HEAT-TRANSFER FEATURES IN CHANNELS WITH FLOW SEPARATION

V. K. Migai, V. V. Pryakhin,
and V. S. Prokhorenko

UDC 536.24:532.54

Heat-transfer features are examined in channels of contractor-diffuser type, and generalizing dependences are presented for the analysis of the heat elimination and hydraulic resistance.

Boundary-layer turbulization significantly intensifies heat transfer, increases turbulent heat conduction, including even in the viscous sublayer. The turbulent viscosity is also raised simultaneously, resulting in the growth of hydraulic losses. However, even under their identical growth and the conservation of a constant Prandtl number, the heat transfer has a higher value for equal power losses in the predominance of resistance. Generation of turbulence in the near-wall domain occurs during the flow around obstacles, turbulizers. Turbulizers were first utilized for heat-transfer intensification in the investigations in [1, 2]. Tubes with an annular knurl were developed independently in [3, 4]. Analysis shows that for resistance losses equal to those for a smooth tube, the thermal extraction increases by 25% in [1, 2] and by 30-40% in [3, 4].

One of the modifications of heat-transfer surfaces with near-wall turbulizers is a tube comprised of alternating contractors and diffusers (Fig. 1). It is interesting to trace the regularities in the change of heat transfer during separated near-wall flows in an example of such tubes by keeping in mind their high thermal-hydraulic efficiency.

Elucidated below are results of investigations of the mean heat elimination and hydraulic resistance of tubes with symmetric contractors and diffusers in a water flow. The outer surface was heated by hot steam. The mean wall temperature was determined by connecting the experimental tube in a resistance thermometer circuit. The relative lengths of the sections were: heated 40 and preconnected 15. A detailed description of the test stand and the method of conducting the experiment is elucidated in [5].

The geometric tube dimensions are given in Table 1. The hydraulic diameter is taken as the characteristic dimension, and the heat flux is referred to the total surface while the mean velocity is taken as characteristic. On the basis of an analysis of the results of the investigations performed, it is established that the geometric parameter characterizing the heat transfer and hydraulic resistance is the slope of the contractor and diffusor generatrices $k = 2h/s$. The parameter k determines the intensity of vortex formation in the channel; therefore, it also governs the level of turbulent kinetic energy as well as the degree of stream compression in the contractor. Presented in Fig. 2 are data on the heat transfer that are approximated by a formula of the form

$$\mathrm{Nu} = A\,\mathrm{Re}^n\,\mathrm{Pr}^{0.43}\left(\frac{\mathrm{Pr}}{\mathrm{Pr_w}}\right)^{0.25},$$

where $A = 6.522k^{1.96}$, $n = 0.8 - 0.833k$ for $k \leqslant 0.18$ and $A = 0.00626k^{-2.093}$, $n = 0.5 + 0.833k$ for $k \geqslant 0.18$.

The quantity n varies between 0.65 and 0.8 in the range of variation $0 < k < 0.32$, i.e., turbulent and mixed flow modes exist as in the case of transverse flow around a tube bundle. For larger values of the parameter k ($k \approx 0.3$), the boundary layer is turbulized, $n = 0.8$, as the flow pattern obtained in a flume (Fig. 3) shows. In the limit case $k = 0$ the boundary layer is also turbulent, $n = 0.8$. As the quantity k ($k < 0.18$) grows, the boundary layer in the contractor part is laminar under the effect of negative pressure gradients, while it remains turbulent in the diffuser part. For $k = 0.18$ this effect appears to the maximum degree. In this case the boundary layer in the contractor part is apparently completely laminar but

"Kaluzhskii Turbine Factory" Production Combine. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 53, No. 3, pp. 398-402, September, 1987. Original article submitted May 5, 1986.

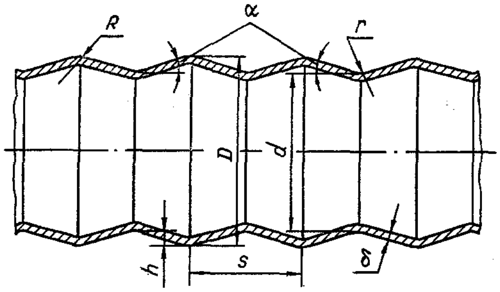

Fig. 1. Experimental tubular surface.

TABLE 1. Geometry of the Tubes Investigated

Tube number	D	d	R	r	s	h	α, deg	δ, mm	k
	mm								
1	22,0	—	—	—	—	—	—	1,0	—
2	25,07	22,57	6,8	1,0	8	1,25	29,55	0,9	0,3125
3	26,38	22,57	9,73	1,0	16	1,905	16,017	0,9	0,2381
4	25,64	22,36	16,25	1,0	16	1,64	16,017	0,9	0,205
5	26,33	22,37	19,0	1,5	24	1,98	11,017	0,9	0,165
6	26,18	22,16	17,37	1,5	24	2,01	11,017	0,9	0,1675
7	20,47	19,04	22,85	2,0	16	0,715	6,0	0,9	0,0894
8	21,19	19,3	15,95	2,0	16	1,03	8,617	0,9	0,1288
9	22,35	19,36	13,1	1,5	16	1,495	12,917	0,9	0,1869
10	22,51	19,14	16,07	1,0	16	1,685	16,583	0,9	0,2106
11	24,85	22,67	12,92	2,0	16	1,09	8,85	0,9	0,1363
12	18,68	16,32	11,13	1,5	16	1,18	9,467	0,9	0,1475
13	15,97	13,95	22,13	1,5	16	1,01	9,233	0,9	0,1263
14	26,31	22,13	20,13	2,5	32	2,09	8,1667	0,9	0,1306

turbulent in the diffuser part. Since the contractor and diffuser surfaces are identical, the mean value of the exponent should be $n = (n_1 + n_2)/2 = (0.8 + 0.5)/2 = 0.65$, as is obtained in tests. As the parameter k ($k > 0.18$) increases further, flow separation occurs (Fig. 3) and a vortex is formed in the corner of the cavity which, on being propagated into the contractor and diffuser, turbulizes the laminar layer in the contractor section. For $k \simeq 0.2$ the vortex has small dimensions and does not turbulize the boundary layer in the contractor domain but only separates the diffuser section with the turbulent and the contractor section with the laminary boundary layer. The hydrodynamic reasons mentioned govern the regularity of the change in the hydraulic resistance coefficient (Fig. 4). Test data are approximated by the following expression

$$\xi = B\,\mathrm{Re}^m,$$

where $B = 10.712k^{1.343}$, $m = -0.25$ for $k \leqslant 0.18$ and $B = 0.318 \cdot 10^{-4} k^{-6.079}$, $m = -11.574k^2 + 8.33k - 1.375$ for $k \geqslant 0.18$. It is seen from Fig. 3 that exactly as for the heat transfer data for $k > 0.18$, a change in the dependence $m = f(k)$ holds for the hydraulic resistance. For $k \leqslant 0.18$ the quantity is $m = -0.25$. This indicates separation-free flow. When $k > 0.18$ flow separation occurs and the dependence of ξ on Re determines the self-similar mode as k increases further ($k > 0.26$).

The stream laminarization phenomena detected are similar in nature to the effects observable in the transverse flow around checkerboard bundles in the mixed flow mode domain $2 \cdot 10^3 < \mathrm{Re} < 2 \cdot 10^5$ when there is a laminar boundary layer in the frontal part, the contractor part, of the tube. The mentioned laminarization effects hold for degrees of contractor and diffuser expansion $n = 1.4$ and unilateral apertures $\alpha = 5\text{–}12°$. The laminarization effect may not occur for other channel parameters, in particular, in narrower plane channels with a wavy surface where the separation vortical domains are a hindrance. The question of the influence of the Prandtl number remains uninvestigated.

Analysis of the results of experimental data showed

$$\mathrm{Nu}_c/\mathrm{Nu}_s = 1{,}4 - 2{,}75,\ \xi_c/\xi_s = 1{,}3 - 4{,}3 \text{ for } k = 0{,}089 - 0{,}24,\ \mathrm{Re} = 15\,000;$$

$$\mathrm{Nu}_c/\mathrm{Nu}_s = 1{,}25 - 2{,}4,\ \xi_c/\xi_s = 1{,}3 - 5{,}2 \text{ for } k = 0{,}089 - 0{,}24,\ \mathrm{Re} = 40\,000;$$

$$\mathrm{Nu}_c/\mathrm{Nu}_s = 2{,}75 - 2{,}3,\ \xi_c/\xi_s = 4{,}3 - 2{,}8 \text{ for } k = 0{,}24 - 0{,}3125,\ \mathrm{Re} = 15\,000;$$

$$\mathrm{Nu}_c/\mathrm{Nu}_s = 2{,}4 - 2{,}2,\ \xi_c/\xi_s = 5{,}2 - 4{,}1 \text{ for } k = 0{,}24 - 0{,}3125,\ \mathrm{Re} = 40\,000.$$

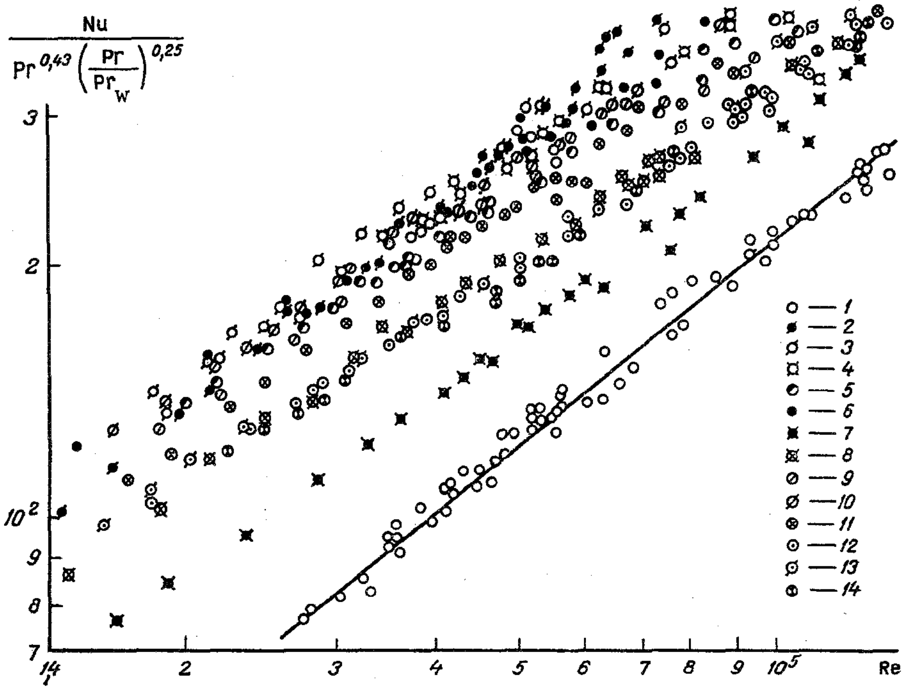

Fig. 2. Heat transfer in tubes of contractor-diffusor type; the point numbers 1-14 correspond to the tube numbers in the table: the curve is $Nu = 0.021Re^{0.8}Pr^{0.43}\ (Pr/Pr_w)^{0.25}\ \varepsilon_l$.

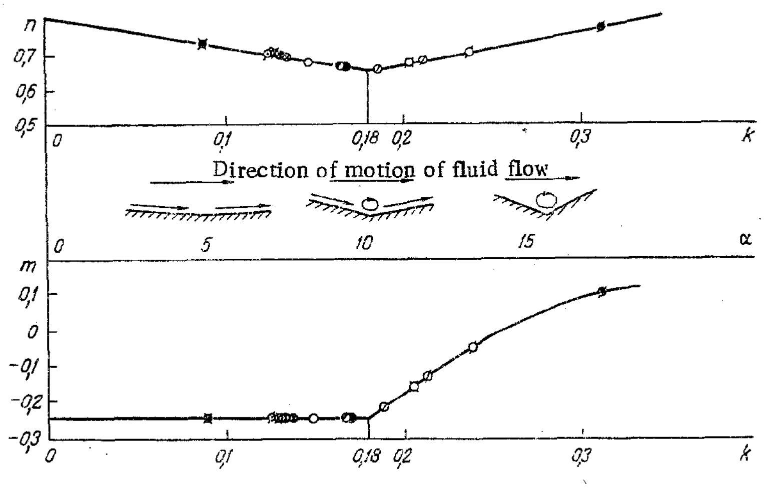

Fig. 3. Influence of the parameter k on the heat transfer and hydraulic resistance characteristics; point notation the same as in Fig. 2. α, deg.

It follows from the values of Nu_c/Nu_s, ξ_c/ξ_s that tubes are effective for $k < 0.16$ and $k > 0.3$. The domain $0.16 < k < 0.3$ has a high hydraulic resistance. For $k > 0.3$ the heat transfer grows 5-7% additionally because of the increase in surface (its kind of fin effect).

A comparison of the investigated surfaces according to the heat elimination coefficient for an identical value of the energetic index will permit the conclusion that tubes of the contractor-diffuser type Nos. 2 and 13 (see table) assure a rise in heat extraction of 60-70% for a power loss required to overcome resistance equal to that for a smooth tube. Upon installation of such tubes in condensers, the heat transfer from the condensing vapor is intensified additionally because of the action of gravity and surface tension on the condensate film.

The strength characteristics of such tubes vary negligible as compared with smooth tubes and they can be used in a contaminated flow since they have no circulation zones.

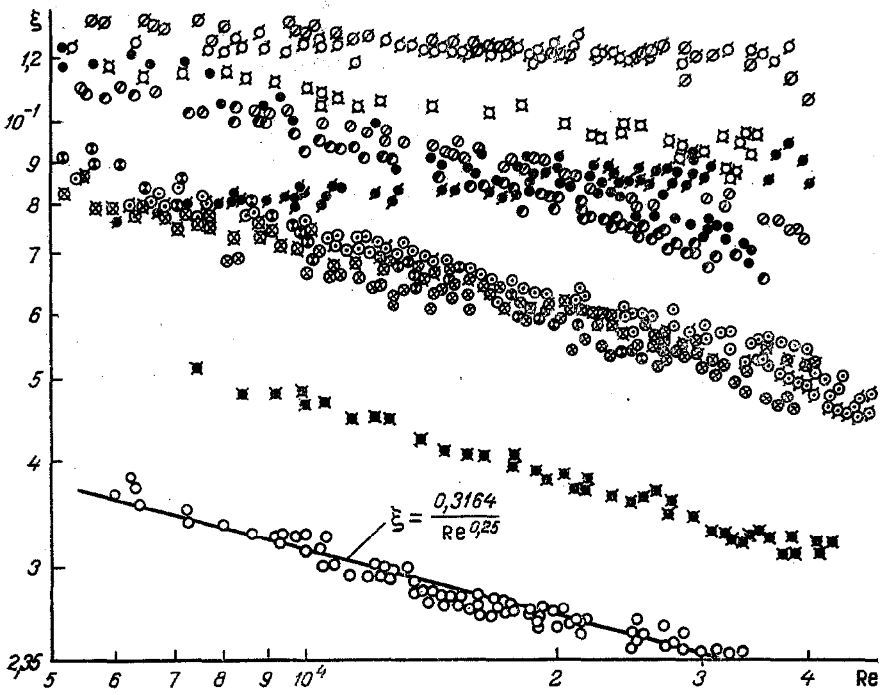

Fig. 4. Hydraulic resistance in contractor-diffusor type tubes; point notation the same as in Fig. 2.

LITERATURE CITED

1. R. Koch, VDI Forschungsheft, 24, No. 469, 5-44 (1958).
2. W. Nunner, VDI Forschungsheft, 22, No. 455, 5-39 (1956).
3. V. K. Migai and I. F. Novozhilov, Izv. Vyssh. Uchebn. Zaved., Energetika, No. 11, 18-21 (1965).
4. É. K. Kalinin and S. A. Yarkho, Inzh.-Fiz. Zh., 11, No. 4, 426-431 (1966).
5. V. K. Migai and V. S. Prokhorenko, Trudy. TsKTI, No. 207, 46-50 (1983).

CALCULATION OF THE INTEGRATED COEFFICIENTS OF ABSORPTION AND TRANSMISSION OF SOLAR RADIATION FOR SEMICONDUCTOR FILMS

A. V. Antropov, S. N. Kirillov,
F. T. Novik, and O. A. Trofimov

UDC 535.341:535.345.1:539.216.2

A method is described for calculating the absorption and transmission of solar radiation by thin semiconductor films as a function of the thickness of the films. Computational results are presented.

Photoelectric transducers based on thin semiconductor films appear to be most promising for solar power, since they will be able to provide a higher electricity output per unit weight than single-crystalline cells. To calculate the efficiency and thermal stability of such transducers it is necessary to determine the integrated optical characteristics of the films. The experimental measurement of solar integrated coefficients of absorption, reflection, and transmission involves significant difficulties and cannot always be performed. In addition, films with different thickness are characterized by different optical coefficients, since these coefficients themselves depend on the thickness of the films.

Knowing the values of the refractive and absorption indices n and k in a wide spectral range it is possible to calculate the integrated coefficients of absorption and transmission

A. A. Zhdanov Leningrad State University. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 53, No. 3, pp. 402-406, September, 1987. Original article submitted June 20, 1986.

0022-0841/87/5303-1024$12.50