Development of a procedure to measure the performance of ventilation filters for nanoparticles

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Abstract. Filtration is a simple and effective way to capture particles of different sizes used in different workplaces. However, the state of current knowledge has shown that the performance of entire filter depending on the particle size are still very limited. The main objective has therefore been to develop a procedure to evaluate the filter performance used in ventilation systems for particles smaller than 300 nm including nanoparticles. The measurement procedure has been validated by comparing the penetration measurements on two different setups for nanoparticles.

1. Introduction
Nanoparticle exposures in the workplace are increasing due to industries looking to exploit their specific properties. Furthermore, their effects on workers' health aren’t yet well known. In order to manage this new exposure matter, filtration is commonly used in order to control it because it’s a simple and effective way to capture particles, in general or specific ventilation, in enclosed space or for punctual exposure. However, in the ANSI/ASHRAE 52.2 standard [1], the filtration efficiency is only evaluated at particles size from 0.3 to 10.0 μm. It then proposes a classification of filters in 16 levels of Minimum Efficiency Reporting Value (MERV). The higher the MERV the better the filter efficiency.

In addition, few studies have been conducted to quantify the performance of entire mechanical filters against nanoparticles under different operating conditions (filtration velocity, relative humidity, time of use) [2]. Nanoparticle-specific studies have provided only phenomenological information: for example, they have shown that the filtration velocity has a very strong influence on MPPS (Most Particle Penetration Size). These conditions have yet to be estimated for entire filters. To our knowledge, there is no study linking penetration as a function of nanoparticle size for entire filters and media. All studies identified were conducted on entire filters or on media samples. Literature data on media provides more detail on the effect of different parameters on their performance. MPPS is then commonly reached for particle size of 100 nm to 300 nm for mechanical media and at low filtration rate, depending on the variability of media and operating conditions [3].

2. Materials and methods
A setup has been constructed to measure entire filter performances for nanoparticles. It has been dimensioned in a small scale to easily control the different parameters.
2.1. Nanoparticle generation
NaCl nanoparticles has been generated using a 1.7 % v/v NaCl solution aerosolized by two collision generators settled at 30 psi. This system permits to generate an aerosol with a 50-nm mode (figure 1). Nanoparticles can then be injected into the small filter test bench.

![Figure 1. Comparison of particle-size distributions produced (means and standard deviations, N=3) during three different tests.](image)

2.2. Small filter test bench
Presented in figure 2, the small filter bench consists of a vein with a 12 x 12 section. A PANDA fan (PAN341 from TSI) regulates the flow in the vein. The particles are injected into the beginning of the bench. Particles are homogenized with a small fan and a honeycomb in the injection section. Its also permits to homogenise the velocity across the 12 x 12 section. Velocities were measured to know precisely the range obtained by the airflow PANDA and verify the homogeneity. The small filter bench allows us then to test filters at velocities ranging from 0.25 to 1.50 m/s.

The filters are then 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 in the lab. The two sampling probes have the same length, to obtain the same retention time and the same losses. Filter penetration is calculated with the concentration ratio between upstream and downstream measurements.

![Figure 2. Small filter test bench.](image)
2.3. Filters used
Three different filter types have been chosen for the validation tests. The first one is composed of a medium inserted into a cardboard frame. The medium is pleated and supported using a reinforcement grid. Used in general filtration, they are simply inserted into the housing. This filter is available at three different thicknesses and these three different thicknesses have been tested in this study. According to the manufacturer, this filter is a MERV 8 and used as a prefilter in general ventilation.

The second filter is composed of a medium based on glass microfibers, with resin separators added in small quantities to ensure rigidity. The medium is inserted into a cardboard frame too. This filter is classified MERV 14 by the manufacturer.

The third filter 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. According to the manufacturer, this filter has an efficiency of 99.99% at 0.3 microns. The manufacturer indicates that this type of filter is generally used in medical or pharmaceutical facility systems.

2.4. Penetration measurement
Once the setup was calibrated, the 12 x 12 sized filter penetration for particles ranging from 20 to 500 nm can be measured using the Scanning Mobility Particle Sizer (SMPS) at flow rates ranging from 0.25 to 1.50 m/s.

Each filter tested is measured without preconditioning, a seal is installed on the filter’s contour to eliminate any leaks between the filter and the bench’s wall. After filling the NaCl solution generators and checking the fans, the airflow PANDA was started, and the generation is settled at 30 psi and stabilized. Performance measurement were then obtained according to the two following procedures.

2.4.1. Initial spectral penetration.
The measurement was obtained with a SMPS. It consists of an Electrical Classifier (EC) and a Condensation Particle Counter (CPC). A Soft X-ray neutralizer charge the aerosol in a well-known charge distribution. Particles passes then through the electrical mobility analyzer. Under the influence of an electric field, the charged particles were deflected and ones that exit have then a given electric mobility. The CPC was used to count the particle concentration at each selected particle size. To detect particles, the aerosol is introduced over a heated alcohol saturator, then passes into a condenser whose walls are cooled. The alcohol vapours condense on the particles increasing their size. They are thus easily detectable using a photodetector.

The particle size distribution of the concentration was then 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).

2.4.2. Initial global penetration
In the case of HEPA filter, due to its high efficiency, the penetration measurement was done differently. The total aerosol was used to measure the filter penetration. The total concentration was then measured using only the CPC.

The total aerosol concentration was measured upstream (for 2 minutes), downstream (for 10 minutes), and upstream (for 2 minutes). Upstream total concentrations were compared to verify the generation stability during all the test period, and the results presented in this study are the mean and the standard deviation obtained for three measures (N = 3).

2.5. Validation by comparison
The penetration results obtained with this setup were compared to those obtained on an ASHRAE bench. An ASHRAE bench has been specially modified for nanoparticle use and has been presented in a previous study [4]. Named in this paper 'ASHRAE inspired' setup, its qualification and measurement
procedure are presented in Abdolghader et al. Penetrations comparison obtained on the two setups is then presented in this paper to validate our setup and its measurement procedure.

The penetration measurements obtained on the two setups were compared for two different velocities: 0.75 and 1.00 m/s. Table 1 below shows the filtration velocities that correspond to measurements velocities. This table shows that this comparison at the two velocities was consistent. Indeed, in the two configurations and according to filtration surfaces provided by the supplier, the filtration velocities used for each filter tested were equivalent on both setups.

| Filter | Thickness (in) | Calculated filtration velocities at 0.75 m/s | Calculated filtration velocities at 1.00 m/s |
|--------|----------------|---------------------------------------------|---------------------------------------------|
|        | in ‘Small Filter’ setup | in ‘ASHRAE inspired’ setup | in ‘Small Filter’ setup | in ‘ASHRAE inspired’ setup |
| Filter 1 | 1 | 0.11 | 0.11 | 0.14 | 0.14 |
| Filter 2 | 2 | 0.18 | 0.17 | 0.24 | 0.23 |
| Filter 3 | 4 | 0.30 | 0.31 | 0.40 | 0.41 |
| Filter 3 | 11.5 | 0.01 | 0.01 | 0.01 | 0.01 |

3. Results - Correlation

The comparison of the penetration at each particle size for the different filters and for the two setups are presented in figure 3. The results of each mean penetrations were plotted on the abscissa axis by measured on the Small Filter setup and on the ordinate axis by the penetration measured on the ‘ASHRAE inspired’ setup.

This comparison presented in the figure 3 shows a fairly good agreement in penetration measurements. One can note that the MERV 8 filters give penetrations higher than 75 %, that is to say an efficiency lower than 25 % for particles smaller than 500 nm. The MERV 14 filter has a penetration less than 40 %. It means that 60 % of the particle below 500 nm Are thus captured by this type of filter. Finally, the last filter shows a very strong penetration: less than one particle per hundred thousand is captured by this filter. The comparison of the two setups over this large measurement range therefore gives a very good correlation since it is $R^2 = 0.994$.
4. Conclusions
The increase in nanoparticle exposure in workplace and the insufficient knowledge of their effects on workers’ health requires to establish the precautionary principle to manage this exposure. Filtration is known to be one of the most used, one of the easiest to implement and one of the most effective. However, the standard ANSI/ASHRAE 52.2 limits the filtration efficiency evaluation to particles ranging from 0.3 to 10.0 µm.

The main objective of this project was to design, realize and validate a measurement procedure to know the mechanical filter performance towards nanoparticles. This validation was carried out by comparing these measurements with those obtained on an ASHRAE inspired setup, specially modified for use of nanoparticles. Three different filters were used for this comparison. They allow to illustrate the full penetration range measured by our setup for nanoparticles. The comparison over this range has a fairly good correlation (R² = 0.994). Therefore, this setup will then permit to study the entire mechanical filter performance according to their characteristics and their uses for nanoparticles.

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