LOCAL HEAT TRANSFER OF A CIRCULAR CYLINDER IN TRANSVERSE MOTION IN A FLUIDIZED BED

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The authors present experimental data on the local heat transfer coefficients over the periphery of a moving cylinder.

The need for uniform heating and cooling of granular materials and the continuous heat treatment of various metal parts, including coils of wire, in a fluidized bed poses the problem of estimating not only the average heat transfer coefficient over the heat transfer surface but also the local value along the perimeter of the body. The question of local heat transfer was examined in [1] for a cylinder in a transverse continuous-directed flow of quartz sand. Obviously, the intense random motion of the particles [2] in a fluidized bed may affect the heat transfer picture described in [1], and we have attempted to establish the degree of distortion experimentally.

In order to find the local peripheral heat transfer coefficients α_β we used the method developed by Kruzhilin and Shvab [3, 4], who proposed the formula

$$\alpha_\beta = \frac{\lambda}{[t_2(\beta) - t_0]\, r_2}\left[\frac{t_1 - a_0}{\ln(r_2/r_1)} - \sum_{n=1}^{n=k} a_n \frac{n\,(r_2^{2n} + r_1^{2n})}{r_2^{2n} - r_1^{2n}} \cos n\beta\right],$$

which is valid for a cylindrical calorimeter under stationary conditions when the temperature t_1 over its inside surface is kept at the same level throughout the experiment and the ambient temperature t_0 is also constant.

To determine experimentally the local values of the temperatures $t_2(\beta)$ on the outer surface of the cylinder on the assumption that they differ appreciably we used a calorimeter (Fig. 1) made of porcelain, a material with a low value of λ. Constancy of the temperature t_1 over the inside surface was achieved by inserting a tightly fitting heat-conducting copper cylinder into the porcelain cylinder. As the temperature t_1 we took the temperature of the outer surface of the inner cylinder. The constancy of t_1 over the surface was verified in preliminary experiments with three thermocouples, whose junctions were secured to the outer surface of the inner cylinder at angles of 0, 45 and 90° to the direction of relative motion of the flow. The total value of the calorimeter heat flux and hence the level of t_1 could be regulated by varying the power of the heat built into the calorimeter.

The temperatures of the outer surface of the porcelain cylinder were measured with thermocouples at two points simultaneously at angles β_1 and β_2 (Fig. 1) reckoning from the front point. We used chromel-alumel thermocouples made of KTMS-2 wire [5] with a stainless steel sheath 1 mm thick. The thermojunctions of the outer thermocouples were imbedded with corundum mastic ("polarite" with waterglass) in grooves 1.6 mm deep, which reduced the nominal value of the outside radius r_2 of the calorimeter and, naturally, gave not the local surface temperature field but the temperature field of some zone near the surface.

The ends of the calorimeter were insulated with textolite plugs, the heat losses through which were negligibly small.

The experiments were performed in a cylindrical fluidized bed apparatus 200 mm in diameter. The thickness of the fixed bed above the distributor was 360 mm. The bed material was corundum with a particle size of 60 μ, and the gas was air.

The calorimeter in the vertical position was attached to a hollow shaft, whose axis coincided with the axis of the apparatus. The coordinates of the center of symmetry of the calorimeter were 70 mm from the axis of the apparatus and 170 mm above the distributor. The shaft was rotated by two dc motors via a system of pulleys.

The electrical leads were run through the shaft cavity. The fixed elements of the heater supply and measuring circuits were coupled with the rotating elements by means of a copper commutator in the upper part of the shaft. Checks revealed that there was no commutator noise.

In constructing the $t_2(\beta)$ curve we considered only half the surface of the cylinder (0–180°), it being assumed that, as in a gas medium [4], the picture was the same in the other symmetrical half. After t_2 had been measured at the points β_1 and β_2, the calorimeter was replaced with a new one with a different position (β) of the thermocouples.

The ambient temperature (fluidized bed) was maintained in the range $t_0 = 20 \pm 4°$ C; the temperature of the inner surface of the calorimeter in the range $t_1 = 135 \pm 5°$ C. These temperature deviations determined (with the measuring error) a maximum relative error in calculating α_β in our experiments of not more than 24%.

The investigations were conducted at different fluidization velocities w, starting with w close to the critical value ($w_{cr} = 0.0056$ m/sec), and at different cylinder velocities W_c (0–2.3 m/sec).

The $t_2(\beta)$ curves obtained in the experiments are presented in Fig. 2. In order to determine the effect of the motion of the particles due to fluidization on the heat transfer characteristics of the moving cylinder, we grouped the curves so that in Fig. 2a they are

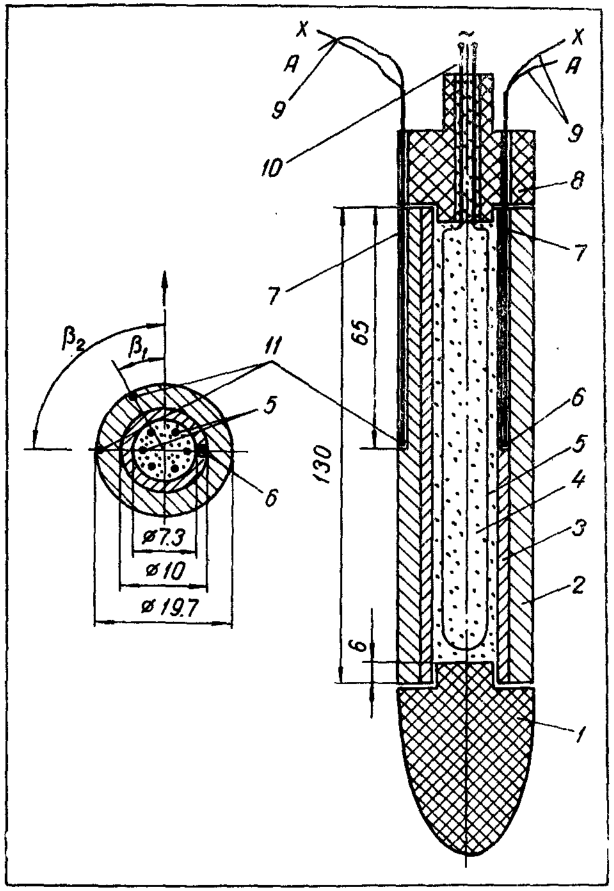

Fig. 1. Calorimeter: 1) lower plug, 2) porcelain cylinder, 3) copper cylinder, 4) corundum filling, 5) nichrome heater, 6) thermojunction of inner thermocouple, 7) thermocouple packing, 8) upper plug, 9) thermoelectrode leads, 10) copper heater leads, 11) thermojunctions of outer thermocouples.

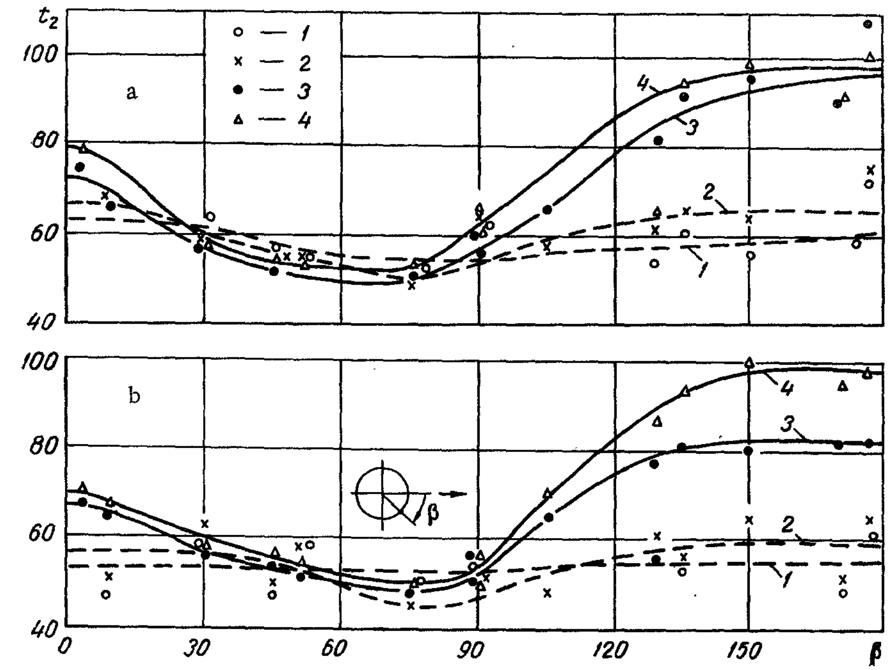

Fig. 2. Temperature distribution over outer surface of calorimeter t_2, °C, at w = 0.00932 m/sec (a) and 0.245 m/sec (b): 1) for W_c = 0.1 m/sec; 2–0.4; 3–1.5; 4–2.3.

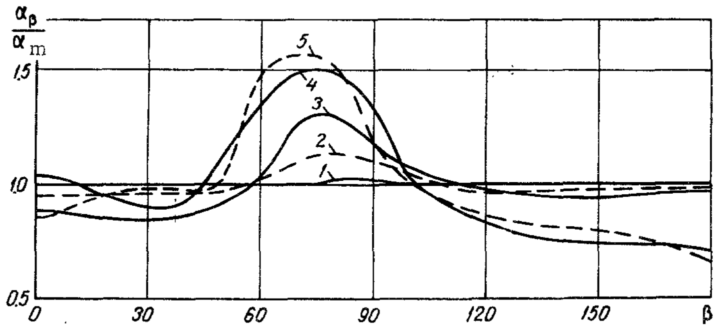

Fig. 3. Relative value of heat transfer coefficient (curves 1, 2, 3, 4 constructed for w = 0.245 m/sec, 5 for w = 0.00932 m/sec): 1) for W_c = 0.1 m/sec; 2—0.2; 3—0.4; 4 and 5—2.3.

given for the least fluidization velocity w (particles almost at rest) and in Fig. 2b for the greatest velocity (intense motion of the particles).

Figure 2a recalls the nature of the curves obtained in [1], i. e., there is no qualitative difference between the heat transfer process for a fixed bed and a directed transverse stream of particles. In this case, even at a cylinder velocity of 0.1 m/sec, there is a clearly expressed change in the temperature t_2 with variation of β (in the figure the direction of motion of the cylinder is indicated by an arrow).

An analysis of Fig. 2b enables us to form a picture of the interaction of the random (in the middle of the bed) motion of the fluidized particles and their directed motion [1] relative to the cylinder.

Experiments at 36 different combinations of the velocities w and W_c (w = 0.00932, 0.017, 0.04, 0.1005, 0.17, 0.245 m/sec; W_c = 0.1, 0.2, 0.4, 1.0, 1.5, 2.3 m/ /sec) led to the conclusion that at velocities $W_c \geq 0.4$ m/sec the motion of the particles due to fluidization does not affect heat transfer. All six of the curves obtained for a particular W_c are very similar (they differ by not more than 20%), the difference being the less, the higher W_c, and the heat transfer coefficients averaged over the surface of the cylinder are very close. This is also confirmed by superposing the graphs in Figs. 2a and 2b.

It should be noted that at small cylinder velocities in the fixed bed the scatter of the t_2 points is higher than at large velocities, as also noted by S. V. Donskov [1], who attributed this to the jerky motion of the particles relative to the cylinder at small W_c.

Figure 3 presents the ratio of the local heat transfer coefficient to its mean value over the surface of the cylinder (calculated graphically) α_β/α_m.

Clearly, the maximum value of α_β is reached at β = 75–80°. At sufficient values of W_c the difference in the values of α_β, maximum and minimum, may reach a factor of two, increasing with increase in W_c. As W_c increases, the value of α_β in the region of high values of β decreases.

Figure 3 also makes it possible to estimate indirectly the mean statistical particle velocity at w = = 0.245 m/sec (developed fluidization) as a quantity of the order of 0.1–0.4 m/sec. This follows from the fact at W_c = 0.1 m/sec the heat transfer coefficient is constant over the entire surface of the cylinder, and this is possible only at a particle velocity not less than W_c, since only then can the stationary prism of particles be displaced from the front of the cylinder and the gas pocket eliminated from the back [1]. When W_c = > 0.4 m/sec a sharp change in α_β over the periphery of the cylinder is already observed; obviously, in this case the absolute particle velocity is less than W_c. A particle velocity of the same order (0.1–0.3 m/sec) is also given in [6, 7].

In order to check the results obtained we also measured the heat transfer coefficients α for a copper calorimeter similar to the porcelain one in size and construction and similarly immersed in a fluidized bed. Since the temperatures over the cylinder surface as a function of β differ by not more than 3%, the average heat transfer coefficient over the surface α_m was found directly from the temperature drop $(t_2 - t_0)$ and the measured heat flux power.

It was found that for developed fluidization (fluidization velocity higher than or corresponding to the maximum heat transfer coefficient) the value of α_m obtained for the stationary porcelain calorimeter was on the average 10–12% lower than for the copper calorimeter; however, when the cylinders moved in a bed at the limit of stability (no mixing or bubbles), on average at the same W_c their α_m and α coincide. This is in good agreement with the idea of quasi-stationary behavior of the process of "external" heat transfer in a fluidized bed [8], if the extremely small thermal conductivity of porcelain (300 times lower than the λ for copper) is taken into account.

NOTATION

r_1, r_2 are the inside and outside radii of calorimeter; β is the position of the radius vector of a point on the cylinder surface relative to its direction of motion; $t_2(\beta)$, α_β are the temperature and heat transfer coefficient at point with the coordinates r_2, β; t_0, t_1 are the temperatures of the ambient medium and the inner surface of the cylinder; λ is the thermal conductivity of the calorimeter material; α_0, α_n are the Fourier series coefficients determined by practical harmonic analysis of the curve $t_2(\beta)$; w, W_c are the fluidization velocity and cylinder velocity.

REFERENCES

1. S. V. Donskov, Teploenergetika, no. 10, 1958.
2. N. B. Kondukov, A. N. Kornilaev, I. M. Skachko, A. A. Akhromenkov, and A. S. Kruglov, IFZh, 6, no. 7, 1963.
3. G. N. Kruzhilin and V. A. Shvab, ZhTF, 5, no. 3, 1935.
4. G. N. Kruzhilin and V. A. Shvab, ZhTF, 5, no. 4, 1935.
5. V. E. Minashin, V. I. Subbotin, P. A. Ushakov, and A. A. Sholokhov, in: Problems of Heat Transfer [in Russian], 1959.
6. A. K. Bondareva and O. M. Todes, IFZh, 3, no. 2, 1960.
7. O. M. Todes and A. K. Bondareva, Khimicheskaya nauka i promyshlennost, 2, no. 2, 1957.
8. A. P. Baskakov, IFZh, 6, no. 11, 1963.

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