Taking into account that $\mu_f + \mu_b + \mu_p = 1$, $\rho_p \approx 0$, it can be written in the form

$$\rho_{den} = \mu_f \rho_f + (1 - \mu_f - \mu_p)\rho_b. \tag{10}$$

We hence find μ_p:

$$\mu_p = \frac{\mu_f \rho_f + (1 - \mu_f)\rho_b - \rho_{den}}{\rho_b}. \tag{11}$$

The results of computations for one of the specimens under investigation by using (11) show that the maximal material porosity corresponds to a thickness with minimal density.

The density of a dry specimen determined by using a tomograph is $\rho_{den} = 1{,}110 \cdot 10^{-3}$ kg/m³. Let us assume that all the pores in the specimen are filled with water. Then after computations by using (8), we obtain $\rho_{den} = 1{,}314 \cdot 10^{-3}$ m. Under ordinary conditions, specimens are in the equilibrium state with the surrounding air, consequently

$$1{,}110 \cdot 10^{-3} \leqslant \rho_{den} \leqslant 1{,}314 \cdot 10^{-3} \ (\mathrm{kg/m^3}).$$

The limits of variation in the density values will be different under other conditions for conducting the experiment.

NOTATION

I_0, intensity of incident radiation on the specimen surface; L, quantity of approximating points; n, degree of the polynomial; μ_f, volume content of bonding filler; μ_b, μ_p, volume contents of binder and pores; ρ_f, ρ_b, filler and binder densities, respectively; ρ_p, air density in the pores; and k, number of repetitions.

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BASE DATA FOR ANALYSIS OF WATER VAPOR RADIATION CHARACTERISTICS

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UDC 536.3

Arrays of parameters are recommended for a narrowband spectrum model which represents the base data for analyzing the absorptivity, emissivity, and their derivatives for water vapor characteristics.

INTRODUCTION

Computations of the emissivity and absorptivity of water vapor are based on Hottel observations in the complete spectrum. Spectral data in a semiempirical treatment have appeared comparatively recently. Formulas are proposed in [1, 2] for the absorption in spectrum bands by utilization of a broadband model and an exponential envelope. Another base in the handbook [3] and its sources is represented in the form of two parameter arrays for a narrowband Goode model in 25 cm^{-1} wide spectrum intervals. Discrepancies in the results of integrated and spectral data were noted in a number of papers, for instance, in [4] and then in [5], where an Edwards computation was selected as base as being simpler as compared with the utilization of the Goode model. In this paper, on the other hand, as in Leckner, preference is given to two parameter arrays of a narrow band model. This base is more detailed, reliable, and ob-

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TABLE 1. Directional Water Vapor Emissivity for $P_* = P = 1$ atm, $p = 0$, with Nitrogen Dilution of the Vapor

x, cm•atm	T, K					
	600	1000	1500	2000	2500	3000
0,2	0165	0100	0047	00233	00130	—
	0180	0096	—	—	—	—
	0177	0096	0045	00235	00136	00083
	0183	0097	0046	00235	00136	00083
1,0	049	035	0200	01130	0066	0041
	055	034	0195	0110	0067	—
	051	035	0196	0110	0066	0040
	053	036	0200	0110	0065	0040
10	155	135	106	078	052	0345
	176	137	106	077	052	—
	158	136	106	077	052	0341
	164	144	114	079	052	0337
100	350	360	335	305	245	185
	385	345	321	297	245	—
	342	345	323	297	248	184
	353	362	346	311	252	185
1000	560	620	660	680	620	500
	610	620	630	—	—	—
	539	610	628	663	617	517
	546	618	639	658	603	504

Remark. The upper number in each cell (all after the decimal) is taken from the nomogram in [3], the second from the nomogram in [10], we computed the third from the parameter arrays set up, and the fourth was obtained by replacing the second array by computations using (1).

tained for temperatures to 3000°K and permits the calculation of all the radiation characteristics of interest in thermal engineering.

BASE SPECTRAL DATA

The initial array of the first parameter $\bar{k}_i$ is published in [6] in a spectrum interval to 11,000 cm^{-1} but was then reexamined, changed somewhat in [7], limited to values to 9300 cm^{-1}, and used to construct the nomograms published in [3, 8]. The second parameter array, $1/\bar{d}_i$, where $\bar{d}$ is the mean spacing between lines, cm^{-1}, is published in [3] in the 1150-7500 cm^{-1} interval. The origin of the data for $\omega < 1150$ and $\omega > 7500$ cm^{-1} is not clear. In a report [9], Leckner indicates his sources of the parameters in detail. Precisely in this situation should the discrepancies between his results [9, 10] and the nomograms in [3, 8] be sought. The difference in our results presented below is also concealed in this. We did not take all the Leckner sources and introduced supplements to the arrays in [3, 8]. Namely, the first parameter array to 9300 cm^{-1} is taken from [3] as in Leckner in [11]. But he supplemented to 11,000 cm^{-1} from data in [6]. The same addition was apparently made in [12]. The $1/\bar{d}_i$ array in the 1150-7500-cm^{-1} interval is taken according to [3, 10]. The parameters for the purely rotational band in the 50-1125-cm^{-1} interval are borrowed from [11]. The interval $\omega = 0 - 50$ cm^{-1} was not taken into account in the calculations. For $\omega > 7500$ cm^{-1} the parameter was computed from an approximate formula we recommended in simplified computations for the whole spectrum

$$\begin{gathered} \lg(1/d) = A + B(\omega/1000), \\ A = -0{,}58 + 0{,}8\Theta - 0{,}08\Theta^2;\ B = -0{,}31 + 0{,}266\Theta - 0{,}044\Theta^2; \\ \Theta \equiv T/1000;\ d,\ \mathrm{cm}^{-1}. \end{gathered} \tag{1}$$

A nomogram in [7] is the basis of the formula.

ANALYSIS

We present a complete record of the set of formulas to compute the directional absorptivity of an isothermal volume of water vapor at a temperature T for an incident flux with a black spectrum at the temperature T_0. It is important to indicate the coefficients taken:

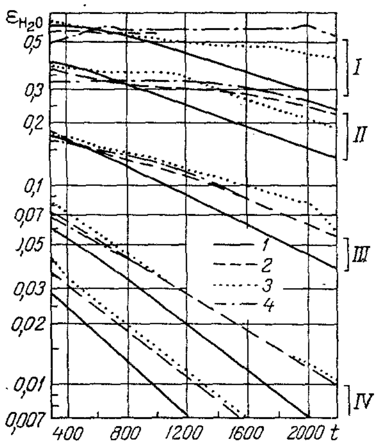

Fig. 1

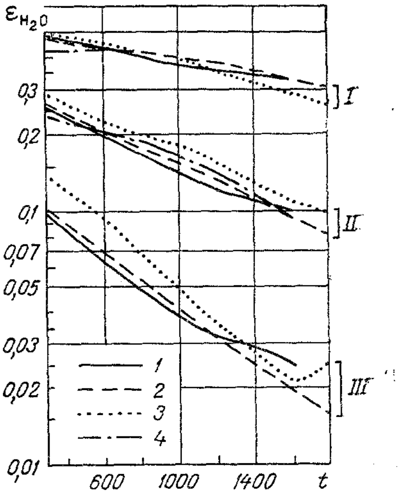

Fig. 2

Fig. 1. Water vapor emissivity for infinite dilution by nitrogen ($p = 0$, $P_* = P = 1$ atm): 1) from the Nevskii nomogram [13]; 2) from the Leckner [10] nomogram; 3) from the weighted sum of grey gases [5] with Edwards [1, 2] base values; 4) from our computation by replacing the second-parameter array by a computation using (1). Optical thicknesses: I) 6 m•atm; II) 0.8; III) 0.1; IV) 0.015. t, °C.

Fig. 2. Pure water vapor emissivity ($P = p = 1$ atm): 1) from Schmidt data in the Leckner report [9]; 2) from the Leckner [10] nomogram; 3) from the weighted sum of grey gases [5] with Edwards [1, 2] base values; 4) from our analysis with the second-parameter array replaced by a computation using (1). Optical thicknesses: 1) 0.8 m•atm; II) 0.1; III) 0.015.

$$a_0 = \frac{\pi\Delta\omega}{\sigma T_0^4} \sum_{i=1}^{439} I_{0i}(T_0)\,\varepsilon_i(T;\ x), \tag{2}$$

$$\Delta\omega = 25\ \text{cm}^{-1};\quad \sigma = 5{,}67\cdot 10^{-8}\ \text{W/(m}^2\cdot\text{K}^4);\qquad \pi I_{0i} = \frac{37{,}412\,(\omega_i/1000)^3}{\exp(1{,}4388\cdot\omega_i/T_0) - 1},$$

$$\varepsilon_i = 1 - \exp\left(-\frac{\bar{k}_i u}{\sqrt{1 + \bar{k}_i u/(4\bar{a})}}\right),\quad a = b/\bar{d};\quad u = x\cdot 273/T;\quad x,\ \text{cm}\cdot\text{atm}; \tag{3}$$

$$b = b_0 P_* \sqrt{273/T};\quad b_0 = 0{,}09\ \text{cm}^{-1};\quad P_* = P(1 + 4{,}89c\sqrt{273/T});\quad c = p/P.$$

The emissivity is obtained as a particular case: $a_0 \to \varepsilon$ as $T_0 \to T$. The rule of left rectangles is taken in the sum (2). The arrays of parameters $\bar{k}_i$ and $1/\bar{d}_i$ contain 6146 numbers for $\omega_i = (i + 1)\cdot 25$ cm^{-1}, i = 1, 2, ..., 439, and 7 values of the temperatures.

RESULTS

Values of the emissivity taken from the nomograms in [3, 10] and computed by the data arrays are compared in Table 1. Also presented are results from the complete replacement of the second array by (1). The existing moderate discrepancies are explained by the different arrays taken. For instance, a slight bending upward is seen in the 1000-2000°K interval for large optical thicknesses on the curves in [3, 8]. We do not have it, as in [10]. For T = 600°K, on the other hand, our data is closer to [3, 8] as compared with [10].

As the temperature rises the maximum of the Planck function shifts towards an increase in the wave number. Correspondingly, the influence of the additional number arrays in the 9300-11,000-cm^{-1} interval appears for sufficiently high thicknesses. They are especially noticeable in Table 1 for T = 3000°K and x = 1000 cm•atm.

The emissivities according to main sources are compared in Fig. 1 in the traditional representation with infinitely high dilution of the vapor by nitrogen. Substantial lowering of the data in the effective nomograms is seen. To a major degree the lines of our computation merge with the Leckner lines. It is impossible to reflect the differences in the arrays in such a graph, whereupon the table is given. The emissivities of pure water vapor are compared in Fig. 2. In contrast to Hottel, the Schmidt observations that are integral in the spectrum are in satisfactory agreement with the data of spectral methods. The arrays mentioned above are recommended as bases for all the radiation characteristics of water vapor.

NOTATION

a_0, directional absorptivity of a gas with temperature T for incident flux with a black spectrum at the temperature T_0; ε, its emissivity; b, line halfwidth, cm^{-1}; $\bar{d}$, mean spacing between halfwidths; referred to the 273°K temperature; x = p, cm·atm; ℓ, gas thickness, cm; p, P, P_*, partial, total, and effective pressures, atm; I_0, Planck intensity, $cm \cdot W/(m^2 \cdot sr)$; T, temperature, °K; and ω, wave number, cm^{-1}.

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