# HEAT TRANSFER IN A LIQUID FLUIDIZED BED WITH A TURBULENT JET INJECTED AT THE WALL

A. I. Safronov, L. K. Vasanova, and N. I. Syromyatnikov

UDC 66.096.5:536.24

It is shown that the heat-transfer coefficient can be increased by using an enclosed turbulent jet.

Accelerated heat transfer is the major purpose of many researches in technology, particularly ones involving granular media, especially fluidized beds. Many studies on fluidization by gas-liquid droplet jets have shown that the heat-transfer rate can be increased by about a factor of 3 by comparison with a homogeneous heat-transfer agent. Any further acceleration of the heat transfer requires research on the external heat transfer in such beds, which is particularly relevant to the injection of turbulent fluid jets into the boundary zone, where one gets an annular enclosed jet flowing along an impermeable surface.

Figure 1 shows the essence of the system; the working part is an annular channel formed by a cylinder of diameter 70 mm and the calorimeter of diameter 22 mm, height 700 mm, which is set at the axis of the cylinder at the level of the distributing grid. The water is drawn from the tank by a 2K-6M pump and fed to the heat exchanger, whence it passes via the distributing grid into the apparatus. The heat exchanger stabilizes the input water temperature. A Kama pump produces a turbulent jet in the boundary layer by independent water feed into an annular slot formed by the cylindrical calorimeter and the filling. The liquid flow rates are monitored by duplicated constructions working with U-tube differential manometers. The water passes from the

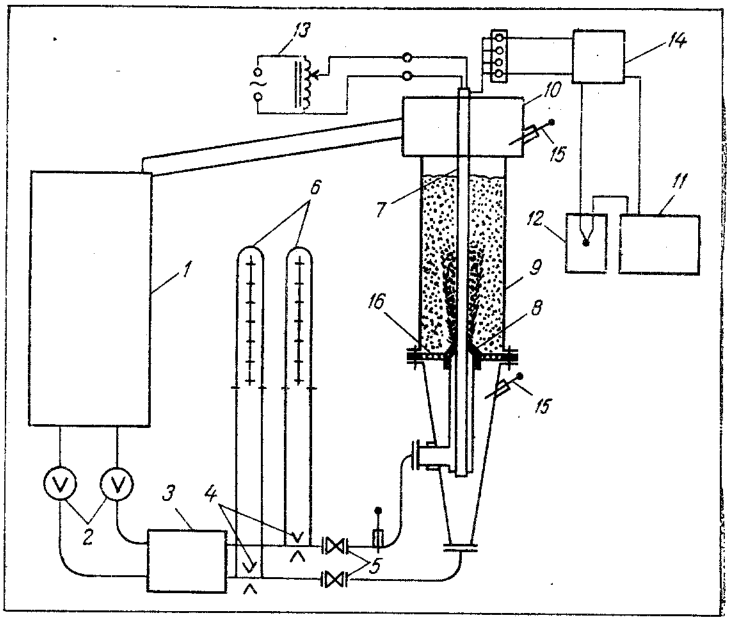


Fig. 1. The apparatus: 1) tank; 2) pump; 3) heat exchanger; 4) constriction; 5) valve; 6) differential U-tube manometer; 7) calorimeter; 8) filling; 9) cylinder; 10) expansion chamber; 11) potentiometer; 12) null thermostat; 13) autotransformer; 14) switch; 15) thermometer; 16) distribution grid.

S. M. Kirov Ural Polytechnic Institute, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 34, No. 3, pp. 404-408, March, 1978. Original article submitted March 21, 1977.

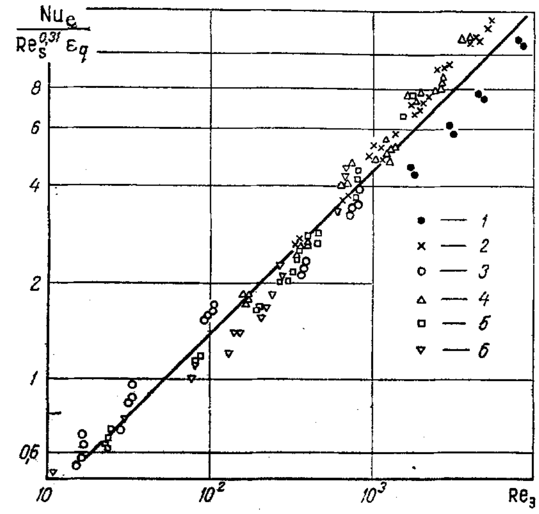


Fig. 2. Generalization of the measurements on stabilized heat transfer: 1) lead, d = 2.17 mm; 2 and 3) alundum, d = 2.27; 0.949 mm; 4, 5, 6) glass, d = 2.36; 1.34; 0.67 mm.

working zone into an expansion volume, hence it returns to the tank. The inlet water temperature in the working zone and that in the slot are the same. The temperature of the bed is determined as the arithmetic mean of readings taken with laboratory thermometers having scale divisions of 0.1°C and inserted at the inlet and outlet, with the maximum temperature difference not exceeding 0.8°C. The temperature of the heat-transfer wall is monitored with copper–Constantan thermocouples, which are fitted into the surface of the calorimeter. The thermo-emf is determined by a balance method with an R-306 potentiometer. The calorimeter is supplied with ac via an RNO 250-5 autotransformer. The major quantities were varied within the following limits: speed of the fluidizing medium 0.006–0.48 m/sec; mean bed porosity 0.684–0.96; density of particle material 2450–11,300 kg/m$^3$; equivalent particle diameter 0.67–2.36 mm; jet speed at the outlet of the slot 4.3–14.7 m/sec; and slot width 0.3–0.6 mm. Initially, the experiments were performed with the jet supplied at a height of 20 mm above the grid with a constant heat flux at the wall. Measurements of the input power and of the wall and bed temperature were used with Newton's equation to calculate the local heat-transfer coefficients, which gave graphs for the height distribution. It was found that thermal stabilization occurred at a certain point in the calorimeter. The graph served to define the length of the stabilization region and the heat-transfer coefficient on the stabilized part.

The measurements on the stabilized heat transfer were approximated (Fig. 2) as

$$Nu_e = 0{,}137\, Re_s^{0.31}\, Re_e^{0.5} \varepsilon_q \quad (1)$$

with a coefficient of variation of 15.6%; the following parameters were used as the definitive ones: the equivalent diameter of a pore channel; the actual speed of the fluidizing medium in the bed; and the temperature of the fluid.

We found that the heat transfer was affected by the diameter and density of the particles, the flow speed, and the jet speed. The stabilized heat-transfer coefficient had a maximum as a function of the flow speed, which was due to competing effects of the actual flow speed, the correlated bed porosity, and the relative speed of the particles. On the other hand, the heat-transfer coefficient increased with the jet speed, and the latter had a maximum at a certain infiltration speed, which occurred because the wall turbulence increases with the jet speed [1, 2], with a corresponding reduction in the thickness of the laminar boundary sublayer and hence in the thermal resistance. The maximum heat-transfer coefficient increases with the particle diameter and density, since the fluidization speed then rises; i.e., fluidization occurs at higher degrees of turbulence [3, 4].

The heat-transfer rate near the grid was much higher than that in the stabilized section, so in the latter experiments we produced a larger effect from the jet by injecting it at a height of 300 mm, i.e., at a height where the heat transfer was previously stabilized.

Figure 3 shows the mode of injection and the variation in the heat-transfer coefficient with height, where one can distinguish the inlet section (near the distributing grid) and the part where the jet occurs. The heat-transfer coefficients in the inlet section do not vary at a given infiltration rate and are described by the

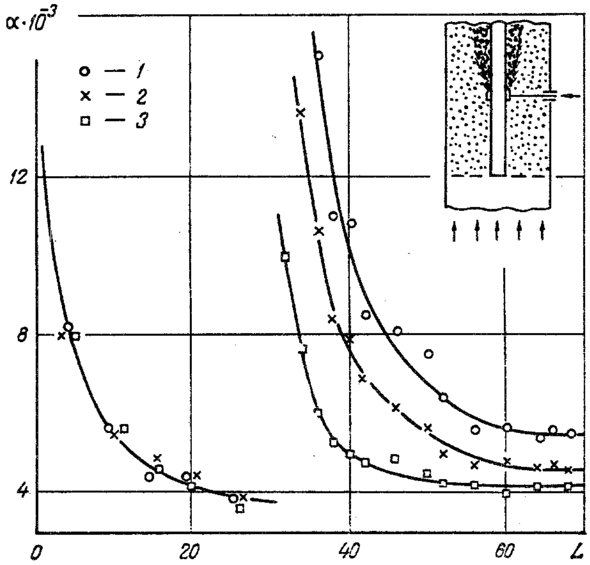


Fig. 3. Variation in heat-transfer coefficient over the height of the calorimeter; $\alpha$ in $W/m^2 \cdot {}^\circ C$ and L in cm; alundum d = 2.27 mm; $\omega_f = 0.21$ m/sec; 1, 2, 3) $\omega_s = 14.7$; 9.44; 5.27 m/sec.

correlation curves of [5], as is the stabilization length. The other section shows an increase in the local heat-transfer coefficient with the jet speed.

We found that the local heat-transfer coefficients in the stabilized range may be described by

$$\frac{\alpha_x}{\alpha_s} = \left(\frac{l}{x}\right)^{0.7}. \tag{2}$$

Here the heat-transfer coefficient for stabilized heat transfer is defined by (1), while the stabilization length is defined by

$$\frac{l}{d_e} = 316\,\frac{Re_s^{0.16}}{Re_e^{0.5}}. \tag{3}$$

Then the integral mean heat-transfer coefficient over the stabilization length is defined by

$$\bar{\alpha} = \frac{1}{l}\int_0^l \alpha_x dx = 3.33\,\alpha_s \tag{4}$$

Consequently, the injected turbulent jet accelerates the heat transfer, particularly when it is injected in the stabilized section; the relationships may be of value in the design of new equipment.

## NOTATION

| | |
|---|---|
| $Nu_e = \alpha d_e/\lambda$ | is the Nusselt number; |
| $d_e = 2\varepsilon d/3(1-\varepsilon)$ | is the equivalent diameter of channel; |
| d | is the equivalent diameter of particles; |
| $\lambda$ | is the thermal conductivity of medium; |
| $\varepsilon$ | is the mean porosity of bed; |
| $\alpha_s$ | is the stabilized heat-transfer coefficient; |
| $\alpha_x$ | is the local heat-transfer coefficient; |
| $\omega_a = \omega_f/\varepsilon$ | is the actual velocity of fluidizing medium; |
| $\omega_f$ | is the filtration speed for total cross section of annular channel; |
| Pr | is the Prandtl number; |
| $\varepsilon_q = (Pr_f/Pr_s)^{0.25}$ | is the correction for nonisothermicity; |
| $l$ | is the thermal stabilization length; |
| $Re_e = \omega_a d_e/\nu$ | is the Reynolds number; |

| | |
|---|---|
| $Re_j = \omega_j\sigma/\nu$ | is the Reynolds number for jet; |
| $\omega_j$ | is the jet velocity at slot; |
| $\nu$ | is the kinematic for bed viscosity; |
| $\delta$ | is the slot width. |

## LITERATURE CITED


1. S. S. Kutateladze, Wall Turbulence [in Russian], Nauka, Novosibirsk (1973).
2. An Experimental Study of Turbulent Flows near Walls [in Russian], Nauka, Novosibirsk (1975).
3. J. Beranek and D. Sokol, Fluidization Technology [Russian translation], Gostoptekhizdat (1962).
4. J. F. Davidson and D. Harrison (editors), Fluidization, Academic Press (1971).
5. A. I. Karpenko, N. I. Syromyatnikov, and L. K. Vasanova, Izv. Vyssh. Uchebn. Zaved. SSSR, Energ., No. 2 (1975).


# LAWS GOVERNING GAS-BUBBLE MOTION IN A FLUIDIZED BED


Yu. S. Teplitskii and A. I. Tamarin



UDC 532.546



Laws governing the motion of particles and gas bubbles in a nonuniform fluidized bed are analyzed on the basis of a variational method for describing the hydrodynamics of a fluidized bed [1] using functions of the potential motion of phases around an individual bubble [2]. Theoretical results are compared with existing experimental data [6-17].


The efficiency of technical processes taking place in a fluidized bed is determined to a considerable extent by the nature of gas-bubble motion.

A large amount of experimental material has been accumulated on the laws governing the motion of individual bubbles artificially injected into a fluidized bed at filtration rates close to the rate for initiation of fluidization [3]. Relations were established which determined the velocity and size of such bubbles. Potential functions were also obtained which described the motion of phases in the neighborhood of a rising gas bubble [2, 4, 5].

There is a large amount of data on the motion of bubbles in a fluidized bed at fluidization numbers greater than one [6-17]. The results of the various investigators are contradictory; the laws governing the motion of bubbles are not clear and there are no sufficiently justified theoretical models which would make it possible to obtain quantitative laws governing the motion of the bubbles.

It was shown [1] that one can obtain a representation of the averaged velocity and phase concentration fields in a nonuniform fluidized bed by using a variational formulation of the motion of a two-phase system.

We consider the following simplified model of a system. We confine ourselves to the two-dimensional case. In accordance with the concepts of the simplest two-phase theory [3], we consider a fluidized bed consisting of an emulsion phase, in which the particle concentration is constant and equal to $E_0$, and ascending gas bubbles. We arbitrarily divide the bed into cells, each of which consists of a bubble with a following hydrodynamic wake and surrounding emulsion phase. The size of the cell and the radius of the bubble will increase during motion from below upwards. The rate of bubble rise will increase correspondingly. We introduce the quantity n − the number of bubbles at a distance h vertically above the gas-distribution grid.

The velocity fields of the gas and particles, and also the static pressure field outside the bubble and its hydrodynamic wake, are described by known functions [2] which in a fixed coordinate system with an origin coinciding with the center of a rising bubble at a given time are of the form

a) velocity of solid phase:


A. V. Lykov Institute of Heat and Mass Transfer, Academy of Sciences of the Belorussian SSR, Minsk.


Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 34, No. 3, pp. 409-416, March, 1978. Original article submitted March 24, 1977.