HEAT TRANSFER BETWEEN A SURFACE AND A FLUIDIZED BED WITH PACKING

R. R. Khasanov, S. S. Zabrodskii,
A. I. Tamarin, and D. M. Galershtein

UDC 536.241:532.546

Heat transfer coefficients were measured under the following conditions: a fluidized bed with a spiral packing and a vertically immersed cylinder; a fluidized bed with a bundle of smooth tubes and with a bundle of lengthwise finned tubes.

Fluidized beds have found wide applications in the chemical technology, especially in the planning of processes which involve a large thermal effect and in cases where a high mobility ("fluidity") of the dispersed particles is useful. The process rate in such a bed is often limited by the usual passage of some gas in the form of bubbles. The bed can be homogenized by means of a packing [1-4]. In a fluidized bed with packing the rate of technological processes becomes higher, which results in higher thermal stresses – especially during processes with a large thermal effect. At the same time, a packing reduces the mobility of particles and this can, as has been noted in [4-6], impede the heat transfer. For that reason, data on the heat transfer in a fluidized bed with packing are of particular interest. Very little information on the subject is available in the published literature.

In order to produce data on the heat transfer between a slower fluidized bed and tubular surfaces immersed in it, the authors performed a series of experiments.

Several kinds of packing were tested; an insert consisting of spirals 55 mm or 20 mm in diameter [12], a bundle of smooth vertical tubes, and a bundle of vertical tubes with three longitudinal straight fins on each. The characteristics of these packings are specified in Table 1.

The tests were performed on an apparatus containing a column 300 mm in diameter; the gas distributor grid consisted of a pad of dense cloth squeezed between two perforated sheets with holes 1.5 mm in diameter and an approximately 20% active cross section. The dispersed phase was either quartz sand or silica gel with an average diameter of particles 0.22 mm and 0.19 mm respectively. Fluidization was achieved by means of air at t = 20-30°C and at a flow rate measured with a diaphragm accurately within 3%. The stationary bed in these tests was 300 mm high.

TABLE 1. Packing Characteristics

Item number	Fraction of volume occupied by packing, %	Packing parameters
1	-	Free bed
2	6.2	Bundle of vertical tubes: diameter 20 mm, spacing 63 x 63 mm
3	8.6	Bundle of vertical tubes: diameter 20 mm, spacing 63 × 63 mm, three fins 20 mm wide
4	3.2	Spirals: loop diameter 55 mm, height 60 mm, pitch 10 mm, wire diameter 2.5 mm
5	4.82	Spirals: loop diameter 20 mm, height 30 mm, pitch 4 mm, wire diameter 1 mm

Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 22, No. 3, pp. 397-402, March 1972. Original article submitted May 19, 1971.

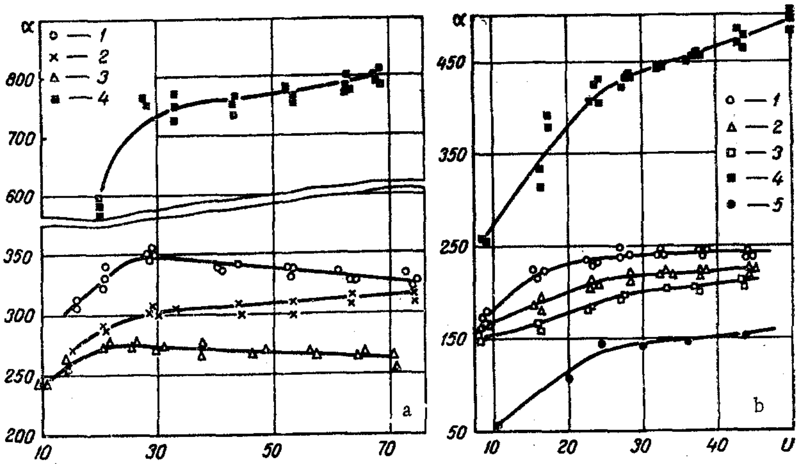

Fig. 1. Dispersed material: (a) sand (d_{av} = 0.22 mm, free bed (1), packing No. 4 (2), packing No. 5 (3) [see Table 1], packing No. 3 (4, α_{nom}). (b) Silica gel (d_{av} = 0.19 mm, free bed (1), packing No. 4 (2), packing No. 3 (3, α_p; 4, α_{nom}; 5, α_f). Coefficients α (W/m^2 · °C), rate U (cm/sec).

The heat transfer between the fluidized bed and a surface was measured with a heater-probe. During the tests we measured the heater power, on the basis of ammeter and voltmeter readings, as well as the temperature difference between bed and probe surface. The error in the measurement of the heat transfer coefficient did not exceed 3%. The following heater-probes were used for the experiment: a smooth cylindrical probe, a probe with integral fins, and a probe with pseudofins. The diameter of the cylindrical element in each probe was 20 mm.

For determining the coefficient of heat transfer between a single tube and a fluidized bed with spiral packing we used the smooth cylindrical heater-probe at the center of the column. It was a copper tube with a 20 mm diameter, a 100 mm height, and a 5 mm wall thickness. Inside this probe was located a nichrome heater wire wound on a ceramic core 4 mm in diameter. In order to minimize the heat leakage through the probe ends, these were covered with 20 mm thick Textolite stoppers. The temperature difference Δt was measured with a differential Chromel–Copel thermocouple using size 0.15 mm (diameter) wire. One thermocouple bead was stuck to the outside of the copper cylinder at the center of the probe. The other bead of this differential thermocouple measured the temperature of fluidized bed. The probe was mounted in a metallic frame having a 20 mm diameter.

For heat transfer measurements with the smooth tubes in the fluidized bed we used the same cylindrical probe. It was then placed in the center of the bundle in lieu of one tube.

The probe with integral longitudinal fins was, in effect, a finned tube 140 mm long made of grade D-16 duraluminum (λ = 190 W/m · °C). Its three longitudinal fins 2.7 × 20 mm in cross section were equally spaced around the perimeter. The electric heater installed along the probe axis was of the same construction as the one in the smooth cylindrical probe just described.

The probe with pseudofins was, in effect, a tube like the one described earlier but with three straight longitudinal fins 1 × 20 mm in cross section and clearing the cylinder surface by about 1 mm. Heat was dissipated here only from the cylindrical element.

In all tests the probes were placed in the bed vertically, with the lower portions of their active surfaces approximately 100 mm away from the gas distributor grid.

Prior to the heat transfer tests, the performance of the smooth cylindrical probe and its measuring circuit in a bed was first checked under conditions of a transverse air blast in an aerodynamic tunnel. The discrepancy between tested and calculated values [8, 9] at high heat transfer coefficients (> 100 W/m^2 · °C) did not exceed 1%.

The test data for a free bed and a bed with packing No. 4 and No. 5 (see Table 1) are shown in Fig. 1a, b corresponding to sand and gel respectively. According to Fig. 1a, the heat transfer coefficient in a free fluidized sand bed was maximum at a filtration rate of 30 cm/sec. For a bed packed with 55 mm spirals the curve bent at the same value of the filtration rate, but then continued to rise slightly. At low

TABLE 2. Compilation of Heat Transfer Coefficients

Item number	Kind of packing	$\frac{1-\varepsilon}{1-\varepsilon_1}$	$\frac{\alpha_2}{\alpha_1}$
1	Free bed	1	1
2	Packing of 55 mm spirals	0,94	0,89
3	Packing of 20 mm spirals	0,84	0,78

gas filtration rates, α in a free bed was approximately 15% higher than in a slower bed. As the filtration rate increased, the difference between the heat transfer coefficients of a free and of a slower bed became less. At the same time, in Fig. 1a is also shown the variation of the heat transfer coefficient in a bed packed with 20 mm spirals. According to the diagram, this curve and the one for a free bed have similar trends, but the curve for this packed bed lies 20-25% lower.

With silica gel as the dispersed phase (Fig. 1b), the curves for a free bed and for a bed packed with 55 mm spirals are almost the same, but α is 8-10% lower in the latter case.

All these data show that with both tested materials the heat transfer rate decreased by up to 25% in a bed with a small-volume packing. This effect became stronger when the packing was changed from 55 mm to 20 mm spirals.

We also measured the average bed porosity. It was determined from the pressure drop in the core under a 300 mm charge height in the case of sand (d_{av} = 0.22 mm). The test results are given in Table 2. Here are also included the relative values of heat transfer coefficients and mass concentrations in the bed. These data correspond to filtration rates (0.3 m/sec) at which the heat transfer coefficient is maximum in a free bed.

On the basis of these data, one may conclude that the observed decrease in the heat transfer in a fluidized bed with small-volume packing is evidently due to the increased bed porosity.

A reduction of the heat transfer rate in a fluidized quartz sand bed with wire packing in the form of horizontal meshes had been observed earlier [10]. Analogously to a bed with spiral packing, the heat transfer coefficient decreased when the bed cell volume was made smaller, i.e., when the mesh eyes were made smaller and the wire spacing closer.

The values of α measured with a vertical bundle of smooth tubes (packing No. 2, Table 1) in a quartz bed and in a silica bed have shown that in this case the heat transfer rate remains the same as with a single tube in the bed. It has been pointed out in [5] that the heat transfer rate decreases somewhat when a closely spaced vertical tube bundle is placed in the fluidized bed, while it changes insignificantly with a widely spaced bundle.

In the tests with packing No. 3 (Table 1) we determined the heat transfer rate separately for the fins and for the cylindrical element of a finned tube. Two probes were used for this purpose. First, at the center of the bundle we placed the probe with integral fins. Afterwards, this probe was replaced by the one with pseudofins. From the first measurement we calculated

$$\alpha_{\text{nom}} = \frac{Q}{\Delta t F_c}, \tag{1}$$

with F_c denoting the area of the cylindrical surface.

For the probe with pseudofins we determined

$$\alpha_p = \frac{Q_1}{\Delta t F_c}. \tag{2}$$

On the basis of test values of the nominal heat transfer coefficient for the finned probe α and its value for the pseudofinned probe, we calculated the heat transfer rate between the fluidized bed and the fins, with the fin efficiency [8] taken into account as follows:

$$\alpha_f = \frac{F_c\,(\alpha_{\text{nom}} - \alpha_p)}{F_f E}, \tag{3}$$

and with E denoting the fin efficiency. In our case E $\simeq$ 0.9. The values of α_{nom} and α_p were taken for each filtration rate from curves approximating the respective test data.

According to Fig. 1a, b, the nominal heat transfer coefficient (α_{nom}) for a finned tube was 2.0-2.3 times higher than for a smooth tube. Consequently, the finning of a tube increases the thermal flux per unit tube length.

On the same diagrams are shown $\alpha_p = f(U)$ curves. From tests with silica gel, the curve for the pseudofinned probe is similar to the curve for the smooth probe but it lies somewhat lower. From tests with quartz sand, the heat transfer coefficient for the pseudofinned probe is 5-10% lower than for the smooth cylindrical probe at rates U up to 40 cm/sec, but at high filtration rates the $\alpha_p = f(U)$ curves for both probes almost overlap. The α_p curve has been omitted in Fig. 1a, in order not to obscure the picture.

The heat transfer coefficient at the fins was, according to the data, somewhat lower than at the cylindrical element of a tube. As U was increased, the magnitude of α_f first increased fast until the filtration rate had been reached at which the heat transfer in a free bed became maximum, and then continued to remain about constant. At the same time, the ratio α_f/α_p of peak values was 0.8 and 0.71 with sand and with gel respectively. These data were typical for fin surfaces in a fluidized stream.

It is interesting to note that a reduction in the heat transfer rate was also observed in [11], where the heat transfer in a bed with horizontal tube bundles and vertical finning had been studied.

Although the heat transfer coefficients for finned tubes seem to be lower, nevertheless, according to our data and the data in [11], the quantity of heat transmitted per unit tube length increases because of the larger heat transfer surface.

NOTATION

U	is the gas filtration rate calculated per full bed cross section;
ε_1, ε	is the porosity of a free and a packed bed respectively, at U = 0.3 m/sec;
α_1, α_2	is the heat transfer coefficient in a free and in a packed bed respectively, at U = 0.3 m/sec;
α_f, α_{nom}, α_p	is the heat transfer coefficients for fins, for tubes with integral fins, and for tubes with pseudofins respectively;
α	is the heat transfer coefficient for smooth tubes;
Q_1, Q	is the quantity of heat dissipated from the cylindrical surface and from the total surface of a probe respectively;
F_c, F_f	is the surface area of tube and fins respectively (for the same tube segment).

LITERATURE CITED

1. D. Kunii and O. Levenspiel, Fluidization Engineering (1969).
2. M. G. Slin'ko and V. S. Sheplev, Kinetika i Kataliz, 11, No. 2 (1970).
3. T. Ishii and G. L. Osberg, J. AIChE, 7, No. 2 (1965).
4. J. R. Grase and D. Harrison, Chemical and Process Eng., June (1970).
5. N. I. Gel'perin, V. G. Ainshtein, and N. A. Romanova, Khim. Promyshl., No. 11, 823 (1963).
6. L. Massimilla, I. Bracale, and A. Cabella, Ricerca Sci., 27, No. 6, 1853 (1957).
7. Handbook of Nonferrous Metals and Alloys Treatment [in Russian], Metallurgizdat, Moscow (1961).
8. S. S. Kutateladze and V. M. Borishanskii, Handbook of Heat Transmission [in Russian], Gosenergoizdat (1959).
9. A. A. Zhukauskas, in: Heat Transmission and Thermal Simulation [in Russian], Izd. Akad. Nauk SSSR (1959).
10. A. I. Tamarin, Candidate's Dissertation [in Russian], ITMO Akad. Nauk BSSR, Minsk (1963).
11. I. C. Petrie, W. A. Freeby, and I. A. Bukchom, Preprint No. 49a, Symp. on Fluidization, New York, November (1967).
12. A. I. Tamarin and V. D. Dunskii, Author's Discl. No. 242146, Byull. Izobret., No. 15 (1969).