	23.6	0.6500	1.40543	34.0901	25.0
0.1500	1.38080	17.8104	23.8	0.7000	1.40673	35.7148	25.1
0.2000	1.38488	19.4394	24.0	0.7500	1.40793	37.3386	25.2
0.2500	1.38839	21.0672	24.1	0.8000	1.40902	38.9607	25.3
0.3000	1.39145	22.6947	24.3	0.8500	1.41003	40.5830	25.4
0.3500	1.39415	24.3244	24.4	0.9000	1.41096	42.2028	25.5
0.4000	1.39656	25.9524	24.5	0.9500	1.41181	43.8194	25.6
0.4500	1.39871	27.5810	24.6	1.0000	1.41259	45.4308	25.7
0.5000	1.40065	29.2089	24.7				
			$T = 298.15$ K				
0.0000	1.35941	12.9332	22.3	0.5500	1.39798	30.8697	23.9
0.0500	1.36624	14.5627	22.6	0.6000	1.39956	32.4976	23.9
0.1000	1.37182	16.1956	22.8	0.6500	1.40100	34.1254	24.0
0.1500	1.37656	17.8272	23.0	0.7000	1.40230	35.7522	24.1
0.2000	1.38059	19.4579	23.1	0.7500	1.40349	37.3764	24.2
0.2500	1.38406	21.0876	23.3	0.8000	1.40458	39.0000	24.3
0.3000	1.38709	22.7168	23.4	0.8500	1.40559	40.6223	24.4
0.3500	1.38977	24.3474	23.5	0.9000	1.40652	42.2431	24.5
0.4000	1.39216	25.9779	23.6	0.9500	1.40737	43.8599	24.6
0.4500	1.39431	27.6090	23.7	1.0000	1.40815	45.4734	24.7
0.5000	1.39624	29.2388	23.8				
			$T = 308.15$ K				
0.0000	1.35531	12.9438	21.5	0.5500	1.39354	30.9028	23.1
0.0500	1.36195	14.5714	21.8	0.6000	1.39513	32.5337	23.2
0.1000	1.36747	16.2062	22.0	0.6500	1.39656	34.1625	23.3
0.1500	1.37218	17.8406	22.2	0.7000	1.39786	35.7907	23.4
0.2000	1.37620	19.4744	22.4	0.7500	1.39905	37.4165	23.5
0.2500	1.37967	21.1076	22.5	0.8000	1.40015	39.0417	23.6
0.3000	1.38268	22.7388	22.6	0.8500	1.40116	40.6651	23.7
0.3500	1.38535	24.3720	22.7	0.9000	1.40210	42.2872	23.8
0.4000	1.38773	26.0045	22.8	0.9500	1.40296	43.9049	23.9
0.4500	1.38987	27.6379	22.9	1.0000	1.40374	45.5208	24.0
0.5000	1.39180	29.2703	23.0				
			$T = 318.15$ K				
0.0000	1.35148	12.9662	20.6	0.5500	1.38910	30.9402	22.2
0.0500	1.35780	14.5878	20.9	0.6000	1.39067	32.5708	22.3
0.1000	1.36327	16.2257	21.1	0.6500	1.39210	34.2015	22.4
0.1500	1.36792	17.8624	21.3	0.7000	1.39340	35.8311	22.5
0.2000	1.37190	19.4986	21.5	0.7500	1.39459	37.4578	22.6
0.2500	1.37533	21.1336	21.6	0.8000	1.39569	39.0837	22.7
0.3000	1.37832	22.7673	21.7	0.8500	1.39670	40.7077	22.8
0.3500	1.38096	24.4020	21.8	0.9000	1.39763	42.3289	22.9
0.4000	1.38332	26.0363	21.9	0.9500	1.39849	43.9458	23.0
0.4500	1.38544	27.6713	22.0	1.0000	1.39927	45.5617	23.1
0.5000	1.38736	29.3052	22.1				

The molar volume V of the mixture was calculated from the following equation

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

where M_i is the molecular weight of component i. ρ is the mixture density and was obtained from the previous study.[3] The values of surface tension and refractive index decrease systematically from 288.15 K to 318.15 K through the whole range of mole fractions, while the values of molar refractions show no significant changes with temperature.

The deviation in the refractive index $\Delta_x n_D$ and the deviation in the surface tension $\Delta\sigma$ from mole fraction average were calculated from the experimental data according to the following equations

$$\Delta_x n_D = n_D - \sum_{i=1}^{2} x_i n_{Di} \tag{3}$$

$$\Delta\sigma = \sigma - \sum_{i=1}^{2} x_i \sigma_i \tag{4}$$

where n_D and n_{Di} are the refractive index of the mixture and the refractive index of the pure component i, respectively. σ and σ_i are the surface tension of the mixture and the surface tension of the pure component i, respectively. The deviation in the molar refraction ΔR was calculated on a mole fraction basis as suggested by Brocos et al.[17]

$$\Delta R = R - \sum_{i=1}^{2} x_i R_i \tag{5}$$

where R and R_i are the molar fraction of the mixture and the molar fraction of pure component i, respectively.

Table 7. Refractive Indices n_D, Molar Refractions R, and Surface Tensions σ for the System Ethyl Phenylacetate (1) + Ethanol (2)

		R	σ			R	σ
x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$	x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$
			$T = 288.15$ K				
0.0000	1.36333	12.9183	23.0	0.5500	1.46909	31.5068	30.3
0.0500	1.38109	14.6248	23.9	0.6000	1.47365	33.1841	31.0
0.1000	1.39604	16.3255	24.6	0.6500	1.47785	34.8617	31.6
0.1500	1.40870	18.0178	25.2	0.7000	1.48174	36.5405	32.2
0.2000	1.41969	19.7067	25.9	0.7500	1.48536	38.2194	32.8
0.2500	1.42932	21.3943	26.5	0.8000	1.48865	39.8943	33.5
0.3000	1.43790	23.0842	27.2	0.8500	1.49170	41.5670	34.1
0.3500	1.44556	24.7739	27.8	0.9000	1.49461	43.2442	34.7
0.4000	1.45242	26.4615	28.4	0.9500	1.49730	44.9176	35.3
0.4500	1.45856	28.1450	29.1	1.0000	1.49971	46.5773	35.9
0.5000	1.46406	29.8256	29.7				
			$T = 298.15$ K				
0.0000	1.35941	12.9333	22.3	0.5500	1.46454	31.5471	29.1
0.0500	1.37693	14.6384	23.1	0.6000	1.46908	33.2261	29.7
0.1000	1.39180	16.3422	23.7	0.6500	1.47324	34.9047	30.3
0.1500	1.40441	18.0380	24.3	0.7000	1.47713	36.5857	30.9
0.2000	1.41536	19.7304	24.9	0.7500	1.48072	38.2657	31.6
0.2500	1.42491	21.4190	25.5	0.8000	1.48403	39.9432	32.1
0.3000	1.43347	23.1126	26.1	0.8500	1.48707	41.6178	32.8
0.3500	1.44111	24.8057	26.7	0.9000	1.48996	43.2947	33.4
0.4000	1.44792	26.4946	27.3	0.9500	1.49266	44.9709	33.9
0.4500	1.45402	28.1797	27.9	1.0000	1.49513	46.6376	34.6
0.5000	1.45953	29.8645	28.5				
			$T = 308.15$ K				
0.0000	1.35531	12.9438	21.5	0.5500	1.45999	31.5898	28.0
0.0500	1.37265	14.6494	22.2	0.6000	1.46451	33.2705	28.6
0.1000	1.38745	16.3566	22.8	0.6500	1.46869	34.9528	29.2
0.1500	1.40003	18.0564	23.4	0.7000	1.47255	36.6343	29.8
0.2000	1.41093	19.7519	23.9	0.7500	1.47613	38.3155	30.4
0.2500	1.42047	21.4449	24.5	0.8000	1.47943	39.9942	31.0
0.3000	1.42899	23.1409	25.1	0.8500	1.48248	41.6717	31.6
0.3500	1.43661	24.8371	25.7	0.9000	1.48539	43.3515	32.2
0.4000	1.44342	26.5298	26.2	0.9500	1.48810	45.0292	32.8
0.4500	1.44951	28.2179	26.8	1.0000	1.49063	46.7029	33.5
0.5000	1.45500	29.9049	27.4				
			$T = 318.15$ K				
0.0000	1.35148	12.9662	20.6	0.5500	1.45524	31.6225	27.2
0.0500	1.36852	14.6683	21.2	0.6000	1.45975	33.3050	27.8
0.1000	1.38323	16.3784	21.8	0.6500	1.46391	34.9880	28.4
0.1500	1.39573	18.0814	22.4	0.7000	1.46775	36.6698	29.0
0.2000	1.40653	19.7776	22.9	0.7500	1.47132	38.3518	29.5
0.2500	1.41597	21.4709	23.5	0.8000	1.47458	40.0290	30.1
0.3000	1.42447	23.1703	24.1	0.8500	1.47763	41.7060	30.7
0.3500	1.43203	24.8674	24.7	0.9000	1.48053	43.3857	31.4
0.4000	1.43878	26.5605	25.4	0.9500	1.48323	45.0633	32.0
0.4500	1.44484	28.2500	26.0	1.0000	1.48583	46.7426	32.8
0.5000	1.45030	29.9383	26.6				

Table 8. Refractive Indices n_D, Molar Refractions R, and Surface Tensions σ for the System Ethyl Caprylate (1) + Ethanol (2)

		R	σ			R	σ
x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$	x_1	n_D	$cm^3 \cdot mol^{-1}$	$mN \cdot m^{-1}$
			$T = 288.15$ K				
0.0000	1.36333	12.9183	23.0	0.5500	1.40882	33.3775	26.2
0.0500	1.37185	14.7808	23.6	0.6000	1.41053	35.2336	26.3
0.1000	1.37876	16.6450	24.0	0.6500	1.41208	37.0895	26.5
0.1500	1.38444	18.5062	24.4	0.7000	1.41350	38.9447	26.6
0.2000	1.38922	20.3664	24.8	0.7500	1.41480	40.7966	26.7
0.2500	1.39327	22.2265	25.1	0.8000	1.41599	42.6478	26.8
0.3000	1.39676	24.0862	25.3	0.8500	1.41709	44.4996	26.9
0.3500	1.39979	25.9456	25.5	0.9000	1.41810	46.3506	27.0
0.4000	1.40245	27.8036	25.7	0.9500	1.41904	48.1993	27.1
0.4500	1.40481	29.6618	25.9	1.0000	1.41991	50.0544	27.2
0.5000	1.40692	31.5199	26.1				
			$T = 298.15$ K				
0.0000	1.35941	12.9332	22.3	0.5500	1.40451	33.4114	25.4
0.0500	1.36779	14.7951	22.9	0.6000	1.40621	35.2688	25.6
0.1000	1.37462	16.6608	23.3	0.6500	1.40776	37.1258	25.7
0.1500	1.38028	18.5255	23.7	0.7000	1.40917	38.9821	25.8
0.2000	1.38502	20.3870	24.0	0.7500	1.41047	40.8343	25.9
0.2500	1.38905	22.2499	24.3	0.8000	1.41166	42.6877	26.0
0.3000	1.39252	24.1116	24.5	0.8500	1.41276	44.5416	26.1
0.3500	1.39553	25.9730	24.8	0.9000	1.41378	46.3942	26.2
0.4000	1.39818	27.8334	24.9	0.9500	1.41472	48.2438	26.3
0.4500	1.40053	29.6930	25.1	1.0000	1.41560	50.1004	26.4
0.5000	1.40263	31.5531	25.3				
			$T = 308.15$ K				
0.0000	1.35531	12.9438	21.5	0.5500	1.40023	33.4504	24.5
0.0500	1.36356	14.8055	22.0	0.6000	1.40193	35.3102	24.7
0.1000	1.37036	16.6743	22.5	0.6500	1.40348	37.1687	24.8
0.1500	1.37601	18.5424	22.8	0.7000	1.40489	39.0261	24.9
0.2000	1.38074	20.4068	23.2	0.7500	1.40619	40.8799	25.0
0.2500	1.38477	22.2730	23.4	0.8000	1.40739	42.7353	25.1
0.3000	1.38823	24.1374	23.7	0.8500	1.40850	44.5916	25.2
0.3500	1.39125	26.0019	23.9	0.9000	1.40952	46.4450	25.3
0.4000	1.39389	27.8645	24.1	0.9500	1.41047	48.2952	25.4
0.4500	1.39624	29.7265	24.2	1.0000	1.41137	50.1540	25.5
0.5000	1.39835	31.5901	24.4				
			$T = 318.15$ K				
0.0000	1.35148	12.9662	20.6	0.5500	1.39591	33.4900	23.7
0.0500	1.35953	14.8260	21.1	0.6000	1.39760	35.3505	23.8
0.1000	1.36625	16.6969	21.6	0.6500	1.39914	37.2100	24.0
0.1500	1.37184	18.5670	21.9	0.7000	1.40054	39.0673	24.1
0.2000	1.37654	20.4340	22.3	0.7500	1.40183	40.9216	24.2
0.2500	1.38054	22.3025	22.6	0.8000	1.40302	42.7764	24.3
0.3000	1.38398	24.1691	22.8	0.8500	1.40412	44.6313	24.4
0.3500	1.38698	26.0358	23.0	0.9000	1.40515	46.48450	24.5
0.4000	1.38961	27.9006	23.2	0.9500	1.40611	48.3359	24.6
0.4500	1.39195	29.7643	23.4	1.0000	1.40702	50.1954	24.7
0.5000	1.39403	31.6281	23.5				

The volume fraction ϕ_i of component i of a mixture is defined by

$$\phi_i = \frac{x_i V}{\sum_{j=1}^{2} x_j V_j} \tag{6}$$

where V and V_j are the molar volume of the mixture and the molar volume of the pure component j, respectively. The deviation in the refractive index $\Delta_\phi n_D$ from the volume fraction average was calculated from the experimental data according to the following equations

$$\Delta_\phi n_D = n_D - \sum_{i=1}^{2} \phi_i n_{Di} \tag{7}$$

To fit data, the Redlich−Kister equation[18] of the following form was used

$$Y = x_1 x_2 \sum_{k=0}^{m} a_k (x_1 - x_2)^k \tag{8}$$

where x is the ester mole fraction and Y refers to either $\Delta_x n_D$, $\Delta_\phi n_D$, $\Delta R/cm^3 \cdot mol^{-1}$, or $\Delta\sigma/mN \cdot m^{-1}$. The values of coefficients a_k were determined by a nonlinear regression analysis based on the least-squares method and are summarized along with the standard deviations of these fits in Table 9. The standard deviation (δ) is defined by

$$\delta = \left[\sum_{i=1}^{n} \frac{(Y_i^{exptl} - Y_i^{calcd})^2}{n - p} \right]^{1/2} \tag{9}$$

Table 9. Coefficients and Standard Deviations δ of $\Delta_x n_D$, $\Delta_\phi n_D$, ΔR, and $\Delta\sigma$ 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	a_5	$\delta\cdot10^4$
				Isoamyl Acetate (1) + Ethanol (2)				
$\Delta_x n_D$	288.15	0.03384	−0.01419	0.00888	−0.00519			1.12
	298.15	0.03291	−0.01318	0.01490	0.00464			1.85
	308.15	0.03215	−0.01378	0.00742	−0.00215	−0.00166		0.10
	318.15	0.03095	−0.01336	0.00699	−0.00063	−0.00296		0.12
$\Delta_\phi n_D$	288.15	−0.00041	0.00033	0.00057	−0.00056			0.10
	298.15	−0.00095	0.00069	0.00102	0.00018	−0.00190		0.08
	308.15	−0.00142	0.00084	0.00109	0.00119	−0.00317		0.11
	318.15	−0.00187	0.00096	0.00084	0.00254	−0.00446		0.15
ΔR/cm^3·mol^{-1}	288.15	0.09420	0.03191	0.03994	−0.03050			6.20
	298.15	0.08796	0.04495	0.09049	−0.01381	−0.12788		5.03
	308.15	0.09524	0.05368	0.08460	0.00500	−0.15456		6.33
	318.15	0.10723	0.05632	0.08991	0.06900	−0.23872		7.77
$\Delta\sigma$/mN·m^{-1}	288.15	0.45111	−0.31345	0.12900	−0.79861	1.20178		53.8
	298.15	0.01266	−0.04704	−0.38263	0.67654	1.17951	−1.70164	37.0
	308.15	−0.18703	0.12547	−0.55478	1.07098	0.72700	−1.57397	47.4
	318.15	−0.38966	0.40876	−0.62988	0.51681			33.2
				Ethyl Caproate (1) + Ethanol (2)				
$\Delta_x n_D$	288.15	0.04394	−0.02076	0.01100	−0.00696	0.00411		0.10
	298.15	0.04293	−0.02033	0.01098	−0.00625	0.00332		0.12
	308.15	0.04214	−0.02003	0.01101	−0.00536	0.00179		0.10
	318.15	0.04096	−0.01969	0.01113	−0.00379			0.11
$\Delta_\phi n_D$	288.15	−0.00032	0.00022	0.00165	−0.00106			0.11
	298.15	−0.00078	0.00044	0.00134	−0.00041			0.09
	308.15	−0.00118	0.00055	0.00134	0.00040	−0.00127		0.09
	318.15	−0.00162	0.00047	0.00156	0.00204	−0.00280		0.15
ΔR/cm^3·mol^{-1}	288.15	0.11483	0.03178	0.10486				6.59
	298.15	0.11417	0.04148	0.09308				9.58
	308.15	0.12699	0.03994	0.06269	0.03709			11.9
	318.15	0.13707	0.03764	0.14316	0.10510	−0.17537		11.0
$\Delta\sigma$/mN·m^{-1}	288.15	2.47764	−1.90377	0.85328	0.05690	0.43251		39.6
	298.15	2.16931	−1.80638	0.77538	0.08821	0.42357		34.5
	308.15	2.02131	−1.73155	0.91882				26.3
	318.15	1.97276	−1.73155	0.85703				61.9
				Ethyl Benzoate (1) + Ethanol (2)				
$\Delta_x n_D$	288.15	0.12823	−0.05612	0.02294	−0.01804	0.01463		0.38
	298.15	0.12700	−0.05571	0.02291	−0.01549	0.01038		0.27
	308.15	0.12571	−0.05516	0.02283	−0.01381	0.00680		0.19
	318.15	0.12380	−0.05461	0.02418	−0.01159			0.28
$\Delta_\phi n_D$	288.15	0.00636	−0.00485	0.00139	−0.00742	0.00997		0.33
	298.15	0.00559	−0.00516	0.00473	−0.00428			0.57
	308.15	0.00515	−0.00463	0.00155	−0.00348	0.00237		0.16
	318.15	0.00440	−0.00467	0.00086	−0.00130			0.24
ΔR/cm^3·mol^{-1}	288.15	0.41779	−0.11979	0.01014	−0.12218	0.30846		12.4
	298.15	0.40843	−0.11925	0.02086	−0.05984	0.13223		8.12
	308.15	0.40919	−0.10836	0.02209	−0.04024			10.7
	318.15	0.40071	−0.10854	0.05448	0.01892	−0.21507		13.3
$\Delta\sigma$/mN·m^{-1}	288.15	2.28621	−3.57438	−1.40988	−4.01779	3.08992	5.56058	93.4
	298.15	1.64256	−3.40470	−0.98967	−4.28467	1.09094	5.50462	78.4
	308.15	1.23204	−3.29476	−0.76888	−4.31770	−0.61115	5.51757	141.8
	318.15	1.03325	−3.36996	−0.75734	−4.05326	−1.94113	5.05729	146.4
				Isoamyl Butyrate (1) + Ethanol (2)				
$\Delta_x n_D$	288.15	0.05077	−0.02474	0.01300	−0.00979	0.00572		0.09
	298.15	0.04986	−0.02396	0.01217	−0.00996	0.00512		0.39
	308.15	0.04909	−0.02368	0.01251	−0.00793	0.00350		0.08
	318.15	0.04790	−0.02249	0.01283	−0.01010	0.00054	0.00527	0.09
$\Delta_\phi n_D$	288.15	−0.00020	0.00137	0.00013	−0.00105			0.08
	298.15	−0.00057	0.00177	−0.00043	−0.00058			0.12
	308.15	−0.00093	0.00190	−0.00125	0.00079			0.18
	318.15	−0.00146	0.00213	−0.00004	0.00257	−0.00411		0.30
ΔR/cm^3·mol^{-1}	288.15	0.13883	0.10643	0.03706	−0.16765	0.06288	0.21365	6.07
	298.15	0.14250	0.13421	0.04200	−0.19029	0.00954	0.22793	4.78
	308.15	0.15150	0.14744	0.04626	−0.21253	−0.06667	0.29692	5.94
	318.15	0.16356	0.17445	0.07921	−0.22743	−0.18942	0.39695	11.6
$\Delta\sigma$/mN·m^{-1}	288.15	1.40303	−1.43060	1.34843	−0.69479			36.7
	298.15	1.06118	−1.13238	1.21290	−0.73059			52.9
	308.15	1.03615	−1.06733	1.29256	−0.85184			43.1
	318.15	0.97710	−1.02749	1.22291	−0.79935			68.7

Table 9 (Continued)

Y	T/K	a_0	a_1	a_2	a_3	a_4	a_5	$\delta \cdot 10^4$
				Ethyl Phenylacetate (1) + Ethanol (2)				
$\Delta_x n_D$	288.15	0.13025	−0.06212	0.02559	−0.00957	0.01616	−0.01115	0.28
	298.15	0.12906	−0.06146	0.02560	−0.01097	0.01373	−0.00847	0.32
	308.15	0.12812	−0.06038	0.02507	−0.01683	0.01236		0.40
	318.15	0.12652	−0.05977	0.02521	−0.01631	0.00957		0.50
$\Delta_\phi n_D$	288.15	0.00374	−0.00263	−0.00115	−0.00325	0.00868		0.38
	298.15	0.00337	−0.00269	−0.00093	−0.00261	0.00638		0.35
	308.15	0.00301	−0.00288	−0.00138	−0.00213	0.00526		0.35
	318.15	0.00248	−0.00296	0.00054	−0.00162			0.50
ΔR/cm^3·mol^{-1}	288.15	0.31528	−0.05673	−0.10927	0.02234	0.39728		17.1
	298.15	0.31514	−0.06250	−0.10365	0.01158	0.28363		17.7
	308.15	0.32503	−0.07281	−0.13054	0.00157	0.22431		16.6
	318.15	0.32897	−0.07655	−0.06499				21.8
$\Delta\sigma$/mN·m^{-1}	288.15	1.01160	−0.75958	0.26447	1.30428	2.27879	−4.25214	132.3
	298.15	0.23154	−0.12920	0.78931	−1.95543			144.5
	308.15	−0.26715	0.03999	−0.16987	−2.18170			121.2
	318.15	−0.57368	0.07444	−1.25362	−2.39765			130.2
				Ethyl Caprylate (1) + Ethanol (2)				
$\Delta_x n_D$	288.15	0.06122	−0.03346	0.01828	−0.00947	0.00670	−0.00378	0.06
	298.15	0.06049	−0.03295	0.01796	−0.00993	0.00590	−0.00231	0.03
	308.15	0.06000	−0.03259	0.01785	−0.01074	0.00465		0.07
	318.15	0.05912	−0.03212	0.01734	−0.00980	0.00338		0.08
$\Delta_\phi n_D$	288.15	−0.00058	0.00032	−0.00014	0.00052			0.08
	298.15	−0.00088	0.00030	0.00013	0.00128	−0.00150		0.09
	308.15	−0.00118	0.00039	0.00011	0.00198	−0.00278		0.15
	318.15	−0.00145	0.00046	−0.00010	0.00285	−0.00403		0.21
ΔR/cm^3·mol^{-1}	288.15	0.13401	0.03493	0.03346	−0.09497	−0.09597		6.32
	298.15	0.14299	0.02289	0.00599	−0.05130	−0.09574		8.92
	308.15	0.16074	0.02761	−0.00388	−0.02980	−0.12600		12.9
	318.15	0.18711	0.03527	−0.01814	−0.01441	−0.19003		12.4
$\Delta\sigma$/mN·m^{-1}	288.15	3.87051	−2.19294	1.16288	−0.82642	0.52225		27.6
	298.15	3.72614	−2.07023	0.94213	−0.82452	0.52666		57.1
	308.15	3.58066	−2.03152	1.10774	−0.73883			34.8
	318.15	3.59324	−2.02934	1.05296	−0.66499			58.9

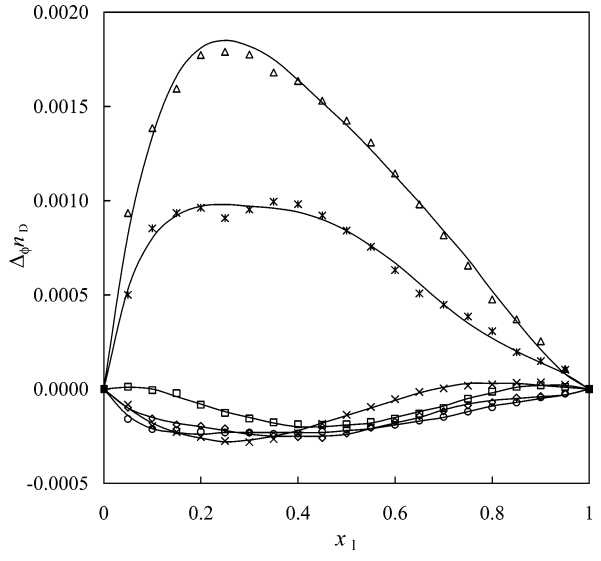

Figure 1. Change of surface tensions $\Delta_\phi n_D$ with mole fraction x_1 at T = 298.15 K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol. Solid curves were calculated from the Redlich−Kister equation.

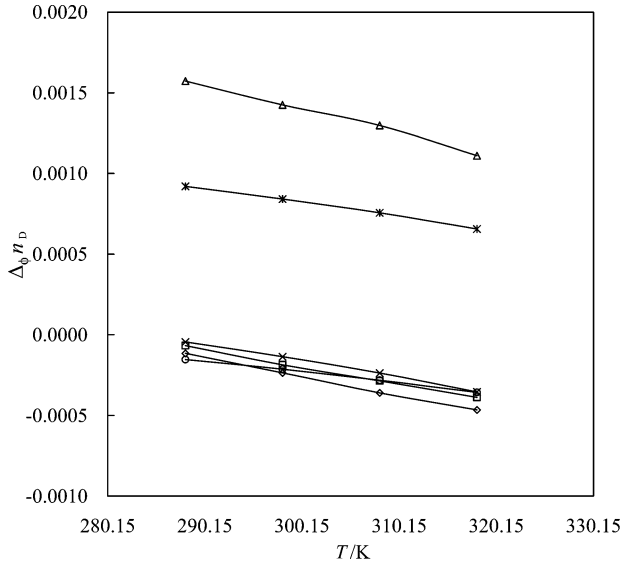

Figure 2. Variation of refractive indices $\Delta_\phi n_D$ at x = 0.5 from T = 288.15 K to T = 318.15 K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol.

where n is the number of experimental points and p is the number of adjustable parameters.

For the whole composition range, the $\Delta_\phi n_D$ values are positive for the mixtures of ethyl benzoate + ethanol and ethyl phenylacetate + ethanol, while the negative values were found for the mixtures of isoamyl acetate + ethanol and ethyl caprylate + ethanol. The $\Delta_\phi n_D$ values are negative for the mixtures ethyl caproate + ethanol and isoamyl butyrate + ethanol over the whole composition range except that some positive values were found at the temperatures of 288.15 K and 298.15 K. Figure 1 shows the results of $\Delta_\phi n_D$ for the six binary systems at T = 298.15 K. The values of $\Delta_\phi n_D(x = 0.5)$ at 298.15 K show the

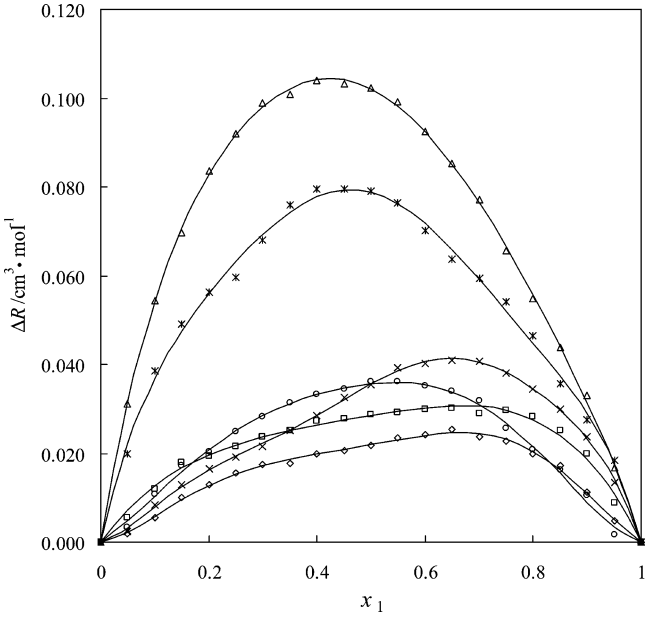

Figure 3. Change of ΔR with mole fraction x_1 at $T = 298.15$ K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol. Solid curves were calculated from the Redlich−Kister equation.

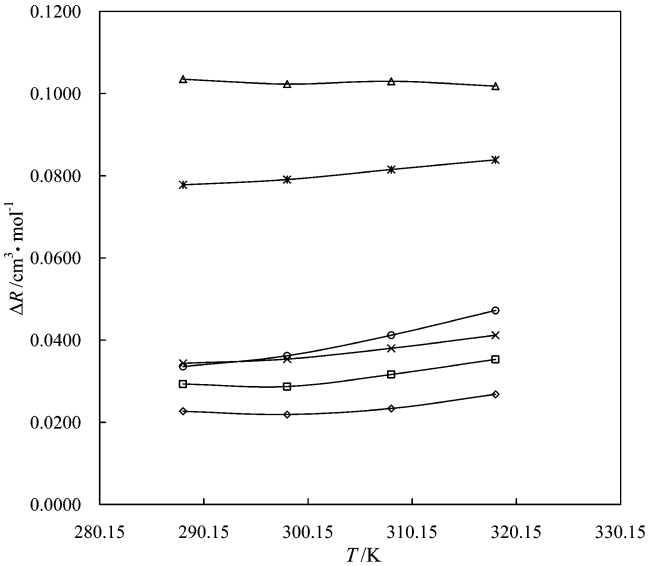

Figure 4. Variation of refractive indices ΔR at $x = 0.5$ from $T = 288.15$ K to $T = 318.15$ K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol.

order as ethyl benzoate + ethanol > ethyl phenylacetate + ethanol > isoamyl butyrate + ethanol > ethyl caproate + ethanol > ethyl caprylate + ethanol > isoamyl acetate + ethanol. Figure 2 plots the values of $\Delta_\phi n_D(x = 0.5)$ from $T = 288.15$ K to $T = 318.15$ K for all of the systems. The values of $\Delta_\phi n_D(x = 0.5)$ decrease systematically with a rise in temperature. The values of $\Delta_\phi n_D(x = 0.5)$ vary from −0.00047 to 0.00159.

The values of molar refraction deviation ΔR are positive for all of the systems. The ΔR values are graphically represented as a function of mole fraction at 298.15 K in Figure 3. The values of $\Delta R(x = 0.5)$ at 298.15 K show the order as ethyl benzoate + ethanol > ethyl phenylacetate + ethanol > ethyl caprylate + ethanol > isoamyl butyrate + ethanol > ethyl caproate + ethanol > isoamyl acetate + ethanol. Figure 4 plots the values of $\Delta R(x = 0.5)$ from $T = 288.15$ K to $T = 318.15$

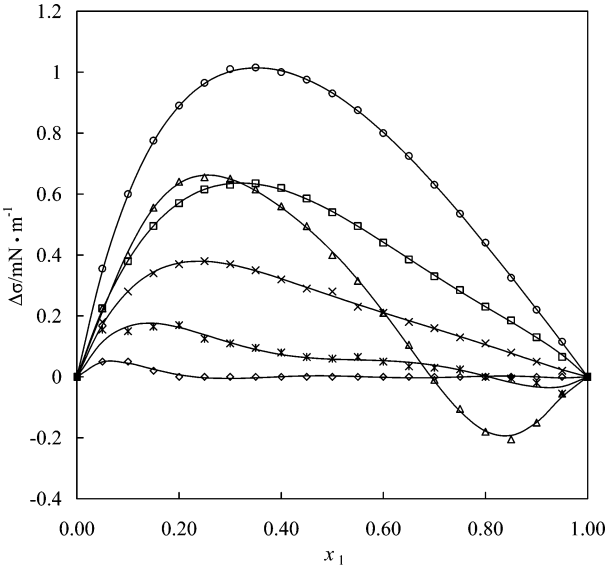

Figure 5. Change of surface tensions $\Delta\sigma$ with mole fraction x_1 at $T = 298.15$ K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol. Solid curves were calculated from the Redlich−Kister equation.

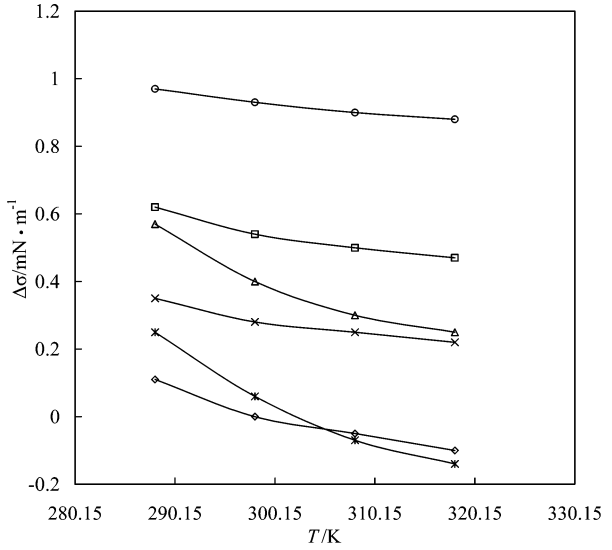

Figure 6. Variation of refractive indices $\Delta\sigma$ at $x = 0.5$ from $T = 288.15$ K to $T = 318.15$ K: ◇, isoamyl acetate + ethanol; □, ethyl caproate + ethanol; △, ethyl benzoate + ethanol; ×, isoamyl butyrate + ethanol; *, ethyl phenylacetate + ethanol; ○, ethyl caprylate + ethanol.

K for all of the systems. The values of $\Delta R(x = 0.5)$ show no clear temperature dependence. The values of $\Delta R(x = 0.5)$ vary from 0.0219 $cm^3 \cdot mol^{-1}$ to 0.1035 $cm^3 \cdot mol^{-1}$.

The values of surface tension deviation $\Delta\sigma$ are graphically represented as a function of mole fraction at 298.15 K in Figure 5. The values of $\Delta\sigma$ are positive for all of the systems except for some negative values that were found for the mixtures of ethyl benzoate + ethanol and ethyl phenylacetate + ethanol in the region of higher ester concentrations. The values of $\Delta\sigma(x = 0.5)$ at 298.15 K show the order as isoamyl acetate + ethanol < ethyl phenylacetate + ethanol < isoamyl butyrate + ethanol < ethyl benzoate + ethanol < ethyl caproate + ethanol < ethyl caprylate + ethanol. Figure 6 plots the values of $\Delta\sigma(x = 0.5)$ from $T = 288.15$ K to $T = 318.15$ K for all of the systems. The values of $\Delta\sigma$ decrease with increasing temperature for all of the mixtures. The values of $\Delta\sigma(x = 0.5)$ vary from −0.14 $mN \cdot m^{-1}$ to 0.97 $mN \cdot m^{-1}$.

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Received for review March 14, 2006. Accepted June 26, 2006. The authors wish to extend their deep gratitude for the support by the National Science Council of Republic of China under Grant NSC 93-2214-E-126-001.

JE0601208