DETERMINATION OF THE COEFFICIENT OF THERMAL EFFICIENCY OF HEATING SURFACES, BOUNDING A FLAT LAYER OF NONISOTHERMAL DISSIPATIVE MEDIUM

V. P. Trofimov and K. S. Adzerikho

UDC 536.3:535.36

A method is proposed for calculating the coefficient of thermal efficiency of flat nonisothermal dissipative media taking into account the radiative characteristics of the bounding surfaces.

In modern heating installations, the working body is a two-phase medium, consisting of a mixture of gaseous combustion products (CO_2, H_2O, CO and other molecular gases) and particles of a condensed phase (particles of soot, finely and coarsely dispersed coal, ashes) [1]. A correct analysis of the emissive properties of such heat carriers requires the use of the modern theory of radiation transfer in two-phase media [1-5, etc.]. The theoretical investigations, conducted in this direction, show that the scattering of radiation by particles of the condensed phase of the combustion products can play a substantial role, especially in cases when the size of the particles is comparable to the wavelengths of radiation in the range usually examined (0.5-10 μm). Previously, we developed an engineering method for calculating the characteristics of radiation of nonisothermal nonscattering media [6]. Using the method indicated and the correctly introduced concept of the effective temperature of the flat layer, we obtained expressions for determining the coefficient of thermal efficiency (CTE) of the surface bounding the layer [7], which permitted proposing a mathematical model of CTE of screens in the burner of a steam generator with the generator operating on gas or fuel oil [8].

For the conditions of combustion of coal dust in the burners of steam generators, the effect of scattering of radiation must be taken into account, because the sizes of ash and coke particles present in the carbon-dust flame greatly exceed the wavelength of thermal radiation. Scattering by these particles to a large extent determines the amount of the radiation falling on the bounding surface, while the nature of the layer of deposits on the screening pipes determines the structure of the effective flow of radiation from the wall.

The effect of scattering of radiation by particles of a two-phase medium can be investigated with the help of the transfer equation for a flat layer [3-5]. For the heating setups indicated above, the boundary conditions must include the reflection of radiation from the bounding surfaces and their characteristic emission $\varepsilon_i B(T_i)$ $(i=1,2)$.

In solving the radiation transfer equation, the anisotropy of scattering can be included, to a good degree of accuracy, by the following representation of the scattering phase function [9, 10]:

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

where a equals twice the hemispherical fraction of backward scattering. In this case, the problem reduces to an examination of isotropic scattering with $\sigma' = a\sigma$.

In this paper, based on the approximate solution of the radiation transfer equation presented in [11] and the relations for the effective temperature of a flat layer of a nonisothermal two-phase medium [12], we propose a method for determining the CTE of the surfaces bounding such media.

According to [11], the expression for the CTE of the bounding surfaces can be represented in the form

$$\Psi = (1-r)\left[1 - \frac{b}{N(r) + (1-r)bM(r)}\right], \tag{1}$$

A. V. Lykov Institute of Heat and Mass Transfer. Institute of Physics, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 46, No. 5, pp. 761-768, May, 1984. Original article submitted February 27, 1983.

 0022-0841/84/4605-0548$08.50

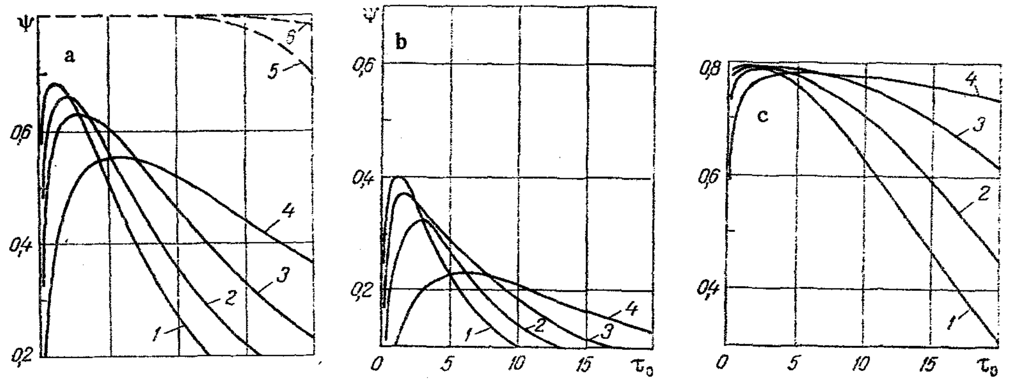

Fig. 1. Dependence $\Psi(\tau_0, \gamma)$ for a layer with a Shlichting temperature profile [6] and radiation properties of the boundary surfaces $\varepsilon_w = 0.8$ and $r = 0.2$: a) $\Theta_c=5\cdot10^{-3}$ m·K (continuous curves), $\Theta_c=1\cdot10^{-3}$ m·K (dashed curves), $\Theta_c/\Theta_w=2$; b) $\Theta_c=15\cdot10^{-3}$ m·K, $\Theta_c/\Theta_w=2$; c) $\Theta_c=5\cdot10^{-3}$ m·K, $\Theta_c/\Theta_w=3$; 1) $\gamma = 0$; 2) 0.5; 3) 0.8; 4) 0.95.

where

$$N(r)=\frac{(1-S)(1-e^{-k\tau_0})}{1-rS+(S-r)e^{-k\tau_0}};$$

$$M(r)=\frac{S(1-rS)+(1-S^2)e^{-k\tau_0}-(S-r)e^{-2k\tau_0}}{(1-rS)^2-(S-r)^2e^{-2k\tau_0}};$$

$$S=\frac{2-k}{2+k}=\frac{1-\sqrt{1-\gamma}}{1+\sqrt{1-\gamma}},\quad b=\frac{1}{(e^{C_2/\lambda T_w}-1)A}; \tag{2}$$

$$A=\frac{k}{1-e^{-k\tau_0}}\int_0^{\tau_0}\frac{e^{-k(\tau_0-\tau')}}{e^{C_2/\lambda T(\tau')}-1}\,d\tau'.$$

Calculations of CTE using these formulas were performed for two types of temperature profiles in the layer: 1) a Shlichting profile $T_1(\tau)$, i.e., the temperature profile in an established turbulent flow, and 2) trapezoidal profiles $T_6(\tau)$ and $T_8(\tau)$, when the maximum value of the temperature is conserved in the core whose size is 50 and 90% of the total optical thickness of the layer, respectively.

An analysis of the computed data obtained indicates the strong effect of radiation scattering on the CTE of the bounding surfaces. Figure 1 shows graphs of the characteristic dependences $\Psi = \Psi(\tau_0, \gamma)$ for Shlichting's temperature profile (temperature profile in an established turbulent flow) for different values of the starting parameters. It is evident from Fig. 1 that if, in the region of large values in the range of optical thickness of the layer τ_0 under examination, the function Ψ increases compared to the nonscattering medium, then for small τ_0 the value of the CTE decreases considerably. These qualitative changes in the dependence of the CTE of the bounding surfaces on the optical thickness of the scattering medium can be explained by the fact that for a purely radiating medium the intensity of the radiation incident on the wall (and, therefore, the CTE also) increases quite rapidly with an increase in the optical thickness of the layer for small values of τ_0 [13]. In the case of a scattering medium, the effective hemispherical emissivity of the layer (and, this is precisely what determines the intensity of the radiation, leaving the layer and incident on the wall) in this region of optical thicknesses, due to trapping of the radiation, increases more slowly with increasing τ_0. As the coefficient γ increases, this leads to a drop in the maximum value of the CTE depending on $\Psi(\tau_0)$ and the shift in the values of τ_0, with which $\Psi = \Psi_{max}$, toward larger optical thicknesses of the layer.

The computed data for CTE, with and without scattering, for different temperature distributions and optical thicknesses of the two-phase medium are compared in Table 1.

It is evident from the table presented that due to the scattering by particles of the solid phase the values of the CTE of the heat-absorbing surfaces, for example, under conditions of heat exchange in burners of the steam generators (emitting volumes with optical

TABLE 1. Comparison of the Computed Values of the CTE of a Bounding Surface with and without Scattering of Radiation with $\varepsilon_W = 0.8$ and $r = 0.2$

$T_i(\tau)$	Θ_C/Θ_W	Θ_C, m·K	τ_0 = 0,5	0,8	1,0	2	5	20
			$\Psi\|_{\gamma=0,5}/\Psi\|_{\gamma=0}$					
$T_1(\tau)$	2	$5\cdot10^{-3}$	0,918	0,922	0,935	0,995	1,120	1,495
		$15\cdot10^{-3}$	0,781	0,846	0,871	0,974	1,184	1,460
	3	$5\cdot10^{-3}$	0,992	0,996	0,997	1,000	1,018	1,144
		$15\cdot10^{-3}$	0,883	0,921	0,942	0,990	1,136	1 429
$T_6(\tau)$	2	$5\cdot10^{-3}$	—	0,966	0,973	0,993	1,033	1,471
		$15\cdot10^{-3}$	—	0,868	0,891	0,963	1,077	1,494
	3	$5\cdot10^{-3}$	—	0,997	0,997	1,000	1,004	1,165
		$15\cdot10^{-3}$	—	0,944	0,955	0,985	1,039	1,403
$T_8(\tau)$	2	$5\cdot10^{-3}$	—	0,973	0,977	0,989	0,995	1,019
		$15\cdot10^{-3}$	—	0,881	0,901	0,946	0,972	1,049
	3	$5\cdot10^{-3}$	—	0,999	0,999	1,000	1,000	1,001
		$15\cdot10^{-3}$	—	0,953	0,962	0,980	0,990	1,022
			$\Psi\|_{\gamma=0,95}/\Psi\|_{\gamma=0}$					
$T_1(\tau)$	2	$5\cdot10^{-3}$	0,205	0,364	0,472	0,526	0,715	3,740
		$15\cdot10^{-3}$	0,093	0,151	0,248	0,428	1,022	3,380
	3	$5\cdot10^{-3}$	0,885	0,925	0,940	0,972	1,021	2,350
		$15\cdot10^{-3}$	0,280	0,374	0,430	0,621	1,052	3,110
$T_6(\tau)$	2	$5\cdot10^{-3}$	—	0,594	0,645	0,793	0,973	2,350
		$15\cdot10^{-3}$	—	0,253	0,293	0,468	0,850	2,780
	3	$5\cdot10^{-3}$	—	0,960	0,967	0,987	1,000	1,288
		$15\cdot10^{-3}$	—	0,464	0,518	0,629	0,933	2,240
$T_8(\tau)$	2	$5\cdot10^{-3}$	—	0,065	0,701	0,824	0,917	0,993
		$15\cdot10^{-3}$	—	0,280	0,324	0,482	0,690	0,919
	3	$5\cdot10^{-3}$	—	0,970	0,976	0,989	0,995	1,000
		$15\cdot10^{-3}$	—	0,516	0,570	0,724	0,861	0,915

thickness of the order of $\tau_0 \approx 1$), decrease appreciably with an increase of the scattering properties of the combustion products. Thus, for $\gamma = 0.5$ the maximum drop in Ψ was 13%, whereas for $\gamma = 0.95$ it already reached 75%, i.e., the relative CTE of the heating surface in the case of the nonscattering medium with the same physical parameters, the magnitude of Ψ decreased by a factor of four. We should emphasize the role of the profile of the temperature field, which greatly decreases the effect of scattering on the CTE of the heating surfaces for the region of variation of τ_0 under study. As far as the appreciable quantitative increase in the ratio $\Psi|_{\gamma=0,95}/\Psi|_{\gamma=0}$ for the profiles $T_1(\tau)$ and $T_6(\tau)$ with large optical thicknesses is concerned, this is related to the very small values of the CTE for surfaces, bounding the layer of nonscattering medium in this range of τ_0.

It should be noted that the analysis indicated above was conducted with the reduced temperature in the profile varying in the range $\Theta_C = 5-15\cdot10^{-3}$ m·K. Above the upper limit $\Theta_C = 15\cdot10^{-3}$ m·K, there is no sense in examining the problem of determining the CTE, because in this case for the range of thermal radiation λ = 0.5-10 μm the coefficient Ψ assumes extremely low values due to the trapping effect. For $\Theta_C < 5\cdot10^{-3}$ m·K, the values of the CTE of the heat-absorbing surface reach large magnitudes. Thus, already with $\Theta_C = 1\cdot10^{-3}$ m·K, the quantity Ψ has a maximum value equal to 0.8, for the specific conditions of the calculation presented in Fig. 1a, almost in the entire range of τ_0 examined for nonscattering media (curve 5) and even for scattering media with $\gamma < 0.5$ (curve 6). From this fact we can conclude that for the given temperature distribution the higher spectral value of Ψ will be achieved when the thermal radiation is shifted into the short-wavelength region, based on the definition of the reduced temperature $\Theta = \lambda T$ [6].

The method developed for determining the radiation characteristics in both nonisothermal scattering [12] and nonisothermal nonscattering media [6, 13] permits directly analyzing their spectral dependence. The numerical results and graphs, used as nomograms, presented in the references indicated, make it possible to make a correct estimate of the radiation characteristics of the two-phase media for realistic conditions, occurring in the combustion

TABLE 2. Values of the Optical Thicknesses of Absorption by Molecular Gases in the Section of the Burner

λ, μm	$\tau^{\varkappa}_{CO_2}$	$\tau^{\varkappa}_{CO}$	$\tau^{\varkappa}_{H_2O}$	$\tau^{\varkappa}_{g}$
1,82	0	0	0,62	0,62
2,27	0	0	0,06	0,06
2,70	0	0	8,30	8,30
4,00	0	0	0,06	0,06
4,26	590	2,37	1,22	596
4,65	2,90	1,34	0,72	4,96
5,00	0,02	0,87	2,55	3,45

TABLE 3. Values of the Optical Thicknesses of Absorption and Scattering $\tau^{\varkappa}_{p}$ and τ^{σ}_{p} by Particles in the Section of the Burner

λ, μm	$\tau^{\varkappa}_{soot}$	$\tau^{\sigma}_{soot}\tau^{\varkappa}_{ash}$	τ^{σ}_{soot}	$\tau^{\varkappa}_{p}$	τ^{σ}_{p}
1,82	0,35	0	0,45	0,35	0,45
2,27	0,25	0	0,65	0,25	0,65
2,70	0,19	0	0,45	0,19	0,45
4,00	0,10	0	0,78	0,10	0,78
4,26	0,09	0	0,76	0,09	0,76
4,65	0,08	0	0,83	0,08	0,83
5,00	0,07	0	0,87	0,07	0,87

chambers of modern heating installations. As an example, we shall analyze the spectral coefficient of the thermal efficiency of screened heating surfaces in burners of steam generators.

Example. We shall examine a burner with a rectangular cross section, whose depth constitutes a_t = 10 m and whose width b_t greatly exceeds the depth. Such conditions are realized, in particular, in the burners of TGMP-1202 ($b_t/a_t \approx 3$), P-57 (≈ 2.2) and other steam generators. In this case, we can use the method to calculate the characteristics of the radiation in a given section of the burner in the approximation of a flat layer. We shall select the starting data for the calculation as follows: the effective temperature in the section of the burner T_{eff}=1500°K; the emissivity of the screened surface ε_W = 0.8, and the reflectivity r = 0.2; the partial pressure of the gaseous components of the combustion products P_{CO_2} = 0.15; P_{CO} = 0.01 and P_{H_2O} = 0.11 atm.

We shall calculate the coefficient of thermal efficiency of the screens for two types of temperature profiles for the medium in the section of the burning space under examination (according to the depth of the burner) $T_6(\tau)$ and $T_8(\tau)$ [6] for the spectral range λ = 1.3-5.0 μm. The number of computed points in this region of the spectrum is 15.

The optical thicknesses of each of the gases was determined with the help of an approximating expression of the form

$$\tau^{\varkappa}_{gj} = \varkappa_j L = \frac{L}{t} \exp\left(A^{\lambda}_j + \frac{B^{\lambda}_j}{t} + \frac{C^{\lambda}_j}{t^2}\right) \frac{300}{T} P_j (j = 1,\ 2,\ 3), \tag{3}$$

where L is the geometric thickness of the layer, t = T/1000 is the dimensionless temperature parameter; T is the gas temperature, °K; A, B, and C are the coefficients in the approximation for the coefficients of absorption of the molecular gases, obtained from the analysis of data in the literature and are functions of the wavelength of the radiation λ; j = 1 — H_2O, j = 2 — CO_2, j = 3 — CO. The results of the calculation of $\tau^{\varkappa}_{r}$ for the starting data indicated above are presented in Table 2.

For a steam generator burning solid fuel, the combustion products contain particles of soot and ash, which contribute both to absorption and scattering of radiation. For each separate type of particle, the optical thicknesses were determined from the formulas

$$\tau^{\varkappa}_{pk} = \pi r^2_{pk} N_{pk} K_{pk} K^{\varkappa}_{pk} L, \quad \tau^{\sigma}_{pk} = \pi r^2_{pk} N_{pk} K^{\sigma}_{pk} L \ (k = 1,\ 2), \tag{4}$$

TABLE 4. Values of the Coefficients of Thermal Efficiency $\Psi(\lambda)$ of Screened Heating Surfaces in the Burner of a Steam Generator as a Function of the Composition of the Combustion Products

λ, μm	1) Gas				2) Gas + soot				3) Gas + soot + ash			
	τ_0	γ	Ψ		τ_0	γ	Ψ		τ_0	γ	Ψ	
			$T_6(\tau)$	$T_8(\tau)$			$T_6(\tau)$	$T_8(\tau)$			$T_6(\tau)$	$T_8(\tau)$
1,38	0.62	0	0,70	0,72	1,09	0	0,73	0,75	1,66	0,34	0,72	0,74
1,44	1,91	0	0,72	0,75	2,36	0	0,72	0,75	2,93	0,19	0,71	0,74
1,48	0,37	0	0,45	0,40	0,83	0	0,72	0,75	1,36	0,39	0,72	0,75
1,82	1,15	0	0,73	0,75	1,50	0	0,73	0,75	1,96	0,23	0,72	0,75
1,90	0,91	0	0,73	0,75	1,23	0	0,73	0,75	1,74	0,29	0,72	0,75
2,27	0,06	0	0	0	0,31	0	0,35	0,35	0,96	0,68	0,68	0,71
2,53	6,66	0	0,61	0,74	6,87	0	0,60	0,74	7,46	0,08	0,59	0,74
2,67	7,74	0	0,58	0,74	7,93	0	0,57	0,74	8,41	0,06	0,56	0,73
2,70	8,30	0	0,55	0,73	8,49	0	0,55	0,73	9,94	0,05	0,50	0,73
2,90	7,82	0	0,57	0,73	7,99	0	0,57	0,73	8,36	0,04	0,56	0,73
3,50	0,35	0	0,41	0,38	0,47	0	0,50	0,50	1,05	0,55	0,71	0,73
4,00	0,06	0	0	0	0,16	0	0	0	0,94	0,83	0.65	0,68
4,26	596	0	0	0	596	0	0	0	597	0	0	0
4,65	4,96	0	0,66	0,74	5,04	0	0,66	0,74	5,87	0,14	0,64	0,74
5,00	3,45	0	0,70	0,75	3,52	0	0,70	0,75	4,39	0,20	0,68	0,74

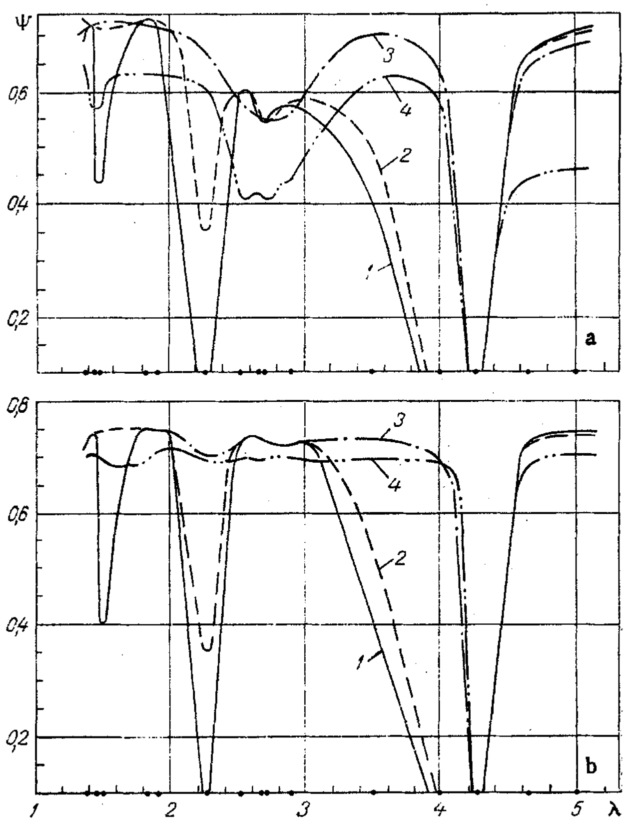

Fig. 2. Spectral dependence of Ψ of the bounding surface, bounding the flat layer of medium with temperature profile $T_6(\tau)$ (a) and $T_8(\tau)$ (b) [6]: 1) gas; 2) gas + soot; 3) gas + soot + ash; 4) gas + soot + ash (Table 5). λ, μm.

where r_{pk} and N_{pk} are the radius and concentration of the k-th type of particle; $K^{\varkappa}$ and K^{σ} are the efficiency factors for absorption and scattering, determined in accordance with Mie's theory; k = 1 for soot particles; k = 2 for ash particles.

The results of the calculation of $\tau_{pk}^{\varkappa}$ and τ_{pk}^{σ} using formulas (4) for soot particles (r_{soot} = 0.02 μm; $N_{soot} = 4 \cdot 10^8$ 1/cm^3) and ash particles (r_{ash} = 2.5 μm, $N_{ash} = 10^3$ 1/cm^3) are presented in Table 3.

TABLE 5. Values of the Averaged Coefficient of Thermal Efficiency $\bar{\Psi}$ of the Heating Surface as a Function of the Composition of the Burner Medium

No.	Composition of the burner medium	$\bar{\Psi}$	
		$T_6(\tau)$	$T_8(\tau)$
1	Gas (composition 1)	0,42	0,46
2	Gas + soot (composition 2)	0,47	0,53
3	Gas + soot (composition 2) + ash ($N_{ash} = 1 \cdot 10^3$ 1/cm^3)	0,60	0,66
4	Gas + soot (composition 2) + ash ($N_{ash} = 2 \cdot 10^4$ 1/cm^3)	0,49	0,63

The particle sizes, for convenience in the example, are chosen according to available data for a realistic carbon–dust flame in the burner of a steam generator in such a way that some particles make the greatest contribution to the attenuation of radiation in the layer to absorption (soot) and the others make the greatest contribution in scattering (ashes). Having information on the values of $\tau^{\varkappa}$ and τ^{σ}, it is not difficult to calculate the corresponding values of the survival probability of a quantum:

$$\gamma = \frac{\tau^{\sigma}}{\tau_0} = \frac{\tau^{\sigma}}{\tau^{\varkappa} + \tau^{\sigma}} = \frac{\tau_p^{\sigma}}{\tau_g^{\varkappa} + \tau_p^{\varkappa} + \tau_p^{\sigma}} = \gamma(\lambda). \quad (5)$$

Using the dependence $\Psi = \Psi(\tau_0, \gamma)$ obtained in this work (or the curves, analogous to those presented in Fig. 1, but calculated for the temperature distributions $T_6(\tau)$ and $T_8(\tau)$ with $\Theta_c = 5 \cdot 10^{-2}$ m·K, $\Theta_c/Q_w = 2$), we can determine the spectral coefficient of thermal efficiency $\Psi(\lambda)$ for the conditions indicated in the burners. Table 4 shows the data from the calculation of $\Psi(\lambda)$ for boundary surfaces of a flat layer for the following media:

1) gas (T = 1500°K; $P_{CO_2} = 0.15$; $P_{CO} = 0.01$; $P_{H_2O} = 0.11$);

2) gas (composition 1) + soot ($r_{soot} = 0.02$ μm; $N_{soot} = 4 \cdot 10^8$ 1/cm^3);

3) gas + soot (composition 2) + ash ($r_{ash} = 2.5$ μm; $N_{ash} = 10^3$ 1/cm^3).

Figure 2 shows graphically the dependence $\Psi(\lambda)$ for the indicated temperature distributions. As expected, the dependence $\Psi(\lambda)$ for $T_6(\tau)$ in the case of only a gaseous medium (continuous curves in Fig. 2) has, in this range, three distinct minima (λ = 1.48; 2.27 and 4.26 μm). For a burner medium, containing additionally soot (composition 2, dashed curves in the graph), the numerical values of Ψ increase in almost the entire range of wavelengths, and in addition, the first of the minima mentioned vanishes, and the second decreases almost by a factor of two. The appearance of ashes in the combustion products (composition 3, dot–dashed curve) leads to an even greater growth of Ψ in separate intervals of the spectrum; in addition, the second minimum vanishes and the interval of minimum values of Ψ in the region of λ = 4.26 μm is greatly reduced. We can see at the same time that a small minimum has formed in the region of 2.7 μm.

It should be noticed, however, that the increase in the number of ash particles in the burner of a steam generator does not always lead to further growth of the numerical values of Ψ in this interval of λ. As a confirmation, we present the dependence $\Psi(\lambda)$ of screens for a burner medium, in which the ash concentration is 20 times greater than with the composition 3 ($N_{ash} = 2 \cdot 10^4$ 1/cm^3). This content of ash greatly decreased the numerical values of Ψ in the entire range of radiation wavelengths examined. The minimum, formed as a result of the presence of a volatile ash in the burner gases, in the region of 2.7 μm in the dependence $\Psi(\lambda)$ is in this case even more distinct.

Thus the dependence of the coefficient of thermal efficiency $\Psi(\lambda)$, taking into account the spectral distribution of the radiation properties of the combustion products in the burner of a steam generator, has an explicitly selective character. Averaging of Ψ with respect to λ in different intervals of the radiation spectrum should lead to different average values of $\bar{\Psi}$. Averaging performed in the range examined λ = 1.3–5.0 μm gave the values of $\bar{\Psi}$ presented in Table 5.

In conclusion, we note that the proposed method for calculating the CTE of the heating surfaces permits determining, as a function of the composition and temperature field, this very important parameter of heat exchange in nonisothermal two-phase media for complicated processes, such as combustion in burners of steam generators.

NOTATION

Ψ, coefficient of thermal efficiency (CTE) of the heating surface; ε and r, emissivity and reflectivity; $\tau=(\varkappa+\sigma)x$, optical thickness of the layer; $\varkappa$ and σ, coefficients of absorption and scattering of the medium; $\gamma=\sigma/(\varkappa+\sigma)$, survival probability of a quantum (Schuster's number); x, geometrical thickness of the layer; $\tau^{\varkappa}$ and τ^{σ}, optical thicknesses of the absorbing and scattering media; τ_g and τ_p, optical thickness of the gaseous media and of the particles in the layer; $\tau_0=\tau_g^{\varkappa}+\tau_p^{\varkappa}+\tau_p^{\sigma}$, total optical thickness of the layer; $\Theta=\lambda T$, reduced temperature; λ, wavelength of the radiation; C_2, spectroscopic constant. The indices w and c refer to the bounding surface (wall) and the center of the layer, respectively.

LITERATURE CITED

1. A. G. Blokh, Thermal Radiation in Boilers [in Russian], Énergiya, Leningrad (1967).
2. A. S. Nevskii, Radiation Heat Transfer in Furnaces and Burners [in Russian], Metallurgiya, Moscow (1971).
3. V. N. Andrianov, Foundations of Radiative and Complex Heat Transfer [in Russian], Énergiya, Moscow (1972).
4. M. N. Otsisik, Complex Heat Transfer [Russian translation], Mir, Moscow (1976).
5. K. S. Adzerikho, Lectures from the Theory of Transfer of Radiant Energy [in Russian], V. I. Lenin Belorussian State University, Minsk (1975).
6. V. P. Trofimov and K. S. Adzerikho, "Radiative heat transfer in nonisothermal radiant media," Preprint No. 6, Inst. Heat and Mass transfer, Academy of Sciences of the Belorussian SSR, Minsk (1981).
7. V. P. Trofimov and K. S. Adzerikho, "Determination of the coefficient of thermal efficiency of surfaces, bounding a flat layer of nonisothermal nonscattering medium," Inzh.-Fiz. Zh., 39, No. 1, 102-108 (1980).
8. A. G. Blokh, K. S. Adzerikho, and V. P. Trofimov, "Coefficient of thermal efficiency of screens in the burners of steam generators," Inzh.-Fiz., Zh., 40, No. 5, 854-863 (1981).
9. K. S. Adzerikho and V. P. Nekrasov, "Calculation of the characteristics of the luminescence of light-scattering media, Pts. I and II," Inzh.-Fiz. Zh., 22, No. 1, 168-170 (1972).
10. K. S. Adzerikho and V. P. Nekrasov, "Effect of the anisotropy of scattering on the emission of a two-phase medium," Inzh.-Fiz. Zh., 34, No. 5, 894-896 (1978).
11. K. S. Adzerikho and V. I. Antsulevich, "Study of radiation properties of a plane inhomogeneous two-phase medium," Int. J. Heat Mass Transfer, 24, No. 1, 57-67 (1981).
12. V. P. Trofimov and K. S. Adzerikho, "Calculation of the effective temperature of a flat layer of a radiating scattering medium taking into account the radiative properties of the bounding surface," in: Heat and Mass Transfer Research and Development [in Russian], Inst. Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk (1981), pp. 101-106.
13. V. P. Trofimov and K. S. Adzerikho, "Calculation of the effective emissivity of flat nonisothermal media with radiating and reflecting bounding surfaces," Teplofiz. Vys. Temp., 19, No. 1, 149-153 (1981).