SCHLIEREN INVESTIGATION OF THE NATURAL-CONVECTION HEAT TRANSFER OF A ROTATING SPHERE

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The results of an experimental investigation are presented. A formula is obtained for estimating the effect of rotation. The schlieren method has been used to investigate the thermal boundary layer.

Data on the heat transfer of a rotating sphere are required in various branches of technology including that relating to equipment employing disperse systems. Data are lacking for the case of a sphere rotating under conditions of natural convection. To solve this problem, we investigated individual rotating spheres by the method of the limiting regular regime [1]. The use of the schlieren technique enabled us to make a qualitative study of the formation of the thermal boundary layer. The aluminum spheres were mounted on a vertical axis in a chamber measuring 300 × 300 × 1000 mm. The diameters of the spheres were 39.7, 30.2, and 19.9 mm. As a check, we also investigated the heat transfer of a stationary sphere. A comparison of the data obtained and the published values showed that, correct to ±6%, the results are consistent with the Mikheev formula:

$$\mathrm{Nu} = 0.54\,(\mathrm{Pr\,Gr})^{0.25}$$

and, correct to ±10%, with the Schell formula [2] for air on the interval $2.7 \cdot 10^4 < \mathrm{GrPr} < 6.2 \cdot 10^5$.

A parallel schlieren investigation of the thermal boundary layer indicated that the mean thickness of the boundary layer corresponds to its thickness at the equator of the sphere. The data obtained were presented in [3] and the schlieren investigation of the nonstationary thermal boundary layer was described in [4].

We also investigated the heat transfer of spheres of the above-mentioned diameters when the rate of rotation n was varied from 300 to 2500 rpm.

The temperature drop varied between 50 and 300° C. The temperature of the sphere was monitored with a copper-constantan thermocouple mounted at the center of the sphere. Since for the bodies investigated Bi < 0.1, this temperature was taken equal to the surface temperature. A class-2 R2/1 potentiometer was used as indicator. When the sphere was rotated, the readings were obtained with a brush-ring system. While measuring the temperatures of the sphere and the ambient medium, we took motion-picture and still photographs of the thermal boundary layer with a IAB-451 instrument.

In correlating the data, by analogy with corresponding investigations of a rotating horizontal cylinder, we took as the characteristic criterion the parameter proposed by Etemad [5]

$$0.5\,\mathrm{Re}_r^2 + \mathrm{Gr}, \text{ where } \mathrm{Re}_r = \frac{\pi d^2 n}{60\nu}.$$

By means of this parameter, we were able to generalize the experimental data on the intervals $6.7 \cdot 10^2 < \mathrm{Re}_r < 1.3 \cdot 10^4$ and $4.7 \cdot 10^4 < \mathrm{Gr} < 6.2 \cdot 10^5$.

The results are presented in Fig. 1 and, correct to ±5%, are generalized by the expression

$$\mathrm{Nu}_r = 0.24\,(0.5\,\mathrm{Re}_r^2 + \mathrm{Gr})^{0.28}.$$

An analysis of the schlieren photos (Fig. 2) enabled us to estimate the local boundary layer thicknesses and separation points as a function of the ratio of the dimensionless temperature head and the dimensionless angular velocity of the sphere. An examination of the schlieren data shows that at Δt = const an increase in angular velocity leads to a hydrodynamic situation similar to the case of rotation of a sphere in a still medium under conditions of isothermicity. The thermal boundary layer is observed to "creep" from the poles toward the equator; there is a decrease in the thickness of the layer over the surface and intense separation in the equatorial region of the sphere [6].

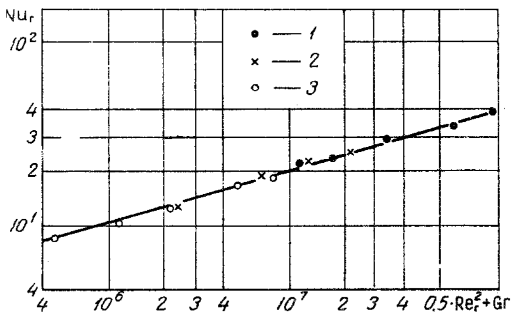

Fig. 1. Generalized relation for the heat transfer of a rotating sphere under conditions of natural convection: 1) sphere diameter 39.7 mm; 2) 30.2; 3) 19.9.

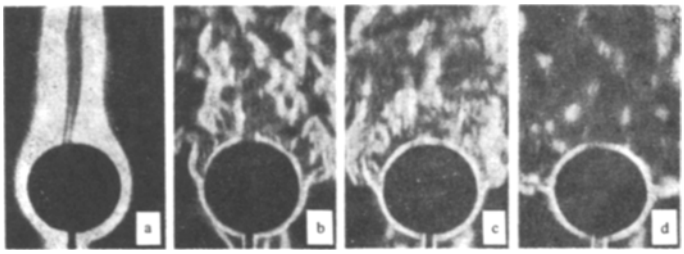

Fig. 2. Typical schlieren photos of thermal boundary layer on a rotating sphere at $\Delta t = 150°$: a) stationary sphere; b) n = 500 rpm; c) 1500; d) 2500.

This is sufficient to intensify the heat transfer as compared with the data for a nonrotating sphere. In Fig. 3 we have plotted the equation

$$\left(\frac{Nu_r}{Nu}\right)_{Gr=idem} = f(n),$$

from which it follows that the relative rate of heat transfer in rotation depends linearly on the speed.

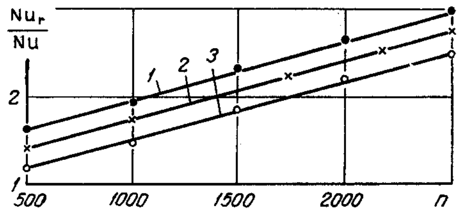

Fig. 3. Relative rate of heat transfer of a rotating sphere as a function of the speed n (rpm) at Gr = idem: 1) sphere diameter 39.7 mm; 2) 30.2; 3) 19.9.

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