J. Chem. Thermodynamics 60 (2013) 105–116

Contents lists available at SciVerse ScienceDirect

J. Chem. Thermodynamics

journal homepage: www.elsevier.com/locate/jct

Densities, ultrasonic speeds, viscosities and excess properties of binary mixtures of methyl methacrylate with *N,N*-dimethylformamide and *N,N*-dimethylacetamide at different temperatures

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ARTICLE INFO

Article history:
Received 30 November 2012
Received in revised form 29 December 2012
Accepted 16 January 2013
Available online 25 January 2013

Keywords:
Density
Ultrasonic speed
Viscosity
Excess properties
Partial molar properties
Molecular interaction

ABSTRACT

The densities, ρ, ultrasonic speeds, u and viscosities, η of binary mixtures of methyl methacrylate (MMA) with *N,N*-dimethylformamide (DMF) and *N,N*-dimethylacetamide (DMA), including those of pure liquids, over the entire composition range were measured at temperatures (288.15, 293.15, 298.15, 303.15, 308.15, 313.15, and 318.15) K and atmospheric pressure. From the experimental results, the excess molar volume, V_m^E, and excess isentropic compressibility, κ_s^E, excess isobaric coefficient of thermal expansion, α_p^E and excess molar isobaric expansion, $E_{p,m}^E$ were calculated. The excess partial molar volume, $\overline{V}_{m,1}^E$ and $\overline{V}_{m,2}^E$ and excess partial molar isentropic compressibility, $\overline{K}_{s,m,1}^E$ and $\overline{K}_{s,m,2}^E$ over the whole composition range; and partial molar volume, $\overline{V}_{m,1}^{\circ}$ and $\overline{V}_{m,2}^{\circ}$, partial molar isentropic compressibility, $\overline{K}_{s,m,1}^{\circ}$ and $\overline{K}_{s,m,2}^{\circ}$, excess partial molar volume, $\overline{V}_{m,1}^{\circ E}$ and $\overline{V}_{m,2}^{\circ E}$, excess partial molar isentropic compressibility, $\overline{K}_{s,m,1}^{\circ E}$ and $\overline{K}_{s,m,2}^{\circ E}$ at infinite dilution, and excess partial molar isobaric expansion, $\overline{E}_{p,m,1}^E$ and $\overline{E}_{p,m,2}^E$ over the whole composition range have also been calculated. The variations of these parameters with composition and temperature of the mixtures are discussed in terms of molecular interaction in these mixtures. It is observed that the MMA-DMF/DMA interactions in these mixtures follow the order: DMF < DMA. Further, the viscosities of these binary mixtures were correlated theoretically by using various empirical and semi-empirical models and the results were compared with the experimental findings.

1. Introduction

Mixed solvents are frequently used as media for many chemical, industrial and biological processes, because they provide a wide range of desired properties and the knowledge of the volumetric, acoustic and transport properties of non-aqueous binary liquid mixtures has significance in theoretical and applied areas of research [1–3]. The ultrasonic speed may be considered as a thermodynamic property, provided that a negligible amount of ultrasonic absorption of the acoustic waves of low frequency and of low amplitude is observed; in which case, the ultrasonic absorption of the acoustic waves is negligible [4]. In continuation to our on-going research [5–7] on binary and ternary mixtures containing acrylate monomers, here we report the results of our study on the binary mixtures of methyl methacrylate (MMA) with *N,N*-dimethylformamide (DMF) and *N,N*-dimethylacetamide (DMA).

The MMA, DMF and DMA are polar, aprotic and non-associated solvents. Amides are convenient model compounds for investigating peptide and protein-solvent interactions [8], whereas, acrylate monomers are often required for their industrial applications such as making cleaning products, antioxidant agents, amphoteric surfactants, paints, inks, adhesives, dispersions for textiles, paper, *etc.*, and are also interesting theoretically as they have unsaturated structure beside a carbonyl group in the molecule [9]. Despite many industrial and theoretical interests, the mixtures containing amides and acrylate monomers are not investigated from their physicochemical behaviour. Literature survey indicates that there have been a number of studies [10–13] on the mixtures of acrylate monomers with alkanols, alkanes, aromatic hydrocarbons, 1,4-dioxane, *etc.* To the best of our knowledge, no studies on the binary mixtures of MMA with DMF/DMA have been reported in the literature.

In the present paper, we report values of density, ρ, ultrasonic speed, u and viscosity, η of the binary mixtures of MMA with DMF and DMA, including those of pure liquids at temperatures (288.15, 293.15, 298.15, 303.15, 308.15, 313.15, and 318.15) K and atmospheric pressure, covering the entire composition range expressed by the mole fraction x_1 of MMA. The experimental values of ρ, u and η have been used to calculate the excess molar volume, V_m^E, and excess isentropic compressibility, κ_s^E, excess isobaric coefficient of thermal expansion, α_p^E and excess molar isobaric expansion, $E_{p,m}^E$ were calculated. The excess partial molar volume,

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http://dx.doi.org/10.1016/j.jct.2013.01.013

TABLE 1
Details of chemical source, purification method, purity and analysis method.

Chemical name (CAS number)	Source	Initial mole fraction purity	Purification method	Final mole fraction purity	Analysis method
Methyl methacrylate (Methyl 2-methyl-2-propenoate) (80-62-6)	Alfa Aeser, USA	0.99	Distillation	0.996	GC[a]
N,N-Dimethylformamide (68-12-2)	s.d. Fine Chemicals, India	0.99	Distillation	0.994	GC
N,N-Dimethylformamide (127-19-5)	s.d. Fine Chemicals, India	0.99	Distillation	0.995	GC

[a] GC = Gas chromatography.

TABLE 2
Experimental values of density, ρ, ultrasonic speed, u and viscosity, η of pure liquids along with the corresponding values available in the literature at T = 298.15 K.

Liquid	$\rho/\text{kg} \cdot \text{m}^{-3}$		$u/\text{m} \cdot \text{s}^{-1}$		$10^3 \cdot \eta/\text{N} \cdot \text{s} \cdot \text{m}^{-2}$	
	Expt.	Lit.	Expt.	Lit.	Expt.	Lit.
MMA	937.63	937.615 [21] 937.63 [23] 937.66 [24]	1183.6	1182.0 [22]	0.5544	0.5540 [21]
DMF	944.60	944.5 [25]	1469.5	1469.3 [26]	0.8123	0.8136 [27]
DMA	936.50	936.60 [20]936.50 [26]	1462.1	1462.6 [28]	0.9443	0.9437 [29]

TABLE 3
Densities, $\rho/\text{kg} \cdot \text{m}^{-3}$ as functions of mole fraction, x_1 of MMA for (MMA + DMF/DMA) mixtures at the temperatures (288.15 to 318.15) K and atmospheric pressure.[a]

x_1	T/K						
	288.15	293.15	298.15	303.15	308.15	313.15	318.15
			MMA + DMF				
0.0000	953.61	949.10	944.60	940.10	935.60	931.10	926.60
0.0696	953.35	948.76	944.17	939.58	934.99	930.40	925.81
0.1417	953.07	948.39	943.71	939.03	934.35	929.67	924.99
0.2110	952.80	948.03	943.26	938.49	933.72	928.95	924.18
0.2855	952.50	947.64	942.77	937.90	933.03	928.16	923.29
0.3573	952.22	947.25	942.29	937.33	932.36	927.40	922.44
0.4308	951.91	946.85	941.79	936.73	931.67	926.61	921.55
0.5042	951.58	946.43	941.28	936.13	930.98	925.83	920.68
0.5780	951.23	946.00	940.76	935.52	930.28	925.04	919.80
0.6552	950.86	945.53	940.21	934.88	929.55	924.22	918.89
0.7204	950.53	945.13	939.73	934.33	928.93	923.53	918.12
0.7873	950.19	944.72	939.24	933.76	928.28	922.81	917.33
0.8548	949.84	944.29	938.74	933.19	927.63	922.07	916.51
0.9268	949.47	943.83	938.19	932.55	926.91	921.26	915.61
1.0000	949.10	943.37	937.63	931.89	926.15	920.41	914.66
			MMA + DMF				
0.0000	945.50	941.00	936.50	932.00	927.50	923.00	918.50
0.0714	946.01	941.45	936.89	932.33	927.77	923.21	918.65
0.1440	946.49	941.87	937.25	932.63	928.01	923.38	918.75
0.2125	946.92	942.23	937.54	932.85	928.16	923.46	918.76
0.2823	947.31	942.55	937.79	933.03	928.26	923.49	918.72
0.3568	947.69	942.84	937.99	933.14	928.29	923.44	918.59
0.4318	948.02	943.08	938.14	933.20	928.26	923.32	918.38
0.5046	948.31	943.28	938.25	933.22	928.19	923.16	918.13
0.5769	948.54	943.43	938.31	933.19	928.07	922.95	917.83
0.6512	948.73	943.52	938.31	933.10	927.89	922.68	917.47
0.7205	948.88	943.58	938.28	932.98	927.68	922.38	917.08
0.7845	948.97	943.59	938.21	932.82	927.43	922.04	916.65
0.8558	949.03	943.54	938.05	932.56	927.07	921.57	916.07
0.9281	949.07	943.46	937.85	932.24	926.63	921.01	915.39
1.0000	949.10	943.37	937.63	931.89	926.15	920.41	914.66

[a] Standard uncertainties s are $s(T) = \pm 0.01$ K, $s(x_1) = \pm 1.0 \cdot 10^{-4}$, $s(\rho) = \pm 2.0 \cdot 10^{-2}$ kg · m^{-3}.

TABLE 4
Ultrasonic speeds, $u/\text{m} \cdot \text{s}^{-1}$ as functions of mole fraction, x_1 of MMA for (MMA + DMF/DMA) mixtures at the temperatures (288.15 to 318.15) K and atmospheric pressure.[a]

x_1	T/K						
	288.15	293.15	298.15	303.15	308.15	313.15	318.15
			MMA + DMF				
0.0000	1503.3	1485.8	1469.5	1448.8	1429.1	1411.5	1392.6
0.0696	1484.1	1466.8	1450.0	1430.3	1411.0	1393.7	1375.2
0.1417	1464.4	1447.2	1430.6	1411.3	1392.3	1375.1	1356.8
0.2110	1445.5	1428.4	1411.8	1393.0	1374.3	1357.1	1338.9
0.2855	1425.2	1408.2	1391.5	1373.1	1354.7	1337.5	1319.4
0.3573	1405.4	1388.5	1371.8	1353.7	1335.6	1318.4	1300.3
0.4308	1384.8	1368.0	1351.3	1333.6	1315.7	1298.4	1280.5
0.5042	1363.9	1347.2	1330.4	1313.1	1295.5	1278.3	1260.5
0.5780	1342.6	1326.0	1309.2	1292.3	1275.0	1257.9	1240.2
0.6552	1320.0	1303.5	1286.7	1270.3	1253.3	1236.2	1218.7
0.7204	1300.7	1284.3	1267.4	1251.4	1234.7	1217.7	1200.3
0.7873	1280.7	1264.4	1247.4	1231.8	1215.4	1198.4	1181.2
0.8548	1260.4	1244.1	1227.1	1211.8	1195.7	1178.7	1161.6
0.9268	1238.7	1222.5	1205.3	1190.4	1174.4	1157.4	1140.4
1.0000	1216.8	1200.5	1183.6	1168.5	1152.6	1135.4	1118.3
			MMA + DMA				
0.0000	1500.2	1482.6	1462.1	1441.8	1420.7	1402.6	1383.5
0.0714	1484.2	1467.3	1448.2	1429.5	1409.8	1392.2	1374.5
0.1440	1468.6	1452.1	1433.9	1415.5	1396.4	1379.6	1362.8
0.2125	1452.9	1436.6	1418.5	1400.7	1382.1	1365.5	1348.2
0.2823	1435.8	1419.2	1400.8	1383.5	1365.2	1348.6	1330.9
0.3568	1416.2	1399.5	1381.0	1363.9	1345.7	1328.3	1310.1
0.4318	1394.9	1378.3	1359.8	1342.9	1324.8	1306.9	1288.6
0.5046	1372.8	1356.3	1338.0	1321.2	1303.4	1285.6	1267.2
0.5769	1349.9	1333.1	1315.4	1298.9	1281.5	1263.9	1245.9
0.6512	1325.5	1308.9	1291.5	1275.4	1258.5	1241.1	1223.7
0.7205	1302.7	1286.3	1269.3	1253.7	1237.5	1220.1	1202.8
0.7845	1282.2	1266.0	1248.9	1233.8	1217.7	1200.9	1184.0
0.8558	1259.7	1243.5	1226.9	1211.8	1196.1	1179.0	1162.4
0.9281	1237.5	1221.3	1204.6	1189.9	1174.2	1157.2	1140.2
1.0000	1216.8	1200.5	1183.6	1168.5	1152.6	1135.4	1118.3

[a] Standard uncertainties s are $s(T) = \pm 0.01$ K, $s(x_1) = \pm 1.0 \cdot 10^{-4}$ and $s(u) = \pm 0.1$ m s^{-1}.

$\overline{V}^{E}_{m,1}$ and $\overline{V}^{E}_{m,2}$, excess partial molar isentropic compressibility, $\overline{K}^{E}_{s,m,1}$ and $\overline{K}^{E}_{s,m,2}$ over the whole composition range; partial molar volume, $\overline{V}^{\circ}_{m,1}$ and $\overline{V}^{\circ}_{m,2}$, partial molar isentropic compressibility, $\overline{K}^{\circ}_{s,m,1}$ and $\overline{K}^{\circ}_{s,m,2}$, excess partial molar volume, $\overline{V}^{\circ E}_{m,1}$ and $\overline{V}^{\circ E}_{m,2}$ and excess partial molar isentropic compressibility, $\overline{K}^{\circ E}_{s,m,1}$ and $\overline{K}^{\circ E}_{s,m,2}$ of the components at infinite dilution, and excess partial molar isobaric