EVALUATION OF GLASS FIBER HEPA FILTERS AS A FUNCTION OF MEDIA VELOCITY

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ABSTRACT

The Department of Energy currently employs high-efficiency particulate air (HEPA) filters in a variety of applications, such as particulate matter removal from ventilation air and treatment of off-gasses from storage or remediation of mixed wastes. Section FC of the ASME AG-1 Code addresses glass fiber HEPA filters and restricts the media velocity to a maximum of 5 ft/min. Advances in filtration media technology now allow glass fiber HEPA filters to function at significantly higher velocities and still achieve HEPA performance. However, no rigorous testing has been performed that can provide policymakers with data needed to determine optimal operating conditions with respect to media velocity. Of particular interest is the removal of ultrafine (< 100 nm) particulate. Because ultrafine particles are removed by a diffusive capture mechanism, increasing media velocity would result in shorter residence times within the media matrix. Therefore, it is highly unlikely that higher media velocities for HEPA filters will be allowed without data to demonstrate the effect of media velocity on removal of particles in the smaller size range. In order to address this issue, static testing has been conducted to generate performance related data and a range of dynamic testing has provided data regarding filter lifetimes, loading characteristics, changes in filtering efficiency and the most penetrating particle size over time. Results of this testing will be provided to the ASME AG-1 FC Committee for consideration in future versions of the HEPA standard.

INTRODUCTION

High-efficiency particulate air (HEPA) filters are commonly employed to control particulate matter (PM) emissions from processes that involve management or treatment of radioactive materials. Facilities within the United States Department of Energy (DOE) complex are particularly likely to make use of HEPA filters in the processing of exhaust gases prior to release to the environment.

Section FC of the ASME AG-1 Code addresses glass fiber HEPA filters and restricts the media velocity to a maximum of 5 ft. min^{-1}. Due to advances in filtration media technology, some glass fiber HEPA filters can operate at higher media velocities and still achieve the definitional > 99.97 % filtering efficiency for 0.3 μm dioctyl phthalate (DOP) particles and meet other performance requirements, such as pressure drop across the filter. However, no rigorous testing has been performed that can provide policymakers with data needed to determine optimal operating conditions with respect to media velocity. In addition, concerns for ultrafine particles in ambient air make it unlikely that higher media velocities for HEPA filters will be allowed without data to demonstrate the effect of media velocity on removal of particles in the smaller size range (< 100 nm). Ultrafine particles are removed by a diffusive capture mechanism which is reduced for shorter residence times within the media matrix.

This testing reported in this manuscript involved evaluating filter performance under a range of media velocities from 3.8 to 8.8 ft. min^{-1} with a solid potassium chloride challenge aerosol with a count mean diameter of approximately 155 nm Stokes diameter and a geometric standard deviation of approximately 2. These data will demonstrate the effect of media velocity on overall filtering efficiency and most penetrating particle size for new filters as a function of media velocity.

EXPERIMENTAL

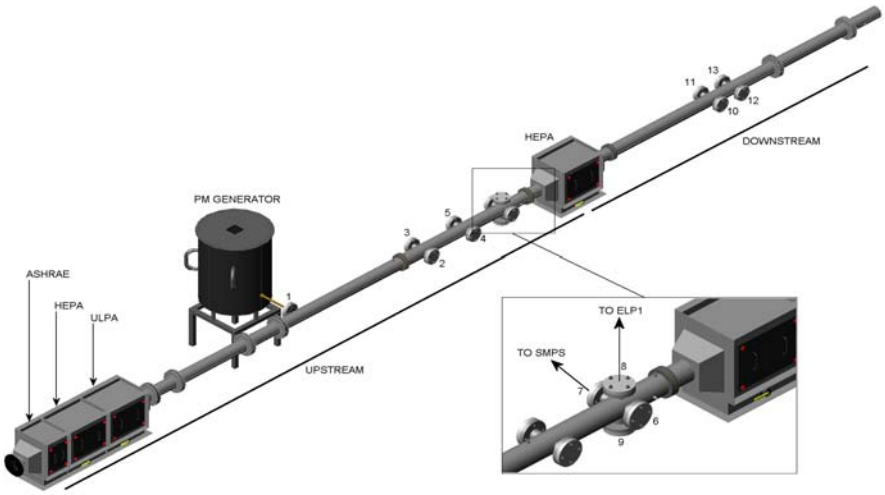
Filter Test Stand and Aerosol Generation

Filters were tested using the Institute for Clean Energy Technology (ICET) HEPA Filter Monitoring Project Test Stand. The test stand consists of a filtered air intake section, two venturi flow meters, a particle injection section, an upstream sampling section, the HEPA filter housing, and a downstream sampling section. A schematic of the facility is depicted in Figure 1.

Inlet air is filtered free of particles to below detectable levels with an ASHRAE filter, a HEPA filter, and an ULPA filter and is drawn into the test stand with a vortex blower. The test stand is constructed of stainless steel tubing with an electro polished inner surface to minimize particle deposition. Sampling ports located upstream and downstream of the HEPA filter housing facilitate aerosol measurements. Pipe fittings have been placed along the length of the stand for affixing thermocouples and relative humidity meters. For these test, the relative humidity was maintained at 20 % by the addition of dry air. Appropriate distance has been provided between the PM injection

and measurement locations to allow mixing of the PM upstream of the filter and the ports where measurements are made.

Figure 1. Aerosol Generator and HEPA Filter Test Stand



The HEPA filter undergoing testing is housed in an AG-1 series (non-bag in/out) stainless steel unit manufactured by Flanders Inc. It accommodates a standard 12 in. x 12 in. x 11.5 in. HEPA filter with a front face gasket. Filters used in this study are AG-l nuclear grade HEPA filters that have been acquired from Flanders Filters Inc. Nuclear grade HEPA filters are normally individually tested with dioctyl phthalate (DOP) to ensure that they are compliant with all specifications. However, to prevent any possibility of DOP residue from interfering with this testing effort, filters used in this study were provided without DOP testing. A dual set of differential pressure transducers along with a Magnehelic pressure transmitter determines the differential pressure across the test HEPA filter.

Potassium chloride (KCl) test aerosol was generated by evaporation of an aqueous 30 % (w/w) solution that was introduced to an aerosol generation chamber via an air atomizing nozzle. This atomizing nozzle is a ¼ in. J SS stainless steel nozzle body with a SU1A SS stainless steel spray set up. A gear pump is used to deliver liquid to the air atomizing nozzle. The aerosol generation chamber is a stainless steel tank 30 in. in diameter and 38 in. in height. The walls of the tank are heated to 200 °F to aid in the process of drying the challenge aerosol and to reduce thermophoretic wall losses. The top of the generation chamber is fitted with a halo made from one inch copper tubing to facilitate addition of dry heated air. This sheath air stream is controlled at 130 liters per minute and is heated by an oven manufactured by Apex Instruments. The oven uses four finned high density strip heaters capable of heating the drying air to approximately 450 °F. The temperature of the air stream as it exits the sheath air halo at the top of the generation chamber is nominally 200 °F. This configuration allows addition of the drying air in a manner so as to reduce wall deposition and increase generation efficiency of the unit.

Aerosols exits the chamber via a one inch diameter stainless steel tube located approximately 10 inches from the bottom of the tank. This exit tube is fitted with a downward pointing 90 degree elbow located along the midline of the chamber. A cyclone is located between the particle generator and the test stand and is employed to remove a majority of the particles larger than 3 μm in diameter. This aerosol generator produces a test aerosol of the stable mass loading rate of approximately 30 mg m^{-3} at a volumetric flow rate of 250 scfm with a count mean diameter of approximately 155 nm. Particle number concentrations are on the order of 10^5 cm^{-3}.

Aerosol Measurement Instrumentation

Upstream particle size distributions were measured with a scanning mobility particle sizer (SMPS) (TSI Inc., model 3936-L22) operating at a sample flow of 0.3 L min^{-1} and sheath flow of 3.0 L min^{-1}. This instrument passes the aerosol stream through a differential mobility analyzer which outputs a monodisperse aerosol with a known diameter to charge ratio that is counted with a condensation particle counter (CPC). Upstream measurements were also made with a TSI aerodynamic particle sizer and a Dekati electrical low pressure impactor.

Downstream measurements were made with a Particle Measuring Systems micro-laser particle counter. This instruments sizes particles from 0.07 to 1.0 μm into seven size classes, plus an oversize class. This laser based optical instrument is ideally suited for generating particle size distributions downstream of HEPA filters. Total downstream particle concentrations were also measured with a TSI CPC.

RESULTS

Figure 2 illustrates initial ΔP as a function of media velocity for nuclear grade AG-1 HEPA filters tested. The linear relationship between ΔP and media velocity demonstrates that filtration will take place in the Darcy Law regime. Media velocity is defined as the volumetric flow rate divided by the filtration surface area.

Figure 2. Variation of initial differential pressure with media velocity.

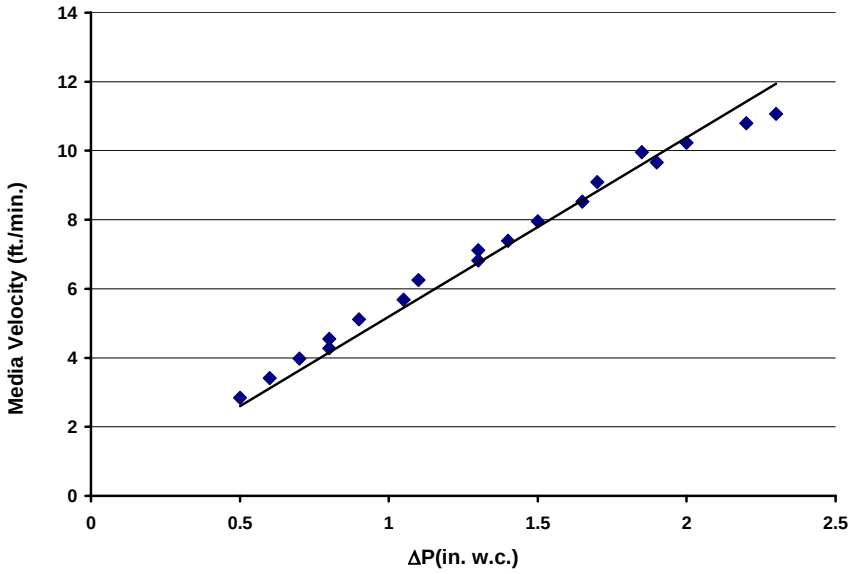
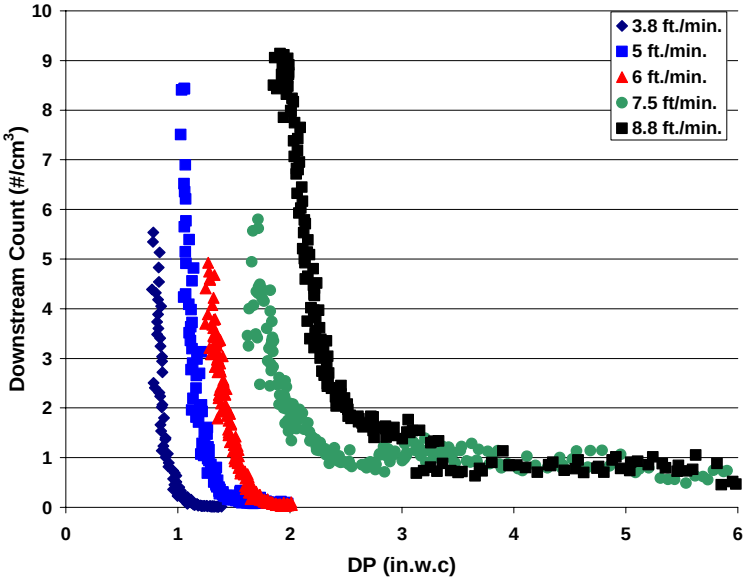


Figure 3 illustrates the typical relationship observed as the filters were loaded between downstream particle count and the differential pressure across the filter.

Figure 3. Downstream particle concentration as a function of differential pressure.

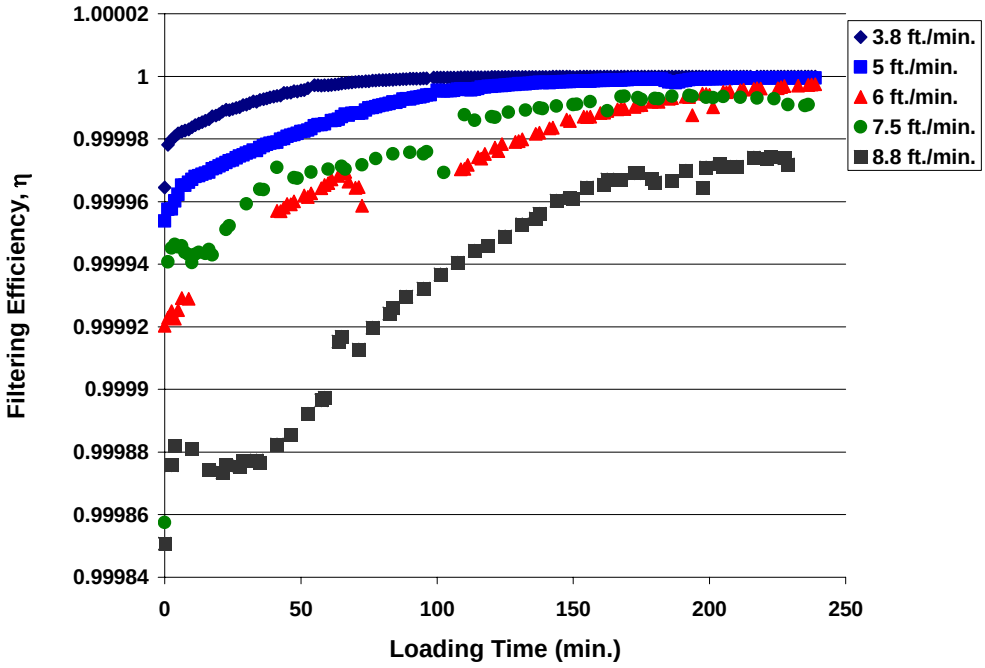


The data show an initial rapid decrease in the downstream particle concentration at the onset of filter challenge. For media velocities of 3.8, 5 and 6 ft. min^{-1}, the downstream particle count decreases to less than 0.1 particles cm^{-3} after achieving a 0.6 in. w.c. increase in ΔP. However, downstream particle counts at 7.5 and 8.8 ft. min^{-1} are

approximately 1 particle cm^{-3} at 3 in. w.c. and remain so though the duration of testing (to 6 in. w.c.).

The overall filtering efficiency during the first four hours of challenge for media velocities ranging from 3.8-8.8 ft. min^{-1} is shown in Figure 4. Filter efficiency,η, is defined as: $\eta = \frac{N_1 - N_2}{N_1}$, where N_1 is the concentration of aerosol entering the filter and N_2 the aerosol concentration leaving the filter.

Figure 4. The variation of overall filter efficiency with media velocity.



We observe a general decrease in filtering efficiency with increasing media velocity, but under no condition is filtering efficiency below 99.97 %.

Figure 5 presents the geometric mean of the particle size distribution measured downstream of the filter at increasingly higher ΔP. The general trend for media velocities 3.8-6 ft. min^{-1} is a decrease in the downstream geometric mean as the filter loads. However, the downstream geometric mean appears to increase for media velocities of 7.5 and 8 ft. min^{-1}. Additionally, the first point in each curve reveals that the initial downstream geometric mean decreases with increasing media velocity, although there is a slight increase on going from 7.5 to 8.8 ft. min^{-1}. This behavior is expected, as particles less then 100 nm are removed almost exclusively by diffusional capture, and those less than 500 nm are removed by a combination of diffusion and interception and increasing the media velocity decreases the residence time of particles in the filter media.

Figure 5. Downstream geometric mean vs. media velocity.

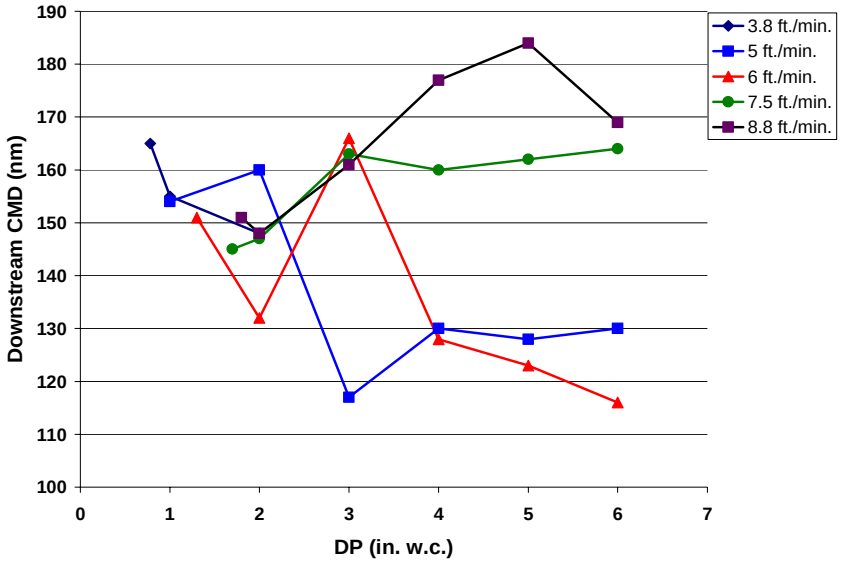


Figure 6 illustrates penetration vs. particle size, averaged over the initial hour of filter challenge. The most penetrating particle size does not span a wide range and is from 145 to 165 nm. Figure 6 also illustrates why the initial downstream geometric mean (Figure 5) increased at 7.5 ft min^{-1} relative to that at 8.8 ft min^{-1}: not only more smaller particle pass though the filter at 8.8 ft min^{-1}, an even greater number of "larger" particles escape filtration at the higher media velocity.

Figure 6. Penetration as a function of particle size for different media velocity.

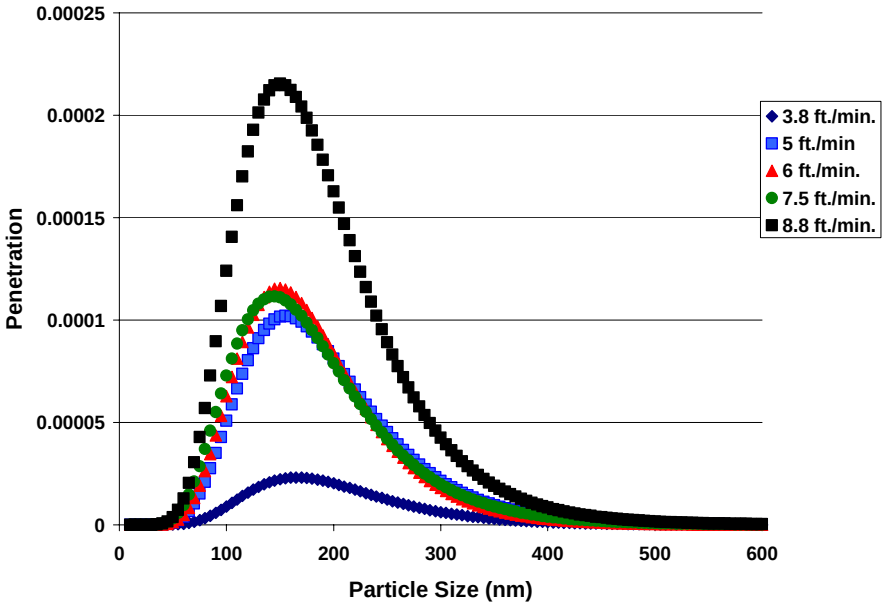


Table 1 shows the initial differential pressure and final differential pressures of the loaded filter, as well as the gravimetrically determined mass of particulate captured on the filter. Normalizing the mass capture to reflect the amount of particulate capture per inch of w.c. increase shows an excellent agreement for media velocities of 5-7.5 ft min^{-1}, however substantially less material is captured per in. w.c. increase at 8.8 ft. min^{-1}.

Table 1. Gravimetrically determined mass captured on the filter

Media Velocity	Initial ΔP	Final ΔP	Mass Captured	Mass Captured / 1 in. w.c. gain
5.0 ft min^{-1}	1.04 in w.c.	5.91 in w.c.	193 g	39.6 g
6.0 ft min^{-1}	1.27 in w.c.	5.90 in w.c.	172 g	37.1 g
7.5 ft min^{-1}	1.68 in w.c.	6.05 in w.c.	165 g	37.8 g
8.8 ft min^{-1}	1.85 in w.c.	5.93 in w.c.	113 g	27.7 g