We have thus tested a simple, economical, and effective method of reducing the contact resistance in VSI. The main effect is obtained with PET film inserts. The optimum temperature, time, and packing density have been established.

NOTATION

d, pipe diameter; n, number of screens; R_c, contact resistance; T, insulation heating temperatures; δ_i, insulation thickness; λ, thermal conductivity; ρ, packing density.

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ANALYSIS OF THE ACCURACY FOR SOLVING PROBLEMS OF RADIANT HEAT EXCHANGE IN SYSTEMS WITH A SELECTIVELY RADIATING MEDIUM

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UDC 536.3

The error in determining the resulting heat fluxes is investigated numerically in a system of bodies for a gray model and a selectively gray model of radiation.

An effective solution of problems of radiant heat exchange in systems with radiant and absorbing media can be carried out by zonal methods. The radiant medium and surrounding surfaces are divided into separate three-dimensional and surface zones, in which the temperature and thermal properties of the radiating objects are assumed to be constant [1, 2]. In this way integral equations can be reduced to algebraic equations, with the number of equations being equal to the number of zones. With increase in accuracy of calculations the number of zones increase sharply and can reach 40-50 in calculating flare burning.

If organic fuels serve as a source of energy, then, when they burn, gaseous CO_2 and H_2O are formed, which have appreciably selective spectra of absorption and radiation. In a selective-gray approximation the entire spectrum is divided into separate bands, inside of which the absorption coefficient is assumed to be constant (usually, 10-12 bands), and the system of zonel equations is solved for each band.

When solving problems with variable temperatures of volumes and surfaces (for example, heating and cooling articles in furnaces), the radiant heat fluxes should be determined at each step of time. This increases considerably the volume of calculations both when constructing matrices of the systems of linear equations of the zonal method (determining the generalized angular coefficients), and also when solving these systems.

Therefore, an increase in the accuracy of determining heat fluxes in a radiating system by using a more detailed description of the process can lead to a volume of calculations that exceeds considerably the possibilities of even contemporary computers, especially for problems with variable temperatures of surfaces and volumes.

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A reasonable way out from the situation is a simplification of the problem of radiant heat exchange, in particular, a less detailed consideration for the selectivity of absorption. However, a complete investigation of the accuracy of calculations according to different models has not yet been given in the literature; moreover, the existing estimates for calculating the effect of different factors on accuracy contradict sufficiently each other [3-5].

In this work, a comparative analysis of three models of radiation is given: the approximation of gray angular coefficients [1], the approximation of selective-gray angular coefficients [6], and also the selective-gray approximation [2]. All variants of the calculations assume that the radiation obeys the laws of Bouguer and Lambert [1], and the surfaces are gray bodies.

In general form, the system of zonal equations for each band of absorption can be written as

$$-\frac{q_{pi}^{\Delta\lambda_j}}{a_i}+\sum_{k=1}^{n}\frac{r_k}{a_k}\psi^{\Delta\lambda_j}(i,\ k)\,q_{pk}^{\Delta\lambda_j}=-\psi_{F-V}^{\Delta\lambda_j}q_{cV}^{\Delta\lambda_j}-\sum_{k=1}^{n}\psi^{\Delta\lambda_j}(i,\ k)\,q_{ck}^{\Delta\lambda_j}+q_{ci}^{\Delta\lambda_j}, \tag{1}$$

$$i=1,\ \ldots,\ n;\ j=1,\ \ldots,\ l\ (l\approx 10\div 12).$$

Here, a gas volume is assumed to be isothermic and the number of equations to be equal to $n\cdot l$. In the case of the gray approximation, one system of n equations is to be solved.

The natural heat fluxes are determined from the Planck law of radiation

$$q_c^{\Delta\lambda_j}=\int_{\lambda_j}^{\lambda_{j+1}}\frac{C_1\lambda^{-5}}{\exp(C_2/\lambda T)-1}\,d\lambda. \tag{2}$$

For the gray approximation

$$q_c=\sigma_0 T^4. \tag{3}$$

We write system (1) in the matrix form

$$\begin{pmatrix} a_{11} & \ldots & a_{1n} \\ \ldots & \ldots & \ldots \\ a_{n1} & \ldots & a_{nn}\end{pmatrix}\begin{pmatrix} q_{p1} \\ \ldots \\ q_{pn}\end{pmatrix}=\begin{pmatrix} b_1 \\ \ldots \\ b_n\end{pmatrix}$$

or

$$(A)_{\Delta\lambda_j}(Q)_{\Delta\lambda_j}=(B)_{\Delta\lambda_j}, \tag{4}$$

wherefrom the resulting heat fluxes for each band are determined as

$$(Q)_{\Delta\lambda_j}=(A)_{\Delta\lambda_j}^{-1}(B)_{\Delta\lambda_j}. \tag{5}$$

As a pattern for investigation, we consider a system of radiating and absorbing bodies consisting of two surfaces with different absorptivities and the isothermic gas volume given in Fig. 1. The calculations were performed for the following values of parameters: R = 0.5; 2.0; 4.0 m; $a_1 = 0.9$; $a_2 = 0.7$; $p_{CO_2} = 0.1$; $p_{H_2O} = 0.2$ N/m^2 and for different values of the surface temperatures. The "gray" and "selective" angular coefficients were calculated by the method developed in [6]. The integrals in [2] were calculated by Simpson's method with automatic selection of the interval [7], systems of type (1) were solved by the method of the inverse matrix. In calculations according to the selective-gray model the entire spectrum of radiation was divided into 10 bands in a manner similar to that presented in [6]. The total coefficient of absorption in the band was calculated from Eq. (6):

$$k_{\Delta\lambda_j}=k_{CO_2}^{\Delta\lambda_j}p_{CO_2}+k_{H_2O}^{\Delta\lambda_j}p_{H_2O}. \tag{6}$$

In order to determine $k_{CO_2}^{\Delta\lambda j}$ and $k_{H_2O}^{\Delta\lambda j}$, the approximation of the effective bandwidth was used, according to which $k_{CO_2}^{\Delta\lambda j}$ and $k_{H_2O}^{\Delta\lambda j}$ in each band of absorption was determined as $\overline{\alpha}/\Delta\omega$, $k_{CO_2}^{\Delta\lambda j}$ and $k_{H_2O}^{\Delta\lambda j}$ was equal to 0 [8] out of the bands (in nonabsorbing bands).

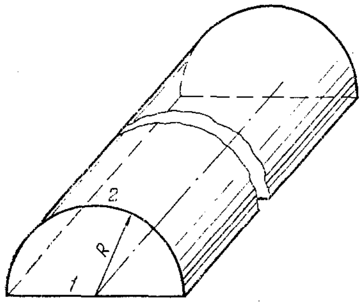

Fig. 1. Radiating surfaces.

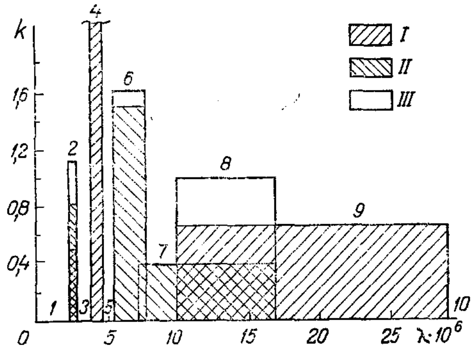

Fig. 2. Spectral ranges of the radiating gas: I) $k_{CO_2} \cdot p_{CO_2}$; II) $k_{H_2O} \cdot p_{H_2O}$; III) k, $\lambda \cdot 10^6$, m; k, m^{-1}.

In Fig. 2, the quantities $k_{CO_2}p_{CO_2}$ and $k_{H_2O}p_{H_2O}$ and also the total coefficient of absorption $k_{\Delta\lambda_j}$ are presented as functions of the wavelength for the gas temperature T_V = 1237 K. The numbers 1-10 designate the numbers of the selected spectral ranges. They are chosen in correspondence with the magnitudes of the absorption bands for the CO_2 and H_2O gases. For the rest of the values of gas temperature, the spectral ranges were selected in a similar way.

The time of calculation of the resulting heat fluxes in the approximation of "gray" and "selective-gray" angular coefficients was equal to ≈1 min, while that for the selective-gray approximation was equal to ≈15 min on the ES-1022 computer.

Figure 3 shows the dependences of the resulting heat fluxes for surfaces 1 and 2 (see Fig. 1) on the gas temperatures for different values of the parameter R and basic surface temperatures: T_1 = 500°C and T_2 = 1000°C. The calculations performed for other surface temperatures do not differ qualitatively from those for the basic temperatures and are not given in the present work.

It should be noted that with increase in the parameter R the path length of the ray and the reduction in the energy of radiation vary. Therefore, computations with different R reveal a dependence of the resulting heat fluxes on the optical and geometrical parameters of heat exchange.

It is seen from Figs. 1, 2, and 3 that all three models reflect the same basic tendencies of distribution of the resulting heat fluxes in the radiating system. Thus, with increase in temperature of the radiating gas, the resulting heat flux toward the lower-temperature surface increases constantly, while the flux toward the higher-temperature surface changes sign, with the sign changing at a lower gas temperature when the path length of the ray (parameter R) increases.

At the same time, the absolute values of the heat fluxes can differ by 20-25%, which can serve as an estimate of the accuracy of calculations according to the gray model.

In Table 1 the values of the resulting heat fluxes are given in different bands of radiation. As is seen, the principal contribution to the total heat exchange is from bands 1-6.

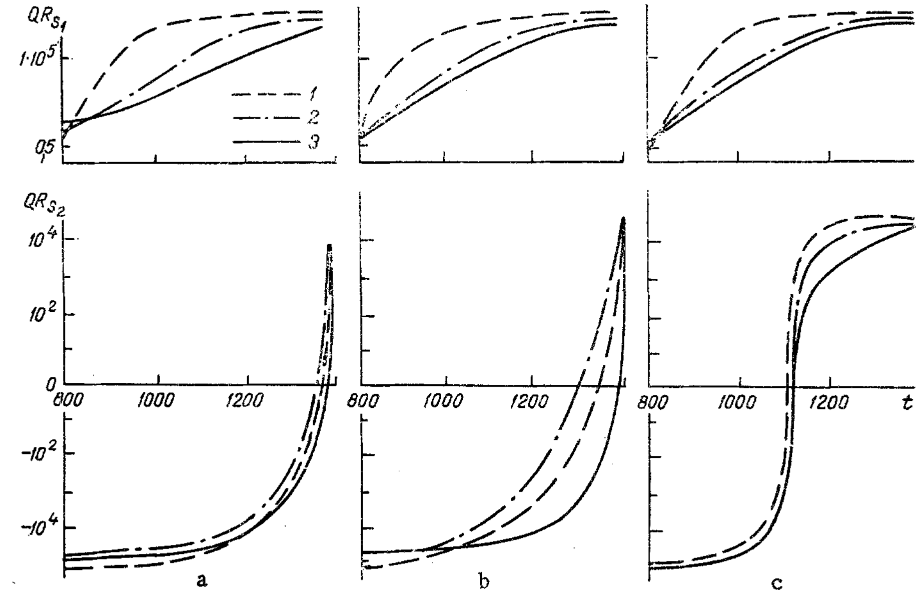

Fig. 3. Dependence ofthe resulting heat flux for surfaces 1 (q_{p1}) and 2 (q_{p2}) on the temperature of the gas volume [a) R = 0.5 m; b) 2.0; c) 4.0]; 1) selective-gray approximation; 2) selective-gray generalized angular coefficients; 3) gray generalized angular coefficients. t, °C; QR_{S1}, W/m².

TABLE 1. Heat Fluxes on the Surface in Different Bands of Radiation (R = 2.0)

Gas temp., °C	Band boundaries, heat fluxes		Band, number 1	2	3	4	5
1000	Band boundaries, μm	Lower	0,2	0,25	0,290	0,387	0,485
		Upper	0,25	0,290	0,387	0,485	0,528
	Heat fluxes, $q \cdot 10^{-4}$, W/m²	1	2,2	2,3	2,7	2,2	0,48
		2	—2,3	—6,6	—2,9	0	—0,51
1200	Band boundaries, μm	Lower	0,2	0,25	0,296	0,386	0,487
		Upper	0,25	0,293	0,386	0,487	0,523
	Heat fluxes, $q \cdot 10^{-4}$, W/m²	1	2,2	4,3	2,6	3,5	0,44
		2	—2,3	2,3	—2,8	1,7	—0,46
1400	Band boundaries, μm	Lower	0,2	0,25	0,29	0,38	0,489
		Upper	0,25	0,29	0,384	0,489	0,519
	Heat fluxes, $q \cdot 10^{-4}$, W/m²	1	2,2	5,9	2,8	5,2	0,34
		2	—2,3	4,6	—2,9	3,7	—0,36

Gas temp., °C	Band boundaries, heat fluxes		Band, number 6	7	8	9	10
1000	Band boundaries, μm	Lower	0,528	0,781	1,01	1,71	2,92
		Upper	0,781	1,01	1,71	2,92	4,0
	Heat fluxes, $q \cdot 10^{-4}$, W/m²	1	1,8	0,53	0,42	0,09	0,01
		2	—0,03	—0,16	—0,03	—0,02	—0,01
1200	Band boundaries, μm	Lower	0,52	0,791	0,985	1,81	3,13
		Upper	0,791	0,985	1,81	3,13	4,0
	Heat fluxes, $q \cdot 10^{-4}$, W/m²	1	2,9	0,59	0,67	0,11	0,01
		2	1,1	0,00	0,18	0,01	—0,01
1400	Band boundaries, μm	Lower	0,519	0,803	0,963	1,91	3,38
		Upper	0,803	0,963	1,91	3,38	4,0
	Heat fluxes, $q \cdot 10^{-4}$, W/m²	1	4,0	0,58	0,94	0,11	0,00
		2	2,5	0,01	0,41	0,03	—0,00

Therefore, the accuracy of calculations according to the selective-gray model depends primarily on the accuracy of calculation of radiation in the bands enumerated above.

NOTATION

q, density of heat flux, W/m^2; r, a, reflectivity and absorptivity, respectively; ψ, generalized angular coefficient; λ, wavelength, m; $C_1 = 3.74 \cdot 10^{-16}$ W/m^2; $C_2 = 1.4387 \cdot 10^{-2}$, m•K; $\sigma_0 = 5.67 \cdot 10^{-8}$, $W/(m^2 \cdot K^4)$; T, temperature, K; (A), matrix of coefficients of the unknowns in the system of zonal equations; (Q), (B), column matrices of the unknowns and of the right-hand sides of the system of equations; $\underline{k}$, absorption coefficient, $m^{-1} \cdot atm^{-1}$; $k_{\Delta\lambda}$, total absorption coefficient in the band, m^{-1}; α, index of absorption, $m^{-2} \cdot atm^{-1}$; ω, wave number, m^{-1} p, pressure, N/m^2; indices: p, resultant; c, natural value or eigenvalue; V, volume; F, area.

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DETERMINATION OF THE THERMAL CONDUCTIVITY OF ANISOTROPIC MEDIA ON THE BASIS OF THE SCANNING METHOD: THEORETICAL MODELS AND EXPERIMENTAL IMPLEMENTATION OF THE METHOD

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Procedures for determining the thermal conductiity of anisotropic media are developed on the basis of an analysis of the temperature fields in anisotropic media under the influence of moving energy sources.

In the multivariety of procedures based on the scanning method for measuring the thermal conductivity of anisotropic media, procedures that utilize the solutions for a point energy source and a combination of a line source and a point source are particularly valuable in practice. Here we discuss theoretical models of the proposed procedures, making use of the analytical relations obtained in the first part of the study [1] for the temperature fields of moving energy sources in anisotropic media.

THEORETICAL MODEL OF THE PROCEDURE BASED ON A POINT ENERGY SOURCE

On the investigated anisotropic sample with two noncoplanar plane surface we choose three arbitrary noncolinear directions, which are not in the same plane and are specified by unit vectors $\mathbf{n}_1$, $\mathbf{n}_2$, and $\mathbf{n}_3$. The surfaces of the sample are scanned successively along the selected directions by a continuously acting point energy source and a temperature sensor, which moves along the line of heating at the speed of the source, following it at a distance d (Fig. 1). The maximum excess temperatures θ_1, θ_2, and θ_3 recorded on the heated surfaces of the sample, according to Eq. (11) (in the first part of the study [1]), are equal to

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