A STUDY OF THE HEAT TRANSFER BETWEEN A LIQUID FLUIDIZATION BED AND A SURFACE

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An experimental study was made concerning the heat transfer between a cylinder and a liquid fluidization bed inside an annular channel. This study included the effect of the charge material and its fractional composition, also of the filtration rate and of the thermo-properties of the fluidizing agent.

It is well known that the injection of suspended particles into an ascending stream of liquid, i. e., the formation of a fluidization bed for solid particles appreciably increases the rate of heat transfer between an immersed surface and the stream [1, 2]. A survey of a few theoretical and experimental studies on the subject of heat transfer in liquid fluidization beds has been made in [3].

In liquid fluidization beds the rate of relaxation processes is the same in the solid and in the liquid phase and, therefore, the mechanism by which particles act on the boundary film is the most significant one of all existing models of the heat transfer enhancement process [1] in a liquid fluidization bed. The laws governing the heat transfer in liquid fluidization beds may also apply to those gaseous fluidization beds where the convective component of heat transfer is appreciable as, for example, during the fluidization of large particles.

The purpose of this study was to determine experimentally how the heat transfer between a liquid fluidization bed and immersed surface is affected by the thermophysical properties of the solid particles and of the liquid as well as by the geometrical characteristics of the bed. The authors considered the case of a long cylinder standing vertically on a grid in the bed.

The essential apparatus and measurement procedures have been described in [4, 5]. A liquid fluidization bed was produced in an annular channel between exchangeable outer cylinders 50, 70, 110, and 150 mm in diameter respectively and an inner cylindrical electrocalorimeter 22 mm in diameter. The length of the heated active segment of one such calorimeter was 100 mm and of another such calorimeter was 705 mm. For the granular material we used glass balls (ρ_S = 2.446 g/cm^3) with diameters d_e from 0.666 to 2.36 mm and alundum balls (ρ_S = 3.59 g/cm^3) with diameter d_e from 0.949 to 2.965 mm. Water served as

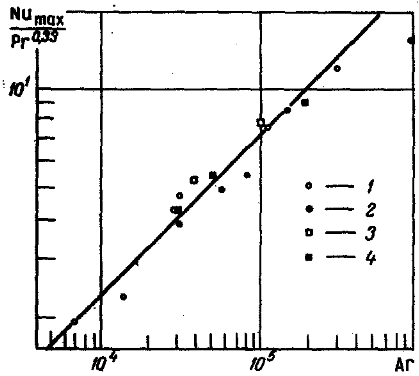

Fig. 1. Curve of $Nu_{max}/Pr^{0.33}$ = f(Ar) for systems: water and glass balls (1), water and alundum balls (2), glycerine and glass balls (3), glycerine and alundum balls (4).

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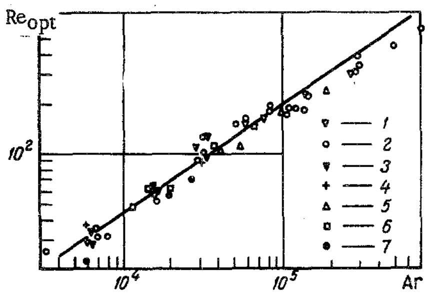

Fig. 2

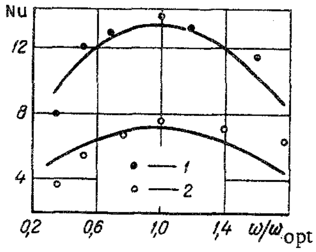

Fig. 3

Fig. 2. Curve of $Re_{opt} = f(Ar)$ for water in the 50 mm diameter apparatus (1), , in the 70 mm diameter (2), in the 110 mm diameter apparatus (3), in the 150 mm diameter apparatus (4), for 20% glycerine solution in the 70 mm apparatus (5), for 35% glycerine solution in the 70 mm apparatus (6), for 50% glycerline in the 70 mm apparatus.

Fig. 3. Nusselt number as a function of the ratio w/w_{opt} (filtration velocity to optimum filtration velocity) for systems: water and glass balls $d_e = 1.106$ mm in diameter (1), water and glass balls $d_e = 0.908$ mm in diameter (2), solid curves represent calculations according to Eq. (3).

the fluidizing agent, also aqueous solutions of glycerine in 20, 35, and 50% concentrations at a mean temperature of 30°C. The fluidization bed of either glass or alundum balls was sufficiently turbulent at such glycerine concentrations. With higher glycerine concentrations, the viscosity of the bed increased sharply and, therefore, the mixing of material abated and the heat transfer became worse. The thermophysical data for the glycerine solutions were taken from [6]. The wall temperature was measured with 15 thermocouples stuck along the height of the active segment. The values of the heat transfer coefficient were determined by the steady-state method.

The test data were evaluated with respect to heat transfer from the 705 mm cylinder, equal to the length of the active segment, in the following steps. First the values of the local heat transfer coefficient were determined and graphs were plotted of this coefficient as a function of the active segment height. These graphs then revealed the length of the thermal stabilization zone and, thus, the heat transfer coefficients for this zone could be determined. The test data on heat transfer within this zone were then evaluated in criterial form, namely in terms of the numbers Nu, Ar, and Pr. The governing parameters here were the particle diameter, the mean bed temperature, and the filtration velocity referred to the total apparatus cross section. The optimum velocity was determined from $\alpha = f(w)$ curves as the velocity at the maximum heat transfer coefficients. The test data corresponding to the maximum heat transfer coefficients were approximated by the equation

$$Nu_{max} = c\,Ar^{0.5}\,Pr^{0.33}, \tag{1}$$

with c = 0.0345 for the short heaters and with c = 0.023 for the stabilized segment.

A universal curve of $Nu_{max}/Pr^{0.33}$ as a function of the Archimedes number Ar is shown in Fig. 1 for the case of stabilized heat transfer.

The measured values of the optimum filtration velocity depending on the properties of the solid material and of the liquid are shown in Fig. 2 for various apparatus diameters and various active segment heights. The graph indicates that the optimum filtration velocity does not depend on the outside diameter of the apparatus, while its dependence on the physical properties of the solid and the liquid phase in the fluidization bed is expressed in terms of the Archimedes number. The solid line here represents the equation

$$Re_{opt} = 0.1\,Ar^{0.66}. \tag{2}$$

The test data on heat transfer at various filtration velocities for the stabilized and for the short segment were generalized by the formula

$$\mathrm{Nu} = \mathrm{Nu}_{\max}\left[\left(\frac{w}{w_{\mathrm{opt}}} - 1\right)^2 (0.22\,\mathrm{Pr}^{0.37} - 1) + 1\right]. \tag{3}$$

The appropriate value of $\mathrm{Nu}_{\max}$ in this equation was calculated according to Eq. (1) and the optimum velocity w_{opt} was calculated according to Eq. (2). The criterial numbers were varied within the following ranges: $3000 \le \mathrm{Ar} \le 50,000$ and $5.5 \le \mathrm{Pr} \le 33.8$. In Fig. 3, for instance, we show the Nusselt number as a function of the velocity, referred to the optimum velocity, for glass balls fluidized by water. According to the diagram, the test data agree closely with calculations according to Eq. (3).

All the relations shown here can be used for the design of heat exchangers.

NOTATION

d_e	is the equivalent diameter of particles;
ρ_S	is the density of solid phase;
ρ	is the density of liquid phase;
ν	is the kinematic viscosity of liquid;
λ	is the thermal conductivity of liquid;
w	is the filtration velocity;
w_{opt}	is the optimum filtration velocity;
α	is the coefficient of heat transfer between surface and bed;
$\alpha_{\max}$	is the maximum coefficient of heat transfer between surface and bed;
$\mathrm{Nu} = \alpha d_e/\lambda$	is the Nusselt number;
$\mathrm{Nu}_{\max} = \alpha_{\max} d_e/\lambda$	is the maximum Nusselt number;
$\mathrm{Ar} = g d_e^3 (\rho_S - \rho)/\nu\rho$	is the Archimedes number;
$\mathrm{Pr} = \nu/a$	is the Prandtl number;
$\mathrm{Re}_{\mathrm{opt}} = w_{\mathrm{opt}} d_e/\nu$	is the optimum Reynolds number.

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