Evaluation of Glass Fiber Hepa Filters as a Function of Media Velocity

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ABSTRACT
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 filter media technology allow glass fiber HEPA filters to function at significantly higher velocities and still achieve HEPA performance. Ultrafine particles (< 100 nm) are removed by a diffusive capture mechanism. The removal efficiency of these particles is reduced at higher media velocities due to shorter residence times within the media matrix. Therefore, it is 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 classes. Additional questions remain regarding particle loading and filter lifetimes at higher media velocities. In order to address these issues, nuclear grade AG-1 HEPA filters obtained from two manufacturers have been evaluated at media velocities ranging from 4 to 8.8 ft./min. KCl was utilized as aerosol challenge material and data regarding filter lifetimes, loading characteristics, changes in filtering efficiency and the most penetrating particle size are presented. Results of this testing will be provided to the ASME AG-1 FC Committee for consideration in future versions of the HEPA standard and will be useful for the development of air filtration systems in a nuclear environment.

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. With 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.

Here we present the results of media velocity dependent studies were performed utilizing 12 in.x12 in.x11.5 in. deep-pleat nuclear grade AG-1 HEPA filters supplied from two manufacturers (Flanders and Camfil Farr). Testing was conducted at media velocities ranging from 4.0-8.8 ft./min. using a solid challenge aerosol composed of KCl. Two set of media velocity data were obtained for each filter type. In one set of evaluations, the maximum aerosol challenge particle size was limited to 3 μm, while particles above 3 μm were not constrained in the second set. This provided for considerable variability in the challenge mass mean diameter and overall mass loading rate. 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

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 thorough description of the test stand has been given elsewhere [1], and a brief description will be given here. 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 electropolished 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.

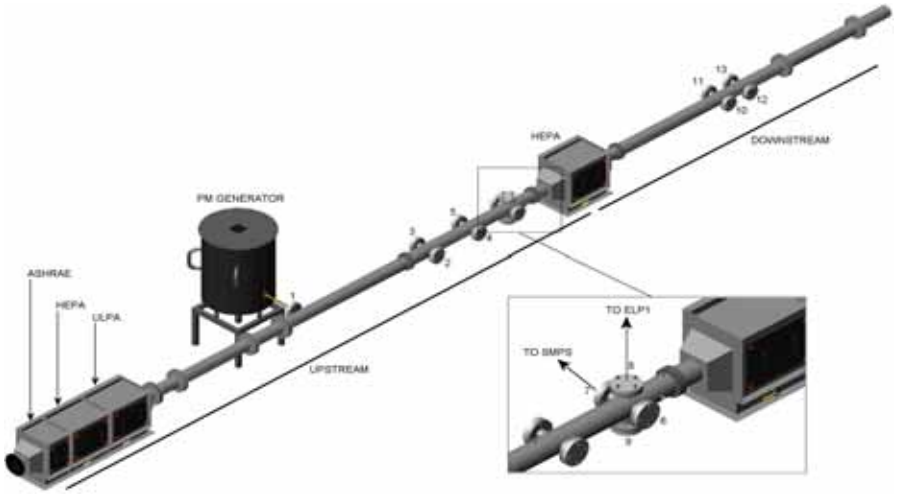

Fig. 1. The ICET HEPA filter test stand and aerosol generator.

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.

AEROSOL GENERATION

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. The generation chamber and location relative to the test stand can be seen in Figure 1. The 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 and delivers dry aerosol at the filter face.

Aerosol Measurement Instrumentation

All 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

Plotting the initial, clean, ΔP vs. media velocity HEPA filters demonstrates a linear relationship, thus indicating 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 demonstrates the relationship of the downstream geometric mean with ΔP for Flanders filters. Data is shown for filters loading with the 3 μm cyclone in place and without the cyclone. The MMD of the aerosol stream when the cyclone was used was approximately 1.5 μm and approximately 3.5 μm when the cyclone was not in place. The number concentrations was generally around $1x10^5$ cm^{-3}.

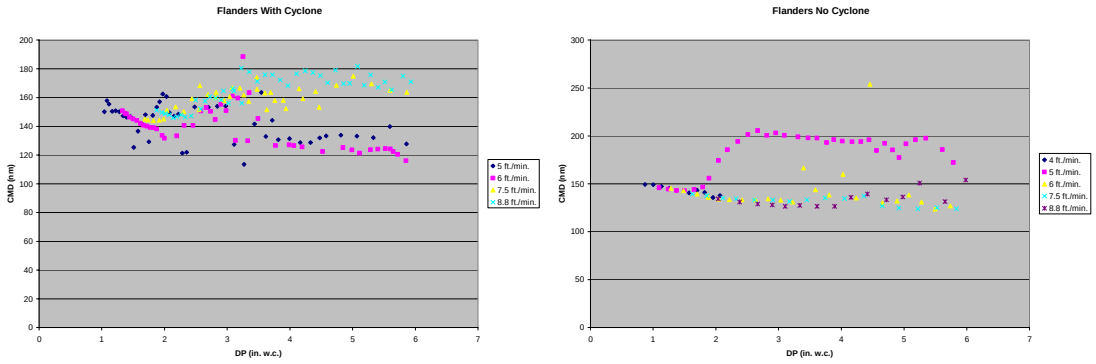

Fig. 2. Downstream CMD vs. DP for Flanders filters, loading with and without the 3 μm cut-point cyclone in place.

In all cases, the downstream geometric standard deviation (GSD) was in the range of 1.3-1.4, this indicating a nearly monodisperse aerosol downstream of the filter. Thus, the downstream CMD is a good approximation of the filtration MPPS. Although not shown here, this has been confirmed via comparing the downstream CMD with the MPPS derived from standard penetration curves. Figure 2 shows that there is a general decrease in the downstream CMD at the onset of loading, however at longer loading time (higher ΔP) the trend becomes somewhat random. This is due in part to the extremely low number counts downstream.

Equivalent data for Camfil Farr filters are shown in Figure 3.

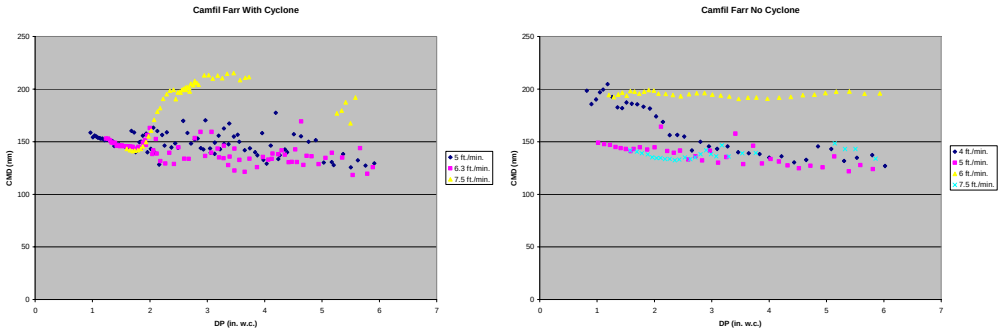

Fig. 3. Downstream CMD vs. DP for Camfil Farr filters, loading with and without the 3 μm cut-point cyclone in place.

Table 1 summarizes the initial downstream CMD (MPPS) and initial percent filtering efficiency observed during filter evaluations.

Table I. Summary of initial downstream count, % F.E. and initial MPPS.

Filter	Cyclone	Media Velocity (ft./min)	Downstream Count (/cm^3)	Initial % F.E.	Initial MPPS (nm)
Flanders	Yes	4	5.2	99.99617	155
Flanders	Yes	5	8.4	99.9958	150
Flanders	Yes	6	4.4	99.9923	151
Flanders	Yes	7.5	5.7	99.9927	145
Flanders	Yes	8.8	8.7	99.9872	151
Flanders	No	4	2.7	99.99873	149
Flanders	No	5	2.6	99.99813	146
Flanders	No	6	13.2	99.99199	145
Flanders	No	7.5	21.0	99.98622	139
Flanders	No	8.8	8.6	99.99324	134
Camfil Farr	Yes	5	2.2	99.99831	158
Camfil Farr	Yes	6.3	2.5	99.99743	153
Camfil Farr	Yes	7.5	2.6	99.99685	143
Camfil Farr	No	4	12.3	99.99524	198
Camfil Farr	No	5	2.1	99.99872	149
Camfil Farr	No	6	27.2	99.97959	194
Camfil Farr	No	7.5	3.0	99.99732	141

REFERENCES

1. Arunkumar, R.; Etheridge, J.A.; Hogancamp, K.U.; Luthe, J.C.; Nagel, B.A.; Norton, O.P.; Parsons, M.S.; Rogers, D.M.;Waggoner, C.A. “Evaulation of Mass Emission Rates Down Stream of HEPA Filters as a Function of Source Terms and Selected Failure Modes”, Waste Management Conference, February 29 – March 4, 2004, Tucson, AZ