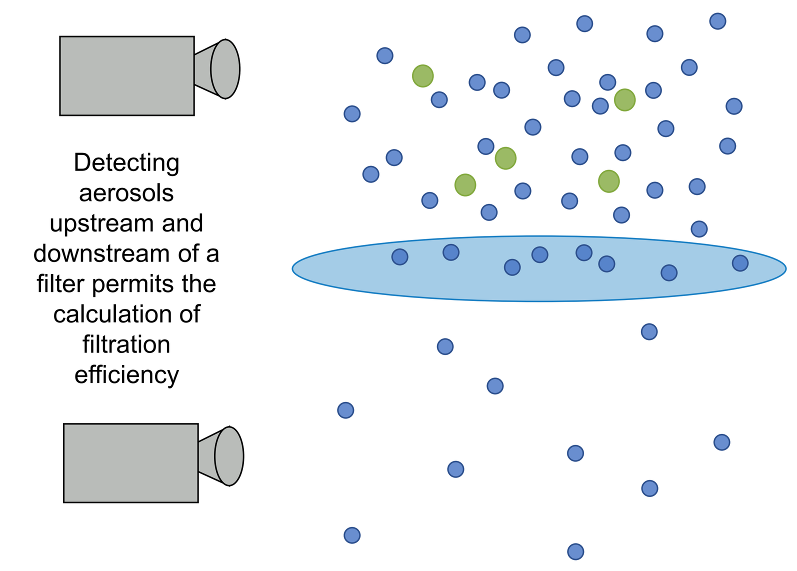


Air Filtration Basics

Testing a filter's efficiency at capturing particles sounds simple in principle, but the reality is more complex. Follow the process shown below to learn more. Be sure to read supporting documents listed under 'Resources'.

Executive Summary

Filter efficiency measurements are the result of several factors working in concert. Filter test results are affected not only by the performance of the filter itself, but also by challenge aerosol characteristics, detector design, and system setup.

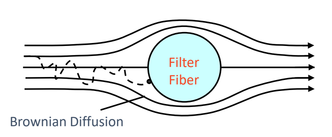
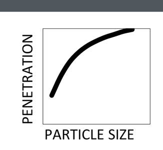
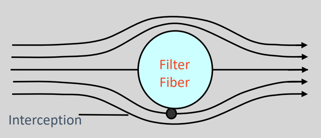
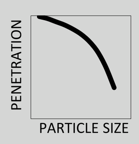
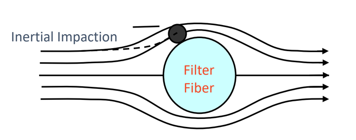
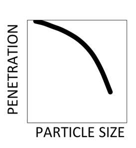
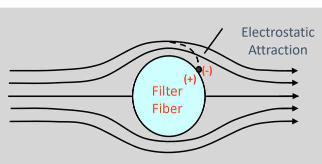
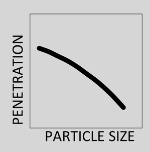
1. Particle Generation and Conditioning

Any filter testing process needs to start with generating aerosols. Once generated, the aerosol particles have to be prepared (conditioned) for use in the filter test.

		TSI Tools		
		Standalone Components	In Automated Filter Testers	
			8130A(-EN)	3160
Generation: Aerosol particles can be generated for filter testing in a few different ways:				
Wet processes	If the particle can be dissolved or suspended in a liquid (or is a liquid itself), then a 'wet' aerosol generation process is used. Atomizers and nebulizers are very common aerosol generators for such 'wet' processes. Examples of aerosols generated in this manner are the salt and oil particles commonly used in filter testing.	3076, 9306, 9307, 8108	X	X
Dry processes	If the particle is dry (such as dust or pollen), then a dry dispersion method is used.	3400A, 3410L, 3410U		
***Note:** Both wet and dry aerosol generation processes almost always create **polydisperse** aerosol – a collection of particles that are not the same size as each other. The formal measure for polydispersity is **geometric standard deviation, or GSD**. Polydisperse aerosols typically have GSD > 1.5. If a monodisperse aerosol is desired, see 'Size selecting', below.*				
Conditioning: Before the aerosols can be used to challenge a filter, they must be conditioned appropriately:				
Drying	If the aerosol generation process involved a solvent (such as water), drying removes it	3062	X	X
Neutralizing	Almost all aerosol generation processes result in final particles carrying an electrical charge. This is particularly the case for salt particles, which are commonly used in filter testing. This excess charge can bias filtration efficiency results. Neutralization removes this excess charge. Common neutralization techniques include radioactive sources and soft x-rays.	3012(A), 3054(A), 3088	X	X
Diluting	The concentration of the aerosols must be in an appropriate range for the detectors.	3302A and 3332	X	X
Size Selecting	In some cases, the aerosol will be size-selected prior to challenging the filter. The purpose of size selection is to remove all the aerosol – except for one size – from the sample stream. This turns a polydisperse aerosol into a ***monodisperse*** aerosol, which typically have GSD ≤ 1.1. Note that while the combination of "3082+3088+3081A" as mentioned at right does perform the size selection, Model 3940A offers a complete monodisperse generation solution, including wet generation, drying, neutralizing, and size selection. As a consequence of removing particles that are not the desired size, the size selection step lowers the concentration significantly. Size-selected challenge aerosol is used to develop a relationship between penetration and particle size; such a relationship is called a penetration curve.	3082 + 3088 + 3081A		X

2. How Do Filters Capture Particles?

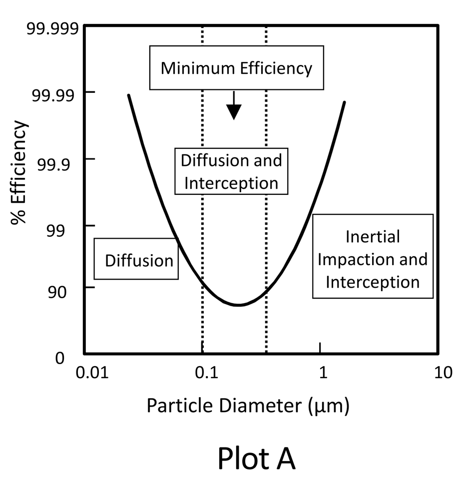
Filters are not like screens or sieves; instead, there are four distinct mechanisms which contribute to a filter's capture of particles. These four work together to produce a characteristic feature of filters, the *Most Penetrating Particle Size (MMPS).*

Mechanism	Description	Filter Performance
Diffusion	Action of Brownian motion. Capture of particles by filter is optimized when particles are small, filter fibers are fine, and velocities are low. Independent of particle density. 	
Interception	Particles travel along streamlines and are caught because of their size. Ratio of particle to fiber size is important. 	
Inertial Impaction	Particles deviate from streamlines due to inertia and impact on the fibers. Capture of particles by filter is optimized when particles are large and have a high material density, filter fibers are fine, and velocities are high. 	
Electrostatic Deposition	Particle is attracted to the fiber by electrical forces. Filter loading can reduce the influence of this mechanism; see below for more information on loading. 	

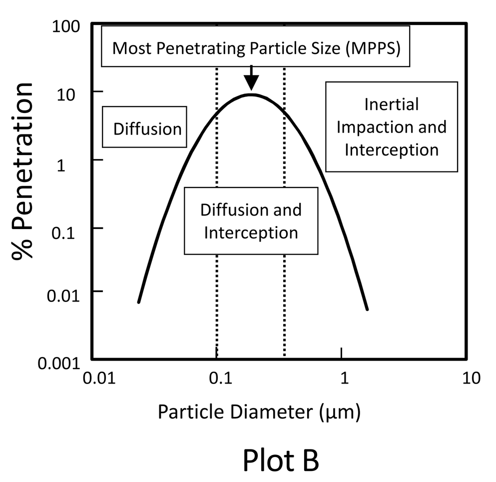
The four mechanisms described above work together to help a given filter capture particles.

The result is a characteristic size-dependent efficiency: a relationship between particle size and the efficiency with which a given filter will capture them. Plot A to the right shows this relationship. The formal name for this curve is a "fractional efficiency curve."

The inverse of this efficiency curve is a penetration curve, Plot B, to the right. The peak of the penetration curve is the Most Penetrating Particle Size, or MPPS. The MPPS is an important characteristic of a filter. MPPS sizes typically range from 100-300 nm for mechanical filter media, and as low as 40 nm for electrostatic filter media.



Plot A



Plot B

3. How are Particles Detected/Measured?

Particle detectors differ in their designs and capabilities. For the purposes of filter testing, they can be divided into two categories: those that detect one particle at a time, and those that detect a cloud of particles at one time.

It is important to pay attention to how aerosol properties affect the results provided by the various kinds of detectors. For example, the optical properties of an aerosol will affect how an optical instrument measures the particle's size.

Each technology has advantages and disadvantages. The key is to remember is that different technologies will produce different results; this is to be expected.

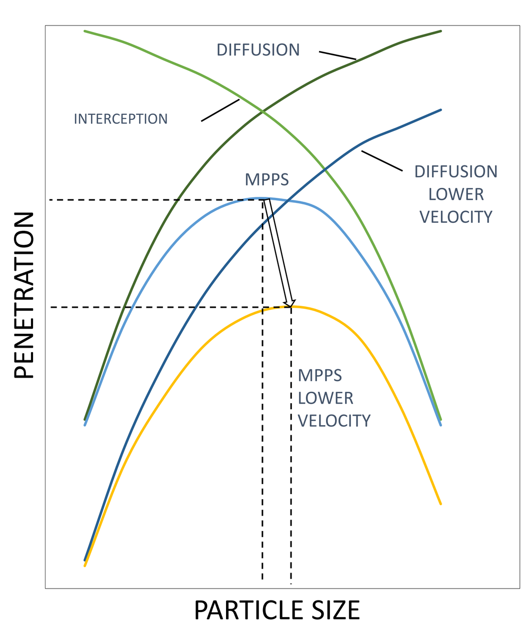
Device Type		Data	Notes	TSI Tools: Standalone Components	TSI Tools: In Automated Filter Testers
Single Particle Detection	CPC	Count	CPC's condense a 'working fluid' onto tiny particles to grow them large enough for a laser to count them. The working fluid is typically water or an alcohol.	375x, 3789	3160 [uses (2) 3750]
	OPC	Count, or Count & Size	Optical instruments detect particles via optical light scattering, without the assistance of a condensed working fluid. In addition to measuring particle count, most of these instruments provide a particle size distribution. This size distribution is based on optical equivalent size, which is influenced by the particle's optical properties.	3330, 3340A, 7110	N/A
	APS™	Count & Size	Aerodynamic particle sizers use the aerodynamic behavior of a particle to determine its size. These instruments provide a particle size distribution. This size distribution is based on aerodynamic size, which is influenced by the particle's density and shape.	3321	N/A
Collective Detection	Photometer	Total Light Scatter (voltage)	Instead of detecting one particle at a time, photometers look at a 'cloud' of aerosol collectively. The light scattered off of this cloud is quantified to indicate concentration. For more information, see the blog post listed under 'References'.	8587A	8130A [uses a dual photometer system]

4. How are Air Filters Tested?

At the most basic level, filters are tested by challenging them with particles, and measuring the concentration of those particles upstream and downstream of the filter. Other considerations also influence the results, though.

Face Velocity

Face velocity is the speed of the air as it passes through the plane (or 'face') of the filter. A given volumetric air flow rate will produce a higher face velocity as it passes through a filter if that filter is smaller. Filters must be tested at face velocities that are either in agreement with a standard, or that are relevant to their intended use.



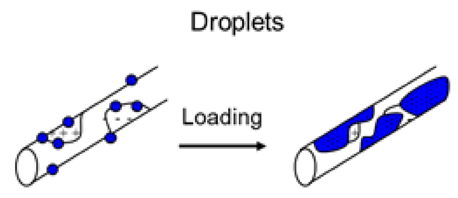
Face velocity affects the 'diffusion' mechanism of particle capture described above; because of this, a change in face velocity will change the measured MPPS of a filter.

Loading

Loading is the accumulation of captured particles on a filter over the course of its use. This accumulation can affect the efficiency of the filter. As shown below, the effects of loading differ between solid and liquid particles.

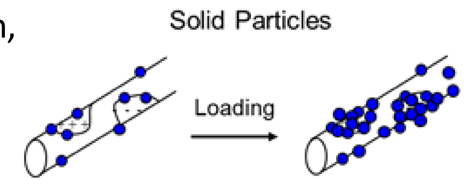
Liquid Particles (Droplets) reduce filter efficiency for two reasons:

- Liquid particles very efficiently shield electric charge sites, reducing particle capture via the electrostatic mechanism. This increases filter penetration.
- Even for mechanical (i.e. not electrostatic) media, loading with droplets can increase penetration slightly because the liquid droplets coat the filter fibers, increasing fiber diameter. This increases air velocity, which decreases particle capture by the diffusion mechanism.

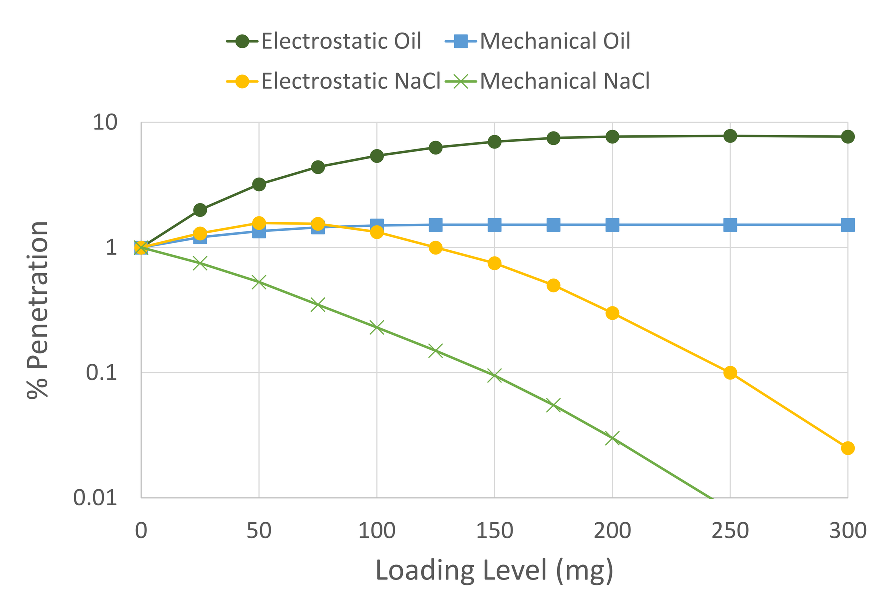


Solid Particles accumulate on the fibers and build 'dendrites'. This accumulation can have two effects on filter penetration, in opposite directions:

- Shielding of charge sites reduces particle capture via the electrostatic mechanism, increasing filter penetration. This effect is less pronounced with solid particles than it is with liquid.
- The growing dendrites serve as additional capture locations for incoming particles via any of the other three mechanisms. This effect is dominant over the shielding effect.



In order to measure how a filter will perform as it accumulates particles (and thus, how well it will protect the people and devices downstream of it), filter testing often includes a "Loading" step, where the filter is intentionally (and rapidly) loaded with captured particles, and its efficiency measured during this process. For example, testing of respirators requires a loading step, to demonstrate how a respirator will perform as it loads with particles during normal use.



5. How is Filter Efficiency Calculated?

The efficiency of the filter being tested is calculated using the data provided by the upstream and downstream detectors. This data may be count-based concentrations, or photometer voltages indicative of total light scatter. Regardless, the filter efficiency is calculated using these equations:

$$Penetration = \frac{C_{down}}{C_{up}}$$

$$Efficiency = 1 - Penetration = 1 - \frac{C_{down}}{C_{up}}$$

Resources

1. "Why are photometers used for air filter testing?" Blog post, https://tsi.com/blog/tsi-blogs/research-academia-blog/january-2019/why-are-photometers-used-for-air-filter-testing/

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