A FLUIDIZED BED WITH A JET-PULSED AGITATION OF FLUIDIZATION

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Abstract

Two variants have been discussed for fluidization of a bed of dispersion particles - by means of a linear-pulse (LPF) and rotation-pulsed fluidization (RPF) input, called by the common name of jet-pulsed fluidized bed (JPFB).

The effect of the way of inputting the fluid into the bed, of the geometrical dimensions and working chamber and gas distributor configuration, of the pulse frequency, of the bed and particles parameters upon hydraulic bed pressure drop and character of particles movement have been followed.

A mathematical model has been proposed utilized for the introduction of generalized variables by means of which empirical equations for calculating bed pressure drop in its three states - fixed, transitory and at a stage of a developed fluidization, have been obtained.

1. General principles

Besides its well-known advantages, conventional fluidized beds exhibit some disadvantages such as aggregative fluidization, difficulty to fluidize flaker or fibrous materials, as well or wet particles with many fine aggregates or clusters.

To improve fluidization the following modifications are used: a) forcing flow of the material (for apparatuses with a continuous operation) [6, 15]; b) mechanical agitation of the bed [2, 11]; c) spouting of the bed [13, 15]; d) vibrating of the bed [2, 6, 14]; e) jet-mixing of the bed [1, 16], where supplementary gas spout results in an intensive motion of the particles producing further disintegration of the aggregates of clotted particles and of the dead zones; f) impulse - fluidizing of the bed [9, 12], where periodical interruptions of the gas flow in the working chamber results in a phase operation - active, when gas fluidizes the bed, and passive, when gas bed is apparently fixed; g) shift-cyclical fluidizing of the bed [2, 3], by rotating of a gas-distributing device. The gas is introduced as a flat jet through a special design orifice.

A new method of fluidization presented here and formed as a fluidized bed with a local jet-pulsed fluidization operates in two versions - linear - [5] and rotation - [4, 7, 8, 10] pulsed fluidized bed.

The distributor with a rotation-pulsed fluidized bed (Fig. 2) consists of a rotating disk with radially located orifices under the working chamber. The bed is separated from the gas-distributor by the supporting grid with a large open area (over 30 %).

The gas-distributor in a linear-pulsed fluidized bed (Fig. 1) is designed as a continuously moving band, situated right under the supporting grid with a large open

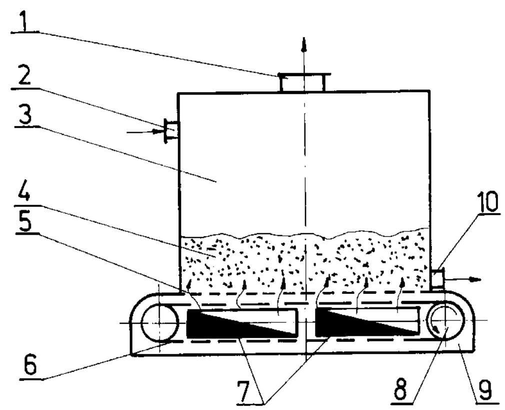

Fig. 1

area. At specified intervals in the band several orifices are made along the width of the drying chamber with a length, defined by the desired open area of the gas distributor. After changing the step between the apertures and the linear velocity of the band, an impulsed flow of the fluidizing agent at the required frequency is achieved in the form of one or several flat high velocity jets, going round the entire section of the drying chamber.

By means of the described devices, we can achieve the following:

a) forced periodical gas feed, which runs out at high velocity on every base point of the particles' bed, due to which dead zones formation is avoided, even if viscous materials are processed;

b) localised flow (in narrow zones) of the entire fluidizing agent, by which high local rate number of fluidization are reached, resulting in a good bed agitation;

c) additional bed macromovement along the dryer length in normal and transverse direction.

The proposed design of a gasdistributing device is simple in construction and of low energy demand; it neither burdens dynamically the construction, nor changes the evenness of the blower and cyclone, it is noiseless and allows a convenient regulation in a large impulse frequency range.

The successful industrial application of the described devices requires a detailed research on hydrodynamics and transfer processes in laboratory conditions.

2. Materials and procedure.

A laboratory set-up, operating on the linearly-pulsed fluidized bed principle, is shown in Fig. 1.

The belt distributors' perforation is made to ensure an open area for the various gas-distributors as follows: 2.8, 3.1, 4.5, 4.9, 5.5, and 7.1%.

The experiments are made with three types of the working chambers: version I - with prismatic shape; version II - with double tapered vertical section area; version III with tapered vertical section area.

The rotation-pulsed fluidized bed stand (Fig. 2) consists of a fan (2), a gas-distributing chamber (8), a fluidizing chamber (4), a driving mechanism (9) and air-ducts (3). In the gas-distributing chamber a rotating disk (7) with radial situated slots (10) is located, forming one or several sectors through which the gas stream is injected into the bed. A fixed perforated grid (6) with a large open area (the experiments were made with 27 and 44%) is located above the rotating disk (7). The cylindrical fluidizing chamber (4), 210 mm in diameter and 800 mm height is made of Plexiglass to allow observation of the particles movement.

The rotating disk (7) is driven by a variable speed D.C. motor (9) with controllable rotational speed 6 - 450 rpm.

The gas flow rate is controlled by the shutter (1) located in the sucker of the fan (2). The fluidizing gas blown by a fan (2); is transported through the air duct (3) to the gas-distributing chamber (8). Afterwards it flows out through the radial orifice (10) of the rotating disk (7), passes through the apertures of the fixed supporting grid (6) and, enters the fluidizing chamber (4) and fluidizes the bed of grainy material.

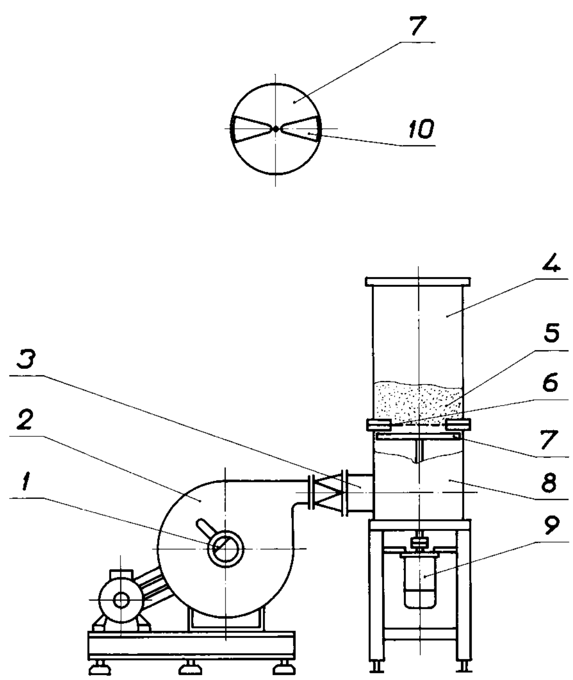

Fig. 2

The pressure drop both in the gas-distributing device and in the bed, as well as the gas- distributors pressure drop, and the pressure drop only in the bed are measured directly with precision 5 Pa.

The hydrodynamic experiments are made with seven type of particles: Poly-ethylene - type I, II, and III with cylinder shape; Teflon - type IV and V respectively cube and cylinder shape; Glass spheres - type VI and VII.

3. Results

3.1. Movement of the particles and the gas in a local jet-pulsed fluidized bed.

3.1.1. Linear-pulsed fluidized bed.

Under the influence of fluidizing agent jet a large group of particles with impermanent content (formed by different particles) makes more or less a describable movement, similar to the bubble formation and movement in a conventional fluidized bed, and to the spouts and jets ones in the spout and jet fluidized beds.

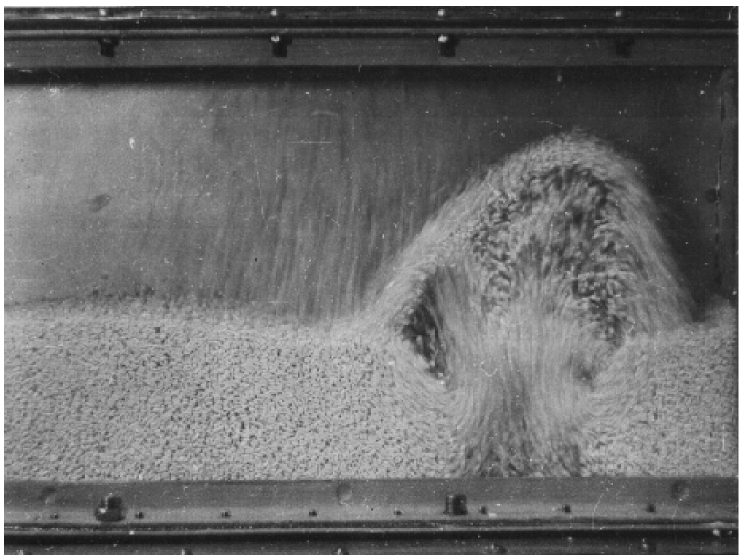

Fig. 3

Basically the structure-defining factors in the apparatuses with linear-pulsed fluidized bed are: the gas flow velocity w_g, the impulse frequency ν, the wall effects, the bed height, the material density, the distributor open area and the working chamber form.

Fig. 3 illustrates initiation of a spout in a fixed band gas-distributor in a chamber with material, type I, when the jet has already pierced the bed and forms a spout of particles.

Fig. 4 shows the same situation at the moving band gas distributor. When gas velocity is increased the angle of repose and the spout density is decreased.

If the rate of gas flow is increased in the upper part of the bed, the bed is rarefied and a dome-shaped projection is formed. The increase in the material density and the bed height improve the uniformity of the gas flow distribution.

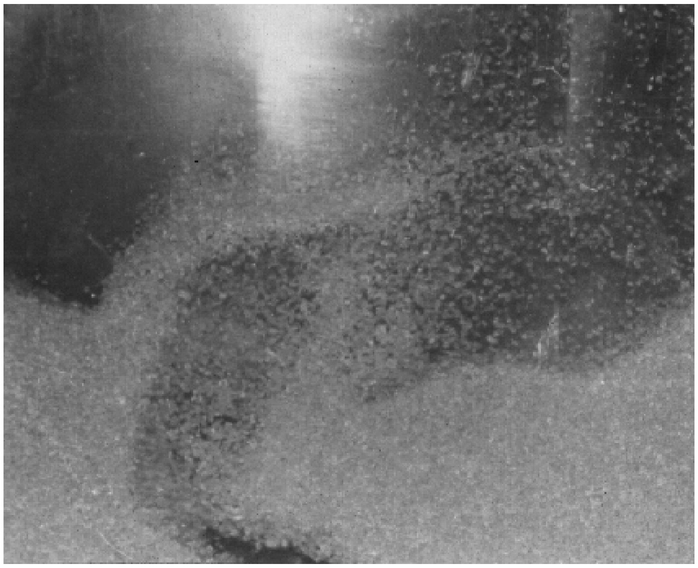

Fig. 4

Investigations show that at the aperture low motion values the bubble is elliptic and does not stop the gas track. When increasing ν, the bubble flattens - it resembles the gas layer in the by-grid zone. The increase in gas velocity enhances the turbulence in the bed and throws more particles above it.

3.1.2. Rotation-pulsed fluidized bed

The particles movement, observed above the radial orifice is similar to that one characteristic of the spouted bed - when carried by the air flow the particles are lifted, and afterwards are moving along the spout periphery into the fixed bed.

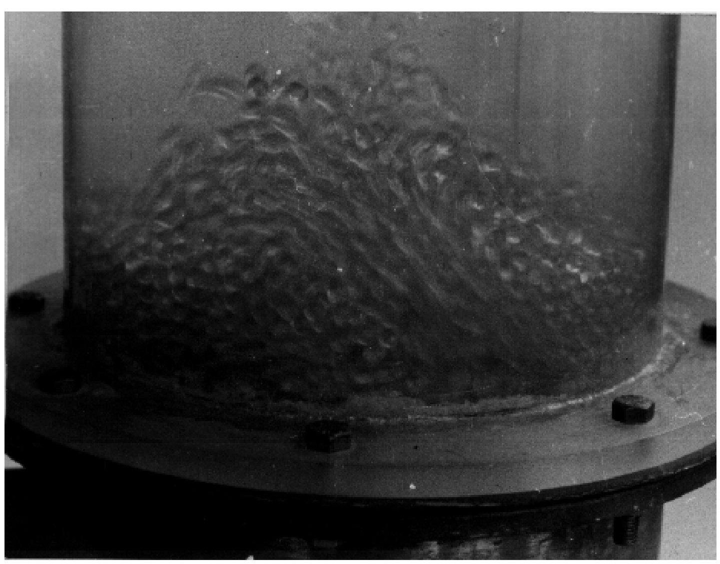

Fig. 5

For a fixed disk, the groups of particles move vertically upwards and vertically downwards. When the disk rotates, the jet deviates in the direction opposite to the disk movement, and drives the particles towards the opening through which it runs out (Fig. 5). The slope of the jet depends on the peripheral velocity, respectively on the disk rotation frequency. Above a certain frequency, the angle of the jet becomes close to 90^{o}, and the jet slides almost parallely to the fixed supporting grid, while loosing its kinetic energy, after which the fluidizing agent blows through the bed in a vertical direction, thus driving the groups of particles into pulsations (Fig. 6). The frequency and the amplitude of these pulsations can be controlled by a suitable choice of the disk rotation frequency and the fluidizing agent velocity.

3.2. Fluidization Curves

3.2.1. Linear-pulsed fluidized bed.

Fig. 7 and 8 present fluidization curves in a linear-pulsed fluidized bed apparatus for different process parameters. In general, the curves are similar to those characteristic of the classical fluidized bed and to the spouted bed. The peak height decreases substantially as the material density and the bed height h, increase. In contrast with the spouted bed curves the developed fluidization stage is defined in a wider fluidization number range.

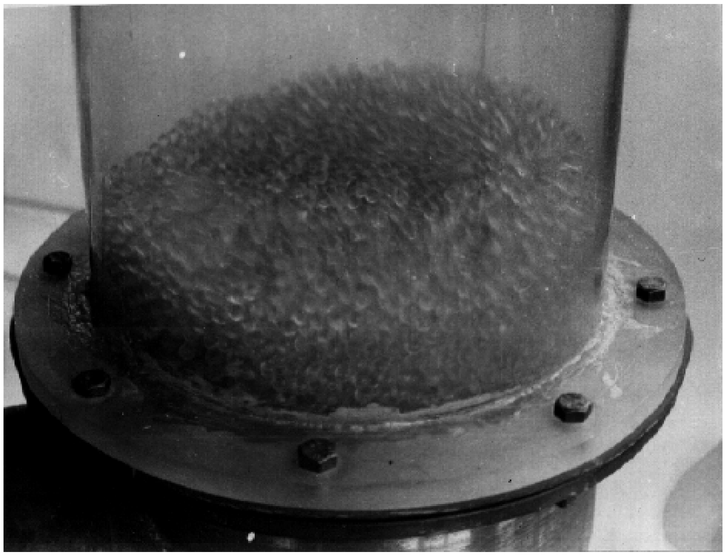

Fig. 6

The material density ρ_m (Fig. 7) influences substantially the bed pressure drop and the minimum fluidization velocity. Fig. 8 shows no influence of the impulse frequency ν on the fluidization curve.

3.2.2. Rotation-pulsed fluidized bed

Fig. 9 and 10 present curves of fluidization of rotation-pulsed fluidized bed.

Although the curves are, in general, similar to the classical fluidization curves the peak in the pressure drop appears only at pulsed frequency below 0.6 s^{-1}. At higher frequencies the pressure drop changes as the bed transforms from a fixed into a fluidized state without peak (Fig. 9 and 10).

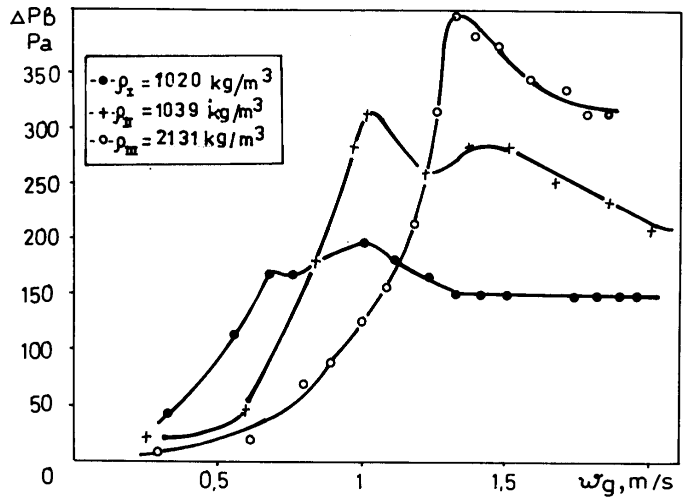

Fig. 7

The loading of the material on the distributing grid m/F_S - exerts the strongest influence over the bed pressure drop (fig. 9).

The rotation frequency of the gas distributing disk does not influence the bed pressure drop at the same bed loading (Fig. 10).

The observations of a local jet-pulsed creation of the fluidized bed can be concluded as follows:

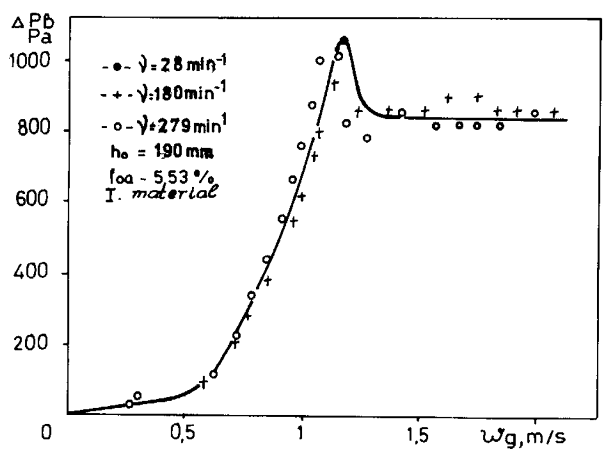

Fig 8

a) the particle mixing is multi-directional and highly intensive throughout the entire bed. Regarding the particle movement in the bed, the ideal mixing model may be recommended.

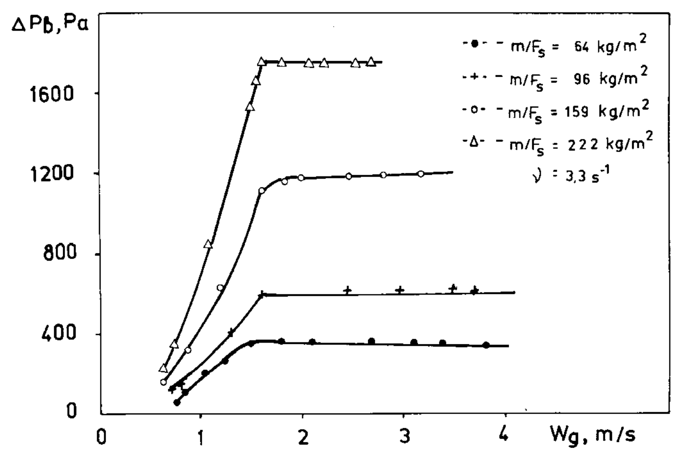

Fig. 9

b) at a suitable impulse frequency, the fluidizing gas filters a long way through a relatively consistent phase, and the gas flow model is close to the ideal thrust-out.

c) there are two clearly-formed zones in the bed: a fixed bed zone (a continuous emulsion phase), in which the particles are gas-streamed at a low relative velocity, and a spout zone with low porosity and a brief continuance of the gas-particle contact. Obviously, there are conditions for fulfilment of heat- and mass-transfer processes in oscillatory regime of the bed, which favour transfer processes kinetics.

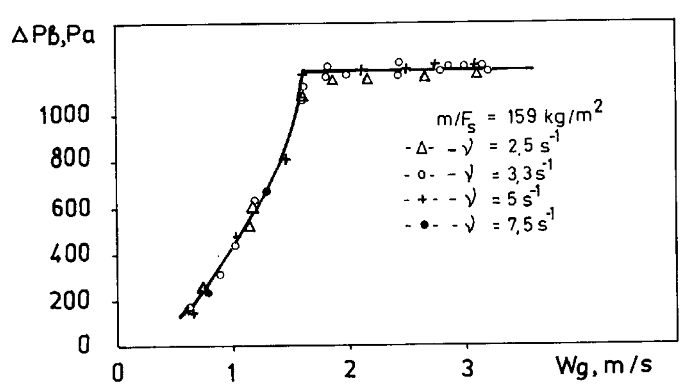

Fig. 10

4. Pressure drops in local jet-pulsed fluidized beds. Mathematical model.

4.1. Linear-pulsed fluidized bed.

The minimum fluidization velocity can be calculated from the equation: /1/

$$\mathrm{Re}_{mf} = 1{,}60.\, Ar^{0{,}35}, \qquad /1/$$

obtained from 50 experiments with particles of types I -VI, where $0.9.10^{-6}<Ar<5.7.10^{-6}$.

Compared to results of Re_{mf} calculation in other known formulae: as formula /I.21/ from [17] and formula /1.13/ from [18], data from equation /1/ present lower values of Re_{mf} than those calculated in literature. Probably this is due to the impulse fluidizing of the bed.

The experimental data from the investigation of the fixed bed pressure drop were correlated in order to determine the coefficients in equations of the type of Kozeny - Carman /1.7/ and Ergun's equations /1.11/ from [18].

Correlation of 214 points with equation of the type /1.7/ and 255 points with equation /1.11/ gives the following correlations /2/ and /3/ with correlation, coefficients respectively 0.908 and 0.862 respectively:

$$\frac{\Delta p}{h_o} = 0{,}905\frac{(1-\varepsilon_o)}{\varepsilon_o^3}\frac{\rho_g w_g^2}{\varphi_s d} - 25{,}856\frac{(1-\varepsilon_o)^2}{\varepsilon_o^3}\frac{\rho_g \nu_g w_g}{\varphi_s^2 d^2} \qquad /2/$$

$$\frac{\Delta p}{h_o} = 1{,}420\frac{(1-\varepsilon_o)^2}{\varepsilon_o^3}\frac{\rho_g w_g^2}{\varphi_s^2 d} - 0{,}359\frac{(1-\varepsilon_o)^2}{\varepsilon_o^3}\frac{1}{\varphi_s^2 d} \qquad /3/$$

Elimination of w_g from equation /2/, or /3/ and /1/ gives the equations for the fluidized bed pressure drop in the stage of fully developed fluidization:

$$\frac{\Delta p_b}{h_o} = \frac{18}{\varphi_s^2 d^{0{,}9}}\frac{(1-\varepsilon_o)^2}{\varepsilon_o^3}\left(\rho_g^{0{,}3}\nu_g^{0{,}6}\rho_m^{0{,}7} - 0{,}02d^{-0{,}1}\right) \qquad /4/$$

$$\frac{\Delta p_b}{h_o} = 11{,}46\frac{(1-\varepsilon_o)^2}{\varepsilon_o^3}\frac{\rho_g \nu_g}{\varphi_s^2 d^2}\left[\frac{\varphi_s d^{1{,}1}\rho_m^{0{,}7}}{(1-\varepsilon_o)\nu_g^{0{,}4}\rho_g^{0{,}7}} - 2{,}257\right]. \qquad /5/$$

4.2. Rotation-pulsed fluidized bed.

In analysing and processing data from rotation-pulsed fluidized bed investigation a physical model has been formulated, complying with the hydrodynamic conditions at jet-pulsed effect upon particles, and on this basis a mathematical model has been created by means of which generalised variables characterising the process have been introduced.

In formulating the physical and mathematical model of jet-pulsed fluidized bed the effect of the following forces upon the bed has been discussed:

- the grain material gravity force - G;
- the ascensional (buoyancy) force - A;
- the force determined by the difference in static pressure of underlattice space and above bed - S;
- impulse force - I, evoked by gas jet shock effect as it escapes from the gas-distributor apertures, and
- normal reaction - N, balancing the above mentioned forces.

The mathematical modelling (simulation) of the bed hydraulic pressure drop has been done by means of dimentionless criteria W and material pressure upon supporting grid H.

The criterion W, known by the name of fluidization number, represents the ratio of the gas velocity in the chamber w_g to initial fluidization rate of particles w_{gmf} measured along the camber cross-section:

$$W = \frac{w_g}{w_{gmf}} \qquad /6/$$

The material pressure related to unit area of the grid can be presented by the expression:

$$H = \frac{m.g}{F_s} . \frac{\rho_m - \rho_g}{\rho_m}, Pa \qquad /7/$$

The hydraulic pressure drop of the static bed can be calculated by the equation:

$$\Delta p_{sb} = H(1 - 16{,}2.10^3 \frac{\varepsilon_o^3}{a_f} W^{-0.38}), Pa \qquad /8/$$

In bed fluidization at the initial moment w_g and w_{gmf} are equilized, at which W will become equal of 1. Then the fluidized bed pressure drop will depend mainly on material load on the supporting grid and can be determined by the expression:

$$\Delta p_{fb} = H\left[1 - 0.52.\varphi_s (1 - 2{,}7.10^{-4}.H)\right], Pa \qquad /9/$$

In transition state (in the range of change of W from 0.7 to 1) the bed pressure drop can be described by the equation:

$$\Delta p_{tb} = H\{1 - 37860.W^2 . \frac{\varepsilon_0^3}{a_f} . \exp\left[(W - 0{,}7).(3{,}1 + 0{,}002.H)\right]\}, Pa \qquad /10/$$

With the jet-pulsed fluidized bed the concept local fluidization number can be introduced - W_L, that in itself means the ratio of the gas velocity filtering through the bed that lies above gas-distributor apertures to the critical gas velocity w_{gmf}:

$$W_L = (W - 1).\frac{F_s}{F_1} + 1, \qquad /11/$$

where F_1 is the aperture area through which jet pierces the bed.

Conclusions.

By using a simple gas-distributing device, a jet-pulsed fluidization agent introduction into the bed can be implemented. In that way, a specific hydrodynamics is created in the bed that allows utilization of fluidization bed technique for the processing of high-moisture content, flakes etc. materials, that are readily subjected to fluidization.

By means of analysis of the physical model proposed by us, a mathematical model has been created that is based on a great volume of experimental material (over 231 experiments). The final results have been presented like equations for hydraulic pressure drop calculation of the bed as a function to the number of fluidization.

NOTATION

a - side of the cube, mm
a_f - dispersity
b - particles height, mm
d - diameter, m
f_{oa} - open area, %
F - cross section of the area, m^2
g - gravitational acceleration, m/s^2
h - bed height, mm
h_o - bed height of the fixed state, mm
k - constant
m - mass, kg
P - pressure, Pa
Δp - pressure drop, Pa
t - temperature, ^oC
V - volume, m^3
w_g - gas velocity, m/s

Greek Symbols

ε - porosity
ν_g - kinematic viscosity
ξ_s - supporting grid pressure drop coefficient
ε_o - porosity of fixed bed
φ_s - shape coefficient
ρ - density, kg/m^3
ν - frequency of pulsation, s^{-1}

Subscripts

b - bed
d - disk
e - equivalent
g - gas
m - material
mf -minimum fluidization
o - total for the grid and the bed
s - supporting grid

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s - fixed bed
f - fluidized bed

Dimentionless numbers

$$Ar = \frac{g.d^3}{\nu_g^2}.\frac{\rho_m - \rho_g}{\rho_g}$$

$$\mathrm{Re}_{mf} = \frac{w_{gmf}.d}{\nu_g}$$

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