INFLUENCE OF THE OPTICAL THICKNESS OF AN EMITTING AND SCATTERING FLAT LAYER ON CHARACTERISTICS OF RADIATIVE HEAT TRANSFER

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Analysis is given for the dependence of density of the radiant flux incident on a heat-absorbing surface on the optical thickness of a flat emitting layer.

State-of-the-art power plants are characterized by elevated temperatures of working media which largely enhances the importance of radiative heat transfer. The latter in this case is substantially influenced by such factors as heterogeneity of a heat transfer agent, selectivity of radiation from working medium gas components, recurrence of radiation scattering on particles of the combustion product condensed phase, etc. To investigate special features of the influence of the mentioned factors on radiative heat transfer is necessary for both a more correct solution of the problems of radiant energy transfer and the study of the possibility to intensify the latter.

A radiative transfer equation in the one-dimensional statement for a flat axisymmetric layer has the form [1]:

$$\mu \frac{\partial I(x,\ \mu)}{\partial x} + (\varkappa + \sigma) I(x,\ \mu) = \frac{\sigma}{2} \int_{-1}^{1} p(x,\ \mu,\ \mu') I(x,\ \mu)\, d\mu' + \varkappa B(T). \tag{1}$$

The boundary condition must allow for the processes of radiation and reflection by a heat-absorbing surface which is set diffusing:

$$I(0,\ \mu)|_{\mu>0} = \varepsilon B[T(0)] + 2(1-\varepsilon) \int_{-1}^{0} I(0,\ \mu')\, \mu' d\mu',$$
$$I(d,\ -\mu)|_{\mu>0} = I(0,\ \mu). \tag{2}$$

As is shown in [2, 3], anisotropy of scattering can be allowed for fairly accurately by the following representation of the scattering indicatrix:

$$p(x,\ \mu,\ \mu') = a(x) + 2[1 - a(x)]\, \delta(\mu - \mu'), \tag{3}$$

where a(x) is the doubled semispherical fraction of backward scattering of radiation in its interaction with the volume element of the medium. Such representation of the scattering indicatrix enables one to reduce the solution of the problem with anisotropic scattering to the isotropic case by formally substituting $a\sigma$ for σ.

The system (1)-(3) was solved by a finite difference method. Magnitudes of the optical thickness τ, averaged over the layer Schuster number Sc, density of the radiant flux incident onto the wall Q_p, and reduced density of the incident radiant flux q, used hereinafter, were determined as follows:

$$\tau = \int_0^d \varkappa(x)\, dx,\quad \mathrm{Sc} = \frac{1}{d} \int_0^d \frac{\sigma(x)\, dx}{\varkappa(x) + \sigma(x)},$$
$$Q_p = 2\pi \int_{-1}^{0} I(0,\ \mu)\, \mu d\mu,\quad q = \frac{Q_p}{\pi B[T(0)]}.$$

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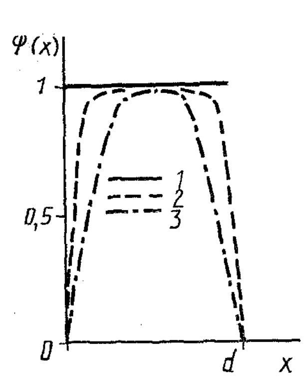


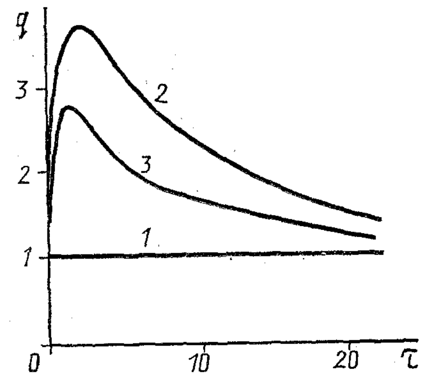
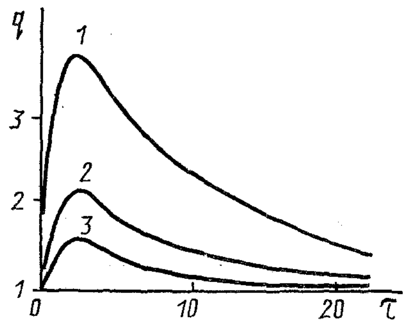


Fig. 1 Fig. 2

Fig. 1. Examples of the function $\psi(x)$ distributions, characteristic of furnaces in power plants.

Fig. 2. Influence of the optical thickness of a nonemitting layer and the form of the function ψ on the reduced density of the incident radiant flux.



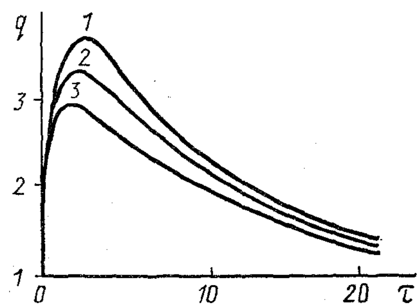


Fig. 3 Fig. 4

Fig. 3. Reduced density of incident radiant flux as a function of radiation wavelength: 1) λ = 1.35 μm; 2) 2.5; 3) 4.

Fig. 4. Influence of scattering on the incident radiant flux density: 1) Sc = 0; 2) 0.3; 3) 0.6.

The density of the radiant flux incident onto the wall substantially depends on the optical thickness of the emitting layer and on the form of the dimensionless function $\psi(x)$, which is determined by the expression

$$\psi(x) = \frac{\varkappa(x)}{\varkappa_0} \frac{T(x) - T_{\min}}{T_{\max} - T_{\min}}. \qquad (4)$$

Here $\varkappa_0$ is the maximum over the layer absorption index of the medium. In our case $T_{min} = T(0) = T(d)$ and $T_{max} = T(d/2)$. There are two forms of the function ψ: $\psi(x)$ = const and $\psi(x)$ – the function convex over the layer – characteristic of power plants. Examples of these distributions are shown in Fig. 2.

Analyzing the results of numerical experiments has enabled one to establish the following special features of the influence of the heat-transfer agent optical thickness on the radiant flux density:

1. At $\psi(x)$ = const (Fig. 1, curve 1) the reduced density of the incident radiant flux does not depend on the optical thickness τ and is equal to $q(\tau) = 1$ (Fig. 2, curve 1).

2. In the case of the function $\psi(x)$, convex over the layer, $q(\tau)$ has its pronounced maximum at a certain value of the optical thickness τ (Fig. 2, curves 2 and 3), $q(0) = 1$ and $q(\tau) \to 1$, as $\tau \to \infty$. Hereinafter this value of the optical thickness will be referred to as the critical optical thickness.

3. A value of the critical optical thickness τ_0 is independent of the wavelength λ (Fig. 3) and depends only on the form of the function $\psi(x)$ (see Fig. 1 and 2, curves 2 and 3).

4. The presence of scattering processes ($\sigma > 0$) decreases the incident flux density and the value of the critical optical thickness τ_0 (Fig. 4).

For the dependencies given in the figures the following conditions are taken: $T_{max} = 1600$ K, $T_{min} = 1300$ K, and $\varepsilon = 0.75$. The curve numbers in Fig. 2 correspond to the distribution numbers of the function $\psi(x)$. The dependencies in Fig. 3 and 4 are obtained for the function ψ distribution shown in Fig. 1 (curve 2).

The obtained results show that there exists a possibility of intensifying radiative heat transfer by changing the optical thickness of a heat-transfer agent which must be close to the critical optical thickness.

NOTATION

$I(x, \mu)$, spectral radiation intensity at the point x in the direction θ ($\mu = \cos\theta$); B(T), black body radiation intensity at temperature $T = T(x)$; $\varkappa$, σ, indexes of absorption and scattering of radiation, respectively.

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