

# ACCELERATED AIR FILTER AGEING WITH A SYNTHETIC NANO-AEROSOL

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## ABSTRACT

To predict the energy impact of air filters for general ventilation it is necessary to estimate correctly the airflow resistance variation of the filtering elements throughout their service life. The particle size distribution of the loading aerosol is essential for determining the kinetics of the air filter loading and clogging process. Current test standards simulate the ageing of air filters by dispersing synthetic dusts in the test duct to load the filter. This experimental procedure determines a “test dust capacity”, commonly referred to as “dust holding capacity”. However, standardized test dusts and typical urban atmospheric aerosols exhibit particle size distributions completely different. In fact, test dusts have particle size distributions shifted towards much larger particle sizes, while the atmospheric aerosols contain a large number of nanoparticles. Therefore, the main purpose of the data provided by the accelerated ageing procedure provided by current test methods is to compare the performance of an air filter against other competitors. To acknowledge this important limitation, test standards include a disclaimer to highlight the difference between the data obtained in the laboratory test procedure and the actual operation performance. Hence, the energy implications of air filtration equipment cannot be reliably predicted by current standards. We can overcome such limitation by using synthetic aerosols with particle size distributions comparable to typical urban atmospheric aerosols to load air filters in the laboratory. By simulating operating conditions similar to reality, we can predict more accurately the airflow resistance trend during the filter service life and consequently optimize the time interval for changing air filters too. Moreover, the data obtained in realistic conditions can help establish a meaningful energy labeling system. However, until now no standardized method to produce typical atmospheric aerosols is available. This is mainly due to the lack of the ability to generate and control large number of nanoparticles suspended in the test air, in a repeatable and reproducible way. We describe a method for generating large amounts of nanoparticles to obtain a loading aerosol with a particle size distribution similar to a typical urban atmospheric one, but with much higher concentration. The aim is to reproduce in a few hours what actually happens to a filter in one year of actual service. We compare different loading curves obtained by clogging air filters with currently standardized synthetic dusts and a synthetic nano-aerosol made up mainly by salt nanoparticles generated by combustion. The results are discussed and the fundamental differences between the laboratory results are highlighted.

## 1. INTRODUCTION

The energy impact and required replacement intervals of air filters used in general ventilation applications depend largely on how their airflow resistance and their capability to capture particles change throughout their service life. These key performance parameters depend on the structure and construction of air filters, the properties of the fibrous materials and, to a very important extent, on the characteristics of the challenging aerosol, i.e. its concentration and particle size distribution (PSD). PSD is a fundamental parameter because particles can either stop on the surface or penetrate into the fibrous filter media. The ones penetrating inside the fibrous matrix can be eventually captured by a depth filtration mechanism [1], while larger particles are most likely stopped on the surface of filter media.

Current standardized laboratory test methods simulate the ageing process of air filters [2] [3] to compare the performance of air filters available on the market and to provide information for choosing the most suitable filter.

Those test methods simulate the ageing process in laboratory by clogging the air filters with standardized synthetic dusts having PSDs shifted towards much larger particles compared to typical atmospheric aerosols. As a consequence, current laboratory test methods tend to reproduce a surface filtration phenomenon. However, in most real air filtration applications cleaning polluted outdoor air, the predominant process is depth filtration. The increase of airflow resistance as a function of the amount of particles captured in case of surface and deep filtration is very different. Hence, laboratory data obtained with these methods cannot be used to predict quantitatively the ageing behavior of HVAC filters in a real environment. ISO 16890 and ANSI/ASHRAE 52.2 standards are aware of this limitation and state it explicitly.

Consequently, the large difference existing between the ageing procedure in the laboratory simulation and the natural ageing process in service limits the usefulness and validity of laboratory data obtained with current synthetic dusts. The energy impact and the required replacement intervals of air filters used in general ventilation applications cannot be estimated reliably and meaningfully by means of current laboratory procedures. That

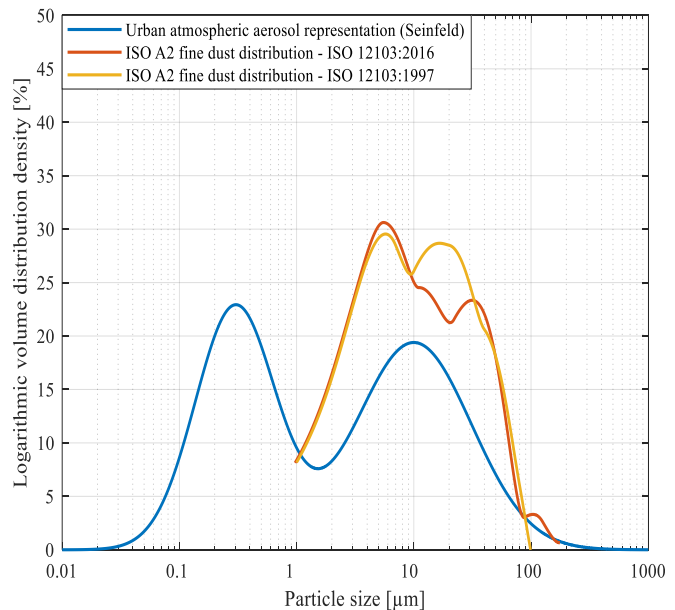


Fig. 1 - Volume PSD plots of ISO A2 Fine synthetic dust and urban

has very important practical implications because 80% of the population of the developed regions live in urban areas [4], where the majority of HVAC systems are installed.

To tackle this problem and improve the ability to simulate in laboratory the actual behavior of air filters exposed to atmospheric aerosols it is fundamental to produce in controlled conditions a synthetic aerosol with PSD much closer to the outdoor or atmospheric ones. Urban atmospheres contain a large portion of anthropogenic nanoparticles (ultrafine particles) [5] [6] which are completely missing in current synthetic dusts. To reproduce the natural loading kinetics inside the fibrous filter media it is therefore essential to include the ultrafine fraction in synthetic aerosols produced in laboratory. Such synthetic aerosol could be included in a new test method to provide meaningful data and to predict in situ air filter service life, especially for filters cleaning outdoor polluted air.

Seinfeld [7] proposes a representation of a typical urban aerosol with a PSD composed by two log-normal modes. This representation is used as the reference for calculating the particle removal efficiency in ISO 16890-1:2016 and provide  $ePM_1$  and  $ePM_{2.5}$  values for classifying the air filters. Fig. 1 compares the logarithmic volume distribution densities of the typical urban atmospheric aerosol proposed by Seinfeld and the ISO A2 Fine dust [8] currently used to determine the gravimetric efficiency of ISO Coarse filters per ISO 16890-3:2016. Due to the lack of any alternative approach, the same dust and procedure is currently used by those willing to simulate the ageing of  $ePM_1$ ,  $ePM_{2.5}$ , and  $ePM_{10}$  filters too. The remarkable difference between the two PSDs has already been discussed above and explains why data obtained with current ageing procedure are not able to predict reliably what happens in real systems.

A comparison between in-situ and artificial filter ageing has been published previously [9]. It demonstrates how current standardized methods provide misleading information, not coherent with the trend of air filters performance challenged by urban aerosols. This limitation should be overcome to allow the optimization of air filter elements and materials for minimizing the energy consequences and for determining the optimum interval change.

The problem above could be probably addressed properly by generating a synthetic aerosol with a PSD close to the one of the typical urban aerosol adopted by ISO 16890-1:2016 for calculating  $ePM_x$  values. The method for generating such new synthetic aerosol should be repeatable and reproducible with a specified tolerance. Accelerated ageing of air filters would be achieved by feeding into the test duct the ultrafine synthetic aerosol at much higher concentrations than in typical urban atmospheres. However, the required PSD shall be maintained also at high particle concentration.

By accomplishing this goal, it should be possible to predict much more accurately the change of the airflow resistance of air filters during their service life. Consequently, it should be possible to optimize the interval change interval and minimize the life cycle cost associated with air filtration. Moreover, the data obtained in realistic conditions can help establish a meaningful energy labeling system for HVAC filters and drive filter media development. We describe our current efforts in this direction.

## 2. APPROACH

We investigated the possibility to generate highly concentrated nano-aerosols to perform realistic accelerated ageing tests of air filters using a thermal aerosol generation method. This was developed in the early '70s and ever since has been used for in-place testing of large filter installations inexpensively [10]. The technique consists in burning a salt stick with an oxy-propane flame from an annular burner, generating large amounts of salt vapor, which condense in an air stream and form a mixture of ultrafine particles. Fig. 2 shows a schematic diagram of a thermal aerosol generator.

It is a reliable solution for generating ultrafine particles at a controlled and constant rate, with the possibility to modulate the PSD of the generated aerosol, and the ability to reproduce the size distribution of ultrafine outdoors particles. To control the aerosol concentration, the salt stick feed rate can vary between 1 and 25 mm/min and the diameter of the salt stick itself can be 10 or 12 mm. Furthermore, the salt stick can be made of potassium or sodium chloride.

In a previous publication [9], we characterized this device studying how the different settings impact the generated aerosol PSD to determine whether this method could be used for clogging air filters in a more realistic way. The tests were performed using KCl sticks of 10 mm diameter and 200 mm length, in a test rig that fulfils all the requirements of ISO 16890 series operated at 3400 m<sup>3</sup>/h.

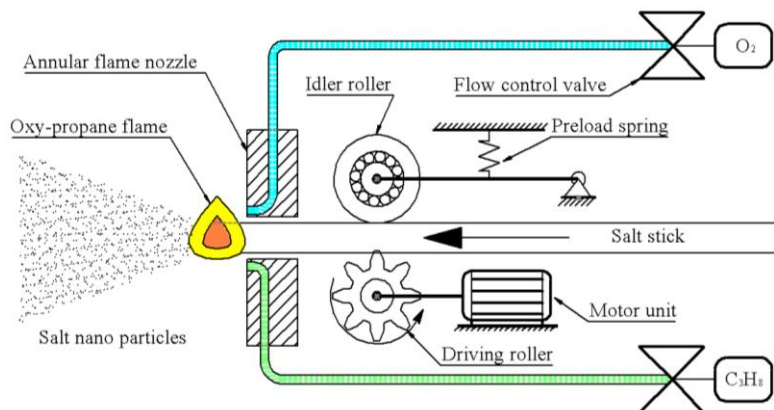


Fig. 2 - Thermal nano aerosol generator.

Fig. 3 compares the PSD of the synthetic salt nano-aerosols obtained in laboratory with a typical urban atmosphere. The results showed that the thermal nano-aerosol generator can reproduce properly the fine particle modes of a typical urban atmosphere.

Hence, we used the generated ultrafine aerosol to clog a few samples of different air filters. Table 1 summarizes the characteristics of the air filters tested and the test conditions for each one.

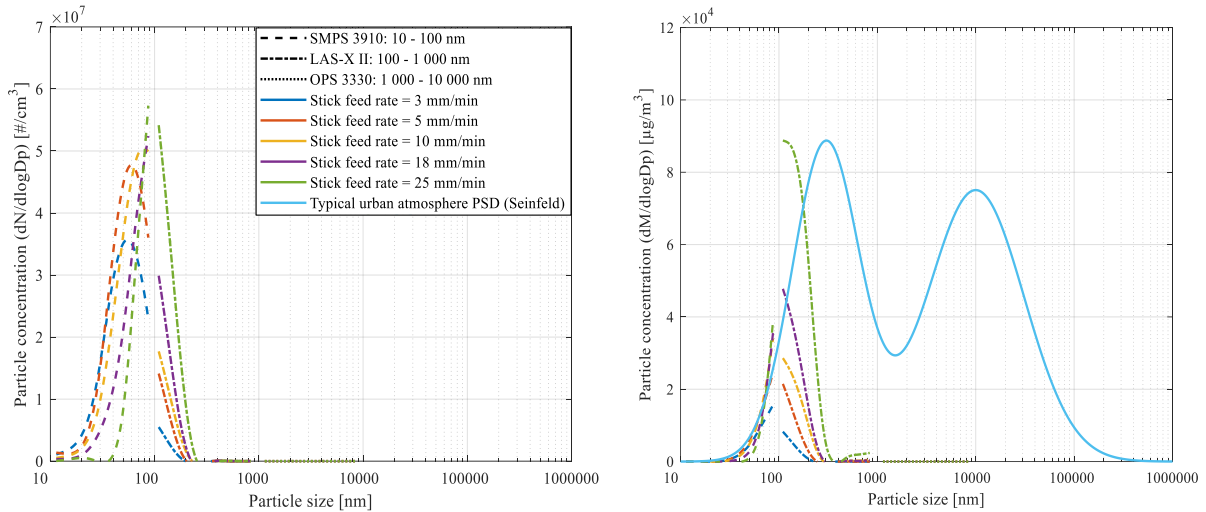


Fig. 3 - Comparison between the number and mass PSDs of ultrafine aerosol obtained with the thermal aerosol generator using 10mm-diameter KCl sticks with various feed rates and the urban atmospheric aerosol according to ISO 16890.

Table 1 - Characteristics of the air filtering devices tested and test conditions.

	Air filter		
	a	b	c
<b>Construction type</b>	Bag	Compact	Cartridge
<b>Type of media</b>	Nonwoven glass fiber	Pleated glass fiber paper	Three-layer composite
<b>Nominal media area [m<sup>2</sup>]</b>	6.0	18.5	20.0
<b>Test airflow rate [m<sup>3</sup>/h]</b>	3 400	3 400	1 220

A generic representation of the filters is shown in Fig. 4. To compare the proposed method to both the standardized ones and to what really happens in real environments, we performed clogging tests on some of the filter samples using two types of synthetic dusts (ISO A2 Fine and Kronos 2160 [11]). Other samples were installed in a real HVAC system and their performance data were collected for one year.

The temperature and relative humidity of the test air was maintained between 20.6 - 34.6 °C and 33- 55%, respectively. We measured the pressure drop across the air filters in the HVAC system using a Siemens QBM65.1-10 differential manometer [12]. In the laboratory tests, we used an Aplsens APRE-2000G/N differential pressure sensor [13] to measure the resistance to airflow of the tested devices.

The types of aerosols/dusts and the corresponding concentrations used during the tests are reported in Table 2.

Table 2 - Summary of the tests performed.

	Air filter		
	A	b	c
<b>Urban atmospheric aerosol (pre-filtered)</b>	-	22 $\mu\text{g}/\text{m}^3$ <sup>(i)</sup>	-
<b>ISO A2 Fine dust</b>	140 $\text{mg}/\text{m}^3$	140 $\text{mg}/\text{m}^3$	140 $\text{mg}/\text{m}^3$
<b>Kronos 2160 dust</b>	-	-	140 $\text{mg}/\text{m}^3$
<b>KCl ultrafine aerosol</b>	19.6 $\pm$ 2.3 $\text{mg}/\text{m}^3$	19.3 $\pm$ 3.8 $\text{mg}/\text{m}^3$	25.1 $\pm$ 6.3 $\text{mg}/\text{m}^3$

<sup>(i)</sup> Average urban PM<sub>2.5</sub> data in Turin, Italy (3/2018-3/2019).

For the clogging tests performed using ultrafine KCl aerosol, the tested filters were fitted in the test duct and the ultrafine KCl aerosol was dispersed from the same point in which the test dust is injected during standard tests.

Each loading step corresponded to burning a KCl salt stick. To determine the KCl mass fed, the sticks were weighed before and after each loading step and the ashes were collected and weighted as well.

Each loading step consisted of the following sequence:

1. To turn on the oxy-propane flame of the thermal nano aerosol generator;
2. To wait a few minutes until reaching a stable thermo-hygrometric condition inside the test duct;
3. To position the KCl stick in the thermal aerosol generator;
4. To start feeding the stick at a constant feed rate;
5. To wait until the stick is completely incinerated;
6. To turn off the oxy-propane flame of the thermal aerosol generator;
7. To wait for reaching both a stable thermo-hygrometric condition inside the test duct and constant resistance to airflow. In fact during each loading step the filter



Fig. 4 - Generic representation of the tested

media is stressed by the challenging aerosol. The airflow resistance of the filter decreases until a stable value is reached.

### 3. RESULTS, INTERPRETATIONS AND DISCUSSIONS

Fig. 5 shows the clogging curves of the tests summarized in Table 2. The results demonstrate that the test dust capacity (TDC) [2] of a filter loaded with ISO A2 Fine dust is much higher than the one obtained using the KCl nano-aerosol. The data also indicates that the KCl nano-aerosol produces results more similar to the ones obtained from the natural ageing of the air filters installed in the HVAC system as can be seen from the orange curve in Fig. 5.b.

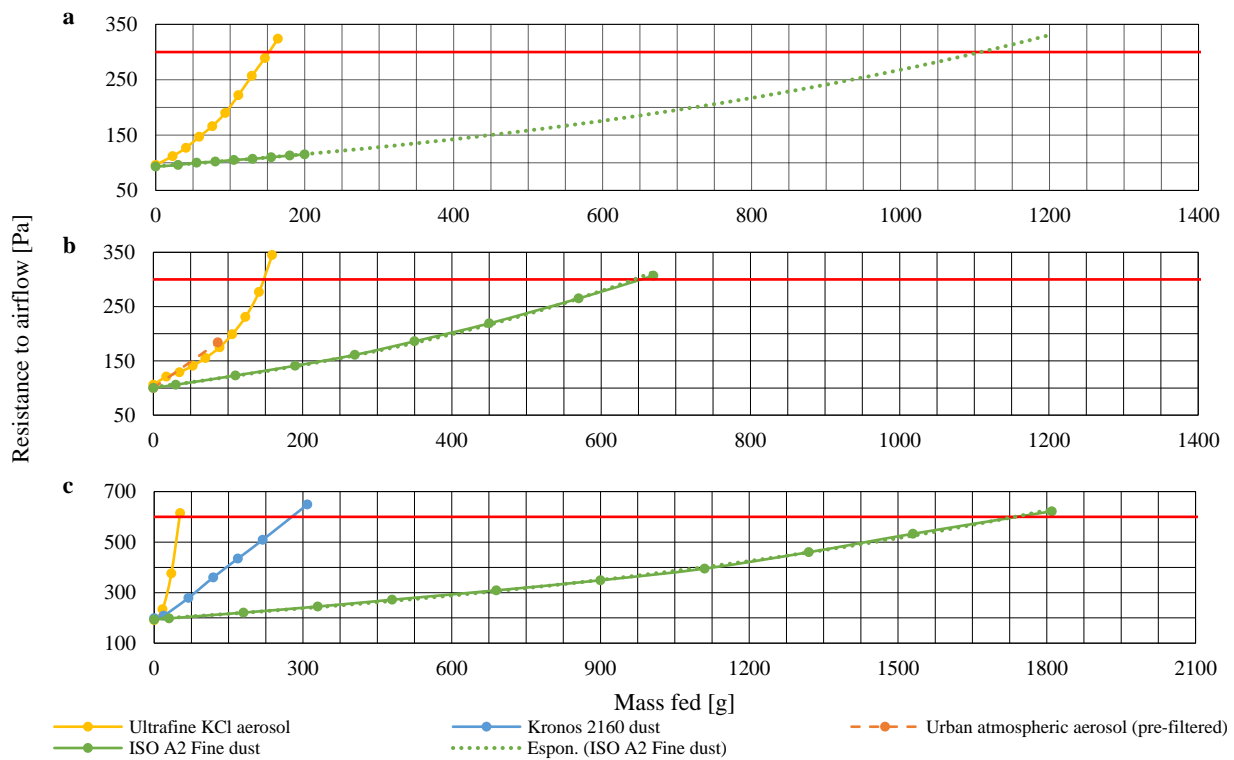


Fig. 5 - Clogging curves of the filter models a, b and c, respectively.

This has important practical implications for air filter designers when estimating the duration of their products. Having realistic accelerated air filter ageing data obtained using KCl nano aerosol and knowing the PM concentration of the ambient in which that would operate allows predicting its service life and ageing behavior more accurately. For instance, the service life of an air filter model “a” predicted based on the TDC obtained using the ISO A2 Fine is 6.7 times greater than the duration predicted by the results from the KCl nano-aerosol. This proportion is different from one filter model to another. In the case of the filter model “b”, the difference is slightly less marked, while the filter model “c” presents a remarkable discrepancy between the two results. However, since filters of type “c” are not intended to be used for general ventilation, the

tested samples were fitted in the test duct by means of an adapter which could introduce some errors when determining their TDC.

The airflow resistance results obtained by loading the test filters with Kronos 2160 dust represent an intermediate point between the results given by the ISO A2 Fine dust and the KCl nano aerosol. This is useful for understanding the effect of loading air filter with test aerosols made of progressively smaller particles.

In all tests, the time required for clogging the filters was less than 8 hours. This indicates that using KCl nano-aerosols is a feasible solution for performing accelerated ageing tests.

#### **4. CONCLUSIONS**

The results from this study demonstrate that it is possible to perform accelerated ageing tests of different types of air filters using an ultrafine KCl salt aerosol produced by a thermal generator. The cost (both time and money) of clogging air filters with this novel approach is not significantly different than the costs involved when using current standardized laboratory test methods.

We also found that the airflow resistance and the mass increase obtained by loading air filters with KCl nano-aerosols could be used to estimate much more meaningfully the service life of air filters installed in an HVAC system for cleaning outdoor air in a city. The information obtained in this way can also be used for determining the energy consequences of air filters during their lifetime and the optimal change intervals.

Despite the promising results, further tests are needed to validate the repeatability of the proposed artificial clogging method. A sensitivity study on some test parameters (e.g. test air temperature and relative humidity, distance between the aerosol injection point and the test device, etc.) will determine whether they impact significantly on the properties of the synthetic nano-aerosol. The goal is to develop a new standardized laboratory test method for assessing the service life of air filters.

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