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LINEAR HEAT TRANSFER IN A FLOW AROUND A CYLINDER OR A SPHERE

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It is shown that the relation between the Nusselt and Reynolds numbers determined by the Reynolds analogy is linear with self-similarity of the hydrodynamic resistance coefficient.

Analysis of the most reliable experimental data obtained by R. Hilpert [1] and A. Zhukauskas and I. Zhyugzhda [2] carried out in [3, 4] has shown that in the case of forced convection heat transfer from a uniformly heated cylinder the relation between the Nusselt and Reynolds numbers has the form of a broken line containing straight sections at Reynolds numbers exceeding 7000. Because of the presence of sections with a linear relation between the heat transfer coefficient and the flow velocity, it is possible to design thermoanemometers with a linear transfer function. Apart from thin wires in the form of cylinder in a transverse flow, films applied to the end face of a cylinder or a spherical surface or silicon IC fixed to similar surfaces can be used as sensors in the thermoanemometers [5].

In the present work an attempt has been made to explain the appearance of linear sections in the Nu-Re curves in the case of a flow past the lateral and end surfaces of a cylinder and the surface of a sphere.

First, we will consider heat transfer from the lateral surface of a cylinder. According to the Reynolds analogy, forced convection heat transfer is largely determined by the flow of a heat-transfer fluid past the heat-releasing surface. It follows then that the dependence of the hydrodynamic resistance coefficient of a body in a flow on the Reynolds number characterizes the heat transfer process and the interrelation between the Nusselt and Reynolds numbers. If we consider the well-known dependence of the hydrodynamic resistance coefficient of a cylinder in a transverse flow on the Reynolds number from Wisilsberg's measurements [6], we can see that up to Re = 600 the hydrodynamic resistance coefficient ξ decreases, in the range $6 \cdot 10^2 \leq \mathrm{Re} \leq 6 \cdot 10^3$ ξ varies slightly over $\xi = 1$, and in the range $7 \cdot 10^3 \leq \mathrm{Re} < 2 \cdot 10^5$ the curve of ξ versus Re passes through the clearcut straight line $\xi = 1.2$ parallel to the abscissa. From the criterial equations [3, 4] it also follows that the straight sections in the Nu-Re curves are observed in this very region of Reynolds numbers (see Fig. 1). With this in view, it is possible to suggest that in a certain region of Reynolds numbers the relation between Nusselt and Reynolds numbers should be observed in the case of self-similarity of the hydrodynamic resistance coefficient in this region.

With the just formulated suggestion in view, we will consider the behavior of the Nu-Re relation in the case of heat transfer from the end face of a cylinder [7]. For this case straight sections are observed in the criterial equations with the following Reynolds numbers:

$$2 \cdot 10^3 \leq \mathrm{Re} \leq 10^4 ; \quad \mathrm{Nu} = 20 + 0.006\,\mathrm{Re} ;$$

$$10^4 < \mathrm{Re} \leq 2 \cdot 10^4 ; \quad \mathrm{Nu} = 30 + 0.005\,\mathrm{Re} .$$

For the end face of a cylinder these ranges of Reynolds numbers differ substantially from the ranges characterizing the straight sections of the criterial relations for the case of heat transfer from the lateral cylindrical surface, which could be expected in principle. From the behavior of the flow over the end face of the cylinder [8] it can be suggested that the relations of the flow around a sphere and heat transfer from it are more suitable for the present case. From consideration of the well-known relation between the hydrodynamic resistance and the Reynolds number [6] one can easily see that two self-similar regions exist for ξ:

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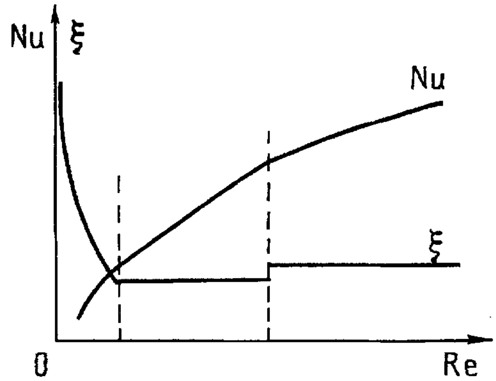

Fig. 1. Plot of the Nusselt number and hydrodynamic resistance coefficient versus the Reynolds number in the case of a heated circular cylinder in a transverse flow.

$$2\cdot 10^3 \le \mathrm{Re} \le 10^4, \quad \xi = 0.4;$$

$$10^4 < \mathrm{Re} \le 2\cdot 10^5, \quad \xi = 0.5.$$

The boundaries of these regions agree well with the boundaries for the case of heat transfer from the end face of a cylinder. However, if the known experimental data on heat transfer from a spherical surface [8-10] are processed with the method used for processing experimental data on forced convection heat transfer [3, 4], it is possible to obtain straight sections of the broken criterial relation:

$$2\cdot 10^3 \le \mathrm{Re} \le 10^4, \quad \mathrm{Nu} = 20 + 0.0075\,\mathrm{Re};$$

$$10^4 < \mathrm{Re} \le 2\cdot 10^5, \quad \mathrm{Nu} = 50 + 0.0045\,\mathrm{Re}.$$

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