Evaluation of the efficiency of prefilter models using numerical simulation

O V Soloveva, S A Solovev and R R Khusainov
Kazan State Power Engineering University, Krasnoselskaja st. 51, Kazan, 420066, Russia
E-mail: solovyeva.ov@kgeu.ru

Abstract. In this work, we estimate the contribution of the prefilter to the operation of the filter-prefilter system and propose two models of prefilters with curved plates. Numerical calculations of the aerosol flow in various combinations of filters and prefilters are carried out. We calculate the particle deposition efficiency of different filter models. The prefilter in the case of five and ten plates increases the limit of deposition efficiency for open cell foam material. A prefilter with five curved plates with parameters \( l=0.33 \) mm and \( h=4 \) mm is more preferably in comparison with ten plates with parameters \( l=0.33 \) mm and \( h=2 \) mm.

1. Introduction
Stricter environmental and safety standards have led to increased filter production. We can also observe the intensive use of membranes in the field of air filtration over the past two decades [1].

Recently, several modern technologies have been developed for the treatment of pollutants that enter the natural ecosystem as a result of human activity [2]. Among them, physical, chemical, or biological reduction technologies, solvent extraction, membrane filtration, coagulation, adsorption, chemical deposition, and reverse osmosis are widely used. Adsorption seems to be a promising technology because it is highly efficient and widely available. The efficiency of numerous adsorbates was investigated in relation to the removal of dyes from wastewater in [3-10).

Environmental problems caused by exhaust emissions from diesel vehicles have become a matter of grave concern. The technology of diesel particulate filters (DPF) is one of the most effective methods for cleaning particles emitted by diesel engines [11], which has many advantages, such as high cleaning efficiency, long service life.

The driving force behind progress in air filtration is the growing need for a clean air environment in many advanced industries. Such industries include microelectronics, medical applications, pharmaceutical manufacturing, biological research, gas turbines, nuclear power plants, and others. With the development of nanotechnology, the filtration of nanoparticles in the air has become a severe problem due to their large production in the synthesis and combustion of materials [12,13] Wang and Otani [14] focused on fiber filters and their characteristics. Shaffer and Rengasamy [15] examined respiratory protection against airborne nanoparticles.

Works [16, 17–22] show that prefilter filter systems use in various fields of production. For example, in animal husbandry, a prefilter is used to supply air to the room before the fine filter [23]. In the production of olive oil, fraction separation is carried out more efficiently using a prefilter [24]. In medicine, in the nanometer range of particles, a fine filter with a higher permeability acts as a prefilter for viruses [25].
Prefilters can be the main component of many filtration systems. For example, in the engines of construction equipment, most of the dust particles can be filtered by a preliminary air filter before supplying gas to the fine filter, which increases the maintenance intervals and its service life. When we develop an optimal filter system, the aim is to reduce the resistance and deposition efficiency in the prefilter. However, it is rather difficult to investigate the flow behavior inside the preliminary filter by an experimental or analytical method. With the steady development of computers and CFDs, numerical methods have become an essential tool for creating new device models [26-28]. This study aimed to create a model of the filter-prefilter system, which can increase the total efficiency of particle deposition and extend the filter’s operating time.

2. Problem formulation and solution methods
In this paper, we compare two options for the geometry of the prefilter, evaluate the operation of the filter-prefilter system. As the primary filter, we chose an open cell foam material of effective thickness, at which the particle deposition efficiency in the filter reaches its maximum, and its further increase is impractical. For the selected medium parameters, the thickness of the porous region is 4 cm. Preliminary filters are curved plates 1 mm high and 1 cm long. The plates are arranged so that there is no transparency between them. In the first case, the number of plates is ten and in the second five. The cell diameter of the open cell foam material is \(d_c = 6\) mm, the porosity of the medium \(\varepsilon = 0.8\). The inlet pipe is located closer to the plates and is 0.5 cm, for the convergence of the calculation, we chose the length of the outlet pipe equal to 3 cm. The total length of the calculation model is 8.5 cm. The geometry data is a combination of a filter with a prefilter in order to increase the filter efficiency with reduced medium resistance. Figure 1 (a, b) presents a scheme of the model used in the calculations.

![Scheme of the model of the prefilter-filter system](image)

**Figure 1.** Scheme of the model of the prefilter-filter system: \(a\) - prefilter with five plates, \(b\) - prefilter with ten plates.
Figure 2. Parameters of the location of the pre-filter plates:

\(a\) - \(l = 0.33\) mm, \(h = 4\) mm; \(b\) - \(l = 0.33\) mm, \(h = 2\) mm.

We use the internal volume of the geometry to calculate the flow of a gas suspension in a porous medium since the flow occurs in the inter-pore space. The estimated speed is 1 m/s, which provides a turbulent flow regime. For direct numerical simulation of the aerosol flow, the number of grid elements averaged 18 million cells. At the boundaries of the computational domain, the following boundary conditions were: the mass flow rate at the inlet and the atmospheric pressure at the outlet, plates, and other zones as default walls. The computational domain is the inter-pore space region; part of the computational model (insert of the porous medium) is shown in figure 3. We performed hydrodynamic calculations in the ANSYS Fluent CFD package (v. 19).

Figure 3. Part of the computational model with open cell foam material.
3. Results

Figure 4 shows the variation in the deposition efficiency depending on the particle diameter with various combinations of filters and prefilters.

The deposition efficiency curve for the filter-prefilter system turns out to be higher than the curve for the model of an open cell foam filter separately. We can conclude that the prefilter increases the ultimate filter deposition efficiency. The figure also shows the curves for the five-plate prefilter model and the filter system. In the latter case, we set the parameters, at which particles settled only on the walls of the prefilter,
but not on the filter itself. It was done to study what kind of load the prefilter removes from the primary filter. The figure demonstrates that the efficiency of the models varies greatly. This fact occurs due to hydrodynamics change in the behind of the preliminary filter, where, in the first case, there is a free flow, and in the second, there is a resistance of the porous medium.

A comparison of the calculation results for the pre-filters shown in figures 4-5 demonstrates that the deposition efficiency of the five-plate pre-filter is higher than the ten-plate pre-filter. It should be noted that with the addition of a pre-filter, the pressure drop increases compared with an open cell foam filter. Estimation of the pressure drop in the preliminary filter shows that for the case with 5 plates the pressure drop is higher than in the preliminary filter with 10 plates.

4. Conclusion
Several prefilter models are considered. A detailed numerical simulation of the gas flow in a porous medium with and without a preliminary filter has been carried out. Comparison of the particle deposition efficiency curves for different filter models demonstrates the ultimate efficiency drag for the filter-prefilter system.

Acknowledgments
The reported research was funded by Russian Foundation for Basic Research, grant № 19-07-01188.

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