Comparison of granular and open cell foam filter models by numerical simulation

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Abstract. A comparison of granular and highly porous mesh filter models is based on the results of numerical simulation. We created models filters with an equal diameter of granules and cells. In order to avoid calculation errors associated with a random arrangement of cells, we averaged the results for five geometries. The values of the pressure drop obtained based on numerical simulation correlate well with the data obtained by the experimental Ergun equation. We calculated particle deposition efficiency and filter quality factor for models with equal porosity, and pressure drop value. Additionally, the filter quality factor for geometries with equal particle deposition efficiency was estimated. The calculation results show that it is advisable to compare the filter models by the value of the differential pressure.

1. Introduction
Today, filtration plays an important role in human activities, both in everyday life and in production [1-2]. Granular filters are widely used. Compared to other types of filters, they have low hydrodynamic resistance and a large surface area. This type of filter in domestic conditions is most often used for drinking water purification [3-5]. In production, granular filters are used to clean hot gases; this may be due to the chemical or thermal activity of the substances being cleaned. Also, thanks to the materials used in the manufacture of granules, researchers observe corrosion resistance, which justifies the advantage of their use in chemical plants [6]. There are several types of granular filters: these are filters with moving, fixed, and fluidized beds. Filtration in them is carried out by various mechanisms, such as particle capture, inertial deposition, diffusion, gravitational, and electrostatic attraction. The most common among granular filters are fixed bed filters.

Many factors influence the efficiency of particle deposition in filters. However, such parameters as pressure drop, flow rate, size, type of granules, and method of packing [6–10] make the most significant contribution. There is also a method of packaging granules, which involves the use of several layers of granules with different diameters. Such a system assumes that at first the filtered medium enters a layer with large granules, which has a low pressure drop, but cannot catch small particles, followed by a layer with small granules, which filters fine particles thoroughly [11].

Open cell foam filters, which are a structure consisting of mutually intersecting cells that are randomly distributed in the volume, can become a replacement for granular filters. The parameters that make the main contribution to the change in geometry are the diameter of the cells and the distance between them. Here, in contrast to granular filters, we can change the filter parameters as necessary for a specific task [12]. Porous media have a developed surface area due to which they can
be used as matrices for applying chemical catalysts, or as radiators for heat removal in microelectronics, where it is not possible to install massive cooling systems. Since porous structures have a large margin of safety concerning their weight, these filters use in aerospace activities and the automotive industry [13].

Until recently, studies of porous media were difficult, and researchers used mainly averaged flow models. For example, according to the Darcy averaged model, the pressure drop per unit length is proportional to the product of the fluid velocity and dynamic viscosity and is inversely proportional to permeability. However, technological progress does not stand still, and today we can use the direct numerical simulation method, which takes into account all the features of the geometry and gives the most accurate and correlated with experimental data results. The main problem of this method is the creation of a geometric model that matches reality. There are many ways to create models; some use matrices consisting of rectangular prisms [14], some use ordered models consisting of tetra-decahedra inside which a cell is randomly created. In some studies, the method of magnetic resonance imaging was used to study the flow of fluid inside a porous medium [15, 16]. A comparison of these two types of filters has become our goal in this work.

2. Problem formulation and methods

The choice of filter depends on the parameters of the technological cycle. Most often, an increase in the efficiency of particle deposition entails an increase in the resistance of the medium. Our goal was to compare the models of granular and open cell foam filters with equal values of geometric and physical parameters. Since it is not possible to change the porosity of the granular filter, a model of a granular filter with a granule diameter of 6 mm was taken as the basis, the porosity of which is $\varepsilon = 0.44$. The set of models of highly porous cellular filters includes models with equal porosity of the medium, differential pressure, and particle deposition efficiency. Table 1 shows the parameters of the models. The filter models used for numerical calculations are tubes with a porous insert. A set of spheres arranged randomly in space forms the porous region in the case of a granular filter and an inverse matrix of intersecting spheres for an open cell foam material. The thickness of the filter part is equal to the length of the nozzles and is 40 mm; the diameter of the tubes is also equal to 40 mm.

We created five filter models to eliminate errors in numerical calculations (due to the random arrangement of cells and granules in space), the results for which were averaged among themselves.

| Filter                | $d_c$, mm | $\varepsilon$ | $\Delta p$, Pa |
|----------------------|-----------|---------------|----------------|
| Granular             | 6         | 0.44          | 140            |
| Open cell foam – 1   | 6         | 0.44          | 4574           |
| Open cell foam – 2   | 6         | 0.7           | 140            |
| Open cell foam – 3   | 6         | 0.8           | 50             |

3. Results

We carried out the hydrodynamic calculations are carried out in the ANSYS Fluent software package (v. 19.0) based on the solution of the Navier-Stokes equations by the finite volume method. It is essential to compare the results of numerical modeling with experimental data to assess the correctness of the calculation. The authors of [17] used the Ergun equation (2) to calculate the pressure drop in the granular layer. Equation (1) determines the specific surface area of the packed granules

$$S_{v,\text{packing}} = 6 \frac{(1 - \varepsilon_{\text{packing}})}{d_p}$$

(1)
where $\varepsilon_{\text{packing}}$ is the porosity of granular bed, $d_p$ is the diameter of the granule.

$$\frac{\Delta p}{L} = 4.17 \left(\frac{S_{v,\text{packing}}}{\varepsilon_{\text{packing}}}\right)^2 \mu w + 0.292 \left(\frac{S_{v,\text{packing}}}{\varepsilon_{\text{packing}}}\right) \rho w^2,$$

where $S_{v,\text{packing}}$ is specific surface area, $\mu$ is the dynamic coefficient of viscosity of a liquid or gas that flows through a filter, $w$ is the flow velocity, $\rho$ is density of the gas or liquid.

![Figure 1](image-url)  
**Figure 1.** The dependence of the pressure drop on the velocity of the flow rate.

The calculation results show that, with equal porosity of the medium, the curve of the deposition efficiency depending on the particle diameter is higher for the case of an open cell foam filter-1 (figure 2). With an equal value of the pressure drop, the efficiency of particle deposition in the case of an open cell foam filter-2 is higher than in the case of a granular filter for low-inertia particles (figure 3). The porosity of the mesh filter, in this case, was 0.7, while the granular filter has a fixed porosity of 0.44, the pressure drop in this case for both filters is 140 Pa. An empirical method yielded a porous structure with a particle deposition efficiency equal to that of a granular filter (figure 4). The porosity parameter of the open cell foam filter-3 for this case was 0.8, and the pressure drop was 50 Pa.
Figure 2. The efficiency of the deposition of particles of open cell foam and granular filters with equal porosity of the medium $\varepsilon = 0.44$.

Figure 3. The efficiency of the particle deposition of open cell foam and granular filters with the equal pressure drop $\Delta p = 140$ Pa.

Figure 4. Closest particle deposition efficiency for granular and open cell foam filter models.
An important characteristic when choosing a filter is the filter quality factor, which is the ratio of the particle deposition efficiency to the differential pressure value. Since an open cell foam filter with a porosity of 0.44 has an extremely high pressure drop, it is not advisable to build a graph for this case. Figure 5 shows a comparison of quality factors for the rest of the filter models.

![Figure 5. Quality factor graphs for porous and granular filters.](image)

We can conclude that an open cell foam filter with equal particle deposition efficiency has a maximum value of the quality factor. The curve of the change in the filter quality factor versus the particle diameter for the case of an open cell foam filter with an equal pressure drop is higher than the curve for a granular filter.

4. Conclusion
The model of an open cell foam filter, which provides a pressure drop equal to the pressure drop in a granular filter, has a deposition efficiency higher for non-inertial particles. When compared in terms of the quality factor, a highly porous cellular material with a deposition efficiency equal to granular proves to be the best. It is much more correct to compare filters of various types by the value of the differential pressure than by the value of the porosity of the medium.

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