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Evaluating ASME AG-1 Section FK Radial Flow HEPA Filters

R. ArunKumar, Jay P. McCown, Michael S. Parsons,
Jaime G. Rickert, Donna M. Rogers and Charles A. Waggoner
Institute for Clean Energy Technology, Mississippi State University
205 Research Blvd Starkville, MS 39759

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 HEPA filters. Section FK filters are expected to be a major element in the HEPA filtration systems of Department of Energy (DOE) operations. However, limited data exist demonstrating the performance of these new FK units. A technical working group for evaluating these filters has developed an ASME NQA-1 compliant test plan. The technical working group includes representatives from DOE Headquarters (EM-30), the Defense Nuclear Facilities Safety Board (DNFSB), the National Nuclear Safety Administration (NNSA), ATI's Filter Test Facility (FTF), DOE sites and contractors, and the Institute for Clean Energy Technology (ICET) at Mississippi State University (MSU).

The test plan calls for evaluation of Section FK radial flow HEPA filters utilizing three different test aerosols varying in particle size distribution from 0.3 μm to greater than 5 μm. Test conditions include: ambient temperature (21 – 24 ^{0}C) and relative humidity (40 – 60%) as well as high temperature (74 – 77 ^{0}C) and relative humidity (90 – 95%) conditions. A test stand has been designed, fabricated, assembled, and characterized at ICET for evaluation of either single or dual FK radial flow filters at volumetric flow rates up to 113 m^3/min (4000 cfm) and differential pressures up to 10 kPa (40" water column). ICET's test stand is equipped with an array of sensors for continuous monitoring of temperature, static pressure, differential pressure, and RH. Test stand control is accomplished using Wonderware InTouch supervisory control and data acquisition software. Data collected will include mass mean diameter of the challenge aerosol, count median diameter and number density of the challenge aerosol on a continuous basis for the lifetime loading curve for each filter. The most penetrating particle size (MPPS) of each filter will also be determined. A total of 18 filters, 12 remote-change and six safe-change, will be evaluated under this testing project.

INTRODUCTION

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 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 at Mississippi State University has conducted research under its DOE sponsored HEPA Filter Monitoring Project. Studies with 12"x12"x11.5" (30.5 cm x 30.5 cm x 29.2 cm) American Society of Mechanical Engineers (ASME) Code on Nuclear Air and Gas Treatment (AG-1) Section FC 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]. These discussions include aerosol generation, filters tested, and aerosol measurement instrumentation utilized.

ASME AG-1 has recently added Section FK establishing requirements for radial flow HEPA filters. Section FK HEPA filters are expected to be a major elements in HEPA filtration systems in Department of Energy (DOE) facilities. Radial flow HEPA filters for nuclear facility applications have been used in Europe for some time, however, a limited amount data exists with respect to the performance of the new Section FK units. Of particular concern is the lack of particle loading and structural failure data for the Section FK radial flow HEPA filters. The DOE currently assumes that the previous loading data (for European filters) will be applicable to the slightly different filter design in Section FK. DOE also assumes that the new radial filters will not have structural failures below 10 inches water column (10 in. w.c. (2.5 kPa)) under humid conditions. These assumptions will be verified in the present test plan.

ICET has developed a larger-scale HEPA filter test stand to evaluate the performance of one to four 1000 CFM (28.32 m^3/min) AG-1, Section FC, axial flow filters or up to two 2000 CFM (56.63 m^3/min) AG-1, Section FK, radial flow filters at rated flow velocities and to differential pressure levels of 40 in. w.c. (10 kPa).

Activities to be conducted during 2010 final development of the new test stand, characterization of its performance, and challenging representative radial flow HEPA filters with various simulants. The test stand and auxiliary equipment include the capability of challenging filters with smoke, soot, high moisture levels, and high temperatures. This test plan has been developed through collaborations with representatives from the DOE facility and representatives from the DOE National Nuclear Security Administration (NNSA) responsible for reviewing DOE-STD-1066-99 "Fire Protection Design Criteria".[9]

ISSUES

Information from public literature currently serves as basic guidance used by engineers to evaluate the potential impact of fires and other events involving abnormally high filter loading rates on HEPA filters employed in confinement ventilation systems and process gas treatment [10, 11]. Bergman's model of HEPA filter plugging [10, 11] has been successfully used in designing the HEPA filtration systems in other DOE facilities. Other models are either limited to a single application or do not have sufficient parameters for practical analysis. For example, Ballinger's paper [12] describes HEPA filter plugging in reprocessing facilities and is limited to filter plugging by kerosene fires. The paper by Beyler [13] describes filter loading in terms of an empirical second order polynomial but has no filter or particle parameters in the equation. Despite the success of the Bergman model for early stage HEPA filter plugging it still requires experimental data for the empirical constants in the equation. Thus experimental data are needed to assess filter plugging for any new filter design and account for effects of particle size for either depth vs. surface loading or bridging between filter media pleats.

Experimental data from Loughborough [14] in the public literature is currently used with Bergman's model by engineers at the facility in the design and development of confinement ventilation and process gas treatment systems for control of particulate matter emissions. Loughborough at AEA Technology Harwell Laboratory in the UK conducted tests challenging radial flow HEPA filters with carbon black over two decades ago. The primary problem with the data is that it was obtained on slightly different filters than those anticipated under Section FK. This scope of work will include testing with the proper HEPA filter to provide data to engineers at DOE facilities and confirm or correct the filter loading and failure assumptions. Loading tests of Section FK representative radial flow HEPA filters will be conducted using carbon black, alumina, and Arizona road dust as compared to the two aerosols (carbon black and sodium chloride) used in the Loughborough study. In addition to the use of a wide range of particle sizes, the ICET tests will also include variable humidity. Loaded filters will be autopsied to provide empirical data for comparison to modeling results.

RESEARCH TEST PLAN

Test Procedure and Test Matrix

Facility representative radial flow HEPA filter testing will be conducted using the ICET large-scale filter test stand illustrated in Figure 1. Standard test conditions are ambient temperature (~70^{0}F (21.1 ^{0}C)), and humidity (40-60%), and these parameters are controlled. The test stand utilizes building air for its inlet air and will discharge the exhaust outside the building placing an additional load of 2,000 cfm (56.63 m^3/min) on the building air supply. The impact of this additional load on the building air supply represents approximately three air changes per hour for the high bay where it is located and has little impact on the HVAC system. Relative humidity levels in the building are typically in the 30% range during the winter and a misting system has been added to the high bay to increase this level to that called for in the test plan. Summer levels can run significantly higher during the summer requiring use of a dual column drier to reduce RH to acceptable levels. During the planned test period, room air of the high bay temperature and humidity are expected to be within 60-80°F (15.6 – 26.7 ^{0}C) and 40 – 60% RH respectively. Both parameters will be recorded for all tests.

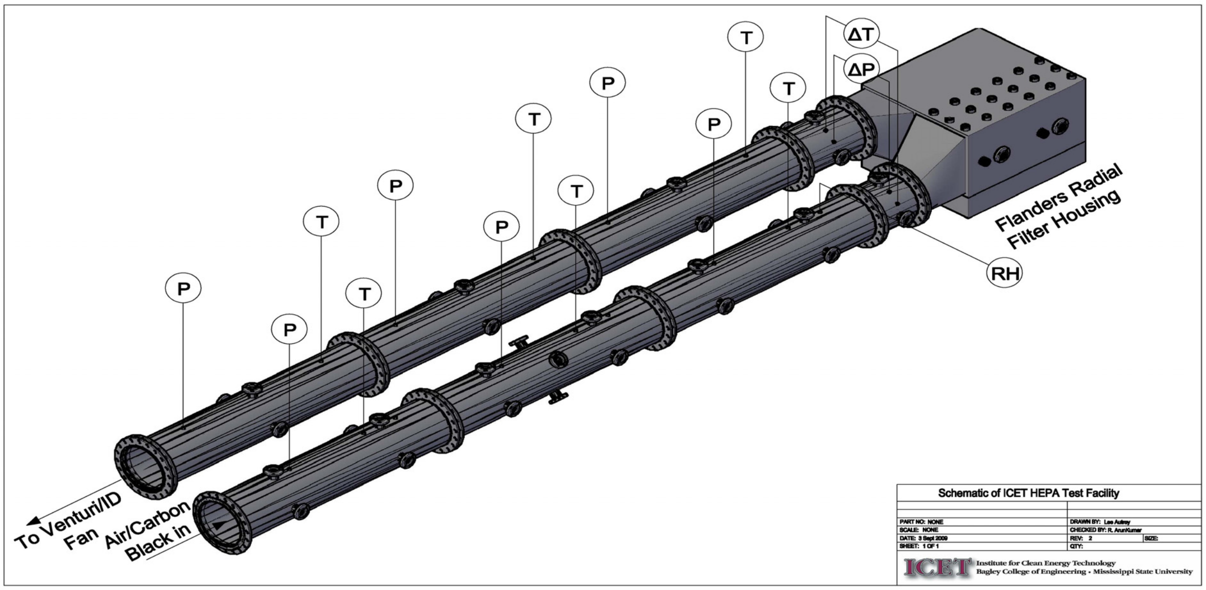

Figure 1. Drawing of test duct and housing.

A series of eighteen Section FK representative radial flow HEPA filters will be tested in this test plan as described in the test matrix given in Table 1. One representative radial flow HEPA filter will be tested at a time, eliminating the concern of non-uniform airflow distribution and particle mixing uniformity in the housing. Test Set 1 conditions shown in Table 1 provide loading conditions for filters under ambient temperature and moisture conditions. Although the normal practice will be to replace the HEPA filter at 4 in. w.c. (1 kPa), testing will be continued to the maximum system dP of 40 in. w.c. (10 kPa) or to structural failure. Test Set 2 conditions shown in Table 1 provide filter loading up to the replacement point at 4 in. w.c. (1 kPa) followed by a simulated accident of high moisture and high temperature.

Two slightly different configurations of Section FK radial flow HEPA filters have been designed. One filter design, (safe change) is used for hands-on applications, and the other (remote change) for remotely handled applications. Representative units of each design are included in the test plan. The “remote change” HEPA filter is expected to have a lower particle loading capacity than the “safe change” HEPA filter and is therefore receiving a higher level of scrutiny.

Table 1. Test Matrix for Single Section FK Representative Radial Flow HEPA Filter.

Test Parameters and Guidelines:			Aerosol #1 0.25 µm (Alumina)	Aerosol #2 2.0 µm (Carbon Black)	Aerosol #3 10.0 µm (AZ Road Dust)
Remote Change HEPA Filter	Data Set 1	**Test Set 1** – Inlet air controlled to 40-60% RH. Test until maximum dP and/or failure is reached	Filter 1	Filter 2	Filter 3
		Test Set 2 – Inlet air controlled to 40-60% RH until filter reaches 4 in. w.c. (1 kPa), then add air at 165-170 ^{0}F (73.9-76.7 ^{0}C) and 90-95% RH for maximum duration. Test until maximum dP and/or failure is reached	Filter 4	Filter 5	Filter 6
Remote Change HEPA Filter	Data Set 2	**Test Set 1** – Inlet air controlled to 40-60% RH. Test until maximum dP and/or failure is reached	Filter 7	Filter 8	Filter 9
		Test Set 2 – Inlet air controlled to 40-60% RH until filter reaches 4 in. w.c. (1 kPa), then add air at 165-170 ^{0}F (73.9-76.7 ^{0}C) and 90-95% RH for maximum duration. Test until maximum dP and/or failure is reached	Filter 10	Filter 11	Filter 12
Safe Change HEPA Filter	Data Set 3	**Test Set 1** – Inlet air controlled to 40-50% RH. Test until maximum dP and/or failure is reached	Filter 13	Filter 14	Filter 15
		Test Set 2 – Inlet air controlled to 40-60% RH until filter reaches 4 in. w.c. (1 kPa), then add air at 168 ^{0}F (75.6 ^{0}C) and 97% RH for maximum duration. Test until maximum dP and/or failure is reached	Filter 16	Filter 17	Filter 18

Performance evaluation of FK representative radial flow HEPA filters will be accomplished 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 ~2µm will be utilized as one challenge aerosol. Alumina, Al(OH)3, with an aerodynamic mass median diameter of 0.3 µm will be the second aerosol used in these tests. The third aerosol will be Arizona Test Dust ISO 12103-1 A1, Ultrafine Test Dust, Powder Technology Inc, or an equivalent test simulant for 5-10 micron size. Test stand flow rates used will be 2000 cfm (56.63 m^3/min) ± 0 – 10% for each representative radial flow HEPA filter. The filters will be intermittently loaded until the desired pressure drop is obtained or until the end of a workday is reached. Projections estimate 4,000 g of the Arizona test dust, 1,000 g of the carbon black and about 150 g of the alumina to reach 10 in. w.c. (2.5 kPa) of pressure drop. Another 30 – 50% of this mass is expected to load the filters to 40 in. w.c. (10 kPa) of pressure drop or to the rupture point. Aerosol concentrations for the different aerosols will be adjusted to complete a filter loading within three days.

Aerosol concentrations will be measured upstream of the filter(s) utilizing three instruments: (1) Scanning Mobility Particle Sizer or SMPS (TSI Model 3936), (2) Aerodynamic Particle Sizer or APS (TSI Model 3321), and (3) Electrical Low Pressure Impactor or ELPI (Dekati). In addition, an inertial impactor will be used to characterize the aerosol mass size distribution to provide comparable measurements to previous loading studies. Since the filter loading consists of measurements of pressure drop as a function of particle mass accumulation, all particle size measurements will be converted to a mass-size distribution. Downstream particle concentration and size will be measured with a Laser Particle Counter or LPC (Particle Measuring System Model LPC-0710) and a Condensation Particle Counter or CPC (TSI Model 3010) for the initial part of the loading until the concentration becomes vanishingly small. In addition, a photometer will be used downstream of the filter to detect filter tears and collapse at the later stages of filter loading above 10 in. w.c. (2.5 kPa) until the point of collapse or at the maximum 40 in. w.c. (10 kPa). The photometer will be referenced to the upstream challenge concentration to provide a relative percent penetration. The effect of high humidity on the particle size distributions and concentration measurements will be determined in calibration tests.

The particle loading tests will consist of initially weighing the filter, recording pressure differential, loading the filter to prescribed pressure drops of 4, 7 and 10 in. w.c. (1, 1,7, and 2.5 kPa) and weighing the filter at each of these pressure drops. Photos of the particle deposits will be taken at each weighing. The filter will then continue to be loaded until the filter ruptures or the system pressure drop of 40 in. w.c. (10 kPa) is reached. The filter will also be weighed at 20 and 30 in. w.c. (5.0 and 7.5 kPa) if the filter has not yet ruptured at this pressure drop. Each test sequence is expected to last approximately three days.

Representative Radial Flow HEPA Filter

The safe change and remote change Section FK radial flow HEPA filters will be tested. The radial filter for remote change housings is illustrated in Figures 2A-B while the radial filter for safe change housings is illustrated in Figures 2C-D as originally designed using gel seals. The two filters differ in their installation sealing and also slightly in the pleat spacing and the ID and OD of the two filters. For the purposes of the ICET tests, the filters will be modified to include a gasket seal rather than the customary gel seal. The housing utilized will likewise be modified to accommodate this change including the addition of a locking mechanism to hold the filters in place. As the remote change HEPA filter has slightly less media area and greater pleat count it is anticipated that it will have a higher pressure drop at the same particle loading compared to the safe change HEPA. Figures 2A-B show the gel seal is on the underside of the inlet flange. This type of filter is installed vertically at the facility using remote cranes and the filter sealed in the gel seal using gravity.

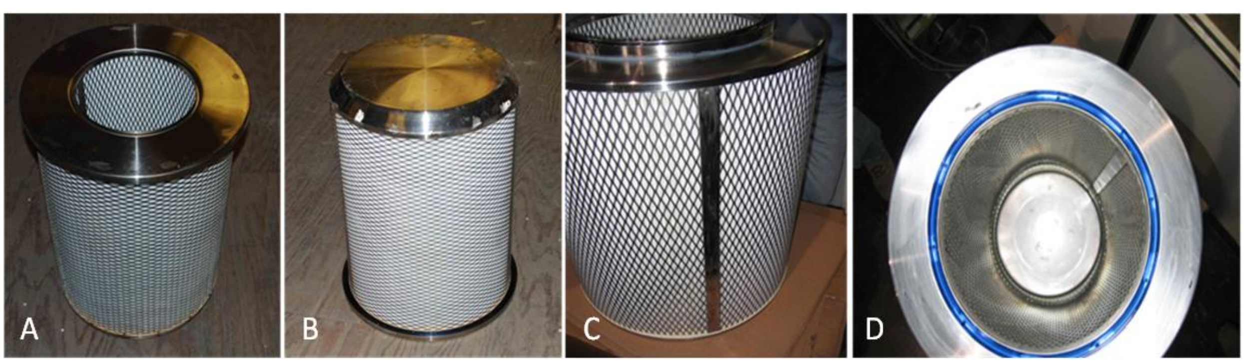

Figure 2. (A) Radial flow HEPA filter for remote change housing. (B) Gel seal shown on the bottom side of inlet flange of remote change HEPA filter. (C) Side view of safe change radial flow HEPA filter. (D) Gel seal in inlet annular groove of safe change radial flow HEPA filter.

Figures 2C-D show the radial flow HEPA filter that is used in the safe change housings. This filter has the gel seal in an annular groove on the inlet flange and is placed in a safe change housing in a horizontal configuration. A special support consisting of a series of guiding bars is needed to allow the filter to be pushed into the gel seal.

The test housing was obtained from Flanders and is designed to use two safe change radial flow HEPA filters. The test filter is placed in the upstream position (nearest the inlet and exit transitions) and a blind is placed in the downstream position. As mentioned previously, the housing has been designed for use with safe change filters, however Flanders made slight modifications to the unit to facilitate testing both safe change and remote change filters.

Figure 3 illustrates the airflow through a single radial flow HEPA filter in the filter housing designed for ICET.

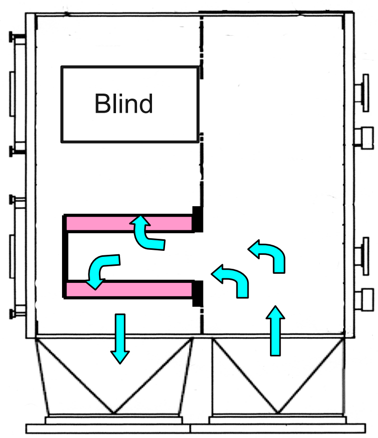

Figure 3. Schematic of air flowing through single radial flow HEPA filter in the filter housing designed for ICET. The housing allows evaluation of both safe change and remote change filter designs.

Obviously, no modifications are necessary to test safe change filters, but testing remote change filters requires modifications. Modifications have been necessary for both the filter housing and the representative filters in order to be able to test the remote change design. Figure 2 shows the differences between safe and remote change filters. The remote change filters employed in this testing have been changed with respect to the type and location of seal and overall filter length. Remote change filters have a dome shaped bottom to aid in alignment in the housing as it is being remotely inserted (see Figure 2B). This domed bottom increases the overall length too much to fit into a safe change housing so remote change filters used in this testing do not have the domed bottom plate. They have been fitted with the same bottom plate as safe change filters. It is important to point out that all other dimensions for the filter pack and the additional flat bars to increase compressive strength of the filter are retained and are the same as "real" remote change filters.

The top plate for the remote change filters have also been modified for use in the safe change housing. The diameter of the top for remote change filters is larger than for safe change filters. This requires removal of four small sections of the top in order for the modified remote change filter to fit between the guide rails of the safe change housing. Figure 4 provides photos of the modified top of the remote change filter. Also seen in these photos is the placement of a gasket seal on the front face of the modified top. This allows clamping the filter against the knife-sealing surface of the housing. Modification of the housing has also been made by adding all thread rod to allow using a clamping bar across the back of the modified remote change filters to compress them against the sealing surface. Neoprene gasket seals are used on all of the test filters rather than the gel seal to avoid loss of gel seal material during filter removal for collecting intermediate loading masses.

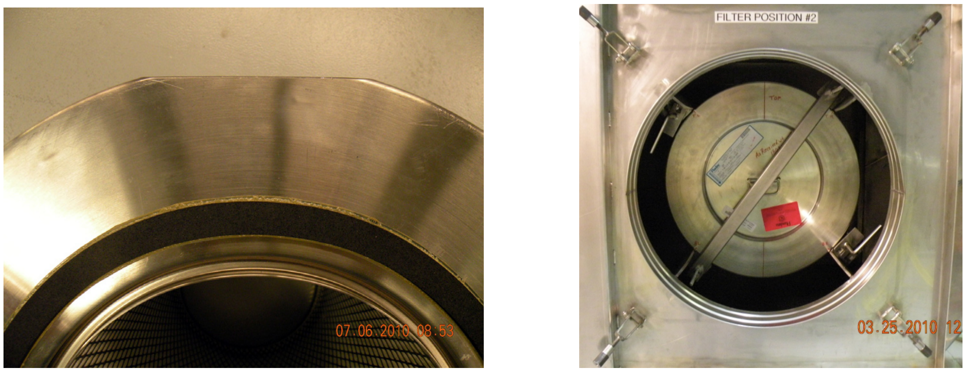

Figure 4. Photos showing (left) the modified top of remote change filters to allow insertion into the safe change housing and (right) a remote change filter installed in the housing along with the clamping bar to secure the filter.

Flow patterns within the upstream section of the test stand have been evaluated to determine the extent of swirl or cyclonic flow. Virtually no swirl was detected for the 2000 cfm (56.63 m^3/min) flow rate. The housing and ducts have been tested and demonstrated to pass the leak test using the procedures in Section TA of ASME AG-1.[15] The traditional filter leak test in Section TA of ASME AG-1 to evaluate the filter seal to the housing is not used during testing because more sensitive and accurate instrumentation are located on the downstream ductwork.

The difference in the design and construction of the safe change and remote change HEPA filters is expected to result in different particle loading. The pleat spacing is somewhat tighter for the filter pack used in the remote change filters with an anticipated lower loading capacity. The specific details of the filter designs are given in Table 2.

Table 2. Comparison of parameters for radial HEPA filters used in remote and safe change filter housing.

Parameter	Remote	Safe Change
Inside Diameter of media pack	12.625 in. (30.068 cm)	13.625 in. (34.608 cm)
Pack Depth	3.0 in. (7.6 cm)	3.0 in. (7.6 cm)
Minimum Effective filter media area	307.7 ft^2 (28.59 m^2)	307.7 ft^2 (28.59 m^2)
Design Effective filter media area	314 ft^2 (29.2 m^2)	320 ft^2 (29.7 m^2)
Pack media width	22.84 in. (58.01 cm)	22.25 in. (56.52 cm)
Pleats per inch at inlet face	8.3 pleats/in. (3.3 pleats/cm)	8.1 pleats/ in. (3.2 pleats/cm)
dP at 1000 cfm (28.32 m^3/min)	1.55 in. (3.94 cm)	1.30 in. (3.30 cm)
Mass of filter (to be confirmed for each filter)	62 lbs (28 kg)	49 lbs (22 kg)

The major difference in the two filter designs is the increased pleat packing density for the remote filter applications. The 8.3 pleats/in. (3.3 pleats/cm) and the nozzle configuration of the remote change filter result in a higher initial pressure drop (1.55 in. w.c. (386 Pa)) compared to the 8.1 pleats/in. (3.2 pleats/cm) and 1.30 in. w.c. (324 Pa) for the safe change filter applications.

Filter Wet Overpressure Tests

Unfortunately, there are no current qualified Section FK filters available for use in this testing activity. The technical working group spent a great deal of effort to ensure that the filters used in this testing activity will meet all of the requirements of the qualification process. The most aggressive qualification testing activity was determined to be the wet overpressure test. Additional consideration was taken into account in specifying methodology for the wet overpressure testing. After specifying the methodology, Flanders conducted the wet overpressure tests on four new filters per ASME AG-1 code to provide confidence that the filters will pass this part of the qualification process.

AEROSOL GENERATION

Carbon black

The first step in the aerosol generation process is the ability to reliably control and vary the particle size distribution of the challenge aerosol. Because of its similarity to dry smoke, carbon black has been chosen as one of three challenge aerosols for evaluating the performance of the facility representative radial flow HEPA filters. Loughborough at AEA Technology Harwell Laboratory in the UK conducted tests challenging radial flow filters with carbon black over two decades ago.[14] Loughborough utilized carbon black with a reported mass median diameter (MMD) of 600 nm dispensed by an ASHRAE dispenser (powder feeder) at a rate of 0.3 to 2.4 g/min. Carbon black products range in particle size from ~50 nm to ~250 nm. The specific product chosen is an N990 carbon black manufactured by CANCARB in Canada. The reported particle size for the CANCARB product is ~250 nm. The following values or ranges with respect to the particle size distribution (PSD) of the carbon black aerosol will be:

1. GMD: 250 to 800 nm (MMD 1 – 5 µm)
2. GSD: ≤ 2.2
3. Number density (#/cc): 10^5 to 10^6

A problem with the carbon black aerosols that will have to be controlled and measured is the tendency to form agglomerates as illustrated in Figure 5.

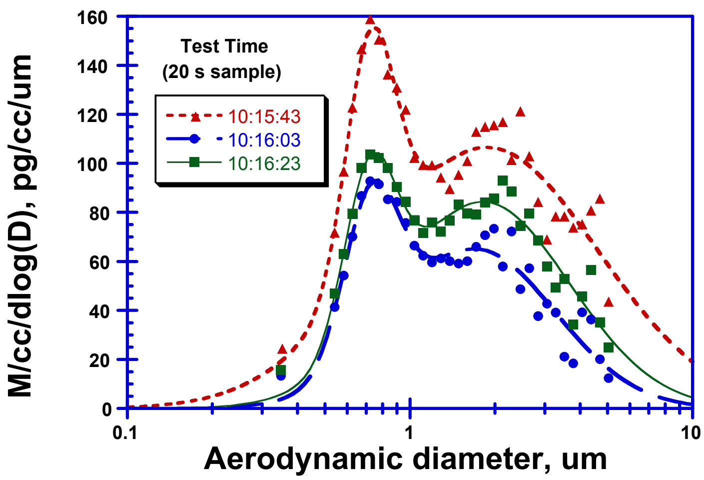

Figure 5. Size distribution of carbon black measured with APS at different times showing the primary size of 0.7 µm and a secondary size of 2.0 µm due to agglomeration of the primary particles.

Alumina

Alumina, Al(OH)3, will be used as a second test aerosol to provide filter loading data for small particle sizes. Alumina has been used successfully in filter loading tests [9,10]. The MMD of alumina particles is 0.3 µm.

Arizona Test Dust

Appropriately sized Arizona Road Dust (ISO 12103-1 A1 Ultrafine or A2 Fine Test Dust from Powder Technology Inc.) will be used as the third challenge aerosol.

DATA COLLECTION

Filter Data

For each filter received for testing, the following information will be recorded. The filter will be weighed prior to first use and after one hour of pre-conditioning to clean ambient air with the filter installed in the housing and operated at the rated flow rate. Filters will be weighed using a Mettler Toledo Model SB32001 top-loading balance.

1. Identification (serial) number
2. Filter manufacturer
3. DOP Filtering Efficiency (FE) (determined by manufacturer and FTF)
4. Filter dimensions (pleat depth, width, ID and OD, pleats/cm)
5. Initial weight (g) prior to use
6. Filter weight (g) after operating in clean air for one hour.

Test Conditions for Dry (40-60% RH) Loading to 30 in.

Protocol for loading filters at 40-60% RH

a. Filters will be inserted into the test stand and exposed to airflow for one hour without aerosols being injected into the test stand, removed, and weighed to establish the tare weight of the filter. Once the tare weight is determined, the filter will be placed back into the test stand and challenge with aerosol will begin.
b. A gravimetric determination of the mass of aerosol captured versus filter dP will be made in order to generate loading curve. The filter mass measurements will be supplemented with upstream mass concentration measurements. Each filter will be loaded with the appropriate aerosol challenge and removed for weighing at regular intervals. Filter mass will be determined at 4.0, 7.0, and 10 in. w.c. (1.0, 1.7, and 2.5 kPa). Additional data will be collected at 20 and 30 in. w.c. (5.0 and 7.5 kPa) or until downstream measurements indicate the loss of integrity of the filter.

Note that the filter is weighed with no drying so that any moisture on the filter is included in the mass. If the RH in the test duct is the same as ambient and during the filter weighings, one can then assume equilibrium moisture on the filter media and on the test particles. This will provide the most accurate relationship between particle mass accumulation on the filter and the filter pressure drop. Since changes in the RH can affect the particle deposit morphology and hence the filter dP, it is desirable to maintain a constant RH as much as possible. Since the three test aerosols are relatively non hygroscopic, the effect of adsorbed moisture should be minimal.

The following information will be recorded for each filter tested. The initial dP of each filter will be recorded and the initial filtering efficiency (FE) will be determined. At the completion of each test segment, the weight of the filter tested will be recorded.

1. Initial Efficiency (Carbon Black, Arizona Test Dust, or Alumina)
   a. Particle number and mass size distribution upstream of filter (PSD_{up})
   b. Number density upstream (N_{up})
   c. Particle number and mass size distribution downstream of filter (PSD_{dn})
   d. Number density downstream (N_{dn})
   e. Feeder conditions (g/min)

2. Particle Loading (Carbon Black, Arizona Test Dust, or Alumina)
   a. Particle number and mass size distribution upstream of filter (PSD_{up})
   b. Number density upstream (N_{up})

c. Particle number size distribution downstream of filter (PSD_{dn})
d. Feeder conditions (g/min)
e. Photometer downstream (periodically upstream for calibration). The downstream photometer is used to monitor the filter efficiency in case of media tears or filter rupture.
f. Pilot cascade impactor periodically for mass size distribution

3. Test Stand Conditions vs Time (t), continuous
    a. Volumetric flow (Q)
    b. Temperature (T)
    c. Relative Humidity (RH)
    d. Differential temperature across filter (dT)
    e. Differential pressure across filter (dP)

4. Interruption of Particle loading for filter weights and photos
    a. The loading test is stopped when the differential pressure reaches 4.0, 7.0, 10, 20 and 30 in. w.c. (1.0, 1.7, 2.5, 5.0, and 7.5 kPa)
    b. The filter is quickly removed from the housing and weighed.
    c. Photographs of the particle deposits on the filter are taken
    d. The filter is replaced in the housing and the test continued.

Structural Failure Tests Under Particle Loading at High Temperature (165-170^{0}F (73.9-76.7 ^{0}C)) and Moisture (90-95% RH) Conditions

A test protocol will be developed that includes particle loading, moist conditions and high temperature. This test is designed to simulate accident conditions described where the HEPA filter is challenged with aerosols under high moisture (90-95% RH) and high temperature conditions (165-170°F (73.9-76.7 ^{0}C)). The test consists of loading the HEPA filter to the normal change condition of 4.0 in. w.c. (1.0 kPa) of dP under ambient humidity conditions (40-60% RH). The same protocol for loading at 40-60% RH in the previous section is used here for particle loading to 4 in. w.c. (1.0 kPa).

The filter is then subjected to a simulated accident condition. Wet air at 90-95% RH and 165-170°F (73.9-76.7 ^{0}C) is added to the filter to simulate moisture and temperature from a steam leak. The added moisture will cause the filter dP to increase. If the filter does not rupture or the dP reaches a plateau, then particle loading is continued under the moist conditions. Particle loading is continued under the moist conditions until the filter ruptures or is blinded. The dP at rupture is recorded. Since the initial structural failure is typically pleat rupture, a photometer is used to monitor the increase in filter penetration.

Protocol for loading filters at 95-100% RH

a. After the filter has been loaded to a differential pressure of 4 inches w.g., weighed and placed back in the test housing, the RH in the test stand will be increased to 90-95%, the temperature in the test stand will be increased to165-170°F (73.9-76.7 ^{0}C), and the differential pressure across the filter will be continuously measured. This will result in a rapid increase in differential pressure. If the filter pressure drop continually increases, the wet filter will be removed from the housing and weighed at 10 in. w.c. (2.5 kPa). The filter is then inserted in the housing and the moisture and high temperature exposure continued. If no plateau in dP is reached, the wet filter is weighed again at 15, 20, and 30 in. w.c. (3.7, 5.0, and 7.5 kPa) or until rupture occurs.

b. If the differential pressure across the test filter plateaus (little or no increase in dP is observed for a 15 minute period), the addition of aerosol challenge will be reinitiated under the elevated RH and temperature conditions. The filter will be weighed at 10, 15, 20 and 30 in. w.c. (2.5, 3.7, 5.0, and 7.5 kPa) if no rupture occurs. Photos of the filter are quickly taken of the wet filter.
c. The filter will continue to be challenged with the combination of the appropriate aerosol and high RH (90-95%) until physical failure or the test stand maximum dP is reached.
d. The determination of filter rupture is made using the photometer downstream of the filter. Since both water droplets and particles will produce photometer readings, a series of calibration curves are required under high temperature and moist conditions and under particle and high temperature and moist conditions.

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 has a multidisciplinary staff of 30 FTE's, a blend of chemists, physicists, computer scientists, and chemical, electrical, and mechanical engineers along with students, both graduate and undergraduate, who further support research operations. Facility staff 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.

Technical Working Group (TWG) of stakeholders and filtration experts has been assembled to ensure that the test plan is properly focused and provide oversight/feedback during the testing process. This TWG is comprised of individuals representing DOE including Headquarters, Hanford Office of River Protection, Hanford-Richland Operations, NNSA, the DOE-funded ATI Filter Test Facility, and selected DOE contractors.

RESEARCH OVERSIGHT AND REVIEW

Due to critical need for data to be derived from the this research effort, the project will be subject to applicable DOE and ASME NQA-1 Quality Assurance requirements as well as final review by industry and academia.

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.[16, 17] An ANSI Z1.13 Quality Assurance Plan has been tailored to accompany the research test plan. All research activities are subject to audit by DOE.

A technical peer review panel comprised of industrial and academic experts in aerosol technology and filtration has been established to evaluate ICET's infrastructure and testing capabilities and to review research results.

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