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Determination of the effective thickness of an open cell foam filter using numerical simulation

O V Soloveva, S A Solovev, R R Yafizov and R R Khusainov

Institute of Heat Power Engineering, Kazan State Power Engineering University, 51, Krasnoselskaja Street, Kazan, 420066, Russia

E-mail: solovyeva.ov@kgeu.ru

Abstract. Numerical simulation of the aerosol flow in a tube with a porous insert (which is a filter model) of the fixed porosity of $\varepsilon = 0.6$ and with different cell diameters was performed. The method of constructing the geometry of the open cell foam material is described. Images of the trajectories of inertia and low-inertia particles inside the porous medium are presented. Figures of changes in the efficiency of particle deposition are presented for a typical filter pore diameter of d_c = 4 mm, d_c = 5 mm and d_c = 6 mm for different thicknesses of the porous insert. It is revealed that the effective thickness of the porous insert, with which the value of the deposition efficiency of media with different pore diameters does not change, is 4 cm. Recommendations are given on the choice of filtering open cell foam materials with specified parameters.

1. Introduction

In recent years, new materials have been increasingly used to improve the efficiency of equipment and reduce economic costs. New materials often reduce the volume of technical devices. Open cell foam materials are new materials and have better mechanical, thermal, acoustic properties, as well as a developed surface area and low weight. The complex internal geometry complicates the numerical simulation of processes in porous media because it requires considerable time and computational resources, and therefore most of the published works reflect experimental studies [1,2].

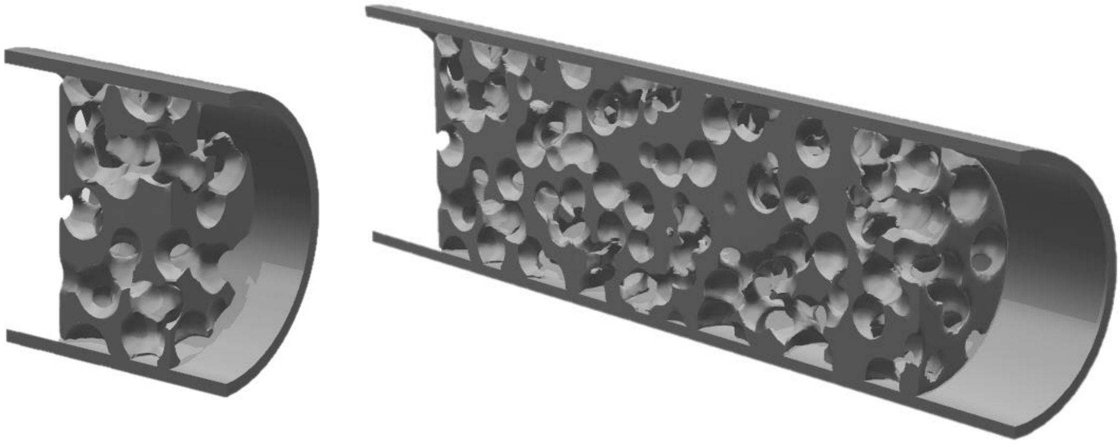
Detailed numerical simulation provides an opportunity to explore the processes when the experiment is not possible, and "to look" inside the porous medium since the smallest geometric features are taken into account in the calculation. However, problems with open cell foam materials are multi-parameter. This is due to the fact that in solving heat transfer problems using porous media [3,4], important parameters affecting the process are the porosity of the medium, pore diameter, thickness of media, etc. This is true for catalytic processes using a porous matrix with a supported catalyst [5-7] for filtration problems [8-10]. In paper [11], the effect of the thickness of an open cell foam material on the heat transfer properties and the pressure drop value in the vertical channel was investigated. This paper is devoted to the study of the aerosol flow in open cell foam material with different parameters and the determination of the effective thickness of the porous insert.

2. Problem formulation and numerical simulation

The purpose of the article is to determine the thickness of a porous material (model of an open cell foam filter), in which the cell size does not affect the efficiency of particle deposition. In [8-10], it has shown that the pore diameter, the diameter of the porous medium section (diameter of the filtering fiber), and the shape of the cells have a significant effect on the efficiency of particle deposition due to changes in hydrodynamics airflow because of the complex material structure.

2.1. Geometry creation
To study the effect of the thickness of an open cell foam filter on the efficiency of particle deposition for three variants of the cell diameter: d_c = 4 mm, d_c = 5 mm and d_c = 6 mm, of fixed porosity of the medium $\varepsilon = 0.6$, 4 geometries were constructed, representing tubes with a diameter of 2 cm with a porous insert of various thicknesses. A feature of the calculation is that the geometry of the porous medium is not rebuilt, but is cut off from the original structure in order to preserve the original arrangement of the pore channels at each new thickness. Thus, a model of a porous filter was initially created, which is a tube with a centrally located insert of porous medium with $L = 4$ cm. The length of the hollow nozzles on each side is 4 cm. It allows minimizing the effect of boundaries on the calculation results. Each subsequent geometry was constructed by cutting off 1 cm from the porous insert with preserving nozzles. Examples of the geometries are presented in Figure 1.

The geometry of open cell foam material was built in the free software Blender. The algorithm for creating a porous medium involves several steps. According to the coordinates, a cylindrical area is constructed that will contain a porous medium. The random number generator sets the coordinates of points in the specified area. The specified points will be the centers of the spheres needed to create a porous medium. By adjusting the distance between mutually intersecting spheres and the diameters of the spheres, we obtain a porous medium with the desired characteristics. The resulting geometry is imported into the ANSYS software package (v. 19.0), followed by preprocessing and creating a grid partition, which ranges from 7 to 20 million cells, depending on the complexity of the geometry. The quality of the grid partitioning is checked using calculations with a different number of grid elements.



(a) (b)

Figure 1. Geometric models of a porous medium with different length of porous insert: (a) $L = 1$ cm, (b) $L = 4$ cm.

2.2. Numerical simulation of the gas flow with aerosol particles.
Detailed numerical simulation of the gas flow containing suspended particles was carried out in the ANSYS Fluent software package in the viscous incompressible gas approximation, in which the Navier-Stokes equations were solved in each cell of the computational domain. The equations of particle motion were calculated in the given gas velocity field. The use of a fine mesh made it possible to set a laminar flow model in the entire selected range of gas flow velocities, since such discretization allowed tracking even small vortices that form inside the pores of the filter material. For calculations, it is necessary to use the geometry of the interstitial space, since the foam of filter material in the calculation is perceived as a "wall", and the flow of the gas suspension occurs inside the pores. The geometry of the computational domain is presented in Figure 2.

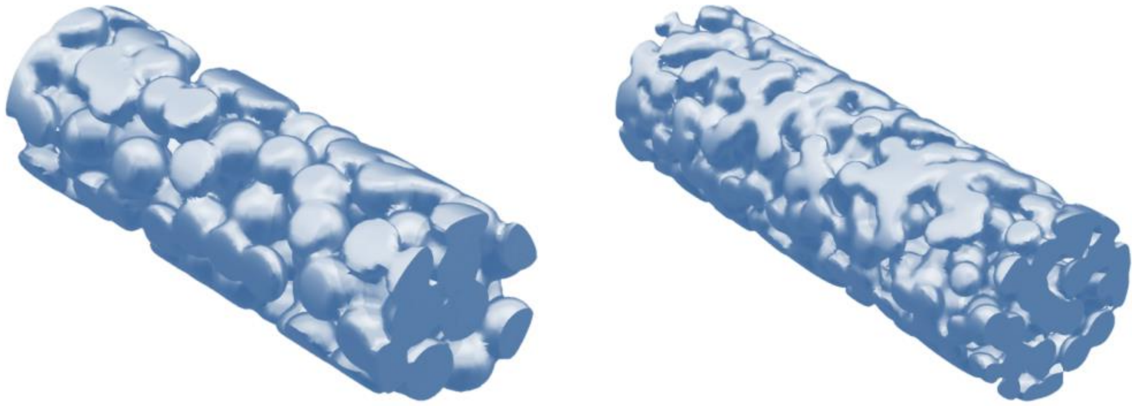


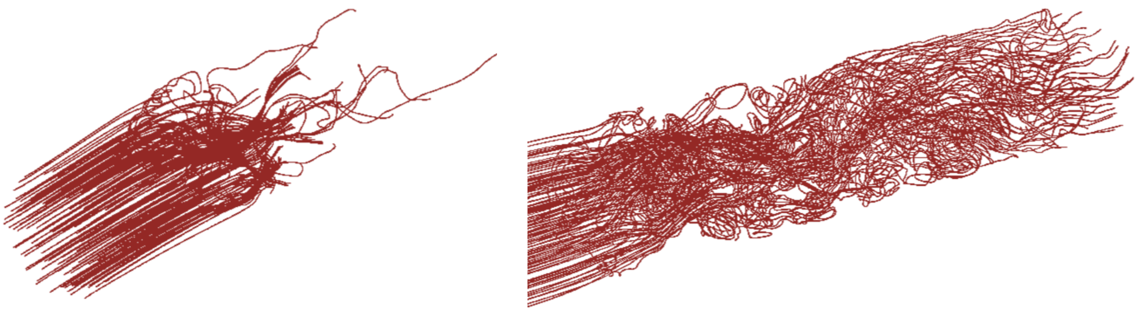
Figure 2. The part of the computational domain containing the insert of the porous medium.

So, the computational domain was a tube with a porous insert of various thicknesses. At the entrance to the computational domain, the mass flow rate of air flow $Q = 0.0015$ m^3/s ("mass flow inlet") was set, the output was atmospheric pressure ("pressure outlet"), the remaining boundaries were automatically set as a wall ("wall"). The residual value in the calculation was 10^{-9}.

3. Results and discussion

3.1. Calculation of the efficiency of particle deposition

The pictures of the particle trajectories in the tube with a fixed flow rate are shown in Figure 3. Figure 3a demonstrates the deposition of inertial particles, it can be seen that they settle even at the initial filter thickness. Low-inertia particles follow the gas streamlines, which inside the porous region represent a system of multiple small vortexes in the cells of the medium, and do not settle in the porous zone (Figure 3b).



(a) (b)

Figure 3. The trajectories of particles in the tube with the porous insert with $L = 4$ cm and the diameter of cells of $d_c = 6$ mm: (a) $d_p = 3$ μm, (b) $d_p = 0.01$ μm.

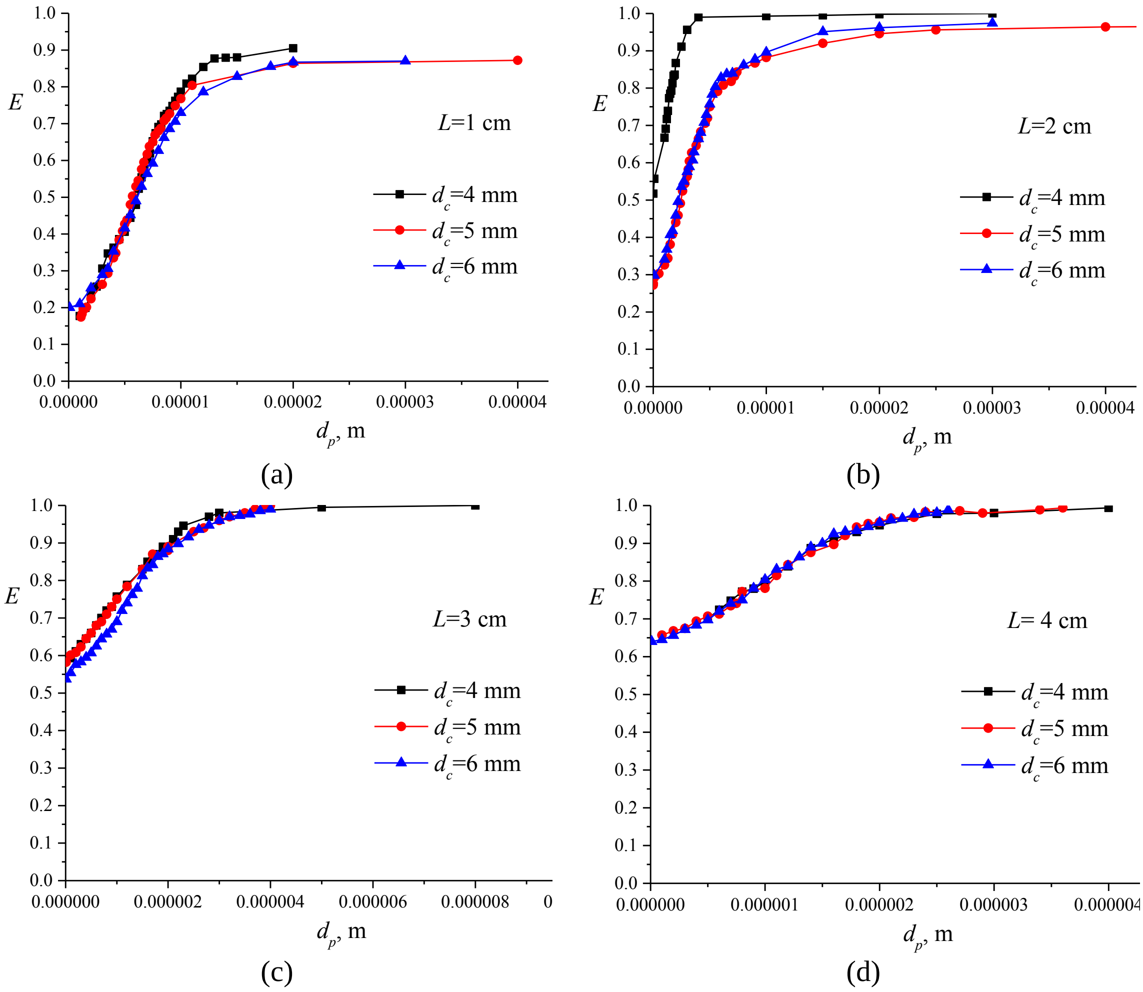


Figure 4. Dependences of the particle deposition efficiency on the particle diameter for three cell diameters and different thickness of the porous insert: (a) L = 1 cm, (b) L = 2 cm, (c) L = 3 cm, (d) L = 4 cm.

Graphs of the particle deposition efficiency for the four thicknesses of the porous insert are presented depending on the particle diameter. The graphs show that the influence of the pore diameter of the filter medium is maximal for the porous inserts of the smallest thickness, even for a thickness of $L=3$ cm. The differences in efficiencies become insignificant, and for $L=4$ cm, the efficiency curves match. The thickness of the porous insert $L=4$ cm for the specified parameters is the effective thickness of the filter. Also, the presented results allow us to conclude that for the use of porous materials in compact technical devices, where the smallest filter thickness is a priority, one should use open cell foam filters with the smallest cell diameter to achieve the highest efficiency of particle deposition. If the technical capabilities allow the use of filter with the thickness of 2 cm and the choice is between using a medium with a pore diameter of 5 or 6 cm, preference should be given to the material with the largest cell diameter since the differences in the values of deposition efficiency are minimal, and the resistance of the medium in the filter with the largest cell diameter will be smaller. The problem of investigating the efficiency of particle deposition in open cell foam material is multi-parametric since, in addition to the pore diameter and length of the material, the value of the porosity of the medium makes a large contribution to the change in the deposition efficiency. The solution to this multi-parameter problem will be the goal of our further research.

4. Conclusion

Studies of the aerosol flow in tubes with porous inserts, which are models of an open cell foam filter, have been carried out. The pictures of inertia and low-inertial particle trajectories inside the porous medium are shown. According to the calculated trajectories, the efficiency of particle deposition is determined. It is revealed that for three media with fixed porosity $\varepsilon = 0.6$, but with different pore diameters $d_c = 4$ mm, $d_c = 5$ mm and $d_c = 6$ mm, the effective thickness, on which the particle deposition efficiency curves are the same, is $L = 4$ cm. For media with a small porous insert thickness, it is preferable to use the material with the smallest cell diameter. Determining the efficiency of particle deposition is a multi-parameter problem and should include not only the cell diameter and thickness of the porous insert, but also the porosity of the medium and other parameters. This is of interest to us and necessitates our further study of the aerosol flow in open cell foam materials.

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