HEPA FILTER MEDIA TESTING: 1950 – 2000

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Abstract

This paper will review the basic instrument components for filter media efficiency testing and the instruments commercially available today. The paper will include a discussion of the relationship between MPPS (most penetrating particle size) penetration and 0.3 µm penetration.

1.Background

High efficiency filters were first researched and designed for use in gas masks during WWII. They contained a filter medium composed of a blend of fine asbestos fibers and cellulose fibers. It was during this time that Irving Langmuir developed his theory for physical capture of small particles by a fibrous filter medium and his conclusion that the most penetrating particle size was 0.3 µm led to the development of a filter test instrument by LaMer and Sinclair that used heated dioctyl phthalate smoke as a test aerosol. Air Techniques, Inc now produces this type of tester. Although the most penetrating particle size of high efficiency filter media is now known to be smaller than 0.3 µm, the filter test standards in place today were written based on 0.3 µm efficiency using the LaMer and Sinclair instrument.

After WWII the driving force for the development of high efficiency filter media was the need for the containment of radioactive aerosols within nuclear reactors. The original filter media for these applications was still an asbestos/cellulose blend, but a fire in the Windscale, UK site in 1957 led to the development and change over to HEPA filters made from non-combustible fine glass fibers with low percentages of organic binders.(1)

From 1970 on the primary market driver for the development of high efficiency filter media has been the electronics industry. In semi-conductor chip manufacturing, filtration is required to protect the product from particulate contamination rather than to protect personnel. ICP chip manufacturing evolution in clean room environments with smaller and smaller line distances led to the need for ultra low penetration air (ULPA) filter media and filter testing based on most penetrating particle size (MPPS) at the rated flow. Aerosol detectors and generators have been developed and are commercially available that satisfy these requirements. Two Institute of Environmental Sciences recommended practices, RP007 and RP021, and the proposed European standard CEN 1822 have been written based on MPPS efficiency determinations using particle counting test systems.

This newer technology has provided filter media manufacturers and users with good alternatives for filter test systems. In this paper I will provide an overview of these systems outlining some of the benefits and disadvantages of each.

2. Filter Test System Components

The five major components needed to build a filter media test system are: an air supply, air flow control and measurement, aerosol generation, aerosol size and concentration measurement (upstream and downstream of the test sample), and pressure differential measurement across the test sample. The components that I will focus on in this discussion are aerosol generation, aerosol size measurement and aerosol concentration measurement.

3. Methods of Measuring Filtration Efficiency

There are two ways of measuring the fractional efficiency of a filter medium. One is to generate a monodisperse aerosol to challenge the sample and then measure the concentration of that aerosol upstream and downstream. An aerosol with a geometric standard deviation, $\sigma_g = 1.0$ is monodisperse while one with a σ_g >/= 2.0 is considered polydisperse. If one is interested in the efficiency of a single particle size, such as 0.3 µm for HEPA filter media, this test can be done quite rapidly. The test time using this technique is lengthened when the efficiency of a number of different particle sizes is desired. The other method is to generate a polydisperse aerosol and then measure particle size and concentration upstream and downstream. Particle counters with sizing capability may be used to determine full efficiency curves using this technique. A relatively new hybrid technique where a narrow distribution polydisperse aerosol is generated that has a median count diameter near the MPPS diameter and a non size discriminating detector is used to measure upstream and downstream aerosol concentrations. This technique has been shown to have good correlation to the MPPS penetration (2)

4. Aerosol Generation

Monodisperse aerosol generators

In the DOP smoke tester dioctyl phthalate is vaporized in a heated chamber and then quenched in a cooling chamber to form an aerosol aerosol of DOP droplets. By carefully controlling the heating and cooling temperatures a monodisperse aerosol with a mean diameter of 0.3 µm may be obtained. Either an optical or electronic owl measures the particle size of this aerosol. An owl is an instrument that measures the particle size by measuring the ratio of scattered light at two polarizations.(3) Figure 1 is a schematic of the optical owl.

The aerosol generated has a high concentration of particles and may be easily detected by an optical photometer. The critical parameter for this type of generator is temperature control to maintain the mean particle size and distribution width. The photometer response is proportional to the particle diameter raised to the sixth power and the number of particles in the upper tail of the distribution can effect the penetration result.

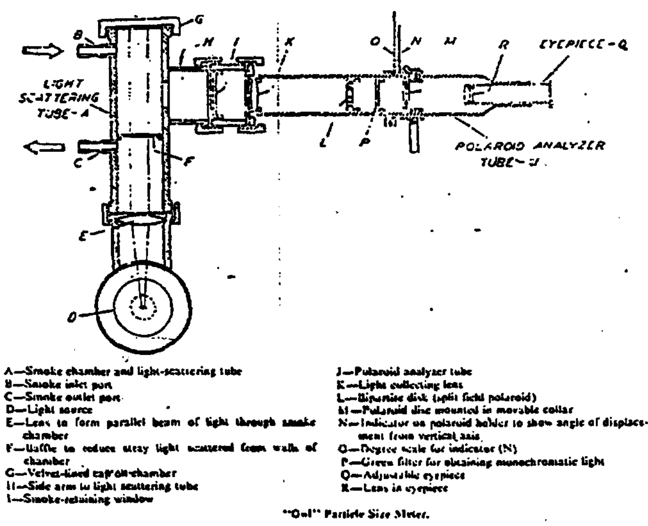
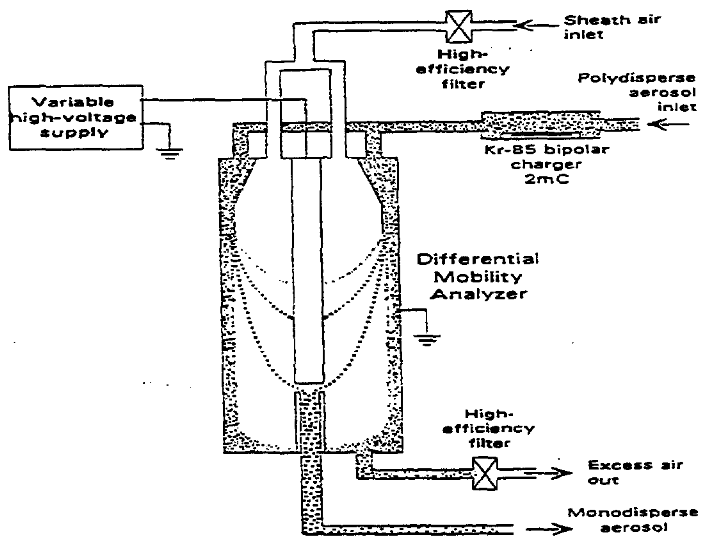


Figure 1.
Schematic of the optical owl

Monodisperse aerosols may also be generated by first generating a polydisperse aerosol by atomization and passing this aerosol through a differential mobility analyzer (figure 2.). A DMA extracts a narrow size range of particles from a polydisperse aerosol. The particle size that passes through the exit slit is dependent on the electrical mobility of the particles.(4) The desired particle may be tuned by adjusting the charge potential on the central core. The monodisperse aerosol generated by this technique has relatively low concentration since it is only a fraction of the total aerosol. For this reason they are typically used in conjunction with condensation particle counters and not photometric detectors.

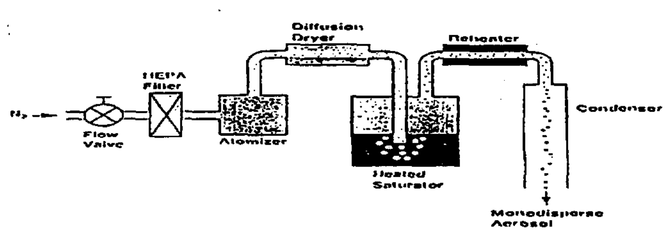
Figure 2.



Schematic of a differential mobility analyzer.

A third type of monodisperse aerosol generator is the condensation aerosol generation. The principal of operation for this generator is the condensation of a supersaturated vapor to form uniform size droplets. The vapor is typically a high vapor pressure liquid such as DOP and condensation may initiate on smaller seed particles, commonly salt. The advantage of this generator is that it produces a high concentration of monodisperse aerosol over a broad particle size range (0.1-8.0 μm) at room temperature. It is useful for testing larger filters.

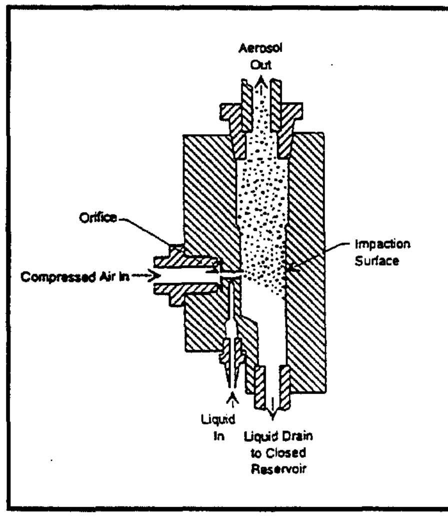
Figure 3.



Schematic of a condensation aerosol generator that uses seed particles.

Polydisperse aerosol generators

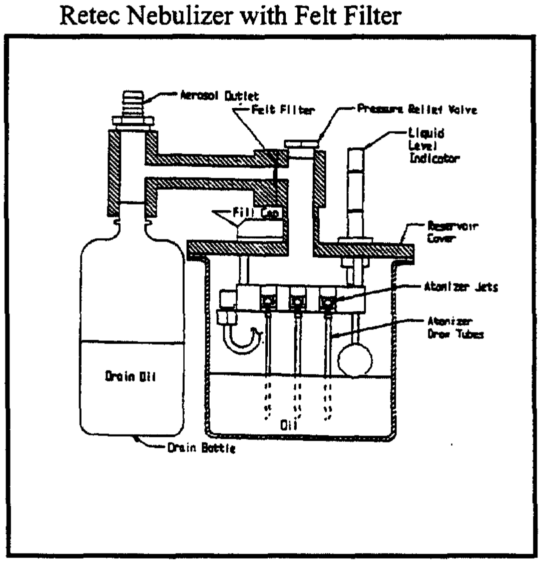
Figure 4.



Atomization is one of the most common methods of generating polydisperse aerosols. Both liquid and solid aerosols are easily produced by atomization (figure 4) . Liquid is pulled through an orifice by creation of a partial vacuum on the surface of the liquid . The mean particle size of the aerosol is proportional to the concentration of aerosol material in the solution. A Laskin nozzle is another type of atomizer, which produces a high concentration of polydisperse aerosol.

A third type of polydisperse generator, The Retec generator, is an oil atomizer with a felt filter positioned at the output (figure 5).(5) The felt filter effectively narrows the size distribution of the final aerosol . Particles in the small end of the distribution are captured by diffusion and the large particles are removed by inertial impaction. By careful choice of filter felt it will produce an aerosol with a median particle size of 0.2 μm which is near the MPPS for HEPA media at rated flow. This generator has the advantage of producing a stable, high concentration aerosol at room temperature. A similar generator generates solid aerosols where the filter felt is replaced by an impaction plate.

Figure 5.
Retec Nebulizer with Felt Filter

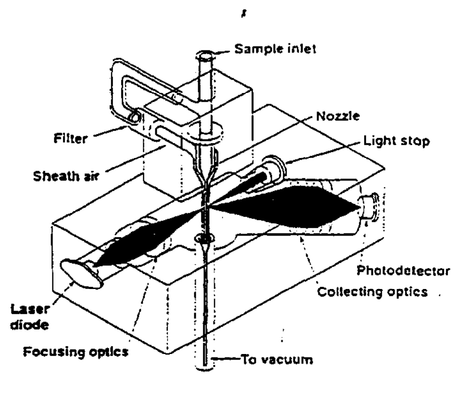


5. Aerosol Detection

Photometers

Photometers measure light scattered from a cloud of particles that passes through a focused light beam. Figure 6 is a schematic of a photometer. They are useful for measuring filter penetrations as low as 0.001% and are used in the hot DOP filter test instruments. Photometric measurements are relative rather than absolute and do not necessarily have to be calibrated for the specific aerosol being measured. The advantage of photometers is that they are low cost and generally low maintenance instruments.

Figure 6.



Schematic diagram of an aerosol photometer.

Optical Particles Counters (OPC)

Figure 7.
Schematic of an Optical Particle Counter

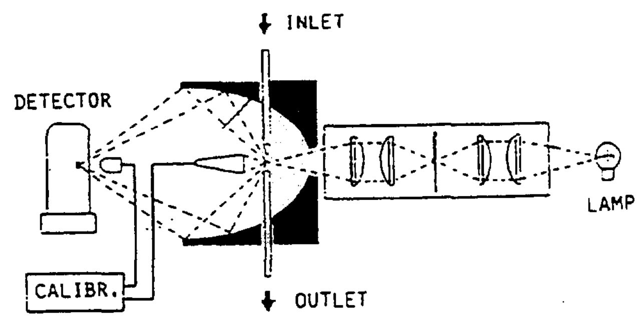
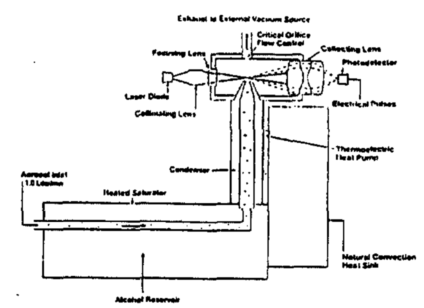


Figure 7 is a basic schematic of an optical particle counter. It is able to detect particles as they pass through a narrow slit that is illuminated by a light source. As each particle passes through the slit the light scattering will cause a voltage response in the photodetector. The particle size is proportional to the signal amplitude. OPC's may be powered by either white or laser light sources. Laser OPC's have the capability of sizing particles as small as 0.12 µm diameter. If multiple particles pass through the view volume simultaneously the instrument sees a single larger particle. This is considered a coincidence error. Coincidence errors will occur if high concentration aerosols are introduced. Therefore, it is normally necessary to dilute the upstream aerosol in a filter test before measuring the particle size and concentration. The other disadvantage that laser OPC's may have is a low signal to noise ratio. The advantage of laser OPC' is that they have both sizing and concentration measurement capability so a polydisperse aerosol may be used to challenge the sample filter.

Condensation Particle Counter (CPC)

Condensation particle counters detect individual particles in concentrations from zero to 10^5 particles/cm^3 . Figure 8 is a schematic of this instrument. In a CPC particle size is enlarged by passing the aerosol through a chamber of supersaturated liquid, typically butyl alcohol, and then through a condensing chamber where the alcohol nucleates on the aerosol particles and they grow large enough to be easily detected by an optical counter. CPC' s do not have particle sizing capability so they are typically designed in conjunction with a monodisperse aerosol generator such as a DMA or condensation aerosol generator.

Filter test systems have been successfully designed using CPC's and the filtered oil aerosol generators. It has been shown that this type of filter tester gives a penetration that correlates very closely to the MPPS penetration over a broad range of filtration efficiencies. (3) (figure 9).



Schematic of a single-particle-counting condensation particle counter.

Figure 8.

Further testing has shown good correlation between this type of tester and the traditional hot DOP smoke filter tester. (Figure 10)(6). The intercept does not pass through zero because the MPPS penetration will be higher than 0.3 μm penetration.

Figure 9.

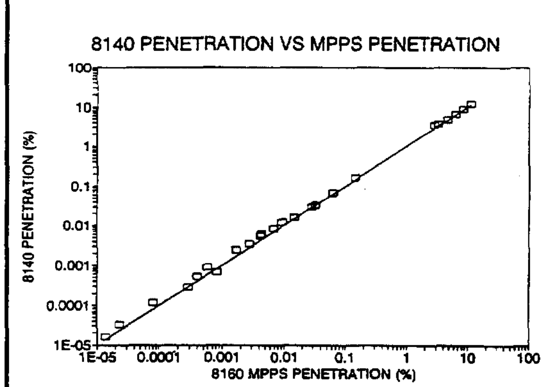
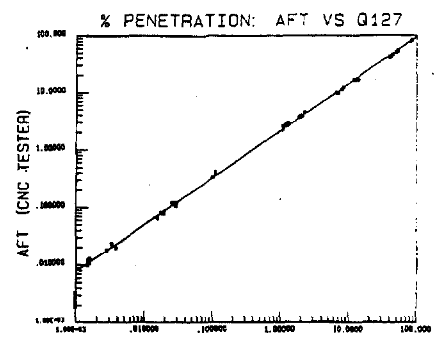


Figure 10.



Comparison graph of AFT and Q-127 penetration data.

Using empirical filter penetration models that were presented in two earlier air cleaning conferences(2 & 7), an estimate may be made of the typical and maximum MPPS penetration of a HEPA filter medium sample at 10.5 fpm, the standard test velocity for media, and at 5.0 fpm, or the typical face velocity of media in filters. A summary of this estimate is given in table 1.

Table 1.
Penetration Summary of HEPA media at 10.5 and 5.0 fpm Face Velocity

	MPPS	0.3 μm
10.5 fpm	(0.13 μm)	
Typical Penetration (%)	0.075	0.015
Maximum Penetration (%)	0.100	0.030
5.0 fpm	(0.15 μm)	
Typical Penetration (%)	0.017	0.007
Maximum Penetration (%)	0.035	0.015

Scanning mobility particle sizer

The scanning mobility particle sizer (SMPS) combines two components previously discussed, the differential mobility (DMA) and the condensation particle counter (CPC). A polydisperse aerosol entering a DMA is size classified and sent to a CPC for concentration measurement. The voltage scan for the DMA is controlled and the concentration from the CPC is measured by a computer that de-convolutes the raw data to a particles size distribution The SMPS is most useful for high concentration stable aerosols. It is the only size discriminating detector that can accurately measure particles below 0.1 µm.

6. Conclusions

Filter testing technology has advanced significantly since the 1950's when high efficiency filter media was first developed. Laser OPC's and CPC's are industry accepted detectors capable of measuring particle sizes that include the MPPS. Aerosol generators that will deliver monodisperse and near monodisperse stable aerosols at concentration levels suitable for filter and filter media testing are also commercially available.

Comparisons of the particle count based testing with the standard hot DOP smoke testers have demonstrated that there is good correlation between the 0.3 µm penetration and the MPPS penetration. This testing technology should be considered an acceptable alternative to the DOP test.

References

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