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The Volumetric Properties of vapor-saturated aqueous HCl solutions from 0° to 100°C, vapor-saturated aqueous $FeCl_2$ solutions at 15° and 18°C, & vapor-saturated $FeCl_3$ from 0° to 35C based on a regression of the available literature data. 77-215

Pressure-volume-temperature-composition (P-V-T-X) data for brines are required to establish optimum operating conditions for the production of geothermal brine fields; to minimize scaling and corrosion; and to intelligently design turbines for the production of electricity. Precise thermodynamic data derived from the volumetric properties of the brines are prerequisite for chemical and reservoir modeling of geothermal brine systems. In view of the importance of P-V-T-X data to the utilization and understanding of geothermal brine systems, a compilation of the available literature data (Potter et al., 1975) and evaluations of these data for NaCl, KCl, $CaCl_2$, Na_2SO_4, K_2SO_4, KOH, and NaOH have been completed (Brown and Potter, 1977; Potter and Brown, 1975, 1976a, 1976b, 1976c; Potter and Clynne, 1976).

Prior to this report, the only extensive tabulation of volumetric data for vapor-saturated hydrochloric acid and aqueous vapor-saturated ferrous and ferric chlorides was the International Critical Tables (National Research Council, 1928). A compilation of density values is presented therein for vapor-saturated hydrochloric acid of 0 to 40 weight percent concentrations from -5°C to 100°C, for aqueous vapor-saturated ferrous chloride of 0 to 35 weight percent concentrations at 15°C and 18°C, and for aqueous vapor-saturated ferric chloride of 0 to 50 weight percent concentrations from 0°C to 35°C. There are no compilations available for these solutions at pressures greater than the saturation vapor pressure (Potter, 1976). The purpose of this report is to present an internally consistent set of density values for vapor-saturated hydrochloric acid from 0°C to 100°C, vapor-saturated aqueous ferrous chloride at 15°C and 18°C, and for vapor-saturated aqueous ferric chloride from 0°C to 35°C based on the currently available experimental data summarized by Potter et al. (1975).

The density data presented in tables 1 and 2 were obtained from a regression of the P-V-T-X data for hydrochloric acid taken from the 30 references cited by Potter et al. (1975). Tables 4, 5, 7, and 8 present density data which were obtained from a computer regression of the volumetric data for aqueous ferrous and ferric chloride taken from the International Critical Tables (National Research Council, 1928). Only three additional references containing P-V-T-X data for ferrous chloride are available, and these were judged inadequate to significantly improve on the density data presented in the International Critical Tables. There are no additional references available containing volumetric data for ferric chloride (Potter et al., 1975). The regression was accomplished by using a linear least squares polynomial fit method in which each data point was weighted with respect to its relative uncertainty. The uncertainties used were for the most part those assigned by the experimentalist. However, in those cases where uncertainties were not stated, an estimate was supplied on the basis of the experimental method employed in the study. The experimental densities were regressed at constant temperature as a function of composition for each solute to equations of the forms described by Brown and Potter (1977). The regression equations and the coefficients for those equations are summarized in tables 3, 6, and 9, and may be used for interpolation to determine densities of solutions with concentrations not included in tables 1, 2, 5, 5, 7, and 8.

Due to an inadequate data base, it was not possible to generate a set of density values at pressures greater than the saturation vapor pressure for the solutions discussed in this paper which would accurately represent the behavior of each solution above its saturation surface.

REFERENCES

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Table 1. Density of HCl (g/cm^3).

Temp(°C)	CONCENTRATION (MOLALITY)																	
	.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0	
0	1.0094	1.0186	1.0274	1.0360	1.0442	1.0522	1.0675	1.0819	1.0955	1.1084	1.1205	1.1320	1.1428	1.1628	1.1808	1.1968	1.2113	1.2242	±.0005
25	1.0066	1.0158	1.0246	1.0332	1.0414	1.0494	1.0647	1.0792	1.0928	1.1056	1.1178	1.1293	1.1402	1.1602	1.1782	1.1943	--	--	±.0005
50	.9966	1.0048	1.0126	1.0202	1.0275	1.0345	1.0480	1.0607	1.0724	1.0839	1.0945	1.1046	1.1142	1.1318	1.1477	1.1620	--	--	±.0005
75	.9837	.9920	1.0000	1.0077	1.0151	1.0222	1.0357	1.0483	1.0601	1.0712	1.0816	1.0914	1.1006	1.1173	1.1322	--	--	--	±.0005
100	.9677	.9766	.9850	.9931	1.0009	1.0084	1.0225	1.0356	1.0478	1.0591	1.0696	1.0794	1.0886	1.1046	--	--	--	--	±.0005

Table 2. Density of HCl (g/cm^3).

Temp(°C)	CONCENTRATION (WEIGHT PERCENT)														
	1	3	5	7	9	11	13	15	20	25	30	35	40	45	
0	1.0052	1.0159	1.0265	1.0371	1.0477	1.0583	1.0690	1.0797	1.1066	1.1336	1.1605	1.1872	1.2132	1.2382	±.0005
25	1.0024	1.0131	1.0237	1.0343	1.0449	1.0555	1.0662	1.0769	1.1038	1.1309	1.1579	1.1846	--	--	±.0008
50	.9929	1.0023	1.0117	1.0211	1.0305	1.0399	1.0493	1.0587	1.0823	1.1060	1.1297	1.1534	--	--	±.0008
75	.9798	.9895	.9991	1.0086	1.0181	1.0276	1.0370	1.0464	1.0697	1.0927	1.1154	1.1374	--	--	±.0008
100	.9636	.9739	.9841	.9941	1.0041	1.0140	1.0238	1.0336	1.0574	1.0807	1.1027	--	--	--	±.0008

Table 3. Interpolation equation coefficients for HCl.

The available density data for HCl solutions were converted to apparent molal volumes and fit by the method of least squares to an equation of the form

$$\phi_V = A + Bm^{\frac{1}{2}} + Cm,$$

where m is the molality of the solution. The coefficients for each temperature are given in the table below. Density, d, may be calculated from apparent molal volume ϕ_V, by using the formula

$$d = \frac{1000d_o + M_2md_o}{1000 + \phi_V md_o},$$

where d_o is the density of water and M_2 = 36.461 g/mole is the molecular weight of the solute. Note that the interpolation equations are valid only for the ranges of concentration indicated in the table.

				range of validity	
Temp(°C)	A	B	10 x C	wt. %	molality
0	16.435	.930274	.011613	0-44.9	0-22.3
25	17.9733	1.022201	-.46310	0-38.0	0-16.8
50	18.5079	.95900	-.27397	0-38.0	0-16.8
75	17.8168	1.201934	-.207553	0-36.0	0-15.4
100	16.5578	1.29456	.379309	0-30.0	0-11.8

Table 4. Density of $FeCl_2$ solutions (g/cm^3).

Concentration (Molality)	Temp(°C) 15.5°C	18.0°C	25°C
0.5	1.056	1.054	--
1.0	1.108	1.105	--
1.5	1.156	1.154	--
2.0	1.203	1.202	--
2.5	1.248	1.249	--
3.0	1.293	1.296	--
3.5	1.338	1.342	--
3.78	--	--	1.3685
4.0	1.382	1.388	--
	±.003	±.001	

Table 5. Density of $FeCl_2$ solutions (g/cm^3).

Concentration (Weight percent)	Temp(°C) 15.5°C	18.0°C	25°C
1	1.005	1.006	--
3	1.027	1.026	--
5	1.047	1.045	--
7	1.066	1.064	--
9	1.086	1.083	--
11	1.105	1.102	--
13	1.125	1.123	--
15	1.146	1.143	--
20	1.200	1.199	--
25	1.260	1.261	--
30	1.327	1.331	--
32.4	--	--	1.3685
35	1.404	1.411	--
	±.003	±.001	

Table 6. Interpolation coefficients, $FeCl_2$.

Only a very limited amount of density data is available for $FeCl_2$. The following coefficients are for the equation $d = A + Bm^{\frac{1}{2}} + Cm$, where m is the molality of the solution, which was fit to the ICT data at 15.5°C and 18°C. Note that these interpolation equations are valid only for solutions with concentrations less than 4 molal (35 wt. %).

Temp(°C)	A	B	C
15.5	.9867	.04402	.07681
18	.9914	.02867	.08485

Table 7. Density of $FeCl_3$ (g/cm^3).

Temp(°C)	CONCENTRATION (MOLALITY)												
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	
0	1.066	1.127	1.183	1.235	1.284	1.331	1.375	1.419	--	--	--	--	±.001
10	1.065	1.125	1.181	1.233	1.282	1.329	1.373	1.415	1.454	1.489	1.519	1.543	±.001
15	1.064	1.123	1.179	1.232	1.281	1.328	1.371	1.412	1.449	1.484	1.517	1.547	±.001
20	1.062	1.122	1.177	1.230	1.279	1.325	1.368	1.409	1.446	1.481	1.513	1.542	±.001
25	1.061	1.120	1.176	1.227	1.276	1.321	1.365	1.406	--	--	--	--	±.001
30	1.060	1.119	1.174	1.225	1.273	1.318	1.361	1.403	--	--	--	--	±.001
35	1.058	1.117	1.172	1.223	1.270	1.315	1.358	1.400	--	--	--	--	±.002

Table 8. Density of $FeCl_3$ (g/cm^3).

Temp (°C)	CONCENTRATION (WEIGHT PERCENT)															
	1	3	5	7	9	11	13	15	20	25	30	35	40	45	50	
0	1.009	1.026	1.044	1.062	1.080	1.099	1.118	1.137	1.188	1.241	1.298	1.359	1.428	--	--	±.001
10	1.008	1.025	1.043	1.061	1.079	1.097	1.116	1.135	1.185	1.238	1.295	1.357	1.424	1.492	1.549	±.001
15	1.008	1.025	1.042	1.059	1.077	1.095	1.114	1.133	1.183	1.237	1.295	1.356	1.420	1.487	1.557	±.001
20	1.007	1.024	1.041	1.058	1.076	1.094	1.112	1.132	1.182	1.235	1.293	1.353	1.417	1.484	1.552	±.001
25	1.005	1.022	1.039	1.057	1.075	1.093	1.111	1.131	1.180	1.233	1.289	1.349	1.415	--	--	±.001
30	1.004	1.021	1.038	1.055	1.073	1.091	1.110	1.129	1.178	1.230	1.286	1.346	1.412	--	--	±.001
35	1.002	1.019	1.036	1.054	1.071	1.089	1.108	1.127	1.176	1.228	1.283	1.343	1.409	--	--	±.002

Table 9. Interpolation coefficients for $FeCl_3$.

The density data for $FeCl_3$ was fit to a polynomial equation of the form

$$d = \sum_{j=0}^{n} A_j m^j ,$$

where m is the molality, d is the density, n is the order of the equation, and the A_j are given in the table below. Note that these interpolation equations are valid only for the range of concentrations indicated in the table.

Temp(°C)	Range of Validity		n	A_0	A_1	$-10^2 xA_2$	$10^3 xA_3$	$-10^3 xA_4$
	m	wt. %						
0	0-4.11	0-40	3	1.00007	.138207	1.2257	.96987	--
10	0-6.17	0-50	4	.99965	.137677	1.4345	2.2537	.19533
15	0-6.17	0-50	3	1.00062	.12949	.72624	.1435	--
20	0-6.17	0-50	3	.9997	.12882	.71403	.1242	--
25	0-4.11	0-40	3	.99725	.13251	.9833	.5627	--
30	0-4.11	0-40	3	.99576	.13300	1.0650	.7125	--
35	0-4.11	0-40	3	.99391	.13346	1.1157	.7945	--