THE HYDRODYNAMICS OF A CENTRIFUGAL FLUIDIZED BED IN A SOLID – LIQUID SYSTEM

G. A. Aksel'rud and D. D. Dragomeretskii

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We have studied the conditions for the appearance of a centrifugal fluidized bed in a solid–liquid system, and these conditions are governed by the critical velocities and pressure difference.

An outstanding feature of a solid–liquid system is the low level of nonuniformity. If the term "level of nonuniformity" is understood to refer to the ratio of the specific weights of the interacting phases, for a gas–solid system this term is on the order of 10^3, whereas for a solid–liquid system it is equal to some small single-valued number.

Because of this feature, in the formation of a fluidized bed in a solid–liquid system we need relatively low velocities for the liquid medium, and these are determined in fractions of m/sec. To increase the streamlining velocities for the solid particles by the liquid, the solid phase must be made heavier, and this can be achieved by placing the system under consideration in a field of centrifugal forces.

We know of no literature specifying the quantitative relationships governing a centrifugal fluidized bed in a solid–liquid system, although similar papers have been written for a solid–gas system [1-10].

Of particular interest is the work by Gel'perin, Einstein, Zaikovskii, and Goikhman [1, 10], dealing with hydrodynamics and heat transfer, and in which we find a method of determining dynamic-heat losses, as well as recommendations for the design of installations with a centrifugal fluidized bed.

The formation of a centrifugal fluidized bed is shown in Fig. 1. A liquid flow Q at a velocity W (whose magnitude may vary) is fed through a bed of granular material positioned above the distribution grid of a rotating conical vessel, with the flow radial to the axis of rotation. As soon as W reaches the W_{cr} value the formation of the fluidized bed begins, and it ceases when $W = W'_{cr}$.

The problem of the hydrodynamics of a centrifugal fluidized bed includes determination of the critical velocities and dynamic-head losses.

As is well known, the critical velocities in a conventional fluidized bed are determined by means of the generalized critical equation

$$\mathrm{Re}_{cr} = f(\mathrm{Ar}). \tag{1}$$

As regards the dynamic-head losses, these are determined approximately by the relationship

$$\Delta P = q_g = G/F, \tag{2}$$

i. e., they are approximately equal to the specific load on the distribution grid.

In making the transition to a centrifugal fluidized bed, we should replace the Ar criterion in (1) by the product ArFr. From this follows the new criterial equation for the centrifugal fluidized bed, and it has the form

$$\mathrm{Re}_{cr} = f(\mathrm{Ar\,Fr}), \tag{3}$$

As well as the new equation for the determination of the specific load on the distribution grid, i. e.,

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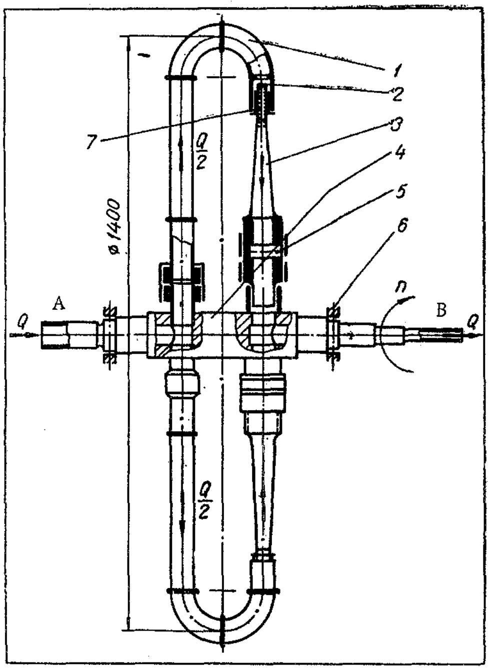

Fig. 1. Diagram of the experimental installation. The rotor assembly: 1) tubular knee; 2) distribution grid; 3) conical chamber; 4) shaft; 5) device with grid, for supply of particles; 6) roller bearing; 7) layer of material being tested.

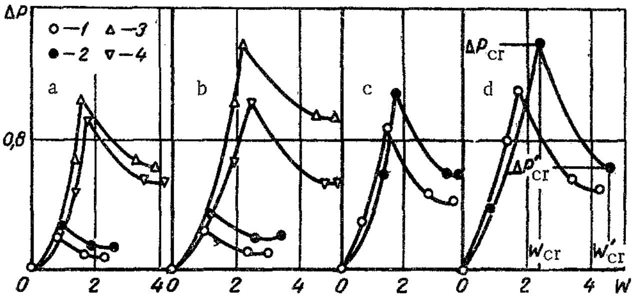

Fig. 2. Pressure difference ΔP in atm, in the layer as a function of the flow velocity W, m/sec: a-d) respectively, rotational velocities of 203, 254, 405, and 507 rpm; 1) kaolin; 2) aluminum; 3) steel; 4) brass.

$$q_c = [(1-\varepsilon)\, h(\rho_s - \rho_l)\, g]\,\mathrm{Fr}. \tag{4}$$

The basic unit of the experimental installation is the rotor (see Fig. 1). The test specimens are placed into conical chamber 3 between the two grids 2 and 5. The rotor is set into rotation by an electric motor operated with a belt drive, making it possible to change the rotor rpm from 200 to 600.

The experimental method used to determine the hydrodynamic conditions for the appearance of the fluidized bed involves the following: a batch of material with particles of identical dimensions is placed into conical chamber 3, following which the feeder orifice of chamber 5 is closed and tightly sealed. The rotor is set into motion, and the liquid feed then begins (water at a specified temperature). The liquid flow rate is monitored with an Ir-1M induction flowmeter; the pressure difference between points A and B is established simultaneously by means of a DM-2.5 differential manometer. Kaolin particles (density 2200 kg/m^3), steel particles (7800 kg/m^3), brass particles (8700 kg/m^3), and aluminum particles (2700 kg/m^3) served as the disperse medium.

With such an installation we can achieve extremely high velocities of liquid motion near the distribution grid (up to 5 m/sec), which offers hope of achieving a substantial effect in the mass-transfer process.

Figure 2 shows the pressure difference as a function of velocity for various rotor rpm's (various values of the Froude number). The curves shown in this figure are typical for a gravitation fluidized bed.

These data have been generalized in the form of critical relationships which are shown in Fig. 3 and correspond to the empirical formulas:

the end of fluidization

$$\mathrm{Re}_{\mathrm{cr}} = 1.444\, (\mathrm{ArFr})^{0.43}, \tag{5}$$

the beginning of fluidization

$$\mathrm{Re}_{\mathrm{cr}} = 1.222\, (\mathrm{ArFr})^{0.43}. \tag{6}$$

Figure 4 shows the dynamic-head losses as a function of the specific load on the distribution grid. These dynamic-head losses are defined by means of the expressions:

the beginning of fluidization

$$\Delta P_{\mathrm{cr}} = \Delta P_1 - \Delta P_2, \tag{7}$$

the end of fluidization

$$\Delta P'_{\mathrm{cr}} = \Delta P'_1 - \Delta P'_2, \tag{8}$$

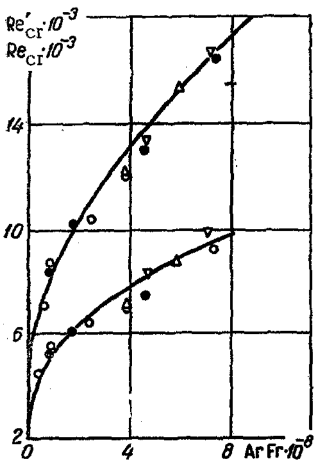

Fig. 3

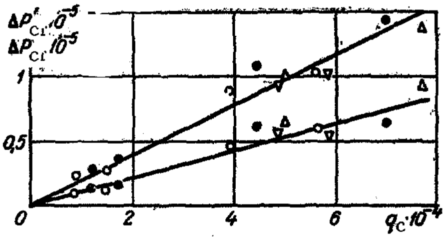

Fig. 4

Fig. 3. Criterial relationship showing Recr (bottom curve) and Re'_{cr} (upper curve) as functions of ArFr (the points are denoted in the same way as in Fig. 2).

Fig. 4. Pressure differences $\Delta P'_{cr}$ (upper curve) and ΔP_{cr} (lower curve) in N/m^2, as function of the specific load q_c in N/m^2, on the distribution grid (the notations for the points are the same as in Fig. 2).

where ΔP_1 and $\Delta P'_1$ are the pressure differences between the points A and B under the conditions of the experiment; ΔP_2 and $\Delta P'_2$ are the pressure differences for the same conditions, but in the absence of a disperse material on the distribution grid.

As we can see from Fig. 4, for the dynamic-head loss as a function of the specific load on the distribution grid direct proportionality is characteristic and it may be determined by means of the following expression:

$$\Delta P = kq_c. \tag{9}$$

NOTATION

d	is the particle diameter, m;
F	is the area of the distribution grid, m^2;
G	is the weight of the bed, kg;
Q	is the flow rate, m^3/sec;
q_g and q_c	are, respectively, the specific loads on the distribution grid, N/m^2, in gravitational and centrifugal force fields;
g	is the acceleration due to the earth's gravity, m/sec^2;
h	is the bed height, m;
r	is the radius of bed rotation, m;
ΔP	is the pressure difference across the bed, atm/m, N/m^2;
ΔP_{cr} and $\Delta P'_{cr}$	are the critical pressure differences, N/m^2;
k	is a proportionality factor;
W	is the flow velocity, m/sec;
W_{cr} and W'_{cr}	are the critical flow velocities, m/sec;
ε	is the bed porosity;
ν	is the kinematic coefficient of viscosity, m^2/sec;
ρ	is the density, kg/m^3;
ω	is the angular velocity, sec^{-1};
$Ar = [(\rho_s - \rho_l)/\rho_s](gd^3/\nu^2)$	is the Archimedes number;
$Re_{cr} = W_{cr}d/\nu$	is the Reynolds number;
$Fr = \omega^2 r/g$	is the Froude number.

Subscripts and Superscripts

s denotes a solid;
l denotes a liquid.

LITERATURE CITED

1. N. I. Gel'perin, V. G. Ainshtein, and A. V. Zaikovskaya, Khim. i Neft. Mashinost., No. 3 (1960).
2. N. I. Syromyatnikov, Trudy Ural'skogo Politekh. Inst., 61, 63 (1956).
3. N. I. Syromyatinkov, Trudy Ural'skogo Politekh. Inst., 76, 61 (1960).
4. N. I. Syromyatnikov, Trudy Ural'skogo Politekh. Inst., 76, 64 (1960).
5. N. I. Syromyatnikov, L. K. Vasanova, and Yu. N. Shimanskii, in: Heat and Mass Transfer in a Fluidized Bed [in Russian], Khimiya, Moscow (1967), pp. 156-162.
6. I. S. Golovanov, Izob. i Ratsionalizator, No. 7 (1950).
7. P. I. Dmitrienko, Izob. i Ratsionalizator, No. 5 (1951).
8. N. I. Syromyatnikov, Dokl. Akad. Nauk SSSR, 97, 2, 881 (1954).
9. N. I. Syromyatnikov, Trudy Ural'skogo Politekh. Inst., 53, 168 (1965).
10. N. I. Gel'perin, V. G. Ainshtein, and I. D. Goikhman, Khim. i Neft. Mashinost., No. 1, 12 (1964).