$$K = \frac{0.25}{(2.3564/0.047125)^2 + (1.51508/0.09471143)^2} = 9.0704 \cdot 10^{-5}\ \mathrm{m}^2;$$

$$a_1 = mK = 5.21528 \cdot 10^{-3} \cdot 9.0704 \cdot 10^{-5} = 4.73047 \cdot 10^{-7}\ \mathrm{m^2/sec}.$$

This value is 4.5% less than that assumed. Hence, the calculation should be repeated. Repeating the calculation for $a_1 = 4.73047 \cdot 10^{-7}$, we obtain the second value $a_1 = 4.7045 \cdot 10^{-7}$. Finally, the third time for $a_1 = 4.7045 \cdot 10^{-7}$ we have $a_1'' = 4.714 \cdot 10^{-7}$ and finally $a_1 = (a_1' + a_1'')/2 = 4.709 \cdot 10^{-7}$ m²/sec, $\lambda_1 = a_1\rho_1 c_1 = 1.006$ W/m·K.

In a test with a thicker shell ($K_L = 1.01351$, $K_R = 1.0131358$), a cooling rate of $m = 4.9375 \cdot 10^{-3}\ \mathrm{sec}^{-1}$ was observed. Repetition of the calculation procedure yields $a_1 = 4.7983 \cdot 10^{-7}$ m²/sec ($\lambda_1 = 1.0249$ W/m·K), whose magnitude is 1.9% greater than the transition value. This indicates the good agreement between the experimental and theoretical results.

NOTATION

T, temperature; τ, time; x, r, cylindrical coordinates; $\Theta = (T(x, r, \tau) - T_f)/(T_0 - T_f)$; L, R, δ, cylinder dimensions (Fig. 1); $\xi = x/L$; $\eta = r/R$; $\mathrm{Fo}_R = a_1\tau/R^2$; $\mathrm{Fo}_L = a_1\tau/L^2$; a, thermal diffusivity; λ, heat conduction; ρ, density; c, specific heat; α, heat-transfer coefficient; $K_a = a_1/a_2$; $K_\varepsilon = \sqrt{\lambda_1\rho_1 c_1/\lambda_2\rho_2 c_2}$; $\mathrm{Bi}_L = \alpha_L L/\lambda_2$; $\mathrm{Bi}_R = \alpha_R R/\lambda_2$; $K_L = 1 + \delta_L/L$; $K_R = 1 + \delta_R/R$; $K_{RL} = R/L$; J_0, J_1, Y_0, Y_1, Bessel functions; ν_n, μ_k, roots of the characteristic equations (15) and (16); $G_0 = J_0(\mu\sqrt{K_a})Y_0(\mu K_R\sqrt{K_a}) - J_0(\mu K_R\sqrt{K_a})Y_0(\mu\sqrt{K_a})$ $G_1 = J_1(\mu\sqrt{K_a})Y_0(\mu K_R\sqrt{K_a}) - J_0(\mu K_R\sqrt{K_a})Y_1(\mu\sqrt{K_a})$. Subscripts: 1, main cylinder, first; 2, shell; L, axial, plate; R, radial, cylinder; 0, initial; f, fluid medium.

LITERATURE CITED

1. G. M. Kondrat'ev, Thermal Measurements [in Russian], Mashgiz, Moscow—Leningrad (1957).
2. H. Tautz, Wärmeleitung-Temperaturausgeich, Akademie-Verlag, Berlin (1971).
3. A. V. Lykov, Theory of Heat Conduction [in Russian], Vysshaya Shkola, Moscow (1967).

THEORETICAL AND EXPERIMENTAL INVESTIGATION OF THE ABSORPTION COEFFICIENT OF DIFFERENT BLACKBODY MODELS

S. B. Kiselev and O. A. Kraev

UDC 536.3

Numerical computations are performed and results are presented of an experimental investigation of the effective absorption coefficient of radiant heat flows of cavities of complex configuration.

The measurement of radiant energy by using thermal detectors—radiometers usually includes two stages: absorption of radiant energy and its conversion into heat, and measurement of the quantity of absorbed heat. Blackbody models in the form of spherical, cylindrical, conical cavities, as well as more complex configurations are used as radiation absorbers in precision radiometers. The computations of the cavity absorption coefficients are fraught with serious technical difficulties and are executed principally for simple shapes [1-4]. Papers [5, 6] are also known in which an attempt is made to analyze absorbers of more complex configuration under definite simplifying assumptions. The lack of experimental work in this area does not permit an assessment of the legitimacy of the assumptions made and of the accuracy of the results obtained. In this paper we present the results of a complex investigation in which the absorption coefficients of cavities of certain complex shapes used in practice were determined by both computational and experimental means.

The problem of theoretical computational determination of the absorption coefficient of combination cavities consisting of N different surfaces by using a generalized zonal method will reduce, in the long run, to solving a system of integral equations of the form [7]

All-Union Scientific-Research Institute of Physicotechnical and Radiotechnical Measurements.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 43, No. 5, pp. 822-826, November, 1982. Original article submitted July 14, 1981.

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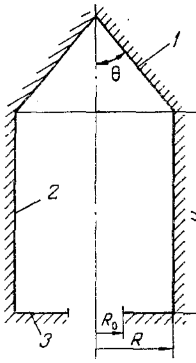

Fig. 1

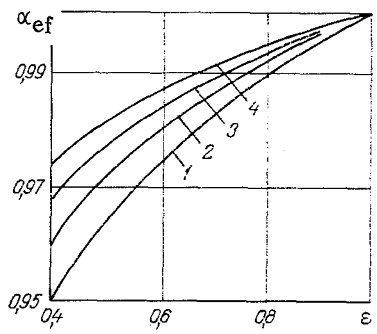

Fig. 2

Fig. 1. Geometric characteristics of a cavity: 1-3) numbers of the surface.

Fig. 2. Change in the effective absorption coefficient of cavities as a function of the degree of wall blackness: 1, 2, 3) H = 0; Θ = 20, 15, 10°, respectively; 4) H = 2.4; Θ = 60°; R = 1, 0; R_0 = 0.333.

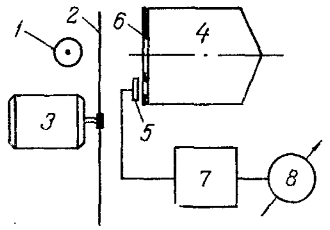

Fig. 3. Diagram of the experimental installation to determine the absorption coefficient of cavities of different configurations.

$$\varphi_i(\vec{r}_i) = g_i(\vec{r}_i) + \lambda_i \sum_{j=1}^{N} \int_{A_j} \varphi_j(\vec{r}_j) K_{ij} dA_j \; (i = 1,\, 2,\, \ldots,\, N), \tag{1}$$

where $\varphi_i(\vec{r}_i)$ is the effective radiation flux density of the i-th surface; $\lambda_i = 1-\varepsilon_i$, reflection coefficient of the i-th surface; $g_i(\vec{r}_i)$, heat-flux density or the temperature distribution on the i-th surface (given in the boundary conditions); and K_{ij}, kernel of the integral equation which is determined by the system geometry.

The effective absorption coefficient of a cavity α_{ef} is determined by means of the known quantity $\varphi_i(\vec{r}_i)$, determined from the solution of the system (1), from the equation

$$\alpha_{ef} = 1 - \frac{Q_{ref}}{Q_{inc}}. \tag{2}$$

Here the magnitude of the reflected heat is defined by the relationship

$$Q_{ref} = \sum_{i=1}^{N} \int_{A_i} \int_{A_0} \varphi_i(\vec{r}_i) K_{i0} dA_i dA_0, \tag{3}$$

where the subscript 0 refers to the hole, and Q_{inc} is set equal to one for simplicity. We performed the solution of the system (1) and the evaluation of α_{ef} for cavities of complex configuration. To find the function $\varphi_i(\vec{r}_i)$ and determine Q_{ref}, we here used the algorithm of [8] that includes successive application of the Gauss formula for 7, 6, 5, and 4 nodal points, respectively, to calculate all the surface integrals (1)-(3). To increase the accuracy in calculating the integrals in (1) in this paper, we use an integration scheme with ten nodal points, while the number of nodal points was increased to 32 when evaluating the expression (3). The application of such an integration scheme permitted raising the accuracy in calculating α_{ef} somewhat (to 0.1% for $\varepsilon_W \geqslant 0.9$) as compared with 2% as presented in [8], and obtaining the error mentioned in [8] for the quantities α_{ef} for $\varepsilon_W \geqslant 0.5$. The computations were executed for cavities of complex configuration (see Fig. 1) for four different values of the parameters H, θ, R_0. The computation results are presented in Fig. 2. From an analysis of the figure there follows that for approximately equal geometric dimensions, the α_{ef} is higher for a cylindrical cavity with a conical bottom (curve 4) than for a simply conical cavity (curves 2 and 3). In order to obtain identical values of α_{ef}, the depth of the conical cavity should be approximately twice as large as for the cylindrical cavity. This circumstance can be utilized in the construction of the actual cavities of radiation detectors.

In order to confirm the described method of computing α_{ef} experimentally and to determine the accuracy of the calculations presented, we performed experimental investigations of the absorption coefficient of the cavities examined above. To do this, we used an installation whose diagram is presented in Fig. 3. The STs-75 lamp 1 of 4-W intensity and 4-V voltage with a small point incandescent body was the radiation source. The radiation flux from this lamp was interrupted periodically at a 90-Hz frequency by using the disc modulator 2 rotated by the electric motor 3, and it was incident on the receiving hole in the cavity being investigated 4. Part of the radiation is absorbed by the cavity, while another part is reflected. To measure the reflected radiation density we used a photoresistor 5 of FS-A1 type, clamped on the diaphragm 6 so that reflected radiation from the cavity was incident on the photoresistor through the side hole located alongside the central entrance hole. Because of the diffuse nature of the reflection, the radiation density being measured will be practically equal to the reflected radiation density in the entrance hole of the diaphragm. The electrical signal from the photoresistor goes to the alternating current amplifier 7 with the rectifier, and is measured by the millivoltmeter 8.

The process of determining the absorption coefficient includes two stages. First the density of the radiation reflected from the cavity is measured, the millivoltmeter readings and the distance r_1 between the radiation source and the entrance hole of the cavity are noted. Then the photoresistor is removed from the diaphragm, is rotated by the receiving surface to the radiation source and is removed to a distance r_2 at which the millimeter reading becomes equal to the previous one. By using the law of inverse squares of the magnitude of the radiation density (or illumination) as a function of the distance from the source, a computational formula can be obtained to determine the reflection coefficient λ of the cavity under investigation:

$$\lambda_{ef} = (r_1/r_2)^2. \qquad (4)$$

The formula to determine the absorption coefficient of the cavity will therefore have the form

$$\alpha_{ef} = 1 - (r_1/r_2)^2. \qquad (5)$$

The absorption coefficient α_{ef} is therefore determined on the basis of measuring the distances r_1 and r_2, here the radiation meter itself operates in the constant signal mode and does not require preliminary calibration. The distances r_1 and r_2 in (4) and (5) can be measured sufficiently accurately, hence the main error in the method described is associated with the assumption about the diffuse nature of the cavity wall reflection and about the uniform distribution of the reflected flux density over the area of the cavity entrance hole. According to our estimates, the error in measuring the reflection coefficient λ is 15-20%, which corresponds to a relative error of $\Delta\alpha_{ef} \leqslant 1\%$ for the cavities being investigated.

Such cavity shapes as are often utilized in radiometers, viz., in the shape of a cone and cylinder with entrance diaphragms, were selected for the measurement of the absorption coefficient. The diaphragm outer diameter was 36 mm, the inner diameter was 12 mm, the length of the cylindrical section was 43 mm, and the angles at the vertex of the conical cavities were 10, 15, and 20°. Specially selected coatings with diffuse nature of the reflection and different emissivities were deposited on the inner surface of the cavities. Dyes based on corundum powders ($\varepsilon_W = 0.51 \pm 0.05$ and 0.7 ± 0.04) and soot ($\varepsilon_W = 0.92 \pm 0.03$) were used as coatings. The coating emissivity ε_W was determined on the same installation by a method analogous to that described.

The absorption coefficients of the cavities were measured for different angles of beam incidence with subsequent averaging. The experimental data and results of computations for

TABLE 1. Computed and Experimental Values of the Absorption Coefficient α_{ef} of the Cavities Being Investigated

ε_w	Cylindrical cavity H=2.4, R_0=0.333		Conical cavity $H=0$, $R_0=0.333$					
	Θ=60°		Θ=10°		Θ=15°		Θ=20°	
	I	II	I	II	I	II	I	II
0,51	0,982	0,980	0,977	0,979	0,972	0,973	0,964	0,966
0,7	0,991	0,990	0,989	0,992	0,987	0,983	0,983	0,980
0,92	0,998	0,997	0,998	0,998	0,996	0,995	0,995	0,993

Remark: I) computation; II) experiment.

the absorption coefficients of different cavities are presented in Table 1, from which it is seen that they are in good agreement. The maximal deviation of the computed values of α_{ef} from the experimental does not exceed 0.4%, which is within the limits of experimental error, and corresponds to the mentioned computational accuracy for the algorithm used. A further increase in the accuracy of calculating α_{ef} is related to the rise in accuracy of the integration in (1)-(3). This can be achieved by utilizing the Gauss formula with 38-40 nodal points in evaluating all the integrals in (1)-(3), which is associated with a significant increase in the computation time (to 40-100 h on an electronic computer of ES-1022 type). Hence, it is expedient to execute such computations for one selected detector construction. The accuracy of calculating α_{ef} can here reach 0.05%, which is completely acceptable for the majority of practical problems.

NOTATION

Θ, cavity cone angle; H, cavity height; R, radius; R_0, radius of cavity diaphragm; ε, emissivity; λ, reflection coefficient; α, absorption coefficient; Θ_{inc}, incident heat; Θ_{ref}, reflected heat.

LITERATURE CITED

1. E. M. Sparrow, E. R. Eckert, and L. W. Albers, "Thermal radiation characteristics of cylindrical cavities," Trans. ASME, Ser. C, No. 1, 90-100 (1962).
2. E. M. Sparrow and V. K. Jonson, "Radiant emission characteristics of diffuse conical cavities," J. Opt. Soc. Am., 53, No. 7, 816-821 (1963).
3. E. M. Sparrow and S. H. Lin, "Radiation heat transfer at a surface having both specular and diffuse reflectance components," J. Heat Mass Transfer, 8, 769-779 (1964).
4. S. H. Lin and E. M. Sparrow, "Radiant interchange among curved specularly reflecting surfaces. Application to cylindrical and conical cavities," J. Heat Transfer, C87, No. 2, 299-307 (1965).
5. Chen Shouren, Chu. Zaixiang, and Chen Hongpan, "Precise calculation of the integrated emissivity of baffled blackbody cavities," Metrologia, No. 16, 69-72 (1980).
6. I. V. Libova, "On a method of computing the emissivity of absolute black body models," Tr. Metrol. Inst. SSSR, No. 236(296), 48-54 (1979).
7. M. N. Otsisik, Complex Heat Transfer [Russian translation], Mir, Moscow (1976).
8. S. B. Kiselev, "Calculation of the effective absorption coefficient of radiant heat fluxes of a cavity with diffuse wall reflection," Inzh.-Fiz. Zh., 39, No. 1, 113-117 (1980).