NUMERICAL INVESTIGATION OF THE RADIATION CHARACTERISTICS OF A PERFORATED CYLINDER IN A CIRCULAR CHAMBER FILLED WITH AN ABSORBING MEDIUM

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A problem on radiant heat exchange in a circular chamber filled with an absorbing medium and containing a perforated cylinder is solved.

The system under consideration consists of a circular chamber with which a perforated cylinder is coaxially dispersed (Fig. 1). The space within the chamber and the perforated cylinder is filled with a pure absorbing medium. Let us find the resultant energy flux emitted by the cylinder on the inner surface of the chamber for given temperature, optical properties, and geometry of the surfaces and for homogeneity of the filler medium.

We make the following assumptions: the cylinder and chamber are infinite, the surfaces of the perforated cylinder and the chamber are diffuse gray. Let the emissivity of the chamber inner surface be one, and its temperature 0°K, and the radii of the perforated cylinder and the chamber are R_1 and R_2, respectively.

We use the generalized zonal method [1] to solve the problem. The system displayed in Fig. 1 consists of three optically homogeneous zones: 1) the inner surface of the perforated cylinder; 2) the outer surface of the perforated cylinder; and, 3) the inner surface of the cylindrical chamber.

We obtain the following expressions for the resultant radiation fluxes of each zone:

$$E_{p1} = \varepsilon_1 \sigma_0 \Psi_{13} E_{31} (1 - \beta) F_1^0, \qquad (1)$$

$$E_{p2} = \varepsilon_1 \sigma_0 \Psi_{23} E_{32} (1 - \beta) F_1^0, \qquad (2)$$

$$E_{p3} = \varepsilon_1 \sigma_0 (\Psi_{31} + \Psi_{32}) E_{13} F_3, \qquad (3)$$

where $E_{ki} = (T^4{}_k - T^4{}_i)$, β are the mean resolving angular coefficients of radiation between the zones with absorption taken into account and are determined from the linear inhomogeneous equations

$$\Psi_{ik} = \psi_{ik} + \sum_{j=1}^{3} (1 - \varepsilon_j) \Psi_{ij} \psi_{jk}, \; i, \; k = 1, \; 2, \; 3, \qquad (4)$$

where ψ_{ik} are the mean generalized angular coefficients of radiation with absorption of the medium taken into account between the i-th and k-th isothermal zones and are determined by the formula [1]

$$\psi_{ik} = \frac{1}{\pi} \int_{F_i} \int_{F_k} \exp(-\alpha r) \frac{\cos \Theta_{M_i} \cos \Theta_{N_k}}{r^2_{M_i N_k}} dF_{N_k} dF_{M_i}. \qquad (5)$$

The exponential function exp (−αr) is the coefficient of diathermy of the medium in a given direction. Extracting the mean value of the exponential function exp $(-\alpha\bar{r})$ from under the integral sign on the basis of the theorem of the mean, we obtain

$$\psi_{ik} = \exp(-\alpha \bar{r}) \int_{F_i} \int_{F_k} \frac{\cos \Theta_{M_i} \cos \Theta_{N_k}}{\pi r^2_{M_i N_k}} dF_{N_k} dF_{M_i}.$$

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For the diathermy coefficient of the medium we have the inequality

$$\exp(-\alpha r_{\max}) \leqslant \exp(-\alpha \bar{r}) \leqslant \exp(-\alpha r_{\min}),$$

where r_{max} and r_{min} are the maximal and minimal ray path lengths between the surfaces F_i and F_k. Assuming

$$\exp(-\alpha \bar{r}) = \frac{1}{2}[\exp(-\alpha r_{\max}) + \exp(-\alpha r_{\min})], \tag{6}$$

we obtain the computational expression to determine the approximate value of the generalized mean radiation coefficient [2]

$$\psi_{ik} = \exp(-\alpha \bar{r})\,\varphi_{ik}. \tag{7}$$

We find the values of the angular coefficients φ_{ik} from [3]:

$$\varphi_{11} = (1-\beta),\quad \varphi_{13} = \beta,\quad \varphi_{31} = \frac{R_1}{R_2}\beta(1-\beta),\quad \varphi_{32} = \frac{R_1}{R_2}(1-\beta).$$

Then taking account of (6) and (7),

$$\psi_{11} = (1-\beta)\frac{1}{2}[\exp(-\alpha 2R_1) + 1],$$

$$\psi_{13} = \frac{1}{2}\beta[\exp(-\alpha R_1 - \alpha R_2) + \exp(-\alpha\sqrt{R_2^2 - R_1^2})],$$

$$\psi_{31} = \frac{1}{2}\frac{R_1}{R_2}\beta(1-\beta)[\exp(-\alpha R_1 - \alpha R_2) + \exp(-\alpha\sqrt{R_2^2 - R_1^2})],$$

$$\psi_{32} = \frac{R_1}{R_2}(1-\beta)\exp(-\alpha R_2 + \alpha R_1).$$

Using (4), we find Ψ_{31} and Ψ_{32} and, substituting them into (3), we obtain an expression to determine the resultant radiant flux from the perforated cylinder onto the chamber inner surface

$$E_{p3} = \varepsilon_1 \frac{R_1}{R_2}(1-\beta)(T_1^4 - T_3^4)\sigma_0 \times$$
$$\times \left\{\frac{\beta[\exp(-\alpha R_1 - \alpha R_2) + \exp(\alpha\sqrt{R_2^2 - R_1^2})]}{2-(1-\varepsilon_1)(1-\beta)[\exp(-\alpha 2R_1) + 1]} + \exp(-\alpha R_2 + \alpha R_1)\right\} F_3. \tag{8}$$

We write (8) in dimensionless form, with respect to the energy flux emitted by a continuous cylinder in a system filled with a diathermic medium [3]:

$$\eta = \frac{E_{p3}}{\varepsilon_1 (T_1^4 - T_3^4)\dfrac{R_1}{R_2}F_3} =$$
$$= (1-\beta)\left\{\frac{\beta[\exp(-\alpha R_1 - \alpha R_2) + \exp(\alpha\sqrt{R_2^2 - R_1^2})]}{2-(1-\varepsilon_1)(1-\beta)[\exp(-\alpha 2R_1) + 1]} + \exp(-\alpha R_2 + \alpha R_1)\right\}, \tag{9}$$

Computations were performed on an ES 1022 electronic computer, the input parameters are α, $K = R_1/R_2$, β.

Results of computing η are represented in Fig. 2 for K = 0.2 and K = 0.6 for different values of ε_1 and α.

It is seen from the figure that as K increases growth of the dimensionless radiant flux density occurs because of diminution of the absorbing layer of the medium between the fixed value R_1 and the chamber wall. However, the change in η as a function of α and ε is more significant than as a function of K.

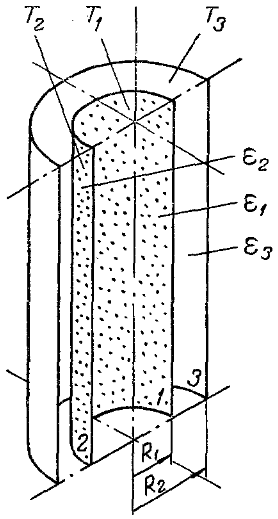

Fig. 1

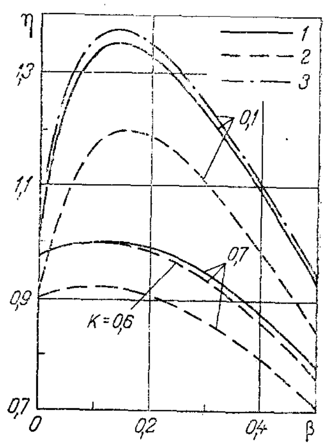

Fig. 2

Fig. 1. Diagram of the system under investigation.

Fig. 2. Ratio of the energy flux emitted by a perforated cylinder in an absorbing medium to the radiation energy of a continuous cylinder in a diathermic medium (K = 0.2): 1) $\alpha = 0.5$; 2) 0.1; 3) data from [3] for a diathermic medium. Numbers on the curves are values of ε.

The radiation maximum with respect to β retains its position for both the cases of the diathermic and the absorbing medium. For $\alpha < 0.2$, the value of η is practically in agreement with the cylinder emission in the diathermic medium. As α increases the radiant flux from the system diminishes.

However, by diminishing the ε of the cylinder, even for the values $\alpha = 0.5$–0.6 the same magnitudes η can be achieved in a broad range of β as for the case with a diathermic filler medium [3].

For small $\beta < 0.1$–0.05 the diminution of ε does not produce this effect. It must be noted that an increase in α results in a diminution in η for all β although the qualitative nature of the dependence $\eta = f(\beta)$ is conserved.

As a result of an analysis of computed data, a deduction is made about the possibility of obtaining practically the same resultant radiant flux density for the system under consideration as for the case of a system filled with a diathermic medium by diminishing ε and β for the cylinder.

NOTATION

T, temperature, °K; ε, surface emissivity; R_1, cylinder radius; R_2, chamber radius; β, ratio between the total perforation area and the cylinder geometric area; E_p, resultant radiation flux.

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