

Viscosity, Density, and Refractive Index of Some (Ester + Hydrocarbon) Binary Mixtures at 303.15 K and 313.15 K

M. V. Rathnam* and Sudhir Mohite

B. N. Bandodkar College of Science, Thane - 400 601, India

M. V. Rathnam* and Sudhir Mohite

Jai Hind College, Deopur, Dhule - 424 002, India.

The viscosity, density, and refractive index of binary mixtures of ethyl formate or formate or ethyl benzoate with o-xylene, m-xylene, p-xylene, and ethylbenzene determined at 303.15 K and 313.15 K and atmospheric pressure for the whole composition range. From the experimental measurements, the deviations in viscosity, D_h , correlated accurately with the Redlich - Kister polynomial equation. The deviations in molar refraction, DR, were calculated from the Lorentz- Lorentz equation. The experimental viscosities were fitted to an empirical equation proposed by Frenkel. It was observed the equation predicts the mixture viscosities reasonably well at both temperatures and agreement between the experimental and calculated values is satisfactory.

INTRODUCTION

A detailed study of the thermodynamic, transport, and dielectric properties of fluids and fluid mixtures is important not only for the solution problems concerning vapor-liquid equilibria, heat transfer, fluidity, and so forth but also for the development of our understanding of molecular motions and interactions in such systems.^{1,2} Recently, interest in the study of liquid mixtures containing esters as one of the components³⁻⁹ has increased. These studies are of great significance because one can get information regarding structural changes that occur in the pure ester because of the mixing, and they are also useful from viewpoint of building up a valid theory and testing the existing ones. Viscosity is an important bulk property that provides a measure of the internal friction of a fluid and is closely related to self-association in liquids. Therefore, viscosity results of liquid

mixtures are essential in chemical engineering for the determination of flow in pipelines, heat transfer, and so forth. A literature survey reveals that very few attempts¹⁰⁻¹⁶ have been made a study the viscosity of liquid mixtures consisting of a variety of esters in different solvents. Esters possess high dipole moments but behave like normal liquids; this behavior is quite different, it is of interest to study the viscosities of esters and their binary mixtures. In continuation of our previous work,^{17,18} we report in this paper the measurements of viscosities, densities, and refractive indexes of binary liquid mixtures of (ethyl formate + o-xylene, m-xylene, p-xylene, or ethylbenzene) and (ethyl benzoate + o-xylene, m-xylene, p-xylene, or ethylbenzene) at the temperatures (303.15 and 313.15) K and atmospheric pressure. The deviations in viscosity and the deviations in molar refraction were then calculated. The deviations in viscosity were correlated by a polynomial expression.

*Corresponding author. E-mail : mvrbnb@hotmail.com

Table 1 : Comparison of Experimental Densities (ρ), Dynamic Viscosities (η), and Refractive Indexes (n_D) of Pure Liquids with Literature Values.

liquid	T/K	$\rho/\text{kg.m}^{-3}$		$\eta/\text{mPa.s}$		n_D	
		exptl	lit ^a	exptl	lit ^a	exptl	Lit ^b
ethyl formate	303.15	908.1	908.5 ^b	0.366	0.58	1.3552	1.3552
	313.15	894.9		0.339		1.3549	
ethyl benzoate	303.15	1037.4	1037.2	1.748	1.751	1.5009	1.5015
	313.15	1.28.5		1.438		1.4997	
o-xylene	303.15	870.7	871.7	0.695	0.693 ^a	1.5001	1.5002 ^a
	313.15	863.3		0.621		1.4981	
m-xylene	303.15	855.3	855.8	0.557		1.4920	1.4921
	313.15	847.1		0.508		1.4901	
p-xylene	303.15	851.9	852.2	0.566	0.566	1.4911	1.4906 ^a
	313.15	844.0		0.517		1.4902	
Ethyl benzene	303.15	857.6	858.1 ^b	0.597	0.590 ^a	1.4910	1.4906
	313.15	849.2		0.538		1.4891	

a Reference 19. b Extrapolated values from ref. 19. c Reference 20.

Experimental Section

Chemicals *o*-xylene, *m*-xylene, *p*-xylene, all analytical grade (BDH), were purified as per the standard procedure given by Riddick et al.¹⁹ Ethyl benzene, ethyl formate, and ethyl benzoate, all (Fluka, AG) with a reported purity of >99%, were used without further treatment. All of the chemicals were distilled before use, and the purity of these samples was tested by measuring their densities, viscosities, and refractive indexes at 303.15 K. Table 1 lists the densities, viscosities, and refractive indexes of the pure components, together with the literature values, 19,20 at 303.15K

Apparatus and Procedure

Liquid mixtures were prepared by mass using a Mettler balance with an accuracy of ± 0.02 mg. The uncertainty of the mole fraction was estimated to be lower than $\pm 4 \times 10^{-4}$. To prevent the samples from preferential evaporation, the mixtures were prepared by transferring aliquots via syringe into suitably stoppered bottles. The mixtures were completely miscible over the whole composition range. Densities

were determined with a pycnometer having a bulb volume of about 20 cm³ and a capillary internal diameter of about 1 mm. The pycnometer was calibrated at 303.15 K and 313.15 K with doubly distilled water. The corresponding uncertainty of the density determination is estimated to be better than ± 0.2 kg.m⁻³. The viscosities of the pure liquids and of the mixture were determined using an Ubbelohde viscometer. The method and calibration of the viscometer have already been reported elsewhere.¹⁷ Kinetic energy corrections were applied to viscosity data, and their uncertainties were estimated to be better than ± 0.003 mPa's. In making determinations, both the pycnometer and the viscometer were maintained in a thermostatic bath until at least three consecutive measurements of the liquid height in the capillaries or the flow time indicated that the sample had reached temperature of the bath. The temperature of the water thermostat was controlled to ± 0.01 K. A proportional integral control model was used to maintain the temperature in the thermostat to be within ± 0.01 K of the desired value. The refractive indexes were measured using a thermostated Abb refractometer (model R-8), which works with the wavelength corresponding to the D line of sodium. The prism was equipped with a tightly fitting lid that preserves the sample from preferential evaporation. The instrument calibration was carried out with doubly distilled water. An average of three measurements was taken for each sample mixture. The uncertainty of the refractive indexes thus estimated is found to be lower than $\pm 2 \times 10^{-4}$.

Results and Discussion

Table 2 shows the experimental densities ρ , dynamic viscosities η , refractive indexes n_D , viscosity deviation $\Delta\eta$, and molar refraction deviations ΔR

Table 2. Densities (ρ), Dynamic Viscosities (η), Deviations in Viscosity ($\Delta\eta$), Refractive Indexes (n_D), and Deviations in Refractive Index (ΔR) for Various Binary Mixtures

X_1	ρ	η	η	$\Delta\eta$	n_D	ΔR	X_1	ρ	η	η	$\Delta\eta$	n_D	ΔR
	kg·m ⁻³	mPa·s exptl	mPa·s eq 3	mPa·s		cm ³ mol ⁻¹		kg·m ⁻³	mPa·s exptl	mPa·s eq 3	mPa·s		cm ³ mol ⁻¹
Ethyl Formate (1) + <i>o</i> -Xylene (2) at 303.15 K													
0.1467	872.7	0.630	0.632	-0.017	1.4906	5.862	0.6940	891.2	0.444	0.444	-0.023	1.4347	12.823
0.2667	877.4	0.586	0.585	-0.021	1.4873	11.704	0.7791	896.7	0.420	0.421	-0.018	1.4072	10.220
0.3779	880.0	0.544	0.544	-0.027	1.4786	12.418	0.8563	901.2	0.400	0.401	-0.013	1.3981	7.893
0.4984	882.6	0.502	0.504	-0.029	1.4721	14.245	0.9337	903.7	0.378	0.382	-0.009	1.3729	3.516
0.5936	886.9	0.471	0.474	-0.028	1.4631	14.456							
Ethyl Formate (1) + <i>o</i> -Xylene (2) at 313.15 K													
0.1467	864.6	0.558	0.556	-0.021	1.4896	6.384	0.6940	881.6	0.402	0.405	-0.023	1.4216	12.267
0.2667	868.5	0.521	0.525	-0.025	1.4819	9.790	0.7791	885.9	0.382	0.385	-0.019	1.4061	10.291
0.3779	871.9	0.487	0.490	-0.027	1.4735	12.395	0.8563	889.6	0.366	0.368	-0.014	1.3969	7.946
0.4984	873.7	0.452	0.456	-0.028	1.4671	14.286	0.9337	891.1	0.359	0.352	-0.001	1.3701	3.922
0.5936	876.9	0.430	0.430	-0.025	1.4612	14.598							
Ethyl Formate (1) + <i>m</i> -Xylene (2) at 303.15 K													
0.1348	858.3	0.524	0.526	-0.008	1.4892	5.778	0.6923	882.8	0.414	0.415	-0.011	1.4265	12.598
0.2728	863.3	0.494	0.496	-0.011	1.4695	9.460	0.7867	888.4	0.398	0.399	-0.009	1.4055	10.231
0.3968	868.7	0.467	0.470	-0.014	1.4561	11.951	0.8591	895.0	0.386	0.388	-0.007	1.3875	7.487
0.4988	873.1	0.449	0.450	-0.013	1.4391	12.761	0.9379	900.1	0.373	0.375	-0.005	1.3856	4.581
0.6032	877.7	0.430	0.431	-0.012	1.4288	12.981							
Ethyl Formate (1) + <i>m</i> -Xylene (2) at 313.15 K													
0.1348	849.8	0.479	0.480	-0.006	1.4820	5.457	0.6923	874.3	0.384	0.383	-0.007	1.4253	12.642
0.2728	854.4	0.453	0.454	-0.009	1.4679	9.589	0.7867	880.1	0.369	0.369	-0.006	1.4043	10.219
0.3968	859.5	0.431	0.431	-0.010	1.4578	12.256	0.8591	884.1	0.357	0.358	-0.006	1.3850	7.445
0.4988	864.3	0.412	0.414	-0.012	1.4380	12.872	0.9379	889.7	0.347	0.347	-0.002	1.3841	4.465
0.6032	869.2	0.397	0.397	-0.009	1.4276	13.070							
Ethyl Formate (1) + <i>p</i> -Xylene (2) at 303.15 K													
0.1658	857.7	0.523	0.525	-0.010	1.4785	6.552	0.6916	883.4	0.418	0.417	-0.010	1.4239	14.827
0.2572	861.1	0.503	0.505	-0.011	1.4746	9.461	0.7854	889.6	0.403	0.401	-0.005	1.4121	10.542
0.4068	868.2	0.472	0.472	-0.013	1.4671	12.882	0.8588	896.0	0.390	0.388	-0.004	1.3901	8.181
0.5039	871.6	0.452	0.453	-0.013	1.4532	13.674	0.9381	902.9	0.375	0.376	-0.003	1.3711	3.976
0.6037	878.8	0.434	0.433	-0.011	1.4510	14.154							
Ethyl Formate (1) + <i>p</i> -Xylene (2) at 313.15 K													
0.1658	849.0	0.477	0.478	-0.010	1.4779	6.414	0.6916	873.5	0.380	0.381	-0.014	1.4201	12.376
0.2572	851.7	0.451	0.450	-0.019	1.4732	9.405	0.7854	877.8	0.371	0.368	-0.006	1.4091	10.560
0.4068	858.8	0.424	0.429	-0.021	1.4611	12.598	0.8588	884.7	0.360	0.357	-0.004	1.3891	8.077
0.5039	861.8	0.407	0.412	-0.020	1.4499	13.596	0.9381	891.0	0.348	0.347	-0.002	1.3689	3.736
0.6037	868.8	0.393	0.395	-0.016	1.4491	14.157							
Ethyl Formate (1) + Ethylbenzene (2) at 303.15 K													
0.1478	862.2	0.558	0.557	-0.005	1.4809	5.767	0.6925	886.6	0.430	0.427	-0.007	1.4157	11.960
0.2728	869.9	0.527	0.525	-0.007	1.4691	9.301	0.7768	891.0	0.413	0.410	-0.005	1.4058	10.371
0.3884	871.2	0.499	0.496	-0.008	1.4568	11.796	0.8510	896.6	0.397	0.395	-0.003	1.3938	7.387
0.4978	876.3	0.473	0.471	-0.009	1.4431	13.617	0.9309	903.7	0.380	0.379	-0.002	1.3709	4.542
0.6000	881.8	0.450	0.448	-0.008	1.4286	12.893							
Ethyl Formate (1) + Ethylbenzene (2) at 313.15 K													
0.1478	853.7	0.502	0.500	-0.007	1.4791	5.836	0.6925	875.9	0.391	0.388	-0.009	1.4142	11.165
0.2728	857.7	0.476	0.471	-0.008	1.4682	9.481	0.7768	880.0	0.376	0.374	-0.007	1.4042	10.409
0.3884	861.8	0.452	0.446	-0.009	1.4532	11.789	0.8510	885.1	0.363	0.362	-0.006	1.3921	8.006
0.4978	866.3	0.420	0.424	-0.010	1.4415	13.017	0.9309	891.7	0.351	0.349	-0.002	1.3695	3.937
0.6000	873.2	0.409	0.398	-0.010	1.4269	12.923							
Ethyl Benzoate + <i>o</i> -Xylene (2) at 303.15 K													
0.0847	887.3	0.758	0.750	-0.026	1.4994	6.352	0.5600	972.3	1.190	1.156	-0.095	1.5009	18.946
0.1749	904.2	0.837	0.813	-0.042	1.4996	11.048	0.6668	988.1	1.312	1.278	-0.085	1.5010	16.886
0.2686	920.9	0.909	0.885	-0.069	1.4999	15.869	0.7675	1001.3	1.433	1.403	-0.070	1.5011	13.456
0.3579	937.5	1.000	0.960	-0.072	1.5001	18.264	0.8768	1021.1	1.566	1.555	-0.052	1.5013	7.912
0.4613	954.0	1.085	1.055	-0.096	1.5007	19.514							
Ethyl Benzoate (1) + <i>o</i> -Xylene(2) at 313.15 K													
0.0847	879.3	0.676	0.666	-0.014	1.4883	5.929	0.5600	963.8	1.015	0.990	-0.063	1.4997	19.116
0.1749	896.1	0.732	0.717	-0.032	1.4986	12.013	0.6668	980.8	1.113	1.083	-0.053	1.4999	16.928
0.2686	913.1	0.800	0.776	-0.040	1.4989	16.078	0.7675	992.7	1.208	1.179	-0.040	1.5001	13.519
0.3579	930.2	0.864	0.835	-0.049	1.4993	18.424	0.8768	1010.9	1.310	1.294	-0.027	1.5003	7.688
0.4613	945.7	0.937	0.911	-0.061	1.4995	19.776							
Ethyl Benzoate (1) + <i>m</i> -Xylene (2) at 303.15 K													
0.0887	871.6	0.612	0.611	-0.051	1.4946	6.953	0.5707	966.5	1.055	1.040	-0.182	1.4990	19.019
0.1713	887.2	0.676	0.672	-0.085	1.4957	11.956	0.6576	981.7	1.161	1.167	-0.179	1.4995	14.935
0.2626	905.2	0.759	0.735	-0.111	1.4964	15.960	0.7831	1002.2	1.352	1.351	-0.138	1.5003	12.095
0.3553	926.0	0.837	0.813	-0.143	1.4970	18.427	0.8832	1018.5	1.500	1.511	-0.109	1.5011	7.692
0.4588	946.8	0.931	0.915	-0.172	1.4974	19.564							

Table 2. (Continued)

X_1	$\frac{\rho}{\text{kg}\cdot\text{m}^{-3}}$	$\frac{\eta}{\text{mPa}\cdot\text{s}}$	$\frac{\eta}{\text{mPa}\cdot\text{s}}$	$\frac{\Delta\eta}{\text{mPa}\cdot\text{s}}$	n_D	$\frac{\Delta R}{\text{cm}^3\text{mol}^{-1}}$	X_1	$\frac{\rho}{\text{kg}\cdot\text{m}^{-3}}$	$\frac{\eta}{\text{mPa}\cdot\text{s}}$	$\frac{\eta}{\text{mPa}\cdot\text{s}}$	$\frac{\Delta\eta}{\text{mPa}\cdot\text{s}}$	n_D	$\frac{\Delta R}{\text{cm}^3\text{mol}^{-1}}$
		exptl	eq 3						exptl	eq 3			
Ethyl Benzoate (1) + <i>m</i> -Xylene (2) at 313.15 K													
0.0887	857.3	0.547	0.552	-0.043	1.4917	7.124	0.5707	966.5	0.910	0.896	-0.129	1.4979	18.815
0.1713	875.0	0.601	0.598	-0.066	1.4925	12.085	0.6576	971.7	0.997	0.982	-0.123	1.4984	17.436
0.2626	895.5	0.664	0.654	-0.088	1.4939	16.090	0.7831	993.7	1.146	1.126	-0.090	1.4988	12.876
0.3553	917.5	0.732	0.740	-0.106	1.4955	18.573	0.8832	1009.8	1.274	1.259	-0.055	1.4993	7.697
0.4588	937.2	0.809	0.797	-0.126	1.4963	19.748							
Ethyl Benzoate (1) + <i>p</i> -Xylene (2) at 303.15 K													
0.0916	871.1	0.622	0.623	-0.052	1.4931	7.233	0.5703	964.8	1.045	1.053	-0.195	1.4970	19.989
0.1757	889.3	0.679	0.681	-0.095	1.4939	12.115	0.6730	982.8	1.181	1.185	-0.180	1.4983	16.810
0.2719	908.4	0.765	0.756	-0.122	1.4951	16.224	0.7781	1000.8	1.325	1.340	-0.161	1.4988	13.659
0.3616	925.3	0.837	0.833	-0.156	1.4957	18.607	0.8651	1022.8	1.469	1.486	-0.120	1.4995	12.295
0.4681	947.1	0.951	0.938	-0.168	1.4965	19.597	0.9370	1040.8	1.603	1.566	-0.070	1.5001	3.928
Ethyl Benzoate (1) + <i>p</i> -Xylene (2) at 313.15 K													
0.0916	863.0	0.550	0.564	-0.051	1.4912	6.919	0.5703	956.0	0.900	0.907	-0.142	1.4963	19.139
0.1757	880.9	0.606	0.610	-0.074	1.4924	11.996	0.6730	974.0	1.008	1.009	-0.129	1.4972	16.928
0.2719	899.9	0.686	0.671	-0.081	1.4948	16.296	0.7781	993.2	1.126	1.127	-0.108	1.4979	13.040
0.3616	917.3	0.739	0.733	-0.111	1.4950	18.646	0.8651	1010.2	1.239	1.240	-0.075	1.4989	8.519
0.4681	937.5	0.825	0.825	-0.123	1.4956	19.736	0.9370	1028.2	1.339	1.341	-0.040	1.4996	4.247
Ethyl Benzoate (1) + Ethylbenzene (2) at 303.15 K													
0.0862	875.1	0.643	0.650	-0.053	1.4920	6.570	0.5625	967.0	1.071	1.065	-0.173	1.4968	18.938
0.1804	892.6	0.711	0.714	-0.094	1.4932	12.202	0.6722	984.9	1.206	1.213	-0.165	1.4971	16.643
0.2589	910.2	0.767	0.773	-0.128	1.4934	15.558	0.7675	1002.0	1.330	1.337	-0.150	1.4992	12.807
0.3522	927.2	0.857	0.851	-0.145	1.4942	18.519	0.8678	1019.0	1.496	1.499	-0.100	1.4998	8.324
0.4720	950.1	0.970	0.966	-0.170	1.4960	19.493	0.9325	1040.9	1.615	1.615	-0.055	1.5003	4.019
Ethyl Benzoate (1) + Ethylbenzene (2) at 313.15 K													
0.0862	867.0	0.570	0.582	-0.046	1.4911	6.646	0.5625	960.4	0.937	0.917	-0.107	1.4959	19.010
0.1804	884.3	0.629	0.635	-0.071	1.4921	12.313	0.6722	976.2	1.063	1.023	-0.080	1.4963	16.803
0.2589	901.3	0.682	0.683	-0.089	1.4930	15.672	0.7675	993.0	1.169	1.127	-0.060	1.4981	13.409
0.3522	918.1	0.745	0.746	-0.110	1.4937	18.385	0.8678	1009.7	1.268	1.251	-0.051	1.4992	8.505
0.4720	941.4	0.844	0.838	-0.119	1.4954	19.672	0.9325	1027.4	1.335	1.339	-0.035	1.4996	4.312

Table 3. Parameters of Equation 2 and the Standard Deviations $\sigma(\Delta\eta)$ of Various Binary Systems

systems	TK	A_0	A_1	A_2	$\sigma(\Delta\eta)/\text{mPa}\cdot\text{s}$
ethyl formate + <i>o</i> -xylene	303.15	-0.1075	0.0092	-0.0387	0.002
	313.15	-0.1210	0.0513	0.0191	0.004
ethyl formate + <i>m</i> -xylene	303.15	-0.0664	-0.0026	0.0262	0.003
	313.15	-0.0506	0.0250	0.0172	0.002
ethyl formate + <i>p</i> -xylene	303.15	-0.0476	0.0223	-0.0182	0.003
	313.15	-0.0790	0.0288	0.0381	0.005
ethyl formate + ethyl benzene	303.15	-0.0317	0.0070	-0.0001	0.001
	313.15	-0.0410	0.0074	-0.0070	0.001
ethyl benzoate + <i>o</i> -xylene	303.15	-0.3480	-0.0940	-0.0559	0.007
	313.15	-0.2374	-0.0299	0.0362	0.003
ethyl benzoate + <i>m</i> -xylene	303.15	-0.6797	-0.2597	-0.2238	0.008
	313.15	-0.4987	-0.0407	-0.0370	0.005
ethyl benzoate + <i>p</i> -xylene	303.15	-0.7117	-0.2866	-0.2500	0.006
	313.15	-0.4996	-0.0782	-0.1769	0.009
ethyl benzoate + ethyl benzene	303.15	-0.6906	-0.1399	-0.1277	0.004
	313.15	-0.4096	0.0613	-0.1755	0.010

obtained for various binary mixtures at 303.15 K and 313.15 K. The dynamic viscosities of the mixtures were determined by multiplying the kinematic viscosity by the density of the mixture at the same composition. The viscosity deviations $\Delta\eta$ were obtained from dynamic viscosity composition data through

$$\Delta\eta = \eta - (x_1\eta_1 + x_2\eta_2) \quad (1)$$

where η , η_1 and η_2 are the dynamic viscosities of the mixture and pure components 1 (ester) and 2 (hydrocarbon), respectively. The $\Delta\eta$ values were correlated satisfactorily using the Ridlich - Kister²¹ equation

$$\Delta\eta = x_1x_2[A_0 + A_1(x_1 - x_2) + A_2(x_1 - x_2)^2] \quad (2)$$

where the values of fitting coefficients A_0 , A_1 and A_2 were determined by a least-squares method. Table 3 shows the fitting coefficients and the standard deviations for each of the binary mixtures at the working temperature. It was observed that the average standard deviation value of the deviations of viscosity $\Delta\eta$ for all the systems is 0.004 mPa. at 303.15 K and 0.005 mPa.s at 313.15 K. The mixture viscosities have been recalculated from Frenkel,²² the one-parameter empirical relation

$$\ln \eta - x_1^2 \ln \eta_1 + x_2^2 \ln \eta_2 + 2x_1x_2 \ln \eta_{12} \quad (3)$$

where the value of η_{12} is obtained by the relation

$$\eta_{12} = 0.5\eta_1 + 0.5\eta_2$$

This value of η_{12} was used to obtain η at other compositions. The calculated viscosity results are included in Table 2. A persual of Table 2 indicate that the agreement between the experimental and calculated values at both temperatures is good and within the

experimental error. The deviations in molar refraction ΔR were calculated as a function of mole fraction x_1 using the following expression

$$\Delta R = R_M - \sum_i x_i R_i \quad (4)$$

where R_M is molar refraction of the mixture obtained from the Lorentz - Lorentz equation²³ and R_i is the molar refraction for component i . As noted from Table 2, the $\Delta\eta$ values were negative over the entire composition range for all of the system in this study at both temperatures. The maximum of the $\Delta\eta$ values was located at about $x_1 = 0.5$. Furthermore, it was observed that in the case of systems containing ethyl formate the viscosity deviation was maximum for *o*-xylene and minimum for ethylbenzene whereas for systems of ethyl benzoates the deviation was maximum for *p*-xylene and minimum for *o*-xylene. These negative $\Delta\eta$ values were ascribed to the dominance of dispersion forces compared to the induced dipole-dipole interactions. The effect of temperature on the viscosity deviations can be justified because an increase in temperature caused an increase (less negative) in $\Delta\eta$ values except for mixtures of ethyl formate + *p*-xylene and ethyl formate + ethyl benzene, for which the $\Delta\eta$ values decrease (more negative) slightly. However, in comparison to the system of ethyl formate the temperature effect was found to be more significant for the

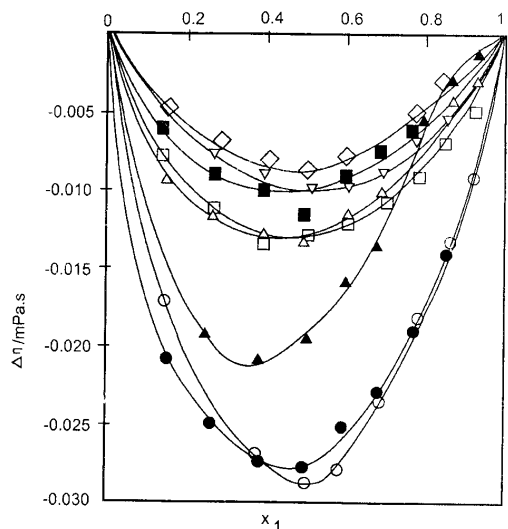


Figure 1. Deviations in viscosity $\Delta\eta$ vs mole fraction of ethyl formate + *o*-xylene (○), + *m*-xylene (□) + *p*-xylene (△), and + ethyl benzene (◇) respectively, at 303.15 K and for ethyl formate + *o*-xylene (●), + *m*-xylene (■), + *p*-xylene (▲), and + ethyl benzene (▽), respectively, at 313.15K.

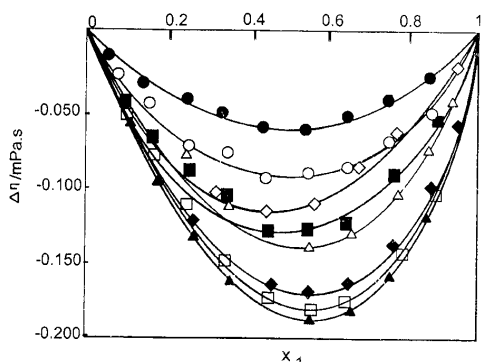


Figure 2. Deviations in viscosity $\Delta\eta$ vs mole fraction of ethyl benzoate + *o*-xylene (○), + *m*-xylene (□), + *p*-xylene (▲), and + ethyl benzene (◆) respectively, at 303.15 K and for ethyl benzoate + *o*-xylene (●), + *m*-xylene (■) + *p*-xylene (△), and + ethyl benzene (◇), respectively, at 313.15K.

systems of ethyl benzoate. Figure 1 and 2 display the isothermal variations of the $\Delta\eta$ values with the mole fraction of ester. In general, the shapes of the

curves were nearly symmetrical except those from the binary mixtures of ethyl formate + *p*-xylene that showed the maxima slightly skewed toward a lower ester mole fraction. The deviations in molar refraction ΔR values were positive over the entire composition range for all of the studied systems. The ΔR values were found to be similar at both temperatures, indicating that the effect of temperature on this property was negligible.

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Received for review March 4, 2004.
Accepted September 10, 2004. The financial support of the University of Mumbai (India) Project APD/237/2003/46 is gratefully acknowledged.

JE0400052