Evaluation of the Performance of AG-1 FC Separator and Separatorless Axial Flow HEPA Filters and the Effects of HEPA Filter Degradation Due to Aging

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ABSTRACT

High efficiency particulate air (HEPA) filters that are used in nearly every operating Department of Energy (DOE) and National Nuclear Safety Administration (NNSA) nuclear facility must meet the American Society of Mechanical Engineers' (ASME) AG-1 Code on Nuclear Air and Gas Treatment (CONAGT). These nuclear grade HEPA filters installed in DOE and NNSA confinement ventilation systems are credited as the final barrier to protect the environment, public, and the worker from accidental release of virtually all airborne radioactive materials. The HEPA filters discussed in this paper are referenced under ASME AG-1 Code Section FC, *HEPA Filters.* In 1999, the Defense Nuclear Facilities Safety Board (DNFSB) raised concerns of the potential vulnerability of HEPA filters in vital safety systems both from a design stand point and the degradation of HEPA filter performance over time. The DOE Office of Environmental Management (DOE-EM) has a Cooperative Agreement with the Mississippi State University (MSU) Institute of Clean Energy Technology (ICET) to conduct testing of HEPA filters. The current scope of work involves evaluation of the performance envelope for separator and separatorless designs of AG-1 Section FC axial flow HEPA filters. ICET has also been awarded funding by the DOE Nuclear Safety Research and Development Program to begin evaluating the effects of aging on Section FC filters.

This paper will present the preliminary test results comparing performance and durability of new axial flow aluminum separator Section FC HEPA filters under ambient and simulated upset conditions. Results from this testing is compared equivalent test data for a limited group of aged separator style HEPA filters provided by the Electric Power Research Institute (EPRI). The aged filters had been kept in level B storage for between eight (8) and twenty-four (24) years. DOE-EM has established a Technical Working Group of over thirty (30) subject matter experts from the nuclear industry to provide input and oversight of ICET projects activities. This has included establishment/approval of testing parameters for evaluating these filters under ASME NQA-1 compliant Test Plans. Testing for both scopes of work evaluate HEPA filter performance under ambient conditions (60^oF - 80^oF) and relative humidity (40-60%), loading of each filter with aluminum trihydrate ($Al(OH)_3$ to 4 inches w.c. changeout differential pressure exposing the filter to elevate temperature and relative humidity conditions. A range of elevated test conditions (T and RH) are used to determine the operating envelope within which DOE nuclear safety experts can credit installed HEPA filter performance thereby establishing a risk-informed DOE service life.

INTRODUCTION

AG-1 Type FC Separator and Separatorless Axial Flow HEPA Filters

Approximately 6000 nuclear grade HEPA filters are purchased each year for use in the DOE/NNSA complex. These filters are designed and tested in accordance with the ASME AG-1 Code that establishes design requirements and qualification procedures. Qualification testing of AG-1 HEPA filters is intended to verify the reliability` of a filter design and confirm the pedigree of components used in manufacture for that filter design. This measure is taken to ensure performance within a given operating envelope. AG-1 qualification testing is a form of destructive testing and is required on a five (5) year cycle, or earlier in the case of any design change [1]. In addition to qualification testing, each HEPA filter purchased for use in the DOE complex is also inspected and tested by the Air Techniques International (ATI) operated Filter Test Facility (FTF) in accordance with DOE-STD-3020 [2] and DOE-STD-3025 Standards [3]. The FTF confirms conformance of each filter unit to AG-1 dimensional requirements, verifies marking and labeling, and visually inspects each filter. The FTF also conducts testing to verify filtering efficiency and conformance to specified dP of clean filters at their rated flow and 20% of rated flow.

The ASME AG-1 Code currently contains two section that address fibrous glass nuclear grade HEPA filters. AG-1 Section FC *HEPA Filters* and AG-1 Section FK, *Special HEPA Filters* establishes design and qualification requirements for fibrous glass axial flow HEPA filters most commonly used in large ventilation systems. Article 4000 of Sections FC and FK describe design requirements for HEPA filters constructed with either physical separators between pleats or embossed media to maintain pleat separation (separatorless design). It should be pointed out that qualification of filters under Article 5000 of Sections FC and FK are equivalent. This equivalence implies that all designs of FC and FK axial filters have the same operating envelope [4].

The majority of nuclear grade HEPA filters purchased annually by the DOE complex are of an axial flow (Section FC) separatorless design. A very limited number of tests indicate that the U-pack version of axial flow separatorless filters are prone to the same temperature and relative humidity induced pleat collapse failure mechanisms as determined for the 2000 cfm radial flow units (Section FK) previously tested [5]. These findings raise concerns about filters used throughout the complex and also about the sufficiency of current AG-1 qualification tests to accurately establish the operating envelope for all existing designs of fibrous glass nuclear grade HEPA filters. Therefore, it is crucial to establish the operating envelope for separatorless filter designs.

A review of AG-1 Sections FC and FK is necessary to gain an understanding of the operating envelope for filters. Applicability statements (FC-1121) indicate that the sections cover dry type filters in air and gas streams operating in temperatures not to exceed 250 ^{o}F. Qualification testing of AG-1 includes exposure to moisture sufficient to soak medium exposed to airflow sufficient to produce a dP of 10 inches water column (in. w.c.) for one hour. Filters are also expected to retain integrity when rapidly increased to 700 °F for a period of five minutes. However, evaluation of prototype Section FK separatorless filters capable of passing the wet overpressure test demonstrated rapid failure when loaded with particles to four inches of dP under ambient conditions of 60-80 ºF and 40-60% RH then exposed to elevated temperatures of 130 °F and air relative humidity values of 50 to 80% in as little time as three minutes [6]. The rate of failure can be fast enough to preclude corrective action or activation of safety measures.

FC Axial Flow HEPA Filter Degradation Due to Aging

Very limited bench-scale testing in the 1990's raised concern that aging HEPA filters do not have the strength to withstand an accident scenario [7,8]. In May of 1999, the DNFSB released a Technical Report 23 entitled *HEPA Filters Used in the Department of Energy's Hazardous Facilities* [9,10]. This report expressed concerns for the potential vulnerability of HEPA filters in vital safety systems. Concerns and uncertainty associated with degradation of HEPA filter performance over time led the DOE sites to limit HEPA filter service life to 10 years from the date of manufacture or five years in cases where filters may become wet. Establishment of a conservative service life needs to be based on data from a structured series of tests comparing the performance envelope of new and aged full-scale filters. A service life that is insufficiently conservative endangers workers and the public. One that is excessively conservative costs can cause hundreds of otherwise unnecessary filter changes. This increases exposure of employees, disrupts facility operations, and increase disposal costs by millions of dollars annually. Conclusive data are needed to resolve uncertainty associated with the damaging effects of aging on durability of HEPA filters. Therefore, this study needs to provide a sufficient body of evidence to allow DOE and site professionals to make prudent decisions.

Research Test Plans

The DOE has established a group of members within its organization to manage and supervise both of the Cooperative Agreement studies that includes the following persons:

- Elaine Diaz, DOE Technical Lead and Chief Engineer, EM Office of River Protection (ORP)
- Patrick Frias, DOE Nuclear Safety Research and Development (NSR&D) Program Manager, Office of Nuclear Safety (AU-30)
- Christian Palay, DOE Quality Assurance Auditor, EM Office of Standards and Quality Assurance (EM-43)
- Rodrigo Rimando, Jr., DOE Office of Environmental Management (EM) Senior Technical Adviser, EM Office of WTP and Tank Farm Program (EM-23)
- Lori Sehlhorst, DOE Contracting Officer, EM Consolidated Business Center (CBC)

For both Cooperative Agreements, a TWG of over thirty (30) subject matter experts from the nuclear industry was established to provide input and oversight of both projects activities, testing parameter for evaluating these filters under ASME NQA-1 compliant test plans. Members of this group continue to serve as active participants throughout the duration of the Cooperative Agreements and testing. TWG Members are listed below**:**

- Elaine Diaz, DOE Technical Lead and Chief Engineer, EM Office of River Protection (ORP)
- Sonya Barnette, DOE, Office of Quality Assurance (AU-33)
- Ron Bellamy, PhD, U. S. Nuclear Regulatory Commission (ret)
- Werner Bergman, PhD, Aerosol Science, LLC
- William Dye, BWXT Conversion Services, LLC
- Matt Forsbacka, Defense Nuclear Facilities Safety Board (DNFSB) staff
- Patrick Frias, DOE, Office of Nuclear Safety (AU-30)
- Deep Ghosh, Southern Company
- David Grover, DNFSB staff
- Mark Hahn, DOE, EM Richland Office (RL)
- Chris Hart, ATITL
- Dennis Irby, DOE, EM ORP
- Sharok Khabir, DOE, EM Richland Office (RL)
- Anika Khanna, DOE, NNSA
- Louis Kovach, Nucon International
- Gail Laws, Washington Department of Health
- Kendrick Leist, DOE, EM
- Alan Levin, DOE, Office of Nuclear Safety (AU-30)
- Scott MacMurry, Savannah River National Laboratory
- John Mocknick, DOE, EM
- Helen Mearns, U. S. Army
- Do Nguyen, U. S. Army CBC
- Thomas Orr, DOE, NNSA
- Greg Orris, PhD, Naval Research Laboratory Ex-Shadwell
- Christian Palay, DOE, Quality Assurance Auditor (EM-43)
- Richard Pepin, Electric Power Research Institute (EPRI)
- Zach Peterson, DOE, EM-ORP
- John Retelle, DOE, NNSA
- Craig Ricketts, PhD, New Mexico State University
- Subir Sen, PhD, DOE, Office of Quality Assurance (AU-33)
- John Shultz, PhD, DOE-EM, Office of Tank Waste Management (EM-21)
- Linda Suttora, EM Office of WTP and Tank Farm Program (EM-23)
- Chauntel Simons, DOE, Idaho Operations Office (ID)
- Myat Win, U. S. Army CBC
- Nick Zaremba, Newport News Shipbuilding

Testing is performed in accordance with both Cooperative Agreements between the DOE and ICET at MSU, award numbers DE-EM0002163 and DE-EM0003163, require the MSU ICET QA program to meet the requirements of EM Quality Assurance Program (QAP) EM-QA-001, Rev. 1, June 11, 2012, which includes the applicable requirements of NQA-1-2008/2009a and DOE Order 414.1D. The MSU ICET QA Program has been qualified by EM Office of Standards and Quality Assurance (EM-43) to meet Subpart 4.2 of NQA-1-2008/2009a entitled *Guidance on Graded Application of Quality Assurance for Nuclear Related Research and Development* and within Section 600, *Application of NQA-1 To Research and Development Activities.* Specifically, Table 600, and the requirements for “Applied” R&D are applicable.

In addition, this testing is conducted in accordance with the ICET test plans “*Test Plan for Investigation into the Performance of Deep-Pleat Pack Designs without Separators, as Compared to Those with Separators, for Axial-Flow HEPA Filters of AG-1/ Type FC,”* document number 14-TP-HEPA-DOE-001 Ver. 1 Rev 0 and “*Test Plan for Study of FC Axial Flow HEPA Filter Degradation Due to Aging*,” 14-TP-HEPA-DOE-002, Ver. 4 Rev 0., which were sent to the TWG for review and comments prior to final approval. For the study on HEPA filter degradation due to aging the initial funding has been provided by the DOE NSR&D. Follow on funding to continue DOE Office of Environmental Management will provide the study.

For the investigation of the separators as compared to the separatorless axial flow HEPA filters study, new HEPA filters were procured from three manufacturers (American Air, Flanders and Camfil) in accordance with the DOE-STD-3020-2005 and the ICET QA Program. As required by the DOE-STD-3020 Standard, all new purchased HEPA filters were sent through DOE FTF in Baltimore, MD for testing and inspection, and when received at ICET a visual inspection upon receipt, according to the ICET filter receipt inspection procedure was performed. Receipt inspection of test filters is performed to verify the filter manufacturer, model, serial number, and absence of visible physical damage during shipping. Filter dimensional tolerances are also documented in accordance with established ICET procedures. Test filters are stored in accordance with Article AA-7000 and ANSI/ASME NQA-1 Level B. Prior to testing, each filter is reevaluated to verify the filter manufacturer, model, serial number, and the absence of physical damage or deterioration during storage at ICET.

The DOE Cooperative agreement for the testing of new separator and separatorless HEPA filter is preliminary sensitivity analysis and will not include a statistically significant number of filters. A scoping study to determine failure thresholds for new axial-flow separatorless HEPA filters include the independent variables of filter dP following particle loading in dry airflow and elevated airstream temperature and relative humidity. The primary driver for this study is the potential risk for the packs of used separatorless filters to mechanically fail unexpectedly in service, as was observed in previous testing of new filters, under what were presumed to be relatively mild operating conditions: 4 in. w.c. dP, 130°F, and 90% RH[8]. Two new, axial-flow (Section FC) separatorless dimple pleated referenced by the manufacturer as DYN-E2 “U” filters were also tested under similar conditions and found to have the same potential for premature failure via tearing of the filter medium as shown in Figure 1 and 2. [9]

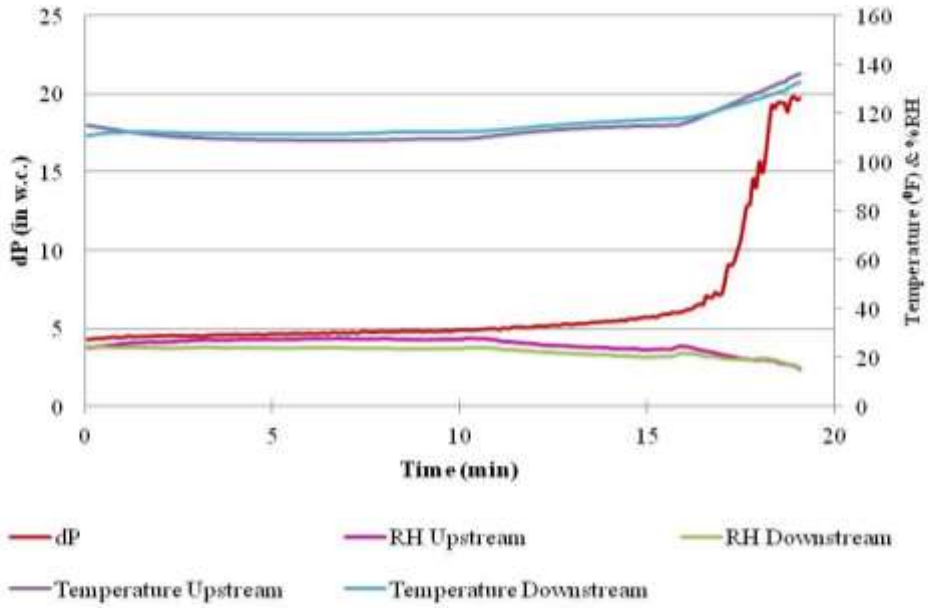

Figure 1. Test data for a 24 x 24 x 11.5 inch Section FC Axial Flow Separatorless HEPA Filter loaded to 4 in. w.c. dP with $Al(OH)_3$ followed by challenge at elevated temperature and relative humidity at rated flow of 1000 cfm.

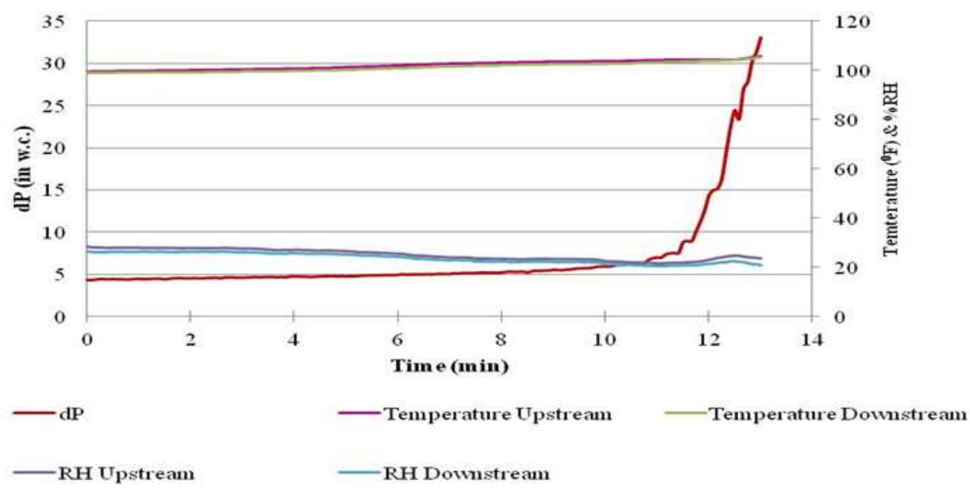

Figure 2. Test data for a 24 x 24 x 11.5 inch Section FC Axial Flow Separatorless HEPA Filter loaded to 4 in. w.c. dP with $Al(OH)_3$ followed by challenge at elevated temperature and relative humidity at rated flow of 1500 cfm.

The development of a test matrix to completely map the performance capabilities of the two distinct new separatorless style HEPA filter packs, (DYN-E2 “U” and the Pureform “W” filters) for the scoping study will achieve goals of the task while staying within the time and financial budget. The suggested starting conditions for testing new, separatorless filters are initial 4 in. w.c., 140 °F, and 60–70% RH. Testing end points will be selected to provide practical data that can support safety-related decisions.

Separatorless radial flow HEPA filters (Section FK) tested at high temperature and humidity have been observed to fail analogous to separatorless axial flow HEPA filters. A gap exists in that no data have been gathered on separator-type radial flow HEPA filters. Data at high temperature and humidity from focused testing on separator-type radial filters are necessary to close the gap and could indicate the need for future testing.

The separator-type deep-pleat filter packs can be expected to be more physically robust than those of the separatorless filters. With this in mind, the suggested starting conditions for testing separator-type filters were established at 4 in. w.c., 140 °F, and 90-95% RH. Assuming that the separator filter designs are found to be reliably passing without physical damage, a minimum of three filters each from Flanders, American Air International, and Camfil will be tested under these conditions. The filters will be tested at rated flow. For filters designed to flows greater than 1000 cfm, testing will initially be conducted at 1000 cfm. Testing of these filters at rates greater than 1000 cfm will be specified as testing activities proceed. These new, separator-type deep-pleat filters will be the first types tested toward providing baseline data against which later results from the two separatorless filter designs will be compared. In addition, providing a base line to compare the results obtained from the aged filter study. If any of the separator-type filters from the three manufacturers fails under these conditions, then a testing matrix will be developed using the methodology detailed further in this section.

The evaluation or testing of HEPA filters routinely uses a reduction of filtration efficiency below 99.97% as the definition of failure. However, in addition, we recommend using pleat collapse as test criterion. These criteria demonstrated by a combination of dramatic changes in the dP versus time curve under elevated temperature and relative humidity conditions. Therefore, functional failure of the filter may be defined as the filter demonstrating both visual (pleat ballooning and collapse) and analytical evidence (dP vs. t curve) of filter pack instability as well as a final filter efficiency value less than 99.97% at 300 nm. Aerosol penetration greater than 0.03% at 300 nm with DOP aerosol indicates failure of the medium by tearing that results in a reduction in dP and particle filtration efficiency.

We are interested in characterizing the performance surface of separating pleat stability/pleat ballooning in terms of filter particle loading (dP) and airstream temperature, and relative humidity, as the independent variables. We have test results for four different filter pack configurations (radial and axial flow) that can provide some degree of insight as to where the boundaries may lie.

Our experimental design starts with the process of identifying the variables and the range of their values. We recommend the following variable ranges be considered for the study of first U- and then W-pack separatorless (Section FC) axial-flow filters:

1. Initial Filter dP: 2, 3, and 4 in. w.c. dP
2. Air Temperature: 120, 130, and 140 °F
3. Air Relative Humidity: 60–70, 80, and 90+%

These values should effectively bracket the range of each test variable.

For the aged filter study, we will utilize the data collected from the new separator and separatorless type filters from each of the three manufacturers. Testing of the new filters first will establish a baseline against which to compare aged filters. The group of aged filters discussed in this presentation was provided to ICET from the EPRI.

The following outline is used to describe the test protocol for both studies. This has been modeled after work previously conducted with dimple-pleat radial-flow filters. An initial dry mass of the filters is obtained by first placing the filters in an oven at 120 °F for four hours and then collecting the mass of the filter. The filters then undergo a conditioning phase prior to testing. Filters are placed into the Axial Flow Large Scale Test Stand (ALSTS) with the FC test filter housing and operated at design flow under ambient air conditions (60–80 °F, 40–60% RH) for one hour. This conditioning phase is followed by performance of an initial FE (filter efficiency) that is used to assess the results of the filter's performance from the FTF. The filter is removed from the filter housing and weighed to determine the filter tare-weight.

The filter is reinstalled in the test and subjected to rated flow at ambient test conditions. The filter is loaded with aluminum trihydrate (SpaceRite S-3 $Al(OH)_3$ from J.M. Huber Corporation) until the target filter dP is reached. The aerosol generator is turned off, the filter removed, and its loaded is mass determined. While the filter is removed, the air temperature and RH within the test stand is adjusted to upset conditions. The filter is reinstalled in the test stand and the test stand is allowed to stabilize at the elevated temperature at rated flow. The filter is then exposed to elevated relative humidity at rated airflow. The filter is exposed to the target test conditions of T and RH for a period of one hour and all test parameters including filter dP are monitored to determine its stability. Upon completion of the one hour, the steam injection is turned off, and the filter is allowed to dry under airflow. The filter is considered dry when the filter dP reaches approximately the target dP and/or when the relative humidity and temperature readings upstream and downstream are about the same. Final FE measurements are made with the test stand operating under ambient conditions. The filter is then removed from the test stand its mass is determined. The filter is dried at 120 °F for four hours and weighed to obtain the final dry mass.

Failure of a filter calls for testing an equivalent second filter under the same condition. This provides insight into repeatability of results between filters. More importantly it calls for collect a different set of data with separatorless filters to evaluate the extent of pleat ballooning. The test protocol for this second filter can also be modified to determine the volumetric flow rate necessary to stabilize ballooning of pleats in the event that the second filter also demonstrates instability under elevated conditions. Operational failure of ventilation systems can occur if airflow drops below thresholds, even if the physical integrity of the HEPA filters have not been breached. Standard operating procedures implemented in the event of high-high alarms for elevated filter dP may require limits to be set for reducing airflow. It is important to know the extent to which airflow will need to be reduced in order to stabilize pleat ballooning.

Data collected during this scoping study will expeditiously provide practical estimates for the following variables:

1. Temperature and relative humidity thresholds for pleat ballooning with respect to the extent of filter loading.
2. Post-rupture filtration efficiencies for the test conditions.
3. Extent to which volumetric flow rates need to be reduced to stabilize ballooning of pleats in order to prevent filter medium rupture.

A matrix of test conditions will be amended based on the findings from test activities. Both separator and separatorless Section FC Filters purchased from three manufacturers (American Air, Camfil, and Flanders) are used in this study to compare their performance and further characterize the results. Filters are chosen from a matrix category that is designed based on three different media pack constructions, including separator, DYN-E2 U-Pack, and Pureform W-Pack style media. From there, the filter is tested at the given dP, temperature, and RH parameters given in the matrix. If the tested filter passes the designated set of parameters, then a second filter from the matrix is tested at those same parameters to confirm a passing result. However, if the first filter fails testing under the parameters the first time, a second filter is tested with a single, modified test variable to better defines the operating envelope. Moreover, if both the first and second filters fail, testing proceeds to a new set of testing parameters all together for that media pack. Testing of filters from each media pack matrix proceeds using a similar test sequence.

Testing is supported by ICET's test control documentation procedure, "Axial Flow Filter Testing Test Control and Documentation" (HEPA-ALSTS-008), which dictates the order of testing to be followed in this study.

Testing Infrastructure

Axial Flow Large Scale HEPA Filter Test Stand

Figure 3. Aerial photograph of the inside portion of the ALSTS.

All filters for both studies are tested utilizing ICET's ALSTS which has been reconfigured to meet the requirements for assessing the function of 24”x24”x11.5” axial flow filters as described in ASME AG-1, Section FC. The ICET ALSTS is designed to tolerate flow rates up to 1500 cfm at 100 in. w.c., temperatures up to 170 °F, and relative humidity up to 90% while also allowing for the introduction of various particulates such as Dioctyl Phthalate (DOP) and Aluminum Trihydrate $Al(OH)_3$ for the purposes of loading the filter.

The test stand is designed in the shape of the letter “U” with its flow path beginning with the air intake outside the building and ending in the high-bay testing area inside the building. There the flow passes through the filter housing containing the filter being tested and immediately turns 180 degrees to flow in the opposite direction. The return leg passes again through the wall of the building to the outside, where the exhaust is located, not far from the inlet. This flow path consists of three main parts in order from upstream to downstream: an inlet section made up of a 24”X24” square duct, the main part of the test stand made up of nominal 24-inch diameter, schedule 10, 304 L stainless steel pipe, and an exhaust section made up of nominal 8-inch diameter, schedule 40, 304 stainless steel pipe. Figure 4 provides an illustration of the ALSTS, including components located inside and outside of the ICET high bay.

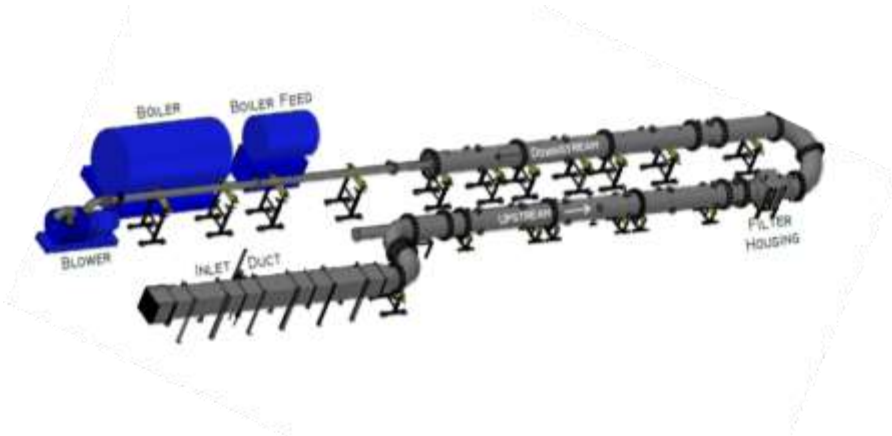

Figure 4. Overview of the ALSTS.

Figure 5 provides a piping and instrumentation diagram (P&ID) for the ALSTS. Portions of the test stand located inside of the high bay and outside the high bay are distinguished by a vertical dotted line, and the colors of the piping indicate diameter and geometry.

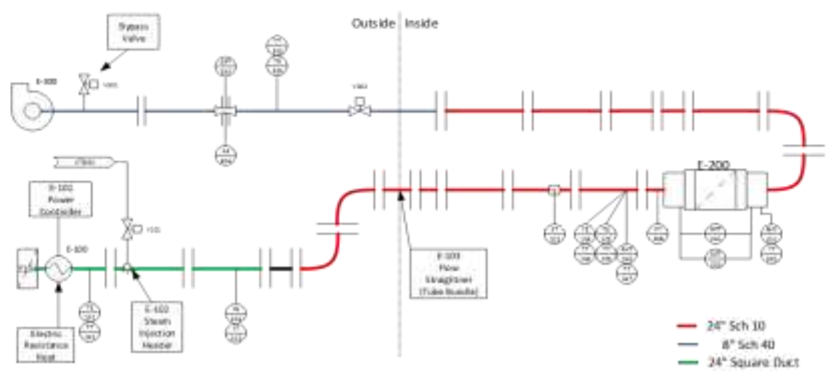

Figure 5. ALSTS P&ID.

Additionally, locations of the test stand sensors are included. Each sensor provides the status of the parameter being monitored. This P&ID representation also serves as the home screen for the test stand control graphical user interface. Figure 6 provides a photograph of the outside portion of the ALSTS.

Figure 6. Photo of the outside portion of the ALSTS.

Figure 7 shows a photograph of the S-shaped portion of upstream ductwork prior to entering the building. This portion has the potential to introduce swirl. A flow straightener is located immediately down stream of this "S."

Figure 7. Photo of the "S" shaped portion of the upstream ductwork of the ALSTS.

Figure 8 shows photographs of the tube bundle and ductwork used to straighten flow.

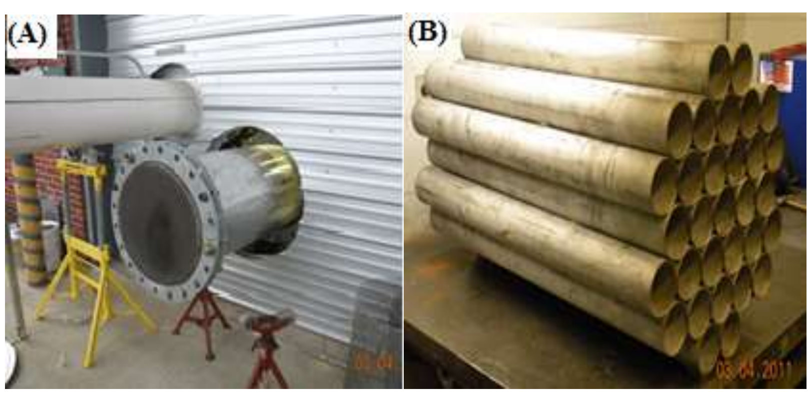

Figure 8. (A) Photo of the ductwork location of the flow straightener. (B) Photo of the tube bundle used for the flow straightener.

The inlet of the upstream section of the test stand includes use of an ASHRAE and HEPA filter to remove environmental particulate matter. A bank of resistance heaters used in concert with steam injection establishes and controls test conditions at elevated temperature and RH. Figure 9 shows a photograph of the inlet section of the upstream section of the ALSTS.

Figure 9. Photo of the inlet section of the upstream section of the ALSTS.

This inlet section includes a screen to prevent larger pieces of debris from entering the filtration section, the filtration section itself, and a bank of resistance heaters. The inlet section is also located under an awning to prevent intake of rain.

The ALSTS uses a Spencer model multistage induced draft fan that is rated to produce 100 in. w. c. negative pressure at 1500 cfm of air flow. A photograph of the fan is shown in Figure 10.

Figure 10. Photo of the Spencer multistage induced draft fan used on the ALSTS.

Figure 11 provides a photograph of the boiler used for both heat and humidity input to the test stand for achieving temperature and humidity conditions. This photograph also shows an awning equivalent to ones used to shelter the inlet section of the test stand and the fan.

Figure 11. Photo of the boiler used to produce elevated humidity and temperature conditions for testing.

Figure 12 shows a photograph of the control panel for the ALSTS boiler.

Figure 12. Photo of the ALSTS boiler control panel.

Figure 13 shows a photograph of the steam inject location on the ALSTS.

Figure 13. Photo of the steam inject location on the ALSTS.

Figure 14 shows a photograph of the tank that supplies water to the ALSTS boiler and the control panel for the tank.

Figure 14. Photo of the water tank for the ALSTS and the control panel for the

Figure 15 shows a photograph of the filter housing for the ALSTS. The housing includes a knife-edge sealing surface for use with both gelatinous and gasket sealed filters. The filter housing accepts a single axial flow 24"X 24"X 11.5" HEPA filter and is reinforced to withstand pressure differentials of 100 in. w. c. The housing utilizes a bag in/ bag out system and is made of gauge 11 and gauge 14T-304 stainless steel. The housing transitions are modified with additional access ports to allow insertion of sampling probes, sensors, and cameras.

Figure 15. Photo of the ALSTS filter housing.

Almatis Spacerite S-3 and Almatis Spacerite S-11 aluminum trihydrate Al(OH)3 purchased from Brenntag Specialties, Inc. is utilized as the test aerosol for this study. Almatis Spacerite S-3 was used for the first 10 filters. Almatis Spacerite S-3 was no longer available from the manufacturer Almatis Spacerite S-3 and was substituted with Almatis Spacerite S-11 which has the same particle size $Al(OH)_3$ is used to simulate loading of the filter medium by small particles. Figure 16 shows a photograph of the aerosol generation equipment for the ALSTS.

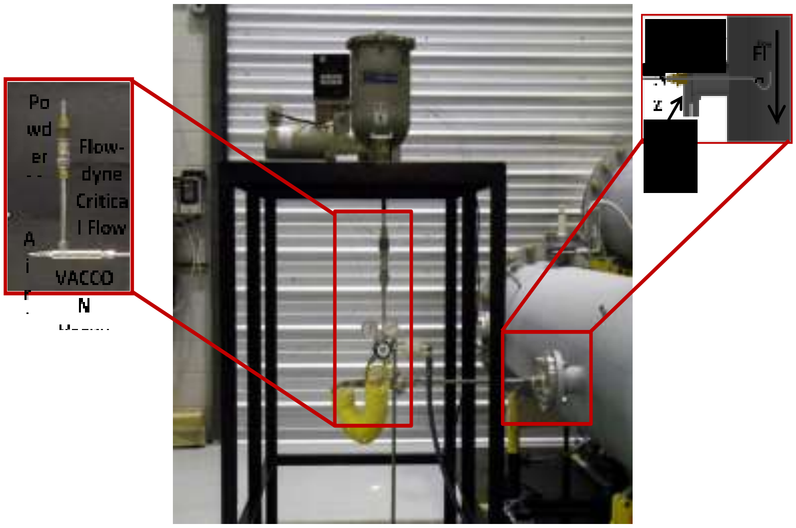

Figure 16. Photo of the aerosol generation using bulk solid powders for the ALSTS.

Aerosol generation using solid powders is accomplished using a K-TRON powder feeder, a Vaccon nozzle, and a 3-inch stainless steel isokinetic sampling nozzle. Bulk material is delivered to the Vaccon nozzle at rates to achieve desired aerosol particle densities in the challenge airflow. Atomization is accomplished by operating the Vaccon nozzle at 60 psig of pressure. The atomized challenge is injected into the test stand in a counter current manner to maximize distribution within test stand airflow. This assembly allows for matching physical and chemical attributes of the challenge to loading conditions that are encountered in field applications.

Rapid atomization of dry bulk material produces triboelectric charging of the particles. The test stand is equipped with an upstream section that is used for neutralizing aerosol particles. Figure 17 shows a photograph of the Sr-90 sealed sources used to accomplish aerosol neutralization. Figure 18 shows a photograph of the section of ductwork where the sealed sources are located.

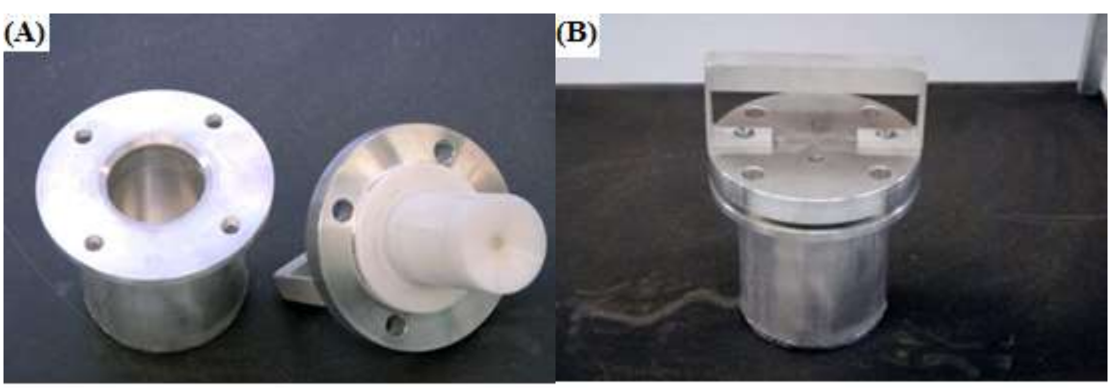

Figure 17. (A) Photo of the sealed source assembly. (B) Photo of the sealed source storage canister.

Figure 18. Photo of the sealed source locations on the ALSTS.

The photograph in Figure 19 shows the location of aerosol measurement instruments, sampling locations, and the return loop for the downstream ductwork. The instrument in the lower left portion of the picture is a TSI Scanning Mobility Particle Sizer (SMPS). A TSI Aerosol Particle Sizer (APS) is located on the lower shelf of the cart on the right. The monitor above the APS connects to a TSI Laser Aerosol Spectrometer (LAS) on the backside of the downstream ductwork.

Figure 19. Photo of the aerosol measurement instrumentation.

The ensemble of APS, LAS, and SMPS is necessary to cover the particle size distribution of aerosol challenges along with particle number densities upstream and downstream of the filter. This method of measurement provides analytical data for characterizing filter performance, including correlating filter efficiency and mass loading rates in order to increase dP.

Upstream aerosol samples are taken before the spool piece immediately to the right of the laptop computer in Figure 19 and include sampling for both the SMPS and APS.

Downstream aerosol samples are taken past the three-foot long spool piece directly across from the instrumentation. Table 1 provides each instrument's operating ranges of particle size, minimum concentration, and maximum concentration.

Table 1. Particle Measurement Instrumentation and Specifications

Instrument	Quantity	#/cc (min)	#/cc (max)	Particle Size Distribution (μm)
TSI Model 3010 Condensation Particle Counter (CPC)	1	<1	1x10^7	0.001–1
TSI Model 3022A CPC	1	2	1x10^8	0.008–1
TSI Model 3772 CPC	1	<1	1x10^4	0.010–3
TSI Model 3775 CPC	1	<1	1x10^7	0.004–3
TSI Model 3936 Scanning Mobility Particle Sizer (SMPS)	3*	1	1x10^7	0.024–1
TSI Model 3321 Aerodynamic Particle Sizer (APS) (with TSI Model 3302A Diluter)	1	1	1x10^3 (1x10^5)	0.5 –20
TSI Model 3340 Laser Aerosol Spectrometer (LAS)	2	<0.02	3.6x10^3	0.09–7.5

*SMPS systems available for use in combination with any of the four CPCs. The SMPS is equipped with a custom-built 95 cm long column Differential Mobility Analyzer (DMA).

To ensure quality data was collected, all instruments were verified before and after testing. The LAS and SMPS were verified using PSL spheres of 0.3 micron size in accordance with ICET technical procedures, *LAS Particle Sizing Verification* (HEPA-M&TE-011) and *SMPS Particle Sizing Verification* (HEPA-M&TE-013). The APS was verified using PSL spheres of 0.9 micron size in accordance with ICET technical procedure, *APS Particle Sizing Verification* (HEPA-M&TE-012). After data was collected in accordance with these procedures, the data was plotted to confirm that the peak channel lay within the appropriate sizing bin for each instrument. Instruments measuring testing conditions were validated in accordance with ICET technical procedure, *Instrument Validation* (HEPA-M&TE-017). Instrument validation involved using calibrated Fluke instrumentation to ensure instruments were outputting appropriate mA values. This procedure was also used when validating the temperature and RH instruments, dP gages, and data acquisition system, and mass flow meters.

The photo in Figure 3 also shows a portion of a flat screen monitor in the upper right corner of the picture. This monitor displays traces for the last 30 minutes of test stand parameters such as volumetric flow rate, dP, RH, and temperature.

Volumetric flow through the test filter is controlled by a Subsonic 8 in. venturi located in the outside (of the high bay) portion of the downstream ductwork. Figure 20 shows a photograph of a venturi similar to the one that is installed inside of the ALSTS.

Figure 20. Photo of a venturi similar to the one installed on the ALSTS.

Differential pressure (dP) of the test stand is monitored by an Endress-Hausser sensor. Figure 21 shows a photograph of the Endress- Hauser dP sensor installed on the ALSTS.

Figure 21. Photo of the dP sensor installed on the ALSTS.

Relative humidity (RH) and temperature of the test stand are monitored by a Vaisala instrument. Figure 22 provides a photograph of the Vaisala RH and temperature instrument installed on the ALSTS.

Figure 22. Photo of the ALSTS RH and temperature instrument installed on the ALSTS.

Upstream and downstream transitions of the filter housing have ports for the insertion of cameras. Figure 23 shows a photograph of the location of the downstream access port along with the cable connecting the camera to the computer and display. Video data is recorded to provide upstream and downstream views of the filter pack.

Figure 23. Photo of the ALSTS downstream of the filter housing showing ports used to view filter along with computer and display.

Figure 24 provides photographs of how a camera is inserted into a test stand filter housing and presents a video recording image of a filter during testing

.

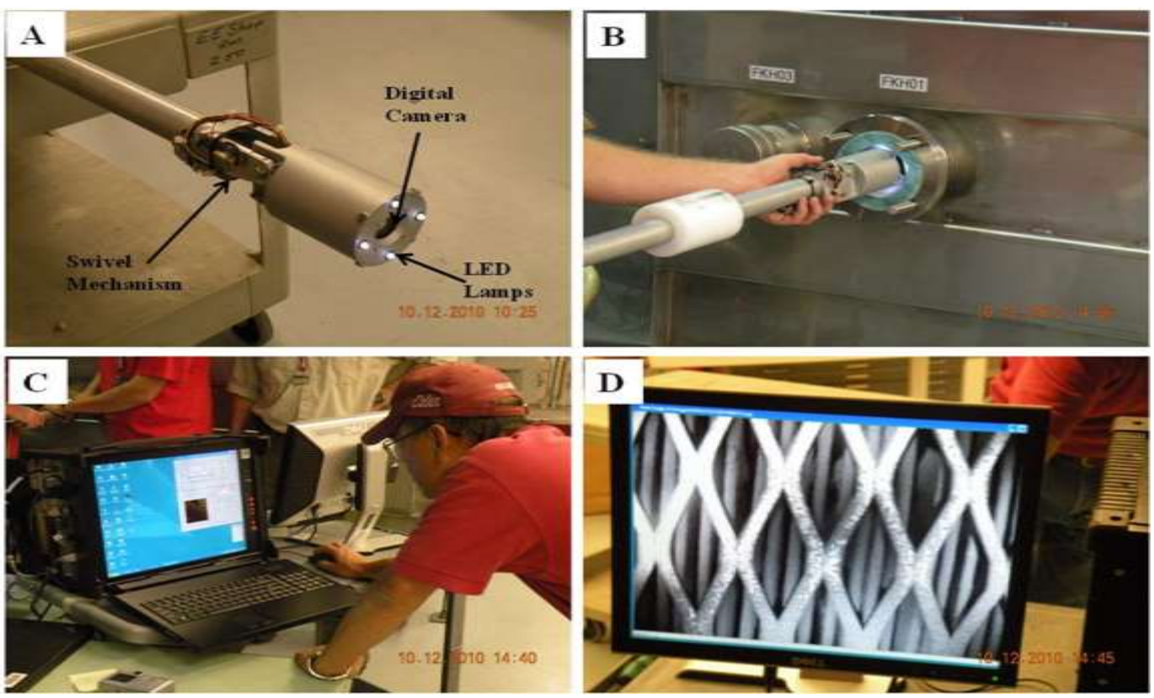

Figure 24. Photos of (A) camera used to collect video data, (B) the camera being inserted into a filter housing, (C) test personnel monitoring and recording data, and (D) example of an image recorded during testing.

The center of the housing for the ALSTS system control and data access (SCADA) system is located near the filter housing and has a variety of control parameters and test parameters that are accessed via touch screen.

Data from all test stand sensors are continuously logged for syncing with instrument data generated by the aerosol measurement instruments. A clock located on the south wall of the high bay is used to synchronize all instruments and data collection activities, including entries into laboratory notebooks. Figure 25 provides a photograph of the Keysight data acquisition system for the ALSTS.

Figure 25. Photo of the Keysight data acquisition system for the ALSTS.

Two screen shot examples of the control system are provided in Figure 26, and the banner of tabs across the top of each of the pages is easily selected from the touch screen.

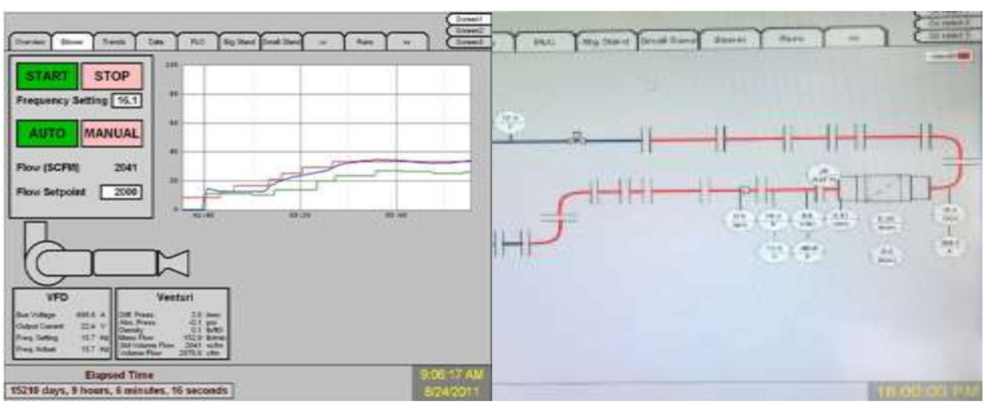

Figure 26. Images of two touch screen images on the ALSTS control system used to monitor or modify test stand conditions.

Software is approved and controlled in accordance with ICET quality procedures, *Software Control* (ICET-QA-036) and/or *Automated Calculational Applications Software* (ICET-QA-038), prior to use. All personnel operating controlled software are trained to a level appropriate for use. Microsoft Excel is used on a stand-alone computer with no network connectivity for data reduction. Wonderware ® software is sourced to control the ALSTS. Table 2 provides a list of software applications for the other test instrumentation that are used in this study.

Table 2. Instrumentation Software Applications

Instrumentation	Software
APS	Aerosol Instrument Manager Software
SMPS	Aerosol Instrument Manager Software
EC	Electrostatic Classifier Software
LAS	LAS Software
ALSTS Data Reduction Computer	Microsoft Excel 2013

A rigorous test control system is in place to ensure that all testing activities are compliant with NQA-1 requirements. ICET technical procedure, *Axial Flow Filter Testing Test Control and Documentation* (HEPA-ALSTS-008), stipulates all of the actions called for in the testing protocol and for documenting document compliance regarding quality purposes**.** This procedure intends to ensure that testing takes place on the identified filter for the duration of testing and provides direction about the proper protocols for operating equipment and the preliminary steps necessary for effective test preparation. It also provides detailed guidance through each phase of testing to safeguard against error and preserves the integrity of the research.

Data for this study is reduced in accordance with ICET quality procedure, *Automated Calculational Applications Software* (ICET-QA-038), and DOE Order 414.1D and its accompanying guide, DOE G 414.1-4. Automated Calculational Applications (ACA) software is used to eliminate the need for repetitive hand calculations or graphing activities in this project and to meet requirements for design and development, verification and testing, application, and control. The ACA design and development process involves originating an ACA package for this study that includes a listing for how calculations are organized within workbook spreadsheets, an instruction or user manual for utilization of the ACA, operational environment specifics, software versions used to develop and test ACA calculations, a name and date or revision for the ACA, applicable codes, standards, or regulations that establish software acceptance criteria, and a description of the allowable or prescribed ranges for inputs and outputs.

Testing Protocol and Test Results of New Separator and Separatorless Filters Tested to Date

Each individual filter is assigned a unique test identification number that describes its attributes and testing parameters. For the new separator and separatorless filter unique test identification is as follows:

- The initial of the Manufacturer: “A” for American Air, “F” for Flanders and “C” for Camfil.
- Type of filter pack: “C” Separator type filters, “W” for Pureform W-Pack separatorless filters and “U” for DYN-E2 U-pack separatorless filters.
- A numeric character to designate the desired dP for testing.

- A designation for the desired temperature for testing.
- A designation for the desired RH for testing.
- A designation for the sequential number of the filter at elevated conditions.

Total number of new separator style filters tested to date includes data for a total of five (5) filters. The data collected is representative of two of the three manufacturers, one manufacturer with three (3) separator style filters and the second manufacturer with two (2) filters tested. The summary of the test results are shown in Table 3. The data shown in Table 3 indicates that the three (3) filters for Flanders met the percent penetration criteria of 0.03%, a calculated efficiency of greater than 99.97% at the stated conditions whereas the American Air filter AA-1-140-90-1 passed the percent penetration criteria when loaded to 1 in. w.c. at 140^{0}F and 90% RH and AA-4-140-90-1 filters tested for American Air did not meet the percent penetration criteria for loading conditions of 4 in. w.c. at 140^{0}F and 90% RH. The penetration and calculated efficiency for failure of American Air are in red text. There was not physical damage noted at the time of receipt inspection for the American Air Filters.

Table 3. Summary of Test Results for New Separator Axial Flow Filters

Filter ID	F-C-1-140-90-1	F-C-4-140-90-1	F-C-4-140-90-2	AA-1-140-90-1	AA-4-140-90-1
Initial Dry Mass (g)	16152	16426	15959	17091	17391
Initial dP (in. w. c.)	0.74	0.74	0.73	0.78	0.65
Initial Penetration with DOP @ 300 (nm)	0.0003	0.007	0.003	0.016	0.190
Initial FE with DOP @ 300 (nm)	99.9997	99.993	99.997	99.984	99.810
Initial Penetration with $Al(OH)_3$ @ 300 (nm)	NA	0.0008	0.0004	0.128	0
Initial FE with $Al(OH)_3$ @ 300 (nm)	NA	99.9992	99.9996	99.872	100.00
Total Loaded Mass (g)	46	512	544	153	1608
Avg. MPPS (nm)	NA	109.74	180.51	NA	352.00
Avg. MMD (μm)	NA	1.18	1.17	NA	1.87
Avg. GSD Upstream	NA	1.69	1.93	NA	1.94
Avg. GSD Downstream	NA	0	1.17	NA	1.24
Final Penetration with DOP @ 300 (nm)	0.00	0.00	0.00	0	0.00
Final FE with DOP @ 300 (nm)	100.00	100.00	100.00	100.00	100.00
Final Filter Mass	16251	16967	16541	17327	19073
Final Dry Mass (g)	16198	16938	16503	17244	18999

A total of four (4) Pureform W-Pack and four (4) DYN-E2 “U” Pack separatorless filters have been tested to date. The summary of the test results are shown in Table 4. The test results indicate that all Pureform W-Pack Separatorless Filters met the percent penetration criteria of 0.03%, and a calculated efficiency of greater than 99.97% when loaded to 1 in. w.c and 4 in. w.c. at elevated conditions of 140^0F and 60% RH and loaded to 4 in. w.c. at elevated conditions of 140^0F and 80% RH. Two (2) of the four (4) DYN-E2 U pack separarless filters met the percent penetration criteria and two (2) failed.

Table 4. Summary of Test Results Pureform “W” Pack and DYN-E2 “U” Pack Axial Flow Separatorless Filters

Filter ID	F-U-1-140-60-1	F-U-4-140-60-1	F-U-3-140-60-1	F-U-3-130-60-1	F-W-1-140-60-1	F-W-4-140-60-1	F-W-4-140-60-2	F-W-4-140-80-1
Initial Dry Mass (g)	17051	17151	17073	17222	16988	16898	17031	17451
Initial dP (in. w. c.)	0.57	0.58	0.59	0.56	0.73	0.72	0.67	0.65
Initial Penetration with DOP @ 300 (nm)	0.0009	0	0	0.0002	0.0015	0	0.007	0.005
Initial FE with DOP @ 300 (nm)	99.9991	100	100	99.9998	99.9985	100.00	99.993	99.995
Initial Penetration with $Al(OH)_3$ @ 300 (nm)	NA	NA	0.0001	0	NA	0.003	0.000	0.001
Initial FE with $Al(OH)_3$ @ 300 (nm)	NA	NA	99.9999	100	NA	100	100	99.999
Total Loaded Mass (g)	35	1572	1153	1258	35	688	745	687
Avg. MPPS (nm)	NA	NA	91.73	105.38	NA	0.096	197.44	96.36
Avg. MMD (µm)	NA	NA	0.67	1.14	NA	1.102	2.56	1.17
Avg. GSD Upstream	NA	NA	2.60	1.68	NA	1.85	2.10	1.77
Avg. GSD Downstream	NA	NA	0	1.43	NA	0.13	0.00	1.34
Final Penetration with DOP @ 300 (nm)	0.0011	NA	NA	0.0021	0.0008	0.0000	0.0005	0.0075
Final FE with DOP @ 300 (nm)	99.9989	**NA**	**NA**	99.9979	99.9992	100.0000	99.9995	99.9925
Final Filter Mass	17117	18768	18255	18526	17039	17625	17820	18183
Final Dry Mass (g)	17086	18723	18226	18480	17023	17586	17776	18138

A summary of the test results for the separatorless filters is shown in Table 5.

Table 5. Summary of Test Results for the Separatorless Axial Flow Filters

Pack Type	Run ID	dP (in w.c.)	Temp (°F)	%RH	Failure (Y/N)
U-Pack	F-U-1-140-60-1	1	140	60	N
U-Pack	F-U-4-140-60-1	4	140	60	Y
U-Pack	F-U-3-140-60-1	3	140	60	Y
U-Pack	F-U-3-130-60-1	3	130	60	N
W-Pack	F-W-1-140-60-1	1	140	60	N
W-Pack	F-W-4-140-60-1	4	140	60	N
W-Pack	F-W-4-140-60-2	4	140	60	N
W-Pack	F-W-4-140-80-1	4	140	80	N

Testing Protocol and Test Results for Aged Axial Flow Filters Tested to Date

A total number of ten (10) aged Section FC axial-flow HEPA filters reported in this paper are of the separator type. This study was funded by NSR&D. The ten (10) filters along with an additional three (3) filters that will be used for autopsy were provided to ICET by EPRI. The EPRI filters came from the Duke Energy Crystal River Nuclear Power Plant #3. Of the ten (10) filters for this study, four (4) of these filters were installed in clean ambient environments with one (1) group of two (2) with age of manufacture established as 1992 and a second group of two (2) with an age of manufacture established as 2009. The remaining six (6) filters were taken from the Warehouse Inventory with their age of manufacture established as 2008. Table 6 provides the original pedigree for the filters provided by EPRI.

Each individual filter is assigned a unique test identification number that describes its attributes and testing parameters. For the aged filters, the unique test identification is as follows:

- The initial character “A” to designate an aged filter.
- “EP” to designate a filter received from EPRI.
- The initial of the manufacturer: “A” for American Air, “F” for Flanders, and “C” for Camfil.
- Type of filter pack: “C” Separator type filters, “W” for Pureform W-Pack separatorless filters, and “U” DYN-E2 for U-Pack separatorless filters.
- A numeric character to designate the desired dP for testing.
- A designation for the desired temperature for testing.
- A designation for the desired RH for testing.
- A designation for the sequential number of the filter at elevated conditions.

Table 6. Original Pedigree for the SNR&D Funded Separator Type Filters Provided by EPRI

Filter Location w/i+M13+B3:K+B3:M13	Enviromental Service or Storage Condition	Purchase Order #	Quality Level	In-Service Date	MFG Name	Model or Part Number	Serial Number	Filter Age (Verified by OEM)	General Comments	Test Conditions	Unique ID No.
Technical Support Center	FL Ambient Enviroment	00475079 Ln #1	3	Installed 01/28/2013	Flanders	0-007-C-42-03-NU-12-13-GG-FU5	1722173	MFG. Date - 12/21/2009	Flanders' supplied as QL-1	140 F, 90% RH Loaded to 4"	A-EP-F-C-4-140-90-1
Technical Support Center	FL Ambient Enviroment	00475079 Ln #1	3	Installed 01/28/2013	Flanders	0-007-C-42-03-NU-12-13-GG-FU5	1722174	MFG. Date - 12/22/2009	Flanders' supplied as QL-1	Determine After Testing at 140	A-EP-F-C-4-140-90-2
Technical Support Center	FL Ambient Enviroment	Unknown*	?*	Installed 08/31/2009	AAF	Astrocel I, P/N 105-883025-1	41451287	MFG. Date - 7/16/1992	AAF Docs are in archive files	140 F, 90% RH Loaded to 4"	A-EP-A-4-140-90-1
Technical Support Center	FL Ambient Enviroment	Unknown*	?*	Installed 08/31/2009	AAF	Astrocel I, P/N 105-883025-1	41451292	MFG. Date - 8/20/1992	AAF Docs are in archive files	Determine After Testing at 140	A-EP-A-4-140-90-2
Warehouse Inventory	68-75F, Humidity 40-50%	00451073 Ln #1	1	Procured 07/22/2009	Flanders	0-007-C-42-03-NU-11-13-GG-FU5	1700953	MFG. Date - 10/30/08	Procured Safety Related QL-1	140 F, 90% RH Loaded to 4"	A-EP-F-C-4-140-90-3
Warehouse Inventory	68-75F, Humidity 40-50%	00451073 Ln #1	1	Procured 07/22/2009	Flanders	0-007-C-42-03-NU-11-13-GG-FU5	1700956	MFG. Date - 10/30/08	Procured Safety Related QL-1	Determine After Testing at 140	A-EP-F-C-4-140-90-4
Warehouse Inventory	68-75F, Humidity 40-50%	00451073 Ln #1	1	Procured 07/22/2009	Flanders	0-007-C-42-03-NU-11-13-GG-FU5	1700978	MFG. Date - 10/29/08	Procured Safety Related QL-1	Determine After Testing at 140	A-EP-F-C-4-140-90-5
Warehouse Inventory	68-75F, Humidity 40-50%	00451073 Ln #1	1	Procured 07/22/2009	Flanders	0-007-C-42-03-NU-11-13-GG-FU5	170119	MFG. Date - 10/30/08	Procured Safety Related QL-1	Determine After Testing at 140	A-EP-F-C-4-140-90-6
Warehouse Inventory	68-75F, Humidity 40-50%	00451073 Ln #1	1	Procured 07/22/2009	Flanders	0-007-C-42-03-NU-11-13-GG-FU5	1701258	MFG. Date - 10/30/08	Procured Safety Related QL-1	Determine After Testing at 140	A-EP-F-C-4-140-90-7
Warehouse Inventory	68-75F, Humidity 40-50%	00451073 Ln #1	1	Procured 07/22/2009	Flanders	0-007-C-42-03-NU-11-13-GG-FU5	1701443	MFG. Date - 10/24/08	Procured Safety Related QL-1	Determine After Testing at 140	A-EP-F-C-4-140-90-8

All ten (10) filters were tested using the previously discussed testing protocol at elevated conditions of 140^{o}F and 90% RH. As indicated by the unique testing identification number, eight (8) of the separator style filters were manufactured by Flanders, and three (3) were manufacturered by American Air. The data in Table 7 shown on the right side of the table, indicates that all seven (7) aged Flanders filters (5.5 - 6.5 years from the manufacturing date) passed with initial FE of 99.98% - 100% and all final FE at 100%. Two (2) of the American Air filters, A-EP-4-140-90-2 and A-EP-4-140-90-3 (22 years from the manufacturing date) failed the initial FE with $Al(OH)_3$ of 99.95% and 99.87%, respectively. American Air filter A-EP-4-140-2 also failed the initial FE with DOP with a reported efficiency of 99.84%.

Table 7. Summary of Test Results for NSR&D Funded Separator Type Filters Provided by EPRI

Filter ID	A-EP-F-C-4-140-90-1	A-EP-F-C-4-140-90-2	A-EP-F-C-4-140-90-3	A-EP-F-C-4-140-90-4	A-EP-F-C-4-140-90-5	A-EP-F-C-4-140-90-6	A-EP-F-C-4-140-90-7	A-EP-F-C-4-140-90-8	A-EP-A-4-140-90-1	A-EP-A-4-140-90-2	A-EP-A-4-140-90-3
Initial Dry Mass (g)	24601	24518	26078	25621	25558	25593	26435	24871	17877	17794	18191
Initial dP (in. w. c.)	0.77	0.77	0.78	0.76	0.77	0.81	0.82	0.87	0.83	0.88	0.87
Initial Penetration with DOP @ 300 (nm)	0.012	0.004	0.001	0.001	0.001	0.00	0.01	0.00	0.02	0.16	0.03
Initial FE with DOP @ 300 (nm)	99.988	99.996	99.999	99.999	99.999	100.00	99.99	100.00	99.98	99.84	99.97
Initial Penetration with $Al(OH)_3$ @ 300 (nm)	0.0192	0.0006	0.0043	0.000	0.0064	0.01	0.00	0.00	0.00	0.05	0.13
Initial FE with $Al(OH)_3$ @ 300 (nm)	99.9808	99.9994	99.9957	100.0000	99.9936	99.99	100.00	100.00	100.00	99.95	99.87
Total Loaded Mass (g)	1299	1269.00	1301	1254	1360	1227.00	1381.00	1127.00	1253.00	NA	1280.00
Avg. MPPS (nm)	91.73	710.50	109.74	187.92	157.08	136.71	943.58	187.92	143.60	NA	91.73
Avg. MMD (µm)	1.95	1.89	1.90	1.97	1.99	1.95	1.97	1.93	1.94	NA	1.85
Avg. GSD Upstream	1.77	2.10	1.87	2.089	1.872	1.65	1.85	1.72	1.74	NA	1.66
Avg. GSD Downstream	1.43	2.14	0	0	1.88	1.46	0.00	1.03	1.12	NA	0.00
Final Penetration with DOP @ 300 (nm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	NA	0.01
Final FE with DOP @ 300 (nm)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NA	99.99
Final Filter Mass	25914	25801	27398	26888	26940	26834	27827	26011	19141	NA	19495
Final Dry Mass (g)	25900	25787	27379	26875	26918	26820	27816	25998	19130	NA	19471

CONCLUSIONS

The preliminary test data as presented provides results indicating that the new separator style FC axial flow HEPA filters as provided by Flanders and aged FC axial flow Flanders HEPA filters as provided by EPRI passed the minimum penetration requirement of 0.03% and the efficiency of being greater than 99.97% when loaded to 4 in. w.c. and subjected to the established elevated test condition of loaded to and 140^0F and 90% RH simulating upset conditions. The American Air, one (1) new and both aged FC axial flow American Air Filters did not pass the minimum penetration and efficiency requirements when subjected to the same test conditions. It was also noted that the Flanders Pureform "W" style pack separatorless filters passed the penetration and efficiency criteria when loaded to 4 in.w.c. and subjected to the elevated conditions of 140^0F and 80% RH and 140^0F and 60% RH. The Flanders DYN-E2 "U" style pack separatorless filters data indicated that when subjected to 3 in. w.c and 4 in. w.c. loading under 140^0F and 60% RH failed the penetration and efficiency requirements but when loaded to 3 in. w.c. subjected to 130^0F and 60% RH one (1) filter passed the penetration and efficiency requirements. Further testing is scheduled to complete both the separator and separatorless filter study and additional filters are being provided by DOE Hanford site to continue the aged filter study.

ACKNOWLEDGEMENTS

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