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STUDY OF RADIATION PROPERTIES OF A PLANE INHOMOGENEOUS TWO-PHASE MEDIUM

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Abstract—An approximate method for calculating the intensity and fluxes of radiation from an inhomogeneous two-phase layer with emitting and reflecting boundary surfaces has been developed. By using the numerical integration of the radiation transfer equation, the accuracy of the method has been ascertained for a wide range of variation of the initial parameters. A general definition of the effective temperature of the layer is presented.

NOMENCLATURE

I, $= I(\tau, \mu)$, radiation intensity at point τ and in direction $\theta = \arccos \mu$;
B, $= (1/\pi)\sigma_0 T^4$, Planck radiation intensity for the temperature $T = T(\tau)$;
σ_0, Stefan–Boltzmann's constant;
S, $= S(\tau)$, function of radiation sources;
κ, σ, absorption and scattering coefficient, respectively;
α, $= \kappa + \sigma$, coefficient of medium attenuation;
λ, $= \sigma/(\kappa + \sigma)$, probability of quantum survival;
$g_1(\mu), g_2(\mu)$, intensity of radiation incident on the left and on the right side of the medium, respectively;
$T_{S1}, r_1(\mu, \mu')$, temperature and reflection coefficient of the left boundary surface, respectively;
$T_{S2}, r_2(\mu, \mu')$, temperature and reflection coefficient of the right boundary surface, respectively;
E_1, E_2, emissivity on the left and on the right side of the inhomogeneous layer, respectively;
R, reflectivity of the semi-infinite two-phase layer;
R_1, R_2, reflectivity on the left and on the right side of the inhomogeneous layer, respectively;
T, transmittivity of the layer;
$0 \leq x \leq x_0$, layer thickness;

$$0 \leq \tau = \int_0^x \alpha(x)\mathrm{d}x \leq \tau_0 = \int_0^{x_0} \alpha(x)\mathrm{d}x,$$

optical thickness of the layer.

1. INTRODUCTION

INCREASING intensification of heat-power engineering equipment places more stringent requirements on the accuracy of solution of heat- and mass-transfer problems, including those of radiative heat transfer. However, incorporation of the real properties of a heat-transfer agent (which, in the general case, is a mixture of molecular gases and particles) and of the working chambers makes the mathematical statement of the problems much more involved (see, for example [1–4]). Modern electronic computers enable one to analyze any problem of radiation transfer in plane two-phase inhomogeneous media. Even so, the development of approximate methods for calculating the luminescence characteristics of inhomogeneous two-phase media has remained to be one of the most pressing problems to date. The results obtained using these methods can be employed to develop algorithms for computing more complex problems and to carry out a host of engineering calculations for establishing certain regularities in the modern technological processes.

The existing literature on the study of radiation transfer in inhomogeneous two-phase media comprises a large number of publications [1–6]. However, all of them present the solution of the radiation transfer theory problems only for particular situations possible in practice. In [7, 8] the method has been suggested for treating homogeneous two-phase systems, which consists in approximate determination of the function of sources with subsequent direct integration of the radiation transfer equation. This method allows one to obtain analytical equations of the emissivity not only for plane, but for spherical and cylindrical two-phase media. Comparison of these calculations with the results of numerical integration of the radiation transfer equation [6] demonstrates that the accuracy of the developed method within a wide range of optical characteristics of the medium and of the experiment conditions is adequate for its practical application.

In the present paper this method has been extended to a most general problem of the theory of radiation transfer in plane two-phase media, such as propagation of radiation in an inhomogeneous medium with emitting and reflecting boundary surfaces. The sole simplification is the assignment of the same function of position for the absorption and scattering coefficients, which results in the constant value of the quantum survival probability. But if we discard this simplification and introduce a certain effective quantity (as is done in the present paper for temperature), then the method suggested can be used for a wide class of problems.

The paper analyzes hemispherical and directed characteristics of radiation emitting from a layer as functions of the optical properties of the medium and the boundary surfaces and also of the temperature profile. The results obtained by this method are compared with those obtained by numerical solution of the transfer equation for the given problem. The comparison has shown that the method is accurate even in the case of exponential temperature approximation over the layer.

When the condition of local thermodynamic equilibrium is satisfied, the radiation transfer equation can be written for the studied problem [1, 9] as:

$$\mu \frac{\mathrm{d}I(\tau,\mu)}{\mathrm{d}\tau} + I(\tau,\mu) = \frac{\lambda}{2}\int_{-1}^{1} I(\tau,\mu')\mathrm{d}\mu' + (1-\lambda)B(\tau). \quad (1)$$

In this equation the scattering function for a volume element of the medium is assumed to be spherical. The anisotropism of scattering [10] can be quite accurately allowed for by representing the scattering function as follows:

$$p(\mu,\mu') = a + 2(1-a)\delta(\mu-\mu'), \quad (2)$$

where a is the doubled hemispherical fraction of the backward scattering. The above representation (2) reduces the solution of the anisotropic scattering problem to the isotropic case, i.e. to the solution of equation (1) with $a\sigma$ formally substituted for σ.

The boundary conditions for the stated problem are:

$$\left.\begin{aligned} I(0,\mu) &= g_1(\mu) + \int_{-1}^{0} r_1(\mu,\mu')I(0,\mu')\mathrm{d}\mu', \quad \mu > 0, \\ I(\tau_0,\mu) &= g_2(\mu) + \int_{0}^{1} r_2(\mu,\mu')I(\tau_0,\mu')\mathrm{d}\mu', \quad \mu < 0. \end{aligned}\right\} \quad (3)$$

Here the functions $g_i(\mu)$ $(i = 1, 2)$ determine both the radiation from the outside and the emitted radiation of the boundary surfaces, $\varepsilon_i B(T_i)$ (ε_i is the emissivity of the boundary surfaces). The reflection coefficients, $r_i(\mu,\mu')$, for the Lambert reflecting surfaces are constant quantities:

$$r_i(\mu,\mu') = r_{0i} = \text{const}\,(i = 1, 2), \quad (4)$$

and in the case of specular reflection these are

$$r_i(\mu,\mu') = r_{0i}\cdot\delta(\mu-\mu'), \quad (5)$$

where δ is the delta function.

2. APPROXIMATE METHOD FOR SOLUTION OF EQUATION (1)

Integrate equation (1) with respect to μ, first within $[0, I]$ and then within $[-I, 0]$. The familiar Schuster–Schwarzschild approximation [1, 11].

$$\int_0^1 \mu I(\tau,\mu)\mathrm{d}\mu \cong \frac{1}{2}\int_0^1 I(\tau,\mu)\mathrm{d}\mu,$$

$$\int_{-1}^0 \mu I(\tau,\mu)\mathrm{d}\mu \cong -\frac{1}{2}\int_{-1}^0 I(\tau,\mu)\mathrm{d}\mu$$

yields a system of two differential equations:

$$\left.\begin{aligned} \frac{1}{2}\frac{\mathrm{d}I_1(\tau)}{\mathrm{d}\tau} + I_1(\tau) &= \frac{\lambda}{2}[I_1(\tau) + I_2(\tau)] + (1-\lambda)B(\tau), \\ -\frac{1}{2}\frac{\mathrm{d}I_2(\tau)}{\mathrm{d}\tau} + I_2(\tau) &= \frac{\lambda}{2}[I_1(\tau) + I_2(\tau)] + (1-\lambda)B(\tau), \end{aligned}\right\} \quad (6)$$

in which

$$I_1(\tau) = \int_0^1 I(\tau,\mu)\mathrm{d}\mu$$

and

$$I_2(\tau) = \int_{-1}^0 I(\tau,\mu)\mathrm{d}\mu. \quad (7)$$

The assumption that

$$k^2 = 4(1-\lambda), \qquad J(\tau) = I_1(\tau) + I_2(\tau)$$

and

$$F(\tau) = I_1(\tau) - I_2(\tau)$$

gives

$$\frac{\mathrm{d}^2 J(\tau)}{\mathrm{d}\tau^2} - k^2 J(\tau) = -2k^2 B(\tau). \quad (8)$$

The solution of (8) is

$$J(\tau) = A_1\,\mathrm{e}^{-k(\tau_0-\tau)} + A_2\,\mathrm{e}^{-k\tau} + \Phi_1(\tau) + \Phi_2(\tau), \quad (9)$$

$$F(\tau) = \frac{k}{2}\left[A_2\,\mathrm{e}^{-k\tau} - A_1\,\mathrm{e}^{-k(\tau_0-\tau)} - \Phi_1(\tau) + \Phi_2(\tau)\right], \quad (10)$$

where

$$\left.\begin{aligned} \Phi_1(\tau) &= k\int_\tau^{\tau_0} B(\tau')\mathrm{e}^{-k(\tau'-\tau)}\mathrm{d}\tau', \\ \Phi_2(\tau) &= k\int_0^{\tau} B(\tau')\mathrm{e}^{-k(\tau-\tau')}\mathrm{d}\tau'. \end{aligned}\right\} \quad (11)$$

From this, the quantities $I_1(\tau)$ and $I_2(\tau)$, which are the average (over the hemispheres) radiation intensities, can be easily obtained

$$
\left.\begin{aligned}
I_1(\tau) &= \alpha_1 A_1\,\mathrm{e}^{-k(\tau_0-\tau)} + \alpha_2 A_2\,\mathrm{e}^{-k\tau} \\
&\qquad + \alpha_1\Phi_1(\tau) + \alpha_2\Phi_2(\tau), \\
I_2(\tau) &= \alpha_2 A_1\,\mathrm{e}^{-k(\tau_0-\tau)} + \alpha_1 A_2\,\mathrm{e}^{-k\tau} \\
&\qquad + \alpha_2\Phi_1(\tau) + \alpha_1\Phi_2(\tau),
\end{aligned}\right\} \quad (12)
$$

where

$$
\alpha_1 = \tfrac{1}{4}(2-k), \qquad \alpha_2 = \tfrac{1}{4}(2+k).
$$

The constants A_1 and A_2 can be found from the boundary conditions (3)

$$
\left.\begin{aligned}
I_1(0) &= \int_0^1 I(0,\mu)\mathrm{d}\mu = G_1 + \rho_1 I_2(0), \\
I_2(\tau_0) &= \int_{-1}^0 I(\tau_0,\mu)\mathrm{d}\mu = G_2 + \rho_2 I_1(\tau_0),
\end{aligned}\right\} \quad (13)
$$

where

$$
G_1 = \int_0^1 g_1(\mu)\mathrm{d}\mu, \qquad G_2 = \int_{-1}^0 g_2(\mu)\mathrm{d}\mu, \quad (14)
$$

$$
\left.\begin{aligned}
\rho_1 &= \frac{1}{I_2(0)}\int_0^1\int_{-1}^0 r_1(\mu,\mu')I(0,\mu')\mathrm{d}\mu\,\mathrm{d}\mu', \\
\rho_2 &= \frac{1}{I_1(\tau_0)}\int_{-1}^0\int_0^1 r_2(\mu,\mu')I(\tau_0,\mu')\mathrm{d}\mu\,\mathrm{d}\mu'.
\end{aligned}\right\} \quad (15)
$$

The quantities $\rho_i (i=1,2)$ are certain effective reflectivities of the boundary surfaces.

Using the conditions (13) and also the relations

$$
\begin{aligned}
\Phi_1(0) &= \phi_1, & \Phi_1(\tau_0) &= 0, \\
\Phi_2(0) &= 0, & \Phi_2(\tau_0) &= \phi_2,
\end{aligned} \quad (16)
$$

we obtain

$$
\begin{aligned}
A_1 = \frac{1}{D}\{&G_2(1+R)(1-\rho_1 R) \\
&- G_1(1+R)(R-\rho_2)\mathrm{e}^{-k\tau_0} \\
&- (R-\rho_2)(1-\rho_1 R)\phi_2 \\
&+ (R-\rho_1)(R-\rho_2)\phi_1\,\mathrm{e}^{-k\tau_0}\},
\end{aligned} \quad (17)
$$

$$
\begin{aligned}
A_2 = \frac{1}{D}\{&G_1(1+R)(1-\rho_2 R) \\
&- G_2(1+R)(R-\rho_1)\mathrm{e}^{-k\tau_0} \\
&- (R-\rho_1)(1-\rho_2 R)\phi_1 \\
&+ (R-\rho_1)(R-\rho_2)\phi_2\,\mathrm{e}^{-k\tau_0}\},
\end{aligned} \quad (18)
$$

where

$$
\left.\begin{aligned}
D &= (1-\rho_1 R)(1-\rho_2 R) \\
&\qquad - (R-\rho_1)(R-\rho_2)\mathrm{e}^{-2k\tau_0}, \\
R &= \frac{\alpha_1}{\alpha_2} = \frac{2-k}{2+k} = \frac{1-\sqrt{(1-\lambda)}}{1+\sqrt{(1-\lambda)}}.
\end{aligned}\right\} \quad (19)
$$

The quantity R has the meaning of the reflectivity of a semi-infinite layer [7].

The solution obtained gives a complete determination of the values of $I_1(\tau)$ and $I_2(\tau)$ at any point of the medium. In a majority of practical problems, radiation from the medium is of fundamental interest, so we shall consider the quantities $I_1(\tau_0)$ and $I_2(0)$ in more detail. Substituting (17) into (12) and performing simple transformations, we obtain

$$
I_1(\tau_0) = E_1 + TG_1 + R_1 G_2, \quad (20)
$$

$$
I_2(0) = E_2 + TG_2 + R_2 G_1, \quad (21)
$$

where

$$
T = \frac{1}{D}(1-R^2)\mathrm{e}^{-k\tau_0}, \quad (22)
$$

$$
R_i = \frac{1}{D}[R(1-\rho_i R) - (R-\rho_i)\mathrm{e}^{-2k\tau_0}](i=1,2), \quad (23)
$$

$$
\left.\begin{aligned}
E_1 &= \frac{1-R}{D}[(1-\rho_1 R)\phi_2 - (R-\rho_1)\phi_1\,\mathrm{e}^{-k\tau_0}], \\
E_2 &= \frac{1-R}{D}[(1-\rho_2 R)\phi_1 - (R-\rho_2)\phi_2\,\mathrm{e}^{-k\tau_0}].
\end{aligned}\right\} \quad (24)
$$

It can be easily seen that T defines the layer transmittivity, R_1 and R_2, the layer reflectivity on the left and on the right side, respectively, and E_1 and E_2 define the contributions of the internal sources to the emission of radiation from the right and from the left side, respectively. However, according to the boundary conditions (3) or (13), relations (20) and (21) determine the emission of radiation to the reflecting boundary surfaces. Consequently, the emission of radiation from the layer will then be determined by the quantities $(1-\rho_2)I_1(\tau_0)$ and $(1-\rho_1)I_2(0)$. It should be noted that G_1 and G_2 define the radiative flux which has already passed through the boundary surfaces and is impinging directly on the layer under study. Therefore, if the intensities of radiation, G_1' and G_2', impinging on the layer from the outside are prescribed in the problem, then $G_1 = (1-\rho_1)G_1'$ and $G_2 = (1-\rho_2)G_2'$.

Thus, the obtained quantities (22)–(24) are characteristics of the layer itself, bound by the partially reflecting surfaces. Characteristics of the layer together with the reflecting walls are defined as $(1-\rho_2)T$, $(1-\rho_2)R_1$, $(1-\rho_2)E_1$ for the emission of radiation to the right and as $(1-\rho_1)T$, $(1-\rho_1)R_2$, $(1-\rho_1)E_2$ for radiation leaving the left-side surface.

3. ANALYSIS OF PARTICULAR CASES

In the case of purely emitting media equation (1) has an exact solution [12]:

$$
\begin{aligned}
I^{\mathrm{ex}}(\tau,\mu)\big|_{\mu>0} &= \frac{1}{1-\rho_1\rho_2\,\mathrm{e}^{-2\tau_0/\mu}}\{b_2' + \varepsilon_1 B(T_{S1})\mathrm{e}^{-\tau_0/\mu} \\
&\qquad + \rho_1\,\mathrm{e}^{-\tau_0/\mu}[b_1' + \varepsilon_2 B(T_{S2})\mathrm{e}^{-\tau_0/\mu}]\},
\end{aligned} \quad (25)
$$

$$
\begin{aligned}
I^{\mathrm{ex}}(0,\mu)\big|_{\mu<0} &= \frac{1}{1-\rho_1\rho_2\,\mathrm{e}^{-2\tau_0/\mu}}\{b_1' + \varepsilon_2 B(T_{S2})\mathrm{e}^{-\tau_0/\mu} \\
&\qquad + \rho_2\,\mathrm{e}^{-\tau_0/\mu}[b_2' + \varepsilon_1 B(T_{S1})\mathrm{e}^{-\tau_0/\mu}]\},
\end{aligned} \quad (26)
$$

where

$$\left.\begin{aligned} b_1' &= \int_0^{\tau_0} B(\tau')e^{-\tau'/\mu}\frac{d\tau'}{\mu}, \\ b_2' &= \int_0^{\tau_0} B(\tau')e^{-(\tau_0-\tau')/\mu}\frac{d\tau'}{\mu}. \end{aligned}\right\} \quad (27)$$

In order to carry out the averaging of the quantities (25) and (26) over the angles, we shall avail ourselves of the stipulation utilized in [6, 7, 12]. It is this: direction-averaged intensity of radiation from the medium is equal to the intensity of radiation emitted by the medium at the angle $\theta = 60^\circ$ ($\mu = 1/2$) about the normal to the layer. This condition holds strictly in the case of radiation propagating in a diffuse manner [13], while in [6, 7] it is shown that this condition is also valid in calculation of the luminescence characteristics of two-phase media. Having applied it for (25) and (26), we obtain the expressions which exactly coincide with (24). Assuming that $T(\tau) = T(\tau_0 - \tau)$, i.e. that the temperature distribution is symmetrical about the middle of the layer, and that $\varepsilon_1 = \varepsilon_1(T_S) = 1-\rho_1$ and $\varepsilon_2 = \varepsilon_2(T_S) = 1-\rho_2$, we find

$$\begin{aligned} I_1(\tau_0) &= I_1^{ex}(\tau_0) \\ &= \frac{1}{1-(1-\varepsilon_1)(1-\varepsilon_2)e^{-4\tau_0}}\{\varepsilon_1 B(T_S)e^{-4\tau_0} \\ &\quad + b[1+(1-\varepsilon_1)e^{-2\tau_0}]\}, \quad (28) \\ I_2(0) &= I_2^{ex}(0) \\ &= \frac{1}{1-(1-\varepsilon_1)(1-\varepsilon_2)e^{-4\tau_0}}\{\varepsilon_2 B(T_S)e^{-2\tau_0} \\ &\quad + \varepsilon_1(1-\varepsilon_2)B(T_S)e^{-4\tau_0} \\ &\quad + b[1+(1-\varepsilon_2)e^{-2\tau_0}]\}. \quad (29) \end{aligned}$$

Here

$$b = 2\int_0^{\tau_0} B[T(\tau')]e^{-2\tau'}d\tau'. \quad (30)$$

The radiative fluxes on the boundary surfaces can be represented as:

$$\left.\begin{aligned} q^+(\tau_0) &= 2\pi\int_0^1 \mu I(\tau_0,\mu)d\mu \cong \pi I_1(\tau_0), \\ q^-(\tau_0) &= 2\pi\int_{-1}^0 \mu I(\tau_0,\mu)d\mu \cong -\pi I_2(\tau_0) \\ &= -\pi[\varepsilon_2 B(T_S) + \rho_2 I_1(\tau_0)], \\ q^+(0) &= 2\pi\int_0^1 \mu I(0,\mu)d\mu \\ &\cong \pi[\varepsilon_1 B(T_S) + \rho_1 I_2(0)], \\ q^-(0) &= 2\pi\int_{-1}^0 \mu I(0,\mu)d\mu \cong -\pi I_2(0). \end{aligned}\right\} \quad (31)$$

The resultant fluxes are

$$\left.\begin{aligned} q_1 &= q^+(0) + q^-(0) \\ &= \pi\varepsilon_1[B(T_S) - I_2(0)], \\ q_2 &= q^+(\tau_0) + q^-(\tau_0) \\ &= -\pi\varepsilon_2[B(T_S) - I_1(\tau_0)], \end{aligned}\right\} \quad (32)$$

where the quantities $I_1(\tau_0)$ and $I_2(0)$ are assigned by relations (28) and (29).

If the medium is transparent and the temperatures of the surfaces are T_{S1} and T_{S2}, we arrive at the well-known relationship [3, 4]:

$$q = \frac{\pi[B(T_{S1}) - B(T_{S2})]}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \quad (33)$$

or, when $\varepsilon_i (i = 1, 2)$ is independent of the wave length, to

$$q = \frac{\sigma(T_{S1}^4 - T_{S2}^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}.$$

In the case of a light-diffusing medium without reflection on the boundary surfaces, equations (22) and (23) go over into:

$$T = T_0 = \frac{(1-R^2)e^{-k\tau_0}}{1-R^2e^{-2k\tau_0}}$$

and (34)

$$R_1 = R_2 = R_0 = \frac{R(1-e^{-2k\tau_0})}{1-R^2e^{-2k\tau_0}}.$$

These expressions coincide with the familiar equations for the transmittivity and reflectivity of a plane layer which were derived for a homogeneous case with disregard of the reflecting boundaries [7]. In the general case, the reflectivities of the layer, R_1 and R_2, differ from each other. The reason for this is the difference between the reflection coefficients of the right and the left surfaces. They coincide at $\rho_1 = \rho_2 = \rho$.

The emissivities of the layer, E_1 and E_2, do not coincide even if $\rho_1 = \rho_2$, because in the case of arbitrary temperature distribution in the layer $\phi_1 \neq \phi_2$. The only exception is the case of temperature distribution symmetrical with respect to the middle of the layer, when the condition $B(\tau) = B(\tau_0 - \tau)$ is satisfied. Then

$$\phi_1 = \phi_2 = \phi = k\int_0^{\tau_0} B(\tau')e^{-k\tau'}d\tau', \quad (35)$$

$$E_{0i} = \frac{1-R}{D}[1 - \rho_i R - (R-\rho_i)e^{-k\tau_0}]\phi, \quad (i = 1, 2) \quad (36)$$

while at $\rho_1 = \rho_2 = 0$

$$E_{01} = E_{02} = E = \frac{(1-R)\phi}{1+Re^{-k\tau_0}}. \quad (37)$$

In the isothermal case, when $B(\tau) = B_0 = \text{const}$,

$$\phi = (1 - e^{-k\tau_0})B_0, \tag{38}$$

$$E_{0i} = \frac{1-R}{D}[1 - \rho_i R - (R - \rho_i)e^{-k\tau_0}](1 - e^{-k\tau_0})B_0, \tag{39}$$

$$E = \frac{(1 - R)(1 - e^{-k\tau_0})B_0}{1 + R\,e^{-k\tau_0}}. \tag{40}$$

The quantity

$$\varepsilon = E/B_0 \tag{41}$$

is, according to [7], the emissivity of a homogeneous two-phase medium. By analogy, the quantities

$$\varepsilon_i = E_{0i}/B_0 \qquad (i = 1,2)$$

may be assumed to be the emissivities of the layer from the right and from the left side with allowance for the reflection properties of the boundary surfaces.

Equations (12) make it possible to determine the thermal efficiency of screens, ψ. The quantity ψ is one of the basic ones used in thermal engineering to calculate the temperature of the combustion products at the exit from the furnaces, the furnace cooling conditions, etc. [14]. This parameter is determined by the difference between the radiative fluxes on the boundary surface related to the flux impinging on the surface. Assuming that radiation is emitted entirely in a diffuse manner, that the properties of the boundary surfaces are similar and that the temperature distribution is symmetrical with respect to the middle of the layer, we obtain

$$\psi = \frac{(1 - \rho)A}{1 + A}. \tag{42}$$

Here

$$A = \left(\frac{1-\rho}{G} - \frac{1 - e^{-k\tau_0}}{\phi}\right)E,$$

$$E = \frac{(1 - R)\phi}{1 - \rho R + (R - \rho)e^{-k\tau_0}}$$

and ϕ is determined by (35).

To simplify the practical calculations it is customary in many problems of radiative heat transfer to replace the non-isothermal layer by a certain hypothetical homogeneous layer with the effective temperature of the layer T_{eff}. In elementary cases these are the arithmetic or geometric means. The results obtained in this paper allow a most correct incorporation of T_{eff} with regard for the optical properties of the medium and of the boundary surfaces. To do this, it is sufficient that $B(T_{eff})$ be substituted for B_0 in the equations for the isothermal case and these equations be equated with those for a nonisothermal layer. Then in the general case we will have

$$B(T_{1\,eff}) = \frac{(1-\rho_1 R)\phi_2 - (R-\rho_1)\phi_1\,e^{-k\tau_0}}{[1-\rho_1 R-(R-\rho_1)e^{-k\tau_0}](1-e^{-k\tau_0})} \tag{43}$$

for calculation of the radiation flux emitting to the right, and

$$B(T_{2\,eff}) = \frac{(1-\rho_2 R)\phi_1 - (R-\rho_2)\phi_2\,e^{-k\tau_0}}{[1-\rho_2 R-(R-\rho_2)e^{-k\tau_0}](1-e^{-k\tau_0})} \tag{44}$$

for the radiative flux emitting to the left. It is quite clear that in the case of arbitrary temperature distribution within the layer, the effective temperatures used in calculation of radiation directed to the right and to the left are different. In the case of temperature distribution symmetrical with respect to the middle of the layer, the effective temperatures are equal:

$$B(T_{eff}) = \frac{\phi}{1 - e^{-k\tau_0}} = \frac{k}{1 - e^{-k\tau_0}}\int_0^{\tau_0} B(\tau')e^{-k\tau'}\,d\tau'. \tag{45}$$

For a grey medium, i.e. when κ and σ are independent of (or weakly dependent on) the wavelength

$$T_{eff} = \left\{\frac{k}{1 - e^{-k\tau_0}}\int_0^{\tau_0} T^4(\tau')e^{-k\tau'}\,d\tau'\right\}^{1/4}. \tag{46}$$

The dependence of T_{eff} on the optical properties of the medium and on the function of temperature distribution over the layer, $T(\tau)$, was analyzed in detail for a purely emitting medium ($k=2$) in [12].

The specific calculations of equations (20) and (21) have been made for a homogeneous medium ($T = \text{const}$) and for two cases of a non-isothermal medium

$$\left.\begin{aligned} &T^a = T^a(\tau) = T_0 \exp\left[-\alpha\left(\tau - \frac{\tau_0}{2}\right)^2\right] \\ &\text{and} \\ &T^b = T^b(\tau) = T_{S1}\,e^{\alpha\tau}. \end{aligned}\right\} \tag{47}$$

While $T^a(\tau)$, being the axisymmetrical temperature profile, is quite frequently realized in practice, $T^b(\tau)$ has been incorporated as an extremely possible case to estimate the uncertainty introduced by the proposed approximate method. The calculations were carried out at $T_{S1}^{a,b} = 300$ K, $T_0 = T_{S2}^b = 300, 500, 1000, 1500$ K, $\tau_0 = 0.1 \div 10$, $\lambda = 0.1, 0.5, 0.9, 0.99$, $\rho_1 = \rho_2 = 0$ and $\rho_1 = 0$, $\rho_2 = 0.5$. The accurate values of (20) and (21) were determined by the iteration method, with their approximate values being taken for the first iteration. For the homogeneous case, the accuracy of the expressions for $E_i\,(i = 1,2)$ is $\lesssim 1\%$ at $\tau_0 \gtrsim 1$ and $\lambda \sim 0.5$ and is worse ($\sim 15\%$) at $\lambda = 0.99$. In the presence of a reflecting surface ($\rho_2 = 0.5$) the calculation accuracy for the transmitted radiation remains almost the same, and is improved in the case of 'reflected' radiation. Thus, for $\tau_0 = 2$ and $\lambda = 0.99$ the accuracy is only 2.9%. In the case of the first temperature profile, calculation of the layer radiation at $\lambda \lesssim 0.5$ leads to the error of about 20–25%, but it decreases sharply with the increase of the probability of quantum survival λ. A similar dependence is also observed for the other temperature profile. The table gives the intensities of

Table 1. Accurate (a) and calculated (app) [by (20) and (21)] values of the intensity of radiation emitting from the layer for the temperature profile $T^b = T^b(\tau)$ at $T_{S1} = 300$ K, $T_{S2} = 1500$ K, $\rho_1 = 0$ and $\rho_2 = 0.5$

λ	$I_1(\tau_0)$						$I_2(0)$					
	0.5		0.9		0.99		0.5		0.9		0.99	
τ_0	a	app	a	app	a	app	a	app	a	app	a	app
0.5	79.8	52.3	20.7	13.3	2.23	1.42	40.8	39.9	12.6	11.1	1.42	1.21
1	130	100	38.7	29.9	4.44	3.42	41.1	43.2	17.5	17.0	2.21	2.09
2	199	173	6.97	6.29	8.98	8.19	28.0	26.7	20.2	20.3	3.27	3.29
4	280	265	115	114	17.7	18.4	10.3	7.41	16.1	15.0	4.44	4.59
6	329	323	146	150	25.5	28.1	4.40	3.01	10.6	8.94	4.95	5.11
10	385	391	187	201	38.2	44.7	1.78	1.52	4.31	3.21	4.95	4.93

radiation from the layer for this case in the presence of a reflecting boundary surface. Note that this case is extreme for a real experiment.

As expected, during calculation of the transmittivity T (22) the approximate relationships start to give an appreciable error as early as at $\tau_0 > 1$. Although it decreases with the increase of λ, these relationships cannot be used at $\lambda = 0.99$ and $\tau_0 > 4$. But at these values of τ_0, the function $T(\tau_0)$ becomes very small. When determining the values of $R_i\,(i = 1, 2)$ (23), the error, according to (20) and (21), amounts to $\sim$10–15% and becomes almost twice as large at $\tau_0 \lesssim 0.1$.

4. ANGULAR DISTRIBUTION OF THE LAYER RADIATION INTENSITY

The initial radiation transfer equation can be represented for a plane two-phase layer as

$$\mu \frac{dI(\tau,\mu)}{d\tau} + I(\tau,\mu) \cong \frac{\lambda}{2}[I_1(\tau) + I_2(\tau)] + (1-\lambda)B(\tau), \quad (48)$$

where $I_1(\tau)$ and $I_2(\tau)$ are specified by relationships (12). This equation has the following solution:

$$I(\tau,\mu) = I(0,\mu)e^{-\tau/\mu} + \frac{\lambda A_1}{2(1+k\mu)}[e^{-k(\tau_0-\tau)} - e^{-k\tau_0-\tau/\mu}] + \frac{\lambda A_2}{2(1-k\mu)}(e^{-k\tau} - e^{-\tau/\mu}) + \frac{\lambda}{2}H_1(\tau,\mu) + \frac{1-\lambda}{k\mu}\psi_1(\tau,\mu), \quad \mu > 0, \quad (49)$$

$$I(\tau,\mu) = I(\tau_0,\mu)e^{-(\tau_0-\tau)/|\mu|} + \frac{\lambda A_1}{2(1-k|\mu|)}[e^{-k(\tau_0-\tau)} - e^{-(\tau_0-\tau)/|\mu|}] + \frac{\lambda A_2}{2(1+k|\mu|)}[e^{-k\tau} - e^{-k\tau_0-(\tau_0-\tau)/|\mu|}] + \frac{\lambda}{2}H_2(\tau,\mu) + \frac{1-\lambda}{k|\mu|}\psi_2(\tau,\mu), \quad \mu < 0, \quad (50)$$

where

$$\left.\begin{aligned} \psi_1(\tau,\mu) &= k\int_0^{\tau} B(\tau')e^{-(\tau-\tau')/|\mu|}\,d\tau', \\ \psi_2(\tau,\mu) &= k\int_{\tau}^{\tau_0} B(\tau')e^{-(\tau'-\tau)/|\mu|}\,d\tau', \end{aligned}\right\} \quad (51)$$

$$\left.\begin{aligned} H_1(\tau,\mu) &= \int_0^{\tau} [\Phi_1(\tau') + \Phi_2(\tau')]e^{-(\tau-\tau')/|\mu|}\frac{d\tau'}{|\mu|}, \\ H_2(\tau,\mu) &= \int_{\tau}^{\tau_0} [\Phi_1(\tau') + \Phi_2(\tau')e^{-(\tau'-\tau)/|\mu|}\frac{d\tau'}{|\mu|}. \end{aligned}\right\} \quad (52)$$

The constants $A_i\,(i=1,2)$ defined by the boundary conditions are determined from (17) and (18), and $\Phi_i(\tau)$, from (11). The functions $\psi_i(\tau,\mu)$ are of the same nature as $\Phi_i(\tau)$. With the function known, calculation of these integrals presents no special problem. It is different with $H_i(\tau,\mu)$ $(i=1,2)$, since these are the double integrals. The double integrals as in (52), however, can be reduced to the sum of the functions $\psi_i(\tau,\mu)$. Consider the first integral of the function $H_1(\tau,\mu)$. Since

$$\frac{d}{d\tau}k\int_{\tau}^{\tau_0} B(\tau')e^{-k(\tau'-\tau)}\,d\tau' = k^2\int_{\tau}^{\tau_0} B(\tau')e^{-k(\tau'-\tau)}\,d\tau' - kB(\tau),$$

$$\frac{d}{d\tau}k\int_0^{\tau} B(\tau')e^{-k(\tau-\tau')}\,d\tau' = -k^2\int_0^{\tau} B(\tau')e^{-k(\tau-\tau')}\,d\tau' + kB(\tau),$$

then

$$\begin{aligned} G_1(\tau,\mu) &= k\int_0^{\tau} e^{-(\tau-\tau')/|\mu|}\frac{d\tau'}{|\mu|}\int_{\tau'}^{\tau_0} B(\tau'')e^{-k(\tau''-\tau')}\,d\tau'' \\ &= \int_0^{\tau} B(\tau')e^{-(\tau-\tau')/|\mu|}\frac{d\tau'}{|\mu|} \\ &\quad + \int_0^{\tau} e^{-(\tau-\tau')/|\mu|}\frac{d\tau'}{|\mu|}\frac{d}{d\tau'} \\ &\quad \times \int_{\tau'}^{\tau_0} B(\tau'')e^{-k(\tau''-\tau')}\,d\tau' \end{aligned}$$

$$= \int_0^{\tau} B(\tau')e^{-(\tau-\tau')/|\mu|}\frac{d\tau'}{|\mu|} + \int_{\tau}^{\tau_0} B(\tau')e^{-k(\tau'-\tau)}\frac{d\tau'}{|\mu|} - e^{-\tau/|\mu|}\int_0^{\tau_0} B(\tau')e^{-k\tau'}\frac{d\tau'}{|\mu|} - \frac{1}{|\mu|}\int_0^{\tau} e^{-(\tau-\tau')/|\mu|}\frac{d\tau'}{|\mu|} \times \int_{\tau'}^{\tau_0} B(\tau'')e^{-k(\tau''-\tau')}d\tau''$$

or

$$G_1(\tau,\mu) = \frac{1}{1+k|\mu|}\,[\psi_1(\tau,\mu) + \Phi_1(\tau) - \phi_1 e^{-\tau/|\mu|}].$$

The remaining three integrals of the functions $H_i(\tau,\mu)$ $(i=1,2)$ can be found in a completely analogous way. After substituting the relations thus obtained for $H_i(\tau,\mu)$ into equations (2) and (3) and performing simple transformations we obtain the equations for the radiation distribution within the medium

$$I(\tau,\mu) = I(0,\mu)e^{-\tau/\mu} + v_1(\tau,\mu), \qquad \mu > 0 \quad (53)$$

$$I(\tau,\mu) = I(\tau_0,\mu)e^{-(\tau_0-\tau)/|\mu|} + v_2(\tau,\mu), \qquad \mu < 0, \quad (54)$$

where

$$v_1(\tau,\mu) = \frac{\lambda}{2(1+k|\mu|)}[A_1(1-e^{-\frac{1+k|\mu|}{|\mu|}\tau})e^{-k(\tau_0-\tau)} + \Phi_1(\tau) - \phi_1 e^{-\tau/|\mu|} + \psi_1(\tau,\mu)] + \frac{2}{2(1-k|\mu|)}[A_2(1-e^{-\frac{1-k|\mu|}{|\mu|}\tau})e^{-k\tau} + \Phi_2(\tau) - \psi_1(\tau,\mu)] + \frac{1-\lambda}{k|\mu|}\psi_1(\tau,\mu). \quad (55)$$

$$v_2(\tau,\mu) = \frac{\lambda}{2(1-k|\mu|)}\{A_1[1-e^{-\frac{1-k|\mu|}{|\mu|}(\tau_0-\tau)}] + \Phi_1(\tau) - \psi_2(\tau,\mu)\} + \frac{\lambda}{2(1+k|\mu|)} \times \{A_2[1-e^{-\frac{1+k|\mu|}{|\mu|}(\tau_0-\tau)}] + \Phi_2(\tau) - \phi_2 e^{-\frac{\tau_0-\tau}{|\mu|}} + \psi_2(\tau,\mu) + \frac{1-\lambda}{k|\mu|}\psi_2(\tau,\mu). \quad (56)$$

For radiation emitting from the medium we find

$$I(\tau_0,\mu) = I(0,\mu)e^{-\tau_0/\mu} + V_1(\mu), \qquad \mu > 0, \quad (57)$$

and

$$I(0,\mu) = I(\tau_0,\mu)e^{-\tau_0/|\mu|} + V_2(\mu), \qquad \mu < 0, \quad (58)$$

where

$$V_1(\mu) = v_1(\tau_0,\mu) = \frac{\lambda}{2(1+k|\mu|)}[A_1(1-e^{-\frac{1+k|\mu|}{|\mu|}\tau_0}) - \phi_1 e^{-\tau_0/|\mu|} + \psi_1(\mu)] + \frac{\lambda}{2(1-k|\mu|)} \times [A_2(1-e^{-\frac{1-k|\mu|}{|\mu|}\tau_0})e^{-k\tau_0} + \phi_2 - \psi_1(\mu)] + \frac{1-\lambda}{k|\mu|}\psi_1(\mu), \quad (59)$$

$$V_2(\mu) = v_2(0,\mu) = \frac{\lambda}{2(1-k|\mu|)}[A_1(1-e^{-\frac{1-k|\mu|}{|\mu|}\tau_0})e^{-k\tau_0} + \phi_1 - \psi_2(\mu)] + \frac{\lambda}{2(1+k|\mu|)} \times [A_2(1-e^{-\frac{1+k|\mu|}{|\mu|}\tau_0}) - \phi_2 e^{-\tau_0/|\mu|} + \psi_2(\mu)] + \frac{1-\lambda}{k|\mu|}\psi_2(\mu), \quad (60)$$

$$\psi_1(\mu) = \psi_1(\tau_0,\mu), \qquad \psi_2(\mu) = \psi_2(0,\mu). \quad (61)$$

Let us discuss determination of $I(0,\mu)|_{\mu>0}$ and $I(\tau_0,\mu)|_{\mu<0}$ figuring in equations (57) and (58). When there is no reflection from the boundary surfaces, according to the boundary conditions for equation (1), we obtain

$$\left.\begin{aligned} &I(0,\mu)|_{\mu>0} = g_1(\mu) \\ \text{and}\quad & \\ &I(\tau_0,\mu)|_{\mu<0} = g_2(\mu). \end{aligned}\right\} \quad (62)$$

When the laws of radiation reflection on the boundary surfaces are specified, the values of $I(0,\mu)|_{\mu>0}$ and $I(\tau_0,\mu)|_{\mu<0}$ are determined by rather a complicated system of integral equations. However, their determination can be considerably simplified by assigning the Lambertian or specular reflection laws. Thus, in the case of a diffuse radiation reflection from the boundary surfaces we find

$$\int_{-1}^{0} r_1(\mu,\mu')I(0,\mu')d\mu' = \rho_1\int_{-1}^{0} I(0,\mu')d\mu' = \rho_1 I_2(0),$$

$$\int_0^1 r_2(\mu,\mu')I(\tau_0,\mu')d\mu' = \rho_2\int_0^1 I(\tau_0,\mu')d\mu' = \rho_2 I_1(\tau_0),$$

in which $I_2(0)$ and $I_1(\tau_0)$ are determined by (20) and (21). The solution of equation (1) can then be presented as

$$\left.\begin{aligned} I(\tau,\mu) &= [g_1(\mu) + \rho_1 I_2(0)] \times e^{-\tau/\mu} + v_1(\tau,\mu), && \mu > 0, \\ I(\tau,\mu) &= [g_2(\mu) + \rho_2 I_1(\tau_0)] \times e^{-(\tau_0-\tau)/|\mu|} + v_2(\tau,\mu), && \mu < 0. \end{aligned}\right\} \quad (63)$$

If the law of specular reflection from the boundary

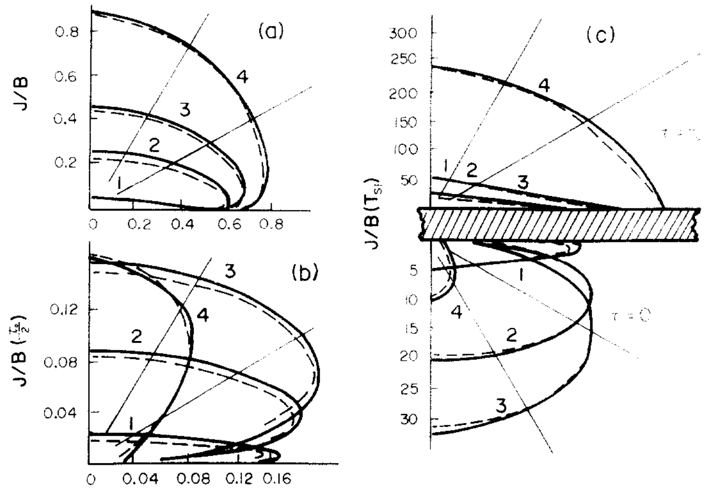

FIG. 1. Angular distribution of radiation emitting from an inhomogeneous layer for different temperature profiles [solid curves, exact calculation; dashed curves, calculation by equation (15)]: $\lambda = 0.5$; $\rho_1 = \rho_2 = 0$; (a) $T = \text{const}$; (b) $T = T^a(\tau)$; (c) $T = T^b(\tau)$; (1) $\tau_0 = 0.1$; (2) 0.5; (3) 1.0; (4) 6.0.

surfaces is prescribed, then

$$I(0,\mu) = g_1(\mu) + \rho_1 \times [I(\tau_0, -\mu)e^{-\tau_0/\mu} + V_2(-\mu)], \qquad \mu > 0,$$

$$I(\tau_0,\mu) = g_2(\mu) + \rho_2 \times [I(0, -\mu)e^{-\tau_0/|\mu|} + V_1(-\mu)], \qquad \mu < 0.$$

From this, allowing for $V_1(\mu) = V_1(-\mu)$ and $V_2(\mu) = V_2(-\mu)$, we obtain

$$I(0,\mu)|_{\mu>0} = \frac{1}{1-\rho_1\rho_2 e^{-(2\tau_0)/\mu}} \{g_1(\mu) + \rho_1[g_2(-\mu) + \rho_2 V_1(\mu)] \times e^{-\tau_0/\mu} + \rho_1 V_2(\mu)\}, \tag{64}$$

$$I(\tau_0,\mu)|_{\mu<0} = \frac{1}{1-\rho_1\rho_2 e^{-(2\tau_0)/\mu}} \times \{g_2(\mu) + \rho_2[g_1(-\mu) + \rho_1 V_1(\mu)) \times e^{-\tau_0/\mu} + \rho_2 V_1(\mu)\}. \tag{65}$$

The data, obtained by calculating the angular distribution of the emergent radiation according to relationships (57) and (58), are presented for the above initial parameters in Figs 1–4. Solid lines in these figures present the results of direct numerical integration of the radiation transfer equation. It can be seen from the figures that the error introduced by the approximate method amounts to 5%. It increases up to 20–25% for the layer of a small optical thickness ($\tau_0 < 1$) with the longitudinal distribution of temperature

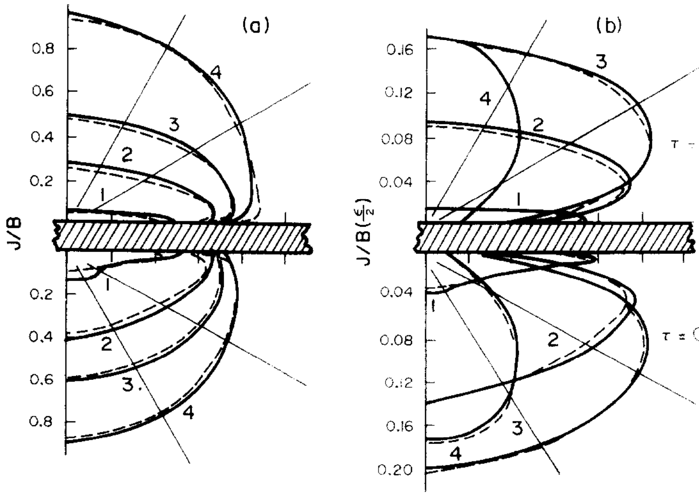

FIG. 2. Angular distribution of radiation emitting from an inhomogeneous layer for different temperature profiles [solid curves, exact calculation; dashed curves, calculation by equation (15)]: $\lambda = 0.5$; $\rho_1 = 0$, $\rho_2 = 0.5$; (a) $T = \text{const}$; (b) $T = T^a(\tau)$.

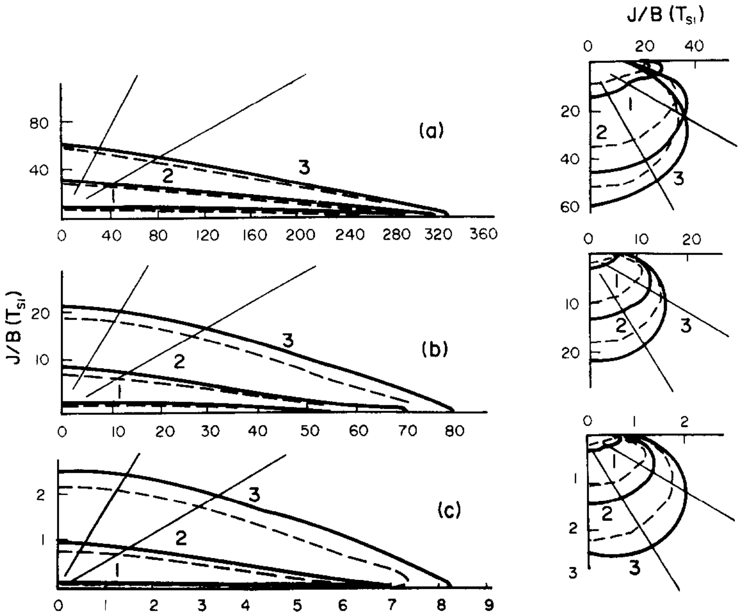

FIG. 3. Angular distribution of radiation emitting from an inhomogeneous layer for different temperature profiles [solid curves, exact calculation; dashed curves, calculation by equation (15)]: on the left side $\tau = \tau_0$, on the right side $\tau = 0$; $T = T^b(\tau)$; $\rho_1 = 0$, $\rho_2 = 0.5$; (a) $\lambda = 0.5$; (b) 0.9; (c) 0.99.

$T^b = T^b(\tau)$ (Fig. 3), but rapidly decreases with the increase in τ_0. The degree of anisotropy in the angular distribution of radiation emitting from the layer

$$r_1 = \frac{I(\tau_0, 1)}{I(\tau_0, 0)} \quad \text{or} \quad r_2 = \frac{I(0, -1)}{I(0, 0)} \tag{66}$$

depends strongly on the value of the quantum survival probability as well as on the temperature profile form, optical properties of the medium and of the boundary surfaces. A decrease in the probability of quantum survival and an increase in the optical thickness predictably results in a lower degree of anisotropy. It should be noted that in the considered cases of temperature distributions there is a pronounced effect of radiation 'blockage', i.e. 'hot' radiation is screened by the cold layers of the medium under study. This effect is the stronger, the larger the optical thickness of the layer or the larger the viewing angle.

5. CONCLUSIONS

Comparison of the data calculated by the developed approximate method with the accurate results shows

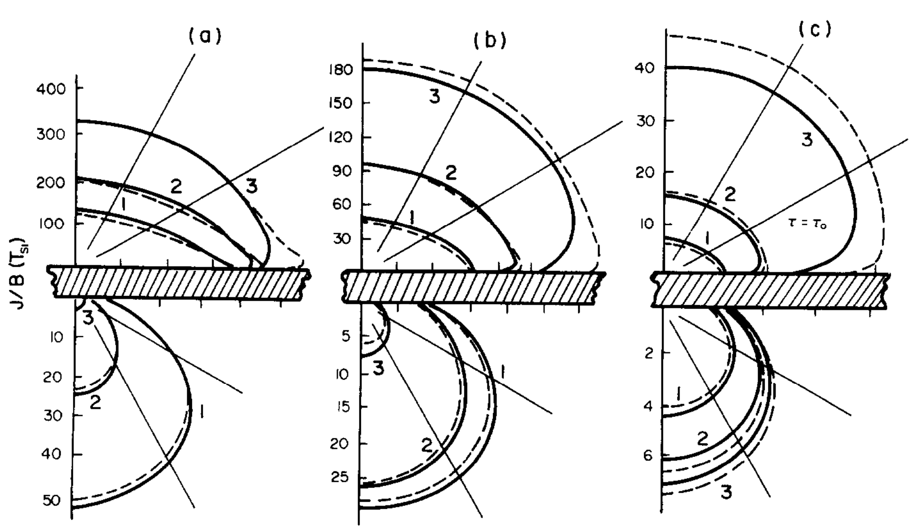

FIG. 4. Angular distribution of radiation emitting from an inhomogeneous layer for different temperature profiles [solid curves, exact calculation; dashed curves, calculation by equation (15)]: $T = T^b(\tau)$; $\rho_1 = 0$, $\rho_2 = 0.5$; (a) $\lambda = 0.5$; (b) 0.9; (c) 0.99; (1) $\tau_0 = 2$; (2) 4.0; (3) 10.0.

that it is possible to use the obtained relationships (12), (20) and (21) for a wide range of variation of parameters with an accuracy adequate for practical purposes. These relationships have an obvious physical sense. The presence of reflecting boundary surfaces reduces the error of the method. The equations reported in literature for the layer radiation characteristics follow from the general relationships as specific cases. The analysis of the emissivity of an inhomogeneous two-phase layer made it possible to correctly introduce the effective temperature which depends on optical properties of the medium and the type of temperature distribution over the layer. An equation is also obtained for the thermal efficiency of screens, which plays a major part in thermal engineering calculations.

Relations (57) and (58) make it possible to analyze the directed emissivity of an inhomogeneous two-phase layer for any temperature profile depending on optical properties of the medium and of the boundary surfaces. Specific calculations of these relations indicate their good accuracy even in the case of a very sharp temperature gradient, $T = T^b(\tau)$. The degree of anisotropy of the angular distribution of radiation emitting from the layer depends strongly on the probability of quantum survival, optical thickness of the layer and the type of the temperature profile. It should be noted in conclusion that on utilizing the convention that radiation is emitted entirely in a diffuse manner and then assuming that $\mu = 1/2$ in (57) and (58), one can obtain the direction-averaged intensities of radiation from the layer. These equations are more accurate than (12) and can be used for a more accurate determination of radiation fluxes as well as of the thermal efficiency parameter of screens, ψ.

REFERENCES

1. V. V. Sobolev, *Radiative Energy Transfer in the Atmosphere of Stars and Planets*. Gostekhizdat, Moscow (1956).
2. V. N. Adrianov, *Fundamentals of Radiative and Complex Heat Transfer*. Energiya, Moscow (1972).
3. R. Ziegel and J. R. Howell, *Thermal Radiation Heat Transfer*. Mir, Moscow (1975) (in Russian).
4. M. N. Özisik, *Complex Heat Transfer*. Mir, Moscow (1976) (in Russian).
5. V. N. Adrianov, A. G. Blokh, N. A. Rubtsov, V. P. Trofimov and B. A. Khrustalyov, Progress in the theory and methods of analysis of radiative and combination heat transfer, *J. Engng Phys.* **34**(1), 155–167 (1978).
6. K. S. Adzerikho, V. I. Antsulevich, J. K. Lapko and V. P. Nekrasov, Luminescence of two-phase inhomogeneous media of cylindrical geometry, *Int. J. Heat Mass Transfer* **22**(1), 131–136 (1979).
7. K. S. Adzerikho and V. P. Nekrasov, Calculation of luminescence characteristics of light-scattering media, Parts 1, 2. *J. Engng Phys.* **22**(1), 168–170 (1972).
8. K. S. Adzerikho and V. P. Nekrasov, Luminescence characteristics of cylindrical and spherical light-scattering media, *Int. J. Heat Mass Transfer* **18**(10), 1131–1138 (1975).
9. S. Chandrasekhar, *Radiative Energy Transfer*. IL Publ., Moscow (1953) (in Russian).
10. K. S. Adzerikho and V. P. Nekrasov, Influence of scattering anisotropy on the emission of two-phase media, *J. Engng Phys.* **34**(5), 894–896 (1978).
11. K. S. Adzerikho, *Lectures on Radiative Energy Transfer Theory*. Izd. BGU im. V. I. Lenina, Minsk (1975).
12. K. S. Adzerikho, A. G. Blokh, V. P. Trofimov and F. D. Lozhechnik, Determination of the effective temperature of a plane layer of a non-transparent medium with the emitting and reflecting walls, *Teplofiz. Vysok. Temp.* **17**(3), 544–551 (1979).
13. A. M. Samson, Angular distribution of resonant radiation emitting from a plane-parallel layer, *J. Engng Phys.* **1**(1), 65–73 (1958).
14. V. V. Mitor, *Heat Transfer in Boiler Furnaces*. Mashgiz, Moscow–Leningrad (1963).

PROPRIETES RADIATIVES D'UN MILIEU PLAN DIPHASIQUE ET NON HOMOGENE

Résumé—On développe une méthode approchée pour calculer l'intensité et les flux de rayonnement pour une couche diphasique non homogène avec des frontières émissives et réfléchissantes. En utilisant l'intégration numérique de l'équation de transfert radiatif, la précision de la méthode a été vérifiée pour un large domaine de variation des paramètres initiaux. On présente une définition générale de la température effective de la couche.

UNTERSUCHUNG DER STRAHLUNGSEIGENSCHAFTEN EINES EBENEN INHOMOGENEN ZWEIPHASENMEDIUMS

Zusammenfassung — Es wurde eine Näherungsmethode entwickelt zur Berechnung der Strahlungsintensität und der Strahlungsdichten an einer inhomogenen Zweiphasenschicht mit emittierenden und reflektierenden Grenzflächen. Unter Verwendung numerischer Integrationsverfahren für die Gleichung des Strahlungsaustausches konnte die Genauigkeit der Methode für einen weiten Variationsbereich der Ausgangsparameter festgestellt werden. Es wird eine allgemeine Definition für die effektive Temperatur der Schicht vorgeschlagen.

ИССЛЕДОВАНИЕ ХАРАКТЕРИСТИК ИЗЛУЧЕНИЯ ПЛОСКОЙ НЕОДНОРОДНОЙ ДВУХФАЗНОЙ СРЕДЫ

Аннотация — Разработан приближенный метод расчета интенсивности и потоков излучения, выходящего из неоднородного двухфазного слоя с излучающими и отражающими граничными поверхностями. С помощью численного интегрирования уравнения переноса излучения определена его точность для широкого диапазона изменения исходных данных. Приведено общее определение эффективной температуры слоя.