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Saturated Humidity, Entropy, and Enthalpy for the Nitrogen-Water System at Elevated Temperatures and Pressures

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A model is used to calculate saturated thermophysical properties (humidity, entropy, and enthalpy) of a nitrogen-water mixture at elevated temperatures and pressures. In the model, a modified Redlich–Kwong equation of state is used to calculate fugacity coefficients for the vapor phase, and the liquid phase follows Henry's law. The model has been investigated by comparing the calculated results with the available experimental data. The comparison shows that the model can be used to calculate saturated thermodynamic properties for the nitrogen-water mixture reliably up to 523.15 K and 300 bar.

KEY WORDS: enthalpy; entropy; humidity; mixtures; nitrogen; saturation; thermodynamics; vapor-liquid equilibrium; water.

1. INTRODUCTION

The evaporative gas turbine (EvGT), or humid air turbine (HAT) cycle is an advanced power generation technology because of the use of evaporative humidification in combination with integration of heat recovery. In addition, the humidification technology is also used for the compressed air energy storage (CAES). Reliable thermophysical properties of an air-water mixture are needed in order to satisfy the needs of process design at the temperatures and pressures of interest (up to 523.15 K and 150 bar).

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For the air-water system, available experimental data are rather limited; these data cover temperatures up to 348.15 K and pressures up to 200 bar [1, 2]. Because of the scarcity of experimental data, thermodynamic properties for the air-water system can only be calculated up to 373.15 K and 50 bar with existing methods [3]. However, for the nitrogen-water and oxygen-water systems, the available experimental data are much more. Furthermore, it has been demonstrated that the properties of the air-water system are similar to those of nitrogen-water and oxygen-water systems [3–5]. Therefore, if a predictive model is proposed and evaluated with the available experimental data for nitrogen-water and oxygen-water systems, it may also be used to predict thermodynamic properties of the air-water system.

Based on this idea, a new model was proposed in this paper, in which a modified Redlich–Kwong equation of state (EOS) was used to calculate fugacity coefficients for the vapor phase, and the liquid phase followed Henry's law. This model was investigated for the nitrogen-water system by comparing the calculated results with experimental data. Moreover, it was used to predict the thermodynamic properties for the nitrogen-water system at elevated temperatures and pressures.

2. THERMODYNAMIC MODEL

The equations governing equilibrium between liquid and vapor phases are

$$T^V = T^L, \tag{1}$$

$$P^V = P^L, \tag{2}$$

and

$$f_i^V = f_i^L, \tag{3}$$

where T is the temperature, P is the total pressure, f is the fugacity, superscripts V and L designate, respectively, the vapor and liquid phases, and the subscript i refers to the component.

2.1. Vapor Phase

The vapor-phase fugacity f is related to the vapor-phase mole fraction y by

$$f_i^V = \phi_i y_i P, \tag{4}$$

where ϕ_i is the fugacity coefficient. The modified Redlich–Kwong EOS, developed by de Santis et al. [6], not only matches the vapor pressure data, but also gives accurate predictions of volumetric and other thermodynamic properties. It was used to calculate fugacity coefficients in this paper. The expression is

$$P = \frac{RT}{v-b} - \frac{a}{\sqrt{T}\, v(v-b)}, \tag{5}$$

where v is the molar volume, R is the gas universal constant, and a and b are the coefficients. a is a function of temperature, with mixing rules for a and b as follows:

$$a = \sum_i \sum_j y_i y_j a_{ij}, \tag{6}$$

and

$$b = \sum_i y_i b_i. \tag{7}$$

With this equation of state, the fugacity coefficient is given by

$$\ln \phi_i = \ln\left(\frac{v}{v-b}\right) + \frac{b_i}{v-b} - 2\frac{\sum_j y_j a_{ij}}{RT^{1.5}b} \ln\left(\frac{v+b}{v}\right) + \frac{ab_i}{RT^{1.5}b^2}\left[\ln\left(\frac{v+b}{v}\right) - \frac{b}{v+b}\right] - \ln\left(\frac{Pv}{RT}\right). \tag{8}$$

The molar volume v can be calculated from Eq. (5) at a fixed temperature, pressure, and vapor composition.

Coefficient a for pure components is split into two parts:

$$a_{ii} = a_{ii}^0 + a_{ii}^1(T), \tag{9}$$

where the constant a_{ii}^0 reflects the intermolecular attraction due to dispersion forces and can be found from critical temperature T_c and pressure P_c [7].

$$a_{ii}^0 = 0.4278 \frac{R^2 T_c^{2.5}}{P_c}. \tag{10}$$

The temperature-dependence part, a_{ii}^1, is attributed to intermolecular attractions from hydrogen bonding and polar forces. For simple nonpolar gases, their values are zero. For water, de Santis et al. [6] tabulated a_{ww}

from 323.15 to 1073.15 K. Heidemann and Prausnitz [8] extrapolated and tabulated a_{ww} from 293.15 to 603.15 K. In order to calculate properties at given temperature and pressure, the tabulated values a_{ww} ($\mathrm{L}^2 \cdot \mathrm{mol}^{-2} \cdot \mathrm{bar} \cdot \mathrm{K}^{0.5}$) by de Santis et al. [6] and Heidemann and Prausnitz [8] were correlated up to the critical temperature of water in this paper.

$$a_{ww} = \begin{cases} 3493.75 - 16.2791(T/K) + 0.0207716(T/K)^2 \\ \qquad (T \leqslant 323.15\ \mathrm{K}) \\ 5518.64 - 37.4866(T/K) + 0.100081(T/K)^2 \\ \quad - 1.19610 \times 10^{-4}(T/K)^3 + 5.34185 \times 10^{-8}(T/K)^4 \\ \qquad (323.15 < T < 647.3\ \mathrm{K}) \end{cases} \tag{11}$$

Coefficients b_i can also be calculated from critical point data [7]

$$b_i = 0.0867 \frac{RT_\mathrm{c}}{P_\mathrm{c}}. \tag{12}$$

For a_{ij}, where $i \neq j$, the nature of intermolecular interactions between different species is taken into account. Hydrogen bonding and polar forces are presumed not to play a significant role in the interactions between simple nonpolar gases and water; therefore,

$$a_{ij} = a_{ji} = (a_{ii}^0 a_{jj}^0)^{0.5}. \tag{13}$$

The temperature-independent parameters for the nitrogen-water system were taken from Heidemann and Prausnitz [8], and their values are listed in Table I.

2.2. Liquid Phase

The liquid-phase fugacities are given by

$$f_i^L = f_i^0 x_i \gamma_i, \tag{14}$$

Table I. Temperature-Independent Parameters for the Nitrogen-Water System from Heidemann and Prausnitz [8]

Substance	a_{ii}^0 ($\mathrm{L}^2 \cdot \mathrm{mol}^{-2} \cdot \mathrm{bar} \cdot \mathrm{K}^{0.5}$)	b_i ($\mathrm{L} \cdot \mathrm{mol}^{-1}$)
N_2 (1)	15.667	0.02678
H_2O (2)	35.464	0.0146

where f_i^0 is the liquid phase reference fugacity of component i, x is the liquid-phase mole fraction, and γ_i is the activity coefficient. The solubility of nitrogen in water is small, and γ_i is assumed to be unity.

f_i^0 is related to the reference state. In this paper, the reference state of water vapor is based on pure liquid. The calculation of f_w^0 was described in detail in Ji et al. [9]. Reference state of gaseous nitrogen is based on infinite dilution in pure water (Henry's constant). Generally, the Henry's constant was determined from experimental data and only suitable within the correlation range. Recently, a comprehensive EOS, Helgeson EOS, was developed for accurate calculations of the standard partial molal properties of aqueous species, minerals and gases at high temperature and pressure [10, 11]. The advantage of their contribution is to predict Henry's constants, salt solubility products, and dissociation and reaction constants of aqueous species that are thermodynamically consistent with a large number of published parameters for geochemical studies. In this paper, it was used to calculate the Henry's constant on a molality basis (H_m). The relation between the molality basis and mole fraction basis (H_x) is

$$H_x = \frac{1000}{18.015} H_m. \tag{15}$$

2.3. Gas Enthalpy and Entropy

For nitrogen, we chose h_i^0 ($T_0 = 273.15$ K) $= 0$ and s_i^0 ($T_0 = 273.15$ K, $P_0 = 1.01325$ bar) $= 0$ for the pure fluid in the ideal-gas state. For water vapor, the specific enthalpy and entropy of the liquid phase were set to zero at the triple point.

The enthalpy and entropy follow from the used EOS (Eq. (5)), that is

$$h = \underbrace{T \sum_i y_i C_{p_i}^0(T)}_{\text{part 1}} \\ \underbrace{+ \frac{RTb}{v-b} - \frac{a}{(v+b)\,T^{0.5}} - \frac{1}{b}\left[\frac{a}{\sqrt{T}} - T\frac{d}{dT}\left(\frac{a}{\sqrt{T}}\right)\right]\ln\left(\frac{v+b}{v}\right)}_{\text{part 2}}, \tag{16}$$

$$s = \underbrace{\int_{T_0}^{T} \sum_{i=1}^{N} y_i \frac{C_{p_i}^0(T)}{T} - R\ln\left(\frac{P}{P_0}\right)}_{\text{part 1}} \\ \underbrace{+ R\ln\left(\frac{v-b}{v}\right) + \frac{1}{b}\frac{d}{dT}\left(\frac{a}{\sqrt{T}}\right)\ln\left(\frac{v+b}{v}\right) + R\ln\left(\frac{Pv}{RT}\right)}_{\text{part 2}}, \tag{17}$$

and

$$\frac{d}{dT}\left(\frac{a}{\sqrt{T}}\right)=-\frac{a}{2T^{3/2}}+\frac{y_w^2}{\sqrt{T}}\frac{da_{ww}}{dT}, \tag{18}$$

where $C_{p_i}^0$ is the ideal-gas heat capacity.

In Eqs. (16) and (17), part 1 represents the ideal-gas state and part 2 is the excess part. Equations (16) and (17) can also be written as

$$h=\sum_i y_i h_i^0(T)+h^E, \tag{19}$$

$$s=\underbrace{\sum_i y_i s_i^0(T,P_0)-R\ln\left(\frac{P}{P_0}\right)}_{\text{part 1}}+s^E, \tag{20}$$

where h_i^0 and s_i^0 are the enthalpy and entropy of component i in the ideal-gas state respectively.

Using different sources of $C_{p_i}^0$, the enthalpy and entropy in the ideal-gas state were calculated and tabulated in books [12, 13]. Some commercial software, for example Aspen Plus [14], can also be used to calculate them. We have compared the calculated results of enthalpy and entropy taken from these three sources and found that the calculated results for gaseous nitrogen are consistence. In this paper, the enthalpy and entropy of gaseous components in the ideal-gas state were taken from the book by Wark [12] and correlated with Eqs. (21) and (22). Because the reference states in this book and in this paper are different, we converted the reference state to be the chosen one in this paper. The correlation and converted results are listed in Table II,

$$h_i^0(T)=\sum_{j=1}^{5} C_{hj}(T/K)^{j-1} \qquad (\mathrm{J\cdot mol^{-1}}), \tag{21}$$

$$s_i^0(T,P_0)=\sum_{j=1}^{7} C_{sj}(T/K)^{j-1} \qquad (\mathrm{J\cdot mol^{-1}\cdot K^{-1}}). \tag{22}$$

The excess part is related to the da_{ww}/dT. Since the a_{ww} was correlated with different polynomials, the da_{ww}/dT was discontinuous at 323.15 K.

Table II. Coefficients of Eqs. (21) and (22) for Calculating the Enthalpy and Entropy of Nitrogen and Water Vapor from 200 to 1773.15 K in the Ideal-Gas State

	N_2	H_2O		N_2	H_2O
C_{h1}	−7968.61	36124.8	C_{s1}	−49.6232	67.3781
C_{h2}	29.6499	32.3258	C_{s2}	0.292825	0.318755
10^3C_{h3}	−2.98280	0.232361	10^4C_{s3}	−5.70954	−5.99710
10^6C_{h4}	4.92163	4.31856	10^7C_{s4}	7.37074	7.64762
10^9C_{h5}	−1.43999	−1.13183	$10^{10}C_{s5}$	−5.59323	−5.76022
			$10^{13}C_{s6}$	2.27254	2.33109
			$10^{17}C_{s7}$	−3.80946	−3.89997

In order to solve this problem, the da_{ww}/dT $(\mathrm{L}^2 \cdot \mathrm{mol}^{-2} \cdot \mathrm{bar} \cdot \mathrm{K}^{-0.5})$ was calculated first and then correlated with the following expression:

$$\frac{da_{ww}}{dT} = -34.9341 + 0.185224(T/K) - 3.30254 \times 10^{-4}(T/K)^2 + 1.95760 \times 10^{-7}(T/K)^3. \tag{23}$$

It should be mentioned that in the paper of Heidemann and Prausnitz [8], the expressions for calculating enthalpy and entropy might be incorrectly printed. However, their calculated results are correct.

2.4. Humidity

The humidity is an important parameter in the design of EvGT. The absolute humidity (HD_a) can be calculated if the mole fraction of vapor is known (y_{N_2} and y_w):

$$HD_a = \frac{y_w}{y_{N_2}} \quad \text{(mole water vapor per mole nitrogen).} \tag{24}$$

The saturation humidity (HD_s) is a special case of HD_a. That is, the calculation formula is the same as that of HD_a, but the mole fraction should be calculated from the above thermodynamic model at a certain temperature and pressure. For unsaturated (superheated) mixtures, the mole fraction is determined easily.

In process design, the relative humidity is often used. It can be calculated directly from the absolute humidity and saturation humidity.

3. VERIFICATION OF MODEL

At fixed temperature and pressure, the equilibrium composition was calculated by performing a flash calculation. Sufficient water was included with nitrogen in the mixture being flashed, to assure that the vapor phase was saturated.

3.1. Water Solubility in Nitrogen Gas

For the nitrogen-water system, many experimental data have been determined, mainly for the solubility of nitrogen in liquid water. In a few papers, the water content in the vapor phase was published directly. Rigby and Prausnitz [15] measured the vapor phase solubility of water up to 373.15 K and 100 bar. We first calculated the vapor composition with our model and compared with the experimental data of Rigby and Prausnitz [15]. The comparisons are given in Table III.

From Table III, it can be seen that the calculated results are very close to the experimental data of Rigby and Prausnitz [15] over the complete range of temperature and pressure. The maximum relative deviation is 1.81% and the average relative deviation is only 0.70%, which indicates that our calculated results are reliable.

Table III. Comparisons of Calculated Results for the Nitrogen(1)-Water(2) System with Experimental Data of Rigby and Prausnitz [15]

		Mole fraction of water in the vapor phase		
Temperature (K)	Pressure (bar)	Rigby and Prausnitz ($y_{2,\text{exp}}$)	This work ($y_{2,\text{cal}}$)	$\lvert y_{2,\text{exp}} - y_{2,\text{cal}}\rvert / y_{\text{exp}}$ (%)
298.15	22.49	0.001529	0.001513	1.05
298.15	30.90	0.001149	0.001130	1.65
298.15	38.70	0.000941	0.000924	1.81
323.15	21.09	0.00626	0.00620	0.95
323.15	37.42	0.00368	0.00364	1.09
323.15	59.82	0.00242	0.00241	0.41
323.15	77.00	0.001956	0.001952	0.20
348.15	42.21	0.01009	0.01008	0.10
348.15	61.15	0.00721	0.00724	0.42
348.15	89.72	0.00523	0.00523	0
373.15	57.17	0.01994	0.01993	0.05
373.15	79.48	0.01503	0.01490	0.87
373.15	101.52	0.01218	0.01212	0.49
average				0.70

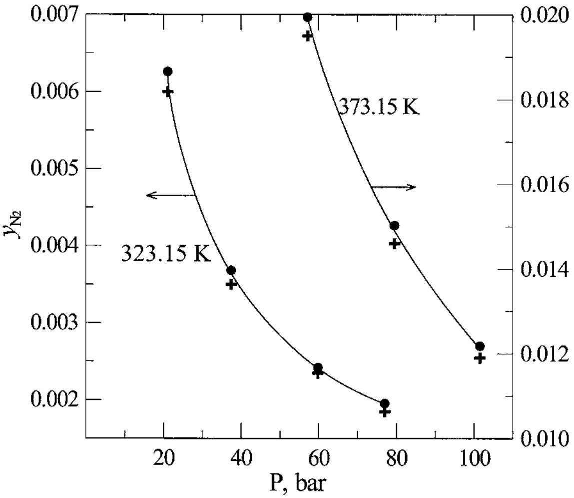

Fig. 1. Comparisons of results for the water content in nitrogen. ——, calculated results of this work; +, calculated results of Heidemann and Prausnitz [8]; ●, exp. data of Rigby and Prausnitz [15].

In the paper of Heidemann and Prausnitz [8], the equilibrium composition of the vapor phase was also calculated. The modified Redlich–Kwong equation of state was also used for vapor mixtures, and Henry's law with the Poynting correction was used for the liquid phase. Their calculated results are shown in Fig. 1 for comparison with those calculated in the present paper and experimental data by Rigby and Prausnitz [15] at 323.15 and 373.15 K and at different pressures. Figure 1 shows that the calculated results of the present work and of Heidemann and Prausnitz [8] agree with the experimental data. Results of this work agree better with the experimental data than do those of Heidemann and Prausnitz [8].

Some data for the solubility of water in nitrogen at higher temperatures and pressures are available from Saddington and Krase [16]. Comparisons with these data are presented in Table IV. At 202.650 bar, most of our calculated results are close to their experimental data, while at 101.325 bar, the deviations between our calculated values and their data become large, especially at 503.15 K. However, our calculated results are very close to those of Heidemann and Prausnitz [8] over the complete temperature and pressure range. Furthermore, as mentioned in the work of Heidemann and Prausnitz [8], both Webster [14] and Rigby and Prausnitz [15] presented reasons for assuming that there are significant errors in the data of Saddington and Krase [16]. In particular, Webster [17] argued

Table IV. Comparisons of Calculated Results of Water Content for the Nitrogen(1)-Water(2) System with Experimental Data of Saddington and Krase [16] and Those Calculated by Heidemann and Prausnitz [8]

Temperature (K)	Pressure (bar)	y_2/y_1 in vapor phase		
		Saddington & Krase	Heidemann & Prausnitz	This work
323.15	101.325	0.001837	0.00156	0.00157
353.15	101.325	0.00629	0.00577	0.00582
373.15	101.325	0.01137	0.0122	0.0123
423.15	101.325	0.0549	0.0582	0.0589
463.15	101.325	0.1404	0.170	0.172
503.15	101.325	0.379	0.482	0.487
323.15	202.65	0.00132	0.000970	0.000980
423.15	202.65	0.0322	0.0322	0.0325
463.15	202.65	0.0929	0.0883	0.0891
498.15	202.65	0.208	0.201	0.200

that the reported water content at 323.15 K and high pressure is too large, which is confirmed in our calculated results. Therefore, the present calculated results in this paper are considered reliable.

3.2. Nitrogen Solubility in Liquid Water

Nitrogen solubility in water has been measured in previous studies. Goodman and Krase [18] determined nitrogen solubilities from 273.15 to 443.15 K at pressures of 101.325, 126.656, 202.650, and 303.975 bar. Wiebe et al. [19] measured the solubility of nitrogen at 323.15, 348.15, and 373.15 K, from 25 to 1013 bar. In the work of Saddington and Krase [16], the solubility of nitrogen in liquid water was measured from 323.15 to 503.15 K at 101.325, 202.650, and 303.975 bar. In the present paper, the liquid composition has been calculated and compared with these experimental data. As shown in Fig. 2, the deviations between different experimental data sets are very large. At 101.325 bar and low temperature, three of them are consistent, however, at higher temperatures, deviations between Goodman and Krase [18] and Saddington and Krase [16] are significant. At 202.650 bar, the experimental data of Wiebe et al. [19] and Saddington and Krase [16] are consistent, while the experimental data of Goodman and Krase [18] are much higher than the others. At 303.975 bar, from 323.15 to 423.15 K, the experimental data of Goodman and Krase [18] are also much higher than those of Wiebe et al. [19] and Saddington and Krase [16]. Therefore, there may be errors in the data of

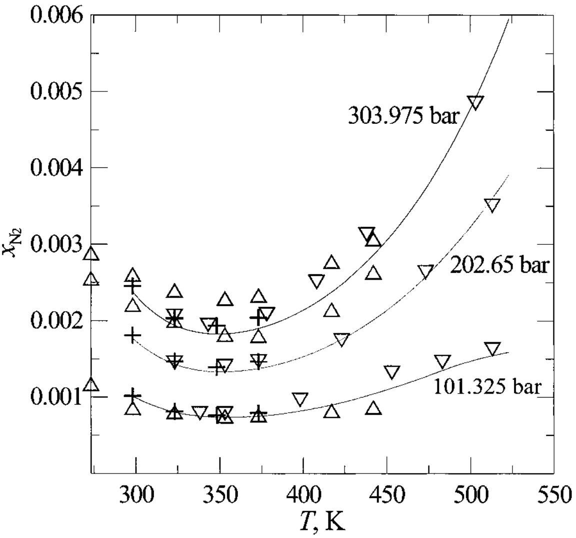

Fig. 2. Comparisons of results for the nitrogen content in water. ——, calculated results of this work; +, exp. data of Wiebe et al. [19]; ▽, exp. data of Saddington and Krase [16]; △, exp. data of Goodman and Krase [18].

Goodman and Krase [18]. The calculated results for the method of this study agree well with experimental data of Wiebe et al. [19] and Saddington and Krase [16].

3.3. Gas Mixing Excess Enthalpy

Many experimental data of mixing excess enthalpy (h_m^E) for nitrogen-water system are available [20–22]. In this paper the mixing excess enthalpy was calculated and compared with experimental data. Figure 3 shows comparisons at four different temperatures of 373.15 390.15, 410.15, and 423.15 K at atmospheric pressure. The calculated results are in reasonable agreement with the experimental data over the complete range. The average deviation is less than 2.4%.

At high temperatures and pressures, Wormald and Colling [21] measured the mixing excess enthalpy for the nitrogen-water system up to 698.2 K and 126 bar. In the work of Lancaster and Wormald [22], the earlier experimental data were corrected. Using the method of this paper, the excess enthalpy was calculated and compared with the corrected experimental data [22]. When the experimental temperature is higher than the critical temperature of water (674.3 K), parameters were extrapolated with the expression given in this paper. The comparisons are shown in Fig. 4.

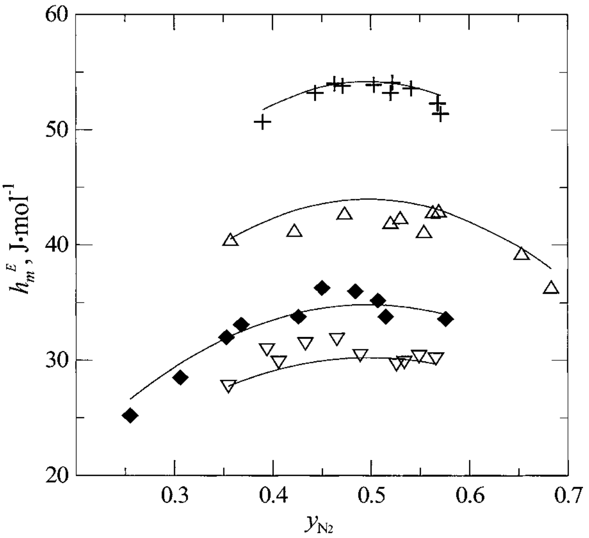

Fig. 3. Comparisons of the calculated mixing excess enthalpy H_m^E of $(yN_2+(1-y)H_2O)$ with experimental data of Richards et al. [20] over a range of composition at 1.01325 bar. ——, calculated results of this work; +, △, ◆, and ▽, exp. data at 373.15, 390.15, 410.15, and 423.15 K, respectively.

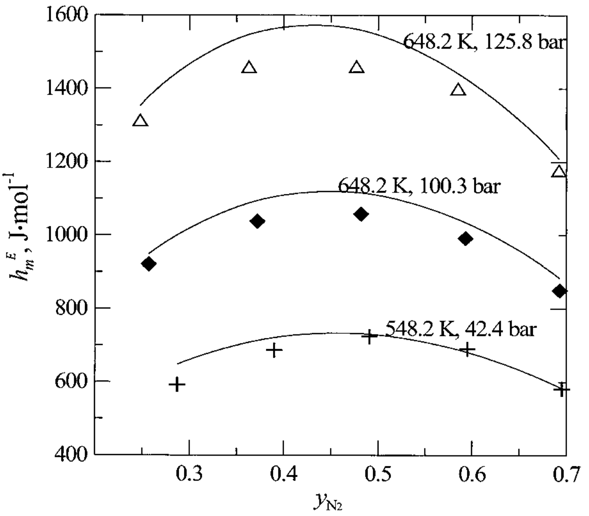

Fig. 4. Comparisons of the calculated mixing excess enthalpy H_m^E of $(yN_2+(1-y)H_2O)$ with experimental data at high temperatures and pressures. ——, calculated results of this work; +, ◆, and △, exp. results of Lancaster and Wormald [22].

Our calculated results are closer to the data of Lancaster and Wormald [22] up to 648.2 K, the average deviation is 4.03%. It also indicates that our model can be extrapolated up to 648.2 K.

4. PREDICTION OF SATURATED VAPOR HUMIDITY, ENTHALPY, AND ENTROPY

The humidity, enthalpy, and entropy are important properties in process design. In this work, the saturated humidity, enthalpy, and entropy were predicted with the proposed model. Table V lists the predicted results

Table V. Predicted Results of Humidity *HD* (mole steam/mole nitrogen), Enthalpy *h* ($J \cdot mol^{-1}$), and Entropy *s* ($J \cdot mol^{-1} \cdot K^{-1}$) from 323.15 to 573.15 K and 10 to 300 bar for the Saturated Humid Gas

P (bar)	10	30	50	75	100	125	150	200	250	300
					323.15 K					
$10^4 HD$	128.8	44.80	28.21	19.98	15.90	13.47	11.87	9.877	8.690	7.895
h	1972	1596	1325	1178	1061	962.8	879.9	752.8	669.2	621.1
s	−12.71	−23.15	−27.88	−31.67	−34.42	−36.58	−38.37	−41.22	−43.43	−45.24
					373.15 K					
$10^3 HD$	116.6	37.51	23.01	15.92	12.42	10.34	8.957	7.238	6.208	5.519
h	7593	4427	3741	3356	3134	2982	2870	2715	2619	2563
s	2.875	−14.89	−21.01	−25.45	−28.47	−30.78	−32.64	−35.56	−37.80	−39.62
					423.15 K					
$10^2 HD$	95.75	20.46	11.74	7.820	5.962	4.877	4.165	3.288	2.767	2.420
h	26409	11929	8954	7433	6652	6171	5843	5426	5177	5020
s	54.04	5.350	−7.033	−14.58	−19.14	−22.34	−24.80	−28.44	−31.10	−33.20
					473.15 K					
$10^2 HD$	–	121.8	52.26	31.14	22.53	17.84	14.90	11.41	9.392	8.078
h	–	30256	21003	16232	13801	12325	11332	10082	9333	8842
s	–	55.22	25.52	9.011	−0.0976	−6.053	−10.35	−16.29	−20.34	−23.37
					523.15 K					
$10 HD$	–	–	50.07	14.68	8.769	6.334	5.004	3.587	2.841	2.379
h	–	–	43345	32899	27312	23830	21452	18412	16554	15306
s	–	–	87.57	55.06	37.06	25.45	17.25	6.250	−0.9350	−6.100
					573.15 K					
HD	–	–	–	–	9.474	3.449	2.140	1.245	0.8936	0.7049
h	–	–	–	–	45222	39903	36055	30854	27495	25144
s	–	–	–	–	89.59	72.43	59.81	42.31	30.62	22.14

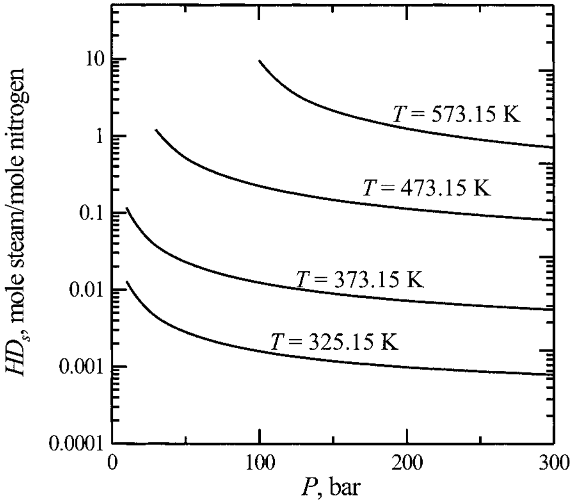

Fig. 5. Predictions of the humidity for the nitrogen-water system as a function of temperature and pressure with the model of this work.

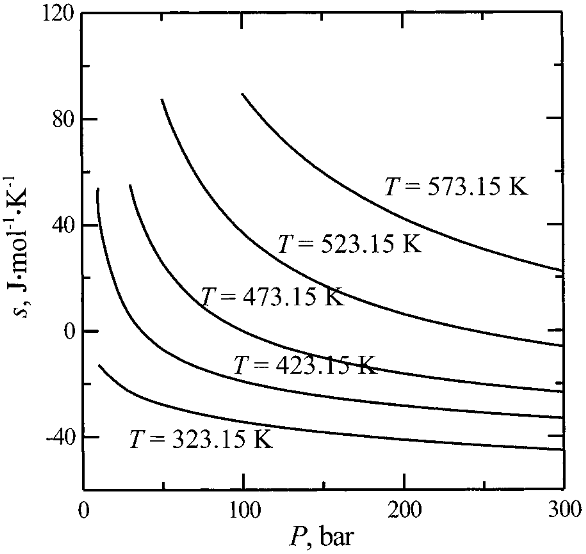

Fig. 6. Predictions of the entropy s for the nitrogen-water system as a function of temperature and pressure with the model of this work.

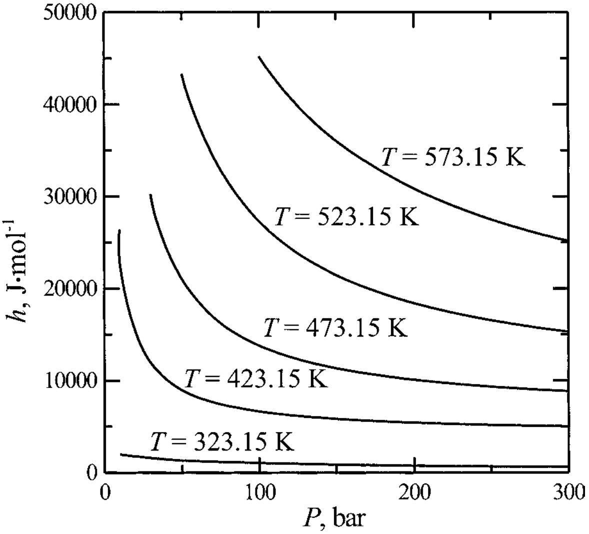

Fig. 7. Predictions of the enthalpy h for the nitrogen-water system as a function of temperature and pressure with the model of this work.

from 373.15 to 573.15 K and 10 to 300 bar. Figure 5 shows the effect of pressure on the saturated humidity for the nitrogen-water system at different temperatures. It is clear that at constant pressure, the humidity increases with an increase in temperature, while at constant temperature, the humidity decreases with an increase in pressure. The dependence of entropy on temperature and pressure is depicted in Fig. 6. Obviously, the entropy decreases with an increase in pressure, while it increases with an increase in temperature. The effect of temperature and pressure on enthalpy is shown in Fig. 7, which is similar to the case for humidity and entropy.

5. CONCLUSIONS

A new model was proposed to calculate the saturated thermodynamic properties of the nitrogen-water system. The comparisons of calculated results with experimental data show that the solubility of water in nitrogen vapor is in close agreement; the average relative deviation is less than 1%, up to 523.15 K and 200 bar. Furthermore, our calculated results appear to be more reliable than existing models.

Also, the comparisons of the solubility of nitrogen in liquid water calculated in this paper with experimental data show that the accuracy of our model is within the experimental error.

Moreover, the mixing excess enthalpy in the vapor phase was calculated and compared with experimental data. At atmospheric pressure and up to 423.15 K, the calculated results in the present work agree closely with experimental data; the average relative deviation is less than 2.4%. At higher temperatures and pressures, our results also agree well with experimental data up to 648 K and 126 bar.

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