Density, Viscosity, Refractive Index, and Speed of Sound in Binary Mixtures of Ethenylbenzene with *N*,*N*-Dimethylacetamide, Tetrahydrofuran, *N*,*N*-Dimethylformamide, 1,4-Dioxane, Dimethyl Sulfoxide, Chloroform, Bromoform, and 1-Chloronaphthalene in the Temperature Interval (298.15−308.15) K

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Density, viscosity, and refractive index at 298.15, 303.15, and 308.15 K and speed of sound at 298.15 K in the binary mixtures of etheny1benzene with *N*,*N*-dimethylacetamide, tetrahydrofuran, *N*,*N*-dimethylformamide, 1,4-dioxane, dimethyl sulfoxide, chloroform, bromoform, and 1-chloronaphthalene are presented. Using these results, excess molar volume, V^E, deviations in viscosity, $\Delta\eta$, molar refraction, ΔR, speed of sound, Δu, and isentropic compressiblity, Δk_S, have been calculated. These quantities are fitted to Redlich−Kister type equation to estimate the binary coefficients and standard errors between the experimental and fitted quantities.

Introduction

In the literature of liquid-state chemistry, binary mixtures containing ethenylbenzene (styrene) have attracted considerable interest in view of the widely varying type of molecular interactions with liquids (Aminabhavi and Patil, 1997; Haijun et al., 1994a,b; Haijun et al., 1995a,b,c; Miller, 1975). In continuation of this research and as a part of our ongoing program of study toward the accumulation of binary mixture physical property data, we now present experimental results on density, ρ, viscosity, η, and refractive index, n_D at 298.15, 303.15, and 308.15 K and speed of sound, u, at 298.15 K for the binary mixtures of ethenylbenzene with *N*,*N*-dimethylacetamide (DMAc), tetrahydrofuran (THF), *N*,*N*-dimethylformamide (DMF), 1,4-dioxane, dimethyl sulfoxide (DMSO), chloroform, bromoform, and 1-chloronaphthalene (1-CNP). Using these data, excess molar volume, V^E, deviations in viscosity, $\Delta\eta$, molar refracton, ΔR, speed of sound, Δu, and isentropic compressibility, Δk_S, have been calculated. These results are fitted to Redlich−Kister type equation (1948) to estimate the binary coefficients and standard errors between the data derived from experiments and those of the computed values.

Experimental Section

Materials and Methods. High-purity spectral grade samples of ethenylbenzene, THF, DMF, DMAc, chloroform, and bromoform were purchased from s.d. fine Chemicals Ltd., Mumbai, India. 1-Chloronaphthalene was purchased from Fluka, Germany; DMSO was purchased from Sisco Research Laboratories, Mumbai. 1,4-Dioxane was procured from E. Merck, Germany. The GLC analyses of these liquids indicated a mol % purity of 99.7, 99.2, 99.2, 99.1, 99.4, 99.3, 99.7, 99.3, and 99.2, respectively. The analyses were performed at 353.15 K on a gas chromatograph, HP Series 6890, using a flame ionization detector with fused silica columns, having a sensitivity better than 10^{-8} g of fatty acid/μL of the solvent. All the samples were used without further purification. Experimental values of ρ and n_D of the pure liquids are compared in Table 1 at 298.15 K with the published results.

Table 1. Comparison of Experimental Densities (ρ) and Refractive Indices (n_D) of Pure Liquids with Literature Values at 298.15 K

	ρ/g·cm^{-3}		n_D	
liquid (mol % purity)	exptl	lit.	exptl	lit.
ethenylbenzene (99.7)	0.9016	0.9015[a]	1.5440	1.5440[b]
DMAc (99.1)	0.9367	0.9363[b]	1.4363	1.4356[b]
DMSO (99.3)	1.0957	1.0954[b]	1.4767	1.4775[b]
DMF (99.2)	0.9445	0.9439[b]	1.4289	1.4282[b]
THF (99.2)	0.8833	0.8892[d]	1.4050	1.4050[d]
1,4-dioxane (99.2)	1.0286	1.0280[c]	1.4194	1.4203[c]
chloroform (99.4)	1.4788	1.4797[b]	1.4432	1.4430[b]
bromoform (99.3)	2.8788	2.8779[b]	1.5948	1.5956[b]
1- chloronaphthalene (99.7)	1.1880	1.1878[e]		

[a] Haijun, et al., 1995a. [b] Riddick, et al., 1986. [c] Suri and Naorem, 1987. [d] Ramkumar and Kudchadkar, 1989. [e] Wilhelm et al., 1986.

Preparations of the binary mixtures, mass, density, refractive index, speed of sound, and viscosity measurements of the pure liquids and their binary mixtures have been described previously (Aralaguppi et al., 1991). The mass measurements (±0.01 mg) were made using an electronic balance (Mettler AE 240, Switzerland) and the reproducibility in mole fraction was within ±0.0001 units.

Densities of pure liquids and their mixtures were measured using a pycnometer having a bulb volume of 15 cm^3 and a capillary bore with an internal diameter of 1 mm. Density values are accurate to ±0.0002 g·cm^{-3}. Viscosities have been measured using a Cannon Fenske Viscometer (size 75, Industrial Research Glassware, Ltd., Roselle, NJ). An electronic digital stopwatch with a readability of ±0.01 s was used for the flow time measurements. The measured viscosity values are accurate to ±0.001 mPa·s. Calibrations of the pycnometer and the viscometer are the same

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S0021-9568(98)00031-4 CCC: $15.00
Published on Web 06/16/1998

Table 2. Experimental Densities (ρ), Viscosities (η), Refractive Indices (n_D), and Speeds of Sound (u) of Binary Mixtures at Different Temperatures

x_1	density/ g·cm^{-3}	viscosity/ mPa·s	refractive index	speed of sound/ m/s	x_1	density/ g·cm^{-3}	viscosity/ mPa·s	refractive index	speed of sound/ m/s	x_1	density/ g·cm^{-3}	viscosity/ mPa·s	refractive index	speed of sound/ m/s
Ethenylbenzene (1) + DMSO (2)														
298.15 K														
0.0000	1.0957	1.848	1.4767	1490	0.3987	0.9995	1.237	1.5156	1445	0.8010	0.9311	0.887	1.5380	1407
0.1017	1.0670	1.642	1.4888	1478	0.5010	0.9801	1.139	1.5220	1434	0.8960	0.9170	0.802	1.5411	1399
0.2022	1.0419	1.475	1.4985	1467	0.6007	0.9626	1.058	1.5281	1425	1.0000	0.9016	0.708	1.5440	1390
0.3096	1.0177	1.326	1.5084	1455	0.6968	0.9471	0.982	1.5333	1416					
303.15 K														
0.0000	1.0907	1.662	1.4747		0.3987	0.9945	1.112	1.5126		0.8010	0.9266	0.827	1.5347	
0.1017	1.0621	1.482	1.4863		0.5010	0.9754	1.044	1.5184		0.8960	0.9125	0.749	1.5381	
0.2022	1.0371	1.343	1.4960		0.6007	0.9580	0.976	1.5240		1.0000	0.8971	0.663	1.5414	
0.3096	1.0129	1.191	1.5057		0.6968	0.9425	0.910	1.5309						
308.15 K														
0.0000	1.0858	1.498	1.4727		0.3987	0.9900	1.014	1.5096		0.8010	0.9220	0.763	1.5315	
0.1017	1.0573	1.335	1.4839		0.5010	0.9708	0.957	1.5167		0.8960	0.9079	0.700	1.5351	
0.2022	1.0323	1.204	1.4935		0.6007	0.9533	0.899	1.5213		1.0000	0.8926	0.623	1.5385	
0.3096	1.0081	1.083	1.5030		0.6968	0.9379	0.837	1.5278						
Ethenylbenzene (1) + DMF (2)														
298.15 K														
0.0000	0.9445	0.816	1.4289	1486	0.3998	0.9281	0.858	1.4886	1439	0.8049	0.9116	0.825	1.5289	1405
0.1090	0.9399	0.831	1.4479	1472	0.5052	0.9240	0.860	1.5011	1428	0.8976	0.9076	0.794	1.5375	1398
0.2013	0.9361	0.845	1.4616	1461	0.6012	0.9201	0.856	1.5107	1420	1.0000	0.9016	0.708	1.5440	1390
0.2959	0.9323	0.854	1.4752	1450	0.6979	0.9161	0.847	1.5206	1413					
303.15 K														
0.0000	0.9397	0.766	1.4267		0.3998	0.9235	0.804	1.4863		0.8049	0.9070	0.768	1.5262	
0.1090	0.9352	0.780	1.4455		0.5052	0.9193	0.802	1.4981		0.8976	0.9030	0.735	1.5345	
0.2013	0.9314	0.790	1.4594		0.6012	0.9155	0.798	1.5076		1.0000	0.8971	0.663	1.5414	
0.2959	0.9276	0.801	1.4726		0.6979	0.9116	0.790	1.5127						
308.15 K														
0.0000	0.9349	0.722	1.4245		0.3998	0.9189	0.750	1.4840		0.8049	0.9025	0.717	1.5235	
0.1090	0.9304	0.732	1.4430		0.5052	0.9147	0.749	1.4958		0.8976	0.8985	0.685	1.5316	
0.2013	0.9267	0.742	1.4561		0.6012	0.9109	0.746	1.5045		1.0000	0.8926	0.623	1.5385	
0.2959	0.9229	0.749	1.4699		0.6979	0.9070	0.739	1.5150						
Ethenylbenzene (1) + DMAc (2)														
298.15 K														
0.0000	0.9367	0.937	1.4363	1468	0.4002	0.9258	0.929	1.4879	1454	0.8005	0.9115	0.851	1.5284	1418
0.1090	0.9341	0.938	1.4505	1466	0.5004	0.9227	0.921	1.4987	1448	0.9015	0.9071	0.808	1.5369	1406
0.1994	0.9316	0.936	1.4630	1463	0.6012	0.9193	0.903	1.5090	1439	1.0000	0.9016	0.708	1.5440	1390
0.2958	0.9289	0.937	1.4752	1459	0.7027	0.9155	0.881	1.5192	1428					
303.15 K														
0.0000	0.9321	0.878	1.4346		0.4002	0.9213	0.863	1.4851		0.8005	0.9071	0.795	1.5253	
0.1090	0.9297	0.874	1.4481		0.5004	0.9182	0.857	1.4960		0.9015	0.9028	0.753	1.5338	
0.1994	0.9271	0.873	1.4605		0.6012	0.9148	0.841	1.5063		1.0000	0.8971	0.663	1.5414	
0.2958	0.9243	0.872	1.4725		0.7027	0.9111	0.821	1.5164						
308.15 K														
0.0000	0.9275	0.823	1.4319		0.4002	0.9168	0.807	1.4825		0.8005	0.9026	0.742	1.5223	
0.1090	0.9253	0.817	1.4458		0.5004	0.9137	0.800	1.4933		0.9015	0.8984	0.700	1.5308	
0.1994	0.9226	0.818	1.4581		0.6012	0.9103	0.785	1.5036		1.0000	0.8926	0.623	1.5385	
0.2958	0.9198	0.815	1.4699		0.7027	0.9066	0.766	1.5137						
Ethenylbenzene (1) + THF (2)														
298.15 K														
0.0000	0.8833	0.472	1.4053	1294	0.4010	0.8976	0.632	1.4778	1342	0.8017	0.9024	0.742	1.5258	1376
0.1011	0.8884	0.514	1.4263	1310	0.4963	0.8995	0.664	1.4911	1352	0.8979	0.9028	0.747	1.5352	1384
0.1990	0.8918	0.535	1.4441	1324	0.6002	0.9009	0.695	1.5035	1358	1.0000	0.9016	0.708	1.5440	1390
0.3001	0.8953	0.595	1.4624	1336	0.6993	0.9019	0.721	1.5149	1366					
303.15 K														
0.0000	0.8779	0.450	1.4028		0.4010	0.8926	0.599	1.4748		0.8017	0.8978	0.695	1.5230	
0.1011	0.8831	0.490	1.4228		0.4963	0.8946	0.625	1.4876		0.8979	0.8982	0.699	1.5322	
0.1990	0.8867	0.528	1.4411		0.6002	0.8961	0.658	1.5005		1.0000	0.8971	0.663	1.5414	
0.3001	0.8901	0.562	1.4593		0.6993	0.8972	0.677	1.5119						
308.15 K														
0.0000	0.8724	0.429	1.4004		0.4010	0.8876	0.564	1.4718		0.8017	0.8933	0.652	1.5202	
0.1011	0.8778	0.463	1.4192		0.4963	0.8897	0.589	1.4841		0.8979	0.8936	0.651	1.5291	
0.1990	0.8815	0.498	1.4381		0.6002	0.8913	0.616	1.4978		1.0000	0.8926	0.623	1.5385	
0.3001	0.8850	0.532	1.4561		0.6993	0.8925	0.637	1.5189						

Table 2 (Continued)

x_1	density/ g·cm^{-3}	viscosity/ mPa·s	refrac-tive index	speed of sound/ m/s	x_1	density/ g·cm^{-3}	viscosity/ mPa·s	refrac-tive index	speed of sound/ m/s	x_1	density/ g·cm^{-3}	viscosity/ mPa·s	refrac-tive index	speed of sound/ m/s
Ethenylbenzene (1) + 1,4-Dioxane (2)														
298.15 K														
0.0000	1.0282	1.178	1.4210	1358	0.3996	0.9695	1.005	1.4804	1369	0.8050	0.9226	0.853	1.5250	1380
0.1012	1.0119	1.119	1.4369	1362	0.5054	0.9563	0.966	1.4937	1371	0.9021	0.9123	0.819	1.5350	1385
0.2139	0.9950	1.069	1.4548	1366	0.6016	0.9448	0.929	1.5050	1373	1.0000	0.9016	0.708	1.5440	1390
0.2989	0.9830	1.043	1.4661	1368	0.7019	0.9336	0.891	1.5157	1376					
303.15 K														
0.0000	1.0225	1.086	1.4180		0.3996	0.9644	0.929	1.4779		0.8050	0.9179	0.795	1.5226	
0.1012	1.0063	1.034	1.4345		0.5054	0.9513	0.893	1.4909		0.9021	0.9078	0.766	1.5324	
0.2139	0.9896	0.987	1.4524		0.6016	0.9400	0.873	1.5025		1.0000	0.8971	0.663	1.5414	
0.2989	0.9777	0.959	1.4637		0.7019	0.9289	0.829	1.5129						
308.15 K														
0.0000	1.0168	0.999	1.4156		0.3996	0.9593	0.862	1.4755		0.8050	0.9133	0.744	1.5203	
0.1012	1.0008	0.957	1.4323		0.5054	0.9463	0.830	1.4885		0.9021	0.9032	0.716	1.5297	
0.2139	0.9843	0.915	1.4500		0.6016	0.9351	0.802	1.4999		1.0000	0.8926	0.623	1.5385	
0.2989	0.9725	0.889	1.4613		0.7019	0.9241	0.774	1.5103						
Ethenylbenzene (1) + Chloroform (2)														
298.15 K														
0.0000	1.4788	0.5565	1.4432	1018	0.4022	1.1968	0.6615	1.4939	1136	0.7962	0.9906	0.7443	1.5272	1297
0.1010	1.3992	0.5838	1.4581	1036	0.5055	1.1372	0.6849	1.5038	1178	0.9000	0.9444	0.7286	1.5350	1342
0.2004	1.3271	0.6109	1.4698	1064	0.5997	1.0865	0.7054	1.5118	1216	1.0000	0.9016	0.7082	1.5440	1390
0.3009	1.2598	0.6357	1.4824	1098	0.7050	1.0335	0.7267	1.5210	1259					
303.15 K														
0.0000	1.4692	0.5344	1.4399		0.4022	1.1899	0.6280	1.4911		0.7962	0.9854	0.6993	1.5250	
0.1010	1.3904	0.5575	1.4555		0.5055	1.1311	0.6463	1.5010		0.9000	0.9378	0.6841	1.5341	
0.2004	1.3190	0.5816	1.4676		0.5997	1.0806	0.6686	1.5091		1.0000	0.8971	0.6627	1.5414	
0.3009	1.2523	0.6033	1.4797		0.7050	1.0280	0.6832	1.5183						
308.15 K														
0.0000	1.4594	0.5133	1.4369		0.4022	1.1830	0.5915	1.4884		0.7962	0.9803	0.6581	1.5228	
0.1010	1.3816	0.5324	1.4529		0.5055	1.1245	0.6109	1.4982		0.9000	0.9349	0.6521	1.5333	
0.2004	1.3110	0.5513	1.4650		0.5997	1.0747	0.6272	1.5065		1.0000	0.8926	0.6231	1.5385	
0.3009	1.2448	0.5742	1.4770		0.7050	1.0226	0.6447	1.5157						
Ethenylbenzene (1) + Bromoform (2)														
298.15 K														
0.0000	2.8788	1.9767	1.5948	928	0.3985	1.9597	1.4262	1.5709	1037	0.7712	1.2671	0.9849	1.5536	1216
0.1005	2.6258	1.8342	1.5882	948	0.5060	1.7455	1.2838	1.5655	1075	0.8948	1.0648	0.8704	1.5489	1296
0.2006	2.3890	1.6973	1.5821	977	0.6032	1.5624	1.1635	1.5608	1122	1.0000	0.9016	0.7082	1.5440	1390
0.2981	2.1713	1.5615	1.5761	1004	0.7008	1.3879	1.0537	1.5562	1172					
303.15 K														
0.0000	2.8659	1.8566	1.5917		0.3985	1.9503	1.3318	1.5678		0.7712	1.2609	0.9179	1.5506	
0.1005	2.6137	1.7136	1.5851		0.5060	1.7370	1.1981	1.5626		0.8948	1.0595	0.8129	1.5460	
0.2006	2.3779	1.5865	1.5788		0.6032	1.5548	1.0839	1.5578		1.0000	0.8971	0.6627	1.5414	
0.2981	2.1610	1.4616	1.5730		0.7008	1.3810	0.9817	1.5532						
308.15 K														
0.0000	2.8530	1.7333	1.5886		0.3985	1.9409	1.2399	1.5647		0.7712	1.2546	0.8595	1.5476	
0.1005	2.6018	1.6026	1.5820		0.5060	1.7286	1.1165	1.5596		0.8948	1.0542	0.7620	1.5432	
0.2006	2.3668	1.4806	1.5756		0.6032	1.5471	1.0104	1.5548		1.0000	0.8926	0.6231	1.5385	
0.2981	2.1508	1.3607	1.5700		0.7008	1.3741	0.9176	1.5502						
Ethenylbenzene (1) + 1-CNP (2)														
298.15 K														
0.0000	1.1880	2.8060		1462	0.4032	1.0855	1.5495		1436	0.7992	0.9688	0.9675		1400
0.1076	1.1621	2.3565		1458	0.5003	1.0585	1.3789		1424	0.9033	0.9348	0.8331		1396
0.2005	1.1388	2.0704		1454	0.6015	1.0293	1.2161		1413	1.0000	0.9016	0.7082		1390
0.3010	1.1129	1.7785		1446	0.6840	1.0047	1.1076		1406					
303.15 K														
0.0000	1.1839	2.4873			0.4032	1.0812	1.4116			0.7992	0.9645	0.9100		
0.1076	1.1580	2.1030			0.5003	1.0542	1.2586			0.9033	0.9310	0.8013		
0.2005	1.1346	1.8637			0.6015	1.0250	1.1155			1.0000	0.8971	0.6627		
0.3010	1.1087	1.6172			0.6840	1.0004	1.0129							
308.15 K														
0.0000	1.1798	2.2138			0.4032	1.0770	1.2834			0.7992	0.9603	0.8446		
0.1076	1.1537	1.8840			0.5003	1.0499	1.1523			0.9033	0.9264	0.7413		
0.2005	1.1304	1.6769			0.6015	1.0206	1.0360			1.0000	0.8926	0.6231		
0.3010	1.1044	1.4695			0.6840	0.9960	0.9455							

as described earlier (Aminabhavi and Bindu, 1995; Aminabhavi et al., 1994).

Refractive indices for the sodium D line were measured with a thermostatically controlled Abbe refractometer

Table 3. Redlich−Kister Coefficients and Standard Deviation

function	temp/K	A_0	A_1	A_2	σ	function	temp/K	A_0	A_1	A_2	σ
					Ethenylbenzene (1) + DMSO (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−1.740	1.096	−0.617	0.012	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	−7.456	−1.872	−0.543	0.012
	303.15	−1.750	1.149	−0.712	0.010		303.15	−7.616	−2.065	−0.604	0.031
	308.15	−1.794	1.141	−0.645	0.012		308.15	−7.624	−2.030	−0.827	0.026
$\Delta\eta$/(mPa·s)	298.15	−0.546	−0.514	−0.136	0.005	Δu/(m·s^{-1})	298.15	−21.840	0.020	9.940	0.302
	303.15	−0.488	−0.508	−0.022	0.008	Δk_s/(TPa^{-1})	298.15	−64.390	−16.520	−13.150	0.383
	308.15	−0.429	−0.483	−0.111	0.008						
					Ethenylbenzene (1) + DMF (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−2.207	0.964	−0.813	0.021	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	−6.441	−1.525	−0.519	0.022
	303.15	−2.231	0.977	−0.870	0.021		303.15	−6.519	−2.058	−1.276	0.076
	308.15	−2.238	0.985	−0.878	0.021		308.15	−6.492	−1.532	−0.837	0.030
$\Delta\eta$/(mPa·s)	298.15	0.387	−0.250	0.228	0.005	Δu/(m·s^{-1})	298.15	−36.2	−9.2	16.7	0.331
	303.15	0.354	−0.210	0.161	0.003	Δk_S/(TPa^{-1})	298.15	−23.7	−9.0	−20.3	0.467
	308.15	0.310	−0.188	0.140	0.002						
					Ethenylbenzene (1) + DMAc (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−2.431	0.915	−0.648	0.011	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	-2.516	-0.299	-0.444	0.015
	303.15	−2.464	0.976	−0.868	0.015		303.15	−2.628	−0.314	−0.800	0.013
	308.15	−2.491	0.978	−1.117	0.019		308.15	−2.599	−0.395	−0.807	0.013
$\Delta\eta$/(mPa·s)	298.15	0.381	−0.278	0.229	0.006	Δu/(m·s^{-1})	298.15	73.2	−12.1	3.6	0.537
	303.15	0.334	−0.273	0.208	0.005	Δk_S/(TPa^{-1})	298.15	−83.4	−34.6	−16.2	0.507
	308.15	0.300	−0.233	0.157	0.004						
					Ethenylbenzene (1) + THF (2)						
$V^E/10^{-6}$ (m^3.mol^{-1})	298.15	−2.373	0.223	−0.781	0.021	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	−5.008	−1.056	−0.720	0.013
	303.15	−2.400	0.281	−0.816	0.019		303.15	−5.092	−1.006	−0.986	0.012
	308.15	−2.435	0.270	−0.895	0.017		308.15	−5.135	−0.816	−1.262	0.024
$\Delta\eta$/(mPa·s)	298.15	0.295	−0.232	0.211	0.004	Δu/(m·s^{-1})	298.15	26.2	−0.5	3.7	0.322
	303.15	0.283	−0.208	0.185	0.004	Δk_S/(TPa^{-1})	298.15	−19.7	5.2	6.8	0.395
	308.15	0.260	−0.186	0.133	0.002						
					Ethenylbenzene (1) +1,4-Dioxane (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−0.567	0.706	−0.729	0.012	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	−3.960	−0.660	−0.928	0.028
	303.15	−0.593	0.732	−0.748	0.015		303.15	−3.911	−0.757	−0.804	0.030
	308.15	−0.584	0.734	−0.821	0.015		308.15	−3.874	−0.746	−0.595	0.023
$\Delta\eta$/(mPa·s)	298.15	0.088	−0.326	0.233	0.012	Δu/(m·s^{-1})	298.15	12.4	25.4	11.6	0.379
	303.15	0.081	−0.329	0.215	0.010	Δk_S/(TPa^{-1})	298.15	4.4	20.5	−1.5	0.425
	308.15	0.070	−0.273	0.258	0.009						
					Ethenylbenzene (1) + Chloroform (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−0.398	0.553	−0.674	0.020	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	−5.048	−1.444	−1.368	0.042
	303.15	−0.549	0.209	−0.561	0.062		303.15	−5.076	−1.437	−0.362	0.037
	308.15	−0.426	0.560	−0.828	0.019		308.15	−5.014	−1.368	−0.007	0.041
$\Delta\eta$/(mPa·s)	298.15	0.204	−0.205	0.195	0.003	Δu/(m·s^{-1})	298.15	−114.0	−61.6	−81.8	0.323
	303.15	0.196	−0.185	0.125	0.004	Δk_S/(TPa^{-1})	298.15	129.4	−69.9	54.1	0.756
	308.15	0.166	−0.192	0.166	0.003						
					Ethenylbenzene (1) + Bromoform (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−0.420	0.532	−0.423	0.006	$\Delta R/10^{-6}$ (m^3·mol^{-1})	298.15	−1.957	−0.334	0.057	0.012
	303.15	−0.400	0.544	−0.436	0.007		303.15	−1.364	−0.562	−1.955	0.156
	308.15	−0.363	0.531	−0.402	0.007		308.15	−1.993	−0.349	−0.061	0.016
$\Delta\eta$/(mPa·s)	298.15	−0.217	−0.104	0.382	0.011	Δu/(m·s^{-1})	298.15	−333.6	107.2	−41.3	2.550
	303.15	0.286	−1.830	0.949	0.343	Δk_s/(TPa^{-1})	298.15	−32.7	−9.9	−8.6	2.174
	308.15	−0.234	−0.104	0.336	0.010						
					Ethenylbenzene (1) + 1-CNP (2)						
$V^E/10^{-6}$ (m^3·mol^{-1})	298.15	−0.809	0.440	−0.226	0.005						
	303.15	−0.823	0.654	−0.805	0.026						
	308.15	−0.879	0.705	−0.735	0.020	Δu/(m·s^{-1})	298.15	−7.0	61.3	29.8	1.477
$\Delta\eta$/(mPa·s)	298.15	−1.525	−0.848	−0.039	0.008	Δk_S/(TPa^{-1})	298.15	−39.4	29.1	−28.6	0.890
	303.15	−1.283	−0.746	0.185	0.012						
	308.15	−1.062	−0.651	0.124	0.009						

(Bellingham and Stanley Ltd., London) with an accuracy of ± 0.0001. The samples were injected using medicine dropper into the orifice provided in the refractometer prism case. The measurements were made quickly before any possible preferential evaporation losses of liquid components.

The speed of sound values have been measured using a variable-path single-crystal interferometer (Mittal Enterprises, model M-84, New Delhi). Interferometer was calibrated using water and benzene. The speed of sound values are accurate to ±2 m·s^{-1} and were measured in a cell having a fixed frequency of 4 kHz. From the results of speed of sound, the isentropic compressibility, k_S, values have been calculated as $k_S = 1/u^2\rho$.

In all the property measurements, an INSREF, model 016 AP thermostat was used at a constant digital temperature display accurate up to ±0.01 K. The results of ρ, η, n_D, and u compiled in Table 2 represent the average of at least three independent measurements for each composition of the mixture.

Results and Discussion

Experimental values of ρ, η, n_D, and u are used to calculate the mixing functions using the general type

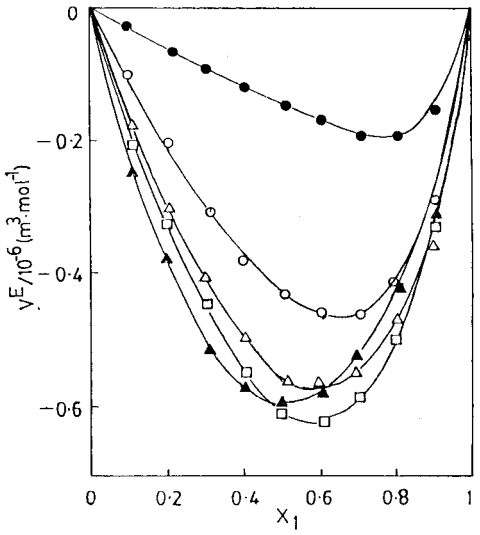

Figure 1. Excess molar volume vs mole fraction of ethenylbenzene with (□) DMAc, (○) DMSO, (△) DMF, (▲) THF, and (●) dioxane at 298.15 K.

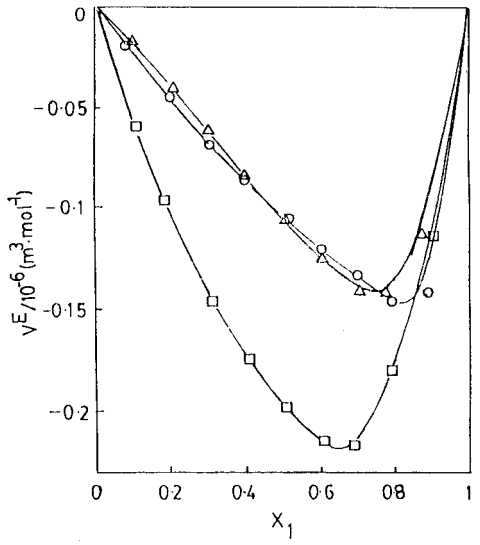

Figure 2. Excess molar volume vs mole fraction of ethenylbenzene with (△) bromoform, (○) chloroform, (□) and 1-CNP at 298.15K.

equation (Aminabhavi and Bindu, 1995; Aminabhavi et al., 1994)

$$V^E \text{ (or } \Delta Y) = V_m \text{ (or } Y_m) - V_1 \text{ (or } Y_1)x_1 - V_2 \text{ (or } Y_2)x_2 \quad (1)$$

where V_m refers to the molar volume of the mixture calculated as

$$V_m = (M_1x_1 + M_2x_2)/\rho_m \quad (2)$$

Here, M_1 and M_2 are molecular weights of the components 1 and 2; V_i ($=M_i/\rho_i$) represent the molar volumes of pure components. The quantity Y_m refers to the mixture properties, viz., η, R, u, and k_S; Y_i refers to properties of the pure components ($i = 1, 2$). The quantity ΔY refers to $\Delta\eta$, ΔR, Δu, and Δk_S. To calculate ΔR, the Lorenz−Lorentz mixing rule was used. For the calculation of ΔR and Δk_S, the volume fraction, ϕ_i was used (Aminabhavi and Bindu, 1995; Aminabhavi et al., 1994) instead of the mole fraction, x_i. The ϕ_i was calculated as

$$\phi_i = \left(\frac{x_iV_i}{\sum_{i=1} x_iV_i}\right) \quad (3)$$

The functions V^E, $\Delta\eta$, Δu, ΔR, and Δk_S have been fitted to the Redlich−Kister type equation (1948)

$$V^E \text{ (or } \Delta Y) = x_1x_2\sum_{i=1}^{2} A_i\,(x_2 - x_1)^{i-1} \quad (4)$$

where the coefficients A_i ($i = 0$ to 2) were obtained by the method of least-squares using the Marquardt algorithm (1963). In solving eq 4 for ΔR and Δk_S, ϕ_i is used in place of x_i. The values of standard error, σ, are computed for each of the functions (V^E, $\Delta\eta$, Δu, ΔR, and Δk_S). The calculated values of A_0, A_1, and A_2 along with σ are given in Table 3. While minimizing the function, we found that the best fits were possible by solving eq 4 up to third degree, i.e., $A_i = 0$ to 2.

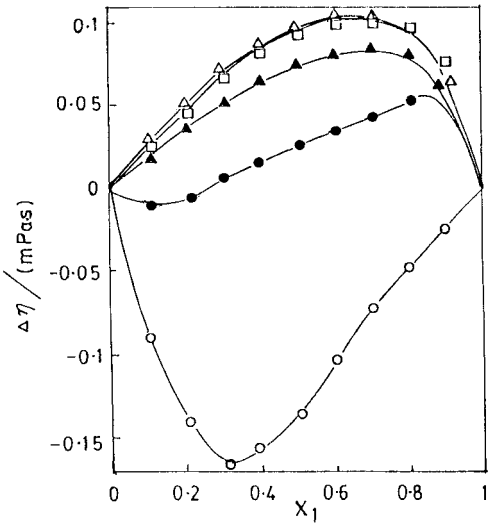

Figure 3. Deviation in viscosity vs mole fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 1.

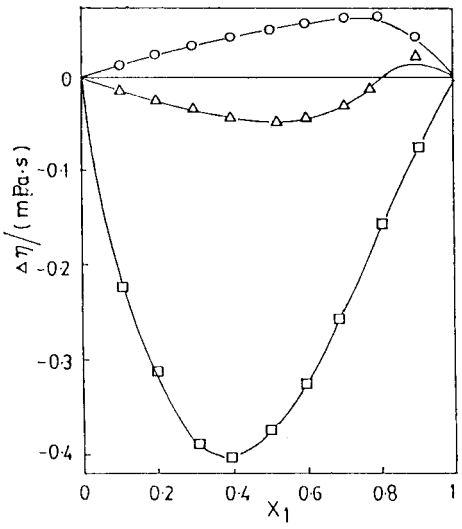

Figure 4. Deviation in viscosity vs mole fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 2.

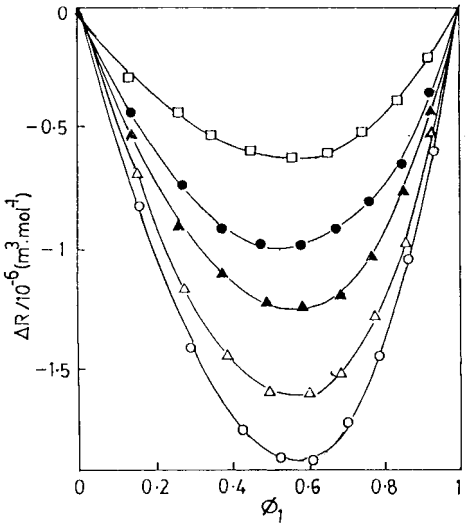

Figure 5. Deviation in molar refractivity vs volume fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 1.

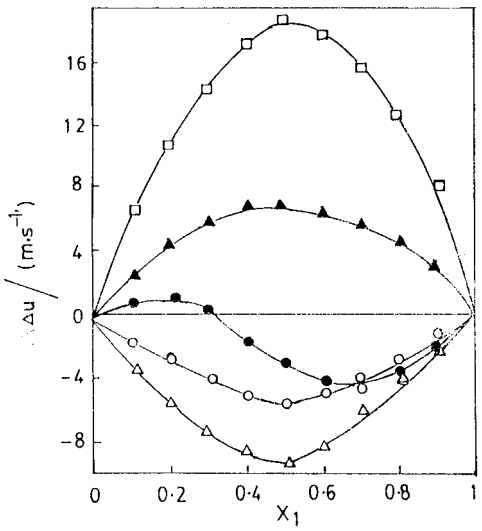

Figure 7. Deviation in speed of sound vs mole fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 1.

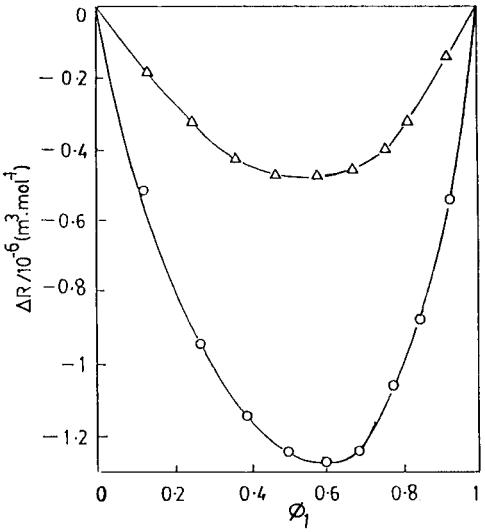

Figure 6. Deviation in molar refractivity vs volume fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 2.

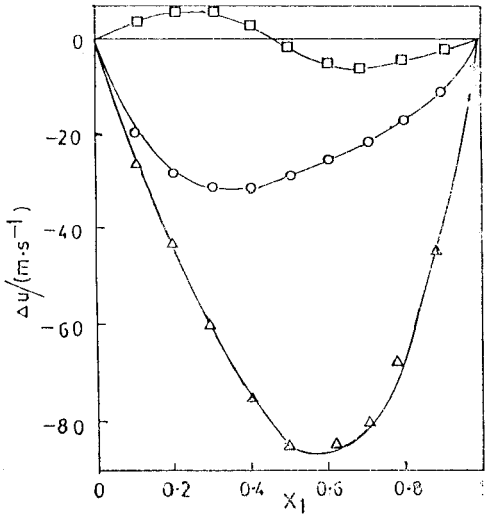

Figure 8. Deviation in speed of sound vs mole fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 2.

The plots of V^E vs x_1 for mixtures of ethenylbenzene with DMAc, DMSO, DMF, THF, and dioxane at 298.15 K are shown in Figure 1. The values of V^E are negative for all the mixtures, and these data vary with the second component of the mixture as DMAc < THF < DMF < DMSO < dioxane. Similar plots for mixtures of ethenylbenzene with bromoform, chloroform, and 1-CNP at 298.15 K are presented in Figure 2. The V^E results for these mixtures are also negative, but the magnitudes of V^E values for these three mixtures are much higher than those presented in Figure 1.

The plots of $\Delta\eta$ on x_1 at 298.15 K are displayed in Figure 3 for mixtures of ethenylbenzene with DMAc, DMSO, DMF, THF, and dioxane. In the case of ethenylbenzene + DMSO mixture, the $\Delta\eta$ values are negative. On the other hand, for all the mixtures except ethenylbenzene + dioxane at lower compositions of ethenylbenzene, the $\Delta\eta$ values are positive. Similar plots for ethenylbenzene + chloroform, + bromoform, or + 1-CNP are presented in Figure 4. These results are negative for mixtures of ethenylbenzene + 1-CNP, while the positive values of $\Delta\eta$ are observed for mixtures of ethenylbenzene + chloroform, or + bromoform. For the latter mixture, a slight sigmoidal variation is observed at higher compositions of ethenylbenzene.

Figure 5 displays the plots of ΔR vs ϕ_1 for mixtures of ethenylbenzene with DMAc, DMSO, DMF, THF, and dioxane at 298.15 K. These data are negative for all the mixtures and vary according to the sequence DMSO < DMF < THF < dioxane < DMAc. Similar plots are displayed in Figure 6 for mixtures of ethenylbenzene with bromoform and chloroform at 298.15 K. The refractive index data for 1-CNP were not measured owing to the limit imposed on the refractometer used. Thus, the ΔR values are not obtained for this mixture. However, wide variations in ΔR values could be seen for bromoform- or chloroform-containing mixtures. For both the mixtures, the ΔR values are negative.

The results of Δu are presented in Figure 7 for mixtures of ethenylbenzene with DMSO, DMF, DMAc, THF, and 1,4-dioxane at 298.15 K. These data are positive for mixtures of ethenylbenzene with DMAc or THF, while for mixtures of DMF or DMSO, the Δu values negative. On the other hand, for ethenylbenzene + dioxane mixtures, the Δu results vary from positive to negative. The plots of Δu vs

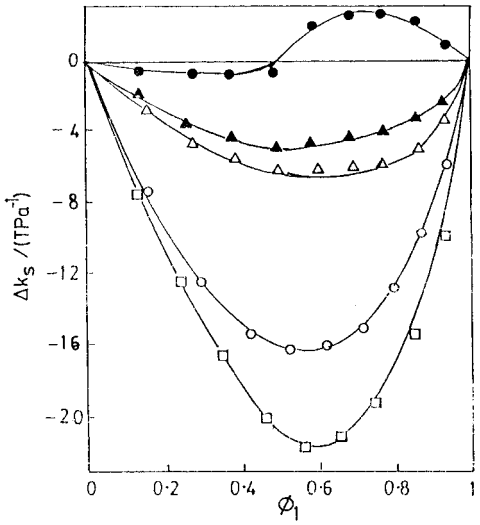

Figure 9. Deviation in isentropic compressibilities vs mole fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 1.

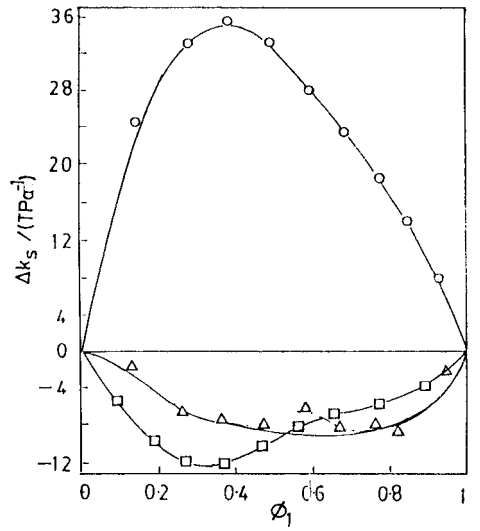

Figure 10. Deviation in isentropic compressibilities vs mole fraction of ethenylbenzene at 298.15 K. Symbols are the same as given in Figure 2.

x_1 at 298.15 K for mixtures of ethenylbenzene with bromoform, chloroform, and 1-CNP are presented in Figure 8. These data are negative for mixtures of ethenylbenzene + bromoform or + chloroform. However, in the case of ethenylbenzene + 1-CNP, the Δu results vary from positive to negative.

The Δk_S results presented in Figure 9 at 298.15 K are negative for all the mixtures except for ethenylbenzene + dioxane, for which a sigmoidal behavior is seen. The results of Δk_S vary according to the sequence DMAc < DMSO < DMF < THF < dioxane. Figure 10 displays the variation of Δk_S with ϕ_1 for mixtures of ethenylbenzene + chloroform, + bromoform, or + 1-CNP at 298.15 K. The negative values are observed for mixtures of ethenylbenzene with bromoform or 1-CNP, whereas positive values of Δk_S are seen for mixtures of ethenylbenzene + chloroform.

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Received for review January 23, 1998. Accepted April 1, 1998. Authors are thankful to the All India Council For Technical Education, New Delhi (F. No. 8017/RDII/BOR/96/ID No. 138.23) for major financial support of this study.

JE980031Y