HEAT TRANSFER TO A CYLINDRICAL SURFACE IMMERSED IN A FLUIDIZED BED AT LOW PRESSURE

Ya. P. Shlapkova

Inzhenerno-Fizicheskii Zhurnal, Vol. 10, No. 3, pp. 318–320, 1966

UDC 541.182

Results are given of an investigation of heat transfer in a fluidized bed to a cylindrical surface over the range of pressures from atmospheric to 133 N/m^2. Equations for determining α_{max} are presented.

The drying of heat-sensitive materials in a fluidized bed at low pressure is of interest provided that it is possible to attain high coefficients of heat transfer to surfaces immersed in the bed.

As far as we know, the literature contains only one study [6] in which the coefficients of heat transfer between a fluidized bed (sand, d = 0.26–0.15 mm) and a surface were determined at low pressure. Bhat and Whitehead carried out tests in the pressure range from 13.3×10^3 N/m^2 to atmospheric and arrived at the conclusion that at constant velocity the heat transfer coefficients do not depend on pressure. No fluidized bed investigations have been carried out at pressures below 13.3×10^3 N/m^2. Our work constitutes an experimental attempt to study the effect of pressure on heat exchange between a fluidized bed and a surface immersed in it.

The tests were conducted using a cylindrical tube 48 mm in diameter. The apparatus was described in [3]. The test materials employed were glass pellets (d = 0.772, 0.273, and 0.1 mm) and sand (d = 0.2 and 0.126 mm). The bed was shallow (h_0 = 10–40 mm) so that the pressure drop across the bed did not exceed the absolute pressure above the bed, which varied between atmospheric and 133 N/m^2.

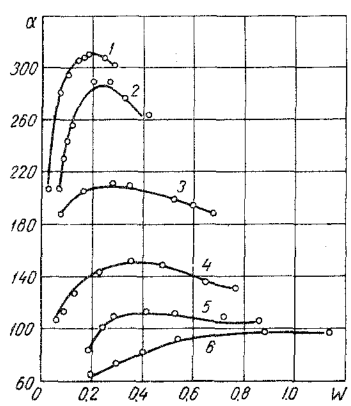

Fig. 1. Dependence of heat transfer coefficient α ($W/m^2 \cdot$ deg C) on the fluid velocity W (m/sec) for sand, d = 0.2 mm, at pressures of: 1) atmospheric; 2) 266×10^2; 3) 133×10^2; 4) 9.31×10^2; 5) 4.0×10^2; 6) 2.66×10^2 N/m^2.

It did not seem worthwhile to carry out tests at pressures above the bed of less than 133 N/m^2, since even in a very shallow bed of sand (h_0 = 10 mm) the pressure drop exceeded this value. There is no obvious practical requirement for fluidized beds shallower than this.

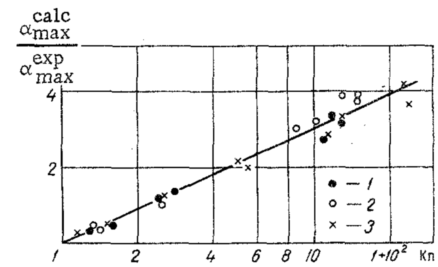

Fig. 2. Relationship for determining the maximum heat transfer coefficient at low pressure: 1,2,3) for glass pellets, d = = 0.273, 0.773, and 0.1 mm.

The heating elements were made of copper wire (d = 0.05 mm) tightly wound on a paper cylinder (D = = 6.8 and 3.4 mm). The heater was arranged vertically in the bed, along the axis. Antonishin's principle [5] was used to determine α. The heat transfer coefficient was calculated from the electrical power produced by the heater, the difference in temperature between the bed and the wall of the heater, and the heater surface ($S_h = 1.665 \times 10^{-4}$; 1.515×10^{-4} m^2). The Kn number was computed from the equivalent diameters of the "channels" between particles d_{eq} = = $2md/3(1-m)$, the molecular mean free path being taken as $7 \times 10^{-8}/P_m$, m. All the air parameters were taken at a mean pressure P_m equal to the arithmetic mean of the pressures above and below the bed.

Zabrodskii, in his study [1] of heat exchange between a surface and a fluidized bed at atmospheric pressure, established that heat exchange is limited by the thickness of the gas layers between the surface and the nearest row of particles. The fluid velocity affects α_{max} only indirectly, through changes in the porosity of the bed and particle velocity. The thermal conductivity of the gas λ_g has a positive effect on α_{max}. This factor should be taken into account at reduced pressures in the region corresponding to slip flow, when λ_g becomes dependent on pressure.

If the gas layer is of negligible thickness the dependence of λ_g on pressure is discernible even at pressures close to atmospheric. The reduction in λ_g

at low pressures is explained by the fact that even at values of Kn of the order of 0.01 the effects of temperature rise and fall are noticeable.

It has been established from investigations on fluidized beds at atmospheric pressure that α diminishes as the porosity increases. With reduction in the average pressure in the bed this dependence becomes weaker. This is because the porosity of the bed m and the thermal conductivity of the air λ_g have opposite effects on α. When m increases, α should fall, but at the same time the λ_g of the gas layer increases and this tends to increase α. At a certain pressure these effects balance out. Then the heat transfer coefficient, once it has attained the maximum, will not depend on the linear fluid velocity, up to the entrainment velocity. At even lower pressures (in our tests at $P_m = 133$ N/m²) the effect of λ_g on α will begin to predominate over that of m. A slight increase in α is observed until the entrainment velocity is reached (Fig. 1).

The maximum heat transfer coefficient increases with increase from low pressure to atmospheric. Starting at a pressure of 4000 N/m² and up to atmospheric the heat transfer coefficient remains practically constant.

The test results at low pressure are well described by the expression

$$\alpha_{max} = \alpha_{max}^{calc}/(1 + 10^2\,\mathrm{Kn})^{0.45}. \qquad (1)$$

Here α_{max}^{calc} is the maximum heat transfer coefficient at atmospheric pressure, computed from the equation

$$\alpha_{max}^{calc} = 2\,\rho_m^{0.2} D^{-0.11} d^{\;0.4}. \qquad (2)$$

It can be seen from Fig. 2 that the scatter of the experimental points does not exceed 14%.

Equation (1) can be used to calculate the maximum heat transfer coefficients for the range of pressures from atmospheric to 133 N/m².

NOTATION

D—heating element diameter; d—particle diameter; d_{eq}—2md/3 × (1 − m)—hydraulic diameter of "channel" between particles; h—depth of fluidized bed; h_0—depth of settled bed; Kn—Knudsen number; m—porosity of bed; P—pressure; W—linear fluid velocity; S_h—surface of heating element; α—heat transfer coefficient; λ_g—thermal conductivity of gas; ρ—density of material. Subscripts: g—gas; m—material; max—maximum values; eq—equivalent.

REFERENCES

1. S. S. Zabrodskii, Hydrodynamics and Heat Exchange in a Fluidized Bed [in Russian], Gosenergoizdat, 1963.

2. K. P. Shumskii, Vacuum Apparatus and Instruments in Chemical Plant Construction [in Russian], Mashgiz, 1963.

3. S. S. Zabrodskii and Ya. P. Shlapkova, "The hydrodynamics of a fluidized bed under low vacuum," in: Heat Exchange in Dispersed Systems [in Russian], Izd. Nauka i tekhnika, Minsk, 1965.

4. W. Heinze, Introduction to Vacuum Technique [Russian translation], Vol. 1, Gosenergoizdat, 1960.

5. N. V. Antonishin, Heat Transfer to a Surface Immersed in a Fluidized Bed with Developed Fluidization [in Russian], AS BSSR, Minsk, 1963.

6. G. N. Bhat and A. B. Whitehead, Heat Transfer in Subatmospheric Fluidized Beds, Austr. J. Appl. Sci., 14, no. 3, 1963.

23 July 1965

Institute of Heat and Mass Transfer, AS BSSR, Minsk