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Densities of (Lithium, Magnesium, or Copper(II)) Sulfates in Ethanol−Water Solutions

Martín F. Hervello and Angel Sánchez*

Departamento de Ingeniería Química, Universidad de Vigo, 36200, Vigo, Spain

The densities of (lithium, magnesium, and copper(II)) sulfates + ethanol + water mixtures have been measured with an oscillating-tube densimeter in the temperature range of (283.15 to 298.15) K and at atmospheric pressure. An empirical correlation for the densities of ternary mixtures has been used to correlate experimental values as a function of the molality of the salt and solvent composition. Data fitting show a good agreement with experimental values.

Introduction

The knowledge of the influence of electrolytes in the phase equilibria of water + alcohol has been treated in numerous papers.[1−3] Also, g^E models have been developed for the reliable prediction of phase equilibria, osmotic coefficients, and mean ionic activity coefficients.[4−7] But the study of densities of these type of mixtures is more scarce than the above properties.

One of the research activities of our group is the physical characterization of the salt effect in ethanol−water solutions.[8] Generally, the densities of electrolyte solutions have been determined at low molalities of salt for using a fitting equation[9] elucidating the nature of solute−solvent interations by partial molar volume at infinite dilution. But the aim of this work is to obtain densities of the studied systems in a broad range of molalities of salt and mass fraction of ethanol. So, we present densities from (283.15 to 298.15) K, at 5 K intervals, of (lithium, magnesium, or copper(II)) sulfate + ethanol + water mixtures. These values were fitted to polynomials as a function of the molality of the salt and the salt-free mass fraction of the solution. The three systems present good agreement with the experimental values. For the systems treated in this paper, we have not been able to find more data in the literature on experimental values for these ternary systems, except data on $MgSO_4$ mixtures at dilute concentrations of salt[10,11] and data on Li_2SO_4-saturated solutions.[12]

Experimental Section

Materials. The chemicals were ethanol (Merck, Lichrosolv quality) with a stated minimum purity of 0.995, degassed with ultrasound, and stored over freshly activated molecular sieves (type 4a or 3a, 1/16 in., Aldrich Catalog No. 20.860-4 or 20.858-2, respectively) for several days before use. The water was Milli-Q quality (resistivity, 18.2 MΩ·cm). Lithium sulfate monohydrate (Merck, mass fraction >0.99), magnesium sulfate (Aldrich, mass fraction >0.99), and copper(II) sulfate (Merck, mass fraction >0.99) were used in sample preparation. The chemicals were recently acquired and stored under sun and humidity protection conditions.

The molality of the $MgSO_4$ and $CuSO_4$ aqueous stock solutions was determined by gravimetric sulfate analysis. Li_2SO_4 stock aqueous solutions were prepared by weight. Final solutions were prepared gravimetrically one by one by dilutions of water and ethanol. All mixtures were prepared using a Mettler AT261 Delta Range balance with a precision of ± 10^{-4} g, yielding an error better than ± $5 \cdot 10^{-5}$ in the salt-free mass and molar fraction and better than ± $5 \cdot 10^{-4}$ mol·kg^{-1} in the molality of the salt.

Table 1. Density for the Binary Mixtures of Salt + Water as a Function of Molality in the Temperature Range from (283.15 to 298.15) K

m/mol·kg^{-1}	t/298.15 K	t/293.15 K	t/288.15 K	t/283.15 K
	Li_2SO_4 + Water, ρ/g·cm^{-3}			
0.2142	1.01689	1.01816	1.01921	1.02000
0.3987	1.03324	1.03460	1.03578	1.03671
0.7939	1.06675	1.06826	1.06962	1.07078
1.1787	1.09756	1.09915	1.10066	1.10196
1.5748	1.12768	1.12933	1.13093	1.13231
1.9713	1.15622	1.15791	1.15958	1.16103
2.3607	1.18289	1.18460	1.18629	1.18776
2.7455	1.20801	1.20969	1.21140	1.21292
3.0903	1.22951	1.23119	1.23284	1.23434
	$MgSO_4$ + Water, ρ/g·cm^{-3}			
0.1933	1.02013	1.02138	1.02246	1.02324
0.3842	1.04203	1.04339	1.04461	1.04558
0.7688	1.08485	1.08638	1.08785	1.08917
1.1636	1.12702	1.12869	1.13034	1.13193
1.5096	1.16237	1.16413	1.16590	1.16767
1.9000	1.20080	1.20266	1.20452	1.20643
2.2691	1.23575	1.23759	1.23958	1.24157
2.6781	1.27267	1.27456		
3.0440	1.30455			
	$CuSO_4$ + Water, ρ/g·cm^{-3}			
0.1346	1.01879	1.02008	1.02112	1.02188
0.3007	1.04485	1.04629	1.04751	1.04845
0.4408	1.06656	1.06813	1.06947	1.07055
0.5896	1.08933	1.09104	1.09250	1.09372
0.7359	1.11135	1.11318	1.11477	1.11610
0.8590	1.12972	1.13165	1.13334	1.13478
1.0160	1.15285	1.15490	1.15670	1.15827
1.1791	1.17668	1.17880	1.18077	1.18245
1.3008	1.19409	1.19632	1.19832	
1.4565	1.21625			

Measurements. The densities of the mixtures were measured with an oscillating-tube Anton Paar DMA-60/602 densimeter with an uncertainty bettter than ± 10^{-4} g·cm^{-3}. The apparatus was calibrated periodically using degassed Millipore quality water and air. The temperature in the cell was measured by means of a digital precision Anton Paar MKT 100 thermometer,

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* Corresponding author. Fax: +34 986812022. E-mail: asanchez@uvigo.es.

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Table 2. Fitting Parameters of Equation 1 and Root-Mean-Square Deviation (σ) of Equation 4 for the Salt + Water System

	t/298.15 K	t/293.15 K	t/288.15 K	t/283.15 K
	Li_2SO_4 + Water			
B_1	$9.60182 \cdot 10^{-2}$	$9.67006 \cdot 10^{-2}$	$9.76578 \cdot 10^{-2}$	$9.87288 \cdot 10^{-2}$
B_2	$-5.55241 \cdot 10^{-3}$	$-5.76391 \cdot 10^{-3}$	$-6.21547 \cdot 10^{-3}$	$-6.44367 \cdot 10^{-3}$
B_3	$-4.66718 \cdot 10^{-3}$	$-4.77856 \cdot 10^{-3}$	$-4.71087 \cdot 10^{-3}$	$-5.03461 \cdot 10^{-3}$
B_4	$6.23854 \cdot 10^{-4}$	$6.61006 \cdot 10^{-4}$	$6.37455 \cdot 10^{-4}$	$7.52730 \cdot 10^{-4}$
σ	$2 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$2 \cdot 10^{-5}$
	$MgSO_4$ + Water			
B_1	$1.22408 \cdot 10^{-1}$	$1.22765 \cdot 10^{-1}$	$1.24218 \cdot 10^{-1}$	$1.25130 \cdot 10^{-1}$
B_2	$-6.24747 \cdot 10^{-3}$	$-5.87396 \cdot 10^{-3}$	$-6.95360 \cdot 10^{-3}$	$-6.66641 \cdot 10^{-3}$
B_3	$-3.44870 \cdot 10^{-3}$	$-3.71655 \cdot 10^{-3}$	$-3.42310 \cdot 10^{-3}$	$-3.74614 \cdot 10^{-3}$
σ	$7 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$6 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
	$CuSO_4$ + Water			
B_1	$1.66582 \cdot 10^{-1}$	$1.67524 \cdot 10^{-1}$	$1.69376 \cdot 10^{-1}$	$1.68694 \cdot 10^{-1}$
B_2	$-1.62210 \cdot 10^{-2}$	$-1.64514 \cdot 10^{-2}$	$-1.90273 \cdot 10^{-2}$	$-1.08154 \cdot 10^{-2}$
B_3	$6.67021 \cdot 10^{-3}$	$7.32802 \cdot 10^{-3}$	$9.88122 \cdot 10^{-3}$	$-1.67126 \cdot 10^{-3}$
B_4	$-3.54104 \cdot 10^{-3}$	$-4.03616 \cdot 10^{-3}$	$-4.95974 \cdot 10^{-3}$	
σ	$4 \cdot 10^{-5}$	$3 \cdot 10^{-5}$	$4 \cdot 10^{-5}$	$3 \cdot 10^{-5}$

Table 3. Density for the Ternary Mixtures of Lithium Sulfate for Various Mass Fractions w_E in w_E Ethanol + (1 − w_E) Water at a Temperature Range from (283.15 to 298.15) K

	m	ρ/g·cm^{-3} at t/K			
w_E	mol·kg^{-1}	298.15	293.15	288.15	283.15
0.04679	0.3523	1.02046	1.02182	1.02298	1.02390
0.04668	0.7056	1.05034	1.05188	1.05316	1.05428
0.05244	1.0510	1.07673	1.07840	1.07976	1.08103
0.05348	1.3899	1.10230	1.10407	1.10556	1.10687
0.04999	1.7485	1.12908	1.13093	1.13241	1.13382
0.04628	2.1002	1.15427	1.15612	1.15766	1.15883
0.04511	2.4445	1.17719	1.17908	1.18074	1.18191
0.10148	0.3307	1.00975	1.01140	1.01274	1.01391
0.10279	0.6558	1.03677	1.03855	1.04003	1.04140
0.10284	0.9789	1.06267	1.06453	1.06616	1.06758
0.10513	1.3216	1.08826	1.09027	1.09198	1.09355
0.10603	1.6367	1.11106	1.11307	1.11487	1.11640
0.10350	1.9849	1.13570	1.13797	1.13976	1.14139
0.15146	0.2694	0.99706	0.99901	1.00070	1.00223
0.15208	0.5433	1.01992	1.02201	1.02383	1.02553
0.15366	0.8066	1.04076	1.04294	1.04488	1.04660
0.15458	1.0806	1.06174	1.06398	1.06602	1.06786
0.15512	1.3506	1.08151	1.08380	1.08595	1.08789
0.15242	1.6306	1.10208	1.10412	1.10644	1.10833
0.20406	0.2500	0.98756	0.99000	0.99212	0.99419
0.20468	0.5081	1.00871	1.01116	1.01345	1.01563
0.19947	0.7565	1.02917	1.03172	1.03403	1.03625
0.20052	1.0090	1.04782	1.05035	1.05276	1.05504
0.20116	1.2556	1.06548	1.06816	1.07047	1.07283
0.24907	0.1823	0.97472	0.97752	0.98007	0.98260
0.24859	0.3785	0.99089	0.99378	0.99638	0.99897
0.24560	0.5717	1.00641	1.00935	1.01198	1.01458
0.24741	0.7687	1.02092	1.02382	1.02657	1.02926
0.24459	0.9586	1.03540	1.03832	1.04097	1.04361
0.29691	0.1756	0.96583	0.96903	0.97200	0.97499
0.29784	0.3609	0.98028	0.97429	0.98650	0.98954
0.30007	0.5605	0.99480	0.99813	1.00110	1.00417
0.29999	0.7388	1.00785	1.01115	1.01417	1.01725
0.34771	0.1945	0.95753	0.96103	0.96432	0.96767
0.34632	0.4373	0.97601	0.97949	0.98277	0.98612
0.39673	0.1227	0.94177	0.94546	0.94900	0.95260
0.39363	0.2489	0.95200	0.95570	0.95919	0.96280
0.39232	0.3882	0.96256	0.96623	0.96968	0.97324
0.44611	0.1067	0.92978	0.93366	0.93735	0.94113
0.44079	0.2123	0.93883	0.94268	0.94632	0.95006
0.49094	0.0467	0.91545	0.91946	0.92328	0.92719
0.49109	0.1143	0.92041	0.92437	0.92817	0.93207
0.48852	0.1729	0.92529	0.92923	0.93300	0.93686

with a resolution of ± 10^{-3} K. The densimeter was thermostated with a polyscience controller bath model 9010 with a temperature stability of ± 10^{-2} K.

Table 4. Density for the Ternary Mixtures of Magnesium Sulfate for Various Mass Fractions w_E in w_E Ethanol + (1 − w_E) Water at a Temperature Range from (283.15 to 298.15) K

	m	ρ/g·cm^{-3} at t/K			
w_E	mol·kg^{-1}	298.15	293.15	288.15	283.15
0.02547	0.4269	1.04234	1.04374	1.04495	1.04588
0.02566	0.8509	1.08933	1.09090	1.09235	1.09351
0.02376	1.2831	1.13546	1.13718	1.13882	1.14018
0.02662	1.7127	1.17837	1.18019	1.18197	1.18345
0.02456	2.1451	1.22072	1.22260	1.22447	1.22602
0.02370	2.5530	1.25858	1.26051	1.26244	
0.02411	3.0154	1.29913			
0.05212	0.3680	1.03086	1.03228	1.03348	1.03441
0.04867	0.7497	1.07406	1.07559	1.07694	1.07807
0.05119	1.1275	1.11379	1.11538	1.11695	1.11817
0.05059	1.5105	1.15326	1.15495	1.15666	1.15798
0.04946	1.9025	1.19220	1.19396	1.19576	1.19716
0.04868	2.2663	1.22696	1.22884	1.23070	
0.04845	2.6940	1.26562			
0.07596	0.3762	1.02785	1.02936	1.03064	1.03158
0.07557	0.7827	1.07262	1.07429	1.07578	1.07696
0.06944	1.0920	1.10658	1.10820	1.10983	1.11108
0.07538	1.5710	1.15426	1.15617	1.15793	1.15938
0.07402	1.9582	1.19233	1.19457	1.19641	
0.07516	2.3628	1.22960			
0.10053	0.3530	1.02124	1.02285	1.02426	1.02536
0.10165	0.7088	1.06028	1.06198	1.06355	1.06488
0.10121	1.0651	1.09803	1.09987	1.10159	1.10307
0.10061	1.4254	1.13490	1.13698	1.13881	1.14040
0.10104	1.7645	1.16815	1.17055	1.17245	
0.09905	2.0540	1.19591			
0.12276	0.4622	1.02992	1.03172	1.03329	1.03462
0.12510	0.9114	1.07761	1.07958	1.08139	1.08297
0.12619	1.3730	1.12470	1.12684	1.12882	1.13058
0.14899	0.2883	1.00662	1.00855	1.01025	1.01170
0.14808	0.5741	1.03803	1.04006	1.04189	1.04349
0.14940	0.8527	1.06729	1.06944	1.07142	1.07310
0.14234	1.0765	1.09178	1.09386	1.09600	1.09769
0.14999	1.4291	1.12554	1.12793		
0.14769	1.6820	1.15021			
0.17559	0.3641	1.01089	1.01306	1.01503	1.01680
0.17221	0.7325	1.05074	1.05301	1.05511	1.05702
0.17390	1.0850	1.08658	1.08895	1.09120	
0.19734	0.2740	0.99756	0.99987	1.00206	1.00401
0.19625	0.5520	1.02771	1.03007	1.03244	1.03448
0.19717	0.8195	1.05524	1.05771	1.06018	
0.19649	1.0842	1.08184			
0.20033	1.2927	1.10113			
0.22356	0.3538	1.00200	1.00459	1.00705	1.00932
0.22305	0.6848	1.03653	1.03922	1.04179	
0.24766	0.2340	0.98522	0.98786	0.99055	0.99301
0.24852	0.4583	1.00856	1.01135	1.01416	1.01671
0.24689	0.6878	1.03222	1.03512		
0.24611	0.7817	1.04146			
0.27243	0.2421	0.98162	0.98459	0.98743	0.99013
0.27274	0.4724	1.00528	1.00831		
0.30013	0.1574	0.96767	0.97083	0.97385	0.97679
0.29823	0.2987	0.98273	0.98586	0.98891	
0.29843	0.4412	0.99704			
0.32441	0.2080	0.96822	0.97151	0.97470	

Results and Discussion

Densities for the salt + water binary mixtures are tabulated in Table 1. These binary data were fitted to polynomials of the form:[13]

$$\rho_{SW} = \rho_W + \sum_{i=1}^{N} B_i m^{(i+1)/2} \tag{1}$$

where ρ_{SW} and ρ_W are the density of the salt + water mixture and density of water, respectively; m is the molality of the salt in the solution; B_i values are fitting parameters; and N is the number of parameters. These parameters are presented in Table 2.

Table 5. Density for the Ternary Mixtures of Copper Sulfate for Various Mass Fractions w_E in w_E Ethanol + (1 − w_E) Water at a Temperature Range from (283.15 to 298.15) K

	m	$\rho/\mathrm{g \cdot cm^{-3}}$ at t/K			
w_E	$\mathrm{mol \cdot kg^{-1}}$	298.15	293.15	288.15	283.15
0.02643	0.1786	1.02083	1.02218	1.02328	1.02410
0.02462	0.3327	1.04542	1.04691	1.04815	1.04913
0.02524	0.4959	1.07047	1.07208	1.07350	1.07462
0.02475	0.6614	1.09578	1.09754	1.09909	1.10036
0.02435	0.8149	1.11893	1.12078	1.12246	1.12386
0.02494	0.9772	1.14287	1.14486	1.14671	
0.02528	1.1943	1.17452			
0.05125	0.1471	1.01148	1.01285	1.01396	1.01479
0.05089	0.3071	1.03657	1.03809	1.03937	1.04035
0.05113	0.4528	1.05891	1.06054	1.06195	1.06307
0.05142	0.6033	1.08162	1.08337	1.08491	1.08619
0.05009	0.7539	1.10445	1.10632	1.10799	
0.05495	0.9581	1.13370			
0.07523	0.1221	1.00357	1.00503	1.00621	1.00711
0.07539	0.2387	1.02174	1.02328	1.02458	1.02560
0.07533	0.3570	1.03994	1.04156	1.04297	1.04411
0.07166	0.4517	1.05492	1.05663	1.05812	1.05934
0.07549	0.6047	1.07732	1.07917	1.08082	
0.07780	0.7385	1.09679			
0.09975	0.1143	0.99855	1.00010	1.00140	1.00244
0.09923	0.2197	1.01493	1.01658	1.01800	1.01913
0.10053	0.3281	1.03138	1.03314	1.03467	1.03593
0.10033	0.4432	1.04872	1.05057	1.05220	
0.10017	0.5503	1.06491			
0.11893	0.0834	0.99080	0.99247	0.99388	0.99502
0.11859	0.1667	1.00376	1.00549	1.00698	1.00821
0.11887	0.2405	1.01504	1.01685	1.01842	1.01973
0.12549	0.3349	1.02836	1.03028	1.03198	
0.12465	0.4223	1.04164			
0.14991	0.0735	0.98478	0.98671	0.98835	0.98976
0.15173	0.1644	0.99852	1.00051	1.00225	1.00377
0.15014	0.2427	1.01059	1.01265	1.01448	
0.15034	0.3242	1.02293			
0.17534	0.0538	0.97816	0.98026	0.98213	0.98377
0.17588	0.1151	0.98747	0.98962	0.99155	0.99326
0.17523	0.1728	0.99627	0.99846	1.00045	
0.17494	0.2481	1.00759			
0.19970	0.0620	0.97582	0.97816	0.98030	0.98221
0.20089	0.1226	0.98484	0.98718	0.98938	
0.19960	0.1806	0.99367			

For the ternary systems of salt + water + ethanol solutions (Tables 3 to 5), a polynomial expansion[14] similar to that used for the salt + water solutions was used to represent ternary densities:

$$\rho = \rho_{EW} + \sum_{i=1}^{P} C_i m^{(i+1)/2} \tag{2}$$

where ρ and ρ_{EW} are the density of the ternary solution and of the ethanol + water solution, respectively; C_i are fitting parameters; and P is the number of parameters in these cases. These parameters are dependent on the mass fraction of the salt-free system:

$$C_i = A_i + \sum_{j=1}^{Q} C_{ij} w_E^j \tag{3}$$

where w_E is the ethanol mass fraction of the salt-free solution; C_{ij} are adjustable parameters, which are in Table 6; Q is the polynomial degree; A_i are the parameters of the salt + water solutions, corresponding to $w_E = 0$. These latter parameters are collected from Table 2. In this way, binary systems (salt + water, ethanol + water) are perfectly represented in the equation of the ternary solution. The necessary densities of water and ethanol + water mixtures are collected in a previous work.[8]

Table 6. Fitting Parameters of Equations 2 and 3 and Standard Deviation (σ) of Equation 4 for Salt + Ethanol + Water Ternary Systems

	t/298.15 K	t/293.15 K	t/288.15 K	t/283.15 K
	Li_2SO_4 + Ethanol + Water			
C_{11}	$-1.75251 \cdot 10^{-2}$	$-1.48063 \cdot 10^{-2}$	$-3.01533 \cdot 10^{-3}$	$-1.22422 \cdot 10^{-2}$
C_{12}	$2.99018 \cdot 10^{-2}$	$1.20548 \cdot 10^{-2}$	$-1.21911 \cdot 10^{-1}$	$-1.81020 \cdot 10^{-2}$
C_{13}	$-3.00609 \cdot 10^{-1}$	$-3.32589 \cdot 10^{-1}$	$-4.80177 \cdot 10^{-3}$	$-4.21446 \cdot 10^{-1}$
C_{14}	$3.97651 \cdot 10^{-1}$	$6.00243 \cdot 10^{-1}$	$3.42214 \cdot 10^{-1}$	$8.02310 \cdot 10^{-1}$
C_{21}	$-2.46795 \cdot 10^{-2}$	$-3.02831 \cdot 10^{-2}$	$-5.57210 \cdot 10^{-2}$	$-3.69098 \cdot 10^{-2}$
C_{22}	$2.51479 \cdot 10^{-1}$	$2.92840 \cdot 10^{-1}$	$5.47533 \cdot 10^{-1}$	$2.91855 \cdot 10^{-1}$
C_{23}	$-9.49543 \cdot 10^{-1}$	$-8.01799 \cdot 10^{-1}$	-1.37195	$-3.57443 \cdot 10^{-1}$
C_{24}	$4.95950 \cdot 10^{-1}$	$-3.64373 \cdot 10^{-1}$	$7.54304 \cdot 10^{-2}$	-1.04635
C_{31}	$2.21599 \cdot 10^{-3}$	$4.60953 \cdot 10^{-3}$	$1.48370 \cdot 10^{-2}$	$3.62382 \cdot 10^{-3}$
C_{32}	$9.83425 \cdot 10^{-2}$	$1.06806 \cdot 10^{-1}$	$2.56209 \cdot 10^{-2}$	$1.85747 \cdot 10^{-1}$
C_{33}	-1.05593	-1.43904	-1.35206	-1.98936
C_{34}	2.70827	3.90848	3.83702	4.52805
σ	$7 \cdot 10^{-5}$	$7 \cdot 10^{-5}$	$6 \cdot 10^{-5}$	$7 \cdot 10^{-5}$
	$MgSO_4$ + Ethanol + Water			
C_{11}	$-4.66787 \cdot 10^{-2}$	$-2.62538 \cdot 10^{-2}$	$-4.36776 \cdot 10^{-2}$	$-7.90857 \cdot 10^{-2}$
C_{12}	1.01323	1.56838	1.78951	3.15800
C_{13}	$-1.04421 \cdot 10^{1}$	$-1.64769 \cdot 10^{1}$	$-1.84145 \cdot 10^{1}$	$-3.40765 \cdot 10^{1}$
C_{14}	$3.75828 \cdot 10^{1}$	$4.99925 \cdot 10^{1}$	$5.95386 \cdot 10^{1}$	$1.17132 \cdot 10^{2}$
C_{15}	$-4.26565 \cdot 10^{1}$	$-3.75736 \cdot 10^{1}$	$-5.41249 \cdot 10^{1}$	$-1.08071 \cdot 10^{2}$
C_{21}	$1.07854 \cdot 10^{-1}$	$7.35947 \cdot 10^{-2}$	$1.05888 \cdot 10^{-1}$	$1.28806 \cdot 10^{-1}$
C_{22}	-2.68570	-3.74892	-4.28505	-5.80641
C_{23}	$2.17285 \cdot 10^{1}$	$2.94953 \cdot 10^{1}$	$3.47197 \cdot 10^{1}$	$4.99051 \cdot 10^{1}$
C_{24}	$-6.46978 \cdot 10^{1}$	$-5.45643 \cdot 10^{1}$	$-7.93538 \cdot 10^{1}$	$-9.44975 \cdot 10^{1}$
C_{25}	$5.06878 \cdot 10^{1}$	$-3.64083 \cdot 10^{1}$	2.26010	$-1.05579 \cdot 10^{2}$
C_{31}	$-2.75034 \cdot 10^{-2}$	$-1.09559 \cdot 10^{-2}$	$-2.50937 \cdot 10^{-2}$	$-2.33350 \cdot 10^{-2}$
C_{32}	$5.51088 \cdot 10^{-1}$	$8.13024 \cdot 10^{-1}$	1.04325	1.11833
C_{33}	-1.76396	$2.62627 \cdot 10^{-1}$	-1.72763	2.73564
C_{34}	$-1.24166 \cdot 10^{1}$	$-5.59257 \cdot 10^{1}$	$-4.84586 \cdot 10^{1}$	$-1.22883 \cdot 10^{2}$
C_{35}	$5.08525 \cdot 10^{1}$	$1.71931 \cdot 10^{2}$	$1.65987 \cdot 10^{2}$	$4.00963 \cdot 10^{2}$
σ	$9 \cdot 10^{-5}$	$7 \cdot 10^{-5}$	$8 \cdot 10^{-5}$	$6 \cdot 10^{-5}$
	$CuSO_4$ + Ethanol + Water			
C_{11}	$-3.28386 \cdot 10^{-2}$	$-3.85575 \cdot 10^{-2}$	$-1.88973 \cdot 10^{-2}$	$-3.42369 \cdot 10^{-2}$
C_{12}	$1.34462 \cdot 10^{-2}$	$2.15758 \cdot 10^{-1}$	$-4.70663 \cdot 10^{-3}$	$3.50891 \cdot 10^{-1}$
C_{13}	$1.66037 \cdot 10^{-1}$	$-5.88692 \cdot 10^{-1}$	$3.84457 \cdot 10^{-1}$	$-2.71487 \cdot 10^{-1}$
C_{21}	$7.43300 \cdot 10^{-2}$	$9.76302 \cdot 10^{-2}$	$5.43468 \cdot 10^{-2}$	$8.71504 \cdot 10^{-2}$
C_{22}	$-5.70023 \cdot 10^{-1}$	$-9.80936 \cdot 10^{-1}$	$-3.45564 \cdot 10^{-1}$	-1.03476
C_{23}	-4.05401	-3.62177	-7.27797	$-1.08771 \cdot 10^{1}$
C_{31}	$7.74049 \cdot 10^{-3}$	$-4.09922 \cdot 10^{-3}$	$2.54827 \cdot 10^{-2}$	$2.31830 \cdot 10^{-2}$
C_{32}	-1.27496	-1.45906	-2.01379	-2.59802
C_{33}	$1.44904 \cdot 10^{1}$	$1.80280 \cdot 10^{1}$	$2.17417 \cdot 10^{1}$	$3.64572 \cdot 10^{1}$
σ	$6 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$3 \cdot 10^{-5}$

All parameters were obtained using an unweighted least-squares method applying a fitting algorithm due to Marquardt.[15] The root-mean-square deviation at each correlation is enclosed as a measurement of the validity of the gathered fitting parameters, and the equation applied is expressed by eq 4:

$$\sigma = \sqrt{\frac{\sum_{i}^{n} (z_{i,\mathrm{experimental}} - z_{i,\mathrm{predicted}})^2}{n - p}} \tag{4}$$

In this equation, the value of the property, the number of experimental data, and the number of parameters are represented by z, n, and p, respectively.

It was observed that the density decreased with an increase in temperature or mass fraction of ethanol. It is also seen that density increased with the molality of the salt. The same behavior was observed for all systems.

Conclusions

This paper reports experimental data for the density of (lithium, magnesium, or copper(II)) sulfate in ethanol + water mixtures from (283.15 to 298.15) K. These data were correlated by the method of least-squares to polynomials. For all systems, the root-mean-square deviation values between the experimental data of this work and the corresponding ones from the proposed equations show a good agreement, and all values are less than 10^{-4} g·cm^{-3} at all temperatures. So, the density solutions are described adequately by these equations, and these polynomials can be used for density prediction to salt saturation.

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