RESEARCH OF BED POROSITY OF VERTICAL DIFFERENT-SHAPED FLUIDIZED BEDS BY C GROUP MATERIAL FLUIDIZATION

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Abstract
Bed porosity plays an important role by the determination of the minimum fluidization velocity of the fluidized material. With decreasing porosity of the bed is to increase the air flow velocity in the fluidized bed/layer. The paper deals with the bed porosity which composites of spherical particles of different diameters (2,4,6,8,10 mm). These particles have different values of porosity in different types of multi-walled fluidized beds and thus lead to different values fluidized velocity. Porosity was determined by experimental means and subsequently evaluated using Rocky software (DEM). The experiment was performed on cells with a regular 3, 4, 5, 6 and 7 multi-walled cross section and the cell of circular cross-section. All cells are characterized by the same cross-sectional size, ie the size of the cross section of S = 1256 mm². Experiments for 3, 4, 5, 6 and 7multi-walled cross cell of fluidizing bed were carried out for a batch of 2 kg of spherical particles.

Keywords: Porosity; Fluidization; Rocky software (DEM)

1. INTRODUCTION
Porosity as a bulk material property is characteristic especially for fine particles, powders and nanoparticles since disproportionately increases contact interparticle surface and thus influences interparticle forces strongly. Porosity is defined as the ratio of pore volume to its total volume.

Another feature worth mentioning in many references is modelling the flow of variously porosity characterized granulates in a rotational fluid bed using the DEM [1] method or simulation of porosity of the fluid bed using a CFD model [3;2;7;8;9;11;15;16;18;19;20;21;22;23;24] applicable for example in pharmaceutical drying [9] and situations where the Euler-Lagrange computation model is applicable [15;17;24].

All of the mentioned references to the literature study cylindrical vertical fluid beds without considering various types of geometry of the vertical bed. Of course there are experimental studies, e.g. for cells of various geometries [27;28] such as conical or rectangular, but they still do not concern research into the fluid bed for further types of geometries, which are discussed in this study.

Next, there are approaches focusing on prediction of pressure drop in the bed of spherical particles [3;4] and particles of bed shapes different from spherical [3], pressure drop in the bed of a conical [23] or prismatic cell [20], but also various shapes of distributors in flat and triangular arrangement [24]. The research, however, constantly focuses on cells with a cylindrical or conical shape, which are not tackled in this essay. The studies further consider pressure drop in the bed in relation to the wall [5;6;8;9;10;12;18;21]. And also various books dealing with Ergun equation [25] and its modification by Wen and Yu equations [13] as well as modification of Ergun equation [25] for fluid bed composed of non-spherical particles [14]. Great interest is paid to the formation of bubbles and their numerical simulation [16]. Formation of bubbles is discussed in reference [19], which performs a numerical simulation of bubble formation for variously arranged grooves of the distributor. A lot of literature [21;22;24] deals with research into air distribution and a filter, which is a component of the fluidizing and transport equipment [26].
2. EXPERIMENTAL

By measurement of pressure drop in the bed of the experimental device (Fig. 1), a pressure peak usually occurs when the air through the distributor is inlet to bed with glass particles because of the resistance of the material layer to a sudden pressurization of air in the bed. This pressure peak is caused by airflow acting on the layer bed of particles. Airflow is not strong enough to goes through the pores among particles and tries to lift the entire bed volume.

The air flows between the particles as long as either the bindings among particles are not broken out. In the case, it is possible to achieve the superficial velocity of the fluid when the resistance force is in balance with the weight of the particles reduced by buoyancy, or air flows among the particles so long until it passes all the interparticle space and bed layers. In other words, this is the case the threshold of fluidization.

Once crossing the mentioned threshold, an irregular layer of fluidization carried out. The irregular fluid layer is characterized by varying the concentration of particles or voids in the layer. This irregular fluid layer shows a pressure drop, which is further processed statistically.

By the measurement procedure, firstly, a steady pressure for a bed batch of 100 g of TiO$_2$ (Table 2) is determined. For every bed batch inserted into each of the fluidizing cells characterized by different cross-section airflow of speed of 0.093 m/s has acted.

![Diagram](image1)

**Fig. 1. Vertical Different-Shaped Fluidized Beds by bed porosity research of fluidization of C group material**

3. DISTRIBUTOR

The air distributor is a fabric made of fine polyester fibres $d_i=40\mu m$ in diameter and mesh size $w=36\mu m$ (Fig. 2, Table 1). The theoretical volume of the air passing through the netting $V_{th}$ (1) is given by the thickness of the fabric $d_k$ measured by a testing method DIN 53 855 and by the openness degree of the netting $a_0$ (2).
\[ V_{th} = \frac{a_o \cdot d_{th}}{100} \]  

(1)

The openness degree of the netting is a proportional amount of all eyes related to the total area of the fabric.

\[ a_o = \frac{w^2 \cdot 100}{(w + d_t)^2} \]  

(2)

Fig. 2. A photo taken by SEM, illustrating the fabric representing an air distributor.

4. **PRESSURE DROPS OF THE BED**

The pressure drop of the fluidized bed is usually expressed by the known relation:

\[ \Delta P = H \cdot (\rho_s - \rho_g) \cdot (1 - \varepsilon) \cdot g \]  

(3)

Where \( H \) represents the height of the bed on the threshold of fluidization, \( \rho_s \) is the density of the fluidizing material, \( \rho_g \) is the gas density and \( \varepsilon \) is the voids content. The mentioned relation is used for a bed the cross-section of which is circular, thus it concerns an equation related to a cylindrical bed. As illustrated below, the drop of pressure for identical thickness of the bed differs in the various shapes of the bed cross-section even if the size of the cross-section is maintained.

Table 1

<table>
<thead>
<tr>
<th>Characteristic sizes of the distributor</th>
<th>( d_t ) [( \mu m )]</th>
<th>( a_o ) [%]</th>
<th>( V_{in} ) [cm(^3)/m(^2)]</th>
<th>( w ) [( \mu m )]</th>
<th>( d_{th} ) [( \mu m )]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre diameter</td>
<td>40</td>
<td>22,43</td>
<td>13,45</td>
<td>36</td>
<td>60</td>
</tr>
<tr>
<td>Mesh openness degree</td>
<td></td>
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<tr>
<td>Volume of passing air</td>
<td></td>
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<tr>
<td>Mesh size</td>
<td></td>
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</tr>
<tr>
<td>Fabric thickness</td>
<td></td>
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</table>
The Ergun equation [25] for the pressure drop looks as follows:

$$\frac{\Delta P}{L} = 150 \cdot \left(1 - \varepsilon\right)^2 \cdot \frac{\eta U}{d_p^2} + 1.75 \cdot \frac{(1 - \varepsilon)}{\varepsilon^3} \cdot \rho_g U^2$$  \hspace{1cm} (4)

where $U$ represents the extra-layer airflow speed, $d_p$ is the medium size of grain, $\varepsilon$ is the voids content, $\rho_g$ the gas density and $\eta$ is viscosity of the bearing medium, in this case the air.

### 5. EVALUATION OF PRESSURE DROPS

The measured pressure drops were statistically evaluated and cells that showed the lowest and the highest pressure drops were determined (Fig. 3). As already mentioned, average values of pressure drops were detected and pressure drops for the 100-500 g thickness were calculated into these average values. The 100g bed shows no pressure fluctuations; the pressure drops have a stable value and the variation range reaches the maximum value of 0.005 Pa. The most stable pressure drops for a 100g dose are detected in a pentagonal and hexagonal cross-section of the fluidization cell. The relative frequency of the registered pressure drops for all 100g dose cells and the airflow speed of 0.093 m/s moves within 0.45 and 0.82. It shows that the detected average values, or the most frequent values (modus) move within 45 - 90 % of the measured values. The relative frequency of the values drops with the rising speed of the fluid air. The reduced frequency of the values is caused by pressure fluctuations of the bed layer, because with the rising airflow speed, the height of the bed also increases; the increased height of the bed results in dropping (falling) of the particles from a greater height, thus a having higher kinetic energy and causing larger fluctuation of the measured pressure drop. Consequently, the higher the thickness of the bed, the higher the pressure fluctuations and the greater range of values occurs, which can already be observed in a 200g dose. Here, the variation range is perceptible even at the lowest airflows, because at the airflow speed of 0.093 m/s, a variation range can be observed for example in a pentagonal cross-section of the fluidization cell where it reaches up to 0.012 Pa; the relative frequency for the airflow speed of 0.093 m/s does not exceed 0.7. The highest variation range is 0.015 Pa for the highest airflow speed of 0.372 m/s, observed in a square cross-section of the fluidization cell. The rise of pressure drop for a 300g dose is specific; the minimum and maximum fluctuation moves within a variation range of 0.031 Pa at the airflow speed of 0.372 m/s; for a 400g dose, this range is 0.034 Pa at the highest airflow speed, while for a 500g dose it reaches 0.055 Pa. It means that with the rising airflow speed and the increased doses of the bed, the pressure fluctuations
increase, causing a so-called piston fluidization. In other words, a plug of material develops in the cell, rises up until the bonds between the particles of the material and the wall of the cell become mutually disrupted.

**Fig. 3.** Average values of pressure drop for the plenum and the bed.

**Conclusion**

When fluidized particulate material of powder matter in nature (i.e. below 100 microns) of cohesive character - TiO₂, it is possible to observe the behavior of different materials at different fluidized in different sections fluidizing bed. In the case of TiO₂ is solely to four types of behavior (bed-bubbling, tunneling, piston flow, belching). Making tunneling occurs when the air flow creates a tunnel between the forming of clusters of particles; this phenomenon occurs particularly in the lower parts of the bed, since the upper portion of the bed the pressure on the bottom of clusters of particles. This phenomenon can be observed at higher altitudes of the fluidized bed and at lower speeds the air flow.

Fig. 3 illustrates that greatest tendency to tunneling effect with a fluidized cell of a triangular cross-section (Fig. 1); an air flows in the inside corners of the fluidized cell, whereas the visible tunnels are formed at the edges. Another observable phenomenon of the same type, i.e. creation of tunnels is observed to the fluidized cell of a regular hexagon, which is characterized by high concentrations of making tunnels in the fluidization regime. The formation of tunnels in fluidization regime affects the natural rate of consolidation (compaction).

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