CHARACTERISTICS OF CONVECTIVE HEAT TRANSFER IN NARROW SLITS

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The results of an experimental investigation of convective heat transfer in narrow slits are presented. It is shown that the length of the transition region depends considerably on the height of the channel b (for small b).

Narrow slit channels of heat exchangers are used widely in various branches of technology – power engineering, chemistry, food industry, etc. Calculation of convective heat transfer for such channels in the transition zone of Reynolds numbers (Re = 2000–10,000) continues to remain the least investigated region. Narrow slits with a channel height of the order of a millimeter were not investigated in the known studies [1, 2]. In the present study we investigated rectangular slit channels with a constant ratio of sides $\psi = a/b = 20$ and channel height b = 1 mm ($l/d_e = 165$), b = 2 mm ($l/d_e = 175$), b = 3.4 ($l/d_e = 100$), and b = 4 mm ($l/d_e = 90$ mm), where l is the channel length. Thus the relative length of the channel in these experiments does not effect heat transfer, since $l/d_e > 50$, which provides stabilization according to [4]. The constancy of the parameter ψ was maintained to eliminate its separate effect on heat transfer. When $\psi = 20$ the channels can be regarded as practically plane. The channels were investigated on air installation by the method presented in [3].

The channel walls were heated by boiling water, which provided constancy of their temperature. The experimental data were referred to the mean logarithmic temperature difference and the physical properties were calculated on the basis of the flow temperature. The data on the hydraulic resistance of the channels are presented in Fig. 1. As follows from the graphs, in the laminar region the points practically correspond to the theoretical relation for $\psi = 20$, having the from $\xi = 96/\mathrm{Re}$. In the turbulent region the points satisfy the Blasius equation ($\xi = 0.316\ \mathrm{Re}^{-0.25}$). The length of the transition zone is not the same. For a channel with b = 2 mm the transition ends at $\mathrm{Re}_2 \sim 8000$ and for the channel with b = 4 mm at $\mathrm{Re}_2 = 4500$–5000. This means that for narrower channels the turbulent flow regime occurs at larger Reynolds numbers (the transition is protracted). This is clearly confirmed by the data on heat transfer shown in Fig. 2.

For the channel with b = 4 mm the transition ends at $\mathrm{Re}_2 \sim 5000$, for b = 3.4 mm at $\mathrm{Re}_2 \sim 5000$, for b = 2 at $\mathrm{Re}_2 \sim 9200$, and for b = 1 at $\mathrm{Re}_2 = 16{,}000$. We note that the values of Re_2 for hydraulics and heat transfer coincide. For a turbulent flow regime the experimental points on heat transfer correspond to the known equation $\mathrm{Nu} = 0.018\ \mathrm{Re}^{0.8}$ [4]. Thus the data on heat transfer and hydraulic resistance indicate that for small channel heights the turbulent flow regime occurs later with respect to Reynolds number with a decrease of height and the transition region is protracted. This circumstance is confirmed by the particular data of [5] denoted by a dashed line in Fig. 2.

Heat transfer in the mounting gaps of blade roots having a shape close to a slit and parameter b less than a millimeter was investigated in [5].

Figure 3 shows the relation $\mathrm{Re}_2 = f(\bar{b})$ plotted on the basis of the graph in Fig. 2. The curve can be approximated by the relation $\mathrm{Re}_2 = (11{,}300/\bar{b}^{\,1.835}) + 4700$, where $\bar{b} = b/b_0$, $b_0 = 1$ mm is the minimum gap investigated in the experiments.

The value $\mathrm{Re}_2 \sim 4700$ is the asymptote of the function. This means that with a further increase of b the transition will end at $\mathrm{Re}_2 \sim 4700$. The graph does not have an asymptote for small b. Apparently a decrease of b to fractions of a millimeter will lead to further protraction of the transition. The noted damping

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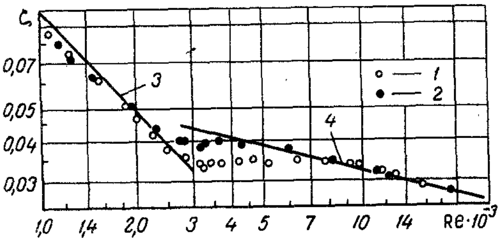

Fig. 1

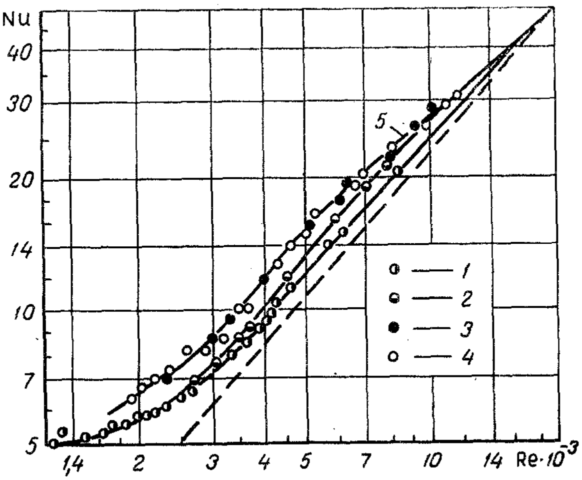

Fig. 2

Fig. 1. Hydraulic resistance in slit channels: 1) b = 2 mm; 2) 4 mm; 3) $\zeta = 96\ \mathrm{Re}^{-1}$; 4) $0.316\ \mathrm{Re}^{-0.25}$.

Fig. 2. Heat transfer in rectangular channels: 1) b = 1 mm; 2) 2 mm; 3) 3.4 mm; 4) 4 mm; 5) $\mathrm{Nu} = 0.018\ \mathrm{Re}^{0.8}$. Dashed line: according to the data in [5].

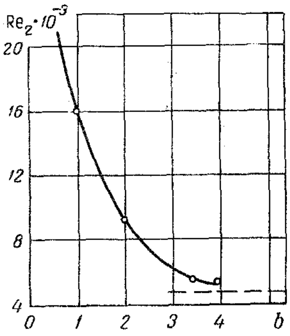

Fig. 3. Length of transition region vs parameter $\bar{b}$.

action of narrow slit channels on the transition region is related with the fact that the development of fluctuations is hampered with a decrease of the gap. According to [7], an increase of the parameter l/d_e in the transition region leads to an increase of the portion of turbulent flow (intermittence coefficient). However, the effects noted cannot be explained by the indicated circumstance, since for channels with b = 4 and 2 mm, conversely, a more protracted transition corresponds to a greater value of l/d_e.

According to Taylor's hypothesis [6], local flow separations occur in the transition region as a consequence of local pressure gradients caused by fluctuations. Apparently this circumstance can explain the fact that the resistance coefficient ζ does not depend on the Reynolds number in the transition region in conformity with Fig. 1.

As is known, the flow in separation regions is practically self-preserving with respect to the Reynolds number. Representing the flow in the transition region as a system of microseparations with subsequent attachment of the boundary layer, we can conjecture that ζ will not decrease with increase of Re. The noted fact that ζ does not depend on Re is indirect confirmation of Taylor's hypothesis.

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