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A Method for Calculating the Absorption Properties of Triatomic Gases

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Abstract—Formulas are proposed for the steam and carbon dioxide absorption coefficients, which are widely used in calculations of radiant heat transfer in industrial ovens and furnaces and containing empirical correction multipliers approximated over the beam length by logarithmic polynomials the coefficients of which are interpolated with respect to gas temperature. Generally, the error in the steam and carbon dioxide absorption capacities calculated using these formulas does not exceed 3%, which is quite acceptable in engineering calculations of radiant heat transfer. It is shown that the absorption capacity of a mixture of steam and carbon dioxide calculated using the exponential function of the total absorption coefficient does need correction for mutual absorption of beam energy by the components of medium.

Keywords: steam, carbon dioxide, absorption coefficient, absorption capacity, approximation of absorption coefficients

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Radiant heat transfer in industrial ovens and furnaces depends to a considerable extent on the radiation properties of triatomic gases contained in fuel combustion products. Experimental values of steam and carbon dioxide absorption capacities are as a rule published in graphic or tabular form, which is not quite suitable for modern computer programs. Therefore, a need arises to develop a sufficiently accurate analytical method for calculating the absorption coefficients for these gases.

Gurvich–Mitor's comparatively simple formula [1] is widely known; however, the temperature range of its application was limited from the very beginning, and the error corresponded to degraded accuracy of the experimental data that were available. Later on, more accurate measurements of the "smoothed" coefficients k_i in the narrow ith parts of the spectrum, were carried out, which can be regarded as Planck's spectral absorption coefficients [2], and a technique was developed using which the integral absorption coefficients averaged over the spectrum can be calculated from these spectral absorption coefficients [3].

The absorption coefficients α_i, m^{-1}, of triatomic gas in narrow parts of the spectrum are calculated from the following formula [3]:

$$\alpha_i = \frac{k_i p_g (273/T)}{\sqrt{1 + k_i p_g l (273/T)/(4 b_i/d_i)}}, \qquad (1)$$

where p_g is the partial pressure of triatomic gas (in fractions of full pressure); T is the thermodynamic temperature of medium, K; l is the radiating layer effective thickness, m; b_i is the average half-width of spectral lines, cm^{-1}; and d_i is the average distance between the spectral lines in a narrow part of the spectrum, cm^{-1} (according to the wave numbers).

In [3], a formula for determining the average half-width of steam spectral lines was recommended, which takes the following form at the full pressure of gases equal to atmospheric pressure:

$$b = 0.09\sqrt{273/T}\left(1 + 4.89 p_{H_2O}\sqrt{273/T}\right), \qquad (2)$$

where p_{H_2O} is the volume fraction of steam in a mixture of gases, which determines its partial pressure.

The average distance d_i between the spectral lines of steam is also calculated according to the recommendations given in [3]. The absorption coefficients α_i determined from expression (1) in narrow intervals of wave numbers are subsequently averaged over the spectrum.

This procedure was used in [3] to calculate the basic values of averaged integral absorption coefficients for steam at six values of gas temperature from 600 to 3000 K. A large amount of computations and, what is most important, lack of experimental data for intermediate values of temperature can be regarded as shortcomings of such an approach. We consider it advisable to find a method of determining absorption coefficients for steam that would be free from these drawbacks.

A METHOD FOR CALCULATING THE RADIATION PROPERTIES OF STEAM

In [4], it was proposed to use the structure of formula (1) directly for calculating the absorption coeffi-