Using the Kanomax NanoAerosol Generator (NAG) 3250 for Face Mask Filter Test Applications

Keywords: Filter Test, Aerosol Generation, NanoAerosol Generator, Nanoparticles, Monodisperse, Face Mask, Covid-19

Abstract

Unlike other commercially available nebulizers, the Kanomax NanoAerosol Generator (NAG) 3250 can generate a near-monodisperse test aerosol from a NIST-traceable particle standard. This monodisperse aerosol allows for controlled filter tests without incurring the cost and complexity of using a size classifier. Results from 29 common face mask materials are presented to illustrate the usefulness of the approach.

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Background

The interest in filtration efficiency characterization tests of face masks and respirators has grown substantially in response to the worldwide spread of Covid-19 and the consequent demand increase of personal protective equipment (PPE) supplies. It is believed the particulate filtration efficiency of the filter material used for manufacturing PPEs primarily affects how effectively they can protect the user against health and safety risks.

The characterization of filtration efficiency is therefore critically required to evaluate the protection level of a PPE product and guide the proper use of it.

The testing procedure to determine the efficiency of a filter in removing particles usually consist of four main components, shown in Figure 1. First, a generation system is needed to generate the test particles, where the properties of the test particles are chosen or decided, such as material, size distribution, and concentration.

Following the generation is a dilution system, which is often designed to adapt to the cross section of the filter fixture at its downstream. This is where the generated particles get diluted concentration to a desired level and/or evenly distributed across the cross section area of the filter to be tested.

A filter fixture is used to securely mount and seal the test filter piece at the end of the dilution system, with two ports, one upstream of the filter and one downstream, for the particle measurement equipment to sample the particles through.

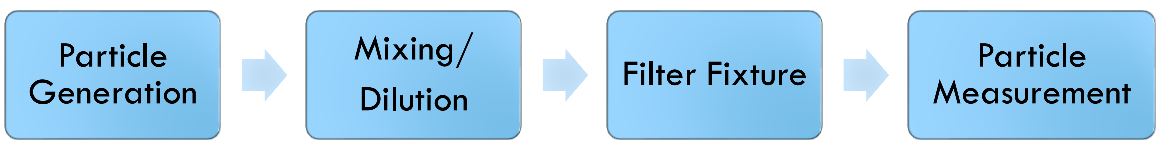


Figure 1. Components of a conventional filter test system.

MONODISPERSE TEST PARTICLES ARE USUALLY PREFERRED FOR TESTING FILTERS DUE TO THE FACT THAT FILTRATION EFFICIENCY IS A PARAMETER THAT IS GREATLY SIZE DEPENDENT

In general, there are two types of test particles used for filter tests differentiated by the particle size distribution profile of their population – polydisperse and monodisperse. With polydisperse particles the direct output from the particle generator is traditionally used, while the monodisperse aerosol is distilled from the polydisperse generation using a classification technique.

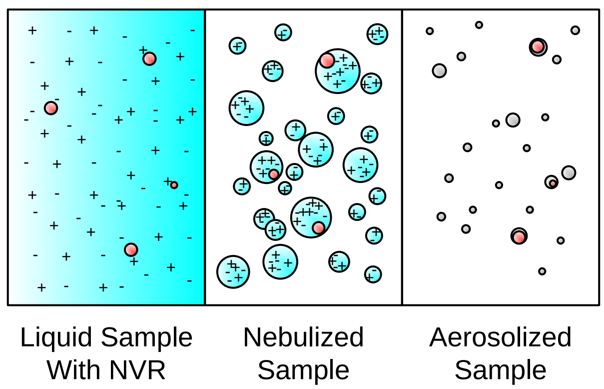
Despite the extra size classification step in their generation, monodisperse test particles are usually preferred for testing filters due to the fact that filtration efficiency is a parameter that is greatly size dependent, a substantial amount of information can get lost in the integral measurements of a polydisperse test, especially for the applications with a few size(s) of interest in particular, e.g. the Covid-19 related studies.

Generation of Test Particles

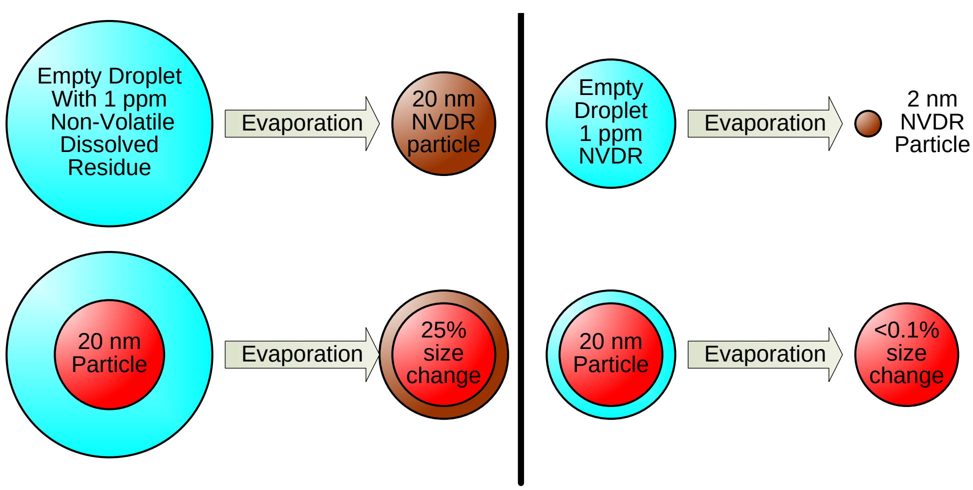
Pneumatic nebulization is the mostly widely used particle generation method and it is also the generation technique recommended in NIOSH standard testing procedure for respirator filtration efficiency evaluation.

In a typical nebulization-evaporation process, as shown in Figure 2a, the liquid sample, usually with particles and non-volatile dissolved residue (NVDR) uniformly distributed in an aqueous base, is first dispersed into small droplets which are then dried by evaporating the volatile part. NVDR is undesirable and is to be minimized.

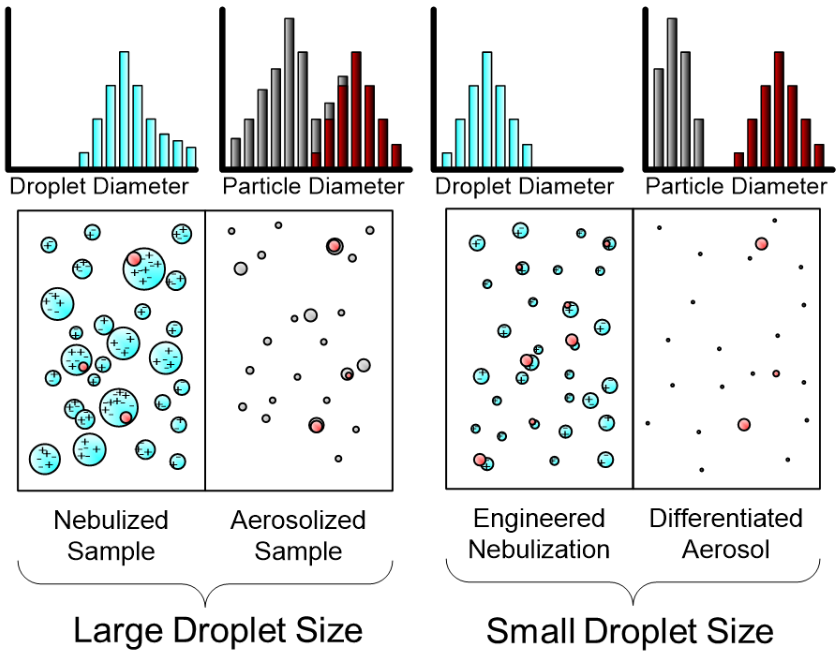
The size properties of aerosol particles generated by a nebulization-evaporation process are closely related to the size distribution of the dispersed droplets as well as the concentrations of both NVDR and discrete non-volatile residue.



a. Operation principle of nebulizer-type particle generation



b. Droplet size effects on generated particles



c. Droplet size effect on size distribution of particles generated

Figure 2. Nebulization-evaporation in particle generation

Figure 2b explains how smaller droplet sizes yield smaller NVDR particles while at the same better retain the original size of non-dissolvable particles, e.g. particle standards such as polystyrene latex (PSL) or silica particles. When the above differences are reflected in the generated particle size distribution, which is the mostly concerned parameter for nebulizer users, the particles generated with smaller droplets are better distinguished in NVDR particles (residual peaks) and non-dissolvable particles, as shown in Figure 2c. This distinct differentiation is particularly preferred in applications where the aerosolization of a particle size standard is needed.

The Advantage of the Kanomax NanoAerosol Generator 3250

The NanoAerosol Generator (Kanomax Model 3250) utilizes the pneumatic nebulization technique but with substantial improvements to significantly decrease the droplet size which distinguish the NanoAerosol Generator (NAG) from conventional nebulizers. When used for generating NVDR particles, e.g. the sucrose particles shown in Figure 3,

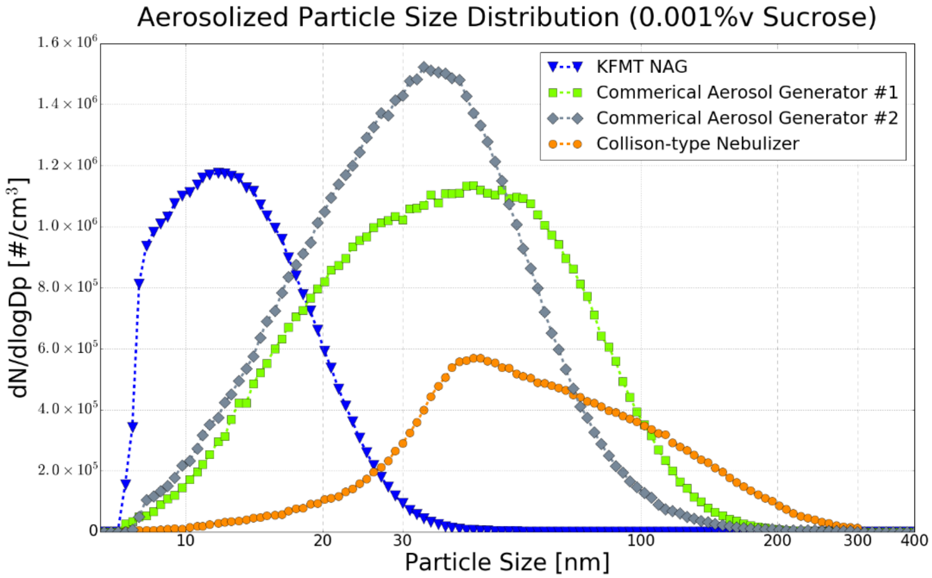


Figure 3. Particle generation using sucrose solution

A smaller NVDR peak size not only benefits the generation of such particles where a tighter size distribution is desired, but also other applications prefer low background noises. Because NVDR substances are ubiquitous in any water type, and these NVDR will form particles through a nebulization-evaporation process as elaborated above, NVDR serves to raise the background noise in measurements of nebulized particles.

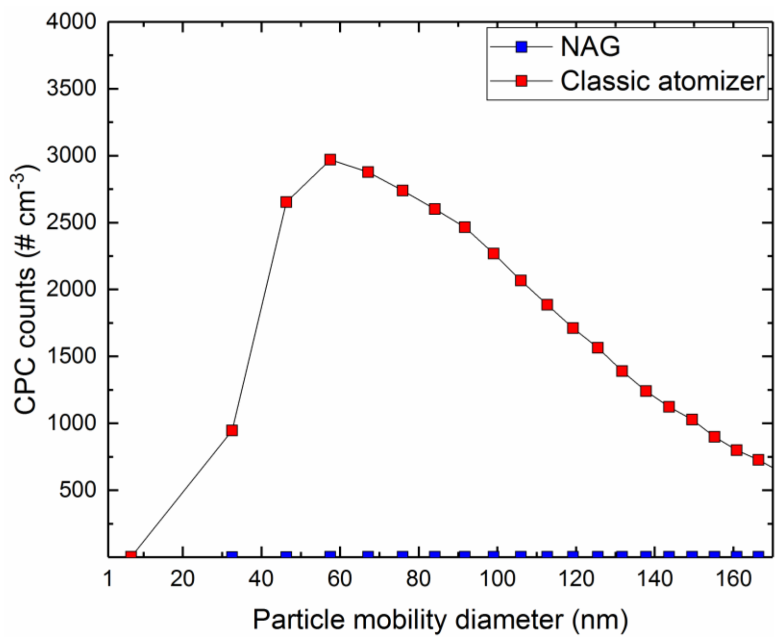


Figure 4. Counts of particle generated from DI water with NAG vs. Collison-type nebulizer

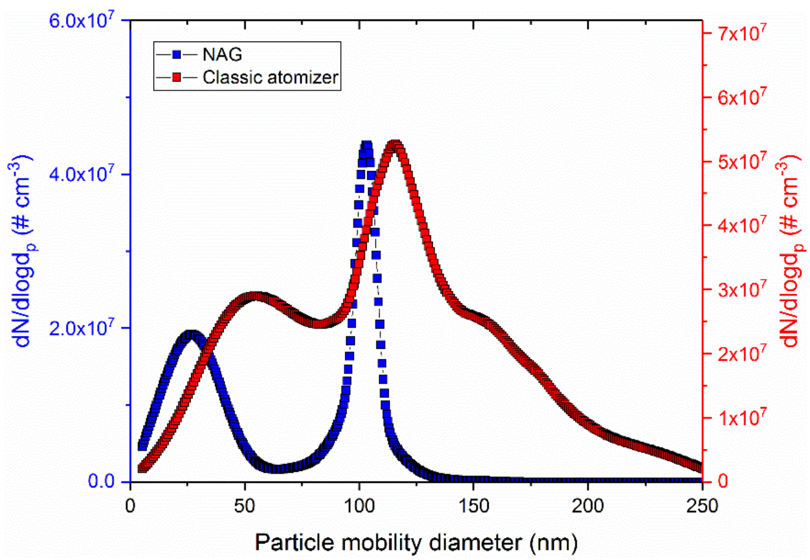
With the smaller droplet size of the NAG 3250, it is able to limit the size of such water background particles below 5 nm so that these background noises will hardly be detected by most aerosol particle instruments.

An example of the comparison is shown in Figure 4, where the NAG and a Collison-type nebulizer dispersing the same quality of DI water, and the respective size distribution of the particles generated is measured downstream over the size range from 8 to 170 nm using the same Differential Mobility Analyzer (DMA) and Condensation Particle Counter (CPC) settings. The background noise particles with a 50 nm peak size generated by the Collison-type nebulizer are completely gone in the case of NAG.

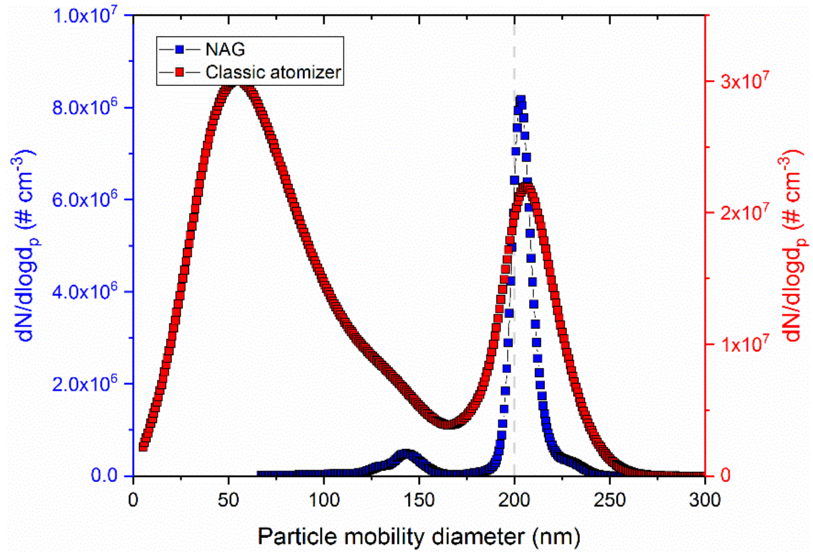
WHEN USED WITH MONODISPERSE PARTICLE SIZE STANDARDS, E.G. THE PSL STANDARDS USED IN FIGURE 5, THE NAG DIRECTLY OUTPUTS A MONODISPERSE AEROSOL NEEDING NO CHARGE CONDITIONER OR SIZE CLASSIFIER.

When it comes to the applications of dispersing particle standards, the advantage of using the NAG goes beyond a low background. Figure 5 shows three examples of using the NAG versus a Collison-type nebulizer in dispersing a. 100 nm PSL, b. 200 nm PSL, and c. 100 nm and 200 nm PSL mix.

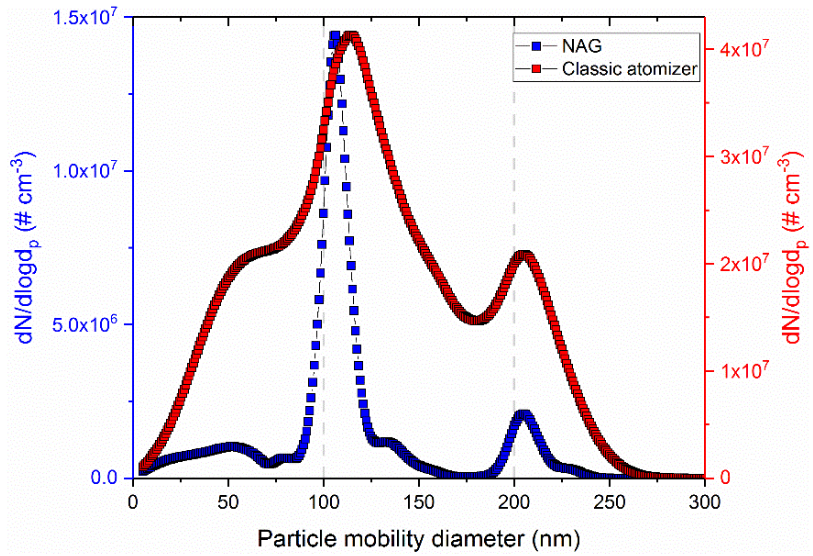
The particles generated by the NAG are not only more monodisperse than those generated by a Collison-type nebulizer in terms of smaller geometrical standard deviation (GSD) values of the size distribution profile, but also their nominal sizes are better retained with less interference from precipitation of the NVDR onto the surface of PSL particles during the evaporation process.



a. 100 nm PSL



b. 200 nm PSL



c. 100 nm and 200 nm PSL mix

Figure 5. NAG vs. Collison-type nebulizer in nebulizing PSL particle standards

Use of the NanoAerosol Generator for Mask Filter Tests

To set up a characterization system for particle-size-dependent filter efficacy measurements usually requires a size classifier to narrow down the size window of test particles that are originally generated with a polydisperse distribution. One commonly used size classifier is the ion mobility classifier (IMC), or alternatively named as differential mobility analyzer (DMA), which classifies particle size based on the corresponding electrical mobility using the relationship shown in the equation below:

$$Z_p = \frac{eCs}{3\pi\mu D_p}$$

where
e is a fundamental charge (1.6E-19 C)
µ is the gas viscosity
Dp is the particle diameter
Cs is the Cunningham slip correction factor:

$$Cs = 1 + 1.257Kn + 0.4e^{\frac{-1.1}{Kn}}$$

and Kn is the Knudsen number

$$Kn = \frac{2\lambda}{D_p}$$

with λ the mean free path of the gas (6.6 E-8 m for air at Standard Temperature and Pressure).

While the electrical mobility of a particle is a monotonic function of particle size, it is also determined by the number of elemental charges the particle is in possession of, i.e. a doubly charged particle will have twice the electrical mobility value of a same-sized particle that is singly charged when they traverse the same electrical field.

THE NANOAEROSOL GENERATOR (NAG), WITH ITS SUBMICRON NEBULIZED DROPLET SIZE, PROVIDES A MUCH MORE COST-EFFECTIVE AND EASY-OPERATION ALTERNATIVE APPROACH FOR SUCH MONODISPERSE PARTICLE GENERATION APPLICATIONS.

Therefore, the accuracy of such electrical mobility-based size classification is primarily affected by the charge distribution of the particles (i.e. the probability of a particle with a given size to carry *n* elemental charges) to be classified. To condition the particles with a known or well characterized charge distribution, an aerosol charge conditioner is needed, which is often designed with a bipolar ion source because an aerosol will stably be established with the thoroughly studied and well characterized Boltzmann equilibrium of charge distribution in the presence of bipolar gas ions. Some typical bipolar ion source for aerosol charge conditioner include radioactive materials, such as Po^{210} and Kr^{85}, and soft x-ray ionizers, which therefore increases the parts cost as well as the complexity of material handling in an experiment set up with such size classifying techniques.

The NanoAerosol Generator (NAG), with its submicron nebulized droplet size, provides a much more **cost-effective and easy-operation** alternative approach for such monodisperse particle generation applications.

This approach was successfully utilized in a recent research project aim at testing alternative face mask materials for building an emergency stockpile in response to the critical shortage in PPE supplies due to the COVID-19 pandemic. Shown in Figure 6 is the experimental setup where the NAG was used as the particle generator for this mask material testing project.

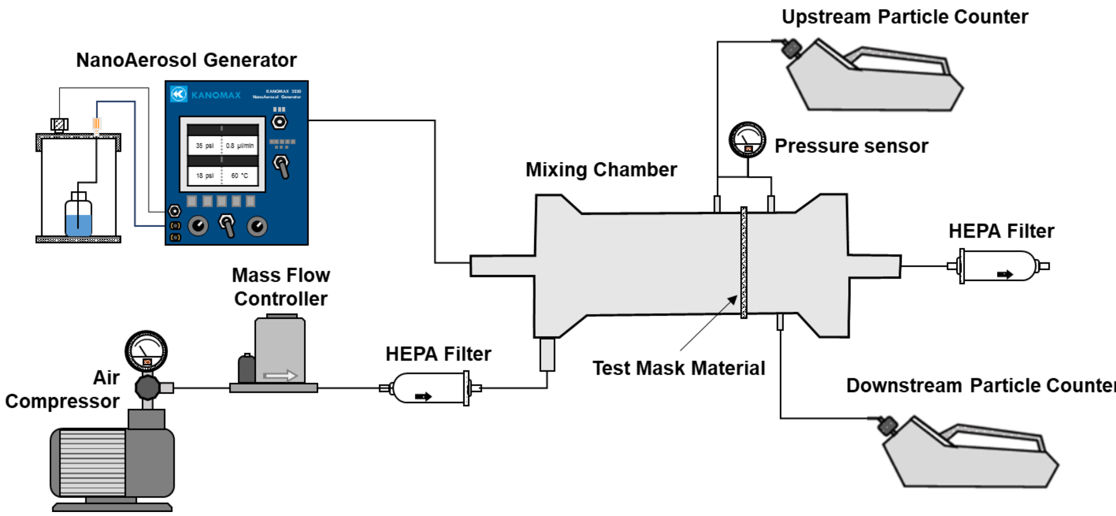


Figure 6. Schematic of a filter test setup using the NAG as the particle generator

In this test system, the NAG generates monodisperse PSL particles of 100 or 300 nm at an aerosol flow rate of 1.7 LPM, which mixes with a dilution flow of clean dry air into a 13.15 or 85 LPM total test flow in a 2.87-inch ID aluminum mixing chamber with 12-inch in length. The test mask material embedded in a filter holder is mounted towards the downstream end of the mixing chamber, and the pressure drop across the test material is monitored by a pressure sensor.

Two particle counters with 20 nm lower cutoff sizes are used for measuring particle concentrations upstream and downstream of the mask material respectively, and the ratio between the upstream and downstream concentration values yields the corresponding mask filter efficiency.

Table 1 lists the parts and supplies needed to build this test system for size-dependent filter efficiency measurements.

Table 1. Bill of materials for the size-dependent filter efficiency test system

Item #	Description	Qty
1	NanoAerosol Generator, Kanomax Model 3250	1
2	Mass Flow Controller for air/nitrogen	1
3	High Efficiency Particulate Air (HEPA) filter	2
4	Customized mixing chamber with filter holder (aluminum duct, 2.87" ID, 12" L)	1
5	Particle Counter (size detection limit: 20 nm)	2
6	Pressure Sensor (0 - 60 mmH2O)	1
7	Static dissipative tubing, 1/4" ID	2 ft

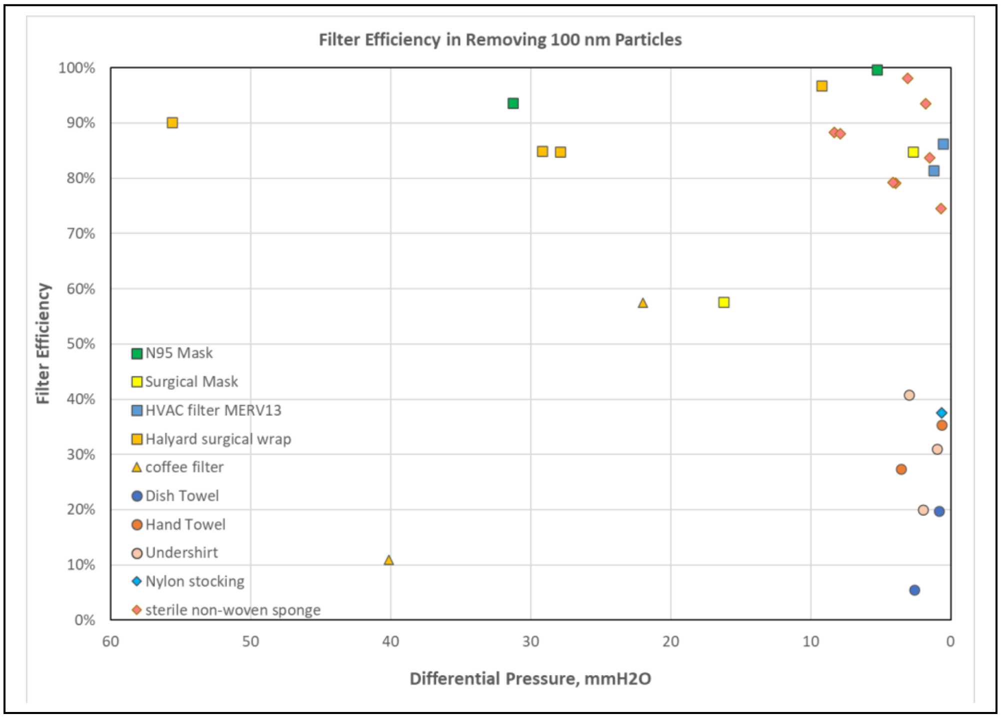
A total of 29 mask material types were tested in this study, the product description and material composition of each tested mask material is listed in Table 2.

Table 2. Mask material tested with the NAG setup

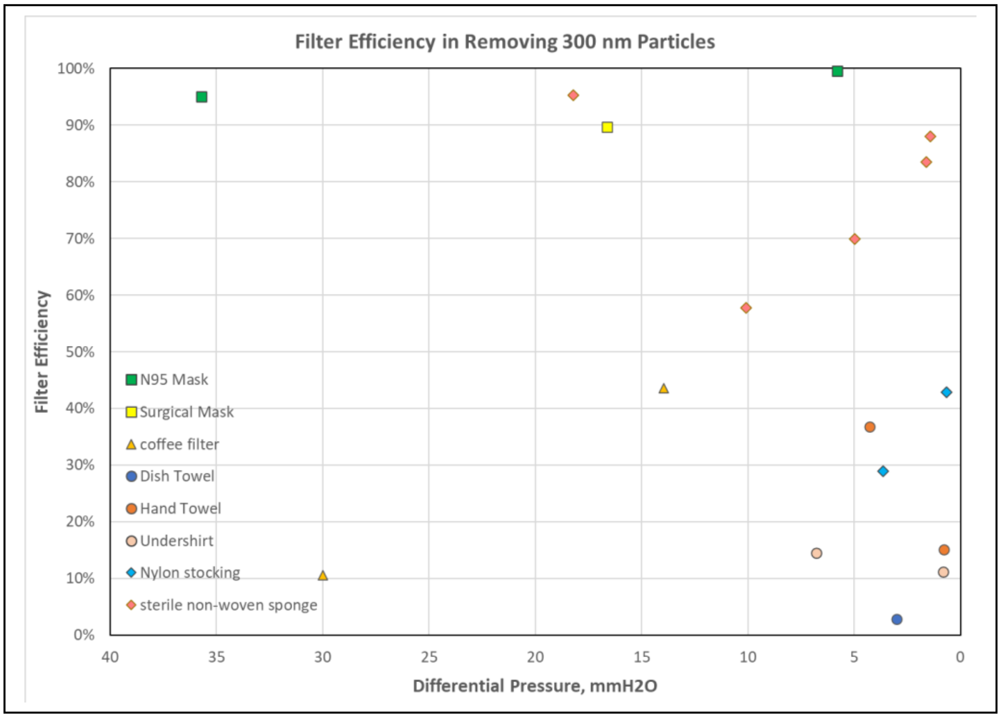
Material No.	Description	Material Composition	Material Category
1	N95 Mask		baseline
2	Surgical Mask		baseline
3	Monadnock	Monadnock	baseline
4	Sponge (Gauze)		woven cotton
5	Undershirt	Cotton	woven cotton
6	Pillowcase	Cotton	woven cotton
7	Bed sheet	Cotton	woven cotton
8	Hand Towel	Cotton	woven cotton
9	Dish Towel	Cotton	woven cotton
10	sterile non-woven sponge	polyester/rayon non-latex	nonwoven synthetic
11	melt blown polypropylene felt	polypropylene felt, 1.5 lbs./SQ. YD. Density, 1/8" thick	nonwoven synthetic
12	CH Surgical Gown Level III		nonwoven synthetic
13	NSWCPD cloth gaiter		woven synthetic
14	NSWCPD cotton mask	4 layers cotton fabric	woven cotton
15	Polypropylene Scrub Wipes	melt blown polypropylene	nonwoven synthetic
16	Cleanroom wipe	45% polyester / 55% cellulose nonwoven	nonwoven synthetic
17	Halyard surgical wrap		
18	Nylon stocking		woven synthetic
19	coffee filter		paper
20	P100 respirator cartridge		baseline

21	HVAC filter MERV13		filter, other
22	polyester sewing interfacing	melt blown polyester	nonwoven synthetic
23	activated carbon mask insert		filter, other
24	vacuum bag		
25	Buff wrap		
26	bandana	polyester	woven synthetic
27	Pellon fusible fabric interface		nonwoven synthetic
28	Air x MERV 13		filter, other
29	Filti Material	polypropylene/polyester	nonwoven synthetic

Filter efficiency test results for selected mask materials are plotted in Figure 7, with y-axis representing average efficiency in % and x-axis representing differential pressure across the test mask material in mmH_2O.



a. Filter efficiency with 100 nm test particles



b. Filter efficiency with 300 nm test particles

Figure 7. Filter efficiency test results of the 29 mask materials

ACCORDING TO THE TEST RESULTS SHOWN ABOVE, HVAC FILTER MEDIA, SURGICAL WRAP, AND STERILE NON-WOVEN SPONGE ARE THE BEST ALTERNATIVES FOR FACE MASKS AMONG ALL TESTED MATERIALS.

The optimal mask material needs to meet two requirements: high performance in filter efficiency and low differential pressure to ensure the user comfort. According to the test results shown above, HVAC filter media, surgical wrap, and sterile non-woven sponge are the best alternatives for face masks among all tested materials.

Conclusion

For particle measurement applications that are interested in obtaining size dependent information of a performance parameter, such as the filter efficiency evaluation for face mask materials, the NanoAerosol Generator (NAG) is a cost-effective alternative to electrical mobility-based size classifiers, and it is particularly ideal for applications that are also fond of fast response time in measurements.