Results from Evaluation of ASME AG-1 Section FK Radial Flow HEPA Filters - 11287

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ABSTRACT

The American Society of Mechanical Engineers (ASME) Code on Nuclear Air and Gas Treatment (AG-1) has recently added Section FK establishing requirements for radial flow High Efficiency Particulate Air (HEPA) filters. AG-1 Section FK radial flow filters are expected to be a major element in the HEPA filtration system of Department of Energy (DOE) facilities. Radial flow filters have been used in Europe for some time, however, a limited quantity of data exists with respect to evaluating the performance of these new AG-1 Section FK units. In consultation with a technical working group, the Institute for Clean Energy Technology (ICET) at Mississippi State University (MSU) is evaluating a series of AG-1 Section FK radial flow HEPA filters. Filters are evaluated utilizing three challenge aerosols ranging in particle size from 0.3 µm to greater than 5 µm. Temperature, static pressure, volumetric flow rate, mass loading rate, differential pressure, and relative humidity are monitored during the course of testing each filter. Testing results include mass loading curve and filtering efficiency versus differential pressure. Also, the Particle Size Distribution (PSD) upstream of the filter is examined. Finally the downstream Most Penetrating Particle Size (MPPS) and Geometric Standard Deviation (GSD) as a function of differential pressure are revealed. Images of the filter pack collected during testing are also presented.

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 US 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. In May of 1999 the Defense Nuclear Facilities Safety Board (DNFSB) released Technical Report 23 entitled *HEPA Filters Used in the Department of Energy's Hazardous Facilities* [1]. This report expressed concerns for the potential vulnerability of HEPA filters used in vital safety systems. Later that same year the DOE initiated a response to the DNFSB's Recommendation 2000-2 [2] by implementing measures with regard to 100 percent quality assurance, testing of HEPA filters, and a review of vital safety systems in general [3]. DOE's actions in this matter were also timely with regard to concerns being voiced by citizen groups over the performance of HEPA filters and how their functional status is monitored. Of particular concern are the threats to HEPA filter performance posed by water and smoke.

For the past several years, the Institute for Clean Energy Technology (ICET) at Mississippi State University (MSU) has conducted extensive research under its DOE sponsored HEPA Filter Monitoring Project. Studies with 30.5 cm x 30.5 cm x 29.2 cm (12in. x12in. x11.5in.) American Society of Mechanical Engineers (ASME) Code on Nuclear Air and Gas Treatment (AG-1) Section FC axial flow HEPA filters have included moisture failure, source term loading, seal and pinhole leak tests, and media velocity. Details related to design, construction, and operation of the test stand utilized in these research efforts have been published [4]. Discussion of the experimental design related to these research efforts as well as results has been presented at numerous conferences [5, 6, 7] and published [8].

Section FK Development

In 2008 the Committee on Nuclear Air and Gas Treatment (CONAGT) added Section FK, titled "Special Round and Duct-Connected HEPA Filters", to the ASME AG-1 Code [9]. Section FK is comprised of four types of HEPA filters. Table I examines the different types of FK Filters, of which, we are primarily concerned with the type 1.

Table I. Types of ASME AG-1 Section FK HEPA Filters

Type 1	Radial Flow HEPA Filter
Type 2	Axial Flow Circular HEPA Filters
Type 3	Axial Flow Rectangular or Circular HEPA Filters with Inlet and/or Outlet Connections
Type 4	Axial Flow Rectangular HEPA Filters that are Size Variations of AG-1 Section FC Filters.

These new radial flow filters present different advantages and challenges as opposed to the AG-1 Section FC axial flow HEPA filters. Due to the higher effective surface area of the Section FK filters, they can accommodate higher media velocities. The FK filters also present several factors in favor of consideration, such as; ease of sealing, handling, and volume reduction or disposal [10]. Another primary difference in FC and FK is the pleat collapse prevention mechanism used by either filter. While FC filters use conventional metal or a glue bead separator, the FK filters make use of either dimples within the pleats or strings as the separator mechanisms. The issue with developing a conventional FC separator for the FK filters is due to the radial nature of their construction, the separator would need to be a wedge shape to accommodate the difference in distance from one pleat to the other. Although the mechanism the filter uses to prevent pleat collapse is not a disadvantage, it does require special consideration.

The DOE Nuclear Air Cleaning Handbook [11] designates that all air filtration systems for waste treatment facilities, such as ones in the DOE Complex, must comply with ASME AG-1 standards. A couple of decades ago DOE facilities would have adhered to military standards, but civilian standards were adopted and AG-1 was determined to be the standard for these facilities. During the design of a new DOE facility, AG-1 Section FK was being developed, and it was determined that the new facility would use these new Section FK radial flow HEPA filters.

Although, radial flow HEPA filters for nuclear facility applications have been used in Europe for some time, insufficient datum exists with respect to the performance of the new AG-1 Section FK units. Current calculations have been based on data collected in the U.K. at the Harwell facility in 1986 [10] using the European design of the radial flow filters. Idaho national laboratory currently use radial HEPA filters of the European design, yet the new DOE facility will be the first facility to utilize AG-1 Standard radial filters. Of particular concern is the lack of particle loading and structural failure data for the radial flow HEPA filters planned for use. It is unclear if the previous loading data from the U.K. can appropriately describe the new AG-1 Section FK filters. The data used for the FK filters must be accurate and stand up to the NQA-1 quality assurance standard. The DOE and DNFSB also question if the new radial filters have structural failures below 2.5 kPa or 10 inches water column (10 in. w.c.) under humid conditions. Since there are no qualified Section FK filters or datum to corroborate these assumptions a DOE Technical Working Group (TWG) was assembled to address these issues.

The ICET at MSU was determined to be the primary location for testing of these new Section FK filters based on that organizations previous experience and the current cooperative agreement under EM-21. In order to assure testing includes all appropriate and reasonable considerations a Technical Working Group (TWG) was assembled. The following are the DOE entities represented in the TWG:

- DOE Headquarters
- DOE Site Representatives
- FTF, ATI Labs
- DOE Contractor Representatives
- NNSA

In conjunction with ICET, the TWG developed a test plan to assess how these filters are tested [12]. To thoroughly test these filters, the test plan consists of testing filters under ambient and of elevated temperature and relative humidity conditions.

Testing will utilize two different AG-1 Section FK radial flow filter designs to provide data for the DOE site. One filter design, safe change, can be changed out safely by hand and the other design, remote change, is replaced by a robotic arm. The test plan calls for 6 of the safe change and 12 remote change filters to be tested. It is important to note that minor modifications were made to the original design to accommodate the ICET filter housing. Table II describes the filter pack design parameters for the two types. Figure 1 displays the modified versions for both the safe and remote change filters that are to be tested at the ICET.

Table II. Filter pack design parameters for the Safe Change and Remote Change filter types.

Filter Type	Safe Change	Remote Change
Number of Pleats	345	330
Media (m^2)	29.73	29.17
Interior Diameter (cm)	33.02	27.94

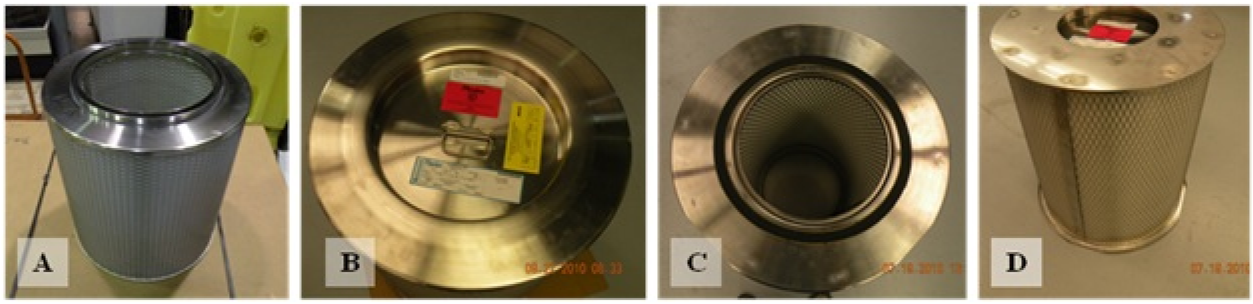

Figure 1. A: Safe Change Filter Top, B: Safe Change Filter Bottom, C: Remote Change Filter Top, D: Remote Change Filter Bottom Displaying Remote Grab Rings.

Research Quality Oversight

To ensure the research is compliant with DOE quality assurance requirements, the research test plan has been developed in compliance with ASME NQA-1-2008, Quality Assurance Requirements for Nuclear Facility Applications as well ANSI/ASQ Z1.13-199, Quality Guidelines for Research [12, 13]. An ANSI Z1.13 Quality Assurance Plan has been developed to accompany the research test plan. All research activities are subject to audit by the DOE. A peer review panel comprised of industrial and academic experts in aerosol technology and filtration has been established to provide and final review of research results.

To assure the highest quality results to base safety decisions the uncertainty, both numerically and conceptually must be minimized. A major factor in the loading capacity of filters is the PSD of the aerosol to which they are exposed. The European data [10] only examines two aerosols that only examine loading of particles with MMD of 0.16 to 2 microns. The test plan calls for three aerosol that will examine the effect of different PSDs.

Testing Apparatus

ASME AG-1 Section FK HEPA filter testing is conducted on the ICET large-scale filter test stand which is illustrated in Figure 2. Test conditions are designated as ambient and elevated conditions. During the ambient conditions, the testing temperature and relative humidity is maintained to within 15.6-26.7 ^{0}C (60-80°F) and 40-60% RH respectively. The elevated conditions are between 73.9-77.7^{0}C (165-170°F) and from 95-100% relative humidity. The test stand flow rate used is 56.63 m^3/min (2000 cfm) ± 0-10% for a single facility representative radial flow HEPA filter.

Figure 2. Large-Scale Test Stand with Section FK Filter Housing

Tests are conducted on each type of the facility representative radial flow HEPA filters using three different test aerosols. Carbon black powder (CanCarb N991 thermal carbon black powder) with a mean particle size of 280 nm and mass median diameter (MMD) of approximately 2 µm is utilized as one challenge aerosol. Alumina, $Al(OH)_3$, with an aerodynamic mass median diameter of 0.3 µm is used to represent particle loading by small particles. The third aerosol to be used is Arizona Test Dust ISO 12103-1 A1, Ultrafine Test Dust, Powder Technology Inc with a MMD of 5-10 µm is used to depict loading by larger particles.

Instrumentation

Aerosol concentration is measured upstream of the filter utilizing two instruments; a Scanning Mobility Particle Sizer (SMPS, TSI Model 3936) to measure sub-micron particles, and an Aerodynamic Particle Sizer (APS, TSI Model 3321) to measure larger particles. Downstream particle concentration and size is measured with a Laser Aerosol Spectrometer (LAS, TSI Model 3340). In addition, a photometer can be used downstream of the filter during the high humidity tests to detect filter tears and collapse at the later stages of filter loading. The concentration and size ranges for the instruments discussed above are presented in Table III.

Table III. Particle Size and Concentration Ranges for Test Stand Instrumentation

Instrument	#/cc (min)	#/cc (max)	PSD (µm)
TSI Model 3936L10 SMPS	1	$1x10^7$	0.001 – 1
TSI Model 3321 APS	1	$1x10^3$	0.3 – 20
TSI Model 3340 LAS	<0.02	$1.8x10^4$	0.90 – 7.5

Other than the aerosol measurements, the test stand is equipped with multiple sensors to acquire data. To assure that the test conditions remain within those set forth in the test plan, the test stand is equipped with temperature and relative humidity sensors. The test stand also measures static and differential pressure. A gravimetric measurement scale is used to obtain the filter mass before and after testing.

TESTING RESULTS

Mass Loading Curves

The most significant parameter of interest is the mass loading curves. These curves depict the mass loading on the filter as a function of the differential pressure across the filter. All filters were loaded to rupture. Based on the type of aerosol and filter design the total mass loaded and rupture differential pressure are different. In Figure 3 we see the mass loading curves for all filters tested to date. From the figure we see the large difference in the quantity of the mass loaded from the different aerosols. It is also illustrated that the AZ Road Dust has, not only a greater mass loading, but a higher rupture differential pressure.

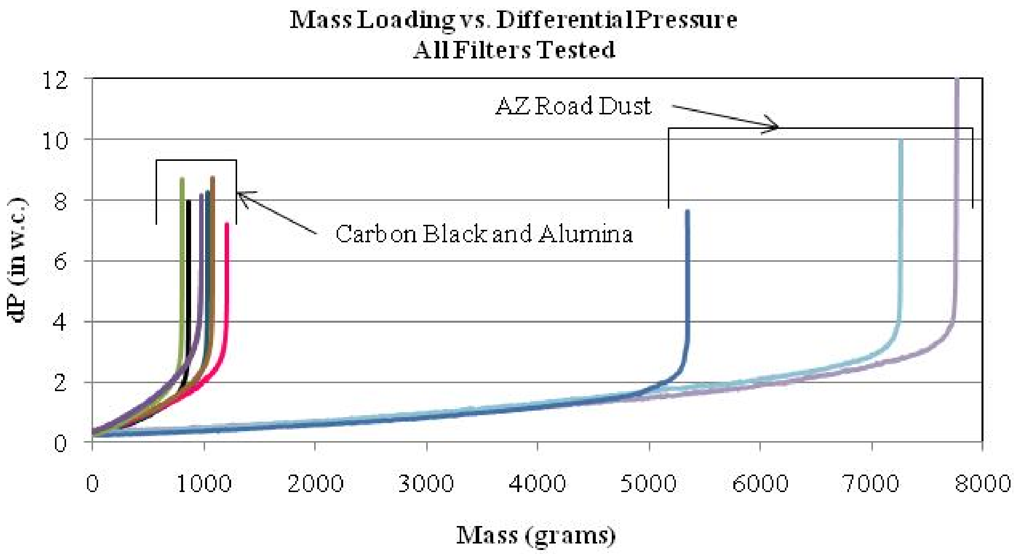

Figure 3. Mass Loading Vs. Differential Pressure for All Filters Tested

In Figure 4 we illustrate the mass loading rate for the Carbon Black and AZ Road Dust loaded filter as A and B, respectively. The figure also depicts the safe change and remote change filter designations as SC and RC. It is seen in the figure that the remote change has a higher mass loading than the safe change; this is despite it having a small surface area. This fact could be due to the rigidity of the RC design in pleat collapse prevention. Mass loading data for the Alumina as the challenge aerosol is forthcoming.

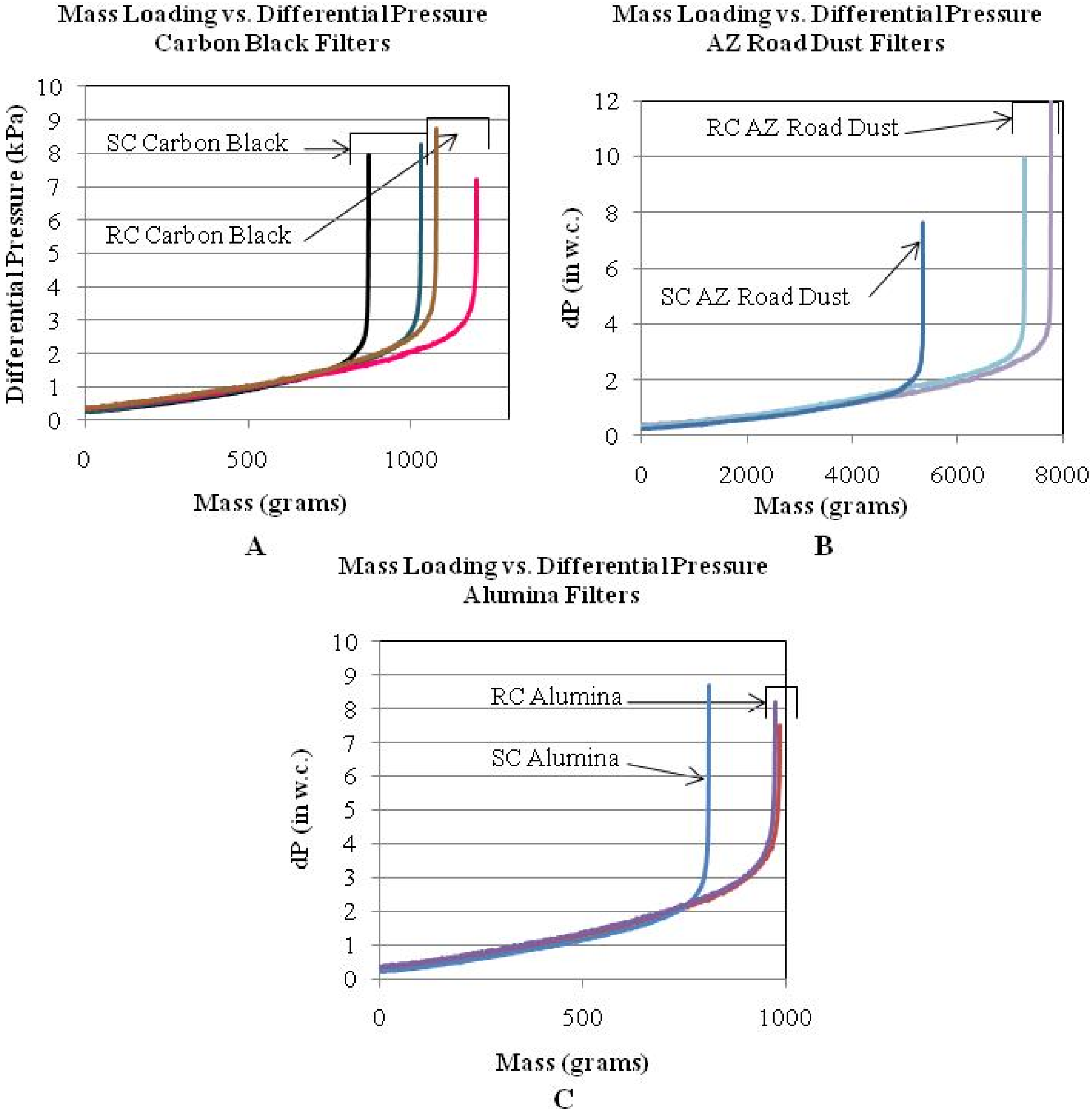

Figure 4. A: Mass Loading vs. Differential Pressure for Carbon Black Dust Loaded Filters, B: Mass Loading vs. Differential Pressure for AZ Road Dust Loaded Filters

Filtering Efficiency

A fundamental requirement of HEPA filters is their filtering efficiency. As previously mentioned, HEPA filters are required to be at least 99.97% efficient at removing particulate matter greater than 0.3 µm from an airstream. All of the filters tested at ICET were above this requirement. As all efficiency curves were virtually identical, we examine a remote change filter loaded with carbon black as a representative filter for the others. The at the point of filter rupture the instruments were shut down to prevent damage. Rupture occurred for this filter at 7.22 kPa (29 in. w.c.). Figure 6 reveals the filtering efficiency and differential pressure versus loading time.

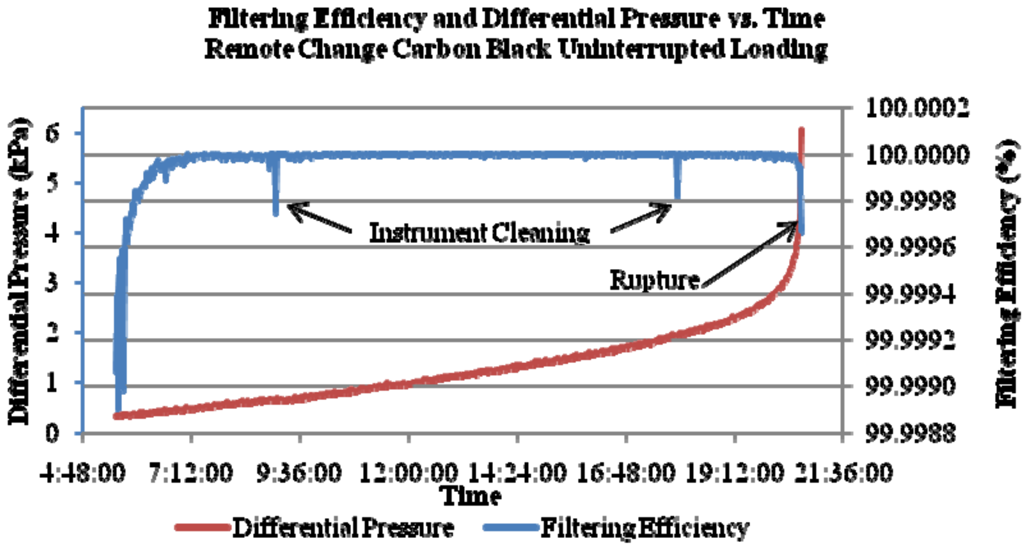

Figure 5. Filtering Efficiency and Differential Pressure vs. Time

It is important to note the initial behavior of the filtering efficiency. This is reviewed with the same remote change filter loaded with carbon black as shown in Figure 5. Figure 6 illustrates that as the filter loads it become increasingly more efficient, and around 0.5kPa (2 in. w.c.) of differential pressure the filter is greater than 99.9999% efficient.

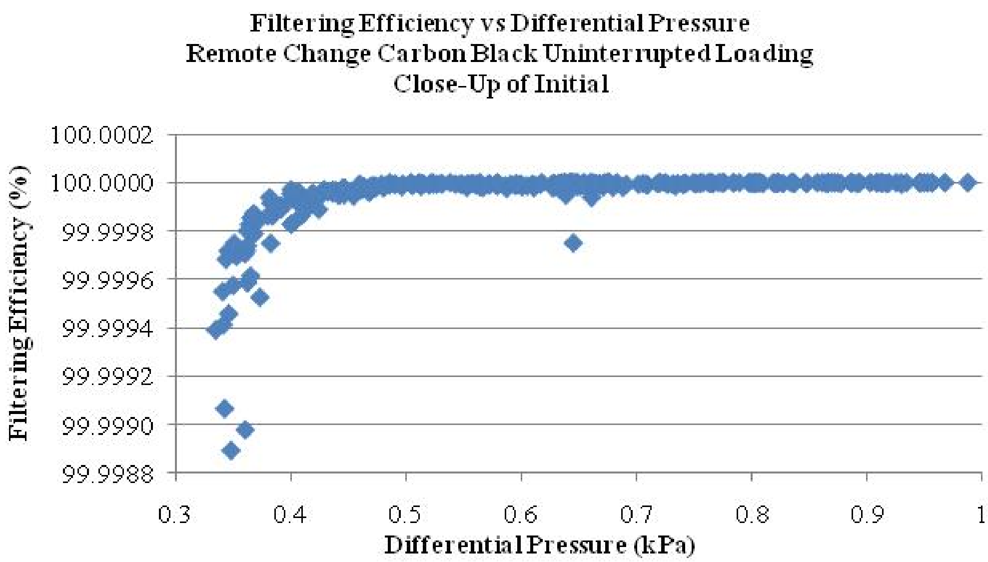

Figure 6. Filtering Efficiency vs. Differential Pressure Initial Close-Up

Particle Size Distribution Plots

Figure 7 displays the PSD for the three aerosols tested based on experimental data collected.

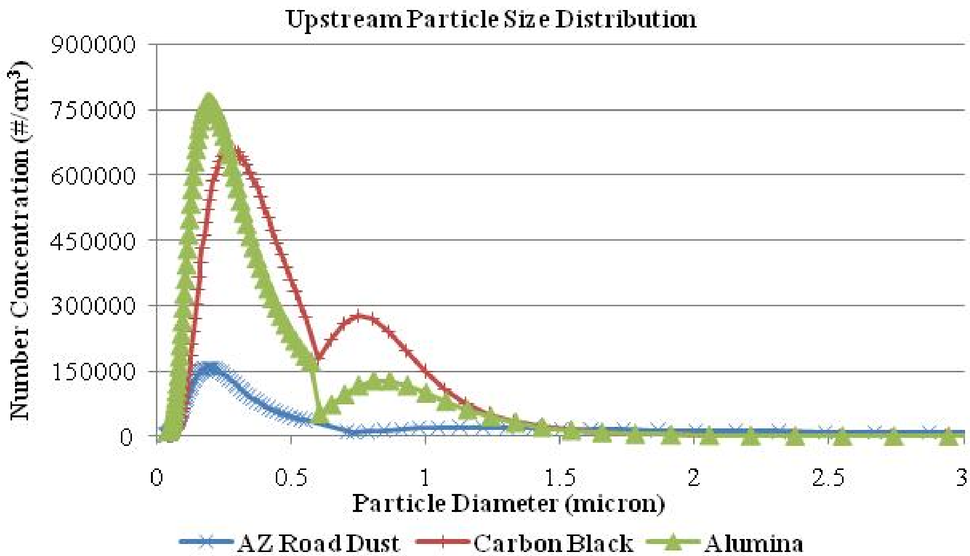

Figure 7. PSD of AZ Road Dust and Carbon Black

Downstream MPPS and GSD

A more sensitive measure of performance derives from further characterization of the downstream concentration. As the aerosols are different a representative figure is displayed for each. The Most Penetrating Particle Size (MPPS) is examined in Figure 8 for carbon black, AZ road dust, and Alumina. From the figure we can see a MPPS of around 100 to 200 nm.

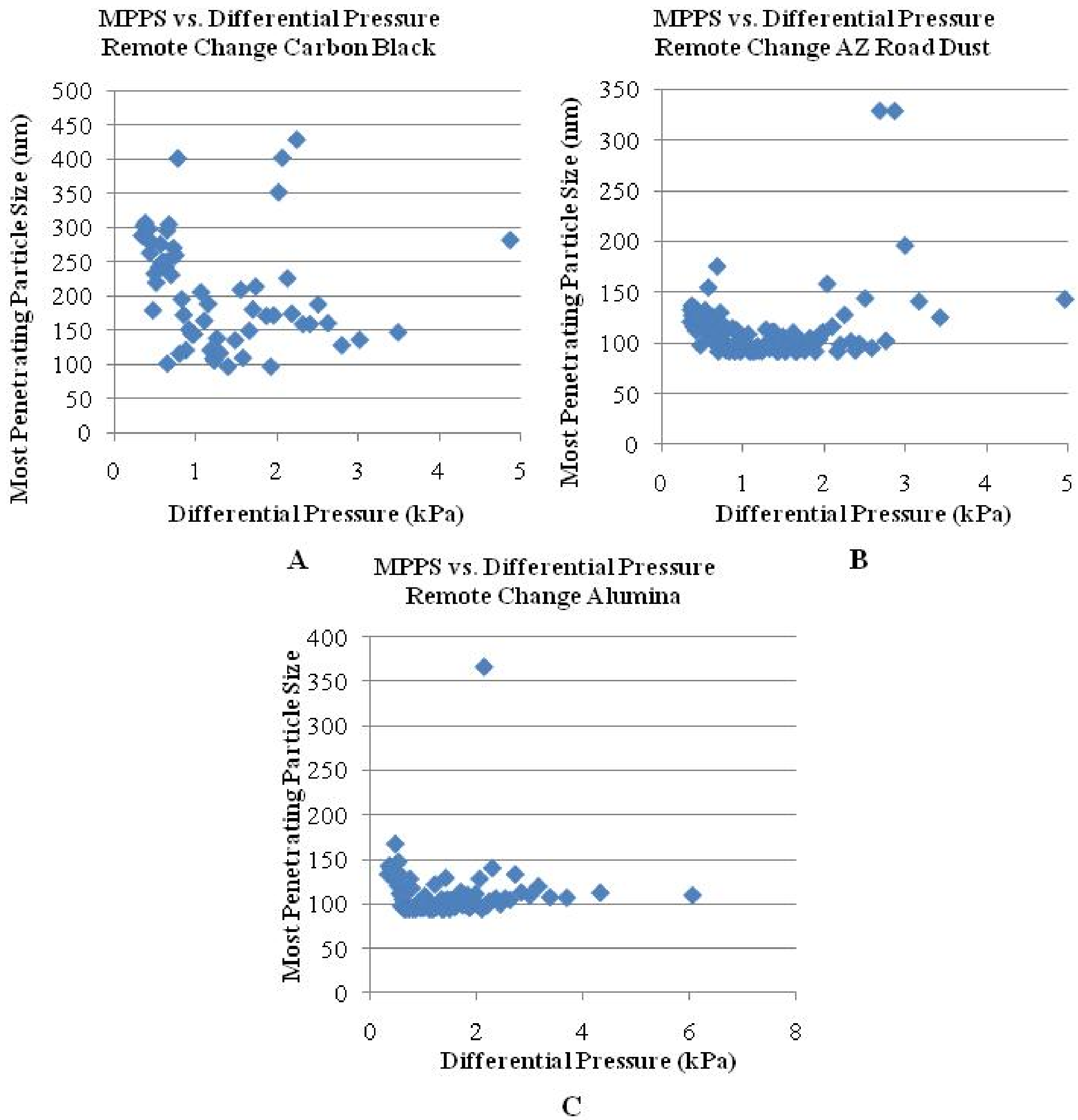

Figure 8. MPPS vs. Differential Pressure for All Aerosols

The Geometric Standard Deviation (GSD) is displayed to further characterize the downstream concentration. The GSD can often be an indicator in filter leak detection. The GSD is described in Figure 9 for carbon black, AZ road dust, and Alumina. The figures depict a GSD of approximately 1.4 after the filter is loaded somewhat, describing a fairly monodisperse aerosol distribution.

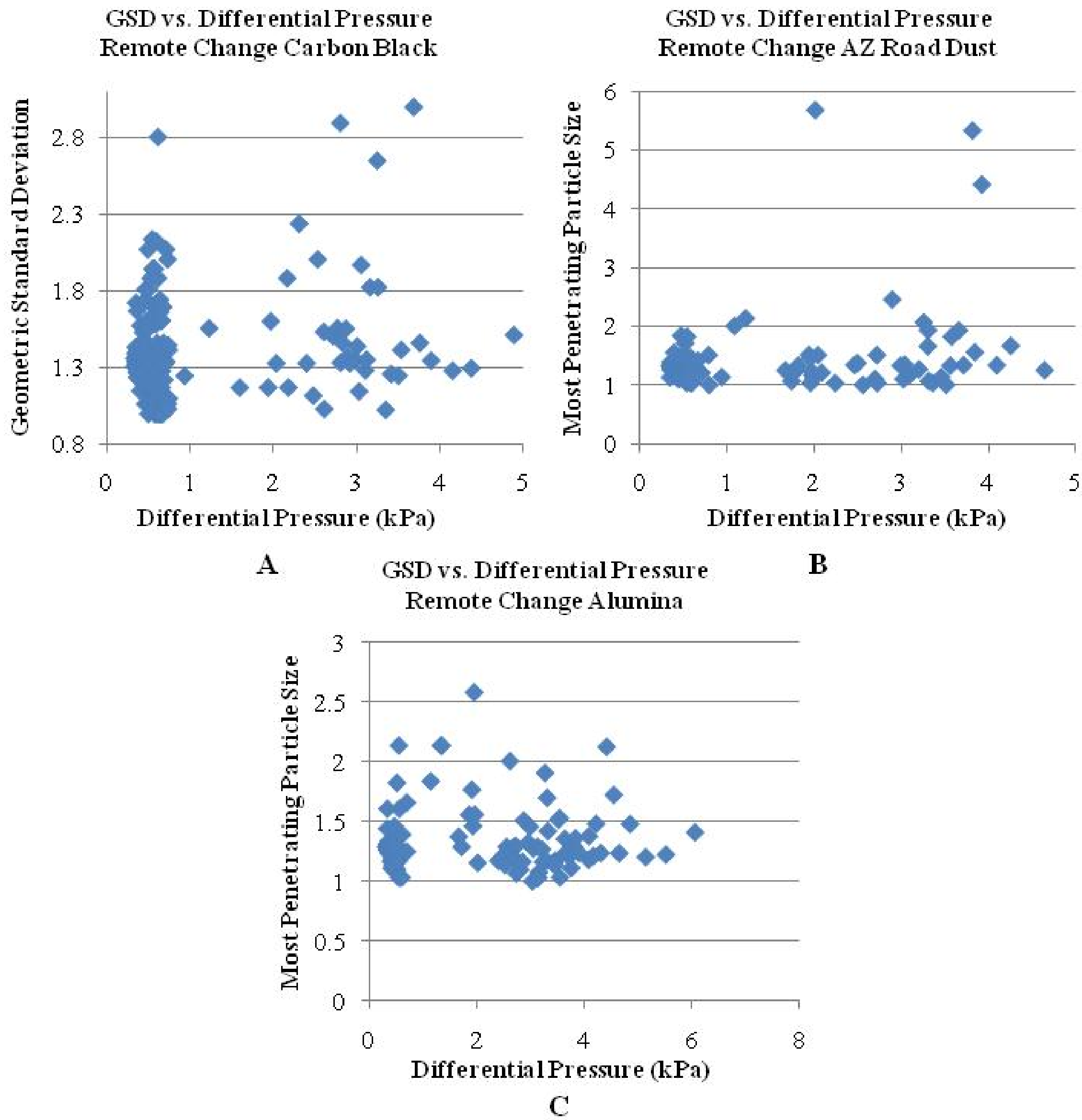

Figure 9. GSD vs. Differential Pressure for All Aerosols

Filter In-Testing Photographs

It became evident that photographs of the filter pack during testing would give insight in determining the source of rupture or tearing of the filter media. The location at which the photo is taken is at the area determined most likely to fail. Figure 10 displays the filter housing, differential pressure sensors, the filter blind or dummy filter, and the orientation of the filter in the test stand.

Figure 10. A: Filter Housing with Doors Closed, B: Filter Housing Differential Pressure Gages, C: Filter Housing with Doors Open, D: Filter Housing Position 2 Displaying Correct Filter Orientation.

The following figure depicts the location at which images are taken on a filter and the previously mentioned remote change filter loaded with carbon black at particular intervals of differential pressure. The intervals are 1.0 kPa (4 in. w.c.), 2.5 kPa (10 in. w.c.), 5 kPa (20 in. w.c.), and the differential pressure at the point of filter rupture, which for this filter was 7.22 kPa (29 in. w.c.). In Figure 11:B we can see the gap between the filter media to allow for maximum filter surface area, but in Figure 11:C the gaps are starting to close which decreases the filter surface area and leads to a rapid rise in differential pressure. Figure 11 parts D and E, taken only a minute apart, displays the filter from 5 kPa (20 in. w.c.), with the pleats virtually collapsed, and at rupture, where the filter media is pressed against the expanded metal screen.

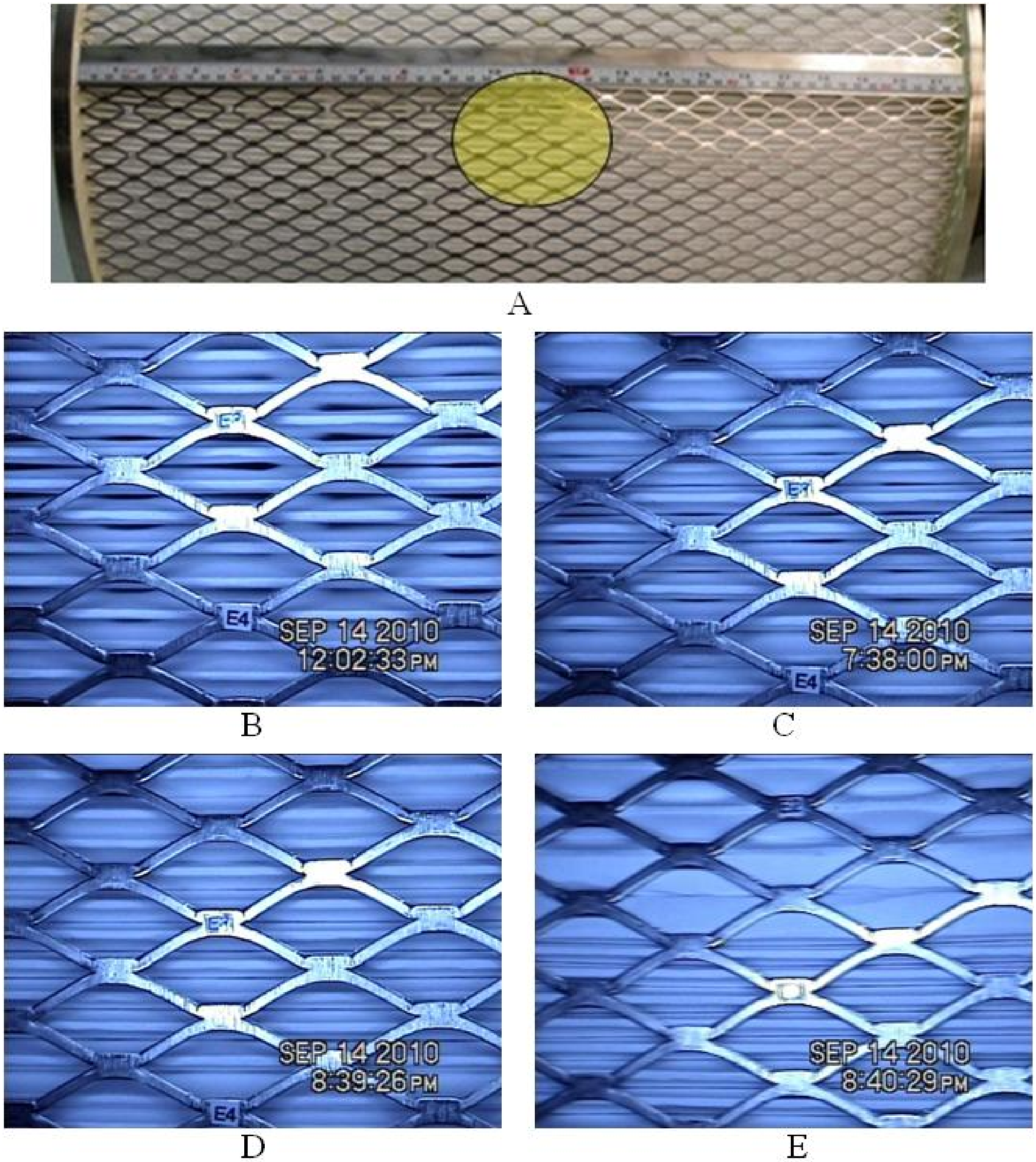

Figure 11. In-testing Images A: Location on Filter, B: 996.3Pa (4 in. w.c.), C: 2490.8 Pa (10 in.w.c.), D:4981.6 Pa (20 in.w.c.), E:7223.3 Pa (29 in. w.c.).

FUTURE WORK

The most immediate work for the test stand is the completion of the DOE site current test plan. To finish the test plan, filters at the elevated conditions must be tested, and the filters must be autopsied to examine the particle loading patterns. The test stand developed at MSU puts ICET in a promising position to provide a test bed for multiple future filter testing projects. One future project is to acquire a new housing that is capable of testing 4 of the ASME AG-1 Section FC axial flow filters at a time. Another item currently on the agenda for testing is the evaluation of ASME AG-1 Section FM, high strength media, filters.

CONCLUSIONS

We have presented a test program capable of lifecycle testing of nuclear grade HEPA filters. The test stand and instrumentation available allow for in depth investigation of a multitude of parameters. The results presented herein are only a sample of the possible data that could be obtained through filter testing. The mass loading curves that are obtained from testing contain a wealth of information that can shed light on the behavior of different filters during their entire lifecycle. An important part of filter testing is characterization of the aerosol that is used. From this test stand we can fully characterize the aerosol upstream and downstream of the filter. The ability to capture images of the filter pack during testing gives additional insight into the changes of the filter pack and rupture. Overall the most significant aspect of the test stand is its versatility to the testing of many different filters types.

RESEARCH PROJECT TEAM

The Institute for Clean Energy Technology (ICET) at Mississippi State University (MSU) was established in 1979 to support the Department of Energy's (DOE) Magnetohydrodynamic (MHD) power program. From its inception, its mission has been the development of advanced instrumentation, and use of that instrumentation to characterize processes and equipment. ICET's testing capability, and its ability to rapidly deploy very sophisticated instrumentation in the field, has been an important component of its success.

ICET has a multidisciplinary staff of 30 full-time employees', a blend of chemists, physicists, computer scientists, and chemical, electrical, and mechanical engineers. ICET scientists have leading-edge expertise in the application of lasers to energy and environmental cleanup. ICET's staff is a unique blend of measurement specialists, control specialists, and an experienced engineering and operations staff, primed to carry out its mission. ICET also employs students, both graduate and undergraduate, who further support research operations. ICET staff also includes a Certified Industrial Hygienist (CIH) and a Certified Hazardous Materials Manager (CHMM). These individuals ensure all activities conducted by ICET adhere to applicable environmental, safety and health practices.

ACKNOWLEDGMENT

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