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Densities, Viscosities, and Heat Capacities of Ammonia + Lithium Nitrate and Ammonia + Lithium Nitrate + Water Solutions between (293.15 and 353.15) K

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The density, dynamic viscosity, and heat capacity of ammonia + lithium nitrate and ammonia + lithium nitrate + water mixtures were measured between (293.15 and 353.15) K at 1.8 MPa, using a vibrating-tube densimeter, a piston-style viscosimeter, and a heat flux Calvet-type calorimeter, respectively. The measured data were correlated as a function of temperature and composition using simple polynomial equations. Kinematic viscosity data of binary and ternary mixtures were also determined.

Introduction

The increasing interest in protecting the environment and saving energy has favored the use of absorption chillers driven by waste heat or solar thermal energy. Commercial refrigeration plants use traditional systems with ammonia + water or water + lithium bromide. In recent decades, several new working fluids have been proposed as alternatives. A promising mixture for solar activated refrigeration systems is ammonia + lithium nitrate, which needs no rectification, and the refrigeration cycle can be operated at lower desorber temperatures than those required by ammonia + water. Nevertheless, the heat and mass transfer in the absorber are limited by the viscosity of the salt solutions. To overcome this drawback, Ehmke et al.[1] and Bokelmann[2] proposed adding water to the binary mixture to be used in absorption heat pumps. Later, Reiner and Zaltash[3,4] proposed using the ternary mixture for GAX systems as an alternative to the ammonia + water systems.

The thermodynamic and transport properties of the working fluids used in absorption refrigeration cycles are very important if these systems are to be appropriately evaluated and designed. In a previous article,[5] vapor−liquid equilibrium data of the binary mixture ammonia + lithium nitrate and the ternary mixture ammonia + lithium nitrate + water were presented at temperatures between (293.15 and 353.15) K for different compositions. In the present study, the density, dynamic viscosity, and heat capacity of these mixtures were measured in the same temperature range at a fixed pressure of 1.8 MPa. The experimental data were correlated with temperature and composition.

The only data available in the literature on these properties were presented by Infante Ferreira[6] and Aggarwal[7] for the binary mixture and by Ehmke[8] and Reiner and Zaltash[4] for the ternary mixture.

Experimental Section

Materials. Ammonia (Carburos Metálicos, 99.98 %), lithium nitrate (Fluka, ≥ 99 %), Millipore water (resistivity lower than 18.2 MΩ), dichloromethane (Panreac, > 99.8 %), *n*-heptane (Fluka, ≥ 99.5 %), benzene (Fluka, ≥ 99.5 %), viscosity reference standard types N10 and N26 (Paragon Scientific Limited), and dry nitrogen (Carburos Metálicos) were used without further purification.

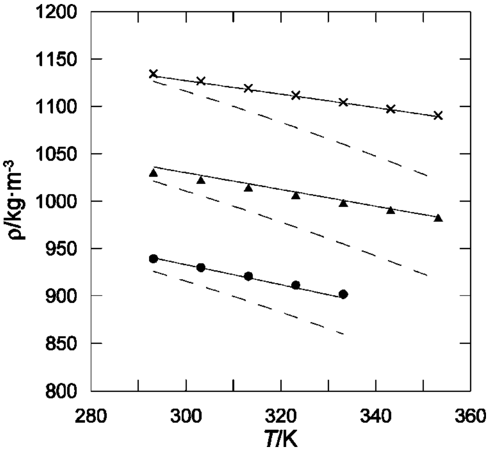

Figure 1. Density for NH_3 (1) + $LiNO_3$ (2) solutions, for several compositions. Experimental values: ×, $w_1 = 0.3988$; ▲, $w_1 = 0.5000$; ●, $w_1 = 0.5999$; −, calculated values; - - -, literature[6] correlated results.

Apparatus and Experimental Procedure. The densities of ammonia + lithium nitrate and ammonia + lithium nitrate + water solutions were measured at 1.8 MPa using an Anton-Paar vibrating-tube densimeter (DMA60/512P) connected to a pressure system. Pressure was chosen higher than the saturation across the range of measures to prevent the boiling of the volatile components. The measurements were made in the temperature range between (293.15 and 353.15) K. Therefore, the vibrating-tube densimeter was thermostatted using a F20-ME (Julabo) water bath with a resolution of 0.1 K. The sample temperature was measured using a digital precision thermometer (Anton Paar MKT100) with ± 0.001 K uncertainty. The experimental apparatus and procedure used have already been described in our previous studies.[9,10] Benzene and dichloromethane were used as reference fluids for the calibration of the densimeter at 1.8 MPa. The validity of the calibration was tested by measuring the density of pure water in the temperature range from (283.15

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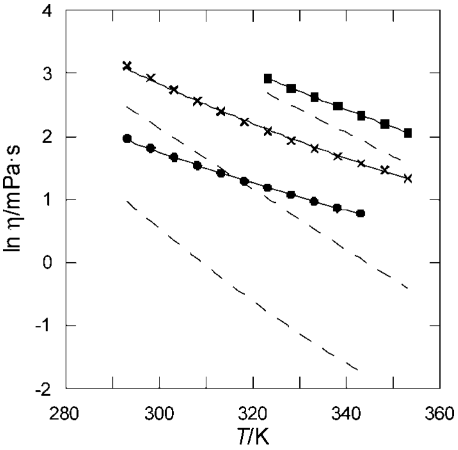

Figure 2. Viscosity for NH_3 (1) + $LiNO_3$ (2) solutions, for several compositions. Experimental values: ■, $w_1 = 0.3000$; ×, $w_1 = 0.4000$; ●, $w_1 = 0.4997$; −, calculated values; - - -, literature[6] correlated results.

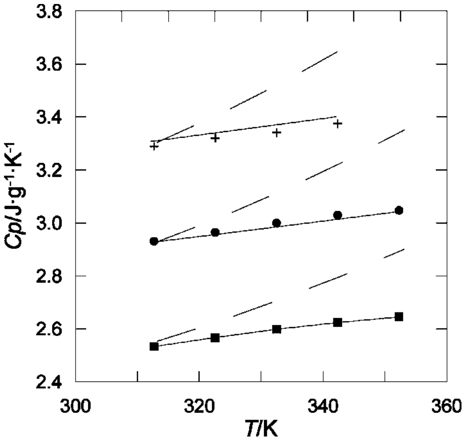

Figure 3. Heat capacity for NH_3 (1) + $LiNO_3$ (2) solutions, for several compositions. Experimental values: ■, $w_1 = 0.3501$; ●, $w_1 = 0.4499$; +, $w_1 = 0.5497$; −, calculated values; - - -, literature[6] correlated results.

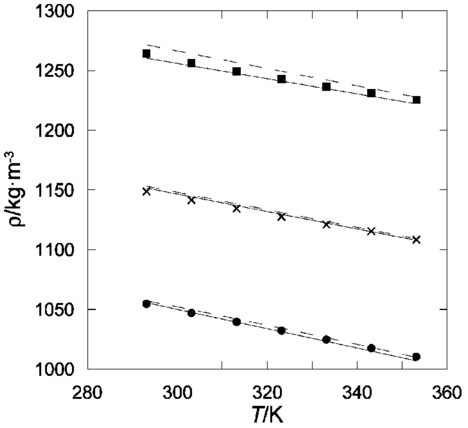

Figure 4. Density for NH_3 (1) + $LiNO_3$ (2) + H2O (3) solutions for several ammonia mass fractions. Water mass fraction fixed to 0.25 in ($LiNO_3$ + H_2O). Experimental values: ■, $w_1 = 0.1998$; ×, $w_1 = 0.2999$; ●, $w_1 = 0.3998$; −, calculated values; - - -, literature[8] correlated results.

to 353.15) K. The average deviation between the measured data and the data from the literature[11] was 0.17 %.

Table 1. Experimental Density (ρ/kg·m^{-3}) for NH_3 (1) + $LiNO_3$ (2) Solutions, For Several Temperatures (T/K) and Ammonia Mass Fractions (w_1)

w_1	ρ/kg·m^{-3}
T = 293.15 K	
0.3501	1188.8
0.3988	1134.2
0.4499	1078.1
0.5000	1030.0
0.5500	983.8
0.5999	939.0
0.6505	896.8
T = 303.15 K	
0.3501	1181.2
0.3988	1126.6
0.4499	1070.3
0.5000	1022.1
0.5500	975.4
0.5999	929.8
0.6505	886.9
T = 313.15 K	
0.3501	1173.8
0.3988	1119.0
0.4499	1062.6
0.5000	1014.1
0.5500	966.8
0.5999	920.6
0.6505	876.7
T = 323.15 K	
0.3501	1166.6
0.3988	1111.5
0.4499	1055.1
0.5000	1006.1
0.5500	958.1
0.5999	911.2
0.6505	866.6
T = 333.15 K	
0.3501	1159.7
0.3988	1104.1
0.4499	1047.5
0.5000	998.0
0.5500	949.4
0.5999	901.6
T = 343.15 K	
0.3501	1153.1
0.3988	1096.9
0.4499	1040.0
0.5000	990.1
0.5500	940.4
T = 353.15 K	
0.3501	1146.9
0.3988	1090.2
0.4499	1032.8
0.5000	982.1

The dynamic viscosities of ammonia + lithium nitrate and ammonia + lithium nitrate + water were experimentally determined using a piston-style viscosimeter (SPL 372, Cambridge). It consists of a 316 stainless steel sensor which is magnetically forced by two magnetic coils to move across a chamber filled with the fluid sample. The time required for the piston to complete a two-way cycle between the coils is an accurate measure of the dynamic viscosity of the fluid. In this study, a piston with a viscosity range (1 to 20) mPa·s was used. The measurements were thermostatted using a F20-ME (Julabo) water bath, and the temperature was measured with a Pt-100 thermometer placed inside the viscosimeter. The process of preparing and injecting the sample into the device is the same as the process for measuring density. The viscosimeter system was calibrated in the factory and validated using two viscosity reference standards (types N10 and N26). The relative deviation was lower than 1 %.

The heat capacity of ammonia + lithium nitrate and ammonia + lithium nitrate + water was determined using a differential heat flux Calvet-type calorimeter (Setaram C-80 II). The details of the apparatus, measurement cells, and procedure have been

Table 2. Experimental Density (ρ/kg·m^{-3}) for NH_3 (1) + $LiNO_3$ (2) + H_2O (3) Solutions, For Several Temperatures (T/K) and Mass Fractions (w_i)

w_1	w_2	ρ/kg·m^{-3}	w_1	w_2	ρ/kg·m^{-3}
	T = 293.15 K			T = 333.15 K	
0.1996	0.5603	1234.5	0.1996	0.5603	1206.4
0.3002	0.4893	1127.4	0.3002	0.4893	1098.9
0.3999	0.4201	1040.4	0.3999	0.4201	1009.3
0.5001	0.3500	966.5	0.5001	0.3500	930.9
0.6000	0.2795	891.5	0.6000	0.2795	850.4
0.1998	0.6002	1263.9	0.1998	0.6002	1236.6
0.2999	0.5249	1148.8	0.2999	0.5249	1121.0
0.3998	0.4496	1054.7	0.3998	0.4496	1024.8
0.5008	0.3744	975.1	0.5008	0.3744	940.7
0.6000	0.3000	899.5	0.6000	0.3000	858.8
0.2003	0.6393	1292.3	0.2003	0.6393	1263.6
0.3001	0.5599	1169.2	0.3001	0.5599	1140.1
0.4001	0.4793	1070.2	0.4001	0.4793	1039.7
0.4999	0.4001	987.1	0.4999	0.4001	952.0
0.6000	0.3198	907.9	0.6000	0.3198	867.8
	T = 303.15 K			T = 343.15 K	
0.1996	0.5603	1227.0	0.1996	0.5603	1200.0
0.3002	0.4893	1120.0	0.3002	0.4893	1092.2
0.3999	0.4201	1032.6	0.3999	0.4201	1001.7
0.5001	0.3500	957.6	0.5001	0.3500	922.0
0.6000	0.2795	881.5	0.1998	0.6002	1230.7
0.1998	0.6002	1256.2	0.2999	0.5249	1115.4
0.2999	0.5249	1141.5	0.3998	0.4496	1017.6
0.3998	0.4496	1047.1	0.5008	0.3744	931.7
0.5008	0.3744	966.4	0.2003	0.6393	1257.4
0.6000	0.3000	889.5	0.3001	0.5599	1133.4
0.2003	0.6393	1284.4	0.4001	0.4793	1032.2
0.3001	0.5599	1161.5	0.4999	0.4001	943.3
0.4001	0.4793	1062.4			
0.4999	0.4001	978.1			
0.6000	0.3198	898.0			
	T = 313.15 K			T = 353.15 K	
0.1996	0.5603	1219.7	0.1996	0.5603	1194.4
0.3002	0.4893	1112.8	0.3002	0.4893	1085.8
0.3999	0.4201	1024.8	0.3999	0.4201	994.2
0.5001	0.3500	948.8	0.1998	0.6002	1225.2
0.6000	0.2795	871.3	0.2999	0.5249	1108.4
0.1998	0.6002	1249.4	0.3998	0.4496	1010.5
0.2999	0.5249	1134.4	0.2003	0.6393	1251.8
0.3998	0.4496	1039.6	0.3001	0.5599	1127.1
0.5008	0.3744	957.9	0.4001	0.4793	1024.9
0.6000	0.3000	879.4			
0.2003	0.6393	1277.1			
0.3001	0.5599	1154.0			
0.4001	0.4793	1054.7			
0.4999	0.4001	969.4			
0.6000	0.3198	888.1			
	T = 323.15 K				
0.1996	0.5603	1212.9			
0.3002	0.4893	1105.8			
0.3999	0.4201	1017.1			
0.5001	0.3500	939.9			
0.6000	0.2795	861.0			
0.1998	0.6002	1242.7			
0.2999	0.5249	1127.6			
0.3998	0.4496	1032.3			
0.5008	0.3744	949.3			
0.6000	0.3000	869.2			
0.2003	0.6393	1270.1			
0.3001	0.5599	1147.0			
0.4001	0.4793	1047.2			
0.4999	0.4001	960.7			
0.6000	0.3198	878.1			

Table 3. Experimental Dynamic Viscosity (η/mPa·s) and Calculated Kinematic Viscosity (υ/mm^2·s^{-1}) for NH_3 (1) + $LiNO_3$ (2) Solutions, For Several Temperatures (T/K) and Ammonia Mass Fractions (w_1)

T/K	η/mPa·s	ν_{calcd}/mm^2·s^{-1}
	w_1 = 0.3000	
323.2	18.6	6.5
328.2	15.9	7.5
333.2	13.8	8.5
338.1	11.9	9.8
343.1	10.9	11.4
348.1	9.0	13.0
353.2	7.9	15.2
	w_1 = 0.4000	
293.2	22.7	3.5
298.2	18.7	4.0
303.2	15.5	4.4
308.2	13.0	4.9
313.2	11.0	5.5
318.2	9.3	6.2
323.2	8.0	7.2
328.2	6.9	8.3
333.2	6.1	9.8
338.1	5.4	11.6
343.1	4.8	13.8
348.2	4.3	16.6
353.1	3.8	20.0
	w_1 = 0.4997	
293.2	7.1	2.2
298.2	6.1	2.4
303.2	5.3	2.6
308.2	4.7	2.9
313.2	4.1	3.2
318.2	3.6	3.6
323.2	3.3	4.1
328.1	2.9	4.6
333.1	2.6	5.2
338.0	2.4	6.0
343.0	2.2	6.9

presented in our previous studies.[9,10,12] As references, vacuum, water, and n-heptane were used to calibrate and validate the technique. The results were compared to those presented by Zábranský et al.[13] and Lide et al.,[14] and the relative deviations obtained were 0.30 % and 0.29 %, respectively.

For all three devices, pressure was applied by means of a controlled atmosphere of dry nitrogen gas. It was adjusted using a pressure generator (HiP 50-6-15). A pressure transducer (Setra C280E) was used for measuring pressure, with an uncertainty of ± 2.2 kPa.

The standard uncertainty of the temperature was ± 0.01 K for density and heat capacity measurements and ± 0.1 K for viscosity. The components were weighed on a Mettler balance (Metter Toledo PR2003DR) with a precision of ± 10^{-3} g. The combined standard uncertainties of density, dynamic viscosity, and heat capacity were ± 0.3 kg·m^{-3}, ± 0.2 mPa·s, and ± 0.006 kJ·kg^{-1}·K^{-1}, respectively.

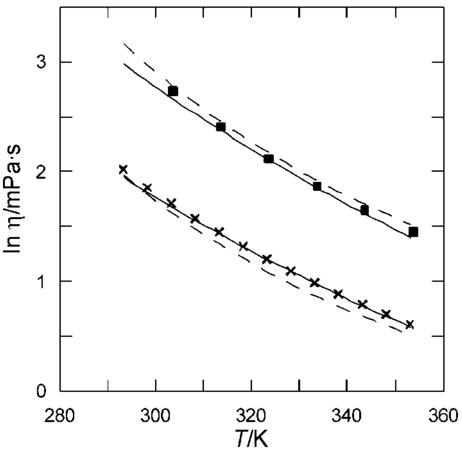

Figure 5. Viscosity for NH_3 (1) + $LiNO_3$ (2) + H_2O (3) solutions for several ammonia mass fractions. Water mass fraction fixed to 0.25 in ($LiNO_3$ + H_2O). Experimental values: ■, w_1 = 0.1999; ×, w_1 = 0.4000; −, calculated values, - - -, literature[8] correlated results.

Table 4. Experimental Dynamic Viscosity (η/mPa·s) and Calculated Kinematic Viscosity (υ/mm^2·s^{-1}) for NH_3 (1) + $LiNO_3$ (2) + H_2O (3) Solutions, For Several Temperatures (*T*/K) and Mass Fractions (w_i)

T/K	η/mPa·s	υ_{calcd}/mm^2·s^{-1}	T/K	η/mPa·s	υ_{calcd}/mm^2·s^{-1}
$w_1 = 0.1999$; $w_2 = 0.6006$			$w_1 = 0.3997$; $w_2 = 0.4803$		
303.6	15.3	13.8	293.2	9.3	10.7
313.6	11.1	10.1	298.2	7.8	9.0
323.6	8.3	7.6	303.2	6.6	7.7
333.6	6.5	5.9	308.2	5.7	6.7
343.7	5.2	4.8	313.2	5.0	5.9
353.7	4.2	4.0	318.2	4.4	5.2
			323.2	3.9	4.6
			328.1	3.5	4.1
			333.1	3.1	3.7
			338.1	2.8	3.3
			343.1	2.5	3.0
			348.0	2.3	2.8
			353.0	2.1	2.5
$w_1 = 0.2961$; $w_2 = 0.4926$			$w_1 = 0.4000$; $w_2 = 0.4500$		
293.1	10.6	11.2	293.2	7.6	8.9
298.1	8.9	9.4	298.2	6.4	7.5
303.1	7.5	8.0	303.2	5.5	6.6
308.1	6.5	6.9	308.2	4.8	5.7
313.1	5.7	6.1	313.2	4.3	5.1
318.1	5.0	5.4	318.2	3.7	4.5
323.1	4.5	4.8	323.2	3.3	4.0
328.1	4.0	4.3	328.1	3.0	3.6
333.1	3.6	3.9	333.1	2.7	3.2
338.0	3.2	3.5	338.1	2.4	2.9
343.0	2.9	3.2	343.1	2.2	2.7
348.1	2.6	2.9	348.1	2.0	2.5
353.0	2.4	2.6	353.0	1.8	2.2
$w_1 = 0.2971$; $w_2 = 0.5294$			$w_1 = 0.4996$; $w_2 = 0.3502$		
293.1	14.0	14.4	293.2	2.9	3.9
298.1	11.8	12.1	298.2	2.6	3.4
303.1	9.8	10.2	303.2	2.3	3.0
308.1	8.4	8.8	308.1	2.0	2.7
313.2	7.2	7.5	313.1	1.8	2.5
318.1	6.3	6.6	318.1	1.7	2.2
323.1	5.6	5.9	323.0	1.5	2.0
328.1	4.9	5.2	328.0	1.4	1.9
333.1	4.4	4.7	332.9	1.3	1.7
338.1	4.0	4.2			
343.1	3.6	3.8			
348.1	3.2	3.5			
353.1	2.9	3.1			
$w_1 = 0.2999$; $w_2 = 0.5600$			$w_1 = 0.4998$; $w_2 = 0.4000$		
293.2	18.9	19.0	293.2	3.7	4.8
298.2	15.7	15.9	298.2	3.2	4.2
303.2	13.1	13.4	303.1	2.9	3.7
308.2	11.1	11.3	308.1	2.6	3.3
313.2	9.5	9.7	313.1	2.3	3.0
318.2	8.1	8.3	318.1	2.1	2.7
323.2	7.0	7.2	323.1	1.9	2.5
328.2	6.2	6.4	328.0	1.7	2.2
333.1	5.5	5.7	332.9	1.6	2.1
338.1	4.9	5.1	337.9	1.5	1.9
343.1	4.4	4.6			
348.1	4.0	4.1			
353.2	3.5	3.7			
$w_1 = 0.3995$; $w_2 = 0.4205$			$w_1 = 0.5000$; $w_2 = 0.3749$		
298.2	5.3	6.3	293.2	3.3	4.4
303.2	4.6	5.5	298.2	2.9	3.9
308.2	4.0	4.8	303.2	2.6	3.4
313.2	3.5	4.3	308.1	2.3	3.1
318.2	3.1	3.8	313.1	2.1	2.7
323.1	2.8	3.4	318.1	1.9	2.5
328.1	2.5	3.1	323.1	1.7	2.3
333.0	2.3	2.8	328.0	1.6	2.1
338.0	2.1	2.5	332.9	1.4	1.9
343.0	1.9	2.3	337.9	1.3	1.8
347.9	1.7	2.1			
352.9	1.6	2.0			

Results and Discussion

Table 5. Experimental Heat Capacities (C_p/J·g^{-1}·K^{-1}) for NH_3 (1) + $LiNO_3$ (2) Solutions, For Several Temperatures (*T*/K) and Ammonia Mass Fractions (w_1)

T/K	C_p/J·g^{-1}·K^{-1}
$w_1 = 0.3501$	
312.67	2.533
322.57	2.567
332.48	2.598
342.38	2.624
352.29	2.645
$w_1 = 0.4003$	
312.67	2.726
322.58	2.763
332.49	2.792
342.39	2.818
352.29	2.836
$w_1 = 0.4499$	
312.67	2.931
322.58	2.965
332.48	3.000
342.39	3.030
352.31	3.047
$w_1 = 0.5000$	
312.65	3.144
322.56	3.173
332.46	3.205
342.37	3.234
$w_1 = 0.5497$	
312.67	3.289
322.58	3.320
332.48	3.341
342.38	3.375

The density, dynamic viscosity, and heat capacity of ammonia + lithium nitrate and ammonia + lithium nitrate + water were measured between (293.15 and 353.15) K, at 10 K intervals and a constant pressure of 1.8 MPa. Several samples were measured with an ammonia mass fraction in the binary and ternary mixtures between 0.35 and 0.65 and between 0.20 and 0.55, respectively. In the ternary mixtures, three $H_2O/LiNO_3$ mass fraction ratios were used (0.20, 0.25, and 0.30). The range of compositions was selected according with our previous paper[5] to reduce the viscosity of the mixture maintaining the level of rectification in the absorption refrigeration cycle. The experimental results are presented in Tables 1 to 6.

The density and heat capacity data were fitted using equations similar to those used by Salavera et al.[12]

$$\rho/\text{g}\cdot\text{cm}^{-3} = A + B\cdot(T/\text{K}) \tag{1}$$

$$C_p/\text{J}\cdot\text{g}^{-1}\cdot\text{K}^{-1} = A + B\cdot(T/\text{K}) \tag{2}$$

where ρ and C_p are the density and the heat capacity; T is the absolute temperature; and A and B are composition-dependent

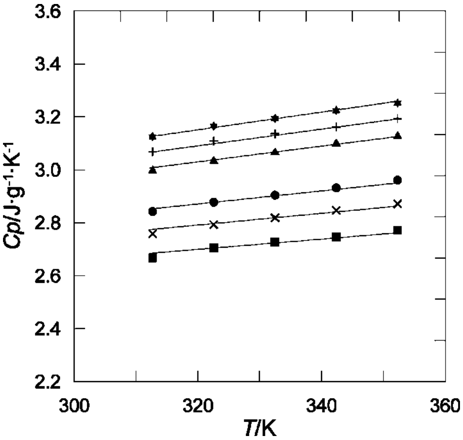

Figure 6. Experimental and calculated heat capacity for NH_3 (1) + $LiNO_3$ (2) + H2O (3) solutions, for a range of temperatures between (312.15 and 353.15) K, for several compositions: ■, $w_1 = 0.2947$, $w_2 = 0.5640$; ×, $w_1 = 0.2993$, $w_2 = 0.5254$; ●, $w_1 = 0.3003$, $w_2 = 0.4901$; ▲, $w_1 = 0.3999$, $w_2 = 0.4799$; +, $w_1 = 0.4000$, $w_2 = 0.4500$; ∗, $w_1 = 0.4001$, $w_2 = 0.4200$; −, calculated values.

parameters according to eqs 3a and 3b for the binary mixture NH_3 (1) + $LiNO_3$ (2)

$$A = \sum_{i=0}^{1} (w_1^i \cdot a_i) \tag{3a}$$

$$B = \sum_{i=0}^{1} (w_1^i \cdot b_i) \tag{3b}$$

and eqs 4a and 4b for the ternary mixture NH_3 (1) + $LiNO_3$ (2) + H_2O (3)

$$A = \sum_{i=0}^{1} \left(w_1^i \cdot \sum_{j=0}^{1} (a_{ij} \cdot w_3^j) \right) \tag{4a}$$

$$B = \sum_{i=0}^{1} \left(w_1^i \cdot \sum_{j=0}^{1} (b_{ij} \cdot w_3^j) \right) \tag{4b}$$

where a_i, b_i, a_{ij}, and b_{ij} are adjustable parameters determined from the experimental data using the least-squares method.

To fit the experimental dynamic viscosity data, eq 5 was used.

$$\ln \eta/\text{mPa}\cdot\text{s} = \frac{1000 \cdot A}{T/\text{K}} + B \tag{5}$$

where A and B are composition-dependent parameters calculated according to eqs 6a and 6b

$$A/\text{mPa}\cdot\text{s}\cdot\text{K} = \sum_{i=1}^{n} \sum_{j=1}^{2} (a_{ij} \cdot w_i^j) + a_0 \tag{6a}$$

$$B/\text{mPa}\cdot\text{s} = \sum_{i=1}^{n} \sum_{j=1}^{2} (b_{ij} \cdot w_i^j) + b_0 \tag{6b}$$

where $n = 1$ for the NH_3 (1) + $LiNO_3$ (2) mixture and $n = 2$ for NH_3 (1) + $LiNO_3$ (2) + H_2O (3).

All the parameters are presented in Tables 7 to 12. The root mean standard deviations (hereinafter rmsd) between the experimental and calculated densities of the NH_3 + $LiNO_3$ and NH_3 + $LiNO_3$ + H_2O solutions were 0.43 % and 0.88 %, respectively; for dynamic viscosities, it was 0.91 % and 1.81 %, respectively; and for heat capacity, it was 0.52 % and 0.28 %, respectively.

Moreover, kinematic viscosity v can be calculated from dynamic viscosity η and density ρ using the following equation

$$v/\text{mm}^2\cdot\text{s}^{-1} = \frac{\eta/\text{mPa}\cdot\text{s}}{\rho/\text{g}\cdot\text{cm}^{-3}} \tag{7}$$

The experimental data of density, heat capacity, and dynamic viscosity for the NH_3 + $LiNO_3$ mixture were compared with the calculated data obtained with the correlations proposed by Infante Ferreira.[6] The deviation in terms of rmsd between our experimental values and those calculated using Infante Ferreira's correlations[6] was 4.0 % with a maximum relative deviation of 9.3 % for density and 5.0 % with a maximum relative deviation of 8.2 % for heat capacity. In the case of the dynamic viscosity, our experimental data are higher than literature values.[6] These discrepancies could be due to the limited data available in the literature.[15] Figures 1 to 3 show the comparison of experimental and calculated data with eqs 1, 2, and 5 for density, dynamic viscosity, and heat capacity and with calculated values using literature correlations[6] for NH_3 + $LiNO_3$ solutions, as a function of the temperature for several compositions. Experimental data and literature[6] results are in agreement at low temperatures, but deviation increases with temperature.

Table 6. Experimental Heat Capacities (C_p/J·g^{-1}·K^{-1}) for NH_3 (1) + $LiNO_3$ (2) + H_2O (3) Solutions, For Several Temperatures (T/K) and Mass Fractions (w_i)

T/K	C_p/J·g^{-1}·K^{-1}
$w_1 = 0.2947$; $w_2 = 0.5640$	
312.67	2.668
322.57	2.705
332.48	2.727
342.38	2.747
352.29	2.772
$w_1 = 0.2993$; $w_2 = 0.5254$	
312.67	2.758
322.57	2.793
332.48	2.819
342.38	2.847
352.29	2.871
$w_1 = 0.3003$; $w_2 = 0.4901$	
312.67	2.843
322.57	2.878
332.48	2.904
342.38	2.932
352.29	2.961
$w_1 = 0.3999$; $w_2 = 0.4799$	
312.67	3.001
322.57	3.037
332.48	3.069
342.38	3.103
352.29	3.131
$w_1 = 0.4000$; $w_2 = 0.4500$	
312.67	3.069
322.59	3.109
332.49	3.136
342.39	3.162
352.29	3.193
$w_1 = 0.4001$; $w_2 = 0.4200$	
312.67	3.125
322.57	3.165
332.48	3.194
342.38	3.224
352.29	3.252
$w_1 = 0.4999$; $w_2 = 0.4001$	
312.67	3.339
322.57	3.37
332.48	3.397
342.38	3.427
$w_1 = 0.4999$; $w_2 = 0.3498$	
312.67	3.431
322.57	3.466
332.49	3.492
342.38	3.523
$w_1 = 0.5000$; $w_2 = 0.3749$	
312.67	3.383
322.58	3.418
332.48	3.445
342.38	3.474

Table 7. Coefficients of Equation 3 for Density of NH_3 + $LiNO_3$ Solutions

coefficient	value
a_0	$1.521 \cdot 10^{0}$
a_1	$-4.528 \cdot 10^{-1}$
b_0	$-1.961 \cdot 10^{-5}$
b_1	$-1.726 \cdot 10^{-3}$

For NH_3 + $LiNO_3$ + H_2O mixtures, Ehmke[8] measured the density and dynamic viscosity with a water mass fraction of 0.25 in absorbent solution ($LiNO_3$ + H_2O), and the author also proposed correlations for each property. Experimental density and viscosity of the current work were compared with calculated values using Ehmke's correlations,[8] showing a deviation for the density of 0.3 % with a maximum relative deviation of 0.6 %

Table 8. Coefficients of Equation 4 for Density of NH_3 + $LiNO_3$ + H_2O Solutions

coefficient	value	coefficient	value
a_{00}	$1.483 \cdot 10^{3}$	b_{00}	$7.859 \cdot 10^{-2}$
a_{01}	$4.213 \cdot 10^{2}$	b_{01}	$-1.963 \cdot 10^{0}$
a_{10}	$-3.541 \cdot 10^{2}$	b_{10}	$-1.762 \cdot 10^{0}$
a_{11}	$-1.674 \cdot 10^{3}$	b_{11}	$1.594 \cdot 10^{0}$

Table 9. Coefficients of Equation 6 for Dynamic Viscosity of NH_3 + $LiNO_3$ Solutions

coefficient	value	coefficient	value
a_0	1.918	b_0	−1.205
a_{11}	10.094	b_{21}	−35.627
a_{12}	−18.394	b_{22}	51.529

Table 10. Coefficients of Equation 6 for Dynamic Viscosity of NH_3 + $LiNO_3$ + H_2O Solutions

coefficient	value	coefficient	value
a_0	1.435	b_0	−5.301
a_{11}	10.523	b_{11}	−24.845
a_{12}	−14.014	b_{12}	31.503
a_{21}	−8.015	b_{21}	23.013
a_{22}	12.676	b_{22}	−30.944

Table 11. Coefficients of Equation 3 for Heat Capacity of NH_3 + $LiNO_3$ Solutions

coefficient	value
a_0	$5.593 \cdot 10^{-1}$
a_1	$3.241 \cdot 10^{0}$
b_0	$2.078 \cdot 10^{-3}$
b_1	$1.847 \cdot 10^{-3}$

Table 12. Coefficients of Equation 4 for Heat Capacity of NH_3 + $LiNO_3$ + H_2O Solutions

coefficient	value	coefficient	value
a_{00}	$2.081 \cdot 10^{0}$	b_{00}	$-2.583 \cdot 10^{-3}$
a_{01}	$1.613 \cdot 10^{-5}$	b_{01}	$8.832 \cdot 10^{-3}$
a_{10}	$3.441 \cdot 10^{-5}$	b_{10}	$1.198 \cdot 10^{-2}$
a_{11}	$1.077 \cdot 10^{-5}$	b_{11}	$-6.316 \cdot 10^{-3}$

and 9.0 % for the dynamic viscosity with a maximum relative deviation of 12.4 %. Figures 4 and 5 show experimental and calculated (by eqs 1 and 5) data obtained in this work for density and viscosity and calculated values using Ehmke's correlations[8] for NH_3 + $LiNO_3$ + H_2O solutions as a function of temperature for some compositions. Figure 6 shows heat capacity experimental and calculated (by eq 2) data obtained in this work as a function of temperature for some compositions.

Conclusions

The density, dynamic viscosity, and heat capacity of NH_3 + $LiNO_3$ and NH_3 + $LiNO_3$ + H_2O solutions were measured between (293.15 and 353.15) K for several compositions. The experimental data were correlated with temperature and composition using different analytical equations. Finally, the experimental data were compared with the scarce literature data. The binary mixture data deviated considerably at high temperatures from Infante Ferreira's equations,[6] but the ternary mixture data are in agreement with the values reported by Ehmke.[8]

Literature Cited

(1) Ehmke, H. J.; Renz, M. *Ternary Working Fluids for Absorption Systems with Salt-Liquid Mixtures as Absorber IIF - IIR Congress, Commission B1*, Paris, France, 1983.

(2) Bokelmann, H. Presentation of new working fluids for absorption heat pumps. *Absorption Heat Pump Congress*, Paris, France, 1985.

(3) Reiner, R. H.; Zaltash, A. *Evaluation of ternary ammonia-water fluids for GAX and regenerative absorption cycles*; Report ORNL/CF-91/263, **1991**.

(4) Reiner, R. H.; Zaltash, A. Densities and Viscosities of ternary Ammonia/Water Fluids. *ASME Winter Annual Meeting*, New Orleans, USA, 1993.

(5) Libotean, S.; Salavera, D.; Valles, M.; Esteve, X.; Coronas, A. Vapor−Liquid Equilibrium of Ammonia + Lithium Nitrate + Water and Ammonia + Lithium Nitrate Solutions from (293.15 to 353.15) K. *J. Chem. Eng. Data* **2007**, *52*, 1050–1055.

(6) Ferreira, C. A. I. Thermodynamic and physical property data equations for ammonia-lithium nitrate and ammonia-sodium thiocyanate solutions. *Sol. Energy* **1984**, *32*, 231–236.

(7) Aggarwal, M. K.; Agarwal, R. S. Thermodynamic Properties of Lithium Nitrate - Ammonia Mixtures. *Energy Res.* **1986**, *10*, 59–68.

(8) Ehmke, H. J. Doctoral Thesis, Universität Essen: Essen, Germany, 1984.

(9) Salavera, D.; Libotean, S.; Patil, K. R.; Esteve, X.; Coronas, A. Densities and heat capacities of the ammonia + water + NaOH and ammonia + water + KOH solutions. *J. Chem. Eng. Data* **2006**, *51*, 1020–1025.

(10) Salavera, D.; Esteve, X.; Patil, K. R.; Mainar, A. M.; Coronas, A. Solubility, heat capacity, and density of lithium bromide + lithium iodide + lithium nitrate + lithium chloride aqueous solutions at several compositions and temperatures. *J. Chem. Eng. Data* **2004**, *49*, 613–619.

(11) Schmidt, E.; Grigull, U. *Properties of Water and Steam in SI-Units;* Springer-Verlag Berlin Heidelberg: New York, 1981.

(12) Salavera, D.; Libotean, S.; Patil, K. R.; Esteve, X.; Coronas, A. Densities and Heat Capacities of the Ammonia + Water + NaOH and Ammonia + Water + KOH Solutions. *J. Chem. Eng. Data* **2006**, *51*, 1020–1025.

(13) Zábranský, M.; Rùička, V., Jr.; Majer, V. Heat Capacity of Liquids: Volumes I and II. Critical Review and Recommended Values. *J. Phys. Chem. Ref. Data* **1966**, Monograph 6.

(14) Lide, D. R.; Kehiaian, H. V. *CRC Handbook of Thermophysical and Thermochemical Data*; CRC Press: Boca Raton, 1994.

(15) Niebergall,W. *Arbeitsstoffpaare für Absorptions-Kältean-lagen und Absorptions-Kuhlschranke*; Markewitz-Verlag G.M.B.H: Darmstandt, 1949.

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