HEAT TRANSFER FROM A SURFACE WITH ARTIFICIAL ROUGHNESS TO A FLUIDIZED BED

V. N. Korolev and N. I. Syromyatnikov

UDC 536.244:66.0.96.5

It is shown experimentally that the roughness of a heat-exchange surface affects the heat-exchange coefficient, although this effect differs depending on the ratio between the characteristic dimensions of the roughness and the diameter of the particles of the solid phase of the fluidized bed.

The intensity of external heat exchange in any two-phase medium depends on the structural-hydrodynamic conditions in the boundary layer, which for a fluidized system differ from those in the remaining volume [1]. Projections and irregularities on the heat-exchange surface can have an additional effect on the structure and hydrodynamics of the boundary layer, and, consequently, on the heat transfer. With this in mind, the purpose of the present study was to clarify the effect of the surface roughness on the heat-exchange coefficient.

A flat calorimeter, one side of which was heat-emitting and detachable while the others were thermally insulated, was used in the experiments. Four plates 55 × 55 mm in size with roughness artificially applied to them were used as the heat-emitting surfaces. The surface roughness of one of them was made on an opticomechanical bench in the form of lengthwise triangular projections with a height (h) of 400 μ and a spacing (s) of 500 μ. The surface roughness of two other plates was obtained through their treatment with a jet of corundum particles. The average heights of the projections were 2 and 10 μ and the average distances between projections were 60 and 100 μ. The surface of the fourth plate, the control, was mirror polished (average roughness 0.5 μ). The cleanness of working of the surfaces was determined on a profilograph — a profilometer of modular construction.

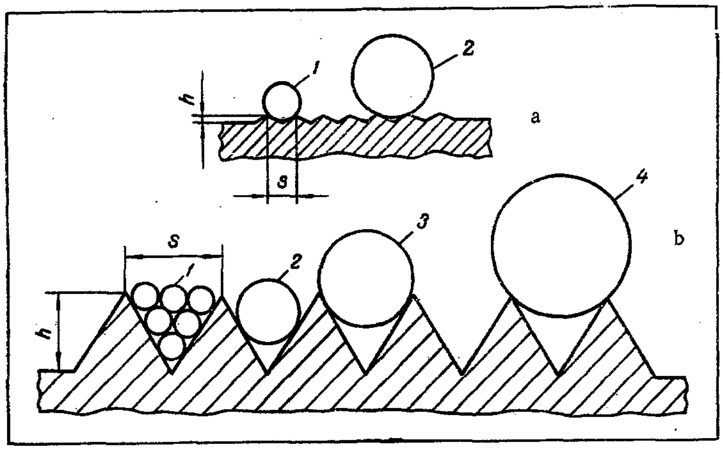

Fig. 1. Possible contact of particles of fluidized bed with a rough heat-exchange surface: a) $h = 10\ \mu$, $s = 100\ \mu$; b) $h = 400\ \mu$, $s = 500\ \mu$. Particle size in mm: 1) 0.12; 2) 0.32; 3) 0.49; 4) 0.72.

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 28, No. 6, pp. 977-980, June, 1975. Original article submitted March 12, 1974.

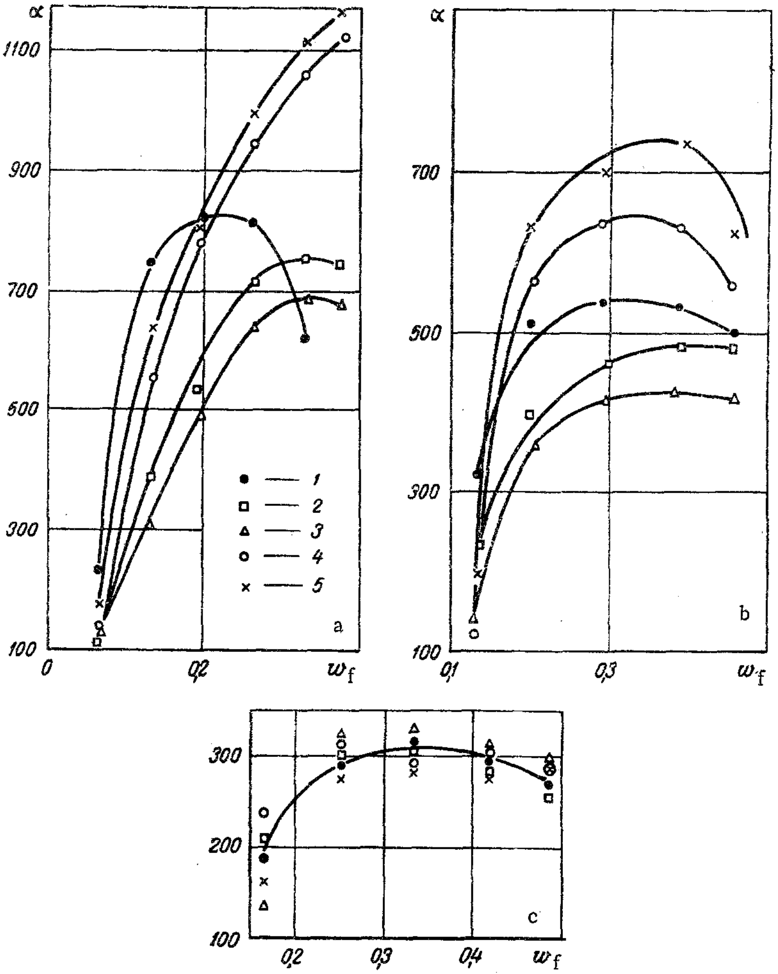

Fig. 2. Coefficient of heat exchange α (W/m^2 · deg) between surfaces with different roughness and a fluidized bed of particles of corundum $d_p = 0.12$ mm (a), chamotte $d_p = 0.32$ mm (b), and polystyrene $d_p = 0.72$ mm (c) as a function of the filtration velocity w_f (m/sec): height of roughness projections in mm: 1) smooth; 2) 2; 3) 10; 4) 400 ≡; 5) 400 |||.

The heat transfer was studied by the steady-state method. A heater of Nichrome fed from an alternating current source was located inside the calorimeter. The temperatures of the heat-emitting surface of the plate, of the fluidized bed, and of the thermally insulated sides of the calorimeter (to allow for the heat loss through them) were measured with copper–Constantan thermocouples.

Particles of corundum with a size of 0.12 mm, of chamotte of 0.32 and 0.49 mm, and spherical polystyrene particles 0.72 mm in diameter served as the fluidized material. The experiments were performed in a column 150 mm in diameter. The fluidizing agent was air. The calorimeter was rigidly fastened to the apparatus at a distance of 30 mm from the perforated gas-distributing grill. The height of the bulk layer was 120 mm in all the experiments.

The possible contact of the particles with the rough surface is shown in Fig. 1 (in scale).

The results of the experiment are presented graphically in Fig. 2, in which the variation in the average heat-exchange coefficient α is shown as a function of the filtration velocity for surfaces with different roughness. In all cases the heat-exchange coefficient is given per unit smooth surface.

For fine particles 0.12 and 0.32 mm in size (Fig. 2a, b, curves 2 and 3) an increase in surface roughness leads to some reduction in the heat-exchange coefficient in comparison with a smooth surface. The cause of the decrease in the heat-exchange coefficient is probably connected with the fact that, firstly, the effective thickness of the gas layer between the surface and the first array of particles increases.

Secondly, the projections and irregularities have a retarding effect on the particles, as a result of which their concentration at the surface increases while their mobility decreases. Also, as shown by an analysis of synchronously recorded oscillograms of the density pulsations of the fluidized bed near the surface of a thermoanemometric pickup and its temperature pulsations, as well as of synchronously taken frames of high-speed motion-picture photography of the process [2], the temperature of the pickup always drops sharply when its surface comes in contact with the hydrodynamic wakes of gas cavities, with large-scale vortices, and with local dispersed streams, and that this is just the time when the heat-exchange coefficient is maximal and not when the surface is in contact with a poorly mobile and more compact aggregate of particles. Evidently, the same thing can also explain the following two experimental facts. The heat-exchange coefficient is lower when the protrusions forming the roughness are arranged crosswise to the stream (Fig. 2b, curve 4 ≡) than when they are arranged lengthwise (Fig. 2b, curve 5 ‖). The maximum value of α from rough surfaces to a fluidized bed (Fig. 2a, b, curves 2-5) is displaced toward higher filtration velocities in comparison with $\alpha_{\max}$ for a smooth surface.

If the height of the roughness projections and the distance between them are greater than the particle size then higher heat-exchange coefficients are obtained (Fig. 2a, b, curves 4 and 5) than for a smooth surface. Evidently such a surface can now be treated as microribs and the increase occurs because of the increase in the true surface area of heat exchange (in our experiments $F_{\text{rib}} = 1.88F_{\text{smooth}}$). Therefore, if the actual surface (with allowance for the microribs) is taken as the calculating surface, the heat-exchange coefficient will be less for rough plates than for a smooth plate. The authors of [3], who conducted experiments on the heat exchange between a fluidized bed and a ribbed cylinder, also note that α is lower on the ribs than on the smooth cylindrical part of the pickup, although the increase in the surface due to the ribs exceeds the reduction in the heat-exchange intensity and therefore the heat flux increases considerably. An analogous conclusion is drawn in [4], in which results are presented on a study of the heat exchange from smooth and rough tubes to a vibrationally fluidized bed.

In a fluidized bed of large particles, particularly particles 0.72 mm in diameter (Fig. 2c), the effect of the surface roughness of the plates on the heat-exchange coefficient is not detected.

LITERATURE CITED

1. V. N. Korolev and N. I. Syromyatnikov, Dokl. Akad. Nauk SSSR, 203, No. 1 (1972).
2. N. I. Syromyatnikov, Inzh.-Fiz. Zh., 25, No. 4 (1973).
3. R. R. Khasanov, S. S. Zabrodskii, A. I. Tamarin, and D. M. Galershtein, in: Summaries of Reports of the Third Republic Conference on Increasing the Efficiency and Perfecting Processes and Equipment of Chemical Production [in Russian], L'vov (1973).
4. N. I. Syromyatnikov (Syromjatnikow) and B. G. Sapoznikov (Sapoznikow), Ogolnopolski Sympozjon "Termodynamika Warstwy Fluidalnej" [in Czech], Czestochowa — Pazdziernik (1973).