LOCAL HEAT EXCHANGE OF A SINGLE TRANSVERSELY BATHED ROUND TUBE WITH EXTERNAL CIRCULAR FINS

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Under conditions of transverse bathing of a finned tube by air the distributions of local heat-transfer coefficients on the lateral faces and ends of a circular fin and on the fin-free surface of the tube proper are determined using heat-flux pickups.

Extensive experimental material has been accumulated on the average heat exchange of tubes with external circular fins [1, 10]. However, the use of such tubes in the heat-releasing surfaces of a heater requires a study of the local heat-exchange characteristics. In particular, it is very essential to have available data on the properties of the distribution of local heat-transfer coefficients over the height of the fins and the arrangement of the sections with the minimum and maximum heat-exchange intensities in the space between fins [2-4].

The results of an experimental study of the local heat exchange of a single tube with external circular fins of constant thickness in a transverse air stream are analyzed below. The construction of the tube with a degree of fin evolution of 9.38 is shown in Fig. 1a. Together with the fins it is made of industrial copper and in the axial direction it consists of two parts 1 and 2 tightly coupled by a threaded joint. Six battery heat-flux pickups Nos. 1-6 [5] are built in on the surface of the middle fin and the fin-free surface of the tube adjacent to it. The pickup dimensions are $5 \times 5 \times 1.2$ mm. They are fastened with nitroputty into recesses of $6 \times 6 \times 1.3$ mm, after which the surface of the tube is polished. The scheme of arrangement of the pickups is illustrated by Fig. 1b. Thermocouple beads which monitor the temperature of the heat-emitting surface are placed in the recesses along with pickups Nos. 1, 3, 4, and 6. The thermocouple and pickup leads are brought out to the instruments along the borings 3, 4, and 5 in the material of the tube and fin.

The tests were performed in an open wind tunnel with a working section 0.071×0.16 m in cross section. A description of the experimental installation is presented in [7]. The calorimetry method is borrowed from [6, 11]. The tube is uniformly heated from within by water boiling at close to atmospheric pressure. Because of the low thermal resistance of the tube walls and fins the temperature distribution on the outer heat-emitting surface is also close to uniform. The orientation of the pickups relative to the velocity of the impinging air stream is varied by rotating the finned tube about the vertical axis.

The measurements are made with a spacing of $\Delta\varphi = 18°$ in rotation angle and with a spacing of 9° and 4°30' in sections with sharp drops in the heat-transfer coefficients. The local heat-transfer coefficient was determined from the equation

$$\alpha_i = \frac{EK_n}{t_i - t_{\text{av}}}, \tag{1}$$

where the average stream temperature equals the half-sum of the temperatures at the entrance and exit.

The values of the constants K_n are obtained by individual graduation of the pickups after their mounting on the surface of the finned tube and are as follows:* $K_1 = 1654$ W/m$^2 \cdot$mV, $K_2 = 1834$, $K_3 = 1855$, $K_4 = 1436$,

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*The heat-flux pickups were made and graduated in the laboratory of thermal measurements of the Institute of Technical Heat Physics, Academy of Sciences of the Ukranian SSR.

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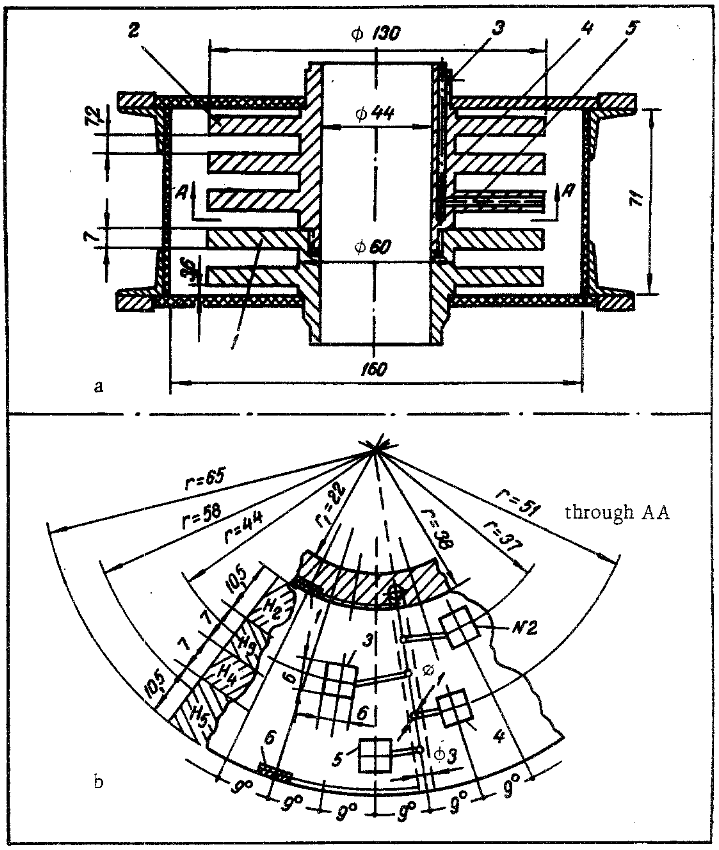

Fig. 1. Construction of calorimeter tube: a) fin structure; b) arrangement of heat-flux pickups.

$K_5 = 1174$, and $K_6 = 1813$ W/m^2 · mV.

The air temperatures at the entrance were measured with a mercury thermometer with a scale division of 0.2° C, while those at the exit were measured with a copper plate 12 mm thick perforated with openings 3 mm in diameter and with two thermocouples caulked in it. The plate is insulated at the ends and set in a flanged socket of the circulating part of the stand at a distance of 430 mm from the axis of the finned tube. The air temperatures at the entrance were $t_{en} = 17\text{-}22°C$ and at the exit $t_{ex} = 25\text{-}33°C$ in the tests.

In the zones where pickups Nos. 2 and 5 were located the temperatures of the fin surface were determined from curves of $t_i = f(r)$ constructed on the basis of measurements of the surface temperatures at the base of the fin, at its top, and at two intermediate points. Since the top-to-base temperature drops were 2-6° C, the interpolation assured an error of less than 1° C in absolute magnitude for temperature heads of $t_i - t_{av} = 50\text{-}60°C$.

The heat-transfer coefficients are measured at five fixed velocities of the air stream in the constricted section in the range of $W = 2.0\text{-}20.0$ m/sec. The distributions of the values of α_i over the angle φ corresponding to velocities of 5.71, 8.68, and 18.2 m/sec are shown in Fig. 2. The curves of $\alpha_i = f(\varphi)$ at the surface of the tube proper are in satisfactory agreement in a qualitative respect with the well-known data for transversely bathed smooth tubes [12, 13]. The profile of the $\alpha_i = f(\varphi)$ curves is altered at the surface of the fin. Within the limits of ± 70° from the frontal neutral point the local heat-exchange intensity is reduced slightly here: by 5-10% at the lateral surface of the fin and by 5-15% at the ends. In this zone one can evidently speak of a distribution of heat-transfer coefficients which is close to uniform over the angle φ. In the stern part of the finned tube a general reduction in the values of α_i by two to four times is observed relative to the point $\varphi = 0°$. In the interval of $\varphi = 100\text{-}150°$ the pickups record a large rise in the local heat transfer at the surface of the fin. For $W > 8.68$ m/sec this rise in heat transfer is also traced at the surface of the tube in the region of $\varphi = 100\text{-}110°$. On the whole, the highest absolute values of α_i appear near the base, near the top, and at the ends of the fin.

The radial distributions of local heat-transfer coefficients are shown in Fig. 3. On the side of the im-

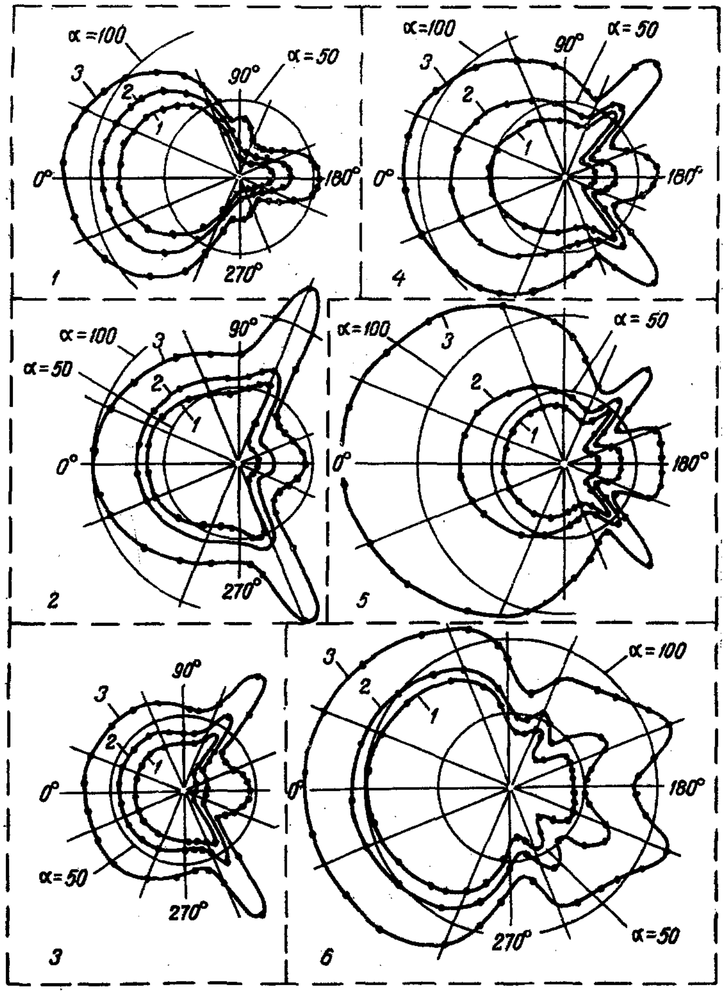

Fig. 2. Distributions of local heat-transfer coefficients over circumference of finned tube: 1) W = 5.71 m/sec; 2) 8.68; 3) 18.2; 1-6) serial numbers of heat-flux pickups from Fig. 1b.

pinging air stream within the limits of ±110° from the neutral point the $\alpha_i = f(r)$ curves have a double-humped configuration, with the highest values of the heat-transfer coefficients lying near the top of the fin for high velocities and near its base for $W < 8.68$ m/sec. The drops in the values of α_i between the minimum and maximum comprise 100-330% here. At the stern in the range of $\varphi = 150$-210° the heat-transfer coefficients grow almost monotonically from the base of the fin to the top. The drops between the minimum and maximum values of α_i are especially high in this zone and reach 500-600% at low velocities.

The analysis of the experimental results is more graphic if one turns to the "topography" of the local heat transfer. In Fig. 4, based on the data of Figs. 2 and 3, the field of local heat-transfer coefficients on the lateral surface of the fin for W = 2.24 and 8.68 m/sec is shown in such a way that the sections with enhanced, average, and reduced heat-exchange intensities are brought out. Within the limits of the light unhatched areas the local heat-transfer coefficients do not differ essentially from the surface-average value α_k (±20%). The areas where the local heat-transfer coefficients are less than 80% of the surface-average value are shown by the cross hatching. Finally, the areas with heat transfer exceeding the surface-average level by more than 20% are shown by one-way hatching. The maximum maximorum is located within region A and the maximum minimorum of local heat transfer is located within region B.

Zone I with an enhanced level of heat transfer near the top of the fin on the side of the impinging air stream develops as a consequence of the separation of the boundary layer in the flow at a 90° angle over the sharp entering edge. Separation at an entrance has been studied rather well in flat channels and on plates [8, 9]. The heat-transfer peak behind a sharp entering edge at a 90° angle is located at a distance of about two plate thicknesses from the edge. This rule agrees well with the data shown in Fig. 4. It should be emphasized

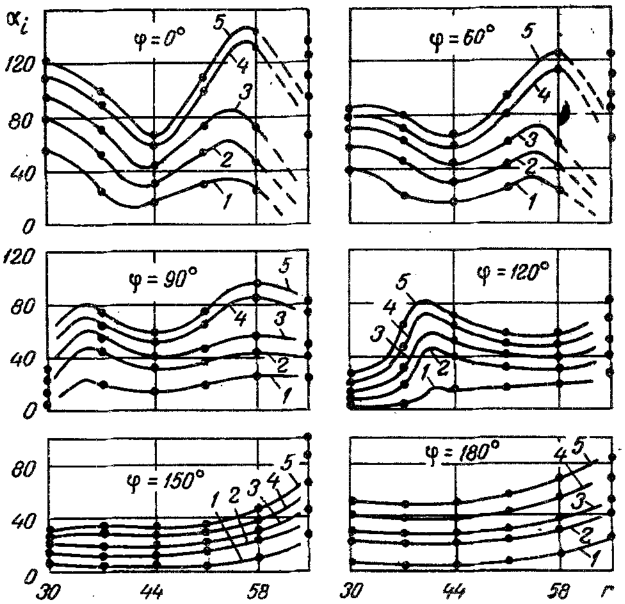

Fig. 3. Radial distributions of local heat-transfer coefficients: 1) W = 2.24 m/sec; 2) 5.71; 3) 8.68; 4) 14.5; 5) 18.2 m/sec. α_i, W/m^2 · deg; r, mm.

that since the existence of a separation peak in the heat transfer is connected with the shape of the edge, rounding of the fin extremities or the use of fins of variable thickness must alter significantly the character of the distribution $\alpha_i = f(r)$ near the entrance to the space between fins.

The second heat-transfer rise II near the base of the fin is caused by the compression of the stream. In approaching the midsection the air stream in the channel between fins enters into a convergent channel. But the increase in velocity, and, consequently, in the heat-transfer coefficients, occurs initially only along the curved wall, i.e., near the surface of the tube proper. This phenomenon must evidently be considered as specific for a transversely bathed round tube with circular fins. The air stream, having an increased velocity, separates from the surface of the tube before the midsection, producing a large rise in the heat transfer on the fin. The configuration of the streamlines along which the increased values of the heat-transfer coefficients are located on the surface of the fin is traced in Fig. 4 by the dashed-dot curves III.

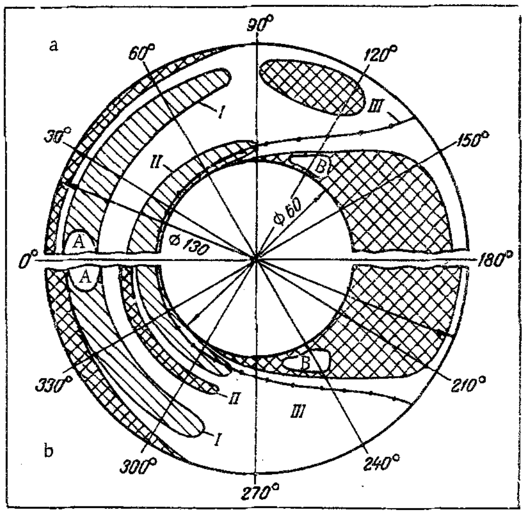

Fig. 4. Topography of local heat transfer on lateral surface of fin: a) W = 8.68 m/sec; b) 2.24.

TABLE 1. Dependence of Reduced Heat-Transfer Coefficients of a Finned Tube on Air Stream Velocity

W, m/sec	2,24	5,71	8,68	14,50	18,20
α_{re}, W/m^2 · deg [based on Eq. (3)]	20,6	36,9	47,6	64,8	75,4
α_{re}, W/m^2 · deg (based on [10])	23,0	41,0	52,5	70,0	79,5

In Table 1 the experimental data are compared with a calculated dependence taken from [10], where the surface-average heat transfer of single copper finned tubes was studied. The reduced surface-average heat-transfer coefficients are calculated by the equation

$$\alpha_{re}=\frac{\sum\limits_{n=1}^{n=6}\alpha_n\xi_n\Delta t_n}{\Delta t_1}.$$

The values of α_n and Δt_n are found by planimetry of the graphs of $\alpha_i = f(\varphi)$ and $\Delta t_i = f(\varphi)$. The values of ξ_n are $\xi_1 = 0.0543$, $\xi_2 = 0.185$, $\xi_3 = 0.154$, $\xi_4 = 0.178$. $\xi_5 = 0.314$, and $\xi_6 = 0.114$. As seen from Table 1, the values of α_{re} are understated on the whole relative to the calculation in accordance with [10], although the disagreements comprise less than 10% and do not go beyond the limits bounding the experimental accuracy (±12-15%).

NOTATION

α_{re}, surface-average reduced heat-transfer coefficient, W/m^2 · deg; φ, angle of rotation of finned tube about central axis; E, emf developed by heat-flux pickup, μV; K_n, calibration constant of n-th pickup, W/mV · m^2; t_{av}, average temperature of air stream, °C; t_{en}, t_{ex}, air temperatures at entrance and exit, °C; W, air stream velocity in transverse axial cross section of finned tube, m/sec; r, current radius of fin, m; ξ_n, portion of heat-exchange surface adjacent to n-th heat-flux pickup.

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