MODELING OF BED PRESSURE DROPS IN ROTATION-PULSED FLUIDIZED BED DRYER

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ABSTRACT

A physical model of rotation-pulsed fluidized bed, applied in high-moisture content materials drying, has been formulated.

A mathematical model considering the influence of the forces acting upon the bed particles is proposed based on the physical one.

As a result of the modelling equations for calculating pressure drops of rotation-pulsed fluidized bed in its three stages - static, transitory and developed fluidization, have been proposed.

The rotation-pulsed fluidized bed of disperse matter (Elenkov, 1989,1992; Gawrzynski, 1987, 1996) has been successfully applied for drying of crystal products apt to aggregation and sticking together (crystal sugar, sea-salt, etc.), as well as for drying and roasting of high-moisture biological products (wet-separated sesame and sun-flower seeds, cocoa etc.).

This study has been done with the purpose of formulating a physical model of movement of the solid and gas phases with apparatuses operating on the principle of rotation-pulsed fluidized bed and on this basis a mathematical model has been deduced for calculating the pressure drop of the bed.

PHYSICAL MODEL

On Fig.1 the gas-distributor has been presented schematically (supporting grid /3/, gas-distributing disk /4/ with sectorial openings /5/) for implementing a rotation-pulsed fluidized bed in the cyllindrical working chamber /1/.

We accept that the working and the gas-distributing chamber have one and the same cross-section- $F_{wch} = F_{gdch} = F$. The supporting grid /3/ has an open area - $f_{oag} = F_{oag}/F$, and the gas-distributor /4/ is a solid disk with two symetrical sectorial openings that have a common open area $f_{oad} = F_{oad}/F$. The distance between the supporting grid and the gas-distributor is minimal 2 to 4 mm.

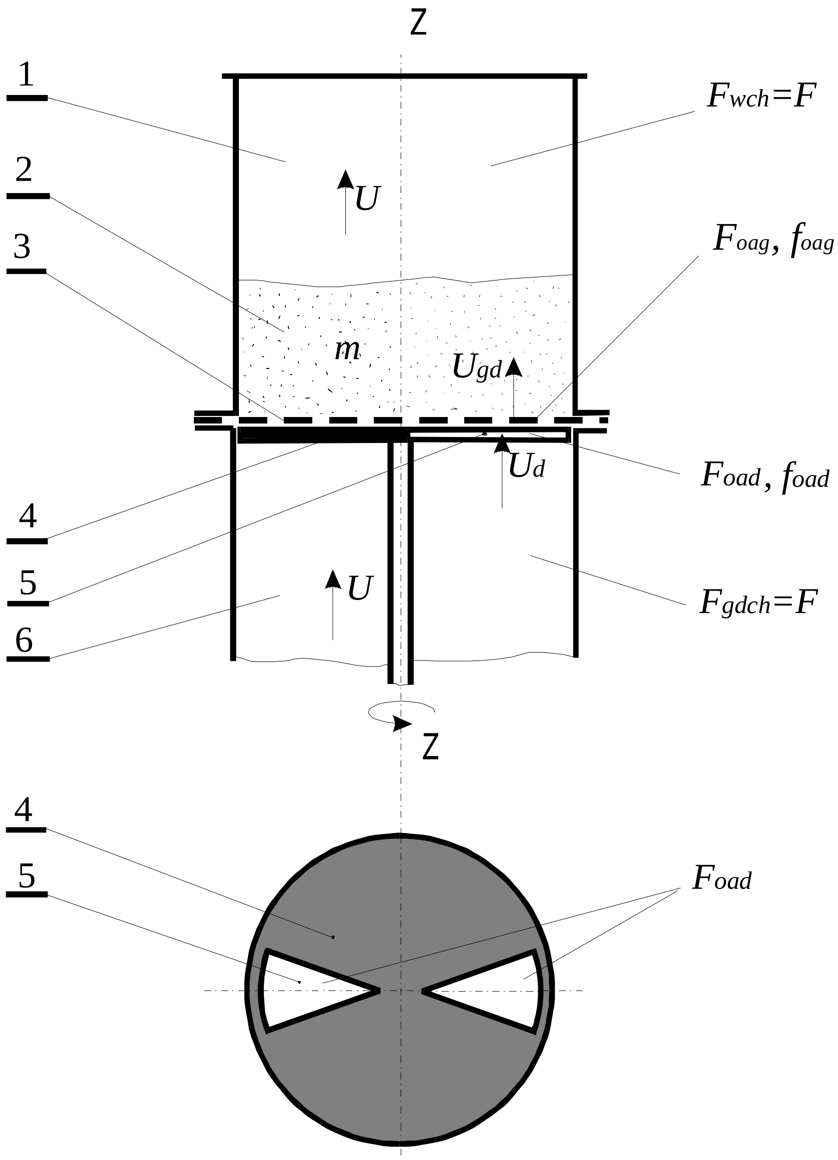

Fig. 1

The fluidized agent has a capacity L, density ρ_g , velocity on the gas-distributor chamber cross-section U flows through the disk openings at that its velocity increases to $U_d = U/f_{oad}$ (Fig.1). When on the last one there is no bulk material because of the gas high velocity and the small distance between the gas-distributor and the supporting grid, we can accept that a part of the fluidized agent (L_1) will go through to the grid openings, positioned against the sectorial openings of the disk with a velocity of $U = U_{gd} = U_d$. The remaining part of the gas (L_2) will struck the solid part of the supporting grid at which the jet kinetic energy will be transformed into a potential one; the pressure in the spaces between the supporting grid and the gas-distributor will be increased to such a degree that the stream filtering (L_2) through the remaining grid openings (those that are not positioned against the sectorial disk openings) with a velocity of $U_{gd} < U_d$ to be ensured. When upon the supporting grid there is a bed of material with weight m, the movement of the gas is analogical to the just described but it can be expected that at low velocity U_d, when the shock power upon the particles forming the bed is small and is not able to set them into motion, U_{gd} will be smaller than U_d, i.e. $U_{gd} = k_U U_d$, where k_U is a number less than 1. The capacity L_1 will be decreased, while L_2 will be increased. The gas filtration through the bed will be more uniform. At high U_d value, the pulse power of the gas stream that has of the grid passed through the disk openings positioned against them will be able to set the particles into motion so that a gas cavern or bed to be formed at which the openings of the grid will be “unplugged” -

i.e. upon them there is no material. The flowing is analogical to the above-described at a grid free from any material. The gas entering the cavern or the gas layer is filtered uniformly or in the form of a jet with a lower or higher particles concentration, thus forming the diluted (the jet) bed phase. The gas stream flowing through the grid openings that are not positioned against those of the disk has a low flowing velocity; it filters through the bed without changing substantially its structure and forms the s. c. thick (emulsion) phase of the bed. At definite high rotation frequencies of the gas-distributor disk (resonant frequencies) a uniform two-phase medium, similar to the uniform fluidized bed, but having a higher porosity, is formed.

MATHEMATICIAL MODEL

Let's look upon equilibrium of forces forming the normal stress upon the supporting grid, positioned along the axis Z - Z, that act upon a column of a material with height *h*, positioned above the supporting grid openings /3/, respectively above the disk sectorial openings /5/ - Fig.1.

The forces that act upon the remaining two axes X - X and Y - Y, lying in the plane of the supporting grid evoke turbulent movements of the particles in the bed that does not influence on the bed equilibrium vertically.

Along the Z - Z axis act forces, as follows:

a) Bed particles gravity - *G*:

$$G = m_{gd} \,.\, g, \tag{1}$$

where: m_{gd} is the weight of the column of material positioned above the supporting grid openings that lie above the sectorial disk openings, kg.

Because:

$$\frac{m}{F} = \frac{m_{gd}}{F_{gd}}, \tag{2}$$

there follows the equation:

$$G = mg\frac{F_{gd}}{F}, \tag{3}$$

where : *m* is the weight of the material along the working chamber cross-section, kg,

F - cross-section of the working chamber, m^2 ,

F_{gd} - cross-section of the opening above the disk and the supporting grid, m^2 .

b) The buoyant (Archimedes) force - *A*

$$A = \frac{m_{gd}}{\rho_m} g\rho_g, \tag{4}$$

where: ρ_m is the particle density of the grain material, kg/m^3.

ρ_g - gas stream density, kg/m^3.

Having in mind the Expression (2) for the buoyant force we can obtain :

$$A = mg\frac{\rho_g}{\rho_m}\frac{F_{gd}}{F}. \tag{5}$$

c) the force determined by the difference in the static pressures in the sub-grid space and above the bed - *S*:

$$S = \Delta p F_{gd} = (p_1 - p_2) F_{gd}, \tag{6}$$

where : p_1 is the gas stream pressure in the sub-grid space, Pa,
p_2 - gas stream static pressure in the above-bed space, Pa.

d) The pulse force - *I*, evoked by the shock action of the gas jet flowing through the disk aperture:

$$I = \rho_g F_{gd} U_{gd}^2, \tag{7}$$

where : U_{gd} is the gas velocity flowing through the openings of the supporting grid, lying above the disk sectorial openings, m/s.

e) The Normal reaction - *N*, equilibrating the above-mentioned forces:

$$N = G - A - S - I, \tag{8}$$

Because the normal reaction *N* is a function of the gas velocity flowing through the grid openings U_{gd}, we can accept that *N* is the function of the pulse force *I*:

$$N = \eta_U I, \tag{9}$$

then:

$$G - A = S + (1 + \eta_U) I. \tag{10}$$

When we replace in Equation (10) the forces with their equations from Equations (3) to (7), we obtain:

$$mg \frac{F_{gd}}{F} \left(1 - \frac{\rho_g}{\rho_m} \right) = \Delta p . F_{gd} + (1 + \eta_U) \rho_g F_{gd} U_{gd}^2. \tag{11}$$

After cancelling of F_{gd} the Expression (11) will appear like this:

$$\frac{mg}{F} \frac{\rho_m - \rho_g}{\rho_m} = \Delta p + (1 + \eta_U) \rho_g U_{gd}^2. \tag{12}$$

By means of the equation of continuity, the gas velocity in grid openings U_{gd} lying above the disk sectorial openings can be expressed by means of the gas velocity referred to the full cross-section of the working chamber - *U*:

$$U_{gd} = k_U U_d = \frac{k_U U}{f_{oad}} \tag{13}$$

where: U_d is the gas velocity in the disk opening, m/s.

The physical sense of the left section of the Equation (12) is the pressure which the bed of material exercises upon the grid.

Let's designate by H the expression:

$$H = \frac{mg}{F}\left(1 - \frac{\rho_g}{\rho_m}\right). \tag{14}$$

Because $h^* = \frac{m}{F\rho_m}$ is the material height, forming the bed at ε = 0, then at ε ≠ 0:

$$\frac{m}{F\rho_m} = h(1-\varepsilon). \tag{15}$$

Hence:

$$H = \frac{mg}{F}\frac{\rho_m - \rho_g}{\rho_m} = h^* g\left(\rho_m - \rho_g\right) = h(1-\varepsilon)g\left(\rho_m - \rho_g\right) \tag{16}$$

or

$$H = \Delta p + \left(1 + \eta_U\right)\rho_g k_U^2 \frac{U^2}{f_{oad}^2}. \tag{17}$$

At velocity lower than U_{mf} the difference between non-equilibrated part of bed pressure upon the grid and the static pressure drop is:

$$H - \Delta p = \left(1 + \eta_U\right)\rho_g k_U^2 \frac{U^2}{f_{oad}^2}. \tag{18}$$

We revise Equation (18) by multiplying the two sections of the equation with the expression $\frac{U_{mf}^2}{HU^2}$ and introduce the dimensionless criterion P:

$$P = \frac{1 - \frac{\Delta p}{H}}{\left(\frac{U}{U_{mf}}\right)^2} = \left(1 + \eta_U\right)\frac{\rho_g}{H}.\frac{k_U^2}{f_{oad}^2}U_{mf}^2 \tag{19}$$

Dimentionless pressure drop P sows the link between dimentionless criteria U/U_{mf} and material pressure upon the supporting grid.

The expression U/U_{mf} is the relation of the current gas velocity in the chamber to the fluidization velocity in the material bed along the cross-section of the chamber and at velocities higher than U_{mf} has been known by the name "number of fluidization".

At the moment of equilibration of the bed in the gas jet action region, the normal reaction N and the function η_U become equal of zero. Then:

$$P_{mf} = \frac{\rho_g}{H} \cdot \frac{k_U^2}{f_{oad}^2} U_{mf}^2 . \qquad (20)$$

Wherefrom we can express k_U:

$$k_U = \sqrt{\frac{P_{mf}}{\rho_g} \frac{H}{U_{mf}^2} f_{oad}^2} . \qquad (21)$$

The finding of the function $P = f(U/U_{mf})$ in an obvious appearance on the basis of the experimental data allows for the calculation of the bed hydraulic pressure drop Δp and the gas jet capacities in the emulsion and jet region of the fluidized bed.

$$\Delta p = H\left[1 - \left(\frac{U}{U_{mf}}\right)^2\right] \qquad (22)$$

$$L_1 = \rho_g f_{oag} F U k_U \qquad (23)$$

$$L_2 = L - L_1 . \qquad (24)$$

The developed mathematical model has been applied when deducing equation describing the pressure drop of the bed of bulk material composed of model particles of glass pearls with a diameter ∅4mm and ∅6mm, Teflon cylinders (∅5mm, h 5mm) and Teflon cubes of 4x4x4 mm.

According to experiments selected by chance taken from the glass spheres (dia. 6mm) trials, diagrams of the function $P = f(U/U_{mf})$ have been constructed in a double logarithmic coordinate system.

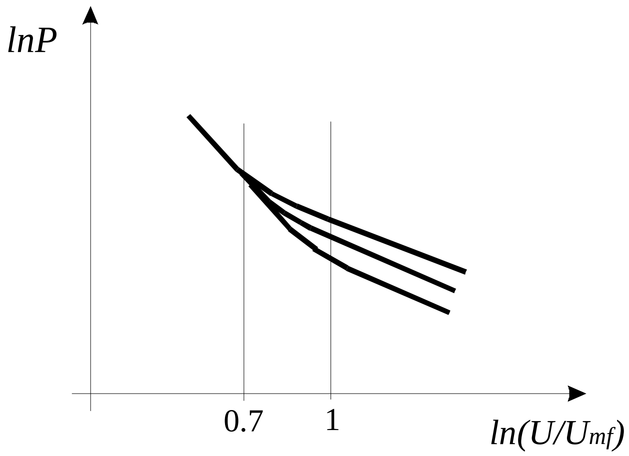

Fig. 2

The general appearance of the curves has been presented on Fig.2. Three sections are clearly seen:

– first section with $U/U_{mf} < 0.65 \div 0.7$, in which the points from all experiments are disposed on one straight line (the dependence $lnP = f[ln(U/U_{mf})]$ is a linear one). This is a section in which the bed is static (thick);

– second section at $0.70 < (U/U_{mf}) < 1$ in which the curve in the double logarithmic coordinate system is a non-linear and is influenced by *H*; in this section the transition from the static to fluidized bed is realised. In a semi-logarithmyc coordinate system the dependence $lnP = f(U/U_{mf})$ is expressed by a straight line;
– third section at $1<(U/U_{mf})$ in which into a double logarithmic coordinate system the points form a bunch of straight lines different for the different *H*.

By using the data from the experiments carried out, after the shape and dimension of the particles have been recorded, the pressure drop of the particles bed can be calculated according to the equations:

– for the static bed:

$$\Delta p_{sb} = \frac{mg}{F\rho_m}\left(\rho_m - \rho_g\right)\left[1 - 16.2.10^3 \frac{\varepsilon_o^3}{a_f}\left(\frac{U}{U_{mf}}\right)^{-0,38}\right], Pa; \qquad (25)$$

– for the transitory stage:

$$\Delta p_{tb} = H\left\{1 - 37860\left(\frac{U}{U_{mf}}\right)^2 \frac{\varepsilon_0^3}{a_f}\exp\left[\left(\frac{U}{U_{mf}} - 0.7\right)\left(3.1 + 0.002H\right)\right]\right\}, Pa; \qquad (26)$$

–for the fluidized bed:

$$\Delta p_{fb} = H\left[1 - 0.52\varphi_s\left(1 - 2.7.10^{-4} H\right)\right], Pa. \qquad (27)$$

The maximum difference between the bed pressure drop calculated according to formula (25) - (26) and the experimentally measured do not surpass 10%.

The above describe model has been used in the design and elaboration of two industrial installations:

– a sesame dryer and roaster with capacity of 100 kg/h;
– a dryer for crystal materials with capacity of 3000 kg/h for salt production.

NOTATION

A	- Archimedes force, N
a_f	- dispersity
f_{oa}	- open area, %
F	- cross section of the area, m^2
G	- gravity force, N
g	- gravitational acceleration, m/s^2
H	- parameter defined by Eq. (14), Pa
h	- bed height, m
I	- impulse force, N
k_U	- constant
L	- fluidizing agent capacity, kg/s
m	- material mass, kg
N	- normal reaction of the forces, N
p	- pressure, Pa
Δp	- pressure drop, Pa

S - force according Eq. (6), N
U - gas velocity, m/s

Greek Symbols

ε - porosity
ε_o - porosity of fixed bed
φ_s - shape coefficient
ρ - density, kg/m^3

Subscripts

b - bed
d - disk
fb - fluidized bed
g - gas
gd - grid - disk
gdch - gas-distributor chamber
m - material
mf -minimum fluidization
oad - open area disk
oag - open area grid
sb - static bed
tb - transitory stage
wch - working chamber

LITERATURE

Elenkov V.R., Djurkov T.G., 1989. Kondov P.S. Fluidized bed device. Bulgarian Patent N 47977.

Elenkov V.R.,Djurkov T.G., 1992. Rotating-pulsed fluidized bed dryer for high-moisture content bioproducts. International Drying Symposium "Drying'92". Montreal. Elsevier SP, pp.1636-1641.

Gawrzynski Z.,1987. Patent PRL 150412.

Gawrzynski Z., Glaser R., 1996. Drying in a pulsed-fluid bed with relocated gas stream. Drying Technology, 14 (5), pp. 1121-1172.