first kind. In physical respects, the singularities established are a result of the intrinsic volume emission of the substance, which results in the appearance of certain effective volume sources in the plate which are variable in thickness and in time, but in mathematical respects are a result of the nonlinearity of the initial equations.

NOTATION

τ, time; T, temperature; T_e, environment temperature; h_e, coefficient of convective heat transfer; x, coordinate; d, layer thickness; α, coefficient of absorption of the substance; n, refractive index; B, surface emission density of blackbody; C_ρ, volume specific heat; K, coefficient of heat conduction; λ, emission wavelength; (λ_t), wavelength band where the material is partially transparent; (λ_0), wavelength band where the material is opaque; ε, surface emissivity in the band (λ_t); $R(\theta)$, coefficient of reflection from the inner surfaces of the layer; Φ^+, intensity of beams making acute angles θ with the internal normal to the surface $x = 0$; Φ^-, intensity of beams making acute angles with the internal normal to the surface $x = d$; m, heating rate; ξ, dimensionless coordinate; q, heat flux.

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HEAT-TRANSFER RADIATION IN A SELECTIVE GAS FLOW IMPINGING ON A HEATING SURFACE

M. M. Mel'man

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The problem of computing the heat-transfer radiation in a selective gas flux impinging on a heating surface is examined on the basis of the Curtis–Godson approximation and a statistical model of the absorption band. Numerical results are presented for carbon dioxide. Their comparison with the results of a computation on the basis of a grey model showed a substantial difference in the magnitudes of the resultant fluxes on the boundary surfaces.

Heat-transfer radiation in a gas flow impinging on a heating surface has been investigated in [1–4]. The medium [1-3] was hence assumed grey, while the heat transfer in carbon dioxide, whose absorption spectrum was borrowed from [5] in the words of the authors, was examined in [4].

In this paper the heat transfer in a selective gas flow is examined on the basis of a statistical model of the absorption band and the Curtis–Godson approximation.

A gas layer of thickness l is bounded by black surfaces 1 and 2 with the given temperatures T_{C1} and T_{C2}. The gas flow, with the temperature T_0, enters at surface 1 and moves toward surface 2 (Fig. 1).

This is a one-dimensional problem, the process is stationary, the pressure is constant, and we neglect the temperature dependence of the specific heat of the gas and the heat conduction.

The energy equation and the boundary condition are written in dimensionless form as follows:

All-Union Scientific-Research Institute of Metallurgical Thermal Engineering, Sverdlovsk.

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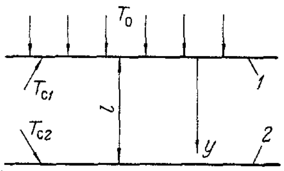

Fig. 1. Physical model and coordinate system.

$$\frac{d\theta}{d\bar{y}} + \frac{\pi_1}{2}\frac{d\bar{E}}{d\bar{y}} = 0, \tag{1}$$

$$\theta(0) = 1, \tag{2}$$

where $\theta = T/T_0$, $\bar{y} = \bar{y}/l$, $\bar{E} = E/\sigma_0 T_0^4$ are the dimensionless temperature, coordinate, and flux density of the resultant radiation, $\pi_1 = 2\sigma_0 T_0^3/c_p \rho v$;

$$\theta + \frac{\pi_1}{2}\bar{E} = \text{const} \tag{3}$$

is the integral of (1), and

$$\bar{E} = \frac{30}{\pi^4}\int_0^\infty \Big[\frac{x^3}{\exp(x/\theta_{c1}) - 1}\int_0^1 \tau_x(\bar{y}l/\mu)\mu d\mu - \frac{x^3}{\exp(x/\theta_{c2}) - 1} \times$$

$$\times \int_0^1 \tau_x(l(1-\bar{y})/\mu)\mu d\mu + \int_0^{\bar{y}} \frac{x^3}{\exp(x/\theta(z)) - 1}\frac{d}{dz}\left(\int_0^1 \tau_x(l(\bar{y}-z)/\mu)\mu d\mu\right)dz -$$

$$-\int_{\bar{y}}^1 \frac{x^3}{\exp(x/\theta(z)) - 1}\frac{d}{dz}\left(\int_0^1 \tau_x(l(z-\bar{y})/\mu)\mu d\mu\right)dz\Big]dx, \tag{4}$$

where $x = hc\nu/kT_0$; $\theta_{c1} = T_{c1}/T_0$; $\theta_{c2} = T_{c2}/T_0$; τ_x is the transmission averaged over a narrow spectrum band.

The statistical model of a band [6] and the Curtis–Godson approximation [6–8] are used to evaluate τ_x.

If the probability density of the line intensity distribution has the form of an exponential, then

$$\ln \tau_x(y/\mu) = -\frac{1}{\mu}\int_0^y \tilde{K}_x(y)\,dy / \left(1 + \frac{\delta}{\pi\bar{\alpha}\mu}\int_0^y \tilde{K}_x(y)\,dy\right)^{1/2}.$$

Here $\tilde{K}_x$ is the gas coefficient of absorption averaged over the narrow spectrum band, δ is the mean spacing between lines in the band, and

$$\bar{\alpha} = \int_0^y \alpha(y)\tilde{K}_x(y)\,dy / \int_0^y \tilde{K}_x(y)\,dy,$$

where α is the line half width of the band.

Superposition of the bands is taken into account by using the equation for multiplication of transmissions [6].

The algorithm to solve the problem is the following.

The layer is partitioned into n (unequal in the general case) parts along the thickness, where $\bar{y}_i$ are the separation points, $i = 0, \ldots, n$, $\bar{y}_0 = 0$ and $\bar{y}_n = 1$. The temperature fields are found from (2)–(4) by using iteration whose convergence is improved by the introduction of the relaxation parameter $R\,(0 < R \leq 1)$ [9]:

$$\tilde{\theta}_i^k = (\bar{E}(\bar{y}_0, \theta_0^{k-1}, \ldots, \theta_n^{k-1}) - \bar{E}(\bar{y}_i, \theta_0^{k-1}, \ldots, \theta_n^{k-1}))\cdot\frac{\pi_1}{2} + \theta(0);$$

$$\theta_i^k = (\tilde{\theta}_i^k - \theta_i^{k-1})\cdot R + \theta_i^{k-1};\quad i = 1, \ldots, n;$$

$$\theta_0^k = \theta_0^{k-1} = \theta(0);\quad k = 1, 2, \ldots$$

This scheme is realized in a program compiled in FORTRAN for the Minsk-32 computer. The program permits computation of the heat transfer in carbon dioxide, and water vapor flows and in their mixtures. The radiation characteristics of these gases are taken from [10].

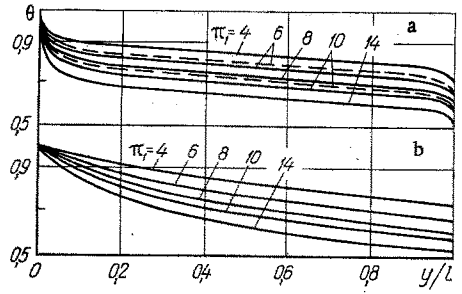

Fig. 2. Temperature distribution over the layer thickness for carbon dioxide: a) for $v \neq 0$; solid lines — $\theta_{c1} = 0$, dashes — $\theta_{c1} = 0.5$; b) the same for the grey model.

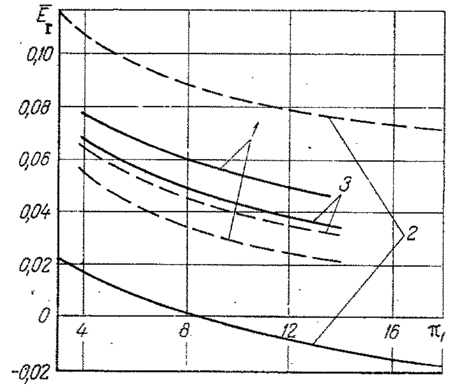

Fig. 3. Values of $\bar{E}_r$ on the boundary surfaces: 1) carbon dioxide, $\theta_{c1} = 0$; 2) the same, $\theta_{c1} = 0.5$; 3) the grey model, $\theta_{c1} = 0$. Solid lines, $\bar{E}_{r1}$; and dashes, $\bar{E}_{r2}$.

The heat-transfer computations were performed for a carbon dioxide flow. It was assumed that $l = 0.5$ m; $P_{CO_2} = 0.101$ MPa (1 atm); $P = 0.101$ MPa (1 atm); $\theta_{c2} = 0$; $T_0 = 2100$°K; π_1 and θ_{c1} were variated.

The quantities π_1 and θ_{c1} in the temperature field in the layer are shown in Fig. 2a. The dimensionless resultant radiant flux densities on the walls 1 and 2, $\bar{E}_{r1}$ and $\bar{E}_{r2}$, are shown in Fig. 3 as a function of π_1 (curves 1 and 2). It is seen from the figures that an increase in θ_{c1} does not reduce the total heat emission in practice, but alters the resultant radiant flux distribution between the layer boundaries considerably.

Computations of the heat transfer on a grey model were performed for comparison. A certain mean coefficient of absorption of the medium $\bar{K}$ was selected for computation of the heat transfer in a real medium when using the grey model. In [11] $\bar{K}$ is found from the relationship

$$1 - \exp(-\bar{K} l_m) = \varepsilon(T_{me}),$$

where $\varepsilon(T_{me})$ is the emissivity of a volume at a certain mean temperature T_{me} and l_m is the mean length of a beam path.

The mean Planck coefficient of absorption $\bar{K}_r$ was taken as $\bar{K}$ in [5, 12]. However, the simple substitution of $\bar{K}_r$ in the equation for the grey gas can result in significant errors in the magnitude of the integrated radiation intensity [13]. In our research $\bar{K}$ is determined from the equation

$$1 - 2E_3(\bar{K} l) = \varepsilon(T_{me}),$$

and ε is calculated by using the statistical model of bands [10], $T_{me} = (T_0 + T_c)/2$.

The temperature fields of $\bar{E}_{r1}$ and $\bar{E}_{r2}$, obtained for the grey model, are given in Figs. 2b and 3 (curve 3), respectively.

Values of T_c and the radiation characteristics of a layer are presented in Table 1 for CO_2 (the selective model) and its grey model. It is seen from Table 1 that the quantities of T_c, and therefore of the total heat transfer, are practically identical for both models.

Comparing Figs. 2a and b shows that, in contrast to the grey model, a sharp rise and fall of the temperature curves at the layer boundaries is characteristic for the selective model. This is explained by the fact that a thin CO_2 layer emits considerably more energy than a thin grey gas layer.

The ratio $\bar{E}_{r1}/\bar{E}_{r2}$ is close to 1 for all π_1 for the grey model, whereas $\bar{E}_{r1}/\bar{E}_{r2}$ grows from 1.42 to 2.19 with the increase in π_1 for the selective model.

The results of a computation based on the Curtis–Godson approximation were also compared with results obtained by using the Nevskii approximation whose crux is that the transmission of gas radiation is inde-

TABLE 1. T_c and the Radiation Characteristics of a Gas Layer for the Selective and Grey Models $\theta_{c1} = 0$

π_1	CO_2			Grey model	
	T_c, °K	T_{me}, °K	$\varepsilon(T_{me})$	$\bar{K}$, m^{-1}	T_c, °K
4	1556	1828	0,121	0,140	1558
6	1415	1757	0,126	0,150	1412
8	1312	1706	0,129	0,154	1313
10	1234	1667	0,132	0,156	1239
14	1121	1611	0,136	0,162	1126

TABLE 2. Comparison of the Computation Results Based on the Curtis–Godson and Nevskii Approximations $\theta_{c1} = 0$

π_1	$T_c(C-G)-T_c(N)$, °K	$\frac{\bar{E}_{r1}(C-G)-\bar{E}_{r1}(N)}{\bar{E}_{r1}(N)}\cdot 100$, %	$\frac{\bar{E}_{r2}(C-G)-\bar{E}_{r2}(N)}{\bar{E}_{r2}(N)}\cdot 100$, %
4	−1	0,91	1,50
6	0	1,03	1,95
8	−2	1,15	2,10
10	−2	0,90	2,54
14	−1	1,08	2,95

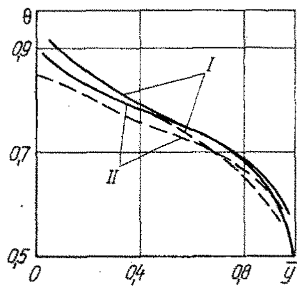

Fig. 4. Temperature distribution over the layer thickness for carbon dioxide at v = 0; I – $P_{CO_2} l$ = 0.005 m. II – 0.05. The solid lines are our computation and dashes are the results from [15].

pendent of the temperature distribution along the transmission path and is calculated at the volume temperature, the radiation source [14].

It was hence obtained that the temperature fields and fluxes practically agree. The good agreement between the results (Table 2) is explained in this case by the fact that the temperature gradients at which significant discrepancies in the quantities $\tau_{gg}(C-G)$, $\tau_{gg}(N)$ can be expected occur only at wall 1 where the temperature drop is 700°K in a thickness of about 5 cm. Verification showed that for this path the values of $\tau_{gg}(C-G)/\tau_{gg}(N)$ are close to one for radiation toward the hot and cold ends.

If the gas velocity is zero, then it is in a state of radiation equilibrium: $\bar{E}$ = const.

The temperature curves we obtained are compared in Fig. 4 for the case of radiation equilibrium of a carbon dioxide layer (T_{c1} = 2000°K; T_{c2} = 400°K; $P_{CO_2} l$ = 0.005 m·atm and 0.05 m·atm; P = 1 atm; $\theta = T/T_{c1}$) with the curves in [15].

NOTATION

ρ, gas density; v, velocity; y, coordinate; E, density of the resultant radiation flux; c_p, specific heat at constant pressure; σ_0, h, k, Stefan–Boltzmann, Planck, and Boltzmann constants; c, speed of light in a vacuum; ν, wave number; μ, cosine of the angle between the beam direction and the normal to the surfaces; θ_i^k; $E(\bar{y}_i, \theta_0^k, \ldots, \theta_n^k)$, dimensionless temperature and resultant radiation flux density at the point $\bar{y}_i$ at the k-th step of the iteration; P_{CO_2}, partial pressure of carbon dioxide; P, total pressure, $E_3(x)=\int_0^1 \mu^2 \exp(-x/\mu)\,d\mu$, exponential integral of the third order; T_c, gas temperature at the exit from the layer; $\tau_{gg}(C-G)$, $\tau_{gg}(N)$, the integrated values of the transmission of gas radiation through a gas according to Curtis–Godson and A. S. Nevskii.

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DETERMINATION OF THERMOPHYSICAL PROPERTIES OF SEMICONDUCTORS FROM MEASUREMENT OF ETTINGSHAUSEN EFFECT BY METHOD OF VARIATION OF MAGNETIC FIELD

I. S. Lisker and M. B. Pevzner

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A method is proposed for determination of the thermophysical coefficients of semiconductors by measurement of the Ettingshausen effect in the unsteady state following the application or removal of a magnetic field.

Investigation of the main galvano- and thermomagnetic effects (GTME) in semiconductors is widely used to obtain information about the electric and magnetic properties of the object [1-4]. The main effects in the specimen are accompanied by superposed thermal effects (Peltier, Ettingshausen, etc.) due to energy transfer by electrons. Lisker [3] proposed an experimental method of determining the kinetic parameters of solids by varying the thermal, electric, and magnetic fields. This enabled him [4] to separate and measure both the main and superposed effects. In view of this it is also possible to determine the thermophysical characteristics of the investigated materials from measurements of the superposed effects. One method, based on the use of the Ettingshausen effect, is examined in this paper. We propose a method of determining the thermal diffusivity k and the thermal conductivity λ from experimental measurements of the Ettingshausen effect in the unsteady state.

The Ettinghausen galvanomagnetic effect is a thermal, i.e., inertial concomitant of the Hall effect, and is characterized by the formation in the specimen of a temperature drop in a direction perpendicular to the current I flowing through it and also to the magnetic field H applied to it. In the steady state the Ettinghausen temperature drop ΔT_E and the heat flux w_E corresponding to it are given by the expressions [2]

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