Density, Refractive Index, Viscosity, and Speed of Sound in Binary Mixtures of Cyclohexanone with Benzene, Methylbenzene, 1,4-Dimethylbenzene, 1,3,5-Trimethylbenzene, and Methoxybenzene in the Temperature Interval (298.15 to 308.15) K

M. I. Aralaguppi,* C. V. Jadar, and T. M. Aminabhavi

Department of Chemistry, Karnatak University, Dharwad 580 003, India

Experimental results of density, refractive index, and viscosity at 298.15, 303.15, and 308.15 K and speed of sound at 298.15 K are presented for the binary mixtures of cyclohexanone with benzene, methylbenzene, 1,4-dimethylbenzene, 1,3,5-trimethylbenzene, and methoxybenzene over the whole range of the mixture composition. From these data, excess molar volume, V^E, deviations in molar refraction, ΔR, viscosity, $\Delta\eta$, speed of sound, Δu, and isentropic compressibility, Δk_S, have been calculated. These results are fit to a Redlich−Kister type polynomial equation. These results are further discussed in terms of the type of intermolecular interactions between the components.

Introduction

Cyclohexanone is a versatile cyclic ketone used in organic syntheses and in many industrial applications. Aromatics are used as solvents in a number of engineering areas. Extensive physical property data on the binary mixtures of cyclohexanone with monocyclic and substituted monocyclic aromatics are not available in the earlier literature. Hence, it was felt essential to obtain physical property data on these mixtures. In our earlier papers, we have measured the physical property data on the binary mixtures comprising aromatic liquids (Aminabhavi et al., 1988, 1989; Aralaguppi et al., 1992a,b,1993). As a further contribution in this area, we present here the experimental data on density, ρ, viscosity, η, refractive index, n_D, for the sodium D-line, and speed of sound, u, for the binary mixtures of cyclohexanone with benzene, methylbenzene, 1,4-dimethylbenzene, 1,3,5-trimethylbenzene, and methoxybenzene. Of these, the values of ρ, η, and n_D have been measured at 298.15, 303.15, and 308.15 K, while the values of u are measured only at 298.15 K. From these results, excess molar volume, V^E, deviations in Lorenz−Lorentz molar refractivity, ΔR, viscosity, $\Delta\eta$, speed of sound, Δu, and isentropic compressibility, Δk_S, have been computed. Calculated results have been fit to the Redlich and Kister (1948) equation to derive the binary coefficients and the standard error values between the experimentally derived data and the calculated quantities. Results of this study have been discussed in terms of the nature of mixing processes and the type of interactions between components of the mixtures.

Experimental Section

Materials. High-purity spectroscopic and HPLC grade samples of cyclohexanone, benzene, methylbenzene, 1,4-dimethylbenzene, 1,3,5-trimethylbenzene, and methoxybenzene were purchased from s.d. fine Chemicals Ltd., Mumbai, India. Their GC analyses indicated purities of 99.6, 99.8, 99.7, 99.5, 99.0, and 98.5 mol %, respectively. All of the samples were used without further purification. Experimental results of ρ and n_D of the pure liquids are compared at 298.15 K with the published data in Table 1.

Table 1. Comparison of Density (ρ) and Refractive Index (n_D) Data for Liquids at 298.15 K with the Literature

	ρ/(g·cm^{-3})		n_D	
liquids	expt	lit.	expt	lit.
cyclohexanone	0.9412	0.9418[a]	1.4485	1.4480[a]
benzene	0.8737	0.8742[b]	1.4982	1.4979[b]
methylbenzene	0.8620	0.8627[b]	1.4944	1.4941[b]
1,4-dimethylbenzene	0.8567	0.8567[c]	1.4937	1.4933[a]
1,3,5-trimethylbenzene	0.8611	0.8615[b]	1.4972	1.4966[b]
methoxybenzene	0.9902	0.9897[b]	1.5155	1.5144[b]

[a] Riddick et al. (1986). [b] Aralaguppi et al. (1992). [c] Singh et al. (1994).

Measurements. Experimental details about the preparation of binary mixtures and measurements of mass, density, refractive index, speed of sound, and viscosity of pure liquids and binary mixtures are the same as those described previously (Aminabhavi and Bindu, 1994; Aminabhavi et al., 1994, 1996; Aralaguppi et al., 1991). The binary mixtures were prepared by mass by mixing the calculated volumes of liquid components in specially designed airtight glass stoppered bottles. The mass measurements (±0.01 mg) were made using an electronic balance (Mettler AE 240). A set of nine compositions was prepared for each system, and their physical properties were measured the same day. The reproducibility in mole fraction was within ±0.0001 units. Densities of pure liquids and their mixtures were measured using the double arm pycnometer having a bulb volume of 15 cm^3 and a capillary bore with an internal diameter of 1 mm. Double distilled, deionized, and degassed water with a specific conductance of 1×10^{-4} Ω^{-1}·cm^{-1} was used for calibration. For all the mixtures and pure solvents, triplicate measurements were performed and the average of these values was considered in all calculations. Density values are accurate to ±0.0002 g·cm^{-3}.

* Author to whom correspondence should be addressed. Fax: 91-836-747884. E-mail: karuni@bgl.vsnl.net.in.

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Table 2. Experimental Density (ρ), Refractive Index (n_D), Viscosity (η), and Speed of Sound (u) of the Binary Mixtures at Different Temperatures

x_1	ρ/ (g·cm^{-3})	n_D	η/ (mPa·s)	u/ (m·s^{-1})	x_1	ρ/ (g·cm^{-3})	n_D	η/ (mPa·s)	u/ (m·s^{-1})	x_1	ρ/ (g·cm^{-3})	n_D	η/ (mPa·s)	u/ (m·s^{-1})
Cyclohexanone (1) + Benzene (2)														
298.15 K														
0.0000	0.8737	1.4982	0.607	1296	0.4039	0.9062	1.4766	0.888	1364	0.8023	0.9316	1.4574	1.472	1400
0.1014	0.8825	1.4924	0.661	1320	0.5020	0.9131	1.4717	0.996	1374	0.9237	0.9381	1.4521	1.773	1408
0.1996	0.8908	1.4871	0.726	1336	0.5997	0.9196	1.4670	1.122	1384	1.0000	0.9420	1.4485	2.229	1412
0.3037	0.8990	1.4817	0.803	1352	0.7018	0.9257	1.4620	1.280	1392					
303.15 K														
0.0000	0.8682	1.4968	0.564		0.4039	0.9012	1.4732	0.824		0.8023	0.9269	1.4551	1.346	
0.1014	0.8773	1.4890	0.616		0.5020	0.9083	1.4686	0.942		0.9237	0.9339	1.4498	1.610	
0.1996	0.8856	1.4845	0.676		0.5997	0.9147	1.4642	1.026		1.0000	0.9374	1.4463	1.799	
0.3037	0.8938	1.4786	0.747		0.7018	0.9209	1.4596	1.175						
308.15 K														
0.0000	0.8628	1.4917	0.528		0.4039	0.8964	1.4706	0.771		0.8023	0.9223	1.4523	1.236	
0.1014	0.8720	1.4860	0.574		0.5020	0.9034	1.4659	0.850		0.9237	0.9291	1.4473	1.472	
0.1996	0.8805	1.4807	0.629		0.5997	0.9100	1.4613	0.945		1.0000	0.9328	1.4439	1.635	
0.3037	0.8888	1.4755	0.694		0.7018	0.9164	1.4568	1.084						
Cyclohexanone (1) + Methylbenzene (2)														
298.15 K														
0.0000	0.8620	1.4944	0.559	1304	0.4055	0.8957	1.4765	0.824	1367	0.7999	0.9268	1.4583	1.391	1400
0.1032	0.8709	1.4900	0.610	1328	0.5040	0.9037	1.4720	0.922	1376	0.9027	0.9347	1.4533	1.654	1408
0.1997	0.8790	1.4858	0.668	1344	0.6020	0.9113	1.4675	1.043	1384	1.0000	0.9420	1.4485	2.229	1412
0.3024	0.8874	1.4812	0.738	1356	0.7012	0.9191	1.4629	1.194	1392					
303.15 K														
0.0000	0.8572	1.4914	0.526		0.4055	0.8913	1.4737	0.767		0.7999	0.9223	1.4558	1.273	
0.1032	0.8662	1.4871	0.573		0.5040	0.8990	1.4692	0.854		0.9027	0.9302	1.4512	1.505	
0.1997	0.8744	1.4825	0.625		0.6020	0.9068	1.4648	0.972		1.0000	0.9374	1.4463	1.799	
0.3024	0.8827	1.4785	0.689		0.7012	0.9147	1.4603	1.103						
308.15 K														
0.0000	0.8526	1.4887	0.498		0.4055	0.8866	1.4712	0.721		0.7999	0.9177	1.4535	1.183	
0.1032	0.8615	1.4843	0.543		0.5040	0.8945	1.4668	0.799		0.9027	0.9256	1.4487	1.382	
0.1997	0.8698	1.4803	0.590		0.6020	0.9022	1.4624	0.903		1.0000	0.9328	1.4439	1.635	
0.3024	0.8782	1.4758	0.648		0.7012	0.9101	1.4580	1.020						
Cyclohexanone (1) + 1,4-Dimethylbenzene (2)														
298.15 K														
0.0000	0.8567	1.4937	0.610	1320	0.4023	0.8879	1.4770	0.834	1365	0.7967	0.9223	1.4587	1.350	1399
0.1013	0.8643	1.4893	0.655	1332	0.5186	0.8976	1.4718	0.938	1376	0.9005	0.9322	1.4539	1.617	1407
0.2048	0.8722	1.4853	0.702	1344	0.6081	0.9053	1.4680	1.040	1384	1.0000	0.9420	1.4485	2.229	1412
0.3016	0.8798	1.4812	0.762	1354	0.7034	0.9138	1.4634	1.194	1392					
303.15 K														
0.0000	0.8523	1.4909	0.570		0.4023	0.8834	1.4748	0.777		0.7967	0.9178	1.4565	1.237	
0.1013	0.8600	1.4869	0.612		0.5186	0.8931	1.4699	0.871		0.9005	0.9278	1.4514	1.481	
0.2048	0.8679	1.4830	0.657		0.6081	0.9009	1.4655	0.965		1.0000	0.9374	1.4463	1.799	
0.3016	0.8754	1.4785	0.711		0.7034	0.9092	1.4609	1.088						
308.15 K														
0.0000	0.8480	1.4881	0.539		0.4023	0.8791	1.4719	0.728		0.7967	0.9133	1.4545	1.144	
0.1013	0.8556	1.4843	0.574		0.5186	0.8887	1.4671	0.819		0.9005	0.9231	1.4490	1.354	
0.2048	0.8634	1.4803	0.618		0.6081	0.8964	1.4632	0.897		1.0000	0.9328	1.4439	1.635	
0.3016	0.8710	1.4761	0.667		0.7034	0.9048	1.4587	1.010						
Cyclohexanone (1) + 1,3,5-Trimethylbenzene (2)														
298.15 K														
0.0000	0.8611	1.4972	0.658	1340	0.4042	0.8866	1.4797	0.882	1374	0.8014	0.9201	1.4594	1.375	1401
0.0996	0.8668	1.4950	0.702	1350	0.5038	0.8939	1.4750	0.965	1381	0.8988	0.9304	1.4540	1.607	1407
0.1988	0.8729	1.4890	0.750	1358	0.6020	0.9019	1.4701	1.067	1388	1.0000	0.9420	1.4485	2.229	1412
0.3039	0.8796	1.4843	0.810	1366	0.7001	0.9105	1.4649	1.193	1395					
303.15 K														
0.0000	0.8571	1.4945	0.619		0.4042	0.8823	1.4773	0.819		0.8014	0.9157	1.4568	1.258	
0.0996	0.8627	1.4909	0.657		0.5038	0.8897	1.4726	0.896		0.8988	0.9260	1.4517	1.484	
0.1988	0.8687	1.4865	0.702		0.6020	0.8975	1.4678	0.987		1.0000	0.9374	1.4463	1.799	
0.3039	0.8753	1.4821	0.755		0.7001	0.9062	1.4623	1.115						
308.15 K														
0.0000	0.8528	1.4921	0.585		0.4042	0.8780	1.4750	0.765		0.8014	0.9113	1.4544	1.168	
0.0996	0.8585	1.4886	0.619		0.5038	0.8854	1.4702	0.835		0.8988	0.9216	1.4491	1.373	
0.1988	0.8645	1.4841	0.659		0.6020	0.8934	1.4654	0.915		1.0000	0.9328	1.4439	1.635	
0.3039	0.8713	1.4796	0.706		0.7001	0.9019	1.4600	1.027						
Cyclohexanone (1) + Methoxybenzene(2)														
298.15 K														
0.0000	0.9902	1.5155	1.017	1420	0.4020	0.9716	1.4888	1.194	1408	0.7976	0.9522	1.4621	1.558	1412
0.1002	0.9858	1.5089	1.048	1428	0.5032	0.9667	1.4820	1.245	1420	0.8978	0.9471	1.4553	1.732	1416
0.2031	0.9811	1.5022	1.096	1432	0.6017	0.9619	1.4752	1.331	1412	1.0000	0.9420	1.4485	2.229	1412
0.3030	0.9764	1.4955	1.131	1416	0.7000	0.9570	1.4686	1.440	1416					

Table 2 (Continued)

x_1	ρ/ (g·cm^{-3})	n_D	η/ (mPa·s)	u/ (m·s^{-1})	x_1	ρ/ (g·cm^{-3})	n_D	η/ (mPa·s)	u/ (m·s^{-1})	x_1	ρ/ (g·cm^{-3})	n_D	η/ (mPa·s)	u/ (m·s^{-1})
Cyclohexanone (1) + Methoxybenzene(2)														
303.15 K														
0.0000	0.9855	1.5123	0.941		0.4020	0.9670	1.4865	1.092		0.7976	0.9476	1.4601	1.421	
0.1002	0.9811	1.5068	0.968		0.5032	0.9621	1.4797	1.151		0.8978	0.9428	1.4536	1.578	
0.2031	0.9765	1.4993	1.004		0.6017	0.9573	1.4728	1.220		1.0000	0.9374	1.4463	1.799	
0.3030	0.9718	1.4926	1.044		0.7000	0.9525	1.4662	1.304						
308.15 K														
0.0000	0.9809	1.5097	0.874		0.4020	0.9625	1.4837	1.012		0.7976	0.9431	1.4574	1.306	
0.1002	0.9765	1.5034	0.905		0.5032	0.9576	1.4770	1.060		0.8978	0.9380	1.4508	1.444	
0.2031	0.9719	1.4968	0.930		0.6017	0.9528	1.4704	1.127		1.0000	0.9328	1.4439	1.635	
0.3030	0.9672	1.4902	0.966		0.7000	0.9480	1.4638	1.207						

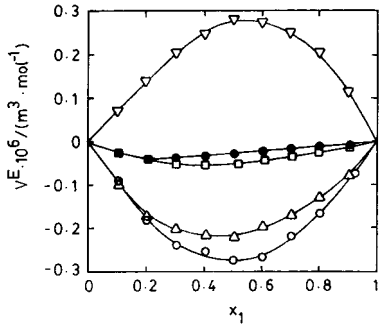

Figure 1. Plots of excess molar volume vs mole fraction for mixtures of cyclohexanone with (○) benzene, (△) methylbenzene, (□) 1,4-dimethylbenzene, (▽) 1,3,5-trimethylbenezene, and (●) methoxybenzene at 298.15 K.

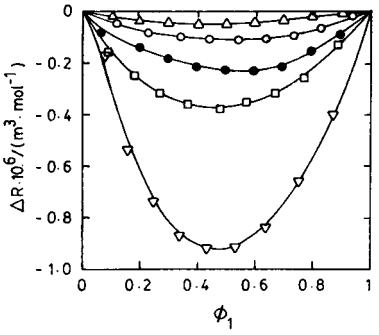

Figure 2. Plots of deviation in molar refractivity vs volume fraction for mixtures of cyclohexanone with aromatics at 298.15 K. Symbols are the same as those given in Figure 1.

Viscosities were measured using a Cannon Fenske Viscometer (size 75, ASTM D 445 supplied by 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 viscometer are the same as those described earlier (Aminabhavi and Bindu, 1994; Aminabhavi et al., 1994).

Refractive indices for the sodium D-line were measured using a thermostatically controlled Abbe refractometer (Atago 3T). A minimum of three independent readings were taken for each composition, and their average is taken for calculation. The refractive index values are accurate to ±0.0001 units. The speed of sound values were measured using a variable path single crystal interferometer (Model M-84, Mittal Enterprises, New Delhi, India). The interferometer was used at a frequency of 1 kHz and was calibrated using benzene and toluene. The speed of sound values are accurate to ±2 m·s^{-1}. In all of the property measurements, an INSREF, Model 016 AP thermostat was used at a constant digital temperature, with a display accurate to

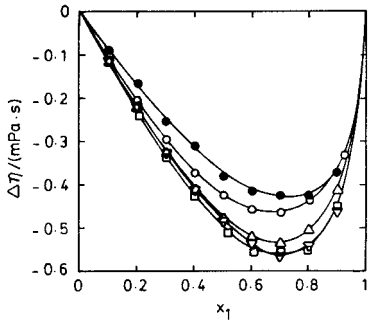

Figure 3. Plots of deviation in viscosity vs mole fraction for mixtures of cyclohexanone with aromatics at 298.15 K. Symbols are the same as those given in Figure 1.

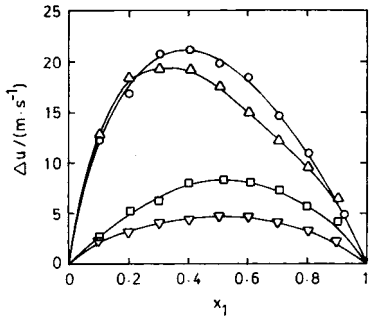

Figure 4. Plots of deviation in speed of sound vs mole fraction for mixtures of cyclohexanone with aromatics at 298.15 K. Symbols are the same as those given in Figure 1.

±0.01 K. The results of ρ, n_D, η, and u compiled in Table 2 represent the averages of three independent measurements for each composition of the mixture.

A Julabo immersion cooler (FT 200, Julabo Labortechnik Gmbh) was used to cool the water bath. This unit was installed at the intake of a heating circulator to draw the heat away from the circulating bath liquid. The immersion probe was connected to the instrument with a flexible and insulated tube. To prevent the immersion probe from icing, it was completely immersed into the bath liquid.

Results and Discussion

The results of V^E, ΔR, $\Delta\eta$, Δu, and Δk_S of the mixtures have been calculated using the average values of ρ, η, n_D, and u given Table 2, from the following equations used earlier (Aminabhavi and Bindu, 1994; Aminabhavi et al., 1996):

$$V^E = V_m - V_1x_1 - V_2x_2 \quad (1)$$

$$\Delta Y = Y_m - Y_1x_1 - Y_2x_2 \quad (2)$$

where V_m is molar volume of the mixture calculated as

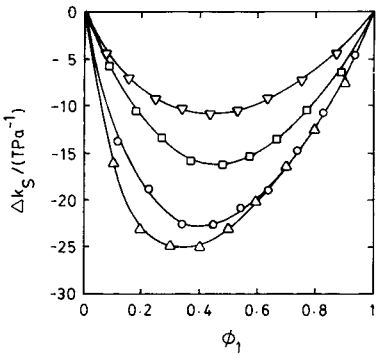

Figure 5. Plots of deviation in isentropic compressibility vs volume fraction for mixtures of cyclohexanone with aromatics at 298.15 K. Symbols are the same as those given in Figure 1.

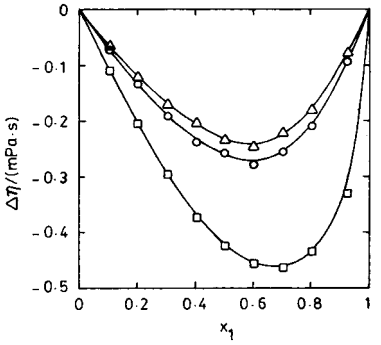

Figure 6. Plots of deviation in viscosity vs temperature for the cyclohexanone + benzene mixture: 298.15 K (□); 303.15 K (○); 308.15 K (△).

suggested before (Aminabhavi and Bindu, 1994; Aminabhavi et al., 1996); V_1 and V_2 are molar volumes of the pure components; x_i represents the mole fraction of the ith component of the mixture; ΔY represents ΔR, $\Delta\eta$, Δu, and Δk_S, respectively; Y_m is the respective mixture property, viz., molar refractivity, R (calculated from the Lorentz−Lorenz relation), viscosity, speed of sound, and isoentropic compressibility for the binary mixtures; and Y_i refers to pure component properties. In the calculations of ΔR and Δk_S, the volume fraction, φ_i, was used instead of mole fraction (Aminabhavi and Bindu, 1994; Aminabhavi et al., 1996, 1997). However, for the calculation of other quantities the mole fraction was used.

The results of excess molar volume vs mole fraction, x_1, of cyclohexanone at 298.15 K are presented in Figure 1. A large negative V^E is observed for the cyclohexanone + benzene mixture, showing the presence of specific interactions. With increasing methyl group substitution on benzene such as in methylbenzene, 1,4-dimethylbenzene, and 1,3,5-trimethylbenzene, the V^E values become less negative, exhibiting the expansion in volume due to the presence of bulkier methyl groups. The V^E values of the cyclohexanone + methoxybenzene mixture are negative but exhibit slightly higher values than those observed for the cyclohexanone + 1,4-dimethylbenzene mixture. Only in the case of cyclohexanone + 1,3,5-trimethylbenzene is a large positive V^E observed, which is attrributed to the presence of weak dispersion type interactions. Almost the same trend was observed earlier with the methyl acetoacetate + aromatic mixtures (Aralaguppi et al., 1992a).

The values of ΔR vs φ_1 at 298. 15 K presented in Figure 2 are negative for all mixtures, and their magnitudes decrease with increasing substitution of methyl groups on benzene. However, for the mixtures of cyclohexanone + methylbenzene, the ΔR values are slightly higher than those observed for cyclohexanone + benzene mixtures. The ΔR values for the cyclohexanone + methoxybenzene mixture are intermediary to those of the cyclohexanone + benzene or + 1,4-dimethylbenzene mixture. It may be noted that such values are due to the electronic perturbation of the individual molecules during mixing and, therefore, depend very much on the nature of the mixing molecules.

The results of $\Delta\eta$ vs x_1 at 298.15 K displayed in Figure 3 are also negative for all of the mixtures and these values show a decreasing trend from benzene to 1,4-dimethylben-

Table 3. Estimated Parameters of Excess Functions for Mixtures

function	temp/K	A_0	A_1	A_2	σ
Cyclohexanone (1) + Benzene (2)					
$V^E \times 10^6/(m^3\cdot mol^{-1})$	298.15	−1.093	−0.041	0.056	0.008
	303.15	−1.117	−0.011	−0.281	0.019
	308.15	−1.235	−0.008	−0.148	0.008
$\Delta R \times 10^6/(m^3\cdot mol^{-1})$	298.15	−0.450	0.006	−0.034	0.005
	303.15	−0.695	0.283	−0.216	0.019
	308.15	−0.563	0.021	−0.028	0.005
$\Delta\eta/(mPa\cdot s)$	298.15	−1.648	1.264	−1.290	0.038
	303.15	−1.037	0.388	−0.112	0.009
	308.15	−1.935	0.315	−0.007	0.005
$\Delta u/(m\cdot s^{-1})$	298.15	80.19	34.25	26.73	0.562
$\Delta k_S/(TPa^{-1})$	298.15	−87.36	33.77	−23.74	0.495
Cyclohexanone (1) + Methylbenzene (2)					
$V^E \times 10^6/(m^3\cdot mol^{-1})$	298.15	−0.861	−0.194	−0.203	0.004
	303.15	−0.925	−0.131	−0.276	0.008
	308.15	−0.961	−0.137	−0.264	0.007
$\Delta R \times 10^6/(m^3\cdot mol^{-1})$	298.15	−0.195	0.078	0.072	0.001
	303.15	−0.244	0.092	0.017	0.011
	308.15	−0.232	0.087	0.036	0.001
$\Delta\eta/(mPa\cdot s)$	298.15	−1.860	1.507	−1.414	0.033
	303.15	−1.234	0.592	−0.280	0.004
	308.15	−1.076	0.486	−0.171	0.003
$\Delta u(m\cdot s^{-1})$	298.15	68.91	43.61	53.51	0.417
$\Delta k_S/(TPa^{-1})$	298.15	−91.12	54.91	−58.29	0.440
Cyclohexanone (1) + 1,4-Dimethylbenzene (2)					
$V^E \times 10^6/(m^3\cdot mol^{-1})$	298.15	−0.209	−0.085	−0.012	0.002
	303.15	−0.170	−0.124	−0.296	0.007
	308.15	−0.238	−0.095	−0.103	0.002
$\Delta R \times 10^6/(m^3\cdot mol^{-1})$	298.15	−1.486	0.268	−0.176	0.009
	303.15	−1.427	0.148	−0.263	0.014
	308.15	−1.456	0.247	−0.018	0.007
$\Delta\eta/(mPa\cdot s)$	298.15	−1.936	1.650	−1.594	0.038
	303.15	−1.316	0.747	−0.391	0.004
	308.15	−1.142	0.632	−0.374	0.037
$\Delta u(m\cdot s^{-1})$	298.15	32.67	−5.52	4.23	0.356
$\Delta k_S/(TPa^{-1})$	298.15	−64.17	9.56	−5.21	0.280
Cyclohexanone (1) + 1,3,5-Trimethylbenzene (2)					
$V^E \times 10^6/(m^3\cdot mol^{-1})$	298.15	1.099	−0.308	−0.117	0.004
	303.15	1.117	−0.197	−0.111	0.008
	308.15	1.027	−0.252	−0.231	0.009
$\Delta R \times 10^6/(m^3\ mol^{-1})$	298.15	−3.761	0.313	0.296	0.044
	303.15	−3.713	0.264	−0.146	0.011
	308.15	−3.731	0.266	−0.218	0.011
$\Delta\eta/(mPa\cdot s)$	298.15	−1.880	1.734	−1.687	0.037
	303.15	−1.263	0.749	−0.426	0.007
	308.15	−1.121	0.611	−0.260	0.004
$\Delta u(m\cdot s^{-1})$	298.15	18.45	−0.40	8.01	0.168
$\Delta k_S/(TPa^{-1})$	298.15	−42.56	11.42	−10.15	0.195
Cyclohexanone (1) + Methoxybenzene (2)					
$V^E \times 10^6/(m^3\cdot mol^{-1})$	298.15	−0.111	−0.132	−0.104	0.001
	303.15	−0.098	−0.078	−0.305	0.008
	308.15	−0.182	−0.124	−0.055	0.001
$\Delta R \times 10^6/(m^3\cdot mol^{-1})$	298.15	−0.927	−0.073	−0.024	0.006
	303.15	−0.815	−0.140	0.645	0.046
	308.15	−0.843	−0.083	0.136	0.006
$\Delta\eta/(mPa\cdot s)$	298.15	−1.445	1.359	−1.366	0.034
	303.15	−0.889	0.486	−0.258	0.002
	308.15	−0.777	0.405	−0.173	0.003
$\Delta u(m\cdot s^{-1})$	298.15	−14.13	28.43	124.63	5.845
$\Delta k_S/(TPa^{-1})$	298.15	8.50	18.32	−88.46	4.268

zene via methylbenzene. The $\Delta\eta$ vs x_1 curves for the mixtures of cyclohexanone + 1,4-dimethylbenzene, or + 1,3,5-trimethylbenzene are almost identical, and the curves overlap for both these mixtures. However, in the case of the cyclohexanone + methoxybenzene mixture, the $\Delta\eta$ values are higher than those observed for all the remaining mixtures.

The results of Δu vs x_1 at 298.15 K presented in Figure 4 are positive for all the mixtures, and these values decrease from benzene to 1,3,5-trimethylbenzene. The speed of sound values for pure cyclohexanone and pure methoxybenzene are somewhat similar, i.e., 1412 and 1420 $m \cdot s^{-1}$, respectively, and hence, the Δu values for these mixtures could not be obtained with sufficient accuracy. Therefore, the Δu data for these mixtures are not presented in Figure 4. The results of Δk_S vs φ_1 for all of the mixtures except that of cyclohexanone + methoxybenzene are presented in Figure 5. In these mixtures, the values of Δk_S are negative and vary via the following sequence: 1,3,5-trimethylbenzene > 1,4-dimethylbenzene > benzene > methylbenzene.

With regard to the temperature dependence of V^E and ΔR, these do not show any systematic variations. However, the $\Delta\eta$ values increase with increasing temperature for all of the mixtures. A typical plot of this dependence is shown in Figure 6 for the cyclohexanone + benzene mixture.

The values of V^E, ΔR, $\Delta\eta$, Δu, and Δk_S have been fitted to the Redlich and Kister (1948) polynomial equation to derive the binary coefficients, A_j, and standard deviations, σ, between the observed and calculated quantities.

$$\Delta Y = x_1 x_2 \sum_{j=1}^{K} A_j (x_2 - x_1)^{j-1} \quad (3)$$

$$\sigma = \left(\sum ((V^E \text{ or } \Delta Y)_{calc} - (V^E \text{ or } \Delta Y)_{expt})^2/(n - m)\right)^{1/2} \quad (4)$$

The parameters A_j and standard errors, σ, are presented in Table 3. It may be noted that while the ΔR and Δk_S values were fitted, φ_1 was used in eq 3 instead of mole fraction.

Literature Cited

Aminabhavi, T. M.; Bindu, G. Densities, Shear Viscosities, Refractive Indices, and Speeds of Sound of Bis(2-methoxyethyl) ether with Nonane, Decane, Dodecane, Tetradecane, and Hexadecane at 298.15, 308.15, and 318.15 K. *J. Chem. Eng. Data* **1994**, *39*, 529−534.

Aminabhavi, T. M.; Patil, V. B. Density, Refractive Index, Viscosity, and Speed of Sound in Binary Mixtures of Ethenylbenzene with Hexane, Heptane, Octane, Nonane Decane, and Dodecane. *J. Chem. Eng. Data* **1997**, *42*, 641−646.

Aminabhavi, T. M.; Manjeshwar, L. S.; Joshi, S. S.; Balundgi, R. H.; Halligudi, S. B. Thermodynamic Properties of Binary Mixtures of Bromoform with Benzene, Toluene, *p*-Xylene, Nitrobenzene, Acetonitrile, and Tetrahydrofuran. *Indian J. Chem.* **1988**, *27A*, 721−724.

Aminabhavi, T. M.; Manjeshwar, L. S.; Halligudi, S. B.; Balundgi, R. H. Thermodynamics of Mixtures of Bromoform with Benzene, Toluene, *p*-Xylene, Acetonitrile, Nitrobenzene, and Tetrahydrofuran at 298.15, 308.15, and 318.15 K. *Indian J. Chem.* **1989**, *28A*, 217−221.

Aminabhavi, T. M.; Aralaguppi, M. I.; Bindu, G.; Khinnavar, R. S. Densities, Shear Viscosities, Refractive Indices, and Speeds of Sound of Bis(2-methoxyethyl) ether with Hexane, Heptane, Octane, and 2,2,4-Trimethylpentane in the Temperature Interval 298.15 to 318.15 K. *J. Chem. Eng. Data* **1994**, *39*, 522−528.

Aminabhavi, T. M.; Patil, V. B.; Aralaguppi, M. I.; Phyade, H. T. S. Density, Viscosity, and Refractive Index of the Binary Mixtures of Cyclohexane with Hexane, Heptane, Octane, Nonane, and Decane at (298.15, 303.15, and 308.15) K. *J. Chem. Eng. Data* **1996**, *41*, 521−525.

Aralaguppi, M. I.; Aminabhavi, T. M.; Balundgi, R. H., and Joshi, S. S. Thermodynamic Interactions in Mixtures of Bromoform with Hydrocarbons. *J. Phys. Chem.* **1991**, *95*, 5299−5308.

Aralaguppi, M. I.; Aminabhavi, T. M.; Balundgi, R. H. Excess Molar Volume, Excess Isentropic Compressibility, and Excess Molar Refraction of Binary Mixtures of Methylacetoacetate with Benzene, Toluene, *m*-Xylene, Mesitylene, and Anisole. *Fluid Phase Equilib.* **1992a**, *71*, 99−112.

Aralaguppi, M. I.; Aminabhavi, T. M.; Harogoppad, S. B.; Balundgi, R. H. Thermodynamic Interactions in Binary Mixtures of Dimethyl Sulfoxide with Benzene, 1,3-Dimethylbenzene, 1,3,5-Trimethylbenzene, and Methoxybenzene from 298.15 to 308.15 K. *J. Chem. Eng. Data* **1992b**, *37*, 298−303.

Aralaguppi, M. I.; Aminabhavi, T. M.; Balundgi, R. H. Shear Viscosities of Binary Mixtures of Methylacetoacetate with Benzene, Toluene, *m*-Xylene, 1,3,5-Trimethylbenzene, and Methoxybenzene at 298.15 K, 303.15 K, and 308.15 K. *Indian J. Technol.* **1993**, *31*, 734−738.

Redlich, O.; Kister, A. T. Algebraic Representation of Thermodynamic Properties and the Classification of Solutions. *Ind. Eng. Chem.* **1948**, *40*, 345−348.

Riddick, A. R.; Bunger, W. B.; Sakano, T. K. *Organic Solvents*; Techniques of Chemistry, Vol II.; Wiley-Interscience: New York, 1986.

Singh, K. C.; Kalra, K. C.; Maken, S.; Yadav, B. L. Excess Values of 1-Propanol and 2-Propanol with Aromatic Hydrocarbons at 298.15 K. *J. Chem. Eng. Data* **1994**, *39*, 241−244.

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