Apparent Molar Volumes of Calcium Nitrate in 1-Propanol + Water at 298.15 K

Ernesto Vercher, Francisco J. Rojo, and Antoni Martínez-Andreu*

Departamento de Ingeniería Química, Facultad de Química, Universitat de València, 46100 Burjassot, Valencia, Spain

The densities of 1-propanol + water + calcium nitrate mixtures have been measured with an oscillating-tube densimeter over a large range of concentrations of the salt and 1-propanol, at 298.15 K. From these densities, apparent molar volumes of calcium nitrate in 1-propanol + water mixtures have been calculated, and partial molar volumes at infinite dilution have been evaluated.

1. Introduction

In previous papers, we studied the vapor−liquid equilibrium of ethanol + water + inorganic salt systems for the following salts: strontium bromide (Vercher et al., 1994); cobalt(II) chloride (Peña et al., 1994); strontium chloride (Peña et al., 1995a); copper(II) chloride (Vercher et al., 1995); potassium nitrate (Vercher et al., 1996a); strontium nitrate (Vercher et al., 1996b); sodium nitrate (Peña et al., 1996b); and, the 1-propanol + water + calcium nitrate system (Vercher et al., 1999). In these works, the composition of the ternary liquid phase was determined by a combined gravimetric and densimetric method. Therefore, we have measured the density of ternary mixtures of alcohol, water, and salt at different compositions (Peña et al., 1995b, 1996a, 1997, 1998; Martínez-Andreu et al., 1999). In the present work, we report densities for the 1-propanol + water + calcium nitrate system at 298.15 K and the apparent molar volumes of calcium nitrate in 1-propanol + water mixtures.

Several papers have appeared in the literature concerning the densities of calcium nitrate aqueous solutions at 298.15 K (Scatchard, 1928; Pearce and Blackman, 1935; Ewing and Mikovsky, 1950; Kuznetsov et al., 1983), as well as apparent molar volumes at 298.15 K of calcium nitrate in water (Ewing and Herty, 1953; Spitzer et al., 1979). Pietsch (1956), Millero (1972), and Krumgalz et al. (1996) have compiled experimental data on the densities and the apparent molar volumes for this salt in aqueous solutions. We did not find any density values for calcium nitrate solutions in 1-propanol or mixtures of 1-propanol, water, and calcium nitrate at 298.15 K.

2. Experimental Section

2.1. Materials. The chemicals were 1-propanol (Merck, GR grade) with a stated minimum purity of 99.5 mass % (maximum 0.05 mass % water), distilled water (Merck, HPLC grade), and calcium nitrate tetrahydrate (Merck, GR grade, >99.0 mass %). The solvents were used directly without further purification, whereas the calcium nitrate was desiccated in an oven hold at 185 °C for at least 24 h. The experimental density for 1-propanol at 298.15 (799.50 ± 0.01 kg·m^{-3}) agrees with those given by Mikhail and Kimel (1963), Ortega (1982), and García et al. (1991). The density of pure water at 298.15 K was taken as 997.05 kg·m^{-3} (Marsh and Richards, 1980).

2.2. Sample Preparation. The 1-propanol + calcium nitrate and water + calcium nitrate binary mixtures were prepared from concentrated solutions by successive dilution and were analyzed gravimetrically by evaporation to dryness. The accuracy of salt mole fractions in the alcohol + salt samples was better than ±0.000 05, and in the water + salt samples was better than ±0.000 015. The 1-propanol + water + electrolyte mixtures were each prepared gravimetrically using a Mettler AE 200 analytical balance with a precision of ±0.0001 g. They were stirred for a sufficient time to ensure dissolution of the salt and then stored in vials prior to use. Samples were kept in a water bath at 303 K to prevent the formation of bubbles in the densimeter. In the ternary mixture, the accuracy of 1-propanol and water mole fractions was better than ±0.000 08, and the accuracy of salt mole fractions was better than ±0.000 012.

2.3. Apparatus and Procedure. The sample densities were measured with a vibrating tube densimeter (Anton Paar DMA 58) with proportional temperature control that kept the samples at (298.15 ± 0.01) K. The densimeter was calibrated with distilled water and dry air. The accuracy of the density values was ±0.08 kg·m^{-3}.

3. Results and Discussion

In Table 1 the densities d of the 1-propanol (1) + calcium nitrate (3) mixtures are reported, and in Table 2 we show the densities of the water (2) + calcium nitrate (3) mixtures, where x_3 is the mole fraction of salt in the binary mixture. In Table 3, densities for 1-propanol (1) + water (2) + calcium nitrate (3) mixtures are reported, where x'_1 is the mole fraction of 1-propanol in the salt-free solvent. From these results, the molar volume of solution V and the molar concentration of salt in the solution c were calculated. In Tables 1−3 we also report values of V and c. The densities of aqueous solutions of calcium nitrate are in good agreement with the experimental values reported by Scatchard (1928), Ewing and Mikovsky (1950), and Spitzer et al. (1979). The values reported by Pearce and Blackman (1935) and Kuznetsov et al. (1983) are not in agreement with the remainder of the data.

The apparent molar volume V_ϕ of the electrolyte in the 1-propanol + water mixture is defined from the molar

* To whom correspondence should be addressed. E-mail: Antoni.Martinez@uv.es.

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Table 1. Densities d, Molar Volumes V, and Molar Concentrations c of 1-Propanol (1) + Calcium Nitrate (3) Mixtures and Apparent Molar Volumes V_ϕ of Calcium Nitrate in 1-Propanol at 298.15 K

x_3	d/kg·m^{-3}	V/cm^3·mol^{-1}	c/mol·L^{-1}	V_ϕ/cm^3·mol^{-1}
0.005 57	809.04	74.997	0.0743	44.7 ± 0.9
0.009 85	816.33	74.872	0.1316	45.2 ± 0.5
0.016 02	826.89	74.692	0.2145	45.5 ± 0.3
0.023 48	839.63	74.482	0.3152	45.99 ± 0.22
0.032 65	855.15	74.246	0.4397	46.95 ± 0.17
0.041 46	870.06	74.027	0.5601	47.67 ± 0.12
0.049 62	883.99	73.820	0.6722	48.03 ± 0.11
0.057 97	898.07	73.629	0.7873	48.64 ± 0.08
0.066 44	911.99	73.472	0.9043	49.65 ± 0.08
0.074 67	925.86	73.295	1.0188	50.10 ± 0.06
0.080 61	936.15	73.149	1.1020	50.14 ± 0.06
0.089 16	950.76	72.961	1.2220	50.42 ± 0.05
0.096 81	963.05	72.856	1.3288	51.29 ± 0.05
0.104 43	976.01	72.700	1.4365	51.55 ± 0.05
0.111 51	987.81	72.577	1.5364	51.94 ± 0.04
0.121 60	1004.57	72.410	1.6793	52.50 ± 0.04
0.126 26	1012.60	72.315	1.7460	52.58 ± 0.04
0.129 54	1017.69	72.289	1.7920	52.95 ± 0.06
0.132 37	1022.27	72.253	1.8321	53.15 ± 0.05
0.139 10	1033.48	72.146	1.9280	53.45 ± 0.06
0.144 81	1041.94	72.130	2.0076	54.19 ± 0.05

Table 2. Densities d, Molar Volumes V, and Molar Concentrations c of Water (2) + Calcium Nitrate (3) Mixtures and Apparent Molar Volumes V_ϕ of Calcium Nitrate in Water at 298.15 K

x_3	d/kg·m^{-3}	V/cm^3·mol^{-1}	c/mol·L^{-1}	V_ϕ/cm^3·mol^{-1}
0.005 07	1030.38	18.203	0.2787	44.6 ± 0.3
0.012 93	1079.69	18.435	0.7014	46.40 ± 0.12
0.015 62	1095.75	18.523	0.8431	47.16 ± 0.10
0.017 88	1109.18	18.596	0.9614	47.59 ± 0.09
0.019 98	1122.03	18.656	1.0708	47.51 ± 0.08
0.022 14	1134.58	18.728	1.1820	47.87 ± 0.07
0.024 35	1146.89	18.810	1.2948	48.50 ± 0.06
0.027 01	1161.91	18.900	1.4291	48.87 ± 0.06
0.029 94	1178.35	19.000	1.5759	49.19 ± 0.06
0.032 73	1193.18	19.105	1.7130	49.74 ± 0.05
0.035 31	1206.79	19.202	1.8387	50.17 ± 0.05
0.037 95	1220.60	19.301	1.9664	50.56 ± 0.04
0.039 34	1227.54	19.357	2.0322	50.82 ± 0.04
0.040 71	1234.47	19.410	2.0972	51.03 ± 0.05
0.042 21	1242.17	19.466	2.1682	51.19 ± 0.04
0.043 35	1247.95	19.510	2.2221	51.33 ± 0.05
0.044 92	1255.71	19.572	2.2952	51.55 ± 0.04
0.046 85	1265.48	19.643	2.3849	51.69 ± 0.04
0.048 35	1272.65	19.705	2.4537	51.92 ± 0.04
0.050 14	1282.00	19.766	2.5368	51.92 ± 0.04
0.051 37	1289.42	19.791	2.5956	51.60 ± 0.04
0.053 54	1297.21	19.916	2.6882	52.58 ± 0.04
0.055 26	1305.17	19.987	2.7647	52.80 ± 0.04
0.056 95	1313.06	20.056	2.8398	52.97 ± 0.03
0.059 49	1324.77	20.158	2.9512	53.20 ± 0.03
0.063 23	1341.14	20.319	3.1116	53.67 ± 0.03
0.065 77	1352.03	20.431	3.2193	53.98 ± 0.03
0.068 75	1364.33	20.566	3.3431	54.39 ± 0.03
0.071 07	1374.35	20.661	3.4396	54.56 ± 0.03
0.073 12	1382.90	20.751	3.5237	54.75 ± 0.03
0.076 68	1397.43	20.907	3.6677	55.09 ± 0.03
0.079 25	1407.73	21.021	3.7702	55.32 ± 0.03
0.083 08	1422.54	21.195	3.9197	55.70 ± 0.02
0.084 40	1428.11	21.248	3.9724	55.74 ± 0.02
0.087 90	1440.96	21.412	4.1049	56.11 ± 0.02
0.091 32	1453.53	21.571	4.2333	56.43 ± 0.02
0.096 34	1471.82	21.801	4.4189	56.82 ± 0.02
0.101 42	1489.58	22.039	4.6016	57.22 ± 0.02
0.104 79	1500.82	22.203	4.7197	57.52 ± 0.02
0.106 90	1507.80	22.304	4.7928	57.69 ± 0.02

volume of solution V by means of the expression

$$V = V_1^\circ x_1 + V_2^\circ x_2 + V_{12}^{E}(x_1 + x_2) + V_\phi x_3 \qquad (1)$$

where V_1° is the molar volume of pure 1-propanol, V_2° is that of pure water, and V_{12}^E is the excess molar volume of the binary 1-propanol + water mixture, which depends on the solvent composition. The apparent molar volume of the electrolyte in a ternary liquid mixture of 1-propanol + water + electrolyte can be calculated for each composition by using eq 1, provided that the following are known: the density of the sample; the molar volumes of pure 1-propanol and pure water; and the compositional dependence of the excess molar volume of the binary 1-propanol + water mixture at the same pressure and temperature conditions. The value of V_{12}^E for each composition of the solvent mixture was calculated by using the correlation proposed by Davis (1990), on the basis of experimental data published by Benson and Kiyohara (1980). The values of the apparent molar volume of calcium nitrate calculated at 298.15 K are also shown in Tables 1−3.

Millero (1971) and Nomura et al. (1985) suggested that the apparent molar volume of an electrolyte in a mixed solvent, at constant solvent composition, could be fitted by the Masson (1929) equation

$$V_\phi = V_\phi^\circ + S_v^e \cdot c^{1/2} \qquad (2)$$

where V_ϕ° is the apparent molar volume of electrolyte at infinite dilution, which is the same as the partial molar volume of electrolyte at infinite dilution, and S_v^e is the experimental slope. Both V_ϕ° and S_v^e depend on the solvent composition and can be correlated using the following expressions:

$$V_\phi^\circ/\mathrm{cm^3{\cdot}mol^{-1}} = \sum_{\nu=0}^{4} b_\nu (x_1')^\nu \qquad (3)$$

$$S_v^e/\mathrm{cm^3{\cdot}mol^{-3/2}{\cdot}L^{1/2}} = \sum_{\nu=0}^{4} c_\nu (x'_1)^\nu \qquad (4)$$

From the V_ϕ values of calcium nitrate in 1-propanol (given in Table 1) we have calculated the apparent molar volume of calcium nitrate at infinite dilution in 1-propanol. The value obtained is $V_\phi^\circ = 43.4$ cm^3·mol^{-1}.

From the V_ϕ values of calcium nitrate in water (given in Table 2) we have calculated the apparent molar volume of calcium nitrate at infinite dilution in aqueous solutions. The obtained value was $V_\phi^\circ = 40.03$ cm^3·mol^{-1}. This value can be compared with the experimental values reported in the literature, shown in Table 4. Our value is very similar to the value obtained by Scatchard (1928) and those reported by Ewing and Mikovsky (1950), Spitzer et al. (1979), Millero (1972), and Krumgalz et al. (1996).

From the V_ϕ values of calcium nitrate in the 1-propanol + water system and at a least-squares minimization, we have found the values of b_ν and c_ν that minimize the sum of squared deviations between experimental and calculated results of V_ϕ in the one-liquid phase range. These parameters are given in Table 5. The mean absolute deviation of the apparent molar volume for calcium nitrate is 0.54 cm^3·mol^{-1}, and the standard deviation is 0.70 cm^3·mol^{-1}.

From the values of b_ν and c_ν and eqs 1−4, we have recalculated the molar volume and the density of the 1-propanol + water + calcium nitrate solutions. The mean absolute deviation of the molar volume is 0.028 cm^3·mol^{-1}, and the corresponding standard deviation is 0.043 cm^3·mol^{-1}. The mean absolute deviation of the density is 0.55 kg·m^{-3}, and the standard deviation is 0.85 kg·m^{-3}.

Table 3. Densities *d*, Molar Volumes *V*, and Molar Concentrations *c* of 1-Propanol (1) + Water (2) + Calcium Nitrate (3) Mixtures and Apparent Molar Volumes V_ϕ of Calcium Nitrate in 1-Propanol + Water Mixtures at 298.15 K

x_3	x'_1	d/kg·m^{-3}	V/cm^3·mol^{-1}	c/mol·L^{-1}	V_ϕ/cm^3·mol^{-1}	x_3	x'_1	d/kg·m^{-3}	V/cm^3·mol^{-1}	c/mol·L^{-1}	V_ϕ/cm^3·mol^{-1}
0.005 04	0.050 11	1003.76	20.772	0.2428	47.8 ± 0.3	0.004 96	0.597 93	848.31	51.605	0.0962	51.1 ± 1.0
0.005 04	0.099 99	977.72	23.460	0.2148	51.7 ± 0.3	0.005 16	0.699 68	836.43	57.458	0.0898	50.1 ± 1.2
0.005 03	0.199 88	934.68	29.014	0.1734	52.4 ± 0.4	0.005 00	0.799 59	825.58	63.258	0.0791	52.3 ± 1.6
0.005 02	0.299 48	903.98	34.611	0.1452	52.0 ± 0.4	0.004 99	0.898 73	816.54	69.041	0.0722	49.8 ± 2.0
0.004 98	0.399 66	880.67	40.284	0.1235	51.7 ± 0.6	0.005 10	0.952 07	812.25	72.170	0.0707	46.7 ± 2.1
0.004 98	0.499 59	862.70	45.973	0.1083	51.4 ± 0.7						
0.010 00	0.049 97	1030.59	20.917	0.4780	49.63 ± 0.16	0.009 98	0.600 15	859.38	51.754	0.1929	53.6 ± 0.5
0.010 00	0.099 86	1001.38	23.604	0.4239	52.71 ± 0.16	0.010 08	0.698 13	846.68	57.365	0.1758	53.2 ± 0.6
0.010 01	0.200 02	954.19	29.145	0.3434	52.96 ± 0.18	0.010 09	0.797 75	835.60	63.093	0.1599	52.0 ± 0.8
0.010 02	0.299 88	920.62	34.728	0.2884	52.67 ± 0.22	0.010 09	0.898 23	825.76	68.914	0.1464	49.9 ± 0.9
0.009 99	0.400 03	895.41	40.362	0.2476	51.7 ± 0.3	0.009 98	0.948 10	821.06	71.824	0.1389	47.9 ± 1.1
0.010 02	0.499 94	875.51	46.037	0.2176	53.0 ± 0.4						
0.020 01	0.050 17	1083.30	21.238	0.9424	50.64 ± 0.08	0.020 07	0.599 17	882.32	51.743	0.3879	54.91 ± 0.23
0.019 98	0.100 02	1046.91	23.936	0.8349	54.23 ± 0.08	0.020 07	0.700 83	866.82	57.504	0.3489	54.6 ± 0.3
0.020 00	0.199 79	991.80	29.416	0.6798	55.17 ± 0.09	0.020 05	0.801 48	853.92	63.232	0.3171	53.8 ± 0.4
0.019 91	0.299 38	952.22	34.940	0.5698	55.74 ± 0.11	0.019 82	0.897 97	843.01	68.741	0.2883	51.4 ± 0.5
0.019 99	0.399 53	923.03	40.531	0.4932	55.86 ± 0.14	0.019 95	0.948 95	838.38	71.644	0.2784	48.5 ± 0.5
0.019 86	0.499 73	899.85	46.149	0.4302	55.75 ± 0.18						
0.029 99	0.049 91	1131.35	21.596	1.3885	53.02 ± 0.05	0.030 01	0.598 18	904.40	51.763	0.5797	56.35 ± 0.15
0.029 94	0.099 93	1090.44	24.273	1.2336	55.35 ± 0.05	0.029 98	0.698 60	887.35	57.374	0.5225	55.43 ± 0.19
0.030 03	0.200 12	1028.15	29.732	1.0099	56.31 ± 0.06	0.029 89	0.800 13	873.00	63.054	0.4741	53.58 ± 0.24
0.030 01	0.299 75	983.64	35.210	0.8523	56.90 ± 0.07	0.030 02	0.900 25	860.84	68.708	0.4369	51 ± 0.3
0.030 15	0.400 76	950.46	40.796	0.7389	57.10 ± 0.09	0.029 99	0.948 50	855.71	71.417	0.4199	49.7 ± 0.3
0.030 05	0.500 26	924.76	46.308	0.6490	56.74 ± 0.12						
0.040 05	0.050 02	1179.09	21.954	1.8243	53.69 ± 0.04	0.040 04	0.600 02	926.54	51.916	0.7713	56.43 ± 0.11
0.039 99	0.099 97	1133.17	24.617	1.6245	55.86 ± 0.04	0.040 03	0.699 84	907.89	57.423	0.6971	55.44 ± 0.14
0.039 92	0.199 65	1064.44	29.980	1.3315	56.37 ± 0.04	0.040 15	0.799 50	892.39	62.946	0.6378	54.29 ± 0.18
0.039 99	0.299 96	1014.43	35.462	1.1276	57.35 ± 0.05	0.040 15	0.902 23	878.82	68.641	0.5850	51.84 ± 0.23
0.039 99	0.399 84	977.88	40.914	0.9773	57.19 ± 0.06	0.040 00	0.947 73	873.39	71.153	0.5622	49.81 ± 0.25
0.039 91	0.400 19	976.82	40.963	0.9744	57.96 ± 0.07	0.039 50	0.950 40	872.49	71.289	0.5541	49.11 ± 0.25
0.040 01	0.500 15	949.26	46.420	0.8619	57.00 ± 0.08						
0.050 01	0.049 95	1223.64	22.324	2.2401	54.58 ± 0.03	0.050 13	0.701 93	928.14	57.529	0.8714	55.67 ± 0.11
0.049 98	0.099 91	1173.16	24.984	2.0006	56.76 ± 0.03	0.050 09	0.801 47	911.36	62.949	0.7957	53.96 ± 0.14
0.050 02	0.199 83	1097.83	30.342	1.6484	57.84 ± 0.03	0.050 18	0.903 25	896.54	68.539	0.7321	52.15 ± 0.18
0.050 05	0.399 43	1004.10	41.126	1.2171	58.44 ± 0.05	0.050 13	0.950 39	890.60	71.105	0.7050	50.34 ± 0.19
0.050 06	0.500 64	972.66	46.615	1.0740	58.16 ± 0.07	0.050 04	0.951 57	890.03	71.192	0.7028	50.71 ± 0.20
0.050 02	0.599 62	948.11	51.991	0.9621	57.41 ± 0.09						
0.060 05	0.500 14	996.08	46.753	1.2844	58.88 ± 0.05	0.059 72	0.796 38	931.22	62.552	0.9547	53.51 ± 0.12
0.060 08	0.600 41	969.43	52.133	1.1524	58.11 ± 0.07	0.060 30	0.903 75	914.57	68.404	0.8815	52.36 ± 0.14
0.060 04	0.700 01	947.85	57.471	1.0447	56.76 ± 0.09	0.059 76	0.945 01	908.09	70.626	0.8462	50.89 ± 0.16
0.069 93	0.399 80	1055.88	41.555	1.6828	59.13 ± 0.04	0.070 06	0.800 77	948.82	62.799	1.1156	55.06 ± 0.10
0.069 91	0.499 37	1020.29	46.821	1.4930	58.63 ± 0.05	0.070 29	0.903 97	931.14	68.355	1.0283	53.92 ± 0.12
0.070 16	0.600 31	991.95	52.173	1.3448	57.85 ± 0.06	0.070 11	0.948 64	925.41	70.647	0.9924	51.42 ± 0.13
0.069 75	0.699 13	968.23	57.395	1.2152	56.46 ± 0.08						
0.079 92	0.399 92	1080.65	41.802	1.9119	59.78 ± 0.03	0.080 04	0.800 56	968.65	62.663	1.2772	54.54 ± 0.08
0.079 77	0.499 09	1042.58	46.994	1.6975	59.40 ± 0.04	0.080 23	0.904 25	948.92	68.218	1.1761	53.95 ± 0.10
0.079 84	0.599 11	1013.18	52.189	1.5299	58.11 ± 0.05	0.079 93	0.946 44	941.67	70.443	1.1346	52.92 ± 0.11
0.079 85	0.698 20	988.90	57.351	1.3923	56.66 ± 0.07	0.078 69	0.950 65	939.24	70.660	1.1137	52.44 ± 0.11
0.089 93	0.399 57	1104.93	42.043	2.1391	60.48 ± 0.03	0.089 97	0.700 09	1010.15	57.385	1.5678	56.01 ± 0.06
0.089 90	0.401 16	1105.55	42.071	2.1370	59.88 ± 0.03	0.089 80	0.796 95	987.98	62.408	1.4389	54.79 ± 0.07
0.089 93	0.499 56	1065.92	47.174	1.9063	59.60 ± 0.04	0.089 73	0.896 68	968.80	67.579	1.3279	53.01 ± 0.09
0.090 03	0.600 02	1034.55	52.334	1.7202	58.46 ± 0.04	0.089 62	0.945 60	960.25	70.120	1.2781	51.87 ± 0.10
0.100 21	0.701 44	1028.79	57.556	1.7411	57.17 ± 0.05	0.100 01	0.899 59	985.28	67.690	1.4774	54.21 ± 0.08
0.100 22	0.801 62	1005.23	62.679	1.5989	55.92 ± 0.06						
0.110 16	0.400 29	1154.60	42.521	2.5906	60.77 ± 0.02	0.110 10	0.950 54	994.13	70.105	1.5705	53.09 ± 0.08
0.119 98	0.499 92	1135.11	47.621	2.5195	59.76 ± 0.03	0.120 08	0.900 79	1022.68	67.382	1.7821	53.63 ± 0.06
0.119 95	0.599 59	1100.54	52.466	2.2862	58.07 ± 0.03	0.119 79	0.948 79	1013.77	69.698	1.7188	52.00 ± 0.07
0.120 20	0.801 06	1044.89	62.429	1.9255	55.33 ± 0.05						
0.130 06	0.699 86	1089.00	57.515	2.2612	57.57 ± 0.04	0.130 15	0.901 17	1040.28	67.303	1.9338	54.08 ± 0.06
0.130 01	0.800 75	1061.81	62.461	2.0814	56.30 ± 0.05	0.129 57	0.943 78	1030.95	69.365	1.8680	52.96 ± 0.06
0.140 07	0.800 07	1082.21	62.305	2.2481	55.95 ± 0.04	0.139 89	0.949 49	1048.74	69.432	2.0148	52.74 ± 0.06
0.139 83	0.899 41	1057.29	67.149	2.0823	54.68 ± 0.05						
0.150 18	0.800 31	1099.65	62.359	2.4084	56.72 ± 0.04	0.150 19	0.950 01	1066.65	69.308	2.1671	53.07 ± 0.05
0.150 26	0.900 70	1076.71	67.029	2.2416	54.45 ± 0.05						
0.160 59	0.903 81	1094.03	67.090	2.3936	54.82 ± 0.05	0.159 69	0.946 66	1082.62	69.107	2.3108	54.00 ± 0.05
0.169 66	0.947 73	1099.20	69.062	2.4566	54.48 ± 0.05						

Table 4. Apparent Molar Volume of Calcium Nitrate in Water at Infinite Dilution, at 298.15 K

ref	V^{o}_{ϕ}/cm^3·mol^{-1}
this work	40.03
Scatchard (1928)	40.92[a]
Pearce and Blackman (1935)	36.2[a]
Ewing and Mikovsky (1950)	40.16
Ewing and Herty (1953)	37.56
Spitzer et al. (1979)	39.4
Kuznetsov et al. (1983)	n.s.[b]
Millero (1972)	40.15[c]
Krumgalz et al. (1996)	40.39

[a] Value obtained from density data reported. [b] n.s.: no satisfactory experimental values for fitting. [c] Value obtained from partial molar volumes of ions, using an additivity rule.

Table 5. Parameters of Eqs 3 and 4

	$\nu = 0$	$\nu = 1$	$\nu = 2$	$\nu = 3$	$\nu = 4$
b_ν	42.677	74.479	−273.90	419.2	−220.5
c_ν	6.636	−16.007	119.94	−243.3	140.2

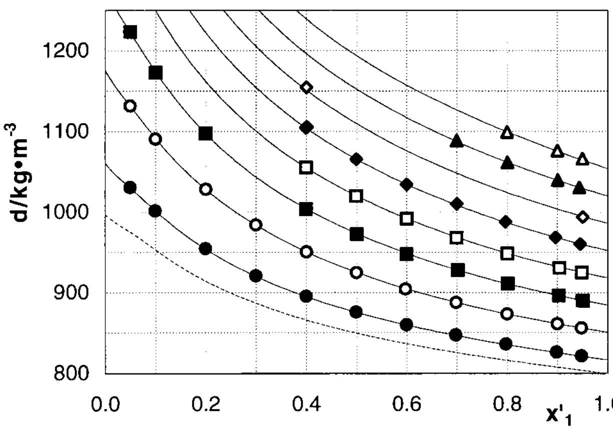

Figure 1. Density of 1-propanol + water + calcium nitrate mixtures against the molar fraction of 1-propanol on a salt-free basis x'_1, for several salt mole fractions, x_3. (●) $x_3 = 0.01$; (○) $x_3 = 0.03$; (■) $x_3 = 0.05$; (□) $x_3 = 0.07$; (◆) $x_3 = 0.09$; (◇) $x_3 = 0.11$; (▲) $x_3 = 0.13$; (△) $x_3 = 0.15$; (solid line) predicted by proposed correlation; (dotted line) salt-free system.

In Figure 1 it can be observed that the addition of calcium nitrate to 1-propanol + water mixtures results in a considerable increase of the density of the liquid mixture. Experimental data agree very well with the values predicted from the proposed correlation.

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