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Improving the efficiency of particle deposition on the filter fiber through its modification

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Abstract. In this work, we performed a numerical study of the parameters of a fiber filter that make the greatest contribution to the efficiency of particle deposition, using the example of a single fiber. The mechanism of inertial particle deposition is considered. The aerosol motion was numerically simulated in the ANSYS Fluent software package. The particle deposition efficiency was calculated for a single solid and porous fiber without a protrusion, with one protrusion and five protrusions. Based on the data obtained, the dependences of the particle deposition efficiency for a single fiber are graphically presented. A new method is proposed for increasing filter efficiency by creating modified fibers.

1. Introduction

The main direction of research in the field of gas suspension filtration is the study of the effectiveness of the mechanisms for capturing suspended particles. The sedimentation of particles on the elements of the porous structure is determined by the size of the particles and the flow rate of the carrier medium. The fundamental mechanisms for removing aerosol particles during filtration are diffusion, engagement, inertial and gravitational deposition, and electrostatic attraction. A theoretical analysis of the main mechanisms of sedimentation of suspended particles in aerosol filters is given in [1-3]. One of the most studied areas is the inertial deposition of particles in porous media [4-6]. The main parameter affecting inertial deposition is the Stokes number; therefore, many studies have studied the dependence of the inertial deposition efficiency of suspended particles on the Stokes number [7-8]. For coarse aerosols containing particles with diameters of more than a few microns, inertial collision and gravitational deposition are the main reasons for the settling of particles. For nanoparticles, the main deposition mechanism is diffusion. Fiber filters can hold medium-sized particles due to the meshing effect. Particles with diameters in the micron range are characterized by a weak manifestation of inertia and diffusion deposition. An electrostatic precipitation method is commonly used to capture such particles. In addition to inertial deposition, an important role is played by the particle engagement effect, in which contact with an obstacle is determined by the geometric size of the particle. It is not required that the trajectory of the particle center intersect the obstacle surface [9-14].

In the process of filter operation and particle capture, a layer of deposited particles is formed on the surface of the fibers, which at the initial stage is a dendritic structure. With further settling of the particles, the layer becomes denser and tends to a dense porous package. A change in the shape of the trapping element of the filter affects the hydrodynamics of the flow between the fibers and the deposition of particles [15]. Numerical simulation of the formation of dendrites on fibers was carried out in [16–

19]. A study of the deposition of submicron particles in a filter model with fibers coated with a porous layer was carried out by V. Kirsh. [20].

2. Problem formulation

In this work, we performed a numerical simulation of the deposition of particles on solid and porous single filter fibers. The fiber diameter is $d = 500\mu\text{m}$, and for a porous fiber, the permeability is $k = 2 \cdot 10^{10}$ 1/m, the flow regime is laminar. Since the fiber is symmetric about the *Ox* axis, in all cases, for numerical simulation, we used the geometry representing half the region, which reduces the estimated time. In order to increase the efficiency of particle deposition by the filter fiber, we decided to add protrusions on the fibers and compare the results of numerical simulations for fibers with protrusions of different lengths. The fiber on which one protrusion was located we designated as *h*. The value of *h* took the values: 0 mm; 0.05 mm; 0.1 mm; 0.15 mm; 0.2 mm; 0.25 mm. The protrusion *h* increased until it became equal to the radius of the fiber. A fiber with more than one protrusion, that is, their number was five, was denoted as *s*. For *s*, the same projection sizes were taken as for *h*: 0 mm; 0.05 mm; 0.1 mm; 0.15 mm; 0.2 mm; 0.25 mm.

The number of grid elements in the calculation ranged from 300 to 800 thousand cells. Parametric calculations were performed to assess the quality of the mesh partition. The indicated number of grid elements turned out to be sufficient to obtain high calculation accuracy. For each calculation, the number of iterations was 2000, which ensures the convergence of the calculation with a residual value of 10^{12}. To exclude the influence of boundaries on the flow field, the distance from the fiber to the boundaries was 30 times larger than the fiber diameter. The location of the protrusions is shown in figure 1.

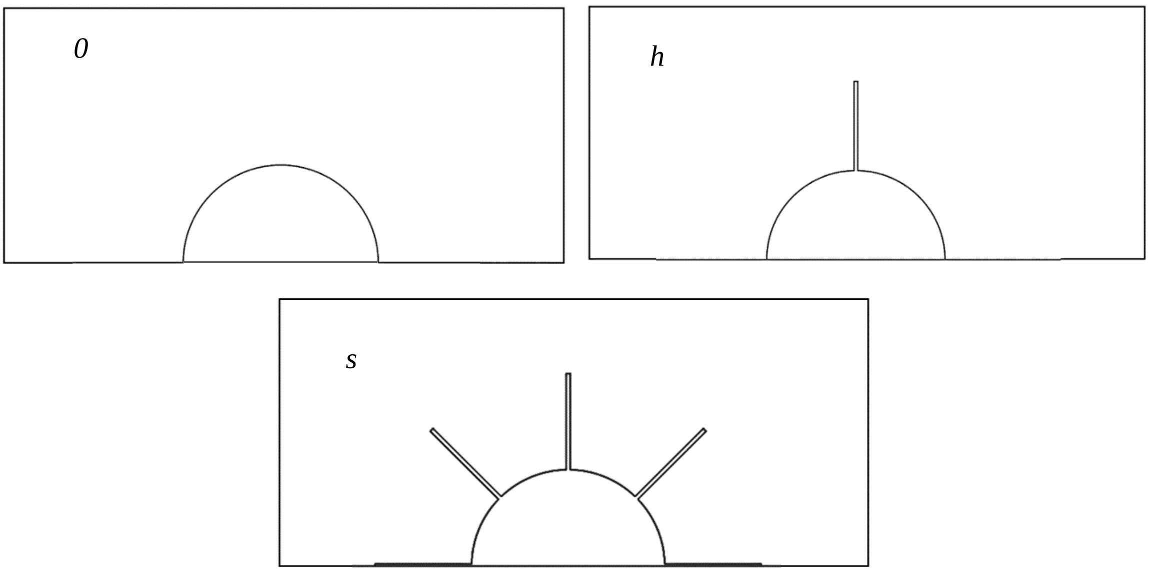

Figure 1. The scheme of the protrusion location on the filter fiber: *0* - fiber without protrusion, *h* - fiber with one protrusion, *s* - fiber with five protrusions.

3. Results

Totally, we conducted 22 computational experiments. The number of starting particles is *n*=1000. All particles started from the starting point *x*=0, and along the *Oy* axis from *y*=0 to *y*=0.00025 m. The results of calculations of the particle deposition efficiency on the fiber are presented in the form of curves (figures 1-6).

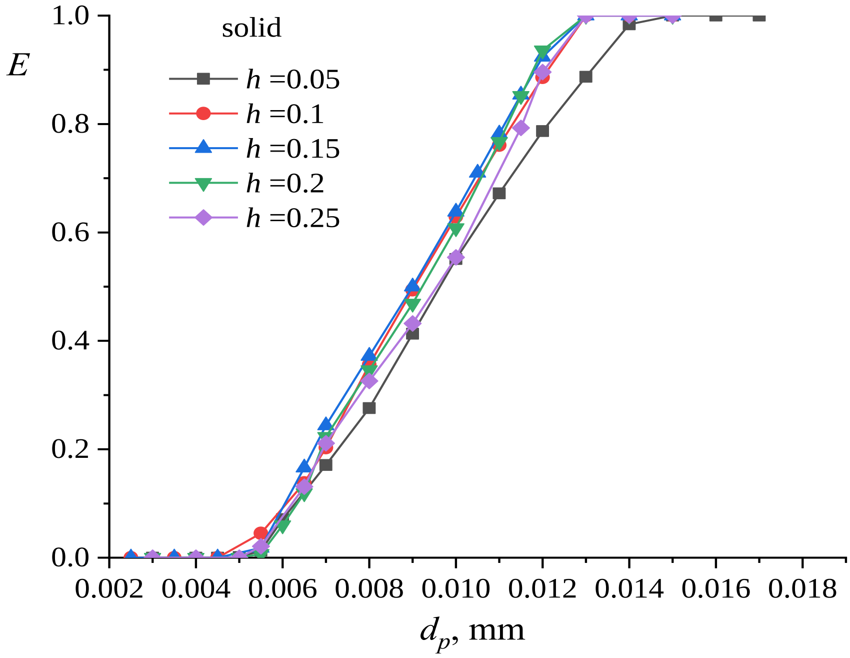

Figure 2. The efficiency of particle deposition on a single solid fiber for various *h*.

Numerical simulations have demonstrated that porous fiber captures particles with greater efficiency than a solid fiber. We will consider how particles behave in the case of a solid fiber for *h* and *s*. Figure 1 shows that in the case of a single solid fiber, the particle deposition efficiency increases with the addition of a protrusion on it, but starting from *h*=0.05 mm, the deposition efficiency does not practically change but increases to a protrusion value of *h*=0.15 mm. Further, efficiency begins to decline. Thus, a fiber with a protrusion of *h*=0.15 mm shows the highest efficiency. We can conclude that in this case of solid fiber *h*, increasing the protrusion size by more than 0.15 mm is not advisable. The decrease in the deposition efficiency for the protrusion of more than 0.15 mm we explain by the hydrodynamic flow: particles of small diameter follow the streamlines around the protrusion.

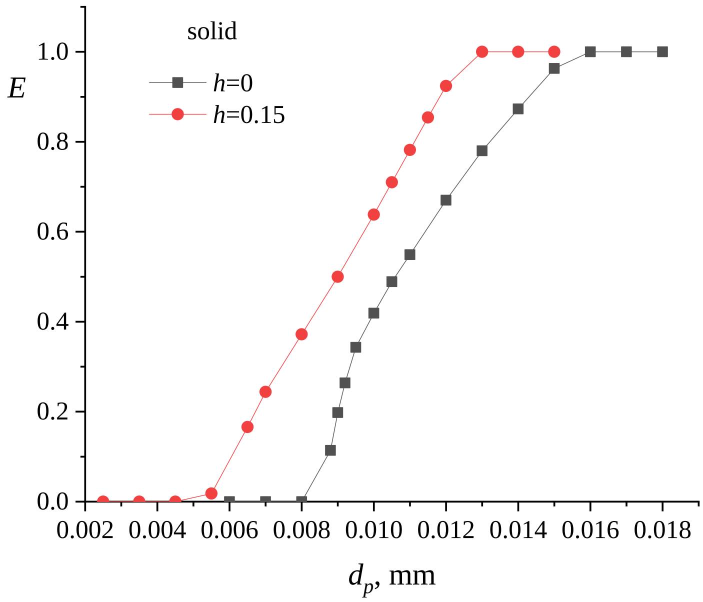

Figure 3. The efficiency of particle deposition on a single solid fiber for *h* without a protrusion and with a protrusion of 0.15 mm.

Figure 2 demonstrates that the addition of a protrusion increases the deposition efficiency, but this makes sense up to values of *h*=0.15 mm.

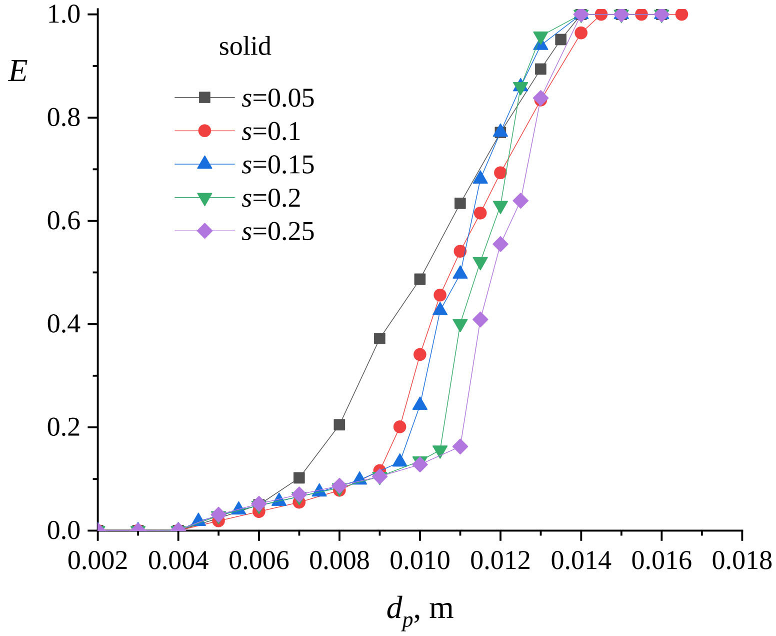

Figure 4. The efficiency of particle deposition on a single solid fiber for various *s*.

Figure 3 demonstrates the dependence of particle deposition efficiency for solid fiber *s* with five protrusions. We see in the figure that with the growth of the protrusion number *s*, the deposition efficiency of particles decreases. Thus, the greatest deposition efficiency is observed for *s*=0.05 mm, and the smallest at *s*=0.25 mm. This we explain by the fact that at the base of the protrusions zones of reduced pressure are created, and the particles follow the streamlines.

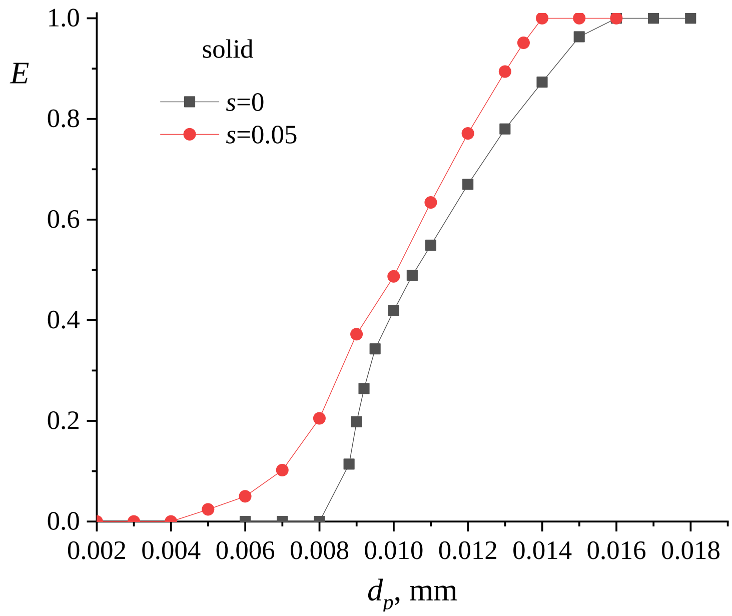

Figure 5. The efficiency of particle deposition on a single solid fiber for two various *s* – without a protrusion and with a protrusion of 0.05 mm.

Figure 4 shows that the deposition efficiency of fiber without a protrusion is lower than with a protrusion, but it is not advisable to increase it by more than 0.05 mm.

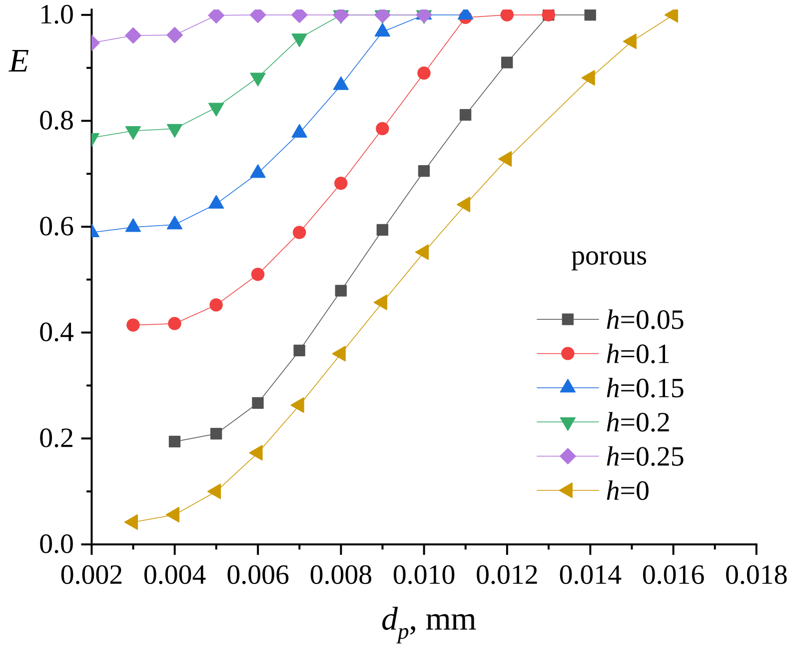

Figure 6. The efficiency of particle deposition on a single porous fiber for various *h*.

Figure 5 shows that if fiber *h* is porous, then the deposition efficiency of particles on the fiber depends on the size of the protrusion – the larger size of the protrusion provides the higher value of the deposition efficiency. So, the best capture of particles for this case is observed at *h*=0.25 mm, and the least at *h*=0.05 mm.

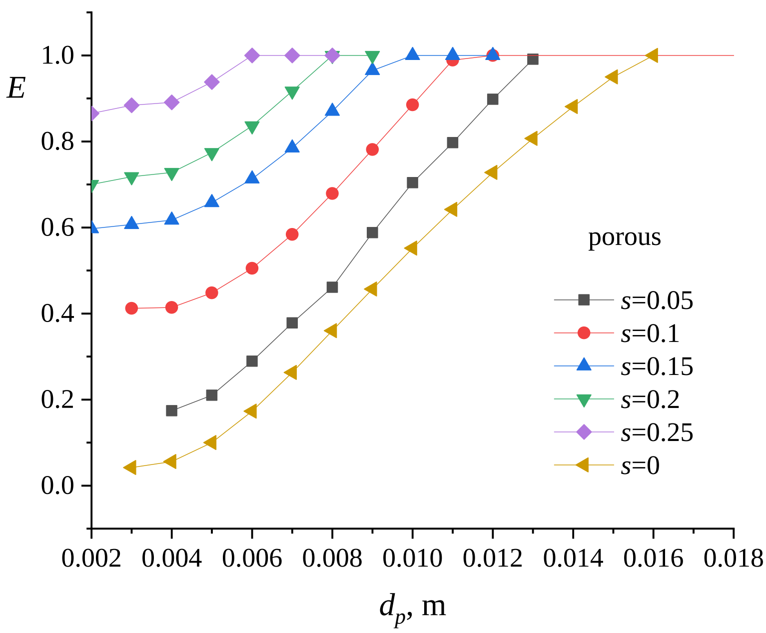

Figure 7. The efficiency of particle deposition on a single porous fiber for various *s*.

Figure 7 shows the same tendency as in the case of a single porous fiber *h*. That is, with the size of the protrusions increasing, the deposition efficiency of the particles on the porous fiber *s* increases. The maximum efficiency of particle deposition on a porous fiber is observed for *s*=0.25 mm.

4. Conclusion

We calculated the aerosol flow for a single solid and a single porous fiber of various geometries (with one and five protrusions). Based on the data obtained, curves of the particle deposition efficiency were plotted for two types of fiber. As a result of the work, it was revealed that the porous fiber *s*, having five protrusions 0.25 mm long, has the highest particle deposition efficiency. The results of the numerical calculation are consistent with the laws of hydrodynamics. These studies contribute to the development of gas mechanics in fiber filters and can underlie the creation of fiber filters with improved properties.

Acknowledgments

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