INVESTIGATION OF THE HEAT TRANSFER IN THE INTERTUBE SPACE OF HEAT-EXCHANGE APPARATUS BY THE METHOD OF ANALOGY WITH MASS TRANSFER

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In heat-transfer investigations in the intertube space of heat exchangers, the heat-transfer coefficient α has so far only been determined for a tubular beam. For a deeper study of this process, it is necessary to determine the distribution of α over the length of each tube of the beam.

In this paper it is suggested that a representation of this distribution can be obtained by investigating the mass transfer in the intertube space of a model of the heat exchanger using the analogy between the heat-transfer and mass-transfer processes.

A quantitative relation between the heat-transfer and mass-transfer coefficients has been established in the case of the transverse flow of a liquid around a single cylinder [1].

In this paper the results of an investigation of the mass transfer in the intertube space of a model – an analog of the heat-exchange apparatus without transverse partitions – are presented. The data given in [2] were used to determine the geometrical dimensions. The tubes in the model are replaced by rods each of which is in the form of a set of 30 test cylinders. The mass transfer was investigated under steady-state conditions of the motion of the liquid in the range of Reynolds numbers Re = 5500-17,000.

Figure 1 shows the distribution of the mass-transfer coefficient k over the length of each rod of the beam.

The criterial equations which describe the mass transfer of each rod of the beam were obtained. For the mass-transfer process of the whole beam of rods in the flow of liquid the equation has the form

$$Nu_D = 0.238 Re_l^{0.62} Pr_D^{0.4}.$$

The part played by each individual rod in the mass-transfer process of the beam was determined. Experimental investigations were made of the heat transfer in the intertube space of a heat exchanger of the same geometrical dimensions, which confirmed the previously obtained relation between α and k.

The proposed method enables a more detailed investigation to be made of the heat transfer in the intertube space of a heat exchanger.

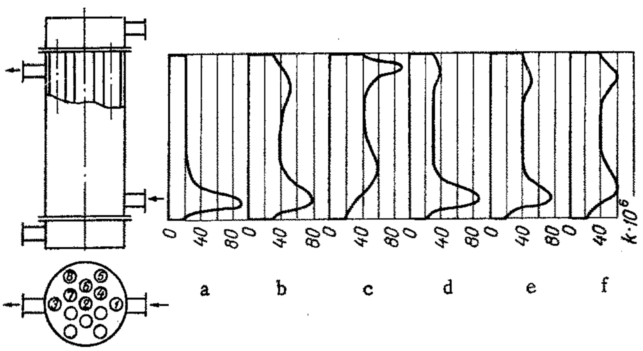

Fig. 1. Distribution of the mass-transfer coefficient k over the length of each rod of the beam: a) rod No. 1; b) No. 2; c) No. 3; d) No. 4, 5; e) No. 6; f) No. 7, 8. $k \cdot 10^6$, m/sec.

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The experimental investigations made using this method of analogy show that the actual values of α considerably exceed the values obtained from the criterial equations.

LITERATURE CITED

1. G. E. Lushistov, "An analogy between heat and mass transfer when a liquid flows around a cylinder," Vestn. Lvov. Politekh. Inst. Presented at the Scientific Conference, No. 6, Lvov, Vishcha Shkola (1976).
2. Heat exchangers, jacket with fixed gratings, steel, general purpose. Construction, basic parameters and dimensions. Mn 5398-64-Mn 5400-64. Izd. Standartov, Moscow (1964).

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DETERMINATION OF THE ACCOMMODATION COEFFICIENT OF THE ENERGY OF IONS USING A THERMOANEMOMETER PROBE

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UDC 533.932

Thermoanemometer probes have been successfully used for the diagnostics of a partially ionized gas. Their use enables one to determine the temperature of the electrons and neutral particles, the concentration of charged and neutral particles, and the potential of a plasma. Under certain conditions thermoanemometer probes can be employed to measure the accommodation coefficients of the energy of ions in the material of the working surface of the probe.

The energy-balance equation for a thermoanemometer probe has the form

$$Q_n+Q_\alpha+J-A\varepsilon\sigma T_w^4-\frac{\partial}{\partial x}\left(-AK_w\frac{\partial T_w}{\partial x}\right)=0,$$

where for $V > 0$

$$Q_\alpha\equiv Q_e\equiv\frac{I_e}{e}(\varkappa+W_e+e|V|),$$

and for $V < 0$

$$Q_\alpha\equiv Q_i=\frac{I_i}{e}[\xi+\alpha_i(W_i+e|V|)-\gamma_i\varkappa],$$

and for intermediate potentials $V \le 0$ $Q_\alpha = Q_i + Q_e$. Here $Q_{n,\alpha}$ is the amount of heat given to the probe by the neutral and charged particles; $\xi = h_i - \varkappa$, difference between the ionization energy and the work function; W_α, energy of a particle transferred to the plasma-layer surface of separation; J, electric heating energy; γ_i, secondary-emission factor; A, area of the working surface of the probe.

In the course of the experiment when working with the thermoanemometer probes, two characteristics are simultaneously plotted: $T_W = T_W(V)$ – the temperature characteristic and $I_\Sigma = I_\Sigma(V)$ – the probe characteristic. On the temperature characteristic there are always points with different temperatures for different potentials of the probe $T_W^A(V^A < 0) = T_W^B(V^B > 0)$. From the energy-balance equation for these points, we obtain $Q_i^A = Q_e^B$ or

$$\frac{I_i^A}{e}[\xi+\alpha_i(W_i+e|V^A|)-\gamma_i\varkappa]=\frac{I_e^B}{e}(\varkappa+W_e+e|V^B|).$$

This relation enables one to determine the accommodation coefficient of the energy of the ions α_i in the material of the working surface of the thermoanemometer probe.

Experimental investigations were made on a gasdynamic plasma arrangement in a flow of rarefied plasma generated by a gas-discharge source. Nitrogen and argon of high purity were used as the working gases. The accelerated beam of ions of intensity $j_\infty \simeq 10^{15}$–10^{17} ions/cm^2 · sec was admitted into the working chamber, the residual gas pressure in which was $\sim 7\cdot10^{-7} - 10^{-6}$ torr. The measurements were made over a

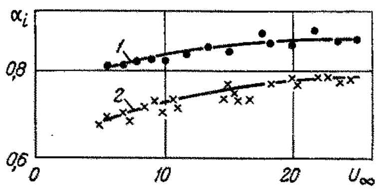

Fig. 1. Accommodation coefficients of the energy of the ions Ar^+ (1) and N_2 (2) in molybdenum. U_∞, km/sec

wide range of ion velocities ($U_\infty \simeq 6.5$–25 km/sec) for a pressure in the working chamber of $\sim 1.5 \cdot 10^{-5}$ torr.

In the measurements we used a plane thermoanemometer probe in the form of a molybdenum disk $\delta \simeq 0.12$ mm with a working surface of diameter 3.5 mm, to the rear side of which current-conducting elements and a thermocouple were connected.

The results of the measurements are shown in the figure. Curve 1 shows the values of α_i of Ar^+ ions and curve 2 shows this coefficient for N_2^+ ions. The temperature of the probe surface when measuring α_i was $T_W = 304$–312°K. It should be noted that when determining α_i the points on the curve $T_W = T_W(V)$ were chosen to be such that $e\,|V^A| \ll W_i$. The results of the measurements are in satisfactory agreement with the values $\alpha_i = 0.75 \pm 0.05$ and $\alpha_i = 0.81$, and 0.84 for Ar^+ ions with energies $W_i = 21$–141 eV on Mo obtained in [1, 2], and the calculated values $\alpha_i = 0.682$ for N_2^+ ions for $W_i = 14.5$ eV on Mo [3].

LITERATURE CITED

1. C. C. Van Voorhis and K. T. Compton, Phys. Rev., 37, No. 8, 1596 (1931).
2. K. T. Compton and E. S. Lamar, Phys. Rev., 44, No. 9, 338 (1933).
3. A. A. Pyarnpii, Interaction of Gas Molecules with Surfaces [in Russian], Nauka, Moscow (1974).

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CALCULATION OF THE STATIC AND DYNAMIC CHARACTERISTICS OF A HEAT EXCHANGER OF FRIABLE MATERIAL

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The main feature of the heat exchanger considered is the fact that the time that the solid and gas heat carriers remain in the apparatus differ by a factor of several hundred. The data available in the literature on mathematical models of heat exchangers ignore this feature which makes it difficult to use them.

Equations describing the cooling of carbon by a gas heat carrier are obtained by considering the thermal balance on an element of length of the heat exchanger taking into account the change with time of the amount of heat in this element. We used an approximation of the mean temperature and its derivatives in the form $t_m = (t_{in} + t_{out})/2$, $dt_m/d\tau = dt_{out}/d\tau$, which gives the best qualitative description of the process at the initial instant of time after a sudden perturbation is applied.

To change from the differential equations in partial derivatives to the usual equations, the heat exchanger was represented in the form of a number of series-connected heat exchangers, i.e., it was divided into several zones with a linear change in the temperature along the length of each zone. As the number of zones is increased the accuracy of the approximation increases, but the number of differential equations also increases, which complicates the problem. When solving a system of differential equations with time constants differing by a factor of hundreds, using a standard Runge–Kutta program, in order to obtain stability it is necessary to choose an extremely small integration step, which involves considerable computation time. To economize on computation time a special procedure of separating the system of equations into algebraic and differential parts is employed.

When investigating the dynamics of a heat exchanger we calculated the transients when there were sudden perturbations in temperature and the flow rate of the solid and gaseous heat carriers. Along the channel the temperature of the solid heat carrier at the input – the temperature of the solid heat carrier at the output of the heat exchanger is approximated by series-connected aperiodic sections, or, to a first approximation, it can be represented by a first-order aperiodic section and a pure delay section. Similar considerations hold for the temperature of the solid carrier at the input and the temperature of the gaseous heat carrier at the output for the channel. For the channel the temperature of the heat carrier at the input and the temperature of the heat carrier at the output of the heat exchanger can be approximated by two parallel-connected sections, one of which is a first-order aperiodic section and the second is an amplifier. Since the flow rate of the carbon and the heat carrier occur in the set of differential equations in the form of a complex function the transients in the flow rate are calculated for different perturbation levels.

Hence, a heat exchanger with a very different time in which the solid and gaseous heat carriers remain in the system is a quite complex object from the point of view of automatic control. The mathematical relations given can be used for numerical calculations of such systems. The mathematical model obtained should serve as a basis for designing systems for the automatic control of the temperature of the solid heat carrier.

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ANALOGY BETWEEN SEMICONDUCTOR THERMISTORS AND A TRANSVERSELY BLOWN ELECTRIC ARC

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To simulate the processes taking place in electric arcs and to design the appropriate electric circuits, an analogy can be drawn between semiconductor thermistors and the electric arc. Despite the difference between the external and internal accompanying physicochemical processes, the basis for considering these thermistors from a single position is the dependence of their static resistance R on the temperature.

We choose as the object of comparison a gas electric arc [1, 2], which burns under conditions of gas-vortex (air) spatial stabilization in the discharge chamber of a coaxial circuit ($d_a = 3 \cdot 10^{-2}$ m, $l_a = 1.2 \cdot 10^{-1}$ m, $d_k = 1.6 \cdot 10^{-2}$ m, and $l_k = 5 \cdot 10^{-2}$ m), and as the solid semiconductor types KMT-1 ($R_{20} = 102.8$ kΩ, B = 4225°K, T_c = 20-80°C) [3], KMT-14 ($R_{20} = 71$ kΩ) [4], and MT-57 (T_T = 60°C, T_c = 21.2°C, W = 6 m·sec^{-1}, and $R_{60} = 1.75$ kΩ). [3].

The qualitative and quantitative comparative analysis carried out on establishing an analogy between semiconductor thermistors and the transversely blows dc electric arc enables us to state the similarity with respect to the following criteria: 1) the current–voltage characteristic (R < 0), 2) the electric-circuit equation (Kirchhoff's second law), and the stability condition (Kaufman's criterion), 3) the range of working modes of operation (boundaries), 4) the circuit supply coefficient ($\gamma \gtrless 0$), 5) the convective sensitivity coefficient of R ($\nu > 0$), 6) the temperature sensitivity coefficient of R ($\Delta\beta_d \approx \Delta\beta_T$), 7) the power sensitivity coefficient of R (m < 0).

LITERATURE CITED

1. A. G. Shashkov and A. S. Sergienko, Izv. Akad. Nauk BSSR, Ser. Fiz.-Energ. Nauk, No. 4 (1970).
2. A. S. Sergienko and N. M. Kuleshov, Izv. Akad. Nauk BSSR, Ser. Fiz.-Energ. Nauk, No. 1 (1976).
3. A. G. Shashkov, Thermistors and Their Application [in Russian], Énergiya, Moscow (1967).
4. I. F. Voloshin and V. A. Palagin, Transients in Thermistor Circuits [in Russian], Nauka i Tekhnika, Minsk (1967).

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TEMPERATURE FIELD OF A THIN SHELL WITH AN OPENING IN CONVECTIVE HEAT EXCHANGE

A. P. Matkovskii and T. A. Nemanezhina

UDC 536.21

Using the heat-conduction equation of thin shells, the nonstationary temperature field of a shell with a circular opening is determined under convective heat-exchange conditions with an external medium, whose temperature is a function of the coordinates and time. Boundary conditions of the first, second, or third kind are specified on the contour of the opening. In the neighborhood of the opening the assumptions of the theory of flat shells are used, viz., that the middle surface of the shell possesses a metric of Euclidean geometry while the principal curvatures are constant.

The problem reduces to solving an equation of the form

$$\Delta F - \mu^2 F - \frac{\partial F}{\partial \tau} = -g$$

with the corresponding boundary conditions. Here μ is a certain constant, the function g is expressed in terms of the temperature of the medium $t^{(c)}$ around the surface of the shell, Δ is the Laplace operator, and τ is the dimensionless time.

The solution of this problem was found using the Fourier method of separation of the variables and the Laplace integral transform. Equations are also presented for the approximate calculation of the temperature field obtained using the asymptotic representation of the Macdonald functions.

A special case is considered in which the temperature of the external medium depends only on time, and the initial temperature of the shell t_0 is constant.

Results of calculations of the integral temperature characteristic T_1 when $t^{(c)} = \cos\omega\tau$, $t_0 = 0$ are presented. In this case convective heat exchange with the medium whose temperature is zero occurs on the contour of the opening. The figure shows values of T_1 on the contour of the opening for $\omega = \pi/12$.

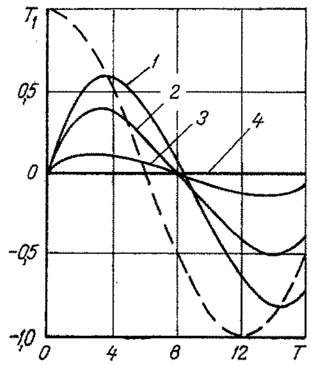

Fig. 1. Dependence of the integral temperature characteristic T_1 on the time T, for different values of Bi – the relative heat-transfer coefficient from the contour of the opening: 1) Bi = 0 (the opening is thermally isolated and has no effect on the temperature field of the shell); 2, 3, 4) Bi = 6.7, 67, and ∞, respectively. The dashed curve is the temperature of the medium on the surfaces of the shell.

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GENERALIZED NONAXISYMMETRICAL PLANE TEMPERATURE FIELDS IN AN INFINITELY LONG CONTINUOUS ORTHOTROPIC CYLINDER IN THE CASE OF RANDOM ACTIONS

N. B. Karavanova and M. P. Lenyuk

UDC 536.21

The problem of constructing an axisymmetrical stochastic plane temperature field in an infinitely long uniform orthotropic continuous cylinder of radius R, under convective heat-exchange conditions obeying Newton's law with the surrounding medium, the temperature of which is a random function of time leads to integration in the region $D = \{(r, \varphi, t), 0 \le r \le R, 0 \le \varphi < 2\pi, 0 \le t \le t_1 \le +\infty\}$ of the equation

$$\frac{1}{w_r^2}\frac{\partial^2 T}{\partial t^2} + b_r \frac{\partial T}{\partial t} - \left[\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\lambda}{r^2}\frac{\partial^2 T}{\partial \varphi^2}\right] = f(t, z, \varphi) \tag{1}$$

with the initial and boundary conditions

$$\begin{gathered} T\Big|_{t=0} = \psi_1(r, \varphi), \quad \frac{\partial T}{\partial t}\Big|_{t=0} = \psi_2(r, \varphi), \\ \left[\frac{\partial}{\partial r} - \beta_1 h\left(1 + \tau_r \beta_2 \frac{\partial}{\partial t}\right)\right] T\Big|_{r=R} = \psi(t, \varphi), \\ \frac{\partial T}{\partial r}\Big|_{r=0} = 0, \quad \frac{\partial^k T}{\partial \varphi^k}(t, r, \varphi + 2\pi) = \frac{\partial^k T}{\partial \varphi^k}(t, r, \varphi), \quad k = 0,1. \end{gathered} \tag{2}$$

Here f and ψ are stationary random functions of time (stationary in the wide sense) [1]. The remaining quantities are the generally accepted ones [2, 3].

The basis for obtaining the structure of the stochastic temperature field in D is the deterministic solution of problem (1)-(2) constructed by the Laplace integral transform method L and by the method of the finite Fourier integral transform F_n, introduced by the authors.

As an example, we present the correlation functions and power of the temperature fields for the most important random processes from a practical point of view (the correlation functions $K_f = \delta(t_2 - t_1)$ and $K_f = \exp\{-\chi|t_2 - t_1|\}$).

By combinations of the limiting ratios of the parameters w_r, b_r, h, β_1, β_2 we obtain the fundamental characteristics of both pure wave and parabolic stochastic temperature fields for one of three types of boundary conditions.

LITERATURE CITED

1. V. S. Pugachev, The Theory of Random Functions and Its Application to Automatic Control Problems [in Russian], Fizmatgiz, Moscow (1962).
2. A. V. Lykov, Theory of Heat Conduction [in Russian], Vysshaya Shkola, Moscow (1967).
3. M. P. Lenyuk, M. I. Bukatar, and L. K. Shelyag, "Random temperature stresses in an elastic half space," Prikl. Mat., 12, No. 5, 29 (1976).

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