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Investigation of the thermal properties and apparent molar volumes of $ZnBr_2$ (aq) in the temperature range from 298.15 to 398.15 K and at pressures up to $p=60$ MPa using a piezometer of constant volume

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Abstract

The (p, ρ, T) and (p_s, ρ_s, T_s) properties and apparent molar volumes V_ϕ of $ZnBr_2$ (aq) at $T=(298.15$ to $398.15)$ K, pressures up to $p=60$ MPa were reported, and apparent molar volumes of $ZnBr_2$ at infinite dilution V_ϕ^0 have been evaluated. The experiments were carried out by the constant volume piezometer installation, (p, ρ, T) and (p_s, ρ_s, T_s) values were described by an equation of state. The isothermal compressibilities k and thermal expansivities α were calculated from the equation of state. An empirical correlation for density of zinc bromide (aq) with pressure, temperature and molality has been derived. The experiments were carried out at molalities $m=(0.06220,$ $0.17341, 0.38183, 0.84419, 1.43444,$ and $4.18418)$ mol kg^{-1} of zinc bromide.
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Keywords: Absorption refrigeration machine; Density; Piezometer; Aqueous zinc bromide solution; Apparent molar volume

1. Introduction

The interest towards absorption refrigerating machines and heat pumps has increased considerably due to the extreme necessity of more effective use of heat, the creation of sustainable technology, and economy of fuel and energy resources [1]. For the analysis of detailed properties of absorption refrigerating machines and heat pumps it is necessary to know the thermodynamic properties of heat transfer fluids.

This paper is a continuation of our previous publication of the investigation of aqueous electrolyte solutions [2,3] presenting the (p, ρ, T) and (p_s, ρ_s, T_s) properties, and apparent molar volumes V_ϕ of $ZnBr_2$ (aq) at $T=(298.15$ to $398.15)$ K, up to $p=60$ MPa. From the experimental results the apparent molar volumes at infinite dilution V_ϕ^0 were evaluated. An empirical correlation for the density of $ZnBr_2$ (aq) with pressure, temperature and molality has been derived. Only three publications [4–6] with the density ρ and apparent molar volume V_ϕ of $ZnBr_2$ (aq) results in the ambient pressure were found in the literature. In this case, it is necessary to investigate these solutions over a wider range of state parameters in order to understand their properties and provide accurate data for the technical installations.

2. Experimental

The (p, ρ, T) and (p_s, ρ_s, T_s) properties were investigated in an experimental constant volume piezometer installation [7]. The main part of the installation is a spherical, thick-walled, high-pressure vessel manufactured of 1Cr18Ni9Ti grade stainless steel. The volume of the piezometer (0.35013 dm^3) was determined at room temperature and ambient pressure by the mass of water filling it at

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Table 1
Experimental (p, ρ, T) and (p_s, ρ_s, T_s) values of $ZnBr_2$ (aq)

p/MPa	ρ/(kg m^{-3})	p/MPa	ρ/(kg m^{-3})	p/MPa	ρ/(kg m^{-3})
m=0.06220 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
0.14	1009.96	0.21	987.01	p_s=0.2311	ρ_s=950.45
5.06	1011.98	5.42	989.11	5.12	952.68
10.42	1014.18	9.87	990.90	10.39	955.09
20.62	1018.36	20.34	995.11	20.75	959.83
30.45	1022.39	31.09	999.43	31.62	964.80
39.84	1026.25	40.08	1003.04	40.58	968.89
50.61	1030.67	49.62	1006.88	49.75	973.09
59.98	1034.51	59.63	1010.90	59.31	977.46
T=323.15 K		T=373.15 K			
0.18	1000.57	0.17	970.17		
4.97	1002.47	5.03	972.22		
9.62	1004.31	10.34	974.47		
19.83	1008.36	21.08	979.00		
30.72	1012.67	30.75	983.09		
41.27	1016.85	40.31	987.12		
49.32	1020.04	49.87	991.16		
58.67	1023.75	58.96	995.00		
m=0.17341 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
0.17	1031.97	0.23	1007.79	p_s=0.2298	ρ_s=970.01
5.86	1034.17	5.89	1009.93	5.08	972.13
10.28	1035.88	11.02	1011.88	10.31	974.43
21.09	1040.06	20.64	1015.52	21.07	979.15
30.07	1043.54	30.75	1019.36	30.27	983.19
40.62	1047.62	40.28	1022.97	41.06	987.93
50.78	1051.56	51.08	1027.06	50.92	992.26
59.23	1054.83	59.12	1030.11	59.28	995.94
T=323.15 K		T=373.15 K			
0.24	1021.99	0.31	990.37		
5.17	1023.83	5.24	992.35		
10.89	1025.96	10.27	994.37		
21.57	1029.94	20.34	998.42		
31.02	1033.46	31.06	1002.72		
40.86	1037.13	41.08	1006.75		
52.07	1041.31	50.27	1010.44		
59.32	1044.01	59.63	1014.20		
m=0.38183 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
0.18	1071.36	0.31	1045.21	p_s=0.2275	ρ_s=1005.19
5.09	1073.08	5.14	1046.84	4.86	1007.09
10.74	1075.06	10.08	1048.52	9.68	1009.07
20.36	1078.43	20.47	1052.04	20.38	1013.46
30.58	1082.02	30.75	1055.52	29.64	1017.26
40.75	1085.58	40.18	1058.71	40.39	1021.66
50.89	1089.13	51.03	1062.39	50.38	1025.76
59.28	1092.07	59.36	1065.21	59.64	1029.56
T=323.15 K		T=373.15 K			
0.21	1060.47	0.24	1026.69		
5.27	1062.15	5.18	1028.50		
10.47	1063.88	10.06	1030.28		
20.08	1067.08	20.07	1033.95		
30.74	1070.62	30.86	1037.89		
41.08	1074.06	40.28	1041.34		
51.06	1077.38	50.17	1044.96		
58.63	1079.90	59.63	1048.42		
m=0.84419 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
0.14	1151.64	0.34	1120.70	p_s=0.2208	ρ_s=1075.69
5.07	1153.10	5.08	1122.08	4.96	1077.56
10.35	1154.66	10.47	1123.64	10.38	1079.70
19.75	1157.45	19.62	1126.30	20.06	1083.52

Table 1 (*continued*)

p/MPa	ρ/(kg m^{-3})	p/MPa	ρ/(kg m^{-3})	p/MPa	ρ/(kg m^{-3})
m=0.84419 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
28.56	1160.05	30.47	1129.45	30.75	1087.75
40.28	1163.52	40.09	1132.24	40.08	1091.43
49.32	1166.20	50.37	1135.23	50.31	1095.47
59.47	1169.20	59.21	1137.79	59.27	1099.01
T=323.15 K		T=373.15 K			
0.19	1137.95	0.18	1099.66		
5.08	1139.34	5.08	1101.33		
9.64	1140.63	10.27	1103.09		
20.75	1143.77	20.36	1106.52		
30.14	1146.43	30.74	1110.05		
40.28	1149.30	40.17	1113.25		
50.74	1152.26	50.08	1116.62		
59.27	1154.67	59.27	1119.75		
m=1.43444 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
0.16	1244.34	0.18	1207.75	p_s=0.2106	ρ_s=1158.79
5.03	1245.67	5.17	1209.24	5.08	1160.79
10.08	1247.05	10.09	1210.71	10.01	1162.82
20.64	1249.93	20.63	1213.86	21.06	1167.37
30.75	1252.69	30.47	1216.80	29.64	1170.91
40.08	1255.23	41.06	1219.96	40.09	1175.21
50.64	1258.11	50.37	1222.74	51.03	1179.72
59.37	1260.49	59.64	1225.51	59.61	1183.25
T=323.15 K		T=373.15 K			
0.24	1227.97	0.34	1184.52		
5.07	1229.32	5.27	1186.25		
10.62	1230.88	11.08	1188.28		
20.27	1233.58	21.03	1191.76		
30.28	1236.38	31.07	1195.28		
41.08	1239.41	40.75	1198.67		
50.09	1241.94	49.38	1201.69		
59.07	1244.45	58.67	1204.94		
m=4.18418 mol kg^{-1}					
T=298.15 K		T=348.15 K		T=398.15 K	
0.18	1608.51	0.27	1557.14	p_s=0.1247	ρ_s=1491.74
5.34	1608.82	5.07	1557.80	4.87	1493.38
11.3	1609.18	11.06	1558.62	10.06	1495.17
21.04	1609.77	19.62	1559.80	20.08	1498.63
29.86	1610.30	29.75	1561.19	30.57	1502.25
41.08	1610.97	40.07	1562.61	40.38	1505.63
51.08	1611.58	49.32	1563.88	50.09	1508.98
59.27	1612.07	59.62	1565.30	59.27	1512.15
T=323.15 K		T=373.15 K			
0.25	1584.02	0.37	1525.48		
5.08	1584.47	5.28	1526.61		
11.34	1585.04	10.08	1527.70		
19.31	1585.78	20.34	1530.04		
29.75	1586.74	29.74	1532.19		
40.08	1587.69	40.38	1534.62		
49.62	1588.57	50.24	1536.87		
59.34	1589.46	59.61	1539.01		

an exactly measured temperature and moderate pressure of the order of 1 to 1.5 MPa. Under these conditions, the density of ordinary water is known with high accuracy (0.001–0.003%) from the IAPWS formulation values for ordinary water [8]. The reliability of the data obtained was verified after each run by a control measurement of the volumetric properties of water. Deviations of all the parameters did not exceed the tolerance given by [8]. In

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