INFLUENCE OF FUNDAMENTAL FACTORS ON THE STREAM TEMPERATURE IN A COOLED CHANNEL

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Results of an investigation of the influence of fundamental factors on the temperature of a stream flowing in a channel are elucidated.

To analyze, utilize, and control heat exchange apparatus automatically, it is required to know the parameters of the stream flowing therein under starting and working mode conditions. The fundamental parameter characterizing the state of the stream is its temperature, which changes along the length and with time. As is known, an experimental determination of the stream temperature along the channel length causes great, frequently insuperable difficulties. Nevertheless, it is quite important to determine its value at any channel section and to establish the factors affecting it.

The influence of the fundamental factors on the stream temperature is examined below (for the case of channel wall cooling).

The analysis is performed on the basis of computations carried out on the "Mir" computer according to a dependence obtained as a result of solving the system of differential equations of the channel heat conduction in the presence of thermal constant intensity sources and heat transfer to the heat carrier stream moving within the channel [1]. The computations were carried out for low thermal source intensities $0 \le \mathrm{Po} \le 0.01$. The system of equations

$$\frac{\partial T}{\partial \mathrm{Fo}} = \frac{\partial^2 T}{\partial R^2} + \frac{1}{R} \cdot \frac{\partial T}{\partial R} + \mathrm{Po};$$
$$\frac{\partial U}{\partial \mathrm{Fo}} + \frac{1}{\mathrm{Fo}'} \cdot \frac{\partial U}{\partial z} = 2\,\mathrm{St}\,\frac{l}{r_0}(T - U) \tag{1}$$

was solved under the conditions

$$\left[\frac{\partial T}{\partial R} + \mathrm{Bi}\,(T - U)\right]_{R=1} = 0;$$
$$\frac{\partial T}{\partial R}\Big|_{R=R_1} = 0;\; T\,|_{\mathrm{Fo}=0} = 1;\; U\,|_{z=0} = 0;\; U\,|_{\mathrm{Fo}=0} = 1. \tag{2}$$

Assumptions were hence made about the absence of axial overflow of heat in the channel, about the constancy of the physical constants of the heat carrier and the coefficient of heat exchange along the length. The dependence to determine the stream temperature is obtained as follows [1]:

$$U = 1 + \frac{k\,\mathrm{Po}}{m^2\mathrm{Fo}'}\left(e^{-m\mathrm{Fo}} + m\,\mathrm{Fo} - 1\right) - e^{-kz}\Big\{\left(e^{-m\mathrm{Fo}''} + m\,\mathrm{Fo}'' - 1\right)$$
$$\times \frac{k\,\mathrm{Po}}{m_2\,\mathrm{Fo}'} + 1 + \int\limits_0^{\mathrm{Fo}''}\left[\frac{k\,\mathrm{Po}}{m^2\,\mathrm{Fo}'}\left(e^{-m(\mathrm{Fo}''-y)} + m(\mathrm{Fo}'' - y)\right.\right.$$
$$\left.\left. - 1\right) + 1\right]\frac{e^{-\nu_0^2 y}}{\sqrt{\dfrac{y}{kz\nu_0^2}}}\,I_1\left(2\sqrt{k\nu_0^2 zy}\right)dy\Big\}. \tag{3}$$

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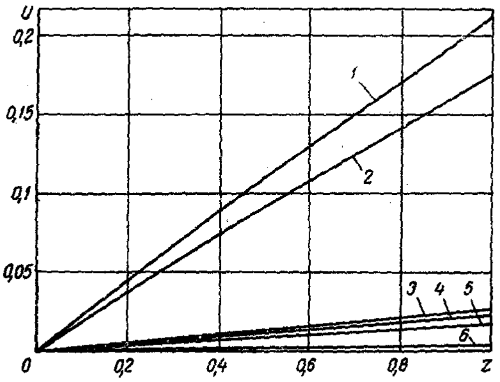

Fig. 1. Change in stream temperature along the channel length: 1) Fo = 0.01; St = 0.01; 2) 0.1; 0.01; 3) 1; 0.01; 4) 0.01; 0.001; 5) 0.1; 0.001; 6) 1; 0.001; 1-6 for Bi = 0.1

The channel and the heat carrier within it are heated to a temperature t_0 at the initial time; the heat carrier flows at a constant rate and constant temperature at the input from the initial time.

The flux of the heat carrier flowing in the channel changes its parameters. As is seen from Fig. 1, its temperature during heating (or cooling) varies at any time along the channel length according to an almost linear law (analogous to the stationary mode); the deviation from the linear law increases as the Stanton criterion grows.

The temperature lines diverge from the origin (entrance section), i.e., stream heating grows as the heat exchange intensity and the channel length increase.

It is characteristic that the tempo of the temperature change along the length is considerably greater in the initial time period (curves 1, 2 and 4, 5 – Fo = 0.01-0.1) than in the later period (curves 2, 3 and 5, 6 – Fo = 0.1-1.0).

Since the heat exchange process under consideration in the channel is nonstationary, the heat carrier temperature undergoes a change not only along the length, but also in time (Fig. 2a and b).

In a broad range of thermal modes taking place during utilization of heat exchangers, the temperature practically takes on a stationary value in the course of a definite time ($Fo \geq 3$). The time to reach this stationary value depends on the value of the Biot and Stanton numbers and the distance from the entrance to the channel. The tempo of temperature reduction in all sections in all heat modes is greatest at the initial instant, but is retarded with the course of time and equals zero for Fourier numbers greater than three; its drop in absolute values is more significant for large Stanton numbers.

As should have been expected, the stream temperature rises as the heat exchange intensity increases (Fig. 3). It is seen from the nature of the change in the curves (Fig. 3) that the achievement of a given temperature level is realizable for completely definite values of the heat exchange coefficient along the channel length and a further intensification of the heat exchange (in this case $St > 0.3$ for $z = 1.0$, curve 6, and $St > 0.5$ for $z = 0.5$, curve 3) is already practically meaningless. There hence results that the stream parameter does not change at the exit if a heat exchange intensity variable along the length is provided; it is not expedient to maintain it at the same height along the whole channel length. Taking account of this circumstance can turn out to be especially essential in constructing and utilizing heat exchangers of great length.

The dependences of the stream temperature on the various factors presented in Figs. 1-3 permit determination of the level and heat liberation law along the channel length from the utilization conditions of the heat exchanger, and also permit variation of its length. The same temperature level (U = 0.8,

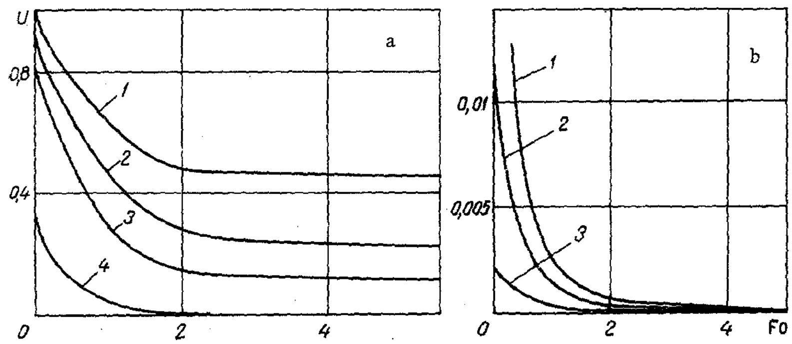

Fig. 2. Change in stream temperature with time. For (a): 1) Bi = 0.015; z = 1; 2) 0.1; 0.1; 3) 0.015; 0.5; 4) 0.015; 0.1; 1-4 for St = 1; for (b): 1) Bi = 0.1; z = 1; 2) 0.1; 0.5; 3) 0.1; 0.1; 1-3 for St = 0.001.

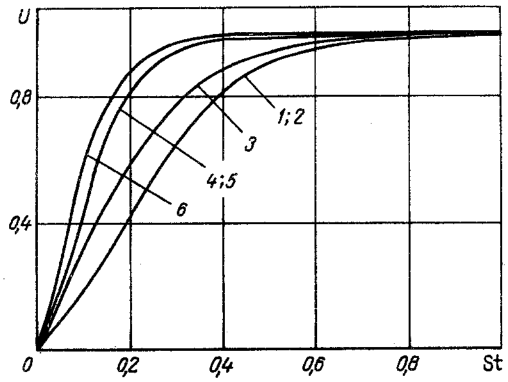

Fig. 3. Dependence of the stream temperature on the Stanton criterion: 1) Bi = 0.15; z = 0.5; 2) 0.1; 0.5; 3) 1.0; 0.5; 4) 0.15; 1.0; 5) 0.1; 1.0; 6) 1.0; 1.0.

St = 0.19, curve 5, Fig. 3) can be obtained in a halved channel but for other values of the Stanton number (U = 0.8, St = 0.376, curve 2).

Therefore, the results of investigating the influence of thermal similarity criteria on the temperature afford the possibility of estimating the expected heat carrier parameters and of determining the optimal modes to obtain them, and of establishing the size of the heat exchanger.

NOTATION

I_1 is the modified first order Bessel function of the first kind;
$k = 2\,StA_0\Phi(\nu_0 R)\,l/r_0$ is a dimensionless complex;
$St = Nu/RePr$ is the Stanton criterion;
l is the channel length;
r_0 is the channel radius;
A_n is the constant of the characteristic equation;
ν_n are the roots of the characteristic equation $Y_1(\nu_n R_1)[\nu_n J_1(\nu_n) + Bi J_0(\nu_n)] - J_1(\nu_n R_1)[\nu_n Y_1(\nu_n) - Bi\, Y_0(\nu_n)] = 0$;
$R = r/r_0$ is the running dimensionless radius;
$R_1 = r_1/r_0$ is the dimensionless radius of the outer channel wall;
$m = \nu_0^2 + k/Fo'$ is the dimensionless complex;
$Fo = a\tau/r_0^2$ is the Fourier criterion;
$Fo' = a\tau_0/r_0^2$ is the dimensionless time of stream particle passage over the whole channel length;
$Po = Wr_0^2/\lambda(t_0 - U_{BX})$ is the Pomerantsev criterion;
W is the intensity of a permanent source in the volume of the channel wall;
$z = x/l$ is the running dimensionless channel length;
$U = u - U_{BX}/t_0 - U_{BX}$ is the dimensionless stream temperature;
u is the mean stream temperature with respect to the heat content;
U_{BX} is the stream temperature at the channel entrance;
t_0 is the channel wall temperature at the initial instant;
$Fo'' = Fo - Fo'z$.

LITERATURE CITED

1. N. A. Minyailenko, Thermophysics and Heat Engineering [in Russian], No. 16, Naukova Dumka, Kiev (1970).