Viscosities, Densities, and Speeds of Sound of Binary Mixtures of Benzene, Toluene, *o*-Xylene, *m*-Xylene, *p*-Xylene, and Mesitylene with Anisole at (288.15, 293.15, 298.15, and 303.15) K

Jasem A. Al-Kandary,* Adel S. Al-Jimaz, and Abdul-Haq M. Abdul-Latif

Department of Chemical Engineering, College of Technological Studies, P.O. Box 42325, Shuwaikh 70654, Kuwait

The viscosities, densities, and speeds of sound of binary mixtures of anisole with benzene, toluene, *o*-xylene, *m*-xylene, *p*-xylene, and mesitylene over the entire range of mole fraction at temperatures (288.15, 293.15, 298.15, and 303.15) K and atmospheric pressure have been measured. Excess compressibility and deviations in viscosity have been calculated and fitted to the Redlich−Kister polynomial relation to estimate the binary coefficients and standard errors. The deviations in viscosities and excess compressibilities are negative for all binary systems. The speeds of sound have been analyzed in terms of collision factor theory and free length theory. The viscosity data were correlated with equations of Grunberg and Nissan, Tamura and Kurata, Heric and Brewer, and McAllister.

Introduction

Study of thermophysical properties of liquid mixtures are of considerable academic and industrial importance. Anisole is one of aromatic ethers that are widely used for a number of practical applications in various fields as dyes, pigment, and perfumery and as a starting point for preparation of different derivatives. Thus, a study of physical properties of the binary mixtures containing anisole has attracted a substantial interest in the literature.[1−8]

As an extension of our previous studies to measure the physical properties of the binary liquid mixtures containing aromatic ethers,[1,7−9] we report in this work the experimental results of viscosity η, density ρ, and speed of sound u at (288.15, 293.15, 298.15, and 303.15) K and atmospheric pressure for pure components and binary mixtures of anisole + benzene, or + toluene, or + isomeric xylenes, or + mesitylene over the whole composition range. From these results, deviations in speed of sound u^D, excess isentropic compressibilities k_s^E, and viscosity deviations $\Delta\eta$ have been calculated and fitted to the Redlich−Kister type polynomial equation[10] to derive the binary coefficients and the standard deviations between experimental and calculated results. The binary mixture viscosities were correlated using equations of Grunberg and Nissan,[11] McAllister,[12] Tamura and Kurata,[13] and Heric and Brewer[14] to test their relative validity. The speeds of sound in the binary mixtures have been predicted using Schaaffs' collision factor theory (CFT)[15] and Jacobson's intermolecular free length theory (FLT)[16] and compared with the experimental values. The variation of excess properties with alkyl substitution on benzene ring and temperature were investigated.

Experimental Section

Chemicals. The purities, densities, viscosities, and speeds of sound of chemicals used in this study are presented in Table 1. The analytical reagents anisole, *o*-xylene, and mestiylene were purified, and their purities were checked and confirmed by GLC analysis as explained previously.[8]

* Corresponding author. Tel: +965-9816583. Fax: +965-4811568. E-mail: jalkandary@yahoo.com.

Table 1. Pure Component Properties and Their Comparison with the Literature Values at 298.15 K

component	supplier	purity/%	ρ/kg·m^{-3} exp	ρ/kg·m^{-3} lit.	η/mPa·s exp	η/mPa·s lit.	um·s^{-1} exp	um·s^{-1} lit.
anisole	Merck	>99.3	989.15	989.15[1] 989.20[18]	1.017	1.0169[1] 1.0170[19]	1408.02	1411.1[17]
benzene	Merck	>99.5	873.60	873.60[20] 873.70[22]	0.604	0.602[20] 0.603[19]	1299.73	1299.4[21] 1299.2[20]
toluene	Merck	>99.8	862.20	862.20[23] 862.91[24]	0.556	0.556[23] 0.554[25]	1305.38	1304.69[21]
o-xylene	Fluka	>99.2	875.53	875.5[26] 875.5[28] 875.05[21]	0.756	0.754[23]	1349.39	1349.00[27] 1348.83[21]
m-xylene	Fluka	>99.5	859.77	859.8[29] 859.8[28]	0.581	0.5790[23]	1320.97	1320.29[21] 1321.2[17]
p-xylene	Fluka	>99.5	856.62	856.6[18] 856.6[20] 856.5[29]	0.611	0.6110[30] 0.6108[23]	1310.00	1309.59[21]
mesitylene	Fluka	>99.2	861.06	861.11[31] 861.11[21]	0.661	0.6603[23] 0.662[31]	1336.88	1336.31[21]

The purity of the solvents was ascertained by comparing the measured densities, viscosities, and speeds of sound of the pure components at 298.15 K with the available literature[1,17−31] as shown in Table 1. The reported experimental values conform closely to their corresponding literature values, with an average of the absolute value of deviation 0.011 kg·m^{-3}, 4×10^{-3} mPa·s, and 0.21 m·s^{-1} for density, dynamic viscosity, and speed of sound, respectively.

Meaurements. The binary mixtures were prepared freshly every time from the degassed liquid components in hermetically sealed glass vials. The mass measurements were carried out using an electronic balance (Mettler AT460) with a stated precision of $\pm 10^{-7}$ kg. The uncertainty in the mole fraction composition was estimated to be $\pm 0.4 \times 10^{-4}$. Densities and speeds of sound were measured at temperature intervals between (288.15 and 303.15) K using a vibrating-tube densimeter and Anton-Paar DSA 5000 sound analyzer. The instrument is made up of two oscillating U-tubes, one designed for measuring density based on the relation between oscillation period and density, and the second one equipped with a piezo transmitter for measuring the speed of sound from the time that sound impulse takes to travel the set distance at constant sample

10.1021/je060170c CCC: $33.50
Published on Web 09/21/2006

Table 2. Experimental Values of Density (ρ), Viscosity (η), Speed of Sound (u), and Isentropic Compressibility (k_s) for Binary Mixtures at Different Temperatures

	ρ	η	u	k_s	ρ	η	u	k_s	ρ	η	u	k_s	ρ	η	u	k_s
x_1	kg·m^{-3}	mPa·s	m·s^{-1}	TPa^{-1}	kg·m^{-3}	mPa·s	m·s^{-1}	TPa^{-1}	kg·m^{-3}	mPa·s	m·s^{-1}	TPa^{-1}	kg·m^{-3}	mPa·s	m·s^{-1}	TPa^{-1}
							Anisole (1) + Benzene (2)									
		T = 288.15 K				T = 293.15 K				T = 298.15 K				T = 303.15 K		
0.0000	884.184	0.709	1347.22	623.13	877.430	0.648	1323.30	650.83	873.580	0.604	1299.73	677.63	868.174	0.571	1276.37	707.03
0.0970	897.546	0.747	1356.78	605.24	890.999	0.683	1332.99	631.64	887.083	0.638	1309.26	657.63	881.745	0.601	1286.90	684.80
0.1750	907.884	0.777	1364.51	591.59	901.497	0.710	1340.74	617.09	897.532	0.664	1316.99	642.37	892.244	0.623	1295.43	667.87
0.2740	920.511	0.817	1374.36	575.14	914.322	0.746	1350.79	599.41	910.286	0.697	1327.13	623.73	905.059	0.651	1306.26	647.54
0.3680	932.009	0.856	1383.76	560.35	926.005	0.781	1360.47	583.46	921.904	0.730	1336.98	606.83	916.731	0.679	1316.61	629.28
0.4971	947.045	0.915	1395.20	542.45	941.295	0.833	1373.87	562.84	937.104	0.779	1350.76	584.87	932.013	0.720	1330.92	605.72
0.6230	960.925	0.976	1406.80	525.83	955.425	0.889	1387.16	543.94	951.156	0.831	1364.61	564.58	946.146	0.767	1344.97	584.28
0.7200	971.118	1.027	1418.40	511.84	965.807	0.936	1397.46	530.19	961.483	0.877	1375.47	549.74	956.542	0.808	1355.85	568.68
0.8003	979.257	1.072	1425.20	502.75	974.102	0.978	1406.11	519.23	969.734	0.918	1384.61	537.89	964.845	0.844	1364.91	556.33
0.8895	988.004	1.126	1437.45	489.84	983.017	1.027	1415.92	507.42	978.597	0.963	1394.84	525.23	973.764	0.883	1375.07	543.12
1.0000	998.441	1.188	1449.09	476.97	993.649	1.084	1428.45	493.21	989.150	1.017	1408.02	509.96	984.374	0.931	1387.66	527.56
							Anisole (1) + Toluene (2)									
		T = 288.15 K				T = 293.15 K				T = 298.15 K				T = 303.15 K		
0.0000	871.412	0.630	1349.98	629.68	866.874	0.588	1327.18	654.91	862.200	0.556	1305.38	680.64	857.464	0.523	1283.80	707.60
0.1152	886.478	0.676	1360.70	609.27	881.927	0.628	1339.06	633.29	877.272	0.594	1316.52	657.67	872.541	0.557	1295.11	683.28
0.2132	899.203	0.725	1369.87	592.63	894.629	0.671	1347.87	615.66	889.988	0.634	1325.81	639.22	885.247	0.592	1304.80	663.51
0.3098	911.684	0.770	1379.13	576.69	907.078	0.710	1357.89	598.98	902.448	0.670	1334.99	621.76	897.698	0.623	1314.38	644.80
0.4182	925.577	0.832	1389.57	559.46	920.940	0.765	1367.19	580.90	925.526	0.721	1345.35	598.56	911.571	0.667	1325.31	624.56
0.5267	939.392	0.891	1400.44	542.78	934.732	0.818	1377.57	563.36	930.133	0.769	1356.50	584.27	925.369	0.709	1336.48	605.00
0.6209	951.306	0.940	1410.05	528.79	946.626	0.861	1387.59	548.65	942.044	0.809	1366.29	568.65	937.281	0.745	1346.39	588.56
0.7382	966.034	1.014	1421.87	512.02	961.327	0.927	1398.71	531.00	956.777	0.871	1378.77	549.80	952.012	0.802	1358.84	568.88
0.8645	981.766	1.094	1434.93	494.69	977.029	0.999	1412.50	512.59	972.508	0.940	1392.74	530.11	967.753	0.862	1372.49	548.55
0.9270	989.474	1.138	1441.49	486.38	984.734	1.039	1418.89	503.60	980.221	0.977	1399.60	520.79	975.465	0.895	1379.36	538.80
1.0000	998.441	1.188	1449.09	476.97	993.653	1.084	1428.45	493.21	989.150	1.017	1408.02	509.96	984.374	0.931	1387.66	527.56
							Anisole (1) + *o*-Xylene (2)									
		T = 288.15 K				T = 293.15 K				T = 298.15 K				T = 303.15 K		
0.0000	883.285	0.871	1390.35	585.67	879.083	0.810	1369.74	608.77	875.532	0.756	1349.39	627.27	870.726	0.708	1328.30	650.91
0.0915	893.348	0.885	1394.98	575.65	889.076	0.821	1374.42	599.14	885.509	0.769	1354.00	615.98	880.756	0.718	1333.42	638.57
0.1980	905.888	0.914	1402.31	563.55	900.830	0.844	1381.74	587.39	897.159	0.790	1359.50	603.08	892.435	0.735	1339.34	624.66
0.3680	924.439	0.944	1409.02	545.18	919.973	0.868	1388.31	568.01	916.136	0.813	1368.57	582.78	911.407	0.753	1348.75	603.15
0.4954	938.936	0.979	1415.73	531.44	934.513	0.899	1394.86	553.51	930.569	0.841	1375.70	567.81	925.824	0.776	1355.92	587.50
0.6554	957.421	1.028	1424.72	514.18	953.102	0.942	1403.87	535.51	948.998	0.881	1385.12	549.24	944.269	0.811	1365.15	568.25
0.7660	970.279	1.066	1431.25	502.31	966.072	0.975	1410.43	523.14	961.882	0.914	1391.92	536.60	957.177	0.840	1371.80	555.17
0.8680	982.607	1.133	1439.41	491.18	978.090	1.035	1418.61	511.61	973.792	0.974	1398.63	524.96	969.125	0.893	1378.13	543.30
0.9160	988.769	1.159	1444.50	485.92	983.748	1.058	1424.01	506.38	979.418	0.996	1402.04	519.41	974.761	0.912	1381.20	537.76
0.9490	992.756	1.172	1447.09	482.28	987.635	1.072	1426.64	501.89	983.270	1.005	1404.30	515.71	978.630	0.922	1383.33	533.99
1.0000	998.440	1.188	1449.09	476.97	993.649	1.084	1428.45	493.21	989.104	1.017	1408.02	509.96	984.372	0.931	1386.66	527.56
							Anisole (1) + *m*-Xylene (2)									
		T = 288.15 K				T = 293.15 K				T = 298.15 K				T = 303.15 K		
0.0000	868.317	0.666	1362.61	620.27	864.049	0.619	1357.05	628.45	859.767	0.581	1320.97	666.55	855.469	0.552	1300.34	691.32
0.1144	882.011	0.696	1369.25	603.88	877.742	0.645	1361.03	615.03	873.473	0.607	1328.53	648.64	869.172	0.574	1308.00	672.48
0.2566	899.519	0.745	1380.52	583.03	895.185	0.688	1367.42	597.42	890.874	0.647	1339.22	625.87	886.499	0.604	1318.65	648.73
0.3821	915.327	0.799	1390.89	564.73	910.905	0.734	1374.34	581.21	906.561	0.687	1349.80	605.43	902.126	0.639	1328.78	627.81
0.5034	930.924	0.856	1401.01	547.27	926.441	0.783	1381.87	565.26	922.056	0.734	1360.06	586.31	917.578	0.677	1339.08	607.78
0.6546	950.873	0.933	1414.06	525.59	946.321	0.851	1392.44	545.01	941.900	0.798	1373.48	562.80	937.368	0.733	1352.59	583.12
0.7535	964.193	0.995	1424.03	511.69	959.605	0.908	1401.69	530.40	955.192	0.852	1382.55	547.71	950.619	0.782	1362.03	567.05
0.8432	976.464	1.049	1431.95	499.25	971.843	0.958	1409.57	517.88	967.423	0.899	1390.95	534.27	962.844	0.824	1370.97	552.57
0.9133	986.213	1.103	1439.34	489.45	981.575	1.008	1417.45	507.06	977.136	0.947	1398.13	523.54	972.502	0.868	1378.31	541.27
0.9576	992.455	1.149	1445.22	483.15	987.755	1.051	1423.98	499.28	983.283	0.988	1403.14	516.56	978.641	0.905	1383.07	534.18
1.0000	998.440	1.188	1449.09	476.97	993.651	1.084	1428.45	493.21	989.150	1.017	1408.02	509.96	984.372	0.931	1387.66	527.56
							Anisole (1) + *p*-Xylene (2)									
		T = 288.15 K				T = 293.15 K				T = 298.15 K				T = 303.15 K		
0.0000	865.253	0.701	1351.99	632.28	860.917	0.650	1331.11	655.56	856.617	0.611	1310.00	680.25	852.255	0.576	1289.68	705.45
0.0822	875.328	0.728	1360.32	618.50	871.032	0.674	1339.53	639.82	866.765	0.635	1317.40	664.76	862.434	0.597	1296.93	689.35
0.1870	888.441	0.778	1373.07	601.29	884.105	0.717	1352.53	618.31	879.807	0.674	1326.46	645.99	875.432	0.628	1306.46	669.24
0.3100	904.181	0.829	1384.40	581.29	899.758	0.761	1364.03	597.35	895.413	0.714	1337.54	624.26	890.974	0.662	1317.59	646.51
0.4700	925.057	0.884	1395.90	555.97	920.561	0.809	1375.26	574.35	916.177	0.759	1352.25	596.91	911.659	0.700	1332.66	617.63
0.6370	947.540	0.958	1410.41	530.42	942.968	0.875	1389.88	548.97	938.559	0.821	1368.24	569.13	933.983	0.754	1349.07	588.29
0.7470	962.692	1.013	1420.62	514.05	958.092	0.925	1400.31	532.28	953.665	0.868	1379.31	551.16	949.069	0.798	1360.53	569.23
0.8220	973.119	1.109	1437.00	503.06	968.502	1.013	1416.71	514.45	964.094	0.952	1387.37	538.88	959.511	0.875	1368.50	556.49
0.8880	982.387	1.145	1443.00	493.41	977.769	1.046	1422.54	505.40	973.344	0.985	1394.84	528.06	968.761	0.903	1375.64	545.48
0.9490	991.051	1.167	1446.30	484.40	986.356	1.066	1425.78	498.73	981.943	1.003	1401.82	518.24	977.313	0.918	1382.26	535.53
1.0000	998.440	1.188	1449.09	476.97	993.651	1.084	1428.45	493.21	989.105	1.017	1408.02	509.96	984.372	0.931	1387.66	527.56
							Anisole (1) + Mesitylene (2)									
		T = 288.15 K				T = 293.15 K				T = 298.15 K				T = 303.15 K		
0.0000	869.169	0.754	1377.49	606.34	865.072	0.705	1357.05	627.71	861.062	0.661	1336.88	649.80	856.95	0.621	1316.82	672.96
0.0740	876.661	0.769	1383.10	596.76	872.553	0.716	1361.68	618.10	868.529	0.674	1342.58	638.75	864.41	0.633	1320.50	663.45
0.1810	887.986	0.802	1390.74	583.08	883.818	0.743	1368.11	604.50	879.758	0.697	1350.07	623.63	875.58	0.650	1326.66	648.91
0.3340	905.232	0.849	1400.32	563.56	900.968	0.782	1376.15	586.08	896.835	0.733	1359.95	602.89	892.57	0.677	1336.13	627.57
0.4982	925.260	0.893	1408.05	542.73	920.888	0.819	1383.27	567.51	916.671	0.767	1370.45	580.84	912.31	0.706	1347.06	604.06
0.6280	942.318	0.965	1420.28	526.08	937.858	0.883	1395.12	547.82	933.575	0.827	1379.42	562.94	929.13	0.758	1356.18	585.18
0.7512	959.611	1.005	1426.34	510.09	955.065	0.920	1401.55	533.03	950.712	0.863	1388.14	545.86	946.19	0.792	1365.36	566.92
0.8140	968.893	1.061	1433.83	501.82	964.301	0.971	1410.01	521.61	959.910	0.912	1392.88	536.96	955.34	0.837	1370.45	557.33
0.8750	978.238	1.101	1438.58	493.73	973.590	1.007	1415.83	512.39	969.162	0.946	1397.60	528.25	964.55	0.870	1375.58	547.90
0.9400	988.554	1.158	1445.56	485.00	983.844	1.058	1424.20	501.11	979.363	0.993	1402.79	518.88	974.70	0.912	1382.77	536.57
1.0000	998.440	1.188	1449.09	476.97	993.651	1.084	1428.45	493.21	989.106	1.017	1408.02	509.96	984.37	0.931	1386.66	527.56

Table 3. Coefficients and Standard Deviations for the Density (ρ), Viscosity (η), and Speed of Sound (u) for the Binary Mixtures from T = (288.15 to 303.15) K

	b_0	b_1	b_2	b_3	b_4	σ	b_0	b_1	b_2	b_3	b_4	σ
Anisole (1) + Benzene (2)												
	T = 288.15 K						T = 293.15 K					
ρ/kg·m^{-3}	884.181	140.467	−30.755	4.792	−0.177	0.0023	877.428	144.127	−32.857	7.057	−1.209	0.0023
η/mPa·s	0.709	0.396	−0.083	0.302	−0.136	0.002	0.648	0.345	−0.004	0.149	−0.055	0.003
u/m·s^{-1}	1346.98	102.41	−8.64	−5.68	14.07	0.12	1323.30	99.05	5.64	−1.93	2.39	0.04
	T = 298.15 K						T = 303.15 K					
ρ/kg·m^{-3}	873.583	142.121	−30.189	2.650	0.920	0.0028	868.173	143.161	−32.041	5.468	−0.443	0.0013
η/mPa·s	0.604	0.308	0.026	0.127	−0.052	0.001	0.571	0.339	−0.335	0.675	−0.320	0.001
u/m·s^{-1}	1299.70	97.64	9.76	0.10	1.39	0.07	1276.39	107.81	5.30	−3.95	2.13	0.01
Anisole (1) + Toluene (2)												
	T = 288.15 K						T = 293.15 K					
ρ/kg·m^{-3}	871.410	133.800	−5.410	−3.114	1.755	0.0038	866.877	134.007	−7.631	0.726	−0.349	0.0043
η/mPa·s	0.629	0.387	0.355	−0.379	0.196	0.003	0.588	0.328	0.296	−0.249	0.121	0.002
u/m·s^{-1}	1350.02	91.05	9.53	−0.67	−0.83	0.04	1327.26	102.43	−22.96	20.35	0.91	0.21
	T = 298.15 K						T = 303.15 K					
ρ/kg·m^{-3}	862.213	134.696	−10.970	6.816	−3.659	0.0059	857.461	131.946	4.880	−12.130	2.217	0.0036
η/mPa·s	0.556	0.327	0.128	0.023	−0.017	0.002	0.523	0.285	0.121	0.016	−0.015	0.001
u/m·s^{-1}	1305.40	97.53	−15.80	36.06	−15.22	0.04	1283.84	96.70	6.69	−1.92	2.32	0.04
Anisole (1) + *o*-Xylene (2)												
	T = 288.15 K						T = 293.15 K					
ρ/kg·m^{-3}	883.285	110.576	0.747	9.132	−5.304	0.0033	879.082	111.654	−6.835	20.823	−11.056	0.0071
η/mPa·s	0.871	0.312	−0.751	1.445	−0.683	0.004	0.810	0.171	−0.209	0.585	−0.262	0.003
u/m·s^{-1}	1389.93	75.72	−11.21	16.25	−68.64	0.19	1369.30	77.75	−12.83	18.17	−75.87	0.15
	T = 298.15 K						T = 303.15 K					
ρ/kg·m^{-3}	875.529	113.353	−18.468	38.338	−19.584	0.0067	870.724	113.562	−20.141	43.532	−23.296	0.0080
η/mPa·s	0.756	0.142	0.004	0.075	0.058	0.003	0.708	0.118	−0.021	0.081	0.063	0.003
u/m·s^{-1}	1349.39	49.65	7.47	−3.55	5.08	0.02	1328.34	55.25	0.28	−0.08	2.90	0.03
Anisole (1) + *m*-Xylene (2)												
	T = 288.15 K						T = 293.15 K					
ρ/kg·m^{-3}	868.319	121.221	0.359	15.760	−7.222	0.0052	864.049	121.249	−0.399	16.174	−7.414	0.0052
η/mPa·s	0.664	0.276	0.290	−0.266	0.228	0.002	0.619	0.149	0.643	−0.834	0.507	0.001
u/m·s^{-1}	1362.52	53.66	84.96	−10.05	52.43	0.22	1357.03	29.43	53.34	−45.13	34.13	0.16
	T = 298.15 K						T = 303.15 K					
ρ/kg·m^{-3}	859.762	119.754	2.188	14.264	−6.997	0.0080	855.467	121.771	−6.465	26.243	−12.639	0.0019
η/mPa·s	0.581	0.227	0.115	0.020	0.074	0.002	0.552	0.180	0.096	0.034	0.069	0.002
u/m·s^{-1}	1321.01	57.09	77.12	−96.45	49.22	0.08	1300.31	63.86	34.89	−24.08	12.73	0.03
Anisole (1) + *p*-Xylene (2)												
	T = 288.15 K						T = 293.15 K					
ρ/kg·m^{-3}	865.253	122.767	6.819	7.649	−4.053	0.0025	860.910	124.325	−1.280	19.049	−9.386	0.0061
η/mPa·s	0.699	0.351	0.038	0.095	0.023	0.001	0.650	0.291	0.056	0.097	0.012	0.003
u/m·s^{-1}	1351.91	17.21	−37.82	59.04	−28.66	0.23	1330.98	17.77	−40.55	64.92	−31.30	0.14
	T = 298.15 K						T = 303.15 K					
ρ/kg·m^{-3}	856.612	124.119	−0.975	19.122	−9.789	0.0078	852.251	126.242	−11.907	35.366	−17.465	0.0018
η/mPa·s	0.611	0.297	−0.025	0.109	0.048	0.002	0.577	0.306	−0.200	0.198	0.076	0.004
u/m·s^{-1}	1310.04	87.97	1.23	2.04	6.75	0.05	1289.74	86.86	8.13	3.80	−0.71	0.09
Anisole (1) + Mesitylene (2)												
	T = 288.15 K						T = 293.15 K					
ρ/kg·m^{-3}	869.165	98.955	26.458	−1.164	5.025	0.0011	865.070	98.888	24.508	1.596	3.589	0.0049
η/mPa·s	0.751	0.263	0.067	0.058	0.050	0.003	0.705	0.192	0.087	0.084	0.017	0.004
u/m·s^{-1}	1377.27	92.77	−13.43	91.53	−79.49	0.18	1356.96	80.44	−13.18	20.59	−83.12	0.11
	T = 298.15 K						T = 303.15 K					
ρ/kg·m^{-3}	861.057	99.278	21.354	5.876	1.619	0.0078	856.953	98.813	20.472	8.271	−0.137	0.0081
η/mPa·s	0.661	0.191	0.015	0.163	−0.004	0.004	0.621	0.199	−0.406	0.987	−0.470	0.003
u/m·s^{-1}	1336.81	71.89	−11.48	0.24	10.39	0.15	1316.78	51.78	21.12	−11.17	8.79	0.23

temperature. The temperature control within the unit was achieved by the built-in integrated thermostat with cascaded Peltier elements and Pt-100 thermometer. The calibration of the instrument was done, at temperature of interest, by dry air and with a certified ultrapure water supplied by manufacturer as a standards with density and speed of sound values (999.099 kg·m^{-3}/1466.25 m·s^{-1}), (998.203 kg·m^{-3}/1482.66 m·s^{-1}), (997.043 kg·m^{-3}/1497.00 m·s^{-1}), and (995.645 kg·m^{-3}/1509.44 m·s^{-1}) at (288.15, 293.15, 298.15, and 303.15) K, respectively. For all mixtures and pure components, triplicate density and speed of sound measurements were performed, and the results were averaged. Although the uncertainty of the measured density and speed of sound were within $\pm$ 7 $\times$ 10^{-3} kg·m^{-3} and $\pm$ 0.15 m·s^{-1}, respectively, the imprecision of the instrument was $\pm$ 1 $\times$ 10^{-3} kg·m^{-3} and $\pm$ 0.1 m·s^{-1}, respectively.

Dynamics viscosity η measurements of all pure components and their binary mixtures were determined by using a digital Anton Paar Stabinger viscometer (model SVM 3000/G2). This instrument is made up of two measuring cells, one designed for measuring density of the samples based on the relation

Table 4. Values of Heat Capacities ($C^{\circ}_{p,i}$) of Pure Components at T = (288.15 to 303.15) K

	$C^{\circ}_{p,i}$ /J·mol^{-1}·K^{-1}			
	T = 288.15 K	T = 293.15 K	T = 298.15 K	T = 303.15 K
anisole	197.50	198.60	199.81	201.60
benzene	134.32	135.38	136.95	137.67
toluene	155.03	155.70	157.29	158.00
o-xylene	182.60	186.40	188.07	190.15
m-xylene	179.04	180.60	182.44	183.74
p-xylene	178.20	179.90	181.66	183.03
mesitylene	206.20	208.10	209.10	210.00

between oscillation period and density. The other one is used for dynamic viscosity measurements and consists of a tube filled with sample liquid rotating at a constant speed ω_1. A hollow measuring rotor (titanium rotor) of low density swims in this tube and is centered in a heavier sample liquid by buoyancy forces. The measuring gap is formed between the tube and the rotor. The rotor is guided axially by a built-in permanent magnet. The rotating magnetic field delivers the speed signal and induces eddy currents in the surrounding copper casing. The rotor speed

Table 5. Coefficients of equation 5 for Density of Pure Components at T = (288.18 to 303.15) K

	A_1	A_2	A_3
anisole	1012.517	−0.94390	0.00021
benzene	908.708	−1.99122	0.02179
toluene	884.298	−0.82458	−0.00234
o-xylene	892.733	−0.54290	−0.00625
m-xylene	880.863	−0.82734	−0.00064
p-xylene	877.948	−0.83834	−0.00060
mesitylene	881.123	−0.79100	−0.00049

Table 6. Isobaric Expansion Coefficients of Pure Components at Temperature Range (288.15 to 303.15) K

	α_i°/kK^{-1}			
	T = 288.15 K	T = 293.15 K	T = 298.15 K	T = 303.15 K
anisole	0.939	0.941	0.953	0.976
benzene	0.983	1.090	1.193	1.203
toluene	1.027	1.059	1.092	1.125
o-xylene	0.838	0.914	0.946	0.963
m-xylene	0.975	0.987	1.005	1.012
p-xylene	0.974	0.985	1.019	1.023
mesitylene	0.927	0.937	0.947	0.957

ω_2 adopts an equilibrium between the viscosity-dependent driving torque, which is proportional to the speed difference between the outer tube and the inner rotor, and the retarding torque caused by eddy currents, which is proportional to the inner rotor speed.

The unambiguous measurement for the dynamic viscosity is calculated by the instrument according to the following expression:

$$\eta = k\omega_2/(\omega_1 - \omega_2) \tag{1}$$

where k is the mean adjustment coefficient of the instrument. By the aid of a built-in program and four certified standard samples supplied by the manufacturer (SHL109, SHM109, SCH100 and SHH110) of dynamic viscosities (3.058, 32.62, 99.51, and 1131) mPa·s, respectively, at 293.15 K, the whole instrument measuring ranges were adjusted automatically. After completing the instrument adjustment, the calibration of the instrument was achieved by a triplicate measurement of the two reference samples, SHL109 and SHM109, at the interested temperatures with reproducibility ± 0.35 % of the measuring range. The estimated uncertainty in dynamic viscosity measurements was within $\pm 3 \times 10^{-3}$ mPa·s with a 95 % confidence interval of all measurements. The temperature control of the cells was achieved by a solid-state thermostat and two integrated Pt-100 measuring sensors of temperature reproducibility of $\pm 10^{-2}$ K.

Results and Discussion

Experimental values of density ρ, viscosity η, and speed of sound u of all binary mixtures, at the four temperatures, are given in Table 2. These properties were fitted to an equation reported in the literature,[32] the errors and derived parameters are shown in Table 3.

The values of the speed of sound u and mixture density ρ_m were used to calculate the isentropic compressibility k_s using the relation

$$k_s = u^{-2}{\rho_m}^{-1} \tag{2}$$

The excess isentropic compressibility k_s^E was obtained from the relation

$$k_s^E = k_s - k_s^{id} \tag{3}$$

where k_s is the experimental compressibility and its values are reported in Table 2. k_s^{id} is the isentropic compressibility for an ideal mixture of the components and is estimated using the following relation:[33]

$$k_s^{id} = \sum \phi_i[k_{s,i}^\circ + TV_i^\circ(\alpha_i^\circ)^2/C_{p,i}^\circ] - T(\sum x_i V_i^\circ)(\sum \phi_i \alpha_i^\circ)^2/\sum x_i C_{p,i}^\circ \tag{4}$$

where ϕ_i is the volume fraction of component i in the mixture stated in terms of the unmixed components, T is the temperature, and $k_{s,i}^\circ$, V_i°, α_i°, $C_{p,i}^\circ$, and x_i are respectively the isentropic compressibility, molar volume, isobaric expansion coefficient, molar isobaric heat capacity, and mole fraction for pure component i. The values of $C_{p,i}^\circ$ were taken from DIPPR database[34] and are listed in Table 4. The experimental data on density ρ for each of the pure liquids in the working temperature range were fitted to the following equation:[35]

$$\rho = \sum_{i=1}^{3} A_i(T - 273.15)^{i-1} \tag{5}$$

where A_i is the equation coefficient (listed in Table 5) and T is the temperature. The values of α_i°, defined as $\alpha_i^\circ = V^{-1}(dV/dT)_P = -\rho^{-1}(d\rho/dT)_p$, were calculated at each temperature using coefficients of eq 5 and are shown in Table 6.

The deviations of the measured speeds of sound from their values in an ideal mixture were calculated from the following equations:[36]

$$u^D = u - u^{id} \tag{6}$$

$$u^{id} = V_m^{id}\{(\sum x_i M_i)k_s^{id}\}^{-0.5} \tag{7}$$

where u^{id}, V_m^{id}, k_s^{id}, x_i, and M_i are respectively the calculated speed of sound, molar volume, and isentropic compressibility of the ideal solution, mole fraction, and molar mass of the pure component.

Deviations in viscosity $\Delta\eta$ were calculated using the following relation:[37]

$$\Delta\eta = \eta_m - \sum_{i=1}^{2}(x_i\eta_i) \tag{8}$$

where x and η are mole fraction and dynamic viscosity of component i, respectively. The subscripts i and m represent pure components and mixture, respectively.

The excess molar isentropic compressibility k_s^E, deviations of the speed of sound u^D, and viscosity deviation $\Delta\eta$ for the binary mixtures are listed in Table 7. k_s^E, u^D, and $\Delta\eta$ values have been fitted by the method of least-squares to a Redlich−Kister[10] polynomial type equation:

$$Y = x_1x_2\sum_{j=1}^{n} a_{j-1}(x_1 - x_2)^{j-1} \tag{9}$$

where Y refers to the property and x_1 and x_2 are the mole fractions of pure components 1 and 2, respectively. a_{j-1} is the polynomial coefficient, and n is the polynomial degree. The correlated results in each case are shown in Table 8, in which the tabulated standard deviation σ was defined as

$$\sigma = ((\sum (Y_{exp} - Y_{cal})^2)/(N - n))^{1/2} \tag{10}$$

where N is the number of data points and n is the number of

Table 7. Viscosity Deviation ($\Delta\eta$), Excess Isentropic Compressibility (k_s^E), and Speed of Sound Deviation (u^D) for the Binary Mixtures from T = (288.15 to 303.15) K

	$\Delta\eta$	k_s^E	u^D	$\Delta\eta$	k_s^E	u^D	$\Delta\eta$	k_s^E	u^D	$\Delta\eta$	k_s^E	u^D
x_1	mPa·s	TPa^{-1}	$m·s^{-1}$	mPa·s	TPa^{-1}	$m·s^{-1}$	mPa·s	TPa^{-1}	$m·s^{-1}$	mPa·s	TPa^{-1}	$m·s^{-1}$
					Anisole (1) + Benzene (2)							
	T = 288.15 K			T = 293.15 K			T = 298.15 K			T = 303.15 K		
0.0000	0.0000	0.00	0.00	0.0000	0.00	0.00	0.0000	0.0000	0.00	0.0000	0.00	0.000
0.0970	−0.0090	−4.40	6.81	−0.0075	−6.50	6.81	0.0970	−0.0066	−6.80	−0.0057	−8.00	3.890
0.1750	−0.0157	−7.32	11.85	−0.0143	−10.07	10.81	0.1750	−0.0128	−10.40	−0.0113	−11.50	6.630
0.2740	−0.0237	−10.44	16.79	−0.0220	−13.02	14.43	0.2740	−0.0203	−13.48	−0.0185	−14.80	9.370
0.3680	−0.0290	−12.06	19.78	−0.0275	−14.37	16.44	0.3680	−0.0260	−14.76	−0.0248	−16.20	11.370
0.4971	−0.0326	−12.72	21.27	−0.0318	−14.23	17.05	0.4971	−0.0306	−15.30	−0.0294	−16.70	12.600
0.6230	−0.0319	−11.90	20.00	−0.0308	−12.53	15.52	0.6230	−0.0299	−14.40	−0.0285	−15.81	12.290
0.7200	−0.0272	−10.12	17.16	−0.0257	−10.22	12.93	0.7200	−0.0240	−12.50	−0.0222	−13.71	10.970
0.8003	−0.0206	−7.93	13.43	−0.0191	−7.46	9.99	0.8003	−0.0170	−10.00	−0.0151	−11.20	9.000
0.8895	−0.0121	−4.99	8.21	−0.0103	−4.29	5.95	0.8895	−0.0090	−6.48	−0.0072	−7.40	5.890
1.0000	0.0000	0.00	0.00	0.0000	0.00	0.00	1.0000	0.0000	−0.02	0.0000	0.00	0.000
					Anisole (1) + Toluene (2)							
	T = 288.15 K			T = 293.15 K			T = 298.15 K			T = 303.15 K		
0.0000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.00	0.0000	0.00	0.00
0.1152	−0.0164	−3.97	5.595	−0.0155	−4.80	5.72	−0.0138	−5.71	3.54	−0.0121	−6.19	2.52
0.2132	−0.0266	−6.79	10.260	−0.0246	−7.84	9.48	−0.0226	−8.85	6.17	−0.0202	−9.60	4.65
0.3098	−0.0342	−8.50	14.000	−0.0327	−9.71	11.93	−0.0297	−11.00	8.63	−0.0274	−12.24	6.34
0.4182	−0.0383	−9.46	16.638	−0.0368	−10.99	13.40	−0.0345	−12.11	10.20	−0.0323	−13.51	7.57
0.5267	−0.0397	−9.53	17.360	−0.0382	−11.05	13.64	−0.0361	−12.29	10.69	−0.0343	−13.71	8.05
0.6209	−0.0388	−8.87	16.400	−0.0373	−10.22	12.83	−0.0354	−11.80	10.28	−0.0330	−12.88	7.89
0.7382	−0.0343	−7.14	13.280	−0.0327	−7.83	10.13	−0.0303	−9.43	8.72	−0.0274	−10.26	6.93
0.8645	−0.0235	−3.81	7.843	−0.0220	−4.40	5.84	−0.0186	−5.20	5.26	−0.0166	−6.10	4.70
0.9270	−0.0158	−2.10	4.469	−0.0146	−2.48	3.38	−0.0119	−2.88	2.88	−0.0107	−3.31	2.92
1.0000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.00	0.0000	0.00	0.00
					Anisole (1) + *o*-Xylene (2)							
	T = 288.15 K			T = 293.15 K			T = 298.15 K			T = 303.15 K		
0.0000	0.0000	0.00	0.0000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000
0.0915	−0.0134	−1.01	2.050	−0.0109	−1.30	2.040	−0.0087	−2.15	1.15	−0.0072	−2.74	1.040
0.1980	−0.0267	−1.93	4.570	−0.0242	−2.85	4.170	−0.0218	−4.35	2.71	−0.0190	−5.60	2.030
0.3680	−0.0426	−3.20	7.650	−0.0400	−4.23	6.370	−0.0373	−6.40	4.69	−0.0345	−8.37	3.450
0.4954	−0.0491	−3.60	8.680	−0.0468	−4.46	6.940	−0.0440	−6.80	5.43	−0.0423	−8.82	4.120
0.6554	−0.0491	−3.16	8.210	−0.0466	−3.77	6.290	−0.0438	−6.00	5.20	−0.0417	−7.76	4.120
0.7660	−0.0417	−2.60	6.530	−0.0403	−2.85	4.740	−0.0373	−4.55	4.10	−0.0345	−6.02	3.450
0.8680	−0.0260	−1.75	4.000	−0.0238	−1.77	2.860	−0.0202	−2.82	2.37	−0.0162	−3.61	2.080
0.9160	−0.0171	−1.20	2.430	−0.0144	−1.08	1.800	−0.0112	−1.98	1.43	−0.0084	−2.23	1.200
0.9490	−0.0100	−0.82	1.310	−0.0090	−0.52	1.060	−0.0065	−1.23	0.84	−0.0040	−1.17	0.620
1.0000	0.0000	0.00	0.000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000
					Anisole (1) + *m*-Xylene (2)							
	T = 288.15 K			T = 293.15 K			T = 298.15 K			T = 303.15 K		
0.0000	0.0000	0.00	0.000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000
0.1144	−0.0224	−2.74	3.100	−0.0208	−3.92	3.270	−0.0177	−4.00	2.00	−0.0149	−4.33	1.510
0.2566	−0.0452	−5.70	6.700	−0.0460	−7.31	5.800	−0.0416	−7.45	4.10	−0.0394	−8.48	3.170
0.3821	−0.0614	−7.32	8.930	−0.0600	−8.92	7.430	−0.0572	−9.12	5.60	−0.0547	−10.40	4.400
0.5034	−0.0686	−7.85	9.944	−0.0665	−9.31	8.000	−0.0635	−9.81	6.22	−0.0615	−11.09	5.020
0.6546	−0.0675	−7.28	9.700	−0.0654	−8.17	7.270	−0.0621	−9.05	5.82	−0.0600	−10.00	5.020
0.7535	−0.0590	−5.91	8.155	−0.0540	−6.40	6.050	−0.0547	−7.10	4.80	−0.0515	−7.84	4.160
0.8432	−0.0427	−4.00	5.700	−0.0380	−3.85	4.250	−0.0430	−4.80	3.20	−0.0394	−5.36	2.800
0.9133	−0.0258	−2.24	3.283	−0.0224	−2.00	2.370	−0.0274	−2.56	1.88	−0.0240	−3.31	1.660
0.9576	−0.0155	−1.07	1.600	−0.0123	−1.08	1.140	−0.0119	−1.36	0.94	−0.0096	−1.78	0.660
1.0000	0.0000	0.00	0.000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000
					Anisole (1) + *p*-Xylene (2)							
	T = 288.15 K			T = 293.15 K			T = 298.15 K			T = 303.15 K		
0.0000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000	0.0000	0.00	0.000
0.0822	−0.0154	−3.27	3.578	−0.0122	−4.62	3.92	−0.0100	−4.62	2.170	−0.0080	−5.27	1.510
0.1870	−0.0320	−6.52	7.362	−0.0279	−8.23	6.78	−0.0252	−8.97	4.440	−0.0214	−9.56	3.470
0.3100	−0.0478	−9.35	10.960	−0.0454	−11.00	9.56	−0.0420	−11.92	6.830	−0.0380	−12.94	5.280
0.4700	−0.0599	−10.74	13.585	−0.0590	−11.92	11.44	−0.0543	−13.12	8.550	−0.0515	−14.47	6.550
0.6370	−0.0597	−9.64	13.324	−0.0590	−10.91	10.70	−0.0540	−12.40	8.310	−0.0511	−13.45	6.620
0.7470	−0.0508	−8.00	11.184	−0.0466	−8.40	8.58	−0.0431	−10.31	6.740	−0.0389	−10.96	5.520
0.8220	−0.0376	−6.21	8.740	−0.0347	−6.15	6.70	−0.0305	−7.90	5.350	−0.0256	−8.10	4.420
0.8880	−0.0245	−4.13	5.977	−0.0207	−3.77	4.66	−0.0182	−5.49	3.700	−0.0147	−5.60	3.310
0.9490	−0.0101	−2.05	3.039	−0.0083	−1.69	2.37	−0.0056	−2.15	1.380	−0.0047	−2.99	1.320
1.0000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000	0.0000	0.00	0.000
					Anisole (1) + Mesitylene (2)							
	T = 288.15 K			T = 293.15 K			T = 298.15 K			T = 303.15 K		
0.0000	0.0000	0.00	0.000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000
0.0740	−0.0238	−0.56	2.639	−0.0200	−0.69	2.780	−0.0171	−1.27	1.56	−0.0115	−1.46	1.000
0.1810	−0.0472	−1.26	5.798	−0.0428	−1.77	5.390	−0.0376	−3.09	3.62	−0.0324	−4.27	2.700
0.3340	−0.0707	−2.18	9.128	−0.0666	−2.80	8.250	−0.0636	−4.95	5.92	−0.0606	−6.63	4.680
0.4982	−0.0824	−2.60	10.728	−0.0796	−3.00	9.560	−0.0762	−5.56	7.25	−0.0736	−7.54	5.730
0.6280	−0.0810	−2.40	10.528	−0.0777	−2.62	8.910	−0.0755	−5.02	7.01	−0.0714	−7.01	5.770
0.7512	−0.0680	−1.82	8.878	−0.0632	−1.85	7.000	−0.0576	−3.82	5.67	−0.0528	−5.42	4.870
0.8140	−0.0565	−1.40	7.280	−0.0500	−1.38	5.880	−0.0431	−2.88	4.44	−0.0376	−4.27	3.930
0.8750	−0.0416	−0.98	5.410	−0.0340	−0.92	4.170	−0.0290	−1.94	3.11	−0.0238	−2.93	2.740
0.9400	−0.0186	−0.40	3.053	−0.0137	−0.46	2.120	−0.0104	−0.74	1.68	−0.0067	−1.27	1.370
1.0000	0.0000	0.00	0.000	0.0000	0.00	0.000	0.0000	0.00	0.00	0.0000	0.00	0.000

Table 8. Redlich−Kister Coefficients (a_i) and Standard Deviations (σ) for the Binary Mixtures from T = (288.15 to 303.15) K

	a_0	a_1	a_2	a_3	σ	a_0	a_1	a_2	a_3	σ
Anisole (1) + Benzene (2)										
			T = 288.15 K					T = 293.15 K		
$\Delta\eta$/mPa·s	−0.1305	0.0120	−0.0238	0.0117	0.0003	−0.1233	0.0104	−0.0162	0.0078	0.0002
k_s^E/TPa^{-1}	−28.54	−3.65	11.26	−0.07	0.0005	−31.90	−11.18	8.23	17.72	0.0007
u^D/m·s^{-1}	85.48	0.63	−6.22	−5.72	0.0009	70.26	25.70	0.20	−31.29	0.0008
			T = 298.15 K					T = 303.15 K		
$\Delta\eta$/mPa·s	−0.1175	0.0122	−0.0039	0.0007	0.0003	−0.1092	0.0120	0.0013	−0.0002	0.0000
k_s^E/TPa^{-1}	−34.41	−5.00	2.67	1.37	0.0005	−38.60	−13.74	−1.21	24.85	0.0008
u^D/m·s^{-1}	58.07	−6.75	−5.38	−5.77	0.0004	51.25	2.94	1.98	−25.76	0.0007
Anisole (1) + Toluene (2)										
			T = 288.15 K					T = 293.15 K		
$\Delta\eta$/mPa·s	−0.1587	0.0060	−0.0316	0.0353	0.0002	−0.1524	0.0103	−0.0227	0.0213	0.0002
k_s^E/TPa^{-1}	−38.63	−3.43	3.98	5.82	0.0034	−43.13	−2.55	−2.00	1.39	0.0010
u^D/m·s^{-1}	69.47	−4.05	−14.66	−6.08	0.0009	51.58	7.57	13.77	−12.16	0.0009
			T = 298.15 K					T = 303.15 K		
$\Delta\eta$/mPa·s	−0.1473	0.0110	−0.0155	0.0128	0.0002	−0.1420	0.0150	−0.0058	−0.0038	0.0003
k_s^E/TPa^{-1}	−46.42	−5.14	−11.52	2.78	0.0009	−55.19	−0.48	−12.39	1.19	0.0032
u^D/m·s^{-1}	42.65	−5.91	−7.26	−0.23	0.0003	32.00	−5.45	1.48	−8.68	0.0007
Anisole (1) + *o*-Xylene (2)										
			T = 288.15 K					T = 293.15 K		
$\Delta\eta$/mPa·s	−0.1965	0.0224	−0.0442	0.0319	0.0005	−0.1876	0.0238	−0.0268	0.0126	0.0007
k_s^E/TPa^{-1}	−18.92	0.91	5.04	−0.13	0.0007	−20.89	0.97	0.64	−2.53	0.0004
u^D/m·s^{-1}	35.18	−5.79	−10.31	2.30	0.0002	28.00	−1.38	−4.69	4.35	0.0062
			T = 298.15 K					T = 303.15 K		
$\Delta\eta$/mPa·s	−0.1822	0.0207	−0.0110	0.0221	0.0003	−0.1764	0.0321	0.0139	−0.0140	0.0008
k_s^E/TPa^{-1}	−23.63	1.29	0.65	−0.84	0.0024	−26.42	6.87	−7.31	−6.03	0.0003
u^D/m·s^{-1}	28.04	−1.37	−5.23	3.79	0.0008	17.05	−7.69	−4.36	8.53	0.0009
Anisole (1) + *m*-Xylene (2)										
			T = 288.15 K					T = 293.15 K		
$\Delta\eta$/mPa·s	−0.2746	0.0356	−0.0744	0.0901	0.0009	−0.2687	0.0337	−0.0538	0.0906	0.0005
k_s^E/TPa^{-1}	−31.92	3.04	4.88	−4.88	0.0003	−33.79	3.35	1.91	−0.93	0.0007
u^D/m·s^{-1}	40.36	−8.21	−7.35	1.61	0.0003	31.93	−4.01	−0.97	8.75	0.0004
			T = 298.15 K					T = 303.15 K		
$\Delta\eta$/mPa·s	−0.2604	0.0308	−0.0126	0.0879	0.0006	−0.2534	0.0555	0.0238	0.0268	0.0008
k_s^E/TPa^{-1}	−35.73	1.85	−0.04	0.20	0.0007	−40.33	4.08	−0.98	−0.09	0.0006
u^D/m·s^{-1}	24.84	−3.01	−5.11	0.30	0.0008	19.95	−4.99	−2.86	0.93	0.0009
Anisole (1) + *p*-Xylene (2)										
			T = 288.15 K					T = 293.15 K		
$\Delta\eta$/mPa·s	−0.2275	0.0245	−0.1256	0.0830	0.0009	−0.2160	0.0251	−0.0842	0.0533	0.0007
k_s^E/TPa^{-1}	−44.22	1.21	5.73	−1.04	0.0006	−39.36	0.04	−11.29	0.36	0.0008
u^D/m·s^{-1}	54.97	−9.48	−0.29	1.01	0.0006	44.44	1.04	7.27	2.48	0.0005
			T = 298.15 K					T = 303.15 K		
$\Delta\eta$/mPa·s	−0.2114	0.0348	−0.0356	0.0231	0.0005	−0.2036	0.0378	−0.0017	−0.0019	0.0004
k_s^E/TPa^{-1}	−46.27	−0.43	−1.62	2.88	0.0007	−45.55	−0.68	−13.85	0.41	0.0003
u^D/m·s^{-1}	34.64	−4.62	−4.66	1.02	0.0002	27.20	−5.78	−2.44	−1.13	0.0001
Anisole (1) + Mesitylene (2)										
			T = 288.15 K					T = 293.15 K		
$\Delta\eta$/mPa·s	−0.3173	0.0465	−0.1264	0.0372	0.0006	−0.3077	0.0653	−0.08266	−0.014	0.0005
k_s^E/TPa^{-1}	−14.24	1.89	3.96	−3.65	0.0003	−15.78	1.37	2.67	−2.39	0.0004
u^D/m·s^{-1}	43.03	−7.97	2.27	1.00	0.0008	37.96	−1.32	1.59	4.17	0.0002
			T = 298.15 K					T = 303.15 K		
$\Delta\eta$/mPa·s	−0.3003	0.0749	−0.0448	−0.0250	0.0005	−0.2961	0.0978	0.0170	−0.0969	0.0007
k_s^E/TPa^{-1}	−17.40	2.10	0.01	−3.47	0.0004	−18.97	1.20	−3.53	−1.39	0.0006
u^D/m·s^{-1}	29.07	−5.33	−4.44	2.32	0.0007	23.72	−6.29	−5.64	0.52	0.0009

the coefficients. Y_{exp} and Y_{cal} denote the experimental and calculated values of Y, respectively.

The values of u^D, k_s^E, $\Delta\eta$, and their representations by eq 9 are plotted against x_1 in Figures 1 to 3.

The deviations of the speed of sound u^D at 298.15 K over the whole composition range for all the mixtures are positive and show a maximum in the sequence: benzene > methylbenzene > *p*-xylene > mesitylene > *m*-xylene > *o*-xylene. With an increase in temperature, the u^D values decrease with the same dependencies and systematic variation in the present binary systems.

The graphical variations of excess isentropic compressibilities k_s^E are negative values for the systems under study as shown in Figure 2. However, no systematic dependence of k_s^E on methyl groups of the parent benzene molecule could be seen. The k_s^E data of the six binary mixtures shows a minimum in the sequence: benzene < *p*-xylene < methylbenzene < *m*-xylene < *o*-xylene < mesitylene. The negative values of k_s^E for all the systems under study indicate that each mixture is less compressible than the corresponding ideal mixture.[36]

With temperature increasing, the absolute values of k_s^E for the six binary mixtures increase with the same dependencies and systematic variation. These results are not presented to avoid overcrowding the curves.

The deviations in viscosity $\Delta\eta$ at 298.15 K for all the systems are shown in Figure 3. The deviations are negative for the entire composition range, and their values decrease in the following order: benzene > methylbenzene > *o*-xylene > *p*-xylene > *m*-xylene > mesitylene.

The speeds of sound in six binary mixtures at 298.15 K were evaluated theoretically from both the free length theory (u_{FLT}) and the collision factor theory (u_{CFT}). The pertinent relations in these calculations and their theoretical basis were described by Jacobson[16] and Schaaffs.[15] Values of molar volume V_m, molar volume at absolute zero V_0, free length L_f, surface area Y,

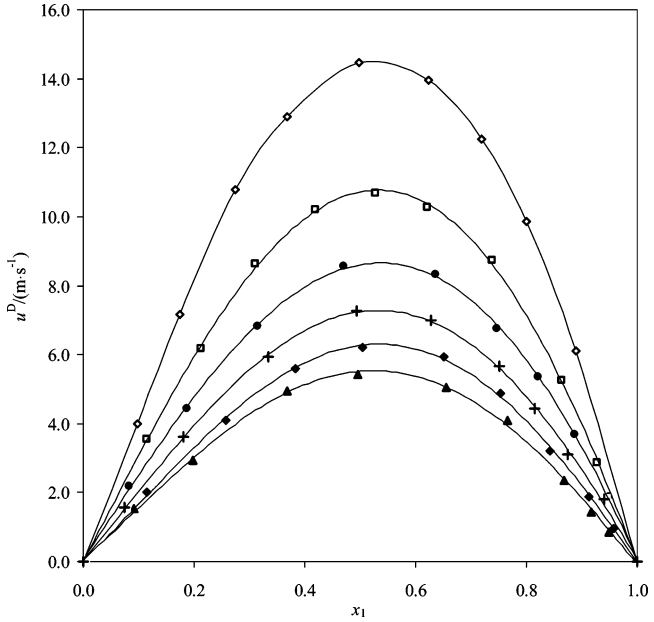

Figure 1. Deviation of speeds of sound (u^D) from their ideal values (u^{id}) for the binary mixtures: ◇, anisole + benzene; □, + toluene; ▲, + *o*-xylene; ◆, + *m*-xylene; ●, + *p*-xylene; +, + mesitylene at 298.15 K; solid line (Redlich−Kister).[10]

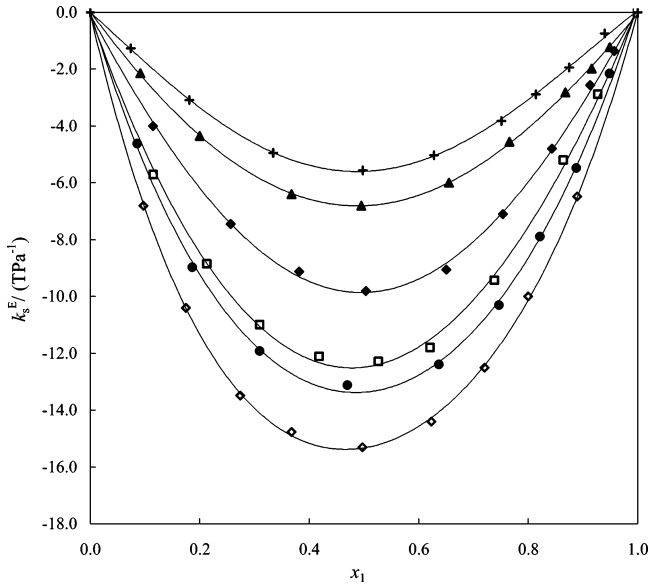

Figure 2. Deviation in isentropic compressibility (k_S^E) vs mole fraction of anisole (x_1) at 298.15 K. Symbols are the same as those given in Figure 1.

collision factor *S*, and space filling factor r_f of the pure components at 298 K are given in Table 9.

The theoretical values of speed of sound u_{FLT} and u_{CFT} at equimolar compositions for all the mixtures are compared with experimental results in Table 10. The values of standard deviations σ for each individual mixture are also included in this Table. The analysis of standard percentage deviations of u_{CFT} and u_{FLT} reveals that their values are in the range from 0.05 to 0.33 and from 1.1 to 3.6, with average values of 0.16 and 2.54, respectively. These values show that the collision factor theory (CFT) of Schaaffs is more appropriate for prediction of speed of sound data for presently investigated mixtures.

To estimate the viscosity of liquid mixtures in terms of pure component values, the experimental viscosity data of the binary mixtures were fitted to semi-empirical relations proposed by

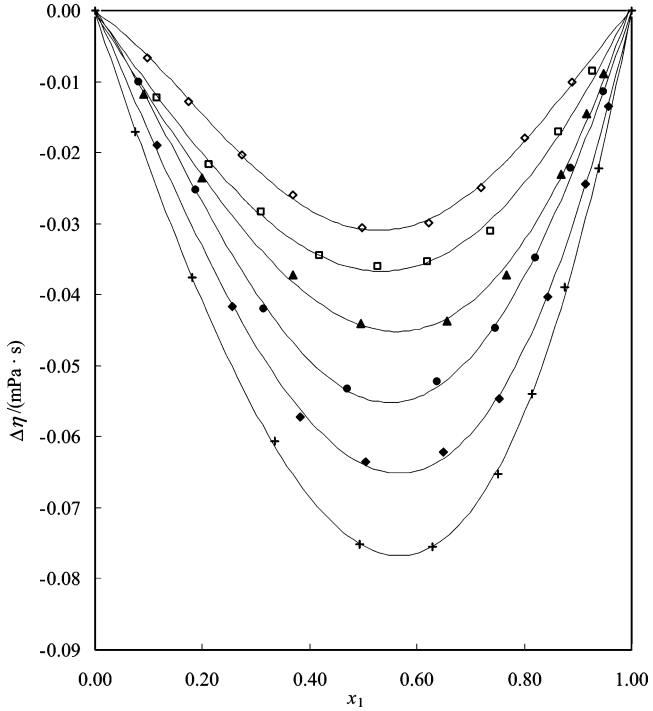

Figure 3. Viscosity deviation ($\Delta\eta$) vs mole fraction of anisole (x_1) at 298.15 K. Symbols are the same as those given in Figure 1.

Table 9. Values of Molar Volume (V_m), Molar Volume at Absolute Zero (V_0), Free Length (L_f), Surface Area (Y), Collision Factor (S), and Space Filling Factor (r_f) of the Pure Components at 298 K

component	V_m / cm³·mol⁻¹	V_0 / cm³·mol⁻¹	L_f / Å	Y / cm²·mol⁻¹	S	r_f
anisole	109.33	90.78	0.4590	80.800	3.070	2.864
benzene	89.41	71.17	0.5312	68.706	2.667	3.043
toluene	106.85	86.59	0.5176	78.290	2.952	2.762
o-xylene	121.26	100.06	0.4919	86.209	3.197	2.637
m-xylene	123.49	101.30	0.5105	86.910	3.190	2.583
p-xylene	123.94	101.64	0.5121	87.111	3.185	2.569
mesitylene	139.60	115.53	0.5746	94.869	3.412	2.444

Table 10. Comparison of Equimolar Experimental Speeds of Sound in Binary Mixtures with Those Estimated from the CFT and FLT at 298.15 K

	u_{exp} / m·s⁻¹	u_{CFT} / m·s⁻¹	σ / %	u_{FLT} / m·s⁻¹	σ / %
anisole (1) + benzene (2)	1352.76	1351.57	0.0517	1373.87	1.0959
anisole (1) + toluene (2)	1349.12	1349.82	0.0610	1368.43	2.2107
anisole (1) + *o*-xylene (2)	1376.90	1377.58	0.0752	1396.86	3.6382
anisole (1) + *m*-xylene (2)	1360.40	1362.67	0.1441	1381.87	3.1161
anisole (1) + *p*-xylene (2)	1358.50	1354.16	0.3269	1375.26	3.0096
anisole (1) + mesitylene (2)	1370.60	1375.60	0.3175	1384.27	2.1828

Grunberg−Nissan,[11] Heric−Brewer,[14] and McAllister[12] as reported in our previous work.[1,7] The data also correlated with Tamura−Kurata[13] of the following form: where

$$\eta_m = x_1\phi_1\eta_1 + x_2\phi_2\eta_2 + 2\,(x_1x_2\phi_1\phi_2)^{0.5}T_{12} \qquad (11)$$

$$\phi_i = \frac{x_iV_i}{\sum_i x_iV_i}$$

where x, η, ϕ, M, T_{12}, and $V_i(= M_i/\rho_i)$ are the mole fraction, dynamic viscosity, volume fraction, molar mass, adjustable parameter, and molar volume, respectively. The subscript *i* and m represent the pure components and mixture, respectively.

The values of average standard deviations for Grunberg−Nissan, Heric−Brewer, McAllister, and Tamura−Kurata equa-

tions are (17×10^{-4}, 8×10^{-4}, 5×10^{-4}, and 27×10^{-4}) mPa·s, respectively. These values show that the above relations predict viscosities adequately for the systems under study. The best correlation method giving the relatively lowest standard deviation is found to be the McAllister four-body equation.

Conclusions

In this work we report experimental data for density, viscosity, and speed of sound of anisole + benzene, or toluene, or *o*-xylene, or *m*-xylene, or *p*-xylene, or mesitylene binary mixtures at temperatures between (288.15 and 303.15) K. Deviation in speed of sound, excess molar isentropic compressibility, and viscosity deviation for binary mixtures have been calculated and fitted to a Redlich−Kister equation. The deviation in speed of sound showed a positive behavior, while the excess isentropic compressibility and the deviations in viscosity exhibited negative behavior for the systems under investigation. A perusal of the average standard deviation between the experimental and the theoretical values of speed of sound showed a better prediction using the CFT. Of all semi-empirical relations used to predict the viscosities of the present binary mixtures, the four-body McAllister equation provided a better representation of viscosities data.

Supporting Information Available:

Five additional figures. This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) Al-Jimaz, A. S.; Al-Kandary, J. A.; Abdu-Latif, A. M.; Al-Zanki, A. M. Physical properties of anisole + *n*-alkanes at temperatures between (293.15 and 303.15) K. *J. Chem. Thermodyn.* **2005**, *37*, 631−642.

(2) Viswanathan, S.; Rao, M. A.; Prasad, D. H. L. Densities and viscosities of binary liquid mixtures of anisole or methyl *tert*-butyl ether with benzene, chlorobezene, benzonitrial, and nitrobenzene. *J. Chem. Eng. Data* **2000**, *45*, 764−770.

(3) Joshi, S. S.; Aminabhavi, T. M. Densities and viscosities of binary liquid mixtures of anisole with methanol and benzene. *J. Chem. Eng. Data* **1990**, *35*, 187−9.

(4) Orge, B.; Marino, G.; Iglesias, M.; Tojo, J.; Piñeiro, M. M. Thermodynamics of (anisole + benzene, or toluene, or *n*-hexane or cyclohexane or 1-butanol, or 1-pentanol) at 298.15 K. *J. Chem. Thermodyn.* **2000**, *32*, 617−629.

(5) Francesconi, R.; Comelli, F.; Castellari, C. Excess molar enthalpies and excess molar volumes of binary mixtures containing dialkyl carbonates + anisole or phenetole at (288.15 and 313.15) K. *J. Chem. Eng. Data* **2000**, *45*, 544−548.

(6) Ottani S.; Comelli, F. Excess enthalpies of binary mixtures containing poly(propylene glycols) + benzyl alcohol, or + *m*-cresol, or + anisole at 308.15 K and at atmospheric pressure. *Thermochim. Acta* **2005**, *430*, 123−128.

(7) Al-Kandary, J. A.; Al-Jimaz, A. S.; Abdu-Latif, A. M. Densities, viscosities, and refractive indices of binary mixtures of anisole with benzene, methylbenzene, ethylbenzene, propylbenzene, and butylbenzene at (293.15 and 303.15)K. *J. Chem. Eng. Data* **2006**, *51*, 99−103.

(8) Al-Kandary, J. A.; Al-Jimaz, A. S.; Abdu-Latif, A. M. Excess molar volumes and refractive indices of (methoxybenzene + benzene, or toluene, or *o*-xylene, or *m*-xylene, or *p*-xylene, or mesitylene) binary mixtures between (288.15 and 303.15) K. *J. Chem. Thermodyn.* (in press).

(9) Al-Jimaz, A. S.; Al-Kandary, J. A.; Abdu-Latif, A. M. Viscosities and densities for binary mixtures of phenetole with 1-pentanol, 1-hexanol, 1-heptanol, 1-octanol, 1-nonanol, and 1-decanol at different temperatures. *Fluid Phase Equilib.* **2004**, *218*, 247−260.

(10) Redlich, O.; Kister, A. T. Algebric representation of thermodynamic properties and classification of solutions. *Ind. Eng. Chem.* **1948**, *40*, 345−348.

(11) Grunberg, L.; Nissan, A. H. Mixture law for viscosity. *Nature* **1949**, *164*, 799−800.

(12) McAllister, R. A. The viscosity of liquid mixtures. *AIChE J.* **1960**, *6*, 427−431.

(13) Tamura, M.; Kurata M. On the viscosity of binary mixture of liquids. *Bull. Chem. Soc. Jpn.* **1952**, 32−38.

(14) Heric, E. L.; Brewer, J. G. Viscosity of some binary liquid nonelectrolyte mixtures. *J. Chem. Eng. Data* **1967**, *12*, 574−583.

(15) Schaaffs, W. *Molecular Acoustics*; Springer: Berlin, 1967.

(16) Jacobson, B. Intermolecular free length in the liquid state. I. Adiabatic and isothermal compressibilities. *Acta Chem. Scand.* **1952**, *6*, 1485−1495.

(17) Aralaguppi, M. I.; Aminabhavi, T. M.; Balunlgi, R. H. Excess molar volume, excess isentropic compressibility, and excess molar refraction of binary mixtures of methyl acetoacetate with benzene, toluene, *m*-xylene, mesitylene and anisole. *Fluid Phase Equilib.* **1992**, *71*, 99−112.

(18) Aminabhavi, T. M.; Banerjee, K. Density, viscosity, refractive index in binary mixtures of 1-chloronaphalene with benzene methylbenzene, 1,4-dimethylbenzene, 1,3,5-trimethlbenzene, and methoxybenzene at 298.15, 303.15, and 308.15 K. *J. Chem. Eng. Data* **1999**, *44*, 547−552.

(19) *TRC Thermodynamic Tables*; Thermodynamic Research Center, Texas A&M University: College Station, TX, 1996.

(20) George, J.; Sastry, N. V. Measurements of densities, viscosities, speeds of sound and relative permittivities and excess molar volumes, excess isentropic compressibilities and deviations in relative permittivities and molar polarizations for dibutyl ether + benzene, + toluene, and + *p*-xylene at different temperatures. *J. Chem. Thermodyn.* **2003**, *35*, 1837−1853.

(21) Tardajos, G.; Diaz Peña, M.; Alcart, E. Speed of sound in pure liquids by pulse-echo-overlap method. *J. Chem. Thermodyn.* **1986**, *18*, 683−689.

(22) Tasić, A.; Djordjevic, B.; Grozdanić, D. Use of mixing rules in predicting refractive indices and specific refractivities for some binary liquid mixtures. *J. Chem. Eng. Data* **1992**, *37*, 310−313.

(23) Singh, K. C.; Maken, S.; Yadav, B. L. Excess volumes of 1-propanol and 2-propanol with aromatic hydrocarbon at 298.15 K. *J. Chem. Eng. Data* **1994**, *39*, 241−244.

(24) Soave, G. Equilibrium constants from a modified Redlich−Kwong equation of state. *Chem. Eng. Sci.* **1972**, *27*, 1197−1203.

(25) Aralaguppi, M. I.; Jadar, C. V.; Aminabhavi, T. M. Densities, viscosities, and speeds 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. *J. Chem. Eng. Data* **1999**, *44*, 446−450.

(26) Nayak, J. N.; Aralaguppi, M. I.; Aminabhavi, T. M. Density, viscosity, refractive index and speed of sound in the binary mixtures of ethylchloroacetate with aromatic liquids at 298.15, 303.15, and 303.15 K. *J. Chem. Eng. Data* **2002**, *47*, 964−969.

(27) Singh, S.; Sethi, B. P. S.; Katyal, R. C.; Rattan, V. K. Viscosities, densities, and speed of binary mixtures of *o*-xylene, *m*-xylene, *p*-xylene, and isopropylbenzene with 4-methylpentan-2-one at 298.15 K. *J. Chem. Eng. Data* **2004**, *49*, 1373−1375.

(28) Tojo, J.; Diaz, C. Densities and refractive indices for 1-hexane + *o*-xylene, + *m*-xylene, + *p*-xylene, and + ethylbenzene. *J. Chem. Eng. Data* **1995**, *40*, 96−98.

(29) Diaz, C.; Dominguez, A.; Tojo, J. Phase equilibria of the binary systems 1-hexene with *o*-xylene, *m*-xylene, *p*-xylene, toluene and ethylbenzene at 101.3 kPa. *J. Chem. Eng. Data* **2002**, *47*, 867−871.

(30) Serrano, L.; Silva, J. A.; Farelo, F. Densities and viscosities of binary and ternary liquid systems containing xylenes. *J. Chem. Eng. Data* **1990**, *35*, 288−291.

(31) Riddick, J. A.; Bunger, W. B.; Sakano, T. K. *Physical Properties and Methods of Purifications*; Techniques of Chemistry, Organic Solvents, Vol. II; John Wiley & Sons: New York, 1986.

(32) Kinart, C. M.; Kinart, W. J.; Ćwiklińska, A. 2-Methoxyethanol + tetrahydrofuran binary liquid system. Viscosities, densities, excess molar volumes and excess Gibbs activation energies of viscous flow at various temperatures. *J. Therm. Anal. Calorim.* **2002**, *68*, 307−317.

(33) Kiyohara, O.; Benson, G. C. Ultrasonic speed and isentropic compressibilities of *n*-alkanol + *n*-heptane mixtures at 298.15 K. *J. Chem. Thermodyn.* **1979**, *11*, 861−873.

(34) DIPPR Project 801. *Evaluated Thermophysical Properties of Pure Chemical Database*; Brigham Young University: February 2003.

(35) Oswal, S. L.; Patel, B. M.; Patel, A. M. Ghael, N. Y. Densities, speeds of sound, isentropic compressibilities, and refractive indices of binary mixtures of methyl methacrylate with hydrocarbons, haloalkanes and alkyl amines. *Fluid Phase Equilib.* **2003**, *206*, 313−329.

(36) Pal, A.; Singh, Y. P. The speed of sound and isentropic functions of $\{xH(CH_2)_v(OC_2H_4)_2OH + (1 - x)(C_4H_9)_2O\}$, ($v = 1$, 2, and 4) at the temperature 298.15 K. *J. Chem. Thermodyn*. **1996**, *28*, 1197−1205.

(37) Aminabhavi, T. M.; Phyada, H. T. S.; Khinnaaver, R. S.; Bindu, G.; Hansen, K. C. Densities, refractive indices, speed of sound, and shear viscosities of diethylene glycol dimethyl ether with ethyl acetate, methyl benzoate, ethyl benzoate and diethyl succinate in the temperature range from 298.15 to 318.15 K. *J. Chem. Eng. Data* **1994**, *39*, 251−260.

Received for review April 22, 2006. Accepted August 8, 2006.

JE060170C