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We present experimental density measurements for the binary systems acetone + water, propionic acid + water, and acetone + propionic acid from 283.15 K to 323.15 K over the entire composition range. A vibrating tube densimeter produced the experimental densities. We have also calculated excess volumes and correlated them with a Redlich−Kister polynomial form.

Introduction

Experimental densities are important for design of and production in industrial plants. Also, excess volumes are of great importance for understanding the nature of molecular interactions. These properties have been used extensively to comprehend how the molecules interact within a mixture. Experimental density measurements for polar systems are needed to develop new correlations or equations of state. Highly polar substances, such as water, produce strong interactions because of its small volume and its large polarity.

Experimental density measurements for the acetone + water mixture come from Dizechi and Marschell,[1] Noda et al.,[2] Howard and McAllister,[3] Lebed and Eddin,[4] Winnick and Kong,[5] Tsuji et al.,[6] Baldauf and Knapp,[7] Konobeev and Lyapin,[8] Subnis et al.,[9] Ernst et al.,[10] and Yergovich et al.[11] For the propionic acid + water mixture, Lebed and Eddin[4] measured the liquid density at 298.15 K over a reduced concentration range. Also, Korpela[12] measured the compression of propionic acid + water and from their results calculated liquid densities at three different temperatures. For propionic acid + acetone, the only existing measurements are those by Lebed and Eddin[4] at 298.15 K and molar compositions higher than 0.7.

In this work, we have measured the density of acetone + water, propionic acid + water, and acetone + propionic acid from 283.15 K to 323.15 K using a vibrating densimeter. We have calculated excess molar volumes from the measured densities and represented their behavior with a Redlich−Kister type polynomial.

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Experimental Section

Apparatus and Procedures. We have used a vibrating densimeter, DMA 5000, from Anton Paar to measure the densities of the three binary systems. The manufacturers stated accuracy for the density measurement is ±0.005 kg·m^{-3}. The cell contains a platinum resistance thermometer that has an accuracy of ±0.01 K on the ITS-90. The precision in the density and temperature measurements is ±0.001 kg·m^{-3} and ±0.001 K, respectively. The measurement cell consists of a borosilicate glass U tube inside a thermostated jacket. The tube holds approximately 1 mL of sample. When the U tube oscillates, assuming that the sample volume trapped in the oscillations node is constant, then the sample density is a function of the oscillation frequency

$$\rho = \frac{(\tau^2 c - 4\pi^2 m)}{4\pi^2 v} \tag{1}$$

where ρ is the sample density, v is the cell volume, m is the cell mass, and c is a spring constant. The manufacturer calibrated the apparatus with ultrapure water and air. To test the calibration, we have measured the density of water before and after measuring all the binary mixture densities.

Chemicals. Fermont International supplied the acetone with a stated purity of 99.7%. Water, propionic acid, and methanol came from J.T. Baker. The stated purities for propionic acid and methanol were 99% and 99.8%, respectively. The water grade was HPLC. We used the reagents as received because the chemicals contain small quantities of several impurities and the manufacturer attempted to

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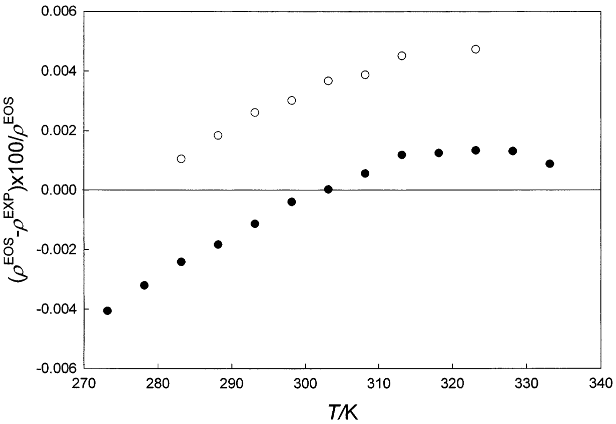

Figure 1. Percentage deviations of experimental densities of water from the equation of state given by Wagner and Pruss:[13] ○, before the experimental measurements; ●, after the experimental measurements.

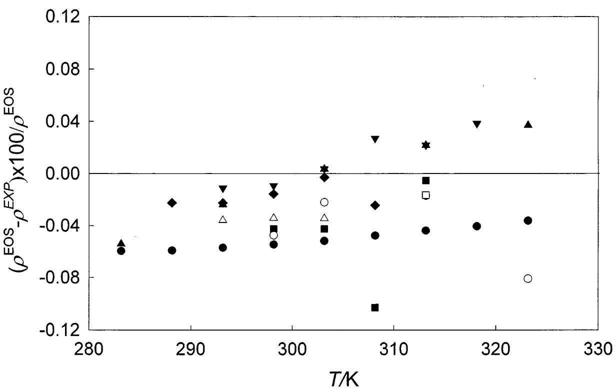

Figure 2. Percentage deviations of experimental densities of methanol from the equation of state given by de Reuck and Craven:[14] ●, this work; ■, Nikam et al.;[35] ▲, Dizechi and Marshall;[1] ▼, Ortega;[36] ◆, Papanastasiou and Ziogas;[37] ○, Garcia;[38] △, Tu et al.;[39] □, Tu et al.[40]

remove them using the same techniques available to us. We prepared mixtures gravimetrically using an analytical balance (Ohaus model AS120S) with a precision of ±0.1 mg. The overall uncertainty in the mole fractions is ±0.2%.

Results and Discussion

We have measured the densities of pure water before and after the experiment to check for possible instabilities during the measurement. Figure 1 shows the deviations of the water measurements from the formulation adopted by the International Association for the Properties of Water and Steam (IAPWS) developed by Wagner and Pruss.[13] Also, we have measured the density of methanol, and we have compared it with the values of different authors as well as with the value from the equation of state from the International Union of Pure and Applied Chemistry developed by de Reuck and Craven.[14] Figure 2 shows that our densities agree with the equation of state within ±0.05%. The agreement with different authors is within ±0.08%. We have also measured the densities of acetone and propionic acid. Table 1 shows that our densities for these two pure substances agree with the literature values within an average value of ±0.24 kg·cm^{-3}.

We have measured experimental densities (ρ) from 283.15 K to 323.15 K at atmospheric pressure. Tables 2−4 show the results for propionic acid + water, acetone + water, and acetone + propionic acid, respectively. We have compared our experimental results with values reported in the literature. Figures 3−5 show that our measurements agree with the values published for acetone + water and propionic acid + water but not with the values published for the system acetone + propionic acid. Our densities agree

Table 1. Comparison of Experimental Density Measurements with Literature Values

		ρ/kg·m^{-3}	
substance	T/K	this work	lit. (ref no.)
acetone	288.15	796.037	795.80 (17)
			795.71 (18)
	293.15	790.355	790.02 (19)
			790.15 (20)
			790.30 (21)
			790.10 (22)
	298.15	784.638	785.00 (4)
			784.37 (23)
			784.80 (24)
			784.37 (18)
			784.45 (19)
			784.40 (17)
			784.70 (2)
	303.15	778.876	780.39 (19)
			779.23 (25)
			779.00 (26)
	308.15	773.065	772.81 (18)
			773.00 (22)
	313.15	767.205	767.40 (27)
	318.15	761.288	761.04 (18)
			761.30 (22)
propionic acid	293.15	993.261	993.30 (28)
			993.48 (29)
	298.15	987.847	998.08 (30)
			987.80 (12)
			987.87 (31)
			987.90 (32)
	303.15	982.440	982.60 (33)
	308.15	977.037	977.58 (34)
	313.15	971.635	971.70 (12)
			971.87 (29)
			971.74 (31)

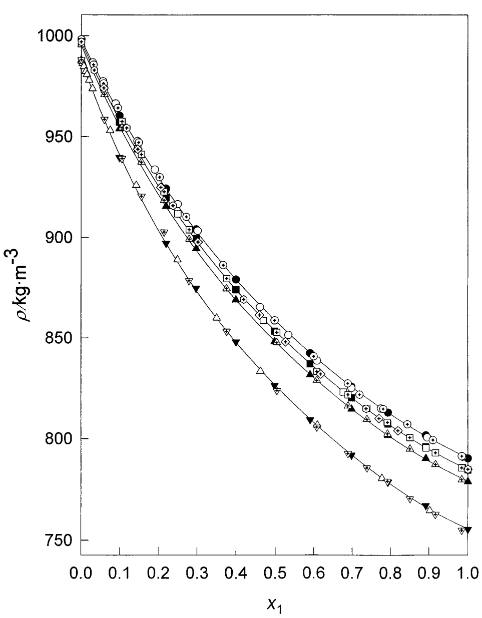

Figure 3. Densities of acetone (1) + water (2) as a function of mole fraction at different temperatures. This work: ●, 293.15 K; ■, 298.15 K; ▲, 303.15 K; ▼, 323.15 K. Howard and McAllister:[3] ○, 293.15 K; □, 298.15 K; △, 323.15 K. Dizechi and Marschall:[1] dot in a box, 293.15 K; dot in a circle, 298.15 K; dot in an up triangle, 303.15 K; dot in a down triangle, 323.15 K. Noda et al.:[2] plus in a diamond, 298.15 K. Lebed and Eddin:[4] plus in a circle, 298.15 K.

Table 2. Experimental Densities (ρ) and Excess Molar Volumes (V^E) for the Propionic Acid (1) + Water (2) Mixture

	T	ρ	V^E		T	ρ	V^E		T	ρ	V^E
x_1	K	$kg \cdot m^{-3}$	$cm^3 \cdot mol^{-1}$	x_1	K	$kg \cdot m^{-3}$	$cm^3 \cdot mol^{-1}$	x_1	K	$kg \cdot m^{-3}$	$cm^3 \cdot mol^{-1}$
1.0000	283.151	1004.112		0.5989	283.153	1025.171	−1.146 62	0.2029	283.153	1033.970	−0.948 42
0.8915	283.155	1010.323	−0.448 80	0.5008	283.150	1029.263	−1.223 02	0.1298	283.151	1026.892	−0.655 73
0.7965	283.153	1015.434	−0.752 08	0.4007	283.152	1032.634	−1.220 36	0.0000	283.150	999.691	
0.6974	283.151	1020.512	−0.990 21	0.3012	283.152	1034.467	−1.127 36				
1.0000	288.149	998.688		0.5989	288.148	1020.223	−1.082 28	0.2029	288.148	1030.054	−0.886 88
0.8915	288.144	1005.044	−0.427 66	0.5008	288.148	1024.441	−1.151 10	0.1298	288.148	1023.974	−0.616 70
0.7965	288.148	1010.263	−0.713 95	0.4007	288.144	1027.989	−1.145 74	0.0000	288.148	999.083	
0.6974	288.149	1015.460	−0.937 75	0.3012	288.148	1029.920	−1.050 12				
1.0000	293.146	993.261		0.5989	293.147	1015.256	−1.022 63	0.2029	293.145	1026.077	−0.830 09
0.8915	293.146	999.760	−0.408 39	0.5008	293.146	1019.592	−1.084 21	0.1298	293.146	1020.975	−0.582 00
0.7965	293.147	1005.103	−0.680 11	0.4007	293.146	1023.308	−1.076 29	0.0000	293.145	998.181	
0.6974	293.145	1010.391	−0.889 12	0.3012	293.145	1025.583	−0.986 38				
1.0000	298.146	987.847		0.5989	298.147	1010.279	−0.966 96	0.2029	298.145	1022.053	−0.777 58
0.8915	298.146	994.478	−0.390 26	0.5008	298.145	1014.722	−1.021 50	0.1298	298.147	1017.845	−0.549 65
0.7965	298.144	999.927	−0.647 69	0.4007	298.146	1018.606	−1.011 52	0.0000	298.146	997.019	
0.6974	298.145	1005.312	−0.843 52	0.3012	298.144	1021.142	−0.924 87				
1.0000	303.145	982.440		0.5989	303.145	1005.287	−0.914 73	0.2029	303.148	1017.971	−0.728 57
0.8915	303.147	989.192	−0.373 00	0.5008	303.145	1009.797	−0.961 04	0.1298	303.145	1014.610	−0.519 79
0.7965	303.145	994.744	−0.617 22	0.4007	303.145	1013.877	−0.950 78	0.0000	303.145	995.617	
0.6974	303.149	1000.223	−0.800 77	0.3012	303.145	1016.760	−0.870 57				
1.0000	308.147	977.037		0.5989	308.146	1000.274	−0.865 26	0.2029	308.146	1013.836	−0.682 64
0.8915	308.146	983.905	−0.356 89	0.5008	308.147	1004.168	−0.872 68	0.1298	308.149	1011.276	−0.492 03
0.7965	308.145	989.551	−0.588 41	0.4007	308.149	1009.120	−0.893 49	0.0000	308.147	994.001	
0.6974	308.146	995.120	−0.760 39	0.3012	308.149	1012.254	−0.816 77				
1.0000	313.145	971.635		0.5989	313.145	995.242	−0.818 49	0.2029	313.145	1009.645	−0.639 49
0.8915	313.145	978.613	−0.341 71	0.5008	313.145	999.956	−0.853 15	0.1298	313.145	1007.848	−0.466 27
0.7965	313.146	984.345	−0.561 03	0.4007	313.146	1004.329	−0.839 21	0.0000	313.146	992.181	
0.6974	313.145	990.001	−0.722 17	0.3012	313.145	1007.692	−0.765 52				
1.0000	318.145	966.240		0.5989	318.145	990.186	−0.774 56	0.2029	318.145	1005.395	−0.599 60
0.8915	318.145	973.307	−0.326 69	0.5008	318.145	994.902	−0.799 68	0.1298	318.145	1004.324	−0.443 01
0.7965	318.145	979.126	−0.535 16	0.4007	318.145	999.507	−0.788 61	0.0000	318.145	990.130	
0.6974	318.145	984.864	−0.686 24	0.3012	318.145	1003.085	−0.717 76				
1.0000	323.150	960.843		0.5989	323.144	985.106	−0.730 50	0.2029	323.145	1001.085	−0.559 36
0.8915	323.144	967.999	−0.312 02	0.5008	323.147	990.008	−0.754 88	0.1298	323.144	1000.708	−0.418 97
0.7965	323.144	973.895	−0.509 27	0.4007	323.145	994.651	−0.737 94	0.0000	323.145	988.003	
0.6974	323.149	979.705	−0.649 99	0.3012	323.145	998.434	−0.669 83				

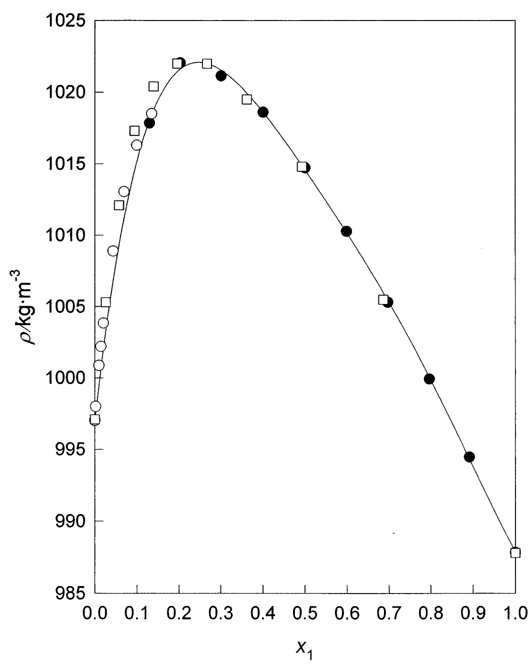

Figure 4. Densities of propionic acid (1) + water (2) as a function of the mole fraction at 298.15 K: ●, this work; ○, Lebed and Eddin;[4] □, Korpalla.[12]

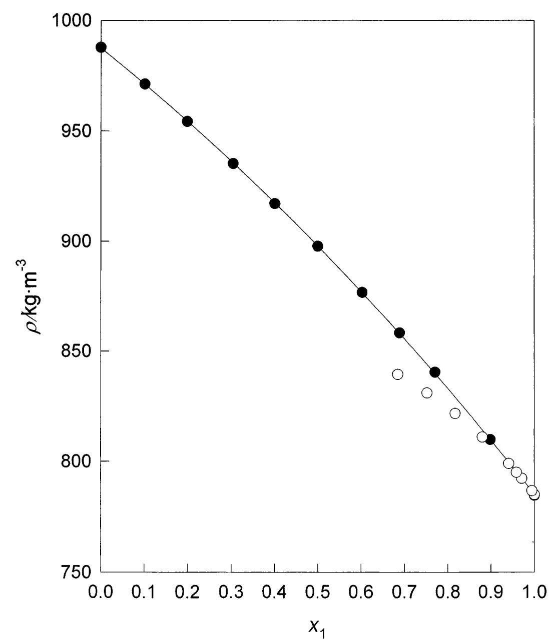

Figure 5. Densities of acetone (1) + propionic acid (2) as a function of the mole fraction at 298.15 K: ●, this work; ○, Lebed and Eddin.[4]

with the experimental values of Leben and Eddin[4] at mole fractions between 0.8 and 1. At compositions between 0.6 and 0.8 a disagreement exists with their values. However, our experimental values for pure propionic acid agree with the values published in the literature. This means that according to the values published by Leben and Eddin[4] the densities must have a change in the slope with respect to composition. Such an anomalous behavior would be difficult to believe.

Table 3. Experimental Densities (ρ) and Excess Molar Volumes (V^E) for the Acetone (1) + Water (2) Mixture

	T	ρ	V^E		T	ρ	V^E		T	ρ	V^E
x_1	K	kg·m^{-3}	cm^3·mol^{-1}	x_1	K	kg·m^{-3}	cm^3·mol^{-1}	x_1	K	kg·m^{-3}	cm^3·mol^{-1}
1.0000	283.154	801.669		0.5903	283.152	853.092	1.084 99	0.2193	283.152	932.823	0.462 92
0.8916	283.154	812.997	0.505 35	0.4986	283.151	868.988	1.035 25	0.0988	283.152	966.507	0.218 23
0.7934	283.151	824.028	0.856 42	0.3998	283.151	889.080	0.873 44	0.0000	283.150	999.691	
0.6984	283.151	836.647	1.029 31	0.2973	283.152	913.382	0.630 51				
1.0000	288.149	796.037		0.5903	288.149	847.829	1.160 73	0.2193	288.148	928.610	0.535 03
0.8916	288.149	807.424	0.525 20	0.4986	288.149	863.861	1.115 95	0.0988	288.149	963.567	0.256 38
0.7934	288.148	818.534	0.907 10	0.3998	288.148	884.145	0.954 59	0.0000	288.148	999.083	
0.6984	288.150	831.252	1.094 19	0.2973	288.148	908.777	0.705 21				
1.0000	293.146	790.355		0.5903	293.146	842.508	1.233 55	0.2193	293.145	924.322	0.596 92
0.8916	293.146	801.797	0.564 31	0.4986	293.146	858.674	1.193 32	0.0988	293.146	960.497	0.291 76
0.7934	293.146	812.982	0.956 46	0.3998	293.145	879.148	1.032 03	0.0000	293.145	998.181	
0.6984	293.146	825.797	1.157 07	0.2973	293.145	904.105	0.776 02				
1.0000	298.146	784.638		0.5903	298.144	837.135	1.304 28	0.2193	298.145	919.968	0.655 52
0.8916	298.145	796.130	0.592 88	0.4986	298.146	853.436	1.267 98	0.0988	298.144	957.313	0.324 70
0.7934	298.145	807.383	1.004 98	0.3998	298.145	874.098	1.106 39	0.0000	298.146	997.019	
0.6984	298.145	820.292	1.218 52	0.2973	298.145	899.375	0.843 53				
1.0000	303.145	778.876		0.5903	303.145	831.707	1.373 12	0.2193	303.145	915.544	0.711 33
0.8916	303.145	790.413	0.621 15	0.4986	303.145	848.142	1.340 35	0.0988	303.146	954.010	0.355 74
0.7934	303.145	801.735	1.052 45	0.3998	303.144	868.996	1.177 86	0.0000	303.145	995.617	
0.6984	303.145	814.735	1.278 54	0.2973	303.144	894.587	0.908 05				
1.0000	308.146	773.065		0.5903	308.145	826.220	1.440 57	0.2193	308.147	911.052	0.764 76
0.8916	308.146	784.645	0.649 01	0.4986	308.149	842.791	1.410 82	0.0988	308.146	950.610	0.384 83
0.7934	308.149	796.028	1.099 65	0.3998	308.149	863.836	1.247 13	0.0000	308.147	994.001	
0.6984	308.146	809.120	1.337 65	0.2973	308.149	889.735	0.970 27				
1.0000	313.145	767.205		0.5903	313.145	820.677	1.506 64	0.2193	313.145	906.488	0.816 17
0.8916	313.145	778.818	0.677 24	0.4986	313.146	837.381	1.479 71	0.0988	313.145	947.117	0.412 07
0.7934	313.145	790.262	1.146 70	0.3998	313.145	858.617	1.314 45	0.0000	313.146	992.181	
0.6984	313.145	803.446	1.396 09	0.2973	313.145	884.822	1.030 30				
1.0000	318.145	761.288		0.5903	318.148	815.068	1.571 25	0.2193	318.145	901.855	0.864 85
0.8916	318.145	772.936	0.704 81	0.4986	318.145	831.924	1.545 66	0.0988	318.146	943.497	0.437 77
0.7934	318.145	784.437	1.192 92	0.3998	318.145	853.341	1.379 06	0.0000	318.145	990.130	
0.6984	318.149	797.707	1.453 60	0.2973	318.145	879.849	1.087 46				
1.0000	323.144	755.314		0.5903	323.146	809.395	1.636 86	0.2193	323.148	897.151	0.914 08
0.8916	323.144	766.990	0.733 31	0.4986	323.145	826.399	1.612 72	0.0988	323.146	939.767	0.464 58
0.7934	323.143	778.546	1.240 38	0.3998	323.144	848.021	1.443 46	0.0000	323.145	988.003	
0.6984	323.145	791.900	1.512 50	0.2973	323.144	874.812	1.145 12				

We have calculated excess molar volumes from the experimental values using

$$V^E = \frac{x_1M_1 + x_2M_2}{\rho} - \left(\frac{x_1M_1}{\rho_1} + \frac{x_2M_2}{\rho_2}\right) \qquad (2)$$

where ρ is the mixture density, x_i is the mole fraction of species i, ρ_1 and ρ_2 are the pure densities of components 1 and 2, and M_1 and M_2 are the molar masses of pure components 1 and 2. Calculated excess volume values appear in Tables 2−4.

A Redlich−Kister[15] type equation can fit the calculated excess molar volumes using a least-squares method from SAS.[16] The Redlich−Kister equation is

$$V^E = x_1x_2\sum a_i(x_1 - x_2)^i \qquad (3)$$

where a_i are the adjusted coefficients and they appear in Table 5 together with their standard deviations defined as

$$\sigma = \left[\frac{\sum(V^E_{\text{exp}} - V^E_{\text{cal}})^2}{n - m}\right]^{1/2} \qquad (4)$$

In eq 4, n is the number of experimental points and m is the number of parameters. Figure 6 shows the variation of the excess molar volumes of acetone + water with mole fraction at different temperatures. This system shows positive deviations and an increase in the excess volume with temperature. This is an indication that, even though water can form hydrogen bonds with acetone, they are not strong enough to form a compact structure. On the other hand, propionic acid + water and acetone + propionic acid systems show negative deviations from ideal solution behavior, as shown in Figures 7 and 8, respectively.

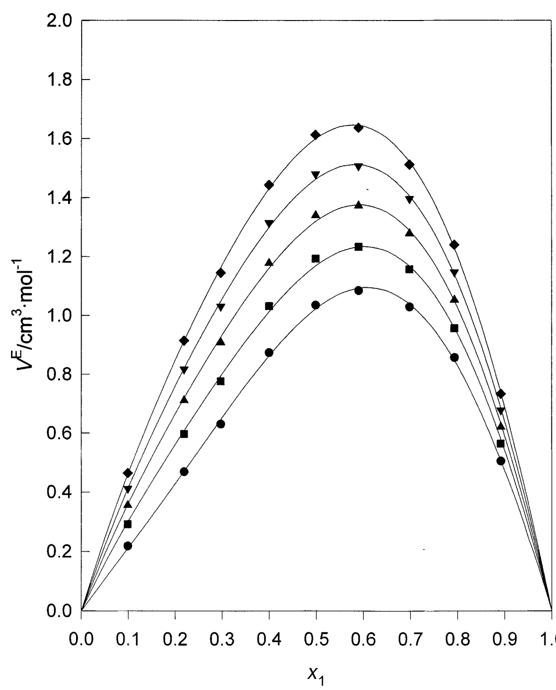

Figure 6. Excess molar volume for the acetone (1) + water (2) mixture as a function of the mole fraction at different temperatures: ●, 283.15 K; ■, 293.15 K; ▲, 303.15 K; ▼, 313.15 K; ◆, 323.15 K; —, eq 3.

Table 4. Experimental Densities (ρ) and Excess Molar Volumes (V^E) for the Acetone (1) + Propionic Acid (2) Mixture

	T	ρ	V^E		T	ρ	V^E		T	ρ	V^E
x_1	K	$kg \cdot m^{-3}$	$cm^3 \cdot mol^{-1}$	x_1	K	$kg \cdot m^{-3}$	$cm^3 \cdot mol^{-1}$	x_1	K	$kg \cdot m^{-3}$	$cm^3 \cdot mol^{-1}$
1.0000	283.154	801.669		0.6030	283.153	892.899	−1.778 68	0.1991	283.151	970.353	−1.093 46
0.8987	283.151	826.598	−0.724 31	0.5001	283.152	913.785	−1.805 24	0.1014	283.151	987.375	−0.625 31
0.7703	283.150	856.850	−1.393 61	0.4011	283.150	933.088	−1.696 24	0.0000	283.151	1004.110	
0.6887	283.151	874.585	−1.620 78	0.3046	283.151	951.246	−1.471 78				
1.0000	288.149	796.037		0.6030	288.148	887.520	−1.822 57	0.1991	288.149	965.023	−1.121 62
0.8987	288.149	821.062	−0.743 53	0.5001	288.148	908.446	−1.850 55	0.1014	288.149	982.013	−0.641 65
0.7703	288.149	851.407	−1.429 39	0.4011	288.148	927.765	−1.738 88	0.0000	288.149	998.688	
0.6887	288.149	869.180	−1.661 85	0.3046	288.148	945.944	−1.510 36				
1.0000	293.146	790.355		0.6030	293.147	882.117	−1.868 72	0.1991	293.146	959.680	−1.150 73
0.8987	293.146	815.482	−0.763 61	0.5001	293.146	903.081	−1.897 58	0.1014	293.146	976.644	−0.658 60
0.7703	293.147	845.923	−1.466 38	0.4011	293.146	922.423	−1.783 32	0.0000	293.146	993.261	
0.6887	293.147	863.740	−1.704 51	0.3046	293.146	940.613	−1.549 39				
1.0000	298.146	784.638		0.6030	298.146	876.699	−1.916 65	0.1991	298.145	954.344	−1.181 12
0.8987	298.145	809.870	−0.784 30	0.5001	298.145	897.705	−1.946 31	0.1014	298.146	971.282	−0.676 06
0.7703	298.145	840.415	−1.504 74	0.4011	298.145	917.072	−1.829 12	0.0000	298.146	987.847	
0.6887	298.145	858.280	−1.748 76	0.3046	298.146	935.277	−1.589 53				
1.0000	303.145	778.876		0.6030	303.145	871.260	−1.966 65	0.1991	303.145	948.999	−1.212 11
0.8987	303.145	804.221	−0.806 02	0.5001	303.143	892.312	−1.997 00	0.1014	303.145	965.920	−0.693 95
0.7703	303.145	834.877	−1.544 83	0.4011	303.145	911.708	−1.876 66	0.0000	303.145	982.440	
0.6887	303.145	852.794	−1.794 92	0.3046	303.145	929.933	−1.631 17				
1.0000	308.146	773.065		0.6030	308.146	865.798	−2.019 06	0.1991	308.148	943.653	−1.244 73
0.8987	308.148	798.532	−0.828 99	0.5001	308.148	886.900	−2.049 98	0.1014	308.146	960.555	−0.712 40
0.7703	308.148	829.305	−1.586 79	0.4011	308.148	906.330	−1.926 30	0.0000	308.147	977.037	
0.6887	308.149	847.276	−1.842 97	0.3046	308.15	924.579	−1.674 58				
1.0000	313.145	767.205		0.6030	313.145	860.309	−2.073 69	0.1991	313.146	938.294	−1.278 19
0.8987	313.146	792.797	−0.852 71	0.5001	313.146	881.462	−2.104 81	0.1014	313.145	955.192	−0.731 96
0.7703	313.145	823.695	−1.630 37	0.4011	313.146	900.935	−1.977 99	0.0000	313.145	971.635	
0.6887	313.146	841.731	−1.893 50	0.3046	313.146	919.210	−1.719 52				
1.0000	318.145	761.288		0.6030	318.145	854.791	−2.130 80	0.1991	318.145	932.928	−1.312 90
0.8987	318.145	787.018	−0.878 01	0.5001	318.145	876.007	−2.162 58	0.1014	318.145	949.825	−0.751 96
0.7703	318.145	818.051	−1.676 52	0.4011	318.145	895.523	−2.031 93	0.0000	318.145	966.240	
0.6887	318.145	836.154	−1.946 56	0.3046	318.145	913.828	−1.766 24				
1.0000	323.144	755.314		0.6030	323.146	849.244	−2.190 83	0.1991	323.144	927.551	−1.349 09
0.8987	323.145	781.194	−0.905 07	0.5001				0.1014	323.148	944.448	−0.772 49
0.7703	323.144	812.366	−1.724 94	0.4011	323.144	890.087	−2.088 02	0.0000	323.148	960.843	
0.6887	323.148	830.541	−2.002 21	0.3046	323.144	908.430	−1.815 02				

Table 5. Parameters for the Redlich−Kister Equation

T/K	a_0	a_1	a_2	a_3	σ
		Acetone + Water			
283.15	4.0987	2.4597	−0.4727	−1.0397	0.0130
288.15	4.4208	2.4004	−0.3995	−1.0624	0.0132
293.15	4.6829	2.3522	0.0000	−1.0927	0.0177
298.15	4.9897	2.3130	0.0000	−1.0996	0.0163
303.15	5.2862	2.2825	0.0000	−1.1036	0.0152
308.15	5.5748	2.2603	0.0000	−1.1028	0.0144
313.15	5.8567	2.2439	0.0000	−1.0878	0.0138
318.15	6.1290	2.2411	0.0000	−1.0843	0.0132
323.15	6.4050	2.2482	0.0000	−1.0997	0.0128
		Propionic Acid + Water			
283.15	−4.9046	0.8884	−0.7600	0.0000	0.0142
288.15	−4.6112	0.7704	−0.7412	0.0000	0.0129
293.15	−4.3424	0.6732	−0.7429	0.0000	0.0109
298.15	−4.0900	0.5824	−0.7430	0.0000	0.0097
303.15	−3.8529	0.5046	−0.7522	0.0000	0.0083
308.15	−3.5858	0.4285	−0.8914	0.0000	0.0140
313.15	−3.4164	0.2292	−0.7736	0.3913	0.0045
318.15	−3.2121	0.1425	−0.8019	0.4682	0.0037
323.15	−3.0186	0.0000	−0.7948	0.6665	0.0036
		Acetone + Propionic Acid			
283.15	−7.2251	−0.8322	−0.3736	0.0000	0.0102
288.15	−7.4061	−0.8511	−0.3999	0.0000	0.0103
293.15	−7.5941	−0.8731	−0.4248	0.0000	0.0104
298.15	−7.7887	−0.8965	−0.4508	0.0000	0.0106
303.15	−7.9913	−0.9238	−0.4756	0.0000	0.0107
308.15	−8.2029	−0.9529	−0.5025	0.0000	0.0109
313.15	−8.4229	−0.9845	−0.5302	0.0000	0.0110
318.15	−8.6534	−1.0217	−0.5591	0.0000	0.0111
323.15	−8.8955	−1.0637	−0.5871	0.0000	0.0122

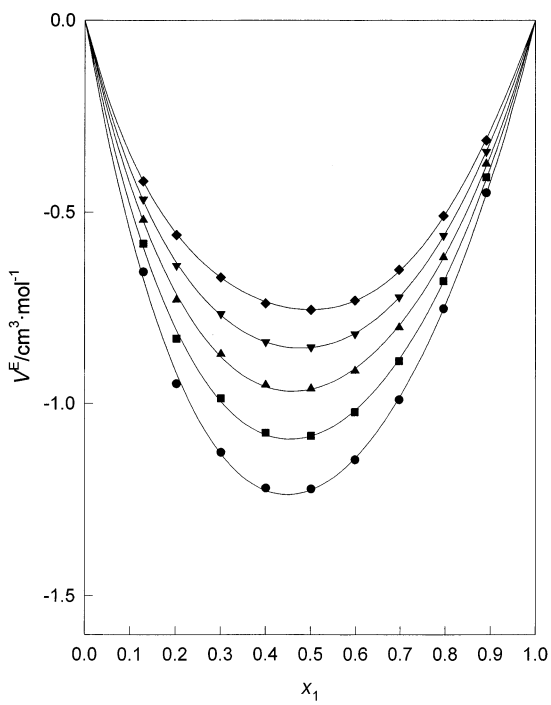

Figure 7. Excess molar volume for the propionic acid (1) + water (2) mixture as a function of the mole fraction at different temperatures: ●, 283.15 K; ■, 293.15 K; ▲, 303.15 K; ▼, 313.15 K; ◆, 323.15 K; —, eq 3.

For the system propionic acid + water, the excess molar volume decreases with temperature while, in the system acetone + propionic acid, the excess molar volume increases with temperature. Because the two systems show negative deviations, this is an indication that systems with propionic

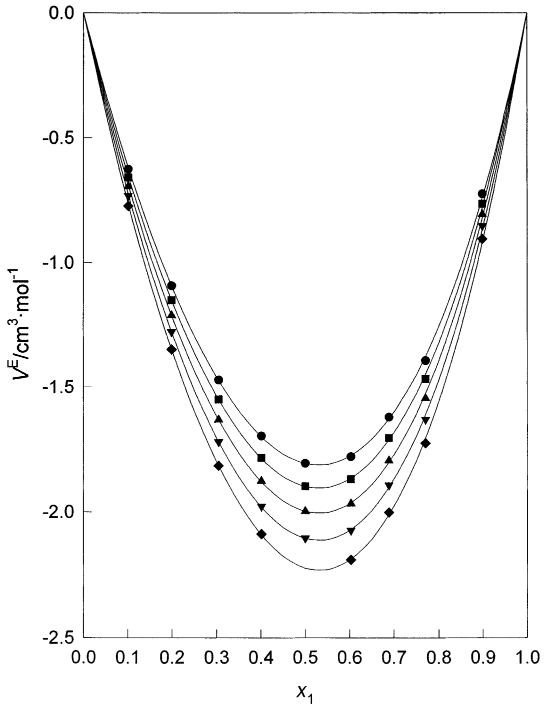

Figure 8. Excess molar volume for the acetone (1) + propionic acid (2) mixture as a function of the mole fraction at different temperatures: ●, 283.15 K; ■, 293.15 K; ▲, 313.15 K; ▼, 323.15 K; —, eq 3.

acid form more compact structures than systems such as acetone + water.

Conclusions

We have measured liquid densities for acetone + water, propionic acid + water, and acetone + propionic acid binary systems using a vibrating densimeter. Also, we have calculated the excess molar volume using a Redlich−Kister type equation. The new measurements can facilitate understanding of behavior among polar substances and developing new theories or equations of state.

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