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THE AERODYNAMICS AND HEAT TRANSFER OF A FALLING (LOOSE) LAYER WITHOUT BLOWING

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Some results of an experimental investigation of a loose layer are presented. Formulas are proposed for evaluating the concentration of such a layer and the heat transfer to the wall over a wide range of temperature.

A dense layer of disperse medium moving in a vertical channel becomes a falling (loose) gravitational layer when its velocity increases above a critical value. The loose layer differs from the compact one not only in having a different concentration of solids, but also in having quite different mechanics of motion and heat transfer mechanism.

Under loose layer conditions there is an ejection effect, first observed by Platonov [1], which causes an appreciable motion of the gas in the channel.

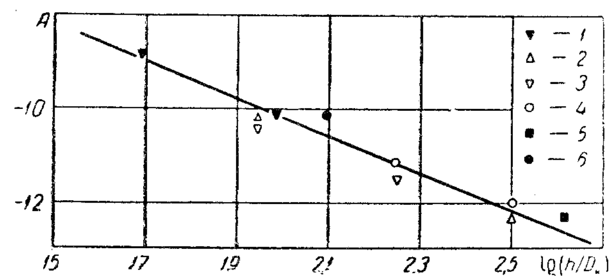

Fig. 1. Generalized relation for the true concentration of the loose layer: 1) channel diameter 35.5, graphite $d_T = 0.03$; 2) 19, sand, 0.371; 3) 19, sand, 0.59; 4) 19, sand, 0.482; 5) 15.6, sand, 0.482; 6) 16, graphite, 0.017 (about 100 tests points in all; the figure shows the averaged points for each channel; $A \equiv \equiv \lg[\beta(G_T/G_{nom})^{-0.49}]$.

An experimental investigation of a loose layer was conducted on two pieces of apparatus. The mass flow and volume concentration of solids and the gas flow rate were measured in an apparatus for investigating the mechanism and aerodynamics. Aluminosilicate, quartz sand, and graphite were used as test materials. In the tests the mean particle diameter, determined from the formula $d_T = 1/\Sigma g_i/d_i$, was varied in the range 0.03–4 mm.

The generalized relation obtained for the true concentration of the loose layer (Fig. 1) is

$$\beta = 0.6\,(G_T/G_{nom})^{0.49}\,(h/D_K)^{-0.4}. \quad (1)$$

Here G_{nom} is the nominal flow rate of the solid, phase determined according to the Rausch formula (for $D_0 = D^K$).

Formula (1) has been verified for

$$0.065 \leqslant G_T/G_{nom} \leqslant 5;\ 48 \leqslant h/D_K \leqslant 316.$$

The investigations showed that at large concentrations the loose layer is a straight-through downward fluidized flow.

The other apparatus was used to investigate heat transfer from the layer to the wall when the layer was cooled in a tubular channel (D^K = 16 mm, h = 2m) at temperatures ranging up to 850° C. A mixture of graphite particles with mean diameter d_T = 0.17 mm was investigated. The heat transfer coefficient was determined by a steady-state method.

The influence of the temperature factor on heat transfer is of particular interest. The tests showed that in the temperature range up to 850° C, increase of α did not match the very appreciable radiation at these temperatures, which is easily explained by the strong screening action of the particles. The temperature effect is allowed for by the choice of $(t_W + t_l)/2$ as characteristic temperature.

It was observed that the chief factor intensifying heat transfer between the layer and the wall is the layer concentration β. We obtained (Fig. 2)

$$\mathrm{Nu} = A\beta^{1.22}. \quad (2)$$

Here $A = f(h_K, D_K, d_T)$; for our conditions A = 1109, and Nu is calculated from the thermal conductivity of air. Formula (2) was verified for $0.025 \leqslant \beta \leqslant 0.31$; $150°\,C \leqslant t^l \leqslant 850°\,C$. Here β should be determined from (1).

The treatment similar to that given in [1, 2] is more general. The dependence of the relative heat transfer rate on the concentration of solids (referred to flow with no dust content) was determined as

$$\frac{\mathrm{Nu}^l}{\mathrm{Nu}_g} = 1 + k\,\frac{c_T\gamma_T}{c_g\gamma_g}\,\beta^m. \quad (3)$$

This relation is shown in Fig. 3. We obtained

$$\text{when } 0.025 \leqslant \beta \leqslant 0.1 \qquad k = 0.178; \quad m = 1.4;$$

$$\text{when } 0.1 \leqslant \beta \leqslant 0.3 \qquad k = 0.068; \quad m = 1.$$

Although the scatter of the points in the latter case is greater than for the previous method (mainly due to inaccuracy in determining the gas velocity in our tests, and therefore in Nu_g), relation (3) may be more widely applied.

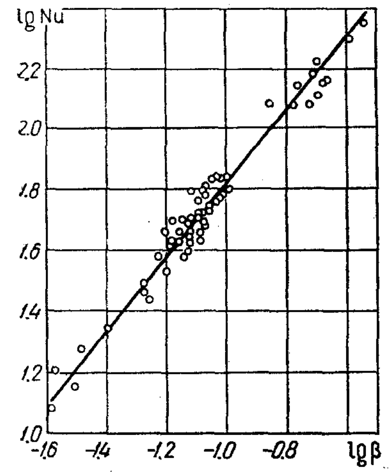

Fig. 2. Generalized relation for heat transfer between the loose layer and the wall.

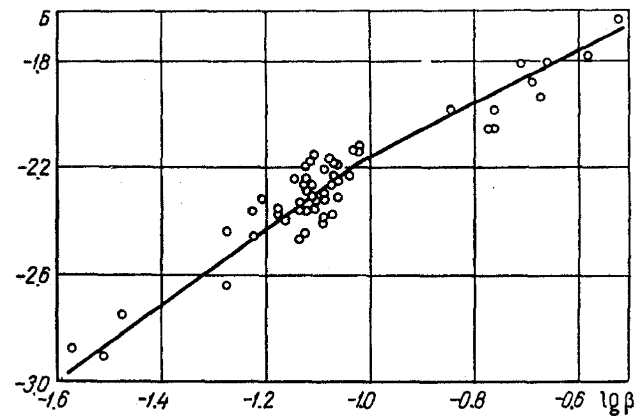

Fig. 3. Dependence of relative rate of heat transfer for the loose layer on volume concentration ($B \equiv \lg[Nu_l/Nu_g - 1)c_{pl}\gamma_g/c_{pT}\gamma_T]$).

In the tests, the maximum average heat transfer coefficients over the length of the channel were of the order of 300–400 $W/m^2 \cdot {}^\circ C$. It is to be expected that with a longer channel and finer particles the loose layer would exhibit greater heat transfer due to increased gas velocity and hence increased Nu_g and Nu_l (3).

REFERENCES

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