Journal of Engineering Physics and Thermophysics, Vol. 68, No. 6, 1995

CALCULATION OF THE THERMODYNAMIC PROPERTIES OF NONPOLAR WET GASES AT ELEVATED PRESSURES

V. G. Beketov, V. A. Rabinovich, and
M. D. Rogovin

UDC 536.74:533.275+541.123.11

A calculation procedure and results for steam solubility in compressed gases and the thermodynamic properties of wet gases at elevated pressures using the Lennard-Jones potential and semi-empirical rules for combining potential parameters are presented.

For a long period of time the properties of wet gases were studied primarily at atmospheric pressure. The development of new technological processes and improvement of equipment in different branches of industry employing high pressures are confronting researchers with the problem of calculating the thermodynamic properties of wet gases at elevated pressures.

A procedure [1] developed by the present authors and certified at the All-Russian Scientific Research Center for Materials Standardization, Information, and Certification (ASRC MSIC) contains a detailed description of the methods used for calculating the equilibrium concentration of steam in a wet gas and the thermodynamic properties of a wet gas and includes estimates of the errors of calculated values within practically important ranges of state parameters: at temperatures of from 200 to 400 K and pressures of up to 10 MPa. We now present the results of the use of the procedure [1] for calculating the solubility of steam and the thermodynamic properties of a number of particular binary systems for which experimental data on wet oxygen, neon, krypton, and xenon are nonexistent.

As a mathematical model for describing the properties of wet gases in the above-indicated ranges of state parameters (at volumes larger than two critical volumes of the solvent gas) we propose a system of two equations: the virial equation of state of a wet gas and the equation of steam solubility in a wet gas [1] obtained on condition that the condensed phase is represented by practically pure water or ice (without crystallohydrates):

$$z = Pv/RT = 1 + B/v + C/v^2, \tag{1}$$

$$\ln (x_{\mathrm{eq}} P/P_{2s}) = \ln [z (T, P, x_{\mathrm{eq}})] - \ln [z_2 (T, P_{2s})] + \int_{P_{2s}}^{P} v_{2k}\, dP/RT + 2B_{22}/v_2'' - 2 [B_{12} + (B_{22} - B_{12}) x_{\mathrm{eq}}]/v'' - 3C_{112} (1 - x_{\mathrm{eq}})^2/(2v''2). \tag{2}$$

In these equations $v = v(T, P, x)$ is the mole volume of the wet gas at the prescribed temperature T, pressure P, and mole concentration x of the steam; the mole concentration can vary from zero to the equilibrium concentration x_{eq}. The virial coefficients of the binary system, i.e., of a wet gas, are represented by functions of the mole concentration x of the steam by the formulas:

$$B = B_{11} + 2 (B_{12} - B_{11}) x + (B_{11} - 2B_{12} + B_{22}) x^2, \tag{3}$$

All-Russian Scientific-Research Center for Materials Standardization, Information, and Certification, Moscow, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 68, No. 6, pp. 887-896, November-December, 1995. Original article submitted November 16, 1994.

$$C = C_{111} + 3\,(C_{112} - C_{111})\,x + 3\,(C_{111} - 2C_{112})\,x^2 + (3C_{112} - C_{111})\,x^3, \tag{4}$$

where B_{11} and C_{111} are the second and third virial coefficients of the pure solvent gas; B_{22} is the second virial coefficient of the steam, and B_{12} and C_{112} are the mixed virial coefficients. Since in the indicated range of temperatures the properties of steam are rather well (with a maximum error of 0.1% for the volume on the condensation line at $T = 400$ K) described by the equation of state with only the second virial coefficient, we ignore the effect of triple interactions between two molecules of water and one molecule of the solvent gas; therefore, expression (4) does not involve the terms C_{222} and C_{122}.

In the equation of solubility (2) P_{2s} is the pressure, v_2'' is the mole volume of saturated steam, v'' is the mole volume of the wet gas in a state of phase equilibrium with the condensed water (ice), and v_{2k} is the mole volume of the condensed water (ice).

It is evident that the solution of system (1) and (2) for determining x_{eq} and for subsequent calculation of the thermodynamic properties of a wet gas from the equation of state (1) requires knowledge of the functions $B_{22}(T)$, $P_{2s}(T)$, and $v_{2k}(T, P)$ and of the expression for isobaric heat capacity in a perfectly gaseous state $c_{p2}^0(T)$ for water and steam, $B_{11}(T)$, $C_{111}(T)$, and the expression for isobaric heat capacity in the perfectly gaseous state $c_{p1}^0(T)$ for the gas-solvent, as well as $B_{12}(T)$ and $C_{112}(T)$ for mixed virial coefficients. Moreover, for calculating the enthalpy and entropy in the perfectly gaseous state, it is necessary to know the values of the integration constants $h_2^0(T_0)$ and $s_{2T}^0(T_0)$ for steam and $h_1^0(T_0)$ and $s_{1T}^0(T_0)$ for the solvent gas.

All the functional dependences and constants necessary for calculating the properties of pure water and steam are given in [1]. In the present article we limit ourselves to the information about these properties that is required for calculating the thermodynamic properties of wet gases at known values of $x_{eq}(T, P)$ (given below).

The virial coefficients B_{11} and C_{111} for each solvent gas are obtained from the tabular P, v, T data [2, 3] for these gases in the temperature range of from 200 to 400 K at pressures of up to 10 MPa and volumes not less than two critical ones. These data are approximated by the virial equation of state

$$z_1 = Pv_1/RT = 1 + B_{11}/v_1 + C_{111}/v_1^2. \tag{5}$$

The mean square and maximum errors of the approximation of tabular P, n, T data are 0.002 and 0.008% for oxygen, 0.009 and 0.033% for neon, and 0.010 and 0.050% for krypton and xenon. We note that the validity region of the equation of state (1) does not lie outside the region of applicability of the equation of state (5) for the pure solvent gas.

The temperature dependences of the virial coefficients of pure solvent gases are represented by the polynomials:

$$B_{11} = \sum_j b_{1j}\tau^{-n_j}, \tag{6}$$

$$C_{111} = \sum_j c_{1j}\tau^{-m_j}, \tag{7}$$

where $\tau = T/100$ K.* The coefficients and exponents of polynomials (6) and (7) are presented in Table 1.

For steam we used the equation

$$z_2 = Pv_2/RT = 1 + B_{22}/v_2, \tag{8}$$

in which

$$B_{22} = \sum_{j=1}^{5} b_{2j}\tau^{-n_j}. \tag{9}$$

---

* This notation is retained below.

Polynomial (9) describes the function $B_{22}(T)$ [4] in the temperature range of from 200 to 400 K with a mean square error of 0.01% at a maximum error of 0.03%. The coefficients and exponents of this polynomial are given in Table 2.

Naturally, the chief problem is derivation of the mixed virial coefficients $B_{12}(T)$ and $C_{112}(T)$. We solved this problem for nonpolar gases on the assumption that the interaction of the solvent gas molecules with one another (1–1) and with the water molecules (1–1–2) is described by the Lennard-Jones (LJ) (12–6) potential; the interaction of steam molecules with one another (2–2), by the Stockmayer potential.

In this case, both the individual virial coefficients for the solvent gas ($i = j = 1$) and the mixed virial coefficients ($i = 1$, $j = 2$) can be calculated from the formulas

$$B_{ij}(T) = (2\pi N_A/3)\,\sigma_{ij}^3 B_{LJ}^*(T_{ij}^*), \tag{10}$$

$$C_{iij}(T) = (2\pi N_A/3)^2\,\sigma_{iij}^6 C_{LJ}^*(T_{iij}^*). \tag{11}$$

The reduced virial coefficients $B_{LJ}^*(T_{ij}^*)$ and $C_{LJ}^*(T_{iij}^*)$ for the LJ potential (12–6) are tabulated in [5] for a wide range of reduced temperatures $T_{ij}^* = kT/\varepsilon_{ij}$ and $T_{iij}^* = kT/\varepsilon_{iij}$ and are reapproximated in [1] with a mean square error of 0.001%. In formulas (10) and (11) and subsaquently, $N_A = 6.02205 \cdot 10^{23}$ 1/mole is the Avogadro number and $k = 1.3807 \cdot 10^{-23}$ J/K is the Boltzmann constant.

To determine the potential parameters σ_{112} and ε_{112} in (11), we used the expressions proposed in [6]:

$$\sigma_{112} = (\sigma_{11}\sigma_{12}^2)^{1/3},$$

$$(\varepsilon/k)_{112} = [(\varepsilon/k)_{11}\,(\varepsilon/k)_{12}^2]^{1/3}. \tag{12}$$

We determined the potential parameters σ_{11} and $(\varepsilon/k)_{11}$ for each of the solvent gases with the help of formulas (10) and (11) at $i = j = 1$* from the same P, v, T-data that were used for deriving the equation of state (5). The values of all the potential parameters and the confidence intervals of these values (for a 95% confidence coefficient) are given in Table 3.

With the available experimental data on steam solubility in a wet gas $\{x_{pi}^{\mathrm{exp}}\}$, it is possible to determine the mixed potential parameters σ_{12} and $(\varepsilon/k)_{12}$ by minimizing the corresponding quadratic functional with respect to x_{eq}, where the values of $x_{\mathrm{eq}}\,[T, P, \sigma_{12}, (\varepsilon/k)_{12}]$ are calculated by solving system (1) and (2) with application of formulas (10)-(12).

We employed a similar scheme for calculating the thermodynamic properties of a number of well-studied wet gases: air, nitrogen, argon, and others; at the same time, experimental data for such technologically and metrologically important gases as oxygen, neon, krypton, and xenon are nonexistent. In the last case, for determining the mixed potential parameters we suggest the semi-empirical rules of combination [1]:

$$\sigma_{12} = 0.5\,(\sigma_{11} + \sigma_{22})\,\xi^{-1/6},$$

$$(\varepsilon/k)_{12} = [(\varepsilon/k)_{11}\,(\varepsilon/k)_{22}]^{1/2}\,\xi^{-2},$$

$$\xi = 1 + 0.892\,[3\alpha_{11}t_{22}^*\,(\varepsilon_{22}/\varepsilon_{11})^{1/2}/2\pi N_A\sigma_{11}^3], \tag{13}$$

where α_{11} is the polarizability of the solvent gas molecules; σ_{22}, $(\varepsilon/k)_{22}$, and t_{22}^* are the parameters of the Stockmayer potential for water. The polarizability values α_{11} for the solvent gases are taken from the data of [7], while the values of the potential parameters σ_{22}, $(\varepsilon/k)_{22}$, and t_{22}^* are from the data of [5].

---

* It is assumed that $\sigma_{111} = \sigma_{11}$, $(\varepsilon/k)_{111} = (\varepsilon/k)_{11}$.

The legitimacy of using formulas (13) for nonpolar wet gases, including the four substances investigated in the present work, is confirmed by comparing the experimental results of [8-13] on the solubility of steam in nitrogen, air, and argon. These results are obtained by two methods: using the indicated data (optimization) and the rules of combination (13) (a model). Table 4 presents the relative mean square (σ) and maximum (δ) errors in the description of the data on x_{eq} for both methods as well as the ranges of the state parameters and references to the sources of the data.

The values of mixed potential parameters, determined by formulas (12) and (13), as well as the confidence intervals of these values (at a 95% confidence coefficient) for oxygen, neon, krypton, and xenon are given in Table 3.

For the convenience of practical calculations, we represent the temperature functions B_{12} and C_{112}, obtained from (10) and (11) in the form of polynomials:

$$B_{12} = \sum_j b_j \tau^{-n_j}, \tag{14}$$

$$C_{112} = \sum_j c_j \tau^{-m_j}. \tag{15}$$

The maximum errors of approximation of the values of B_{12} and C_{112} by polynomials (14) and (15) do not exceed 0.016 and 0.110%, respectively, which is by two orders of magnitude smaller than the confidence intervals of the values of the approximated quantities. The coefficients and exponents of polynomials (14) and (15) for each of the wet gases are presented in Table 5.

Tables 6-9 give the values of the equilibrium mole concentration of steam x_{eq} in oxygen, neon, krypton, and xenon within the ranges of state parameters of from 200 to 400 K and of from 0.1 to 10 MPa (with account for restrictions on the applicability of the equation of state (1) and the presence of the crystal hydrate phase) determined by solving system of Eqs. (1) and (2).

The isobaric heat capacity of oxygen in a perfectly gaseous state is represented by a polynomial of the form

$$c^0_{p1}/R = \sum_{j=1}^{8} c_{1j} \tau^{n_j}, \tag{16}$$

which without loss of accuracy reproduces the tabular data of [2] in the temperature range of from $T_0 = 100$ K to $T = 400$ K, while the isobaric heat capacity in a perfectly gaseous state for steam is represented by a polynomial of the form

$$c^0_{p2}/R = \sum_{j=1}^{4} c_{2j} \tau^{m_j}, \tag{17}$$

which approximates the tabular data of [4] in the temperature range of from 100 to 500 K with a mean-square error of 0.026% at a maximum error of 0.1%. The coefficients and exponents of polynomials (16) and (17) are given in Table 10. For such inert gases as neon, krypton, and xenon $c^0_{p1}/R = 2.5$. The integration constants $h^0_2(T_0)$, $s^0_{2T}(T)$ for steam and $h^0_1(T_0)$, $s^0_{1T}(T_0)$ for the solvent gases are given in Table 11.

On the basis of the obtained equations of state of the form (1) for four wet gases in the indicated ranges of temperatures and pressures at a relative moisture content $\varphi = x/x_{eq}$ of from 0.2 to 1.0 and using the well-known integrodifferential equations of thermodynamics, we calculated the tables of values of the specific volume, enthalpy, entropy, isobaric heat capacity, the steam partial pressure, mass moisture content, and of absolute humidity. These tables have been certified by the ASRC MSIC of the State Standard of the Russian Federation as recommended reference data [14].

An estimate of the errors in the calculated values of the above-indicated thermodynamic properties was made with the aid of covariance matrices of the parameters of computational equations and error-transport theory by the formulas given in [1] for mole quantities. The relative errors in the specific and mole thermodynamic properties are virtually the same, since the relative errors in the mole mass of a wet gas is less than 0.01%.

Tables 12 and 13 present the ranges of the relative errors (the errors were calculated at a 95% confidence coefficient) in the thermodynamic properties of four wet gases with indication of the parameters of the points at which these errors are maximal.

The work was carried out under a grant (93-02-16532) from the Russian Fundamental Research Fund.

TABLE 1. Coefficients and Exponents of Polynomials (6) and (7) for the Virial Coefficients B_{11} and C_{11} of Solvent Gases

Gas	j	n_j	b_{1j}, cm^3/mole	m_j	c_{1j}, (cm^3/mole)^2
Oxygen	1	0	37,725	0	740,00
	2	1	−135,37	2	3058,7
	3	2	−70,972	4	1988,7
	4	4	−30,389		
Neon	1	0	13,68	0	264,45
	2	2	−22,26		
Krypton	1	0	50,388	0	1859,87
	2	1	−275,866	2	−35140,7
	3	3	−221,142	3	178560
	4			4	−187187
Xenon	1	0	61,96	0	2204,1
	2	1	−486,26	2	33837
	3	3	−781,87		

TABLE 2. Coefficients and Exponents of Polynomial (9) for B_{22} of Steam

j	n_j	b_{2j}, cm^3/mole
1	1	197,258
2	2	−4018,29
3	5	−323492
4	6	$1,39840 \cdot 10^6$
5	7	$-2,89960 \cdot 10^6$

TABLE 3. Values of the Potential Parameters of Intermolecular Interaction

Interacting molecules		σ, Å	ε/k, K	a_{11}, Å^3	t^*_{22}
H_2O–H_2O	(22)	2,65 ± 0,19	380 ± 19		1,2
O_2–O_2	(11)	3,440 ± 0,009	118,18 ± 0,28	1,60	
O_2–H_2O	(12)	3,016 ± 0,086	188,67 ± 3,76		
O_2–O_2–H_2O	(112)	3,151 ± 0,060	161,43 ± 2,15		
Ne–Ne	(11)	2,717 ± 0,005	33,18 ± 0,28	0,398	
Ne–H_2O	(12)	2,659 ± 0,086	100,50 ± 2,08		
Ne–Ne–H_2O	(112)	2,678 ± 0,058	69,46 ± 0,98		
Kr–Kr	(11)	3,694 ± 0,009	164,40 ± 0,46	2,48	
Kr–H_2O	(12)	3,140 ± 0,086	221,00 ± 4,38		
Kr–Kr–H_2O	(112)	3,314 ± 0,061	200,24 ± 2,65		
Xe–Xe	(11)	4,172 ± 0,061	218,30 ± 4,77	4,01	
Xe–H_2O	(12)	3,377 ± 0,092	255,45 ± 5,39		
Xe–Xe–H_2O	(112)	3,624 ± 0,068	242,41 ± 3,84		

TABLE 4. Results of Calculation of the Equilibrium Mole Concentration of Steam x_{eq} in Wet Gases According to Model (13) and Experimental Data (Optimization)

Gas	Model		Optimization		Range of parameters, t, °C, at $P \leq 10$ MPa	Reference
	σ, %	δ, %	σ, %	δ, %		
Nitrogen	3,1	8,1	2,8	7,7	−50...150	[8–10]
Air	2,8	7,5	2,1	5,8	−50...70	[8, 11, 12]
Argon	2,2	8,1	1,6	5,9	−40...100	[9, 13]

TABLE 5. Coefficients and Exponents of Polynomials (14) and (15) for the Mixed Virial Coefficients B_{12} and C_{112} of Wet Gases

Wet gases	j	n_j	b_j, cm³/mole	m_j	c_j, (cm³/mole)²
Oxygen	1	0	25,694	0	545,168
	2	1	−145,422	1	−830,458
	3	2	−125,780	2	3973,83
	4	5	−25,6458	4	8411,01
	5			5	−23193,04
Neon	1	0	15,34208	0	131,3526
	2	1	−34,50560	1	407,9489
	3	2	−83,16181	2	−1304,612
	4	3	84,76602	3	2189,682
	5	4	−47,49904	4	−1166,812
Krypton	1	0	28,858	0,5	86806,5
	2	1	−188,966	1	−765465
	3	2	−219,100	1,5	2795924
	4	3	79,6379	2	−5202249
	5	4	−117,823	2,5	4943515
	6			3	−1916743
Xenon	1	0	39,85368	0,5	563225
	2	1	−318,4079	1	−5070722
	3	2	−162,5144	1,5	18484890
	4	3	−226,5479	2	−34026340
	5			2,5	31752240
	6			3,0	−12053340

TABLE 6. Values of the Equilibrium Mole Concentration of Steam in Wet Oxygen, $x_{eq} \cdot 10^6$

T, K	P, MPa							
	0,1	0,5	1,0	2,0	4,0	6,0	8,0	10,0
200	1,640	0,338	–	–	–	–	–	–
220	26,72	5,48	2,83	1,51	–	–	–	–
240	274,2	56,0	28,7	15,1	8,4	–	–	–
260	1967,3	400,3	204,5	106,8	58,4	43	–	–
280	9957	2020	1028	533	287	206	167	144
300	35510	7190	3650	1880	1000	710	570	490
320	105950	21420	10860	5580	2950	2070	1640	1390
340	273300	55250	27960	14320	7510	5250	4140	3470
360	624230	126540	63980	32700	17100	11900	9300	7800
380	–	262400	132700	67700	35200	24400	19000	15800
400	–	499330	253400	129300	67100	46400	36000	29900

TABLE 7. Values of the Equilibrium Mole Concentration of Steam in Wet Neon, $x_{eq} \cdot 10^6$

T, K	P, MPa							
	0,1	0,5	1,0	1,5	2,0	3,0	4,0	5,0
200	1,6327	0,3311	0,1684	0,1142	0,0872	0,0601	0,0466	0,0386
220	26,633	5,3871	2,7317	1,8468	1,4046	0,9627	0,7422	0,6101
240	273,47	55,209	27,929	18,838	14,293	9,751	7,483	6,124
260	1962,8	395,68	199,80	134,52	101,88	69,26	52,96	43,19
280	9938,2	2000,6	1008,4	677,7	512,4	347,1	264,5	215,0
300	35454	7131,0	3590,5	2410	1820	1231	935,6	758,8
320	105825	21275	10703	7179	5417	3656	2775	2247
340	273112	54934	27621	18515	13962	9409	7132	5767
360	624125	125982	63340	42442	31989	21535	16308	13172
380	–	261650	131700	88252	66505	44740	33860	27320
400	–	498723	252020	169060	127450	85746	64860	52320

TABLE 8. Values of the Equilibrium Mole Concentration of Steam in Wet Krypton, $x_{eq} \cdot 10^6$

T, K	P, MPa							
	0,1	0,5	1,0	1,5	2,0	3,0	4,0	5,0
200	1,6409	–	–	–	–	–	–	–
220	26,738	–	–	–	–	–	–	–
240	274,34	56,12	–	–	–	–	–	–
260	1968,0	401,0	205,3	–	–	–	–	–
280	9960,0	2023,3	1031,8	701,8	537,2	373,5	–	–
300	35517	7199	3661	2483	1895	1309	1018	846
320	105966	21447	10883	7364	5606	3853	2982	2463
340	273326	55300	28015	18923	14382	9848	7590	6240
360	624243	126630	64090	43240	32820	22410	17220	14120
380	–	262520	132920	89620	67960	46310	35500	29040
400	–	499440	253630	171080	129700	88280	67580	55180

TABLE 9. Values of the Equilibrium Mole Concentration of Steam in Wet Xenon, $x_{eq} \cdot 10^6$

T, K	P, MPa							
	0,1	0,5	1,0	1,5	2,0	3,0	4,0	5,0
280	9956,3	–	–	–	–	–	–	–
300	35507	7188	3650	2471	1882	–	–	–
320	105945	21422	10856	7337	5579	3826	2954	2438
340	273296	55250	27960	18870	14330	9796	7540	6200
360	624228	126550	64000	43150	32730	22320	17140	14050
380	–	262430	132800	89490	67830	46190	35400	28960
400	–	499380	253510	170930	129550	88140	67470	55120

TABLE 10. Coefficients and Exponents of Polynomials (16) and (17) for Perfectly Gaseous Isobaric Heat Capacity of Oxygen and Steam

j	Oxygen		Steam	
	n_j	c_{1j}	m_j	c_{2j}
1	0	3,520946	0	4,00706806
2	1	$-5,859106 \cdot 10^{-2}$	2	$-8,22462863 \cdot 10^{-4}$
3	2	$6,130341 \cdot 10^{-2}$	5	$3,24333221 \cdot 10^{-4}$
4	3	$-2,354807 \cdot 10^{-2}$	6	$-5,00436516 \cdot 10^{-5}$
5	6	$1,818934 \cdot 10^{-3}$		
6	7	$-8,161384 \cdot 10^{-4}$		
7	8	$1,359769 \cdot 10^{-4}$		
8	9	$-8,122845 \cdot 10^{-6}$		

TABLE 11. Integration Constants for Calculating the Enthalpy and Entropy in a Perfectly Gaseous State of Oxygen [2], Neon, Krypton, Xenon [3], and Steam [1] at Temperature $T_0 = 100$ K*

Gas	i	h_i^0, J/mole	s_{iT}^0, J/(mole·K)
Oxygen	1	11718	173,19
Neon	1	3998,6	123,51
Krypton	1	13270	141,27
Xenon	1	17935	146,87
Steam	2	50676	148,80

*The state of a crystal at 0 K is taken as the start of the reading.

TABLE 12. Ranges of Relative Errors in the Calculated Values for the Equilibrium Mole Concentration x_{eq}, Steam Partial Pressure $\bar{p}_2$, Mass Moisture Content d, and Absolute Humidity a

Wet gases	δx_{eq}, %				$\delta \bar{p}_2$, %				δd, %				δa, %			
	min	max	P	T	min	max	P	T	min	max	P	T	min	max	P	T
Oxygen	0,01	3,5	10	280	0,04	2,2	10	320	0,01	2,3	10	320	0,04	2,3	10	320
Neon	0,01	0,9	5	200	0,07	0,20	4	300	0,01	0,17	5	320	0,07	0,20	4	300
Krypton	0,01	2,2	5	300	0,07	2,2	5	300	0,01	2,2	5	300	0,07	2,2	5	300
Xenon	0,01	3,6	5	320	0,08	3,6	5	320	0,02	3,6	5	320	0,08	3,6	5	320

TABLE 13. Ranges of the Relative Error in the Calculated Values of the Thermodynamic Properties of Wet Gases

Wet gases	δv, %				δh, %				δs, %				δc_p, %			
	min	max	P	T	min	max	P	T	min	max	P	T	min	max	P	T
Oxygen	0,04	0,09	0,5	400	0,03	0,07	10	400	0,01	0,03	0,5	400	0,1	0,9	0,5	400
Neon	0,07	0,10	5	400	0,04	0,10	0,1	200	0,04	0,07	0,1	200	0,5	1,1	0,5	400
Krypton	0,07	0,11	5	400	0,04	0,11	5	400	0,03	0,06	5	400	0,5	1,1	0,5	400
Xenon	0,08	0,45	5	320	0,05	0,15	5	400	0,04	0,11	5	320	0,6	1,6	5	320

NOTATION

T, temperature; P, pressure; R, universal gas constant; z, compressibility factor; B, C, second and third virial coefficients; σ, ε/k, t^*, parameters of the potentials of intermolecular interaction; x, mole concentration of steam; v, mole volume; h, enthalpy; s, entropy; c_p, isobaric heat capacity; $\bar{p}_2$, partial pressure of steam in a wet gas; d, mass moisture content; a, absolute humidity.

REFERENCES

1. V. G. Beketov, V. A. Rabinovich, and M. D. Rogovin, Calculation of the Thermodynamic Properties of Wet Gases in Parameter Ranges of from 200 to 400 K and from 0.1 to 10 MPa. Procedure of GSSSD. MR 99-93 [in Russian], Moscow (1993), Deposited at ASRC MSIC of the State Standard of Russia.
2. V. V. Sychev, A. A. Vasserman, A. D. Kozlov, et al., Thermodynamic Properties of Oxygen [in Russian], Moscow (1981).
3. V. A. Rabinovich, A. A. Vasserman, V. I. Nedostup, and L. S. Veksler, Thermophysical Properties of Neon, Argon, Krypton, and Xenon [in Russian], Moscow (1976).
4. L. Haar, J. S. Gallagher, and G. S. Kell, NBS/NRC Steam Table (1984).
5. J. Hirschfelder, Ch. Curtiss, and B. Bird, Molecular Theory of Gases and Liquids [Russian translation], Moscow (1961).
6. E. Mason and T. Spurling, Virial Equation of State [Russian translation], Moscow (1972).
7. H. Landolt, R. Börnstein, Zahlenwerte und Funktionen, Springer Verlag, Bd. 1, Teil 1, 3, Berlin (1951).

8. M. B. Iomtev, V. G. Piskunov, V. L. Kadzhaev, et al., Gas-Ice Systems. Solubility of Ice in Nitrogen and Air at Temperatures of from −50°C to −2°C and Pressures of from 0.2 MPa to 61.0 MPa. RSD Tables, GSSSD R 88-84 [in Russian], Moscow (1984), Deposited at VNIIKI 10.12.84, No. 220.
9. M. Rigby and G. M. Prauznitz, J. Phys. Chem., 72, No. 1, 330-336 (1968).
10. A. Yu. Namiot, Solubility of Gases in Water [in Russian], Moscow (1991).
11. R. W. Hyland and A. Wexler, J. Res. NBS (US) Phys. and Chem., 77A, No. 1, 133-177 (1973).
12. R. W. Hyland, J. Res. NBS (US) Phys. and Chem., 79A, No. 4, 551-560 (1975).
13. M. B. Iomtev, V. G. Piskunov, V. L. Kadzhaev, and G. P. Gubanova, Gas-Ice System. Solubility of Ice in Argon at Temperatures of from −40°C to −2°C and Pressures of from 0.2 MPa to 35.5 MPa. RSD Tables, GSSSD R 178-86 [in Russian], Moscow (1986), Deposited at VNIIKI 20.04.87, No. 340.
14. V. G. Beketov, V. A. Rabinovich, and M. D. Rogovin, Wet Gases: Oxygen, Neon, Krypton, Xenon, Ethane. Thermodynamic Properties at Temperatures of from 200 to 400 K, at Relative Moisture Contents of from 0.2 to 1, and Pressures of up to 10 MPa. RSD Tables, GSSSD R 439-94 [in Russian], Moscow (1994), Deposited at ASRC MSIC 14.09.94, No. 123.