Densities, Viscosities, and Refractive Indices of Binary Mixtures of Anisole with Benzene, Methylbenzene, Ethylbenzene, Propylbenzene, and Butylbenzene at (293.15 and 303.15) K

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Density (ρ), viscosity (η), and refractive index (n_D) data of the binary mixtures of anisole + benzene, + methylbenzene, + ethylbenzene, + propylbenzene, and + butylbenzene were measured over the whole composition range at (293.15 and 303.15) K and atmospheric pressure. The viscosity data were correlated by empirical and semiempirical equations. The refractive index data were compared with calculated values using different models based on mixing rules. The excess molar volumes (V^E) and viscosity deviations ($\Delta\eta$) were derived from the measurements. The V^E and $\Delta\eta$ of binary mixtures were fitted to Redlich−Kister polynomial equation. The excess and deviation functions are negative and decrease with increasing side chain length of the parent benzene molecule in the following order: benzene > methylbenzene > ethylbenzene > propylbenzene > butylbenzene.

Introduction

Physical properties of liquid mixtures are required in most engineering calculations where fluid flow or mixing is an important factor in many practical problems concerning mass transport applications. A number of studies were carried out on binary mixtures of aromatic ethers and different types of hydrocarbons. Anisole is one of the aromatic ethers that is widely used as a starting point for preparation of various derivatives. It is also used together with alkylbenzene as mixed solvents in production of dyes, pigment, and perfumery. A perusal of the literature on physical properties of the aforementioned systems revealed that data on their mixtures were limited.[1−6] So it seems to be very useful in this area of research to carry out the systematic investigations involving the physical properties for the binary mixtures of anisole and alkylbenzenes.

Continuing our pervious studies[1,7] on the measurement of transport properties of binary liquid mixtures containing aromatic ether, we present here the experimental results of density, viscosity, and refractive index at (293.15 and 303.15) K and atmospheric pressure for the pure components and binary mixtures of anisole + benzene, or + methylbenzene, or + ethylbenzene, or + propylbenzene, or + butylbenzene. The excess molar volumes were calculated from density data and fitted to the Redlich−Kister-type polynomial equation.[8] While the viscosities were correlated by the equations of Grunberg and Nissan,[9] four-body McAllister,[10] and Heric and Brewer,[11] the refractive index data were correlated by Lorentz−Lorenz and Gladstone−Dale equations, which are reported elsewhere.[1,12,13] The variation of excess properties with the length of side chain of the aromatic ring and temperature were investigated.

Experimental Section

Chemicals. The purities, densities, viscosities, and refractive indices of chemicals used in this study are presented in Table 1. The purities were checked and confirmed by GLC analysis using Varian GC (Star 3400-cx) with capillary column (50 m × 0.22 mm i.d.), WCOT (wall-coated-open-tube) fused silica (Chrompack Catalog no. 7525), carrier gas (H_2; 180 kPa), injector (Splitter; 100 $cm^3 \cdot min^{-1}$), and flame ionization detector (FID, 32×10^{-12} afs).

All reagents were used without further purification. The purity of these solvents was ascertained by comparing the measured densities, viscosities, and refractive indices of the pure components at 293.15 K with the available literature values[1,2,14−16] (reported in Table 1). The results confirmed closely with an average absolute value of deviation 0.065 $kg \cdot m^{-3}$, 3×10^{-3} mPa·s, and 10^{-4} for density, dynamic viscosity, and refractive index at 293.15 K, respectively. The agreement is within the uncertainty of pure components measurements at the temperature of interest.

Measurements. Mixtures were prepared by mass, using an electronic balance (Mettler AT460) with a stated precision of $\pm 10^{-7}$ kg. Triplicate measurements were performed, and the uncertainty was $\pm 2 \times 10^{-5}$ in the mole fraction. The binary liquid mixtures were prepared and measured as described in our earlier work.[1,7]

Density measurements of pure components and binary mixtures over the complete composition range were carried out at (293.15 and 303.15) K using a precision digital Anton Paar oscillating u-tube densimeter DMA4500 with reproducibility of $\pm 10^{-2}$ $kg \cdot m^{-3}$. The calibration was done at the temperatures of interest by dry air and ultra pure water for readjustment of instrument constants as recommended by the manufacturer. The measuring cell was thermostated with a solid-state thermostat and two integrated Pt 100 measuring sensors with temperature reproducibility of $\pm 10^{-2}$ K. The estimated uncertainty in the density measurements was $\pm 5 \times 10^{-2}$ $kg \cdot m^{-3}$.

The kinematic viscosity measurements were performed using an automatic viscosity measuring unit (Visco-Clock, Petrotest) and two Ubbelohde capillary viscometers (type MA, ASTM D445-IP-71, Petrotest Instruments GmbH products) of sizes 0 and 0C and of the range (0.3 to 1.0) and (0.6 to 3.0) $mm^2 \cdot s^{-1}$, respectively. The viscosity measuring unit were held in a

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Table 1. Details of the Pure Chemicals: Purities, Densities, Viscosities, and Refractive Indices at 293.15 K

				ρ/(kg·m^{-3})		η/(mPa·s)		n_D	
compound	supplier	CAS Registry No.	GC purity%	exp	lit	exp	lit	exp	lit
anisole	Fluka	100-66-3	99.15	993.80	993.81[a] 993.86[b]	1.084	1.085[a]	1.5177	1.5177[b] 1.5175[c]
benzene	Fluka	71-43-2	99.46	877.43	877.48[e] 878.9[c]	0.647	0.648[d] 0.6480[e]	1.5011	1.5011[b] 1.5010[c]
methylbenzene	Aldrich	108-88-3	99.49	866.88	866.89[d]	0.588	0.5877[d] 0.585[e]	1.4962	1.4960[b]
ethylbenzene	Aldrich	100-41-4	99.75	866.95	866.92[d]	0.669	0.6701[d]	1.4957	1.4958[b]
propylbenzene	Aldrich	103-65-1	99.21	863.13	863.30[e] 864.1[d]	0.855	0.8565[e]	1.4916	1.4919[b]
butylbenzene	Aldrich	104-51-8	99.21	861.26	861.3[b] 861.22[e]	1.034	1.032[e]	1.4895	1.4898[b]

[a] Al-Jimaz et al.[1] [b] Riddick et al.[14] [c] Prasad et al.[2] [d] TRC tables.[15] [e] DIPPR.[16]

thermostatic bath (TV-1000, TAMSON) and connected to a circulating water bath (HAAKE C25, with temperature control unit F6) to maintain the desired temperature within $\pm 10^{-2}$ K. A digital thermometer (model F250 Automatic System Laboratories, UK) with a thermistor probe was used to ensure the measurement of the bath temperature within an uncertainty of $\pm 2 \times 10^{-2}$ K. The efflux times (t/s) were determined on a digital display within an uncertainty $\pm$ 0.01 s/+1 digit, when the meniscus of the liquid flows from the upper to lower measurement mark of the measurement bulb of the viscometer. The efflux time was converted to kinematic viscosities (υ) by means of the following equation:

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

where k is the capillary constant of viscometer, t is the efflux time, and υ is the Hagenbach correction. The viscometer was calibrated with standard samples N.4 (b), N.8 (b), and N1.0 of kinematic viscosity (0.47, 0.95, and 1.3) mm^2·s^{-1}, respectively, at 293.15 K (Canon Instruments Co.). The average of three calculated values of k was used in the calculation at each working temperature, which did not differ by more than $\pm 10^{-3}$ mm^2·s^{-2}. The uncertainty of kinematic viscosity was estimated, through error analysis, to be better than $\pm 2.5 \times 10^{-3}$ mm^2·s^{-1}. The values of dynamic viscosity (η) were calculated by using the relation

$$\eta = \rho \cdot \upsilon \tag{2}$$

where ρ and υ are density and kinematic viscosity, respectively.

Refractive indices were measured for the sodium D-line at temperatures (293.15 and 303.15) K, using a thermostated Digital refractometer (ABBE Mark II model 10481, Cambridge Instruments Inc. USA) with a precision of 10^{-4}. The temperature is controlled by circulating water into the instrument through a thermostatically controlled bath (HAAKE C25) with temperature control unit (F6) to maintain the desired temperature within $\pm 10^{-2}$ K. The calibration of the instrument was done by means of a glass test piece of known refractive index supplied by the manufacturer. The sample mixtures were injected into the prism instrument assembly by a Hamilton airtight syringe. The refractive index values were recorded when the liquid mixtures attained the constant temperature. For all the mixtures and pure components, triplicate measurements were performed, and the uncertainty in refractive indices was estimated to be better than $\pm 1.4 \times 10^{-4}$.

Results and Discussion

Experimental values of density (ρ), viscosity (η), and refractive index (n_D) of all binary mixtures are given in Table 2.

Excess molar volume (V^E), viscosity deviation ($\Delta\eta$), and molar refraction deviation (ΔR_m) were calculated through the following relations,[17,12,13] respectively:

$$V^E = \sum_{i=1}^{2} x_i M_i \left(\frac{1}{\rho_m} - \frac{1}{\rho_i}\right) \tag{3}$$

$$\Delta\eta = \eta_m - \sum_{i=1}^{2} (x_i \eta_i) \tag{4}$$

$$\Delta R_m = \frac{\sum_i x_i M_i}{\rho_m} \frac{{n_D}^2 - 1}{{n_D}^2 + 2} - \sum_i x_i \frac{M_i}{\rho_i} \frac{{n_{Di}}^2 - 1}{{n_{Di}}^2 + 2} \tag{5}$$

where x, M, ρ, η, and n_D are mole fraction, molar mass, density, dynamic viscosity, and refractive index, respectively. The subscripts i and m represent pure components and mixture, respectively.

The calculated values using the above relations for the binary mixtures of anisole + benzene, + methylbenzene, + ethylbenzene, + propylbenzene, and + butylbenzene at (293.15 and 303.15) K and at atmospheric pressure are listed in Table 3.

The excess properties fitted to a Redlich −Kister[8] polynomial type:

$$Y = x_1 x_2 \sum_{i \geq 0} a_i (x_1 - x_2)^i \tag{6}$$

where Y refers to V^E, $\Delta\eta$, or ΔR_m, and x_1 and x_2 are the mole fractions of pure components 1 and 2, respectively. a_i is the adjustable parameters, which were estimated using multiple regression analysis based on least-squares method.[18] The correlated results are shown in Table 4, in which the tabulated standard deviation (σ) was defined as

$$\sigma = \left[\frac{\sum_{i=1}^{n} (Y_{exp} - Y_{cal})^2}{(n - p)}\right]^{1/2} \tag{7}$$

where Y_{exp}, Y_{cal}, n, and p denote the experimental, calculated excess properties, number of data points, and number of coefficients, respectively.

Figure 1 shows that the excess molar volume (V^E) is negative over the whole composition range for all the binary mixtures at 293.15 K. As the side chain length in the aromatic ring increases from benzene to butylbenzene, the magnitudes of V^E decrease in the following order: benzene > methylbenzene >

Table 2. Experimental Values of Density (ρ), Viscosity (η), and Refractive Index (n_D) for the Binary Mixtures at (293.15 and 303.15) K

	293.15 K			303.15 K		
x_1	ρ kg·m^{-3}	η mPa·s	n_{Dm}	ρ kg·m^{-3}	η mPa·s	n_{Dm}
			Anisole (1) + Benzene (2)			
0.0000	877.43	0.647	1.5011	868.26	0.563	1.4947
0.0938	889.80	0.677	1.5032	881.47	0.587	1.4967
0.1955	903.56	0.711	1.5053	895.16	0.616	1.4989
0.3053	917.74	0.751	1.5074	909.24	0.649	1.5011
0.3994	929.35	0.788	1.5091	920.76	0.679	1.5028
0.5000	941.27	0.829	1.5108	932.57	0.714	1.5046
0.6005	952.68	0.874	1.5124	943.88	0.751	1.5064
0.6996	963.47	0.921	1.5139	954.56	0.791	1.5080
0.8013	974.11	0.972	1.5153	965.08	0.836	1.5096
0.8978	983.80	1.025	1.5166	974.66	0.880	1.5110
1.0000	993.80	1.084	1.5177	984.37	0.931	1.5124
			Anisole (1) + Methylbenzene (2)			
0.0000	866.88	0.588	1.4962	857.46	0.523	1.4914
0.0966	879.58	0.620	1.4993	870.21	0.549	1.4936
0.1954	892.47	0.656	1.5016	883.13	0.579	1.4959
0.2911	904.89	0.693	1.5037	895.55	0.610	1.4981
0.3936	918.06	0.736	1.5060	908.76	0.645	1.5003
0.5043	932.17	0.787	1.5083	922.89	0.687	1.5027
0.5985	944.06	0.834	1.5102	934.80	0.726	1.5046
0.6995	956.70	0.890	1.5122	947.44	0.772	1.5067
0.7956	968.63	0.947	1.5140	959.38	0.818	1.5085
0.8986	981.29	1.013	1.5159	972.06	0.872	1.5105
1.0000	993.80	1.084	1.5177	984.37	0.931	1.5124
			Anisole (1) + Ethylbenzene (2)			
0.0000	866.95	0.669	1.4957	858.01	0.596	1.4902
0.1061	879.21	0.691	1.4977	870.49	0.616	1.4922
0.2202	892.90	0.721	1.5000	884.19	0.639	1.4944
0.3206	905.19	0.752	1.5020	896.45	0.662	1.4964
0.4278	918.51	0.789	1.5041	909.71	0.689	1.4986
0.5402	932.69	0.834	1.5065	923.84	0.725	1.5010
0.6322	944.49	0.876	1.5086	935.58	0.759	1.5031
0.7282	956.99	0.923	1.5108	948.02	0.798	1.5053
0.8198	969.11	0.973	1.5130	960.07	0.841	1.5075
0.8994	979.84	1.020	1.5153	970.71	0.878	1.5099
1.0000	993.80	1.084	1.5177	984.37	0.931	1.5124
			Anisole (1) + Propylbenzene (2)			
0.0000	863.13	0.855	1.4916	854.71	0.744	1.4858
0.1216	876.73	0.857	1.4944	868.36	0.748	1.4886
0.2422	890.73	0.862	1.4972	882.36	0.752	1.4914
0.3455	903.18	0.874	1.4996	894.78	0.758	1.4939
0.4531	916.62	0.892	1.5023	908.15	0.770	1.4966
0.5658	931.23	0.915	1.5051	922.67	0.790	1.4995
0.6574	943.52	0.940	1.5076	934.90	0.812	1.5019
0.7486	956.19	0.971	1.5101	947.46	0.840	1.5045
0.8349	968.57	1.005	1.5126	959.71	0.870	1.5070
0.9160	980.65	1.042	1.5150	971.62	0.899	1.5095
1.0000	993.80	1.084	1.5177	984.37	0.931	1.5124
			Anisole (1) + Butylbenzene (2)			
0.0000	861.26	1.034	1.4895	852.23	0.893	1.4845
0.1238	873.01	1.005	1.4923	865.04	0.872	1.4872
0.2250	884.01	0.985	1.4948	875.92	0.855	1.4896
0.3541	898.83	0.971	1.4980	890.71	0.841	1.4927
0.4800	914.40	0.965	1.5014	906.13	0.837	1.4961
0.5810	927.77	0.970	1.5042	919.36	0.842	1.4989
0.6700	940.23	0.983	1.5068	931.73	0.851	1.5014
0.7672	954.65	1.002	1.5097	946.15	0.867	1.5043
0.8483	967.50	1.027	1.5123	958.84	0.885	1.5068
0.9201	979.53	1.052	1.5148	970.60	0.905	1.5093
1.0000	993.80	1.084	1.5177	984.37	0.931	1.5124

ethylbenzene > propylbenzene > butylbenzene. The absolute values of V^E increase with an increase in temperature with the same dependencies and systematic variation for all of the mixtures as listed in Table 3. Figure 2 shows the decrease of equimolar excess molar volumes (V^E) at $x_1 = 0.5$, with the number of carbon atoms on the alkyl group attached to benzene ring at (293.15 and 303.15) K. The comparison of $V^E_{(x=0.5)}$ values of binary liquid mixtures, composed of a branched chain ether (methyl-1,1-dimethylethyl ether) + benzene, or methylbenzene, or ethylbenzene, or propylbenzene at 303.15 K,[19] with $V^E_{(x1=0.5)}$ values in this study at 303.15 K, shows similar trend of behavior for both studies as shown in same figure. However, the equimolar excess molar volumes at 303.15 K, (−0.037 to −0.266) cm^3·mol^{-1}, are smaller in magnitude than in branched chain ether systems, (−0.213 to −0.623) cm^3·mol^{-1}.

Table 3. Excess Molar Volume (V^E), Viscosity Deviation ($\Delta\eta$), Molar Refractivity Deviation (ΔR_m) for the Binary Mixtures at (293.15 and 303.15) K

	293.15 K			303.15 K		
	V^E	$\Delta\eta$	ΔR_m	V^E	$\Delta\eta$	ΔR_m
x_1	cm^3·mol^{-1}	mPa·s	cm^3·mol^{-1}	cm^3·mol^{-1}	mPa·s	cm^3·mol^{-1}
			Anisole (1) + Benzene (2)			
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0938	−0.0129	−0.0114	0.0055	−0.0191	−0.0100	0.0032
0.1955	−0.0233	−0.0220	0.0128	−0.0343	−0.0189	0.0070
0.3053	−0.0313	−0.0297	0.0191	−0.0453	−0.0265	0.0095
0.3994	−0.0353	−0.0344	0.0221	−0.0500	−0.0308	0.0110
0.5000	−0.0367	−0.0367	0.0240	−0.0512	−0.0330	0.0117
0.6005	−0.0347	−0.0362	0.0224	−0.0496	−0.0325	0.0114
0.6996	−0.0308	−0.0324	0.0194	−0.0433	−0.0288	0.0102
0.8013	−0.0240	−0.0253	0.0145	−0.0333	−0.0219	0.0074
0.8978	−0.0140	−0.0150	0.0087	−0.0203	−0.0127	0.0038
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			Anisole (1) + Methylbenzene (2)			
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0966	−0.0230	−0.0162	0.0024	−0.0289	−0.0134	0.0010
0.1954	−0.0423	−0.0293	0.0045	−0.0516	−0.0241	0.0019
0.2911	−0.0579	−0.0398	0.0057	−0.0683	−0.0321	0.0028
0.3936	−0.0657	−0.0475	0.0068	−0.0797	−0.0383	0.0035
0.5043	−0.0694	−0.0516	0.0072	−0.0840	−0.0413	0.0038
0.5985	−0.0667	−0.0509	0.0071	−0.0814	−0.0410	0.0038
0.6995	−0.0584	−0.0457	0.0060	−0.0710	−0.0365	0.0032
0.7956	−0.0446	−0.0359	0.0044	−0.0552	−0.0289	0.0022
0.8986	−0.0253	−0.0212	0.0022	−0.0340	−0.0170	0.0009
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			Anisole (1) + Ethylbenzene (2)			
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.1061	−0.0413	−0.0172	−0.0109	−0.0612	−0.0149	−0.0168
0.2202	−0.0866	−0.0320	−0.0243	−0.1152	−0.0295	−0.0323
0.3206	−0.1181	−0.0424	−0.0336	−0.1498	−0.0392	−0.0428
0.4278	−0.1364	−0.0496	−0.0392	−0.1669	−0.0454	−0.0494
0.5402	−0.1361	−0.0513	−0.0395	−0.1666	−0.0476	−0.0494
0.6322	−0.1240	−0.0488	−0.0353	−0.1518	−0.0454	−0.0449
0.7282	−0.1009	−0.0417	−0.0269	−0.1256	−0.0397	−0.0370
0.8198	−0.0711	−0.0313	−0.0176	−0.0907	−0.0290	−0.0257
0.8994	−0.0420	−0.0187	−0.0089	−0.0546	−0.0170	−0.0133
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			Anisole (1) + Propylbenzene (2)			
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.1216	−0.0950	−0.0256	−0.0224	−0.1240	−0.0240	−0.0280
0.2422	−0.1640	−0.0431	−0.0428	−0.2060	−0.0395	−0.0496
0.3455	−0.2031	−0.0536	−0.0554	−0.2510	−0.0500	−0.0622
0.4531	−0.2220	−0.0590	−0.0611	−0.2710	−0.0547	−0.0685
0.5658	−0.2170	−0.0589	−0.0600	−0.2640	−0.0556	−0.0672
0.6574	−0.1940	−0.0540	−0.0542	−0.2410	−0.0514	−0.0613
0.7486	−0.1560	−0.0447	−0.0440	−0.1970	−0.0427	−0.0504
0.8349	−0.1080	−0.0329	−0.0311	−0.1400	−0.0305	−0.0369
0.9160	−0.0560	−0.0183	−0.0163	−0.0750	−0.0183	−0.0218
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
			Anisole (1) + Butylbenzene (2)			
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.1238	−0.1340	−0.0328	−0.0340	−0.1670	−0.0298	−0.0400
0.2250	−0.2099	−0.0523	−0.0558	−0.2390	−0.0470	−0.0634
0.3541	−0.2650	−0.0684	−0.0731	−0.3020	−0.0622	−0.0811
0.4800	−0.2780	−0.0743	−0.0773	−0.3225	−0.0685	−0.0849
0.5810	−0.2645	−0.0727	−0.0697	−0.3030	−0.0667	−0.0768
0.6700	−0.2330	−0.0669	−0.0620	−0.2740	−0.0594	−0.0691
0.7672	−0.1842	−0.0548	−0.0542	−0.2330	−0.0503	−0.0609
0.8483	−0.1307	−0.0396	−0.0435	−0.1740	−0.0353	−0.0494
0.9201	−0.0740	−0.0230	−0.0279	−0.1000	−0.0203	−0.0315
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figure 3 shows the viscosity deviations ($\Delta\eta$) at 293.15 K for all the mixtures. The viscosity deviations are negative and

Table 4. Redlich−Kister Coefficients (a_i) and Standard Deviation (σ) for the Binary Mixtures at (293.15 and 303.15) K

	T/K	a_0	a_1	a_2	a_3	σs
			Anisole (1) + Benzene (2)			
V^E/cm^3·mol^{-1}	293.15	−0.14644	0.00050	−0.00890	0.00025	0.00026
ΔR_m/cm^3·mol^{-1}		0.09439	0.00231	−0.02191	−0.03190	0.00022
$\Delta\eta$/mPa·s		−0.14674	0.01848	−0.00309	−0.00178	0.00018
V^E/cm^3·mol^{-1}	303.15	−0.20515	−0.01114	−0.02781	0.01460	0.00029
ΔR_m/cm^3·mol^{-1}		0.04726	−0.00486	−0.01144	0.0044	0.00026
$\Delta\eta$/mPa·s		−0.13119	0.01654	0.00573	−0.0047	0.00011
			Anisole (1) + Methylbenzene (2)			
V^E/cm^3·mol^{-1}	293.15	−0.27700	0.00455	0.01000	0.00647	0.00064
ΔR_m/cm^3·mol^{-1}		0.02904	−0.00176	−0.00507	0.00604	0.00008
$\Delta\eta$/mPa·s		−0.20315	0.03113	−0.00574	−0.00341	0.00046
V^E/cm^3·mol^{-1}	303.15	−0.33264	0.00553	−0.02017	0.01740	0.00087
ΔR_m/cm^3·mol^{-1}		0.01554	−0.00261	−0.00800	0.00505	0.00006
$\Delta\eta$/mPa·s		−0.16519	0.02531	−0.00734	−0.00779	0.00029
			Anisole (1) + Ethylbenzene (2)			
V^E/cm^3·mol^{-1}	293.15	−0.55377	−0.03963	0.16791	0.09229	0.00035
ΔR_m/cm^3·mol^{-1}		−0.16068	−0.01378	0.08583	0.00671	0.00013
$\Delta\eta$/mPa·s		−0.23717	0.02051	−0.00188	−0.01425	0.00031
V^E/cm^3·mol^{-1}	303.15	−0.67610	−0.06668	0.08268	0.06495	0.00045
ΔR_m/cm^3·mol^{-1}		−0.20292	−0.00090	0.06444	−0.02776	0.00060
$\Delta\eta$/mPa·s		−0.20491	0.02908	0.03664	0.00448	0.00057
			Anisole (1) + Propylbenzene (2)			
V^E/cm^3·mol^{-1}	293.15	−0.89199	−0.05191	0.12145	−0.0697	0.00014
ΔR_m /cm^3·mol^{-1}		−0.24752	−0.00564	0.05801	0.01948	0.00028
$\Delta\eta$/mPa·s		−0.26739	0.00733	−0.00594	−0.00448	0.00026
V^E/cm^3·mol^{-1}	303.15	−1.08905	−0.05010	0.01865	−0.10300	0.00079
ΔR_m/cm^3·mol^{-1}		−0.27438	−0.00783	0.00885	0.03020	0.00050
$\Delta\eta$/mPa·s		−0.22242	0.02498	−0.00630	−0.00107	0.00031
			Anisole (1) + Butylbenzene (2)			
V^E/cm^3·mol^{-1}	293.15	−1.10817	−0.16801	−0.02693	0.03406	0.00047
ΔR_m/cm^3·mol^{-1}		−0.28807	−0.09481	−0.06004	0.18885	0.00013
$\Delta\eta$/mPa·s		−0.33583	0.00468	−0.01226	0.00590	0.00029
V^E/cm^3·mol^{-1}	303.15	−1.21926	−0.18421	−0.31928	0.01021	0.00062
ΔR_m/cm^3·mol^{-1}		−0.31641	−0.09969	−0.09684	0.18371	0.00017
$\Delta\eta$/mPa·s		−0.35866	−0.02177	0.09394	0.05520	0.00007

their magnitudes decrease in the sequence: benzene > methylbenzene > ethylbenzene > propylbenzene > butylbenzene.

The deviations in the molar refractivity (ΔR_m; listed in Table 3) are positive for binary mixtures of anisole with benzene or methylbenzene and negative for binary mixtures of anisole with ethylbenzene, propylbenzene, or butylbenzene.

The viscosity data of the binary mixtures were correlated with the semiempirical equations proposed by Grunberg−Nissan and McAllister as reported in our previous work[1]. The data were also correlated with the Heric and Brewer[11] equation. The correlation with these equations showed the suitability of all the three relations for representing the mixing viscosities of the binary mixtures of anisole + benzene or alkylbenzene. The best correlation representing our binary system data is found to be the McAllister equation with an average standard deviation of 15×10^{-5} mm^2·s^{-1}.

For prediction of the refractive indices, the Lorentz−Lorenz equation (used in our earlier work[1]) and the following equation

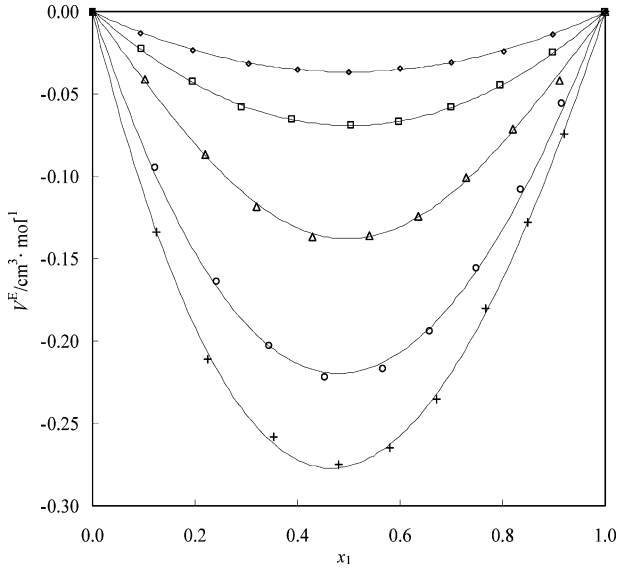

Figure 1. Excess molar volumes (V^E) for the binary mixtures: ◇, anisole + benzene; □, + methylbenzene; △, + ethylbenzene; ○, + propylbenzene; +, + butylbenzene at 293.15 K, solid line (Redlich−Kister).[8]

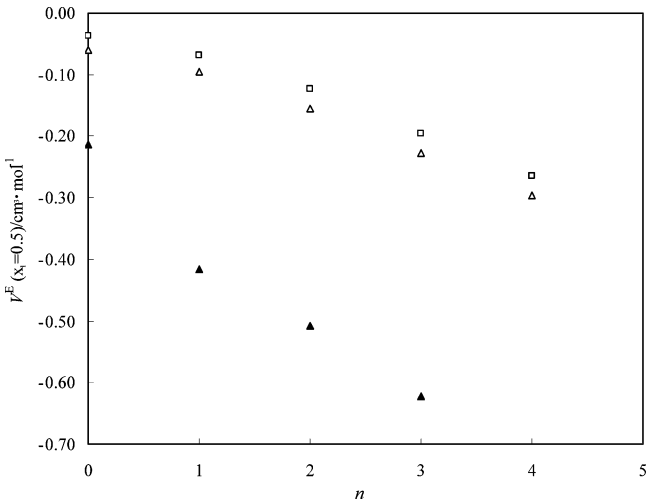

Figure 2. Equimolar excess molar volumes (V^E) against the number of carbon atoms (n) on the alkyl group for anisole (1) + alkylbenzene (2): □, 293.15 K; △, 303.15 K; branched ether (1) + alkylbenzene (2): ▲, 303.15 K (Sharma et al.).[19]

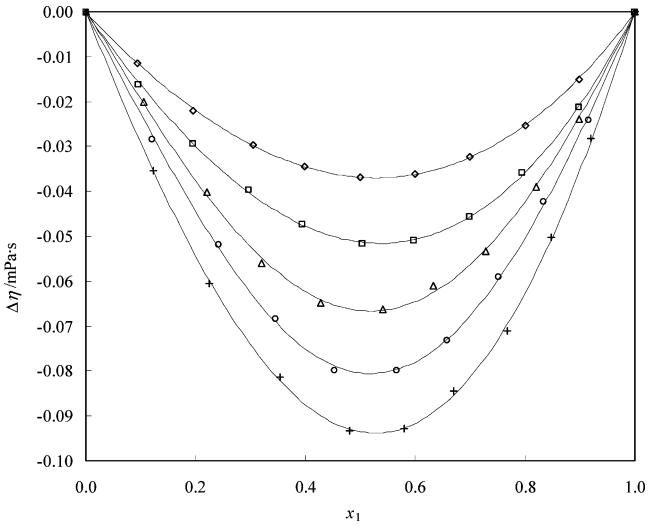

Figure 3. Viscosity deviation ($\Delta\eta$) for the binary mixtures: ◇, anisole + benzene; □, + methylbenzene; △, + ethylbenzene; ○, + propylbenzene; +, + butylbenzene at 293.15 K, solid line (Redlich−Kister).[8]

proposed by Gladstone−Dale (as reported elsewhere[12,13]) have been used:

$$n_{Dm} = \rho_m\left[\frac{n_{D1}-1}{\rho_1} - (n_{D1}-1)\frac{(1-w_1)}{\rho_1} + (n_{D2}-1)\frac{(1-w_1)}{\rho_2} + n_D\right] + 1 \quad (8)$$

where w_1 is the mass fraction of the more volatile component; ρ_m and n_{Dm} are the density and refractive index of the binary mixtures (n_{D1} and n_{D2}); and ρ_1 and ρ_2 are the refractive indices and densities of the pure components 1 and 2, respectively.

The experimental refractive index data (n_D) of anisole + benzene or alkylbenzene binary mixtures at 293.15 K were compared with the corresponding calculated values (n_{Dcal}) using the Lorentz−Lorenz and Gladstone−Dale equations with an average deviation of (32×10^{-5} and 25×10^{-5}) and (35×10^{-5} and 29×10^{-5}) at (293.15 and 303.15) K, respectively. The mixing rule proposed by Lorentz−Lorenz equation is more suitable for prediction of our data.

Conclusions

This paper reports experimental data for density, viscosity, and refractive index of anisole + benzene or methylbenzene, or ethylbenzene, or propylbenzene, or butylbenzene binary mixtures at (293.15 and 303.15) K. Excess molar volume, viscosity deviation, and molar refraction deviation have been calculated and fitted to the Redlich−Kister equation. The values of excess molar volume and viscosity deviation are negative over the entire composition range of the systems studied and exhibit a decreasing trend with the following order: benzene > methylbenzene > ethylbenzene > propylbenzene > butylbenzene. The best correlation methods for representing the viscosities and refractive index data for our binary systems were found to be the McAllister and Lorentz−Lorenz equations, respectively.

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