Performance of mechanical filters used in general ventilation against nanoparticles

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Abstract. Filtration is a simple and effective way to capture particles of different sizes. According to ANSI/ASHRAE 52.2 standard, ventilation filters efficiency is tested for particles ranging from 0.3 to 10.0 μm. To our knowledge, performances of entire filters for nanoparticles are still very limited and particle size of 300 nm is commonly used as the Most Particle Penetration Size (for mechanical media). In order to evaluate the filter performance for nanoparticles, five type of filters (from MERV 8 to HEPA) were evaluated via two measurements: penetration and pressure drop. Results are consistent with previous experimental measurements on media and entire filters. These data show that the range of 150 to 500 nm is a better estimation of the MPPS, unlike the fixed diameter of 300 nm.

1. Introduction
Filtration is one of the most used technique in health and safety at work to control exposure to nanoparticles. However, ANSI/ASHRAE 52.2 [1] limits the filtration efficiency evaluation to particles ranging from 0.3 to 10.0 micrometers. The most penetrating particle size (MPPS) is the size of particles that are most able to pass through the filter. It is generally estimated at about 300 nm, and it is the smallest particle size measured in ANSI/ASHRAE 52.2. However, many studies have shown that MPPS can vary considerably from one media to another and that is strongly depends on the operating conditions [2].

Considering entire filters studies, Brochot et al [3] clearly indicates that current knowledge of their performance for nanoparticles is still very limited. However, data from the literature on media provides more details on the parameters affecting their performance. Indeed, in recent years, many experimental studies have been published on media filtration for nanoparticles. MPPS can then vary depending on medium type [4-6], particles’ shape [5,6,7], particle’s charge [8] or relative humidity [8]. Therefore, MPPS is generally expressed by a particle size range of 100-300 nm.

The main objective of this study is to measure the performance for different filters to observe the MPPS range and compare these results with data from literature. To obtain these performances, the previously validated setup was used [9]. Five different filter types have been chosen for this study: three MERV 8 filters, a MERV 14 filter and a filter classified HEPA.

2. Materials
2.1. Small filter setup
NaCl nanoparticles aerosol (centered at 50 nm) has been injected into a small filter test bench [10]. This bench (figure 1) consists of a duct with a 12 x 12 section with a PANDA fan (PAN341 from TSI) for flow regulation.
The tested filters were installed in the test chamber and two probes are installed upstream and downstream the filter. At the end of the bench, a HEPA filter is used to remove particles from the ambient air. This setup permits to test filters at velocities ranging from 0.25 to 1.50 m/s.

The two sampling probes used have the same length, to obtain the same retention time and the same losses. Filter penetration is then calculated with the concentration ratio between upstream and downstream. The concentrations were measured using a Scanning Mobility Particle Sizer (SMPS) to obtain filter penetration for particle sizes ranging from 20 to 500 nm.

![Small filter test bench](image)

**Figure 1.** Small filter test bench.

2.2. Filters tested

Five different filter types have been chosen for this study:

The first three filters (thickness 4 in) are composed of a medium (pleated and supported with grid) inserted into a cardboard frame. According to the manufacturer, these filters are MERV 8 and used as a prefilter in general ventilation.

The fourth filter (thickness 4 in) is composed of a medium based on glass microfibers and inserted into a cardboard frame. Resin separators are added to ensure rigidity. This filter is classified MERV 14 by the manufacturer.

The fifth filter (thickness 11.5 in) is composed of a steel frame in which the medium is glued to seal the filter on the frame. Gaskets are also placed downstream around the frame. The medium is based on glass microfibers, pleated and separated by corrugated aluminium. Aluminium ensures uniform flow and maintain the stability of the filter. Manufacturer information indicates that this filter has an efficiency of 99.99% at 0.3 microns.

Each filter tested is measured without preconditioning, a seal is installed on the filter’s contour to eliminate effects of leaks.

3. Method

3.1. Pressure drop

Pressure drop measurements were performed on all the filters tested. They were obtained using a TSI DP-Calc 5825 pressure sensor. This instrument has a measuring range of ± 15 inches of water, with a reading accuracy of ± 1 %. The results presented in this study are the mean and the standard deviation obtained for three filters (N = 3), except for filter 5 (only one sample).

3.2. Initial spectral penetration

The measurement is obtained with a Scanning Mobility Particle Sizer (SMPS). It permits to measure the particle size distribution. This particle size distribution was measured at upstream (4 scans), downstream (4 scans) and upstream of the filter (2 scans). Upstream scans were compared to verify the generation stability during all the test period. The penetration was obtained by the ratio of the average concentrations downstream and upstream, according to particle size. The results presented in this study...
are the mean and the standard deviation obtained for two measures in three filters (N = 6) except for filter 5. Results for filter five were a mean and a standard deviation of three separates measurements obtained with the same filter.

4. Performance results

4.1. Pressure drop

Pressure drop results as a function of the calculated filtration velocity are presented in figure 2 for all the filters tested. One can first observe that the pressure drop is higher when the efficiency of the filter tested is greater. One can also note that the pressure drop increase when the filtration velocity increases.

Figure 2. Pressure drops measured according to filtration velocity for 5 filters.

4.2. Penetration – Filters 1, 2, 3 and 4

Figure 3 shows penetration results as a function of particle size for the first four filters (4 in thickness) and at different velocities.

The first obvious remark that can be observed is the difference in efficiency between filters 1, 2 and 3 on one side and the filter 4 on the other. The MERV class difference is easily observed on these graphs.

It can also be observed that the measured penetration is lower when the particle size is decreased below 100 nm and the most penetrating particle size is greater than 100 nm. This is in accordance with the classical filtration theory for mechanical media and with previous experimental measurements on media and filters. The measured MPPS range (200-500 nm) contain 300 nm, the value generally used to define the MPPS. Filters 1, 2 and 3 (MERV 8) have an MPPS generally greater than 150 nm and less than 450 nm. Filter 4 shows an MPPS in the range 200-350 nm. Data below shows then that the 200-500 nm range provides a better estimate of the MPPS, in contrast to 300 nm size in these conditions.
Figure 3. Penetrations measured according to filters 1 to 4.

The maximum penetration measured for filters 1, 2 and 3 is very close to 100%. These filters are not efficient for sub-micron particles, it’s impossible to draw other trends. At the velocity tested, one cannot see any effect of velocity on the MPPS or maximum penetration on these filters.

Filter 4 (MERV 14) shows a maximum penetration around 20-40% and it seems to increase as the velocity increases. Also, MPPS appears to shift to smaller particles as the velocity increases from 1.00 to 1.50 m/s.

4.3. Penetration – Filter 5

Figure 4 presents penetration results for the filter five at 1.50 m/s and for three particle sizes and one global penetration (by using all the aerosol) at the same velocity. Due to the aerosol concentration and the high efficiency of the filter, it was only possible to measure these penetrations. The overall aerosol is then used to measure the global penetration: the overall concentration is measured upstream (2 minutes), downstream (10 minutes) and upstream (2 minutes). Upstream concentrations are compared to verify the stability over the entire period and the global penetration is calculated by the ratio of the average concentrations upstream and downstream of the filter five.
Figure 4. Penetration measured according to filter 5.

One can observe that the penetration at 50 nm is equivalent to the global penetration for the aerosol centred at 50 nm. One can also note that penetration decreases when the particle diameter decreases below 200 nm as expected by the filtration theory.

5. Conclusions

The objective was to measure performance for five different filters in order to observe the MPPS range. Performance measurements (pressure drop and penetration) of five filters were thus obtained using the ‘Small Filter’ setup. Results obtained are in good agreement with classical filtration theory for mechanical media and with previous experimental measurements. Data presented in this study show that the 150-500 nm range provides a better estimation of the MPPS than the fixed size of 300 nm.

One can remark that, for nanoparticle exposures, the levels should be as low as possible, because of their greater toxicity and the lack of standard limit values for nanomaterials. However, the question remains what is the acceptable value of filter performance in order to better protect workers.

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