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RADIATION OF A PERFORATED CYLINDER

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The generalized zonal method is used to find the energy radiated by a perforated cylinder. The existence of a range of geometric optical parameters is established, wherein the perforated cylinder radiates more energy than a continuous cylinder.

We will consider a cylindrical surface uniformly perforated by orifices. We will find the resultant energy flux (or surface density) radiated by the cylinder at specified temperature, optical properties, and surface geometry.

We make the following assumptions: 1) the cylinder is infinitely long; 2) the unperforated portion of the cylinder is diffuse-gray and homogeneous; 3) the surfaces, inner surface 1 and outer surface 2, are isothermal while $T_1 = T_2 = T > 0$; 4) the medium is diathermal.

We close the surfaces 1, 2 of the perforated cylinder with a coaxially located black ($\varepsilon = 1$) continuous cylindrical surface 3 of arbitrary diameter D_3 and temperature $T_3 = 0$°K. We now apply the generalized zonal method of [1] to this system of surfaces.

For the resultant fluxes from each zone, we obtain the following expressions:

$$Q_{f1} = -\varepsilon_1 E_{13} \gamma \varphi_{13} (1 - \beta) F_0, \tag{1}$$

$$Q_{f2} = -\varepsilon_2 E_{13} \varphi_{23} (1 - \beta_0) F_0, \tag{2}$$

$$Q_{f3} = E_{13} (\varepsilon_1 \gamma \varphi_{31} + \varepsilon_2 \varphi_{32}) F_3, \tag{3}$$

where $\gamma^{-1} = 1 - R_1 \varphi_{11}$; $E_{13} = \sigma_0 T^4$; $\beta = F/F_0$; F is the area of the perforations; F_0 is the geometric area of the cylinder surface.

In Eqs. (1)-(3) the mean angular radiation coefficients (ARC) φ_{ik} can be expressed in terms of the average ARC φ_{11} of the perforated cylinder itself with the aid of the closure and reciprocity equations. Thus, the problem reduces to determination of φ_{11}.

It follows from the physical meaning of the mean angular radiation coefficient that

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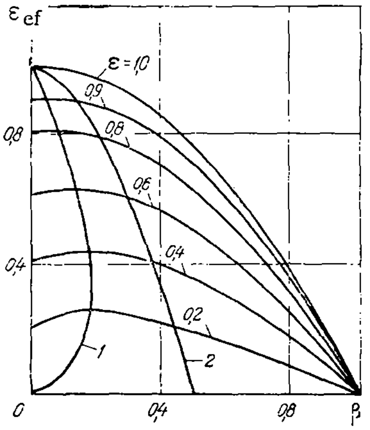

Fig. 1

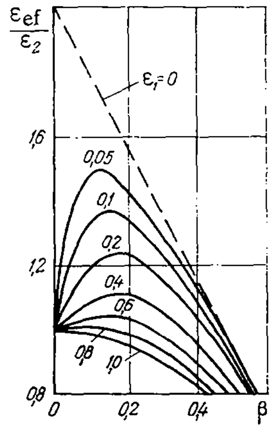

Fig. 2

Fig. 1. Ratio of energy radiated by perforated cylinder to energy radiated from continuous black cylinder; 1) function $\varepsilon_{ef}(\beta_{max})$; 2) $\varepsilon_{ef}(\beta_0)$.

Fig. 2. Ratio of energy fluxes radiated by perforated and continuous cylinders, the function $\varepsilon_{ef}/\varepsilon_2$.

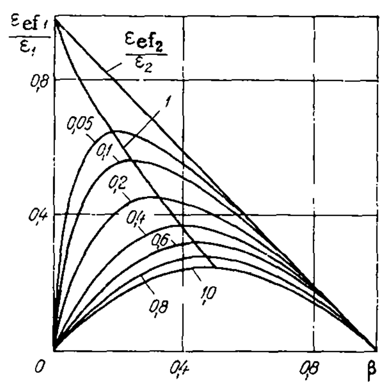

Fig. 3

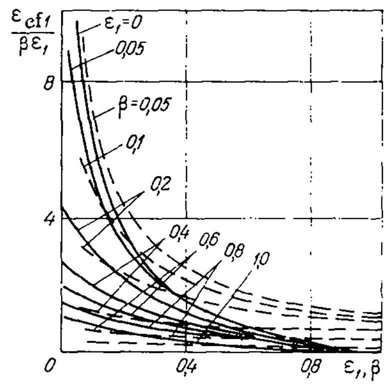

Fig. 4

Fig. 3. Ratio of energy fluxes of outer (curves $\varepsilon_{ef2}/\varepsilon_2$) and inner ($\varepsilon_{ef1}/\varepsilon_1$) surfaces of perforated cylinder to energy flux of solid cylinder. Curve 1, $\varepsilon_{ef1}/\varepsilon_1$ vs $(\beta_{max})_1$.

Fig. 4. Ratio of energy radiated by inner surface of perforated cylinder through orifices β to energy radiated by outer continuous surface of area βF_0.

$$\varphi_{11} = 1 - \beta. \tag{4}$$

Using this value for φ_{11}, for the remaining mean ARC's appearing in Eqs. (1)-(3) we will have

$$\varphi_{13} = \beta; \quad \varphi_{23} = 1; \quad \varphi_{31} = \zeta\beta(1-\beta); \quad \varphi_{32} = \zeta(1-\beta), \tag{5}$$

where $\zeta = D/D_3$. Substituion of Eq. (5) in Eqs. (1)-(3) produces

$$Q_{f1} = -\varepsilon_1\sigma_0 T^4 \gamma (1-\beta) F_0 \equiv -\varepsilon_{ef1}\sigma_0 T^4 F_0, \tag{6}$$

$$Q_{f2} \equiv -\varepsilon_2\sigma_0 T^4 (1-\beta) F_0 \equiv -\varepsilon_{ef2}\sigma_0 T^4 F_0, \tag{7}$$

$$Q_{f3} = \varepsilon_2\sigma_0 T^4 (1-\beta)\left(1 + \frac{\varepsilon_1}{\varepsilon_2}\beta\gamma\right) F_0 \equiv \varepsilon_{ef}\sigma_0 T^4 F_0. \tag{8}$$

where

$$\gamma^{-1} = \beta + \varepsilon_1(1-\beta). \tag{9}$$

It follows from Eqs. (6)-(8) that the perforated cylinder radiates an energy flux equal to $Q_f = Q_{f1} + Q_{f2} = Q_{f3}$ and is described by Eq. (8).

We now write the flux radiated by the perforated cylinder in dimensionless form, referenced to the energy flux radiated by a continuous black cylinder:

$$\varepsilon_{ef} = \frac{Q_f}{\sigma_0 T^4 F_0} = \varepsilon_2(1-\beta)\left(1 + \frac{\varepsilon_1}{\varepsilon_2}\beta\gamma\right). \tag{10}$$

The function $\varepsilon_{ef}(\varepsilon_i, b)$ has a maximum within the range $0 < \varepsilon_1 < 1$, which for the special case $\varepsilon_1 = \varepsilon_2 = \varepsilon$ is achieved at the values

$$\beta_{max} = \frac{\sqrt{\varepsilon(2-\varepsilon)} - \varepsilon(2-\varepsilon)}{(1-\varepsilon)(2-\varepsilon)}. \tag{11}$$

In the range $0 < \varepsilon < 1$ and $0 < \beta < \beta_0$, where for $\varepsilon_1 = \varepsilon_2 = \varepsilon$ β_0 is defined by

$$\beta_0 = \frac{1-\varepsilon}{2-\varepsilon}, \tag{12}$$

the function $\varepsilon_{ef}(\varepsilon, \beta) > \varepsilon$, i.e., in the range of ε and β values indicated the perforated cylinder radiates more than a continuous one. Figure 1 shows graphs of the function $\varepsilon_{ef}(\varepsilon, \beta)$ for various values of ε together with $\varepsilon_{ef}(\beta_{max})$, curve 1, and $\varepsilon_{ef}(\beta_0)$, curve 2, for varying ε values.

The greater energy effectiveness of the perforated cylinder as compared to the continuous in the parameter range $\varepsilon < 1$ and $\beta < \beta_0$ is shown more clearly by the curves of Fig. 2, where for the case $\varepsilon_1 = \varepsilon_2 = \varepsilon$ the function $\varepsilon_{ef}/\varepsilon$ is shown, representing the ratio of the energy fluxes radiated by these cylinders. The difference between the fluxes radiated is greater, the less ε and β. As $\varepsilon_1 \to 0$ it tends to $2(1-\beta)$, while for $\beta \to 0$ it reaches its maximum value of two. The function $(\varepsilon_{ef}/\varepsilon_2)_{\varepsilon_1 \to 0}$ is shown in Fig. 2 by the curve $\varepsilon_1 = 0$.

Figure 3 shows the functions $\varepsilon_{ef_2}/\varepsilon_2$ and $\varepsilon_{ef_1}/\varepsilon_1$, describing the ratios of energies radiated by the outer and inner surfaces of the perforated cylinder to the energy radiated by a continuous cylinder. The first function has no singularities, is independent of ε_2, and decreases monotonically [as $(1-\beta)$] with growth in β. The second function has a maximum at

$$(\beta_{max})_1 = \frac{\sqrt{\varepsilon_1} - \varepsilon_1}{1-\varepsilon_1}. \tag{13}$$

This is shown by curve 1 of Fig. 3.

A comparison of the energy radiated by the inner surface through the orifices β with the energy which would be radiated by an outer surface of area βF_0 with the same emissivity is shown in Fig. 4, which presents graphs of the function $\varepsilon_{ef_1}/\beta\varepsilon_1$ vs β (solid curves) and vs ε_1 (dashed curves). It is evident that there exist ranges of β and ε_1 values at which $\varepsilon_{ef_1} > \beta\varepsilon_1$.

We find this condition to be satisfied in the parameter range $0 < \varepsilon_i < 1$ and $0 < \beta < (\beta_0)_1$, where

$$(\beta_0)_1 = \frac{1-\varepsilon_1}{2-\varepsilon_1}. \tag{14}$$

The difference in the radiant fluxes is more marked, the smaller β and ε_1.

Peculiarities develop in the radiation of the inner surface of the perforated cylinder due to the fact that it radiates its energy through small orificies. This is equivalent to increasing the emissivity of the radiating surface, and thus, the energy radiated by it. For this reason the effective emissivity of the perforated cylinder differs from the emissivity of the outer surface and has the peculiarities noted above.

For $\varepsilon_1 = \varepsilon_2 = 1$ it follows from Eq. (9) that $\varepsilon_{ef} = 1-\beta^2$, i.e., in this case the relative radiant energy from the perforated cylinder is determined solely by the geometric factor, the value of the ratio of the perforations to the geometric area of the cylinder.

Analysis of data from [2] on heat exchange between perforated and continuous coaxial cylinders shows that the results obtained are comparable, and that the conclusions arrived at herein are correct.

NOTATION

T is the temperature, °K;
ε is the net emissivity (degree of blackness);
D is the cylinder diameter;
φ_{ik} is the mean angular coefficient of radiation (ARC) between i-th and k-th elements of finite area surface;
R is the coefficient of reflection;
σ is the Stefan–Boltzmann constant;
ξ is the dimensionless parameter equal to the ratio of the diameter of coaxial cylinders;
β is the ratio of the total area of perforations to the geometric area of the cylinder;
β_{max} is the β value at which radiant energy from the surface is maximum;
β_0, β is the value below which radiant energy of the perforated cylinder is equal to or greater than the radiant energy of the continuous cylinder;
Q_f is the resultant radiation flux.

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EFFECT OF THE ELASTIC FACTOR ON THE HYDRODYNAMIC STABILITY OF A STRUCTURALLY VISCOUS MEDIUM

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The effect of relaxation phenomena on the hydrodynamic stability of the plane gradient flow of a structurally viscous medium is investigated using linear theory.

There has recently been interest in various problems of the hydrodynamics of structurally viscous liquids [1, 2] due to the wide use of these media in modern technological processes. These media have a complex physicochemical structure which leads to the appearance of relaxational mechanical properties in addition to Newtonian properties.

The simplest rheological law that simultaneously takes into account the relaxational and Newtonian properties of structurally viscous media can be postulated, e.g., in the form

$$\tau_{ij} + \frac{1}{T_M}\frac{\partial}{\partial t}\tau_{ij} = 2\eta(\Omega)F_{ij},\ \Omega = \sqrt{2F_{ij}F_{ij}}\ . \tag{1}$$

Here T_M is the characteristic relaxation time (the "Maxwellian" time); $\eta(\Omega)$, apparent viscosity, which is different in different intervals of the variation of the intensity of the velocity deformation tensor Ω [3]. If $\Omega \geq \Omega_1$ (Ω_1 is a characteristic of the medium), then $\eta(\Omega) = \eta^* + \tau_0/\Omega$, η^* is the plastic dynamic viscosity, and τ_0 is the limiting shear stress. When $\Omega \leq \Omega_1$, $\eta(\Omega)$ depends monotonically on Ω within the limits $\eta(0) \geq \eta(\Omega) \geq \eta(\Omega_1)$, and $\eta(\Omega_1) \gg \eta^*$.

The motion of an incompressible structurally viscous medium can be described by the following system of equations of motion:

$$\frac{\partial U_i}{\partial t} + U_j\frac{\partial}{\partial x_j}U_i = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\tau_{ij},\ \frac{\partial U_i}{\partial x_i} = 0, \tag{2}$$

where τ_{ij} is given by Eq. (1).

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