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Evaluation of 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

This paper will present the updated preliminary test results of new and aged axial flow filters tested at ICET. Results in this paper include data collected from new separator and separatorless type FC HEPA filters and equivalent test data for a group of aged separator and separatorless type FC HEPA filters provided by the Electric Power Research Institute (EPRI), DOE Hanford Site (Hanford), and the Filter Test Facility at Air Techniques International (FTF). Ten filters from EPRI where removed from service. All other aged filters from EPRI, Hanford, and the FTF have been maintained in level B storage between 5 years and 45 years.

Testing for both scopes of work evaluate HEPA filter performance under ambient conditions of temperature (60º F - 80º F) and relative humidity (40-60%), loading of each filter with Aluminum Trihydrate, $Al(H_2O)_3$, to a specified differential pressure, and then exposing the filter to specified elevated temperature and relative humidity conditions. A range of elevated test conditions (T and RH) have been used to determine the operating envelope within which DOE nuclear safety experts can credit installed HEPA filters performance, thereby establishing a risk-informed DOE service life.

INTRODUCTION

High efficiency particulate air (HEPA) filters are used extensively throughout nearly every operating Department of Energy (DOE) site. These filters provide a final barrier to protect the environment, public, and employee from the accidental release of airborne radioactive materials and therefore must be verified for their performance. Approximately 3000 nuclear grade HEPA filters are purchased each year for use in DOE and National Nuclear Safety Agency (NNSA) complexes. 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 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. Additional information regarding filter performance is necessary to evaluate new and aged filter performance at upset conditions.

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

The ASME AG-1 Code currently contains two sections that address fibrous glass nuclear grade HEPA filters. AG-1 Section FC *HEPA Filters* and AG-1 Section FK, *Special HEPA Filters* establish 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 Section FK filters 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 °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 °F 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

Despite extensive testing efforts, aging of filter fabrication materials and the performance of HEPA filters over time have yet to be conclusively studied. The effects of aging on filters require more investigation to preserve the integrity of filter distribution and confidence in filter service life.

Aging of filter fabrication materials can lead to significant degradation in their performance characteristics. Two particularly relative examples include decreases in filter medium tensile strength across the face of filter media pleats and water repellency. Key influences suspected in filter aging involve the environmental conditions during filter storage or while in service that include high air humidity, direct moisture exposure, elevated temperature, chemical reaction, and pleat flutter. Off-gassing of volatiles from the medium binder and/or water repellency agents of the filter medium also represent likely variables for degradation in performance over time.

While these factors have been investigated and discussed to some extent in proceedings of the Nuclear Air Cleaning Conference, more sufficiently reliable data is needed to provide clearer evidence about filter performance after aging. Though DOE sites have implemented programs to administratively address and manage HEPA filter service life, these programs are currently based on guidelines set forth in the DOE Nuclear Air Cleaning Handbook, DOE-HDBK-1169-2003, Appendix C. Still, unknown technical data that takes into account other more specific storage or in-service conditions regarding air humidity, elevated temperature, and moisture exposure will help better define more accurate operating parameters for filters over time.

Very limited bench-scale testing in the 1990s 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. In cases where filters become wet they are required to be removed from service immediately.

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 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.

PROJECT BACKGROUND AND OBJECTIVES

The evaluation of filters in this project allows for the comparison of performance and durability of new filters under upset or design basis conditions with aged filters that were either in service under ambient conditions or retained from storage. In particular, this testing will evaluate the effects of pack loosening and subsequent flutter/vibration, which may cause fatigue failure of filter pleats and are believed to be the leading causes of filter aging following installation in operating plants. Testing will fulfill the requirements set forth with Mississippi State University (MSU) Institute for Clean Energy Technology (ICET) Cooperative Agreement DE-EM0003163.

Testing involves a baseline evaluation of a small sample of new, 24"X"24"X11.5" AG-1, Section FC axial-flow filters with separators that have been rated for 1000 cfm of flow that are loaded to 4 inches water column (in. w. c.) with aluminum trihydrate, $Al(H_2O)_3$ under ambient conditions followed by exposure to elevated conditions of 140 °F and 90% relative humidity (RH). Testing of new filters will be performed in accordance with the "Test Plan for Investigations 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.

Testing of aged filters provided by the Electric Power Research Institute (EPRI), ATI Filter Test Facility (FTF), and DOE Hanford site will likewise involve loading the filters to the operating envelope found in the separator separatorless study with $Al(H_2O)_3$ under ambient conditions followed by exposure to elevated conditions up to 140 °F and 90% RH. Aged filter testing will be performed in accordance with the "Test Plan for Study of FC Axial Flow HEPA Filter Degradation Due to Aging," document number 14-TP-HEPA-DOE-002.

This paper is an update to Julie Stormo's 2016 paper of the same title presented at the 34th Nuclear Air Cleaning Conference [11]. 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. Aged testing was made possible by funding through DOE NSR&D and aged filters from EPRI.

RESEARCH TEST PLANS

Testing is performed in accordance with a Cooperative Agreement between the DOE and ICET at MSU, award DE-EM0003163, that requires the MSU ICET QA program to meet the requirements of EM Quality Assurance Program (QAP) EM-QA-001, Rev. 1, June 11, 2012, that 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.

The DOE has established a group of members within its organization to manage and supervise both of the Cooperative Agreement studies. 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. Members of this group continue to serve as active participants throughout the duration of the Cooperative Agreements and testing. 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 and "*Test Plan for Study of FC Axial Flow HEPA Filter Degradation Due to Aging,*" 14-TP-HEPA-DOE-002, which were sent to the TWG for review and comments prior to final approval.

For the investigation of the separators as compared to the separatorless axial flow HEPA filters study, new HEPA filters were procured from three manufacturers 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 is performed upon receipt according to the ICET filter receipt inspection procedure.. 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 a preliminary sensitivity analysis and does not include a statistically significant number of filters. The scoping study to determine failure thresholds for new axial-flow separatorless HEPA filters included 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 80% RH[6]. Two new, axial-flow (Section FC) separatorless dimple pleated filters referenced by the manufacturer as U-pack 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. [12]

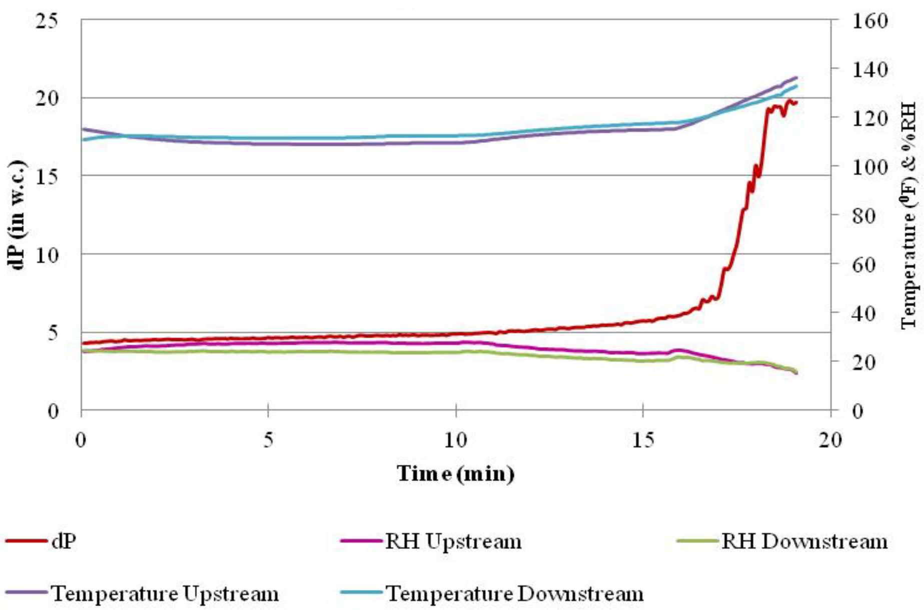

Figure 1. Test data for a 24 x 24 x 11.5 inch Section FC Axial Flow Separatorless HEPA Filter loaded to 4 in. w.c. dP with $Al(H_2O)_3$ followed by challenge at elevated temperature and relative humidity at rated flow of 1000 cfm.

The envelope for testing, separatorless U-pack filters has been determined as 1.5 in. w. c. of loading and elevated conditions of 140 °F, and +90% RH. Separator and W-pack filters testing conditions have been established as 4 in. w. c. of loading and elevated conditions of 140 °F, and +90% RH

The separator and W-pack filter designs were found to be reliably passing without physical damage at the starting conditions. Three filters from each of the manufacturers were tested at the conditions. The new, separator-type deep-pleat filters provided baseline data against which later results from the two separatorless filter designs and the aged filter study have been compared.

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 collection of 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.

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.

Both separator and separatorless Section FC Filters purchased from three manufacturers 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, U-pack, and 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 passed the designated set of parameters, then a second filter from the matrix was tested at those same parameters to confirm a passing result. However, if the first filter failed testing under the parameters the first time, a second filter was tested with a single, modified test variable to better defines the operating envelope.

TESTING INFRASTRUCTURE

Axial Flow Large Scale HEPA Filter Test Stand

All filters for both studies are tested utilizing ICET's axial flow large scale HEPA filter test stand (ALSTS) which has been configured 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 $Al(H_2O)_3$ for the purposes of loading the filter. The ALSTS can be seen in Figure 2.

Figure 2. Aerial photograph of the inside portion of the ALSTS.

An ensemble of aerosol instrumentation manufactured by TSI consisting of Aerodynamic Particle Sizer (APS), Laser Aerosol Spectrometer (LAS), and Scanning Mobility Particle Spectrometer (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 collected utilizing the SMPS, LAS and APS. The LAS and SMPS are used to collect the downstream samples.

Overview of Test Parameters

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. The following summarizes the test outline for each filter.

- An initial dry mass of the filters is obtained by drying the filters in an oven at 120 °F for four hours and weighing the filter.
- Filters are placed into the ALST) with the FC test filter housing and operated at design flow under ambient air conditions (60–80 °F, 40–60% RH) for one hour to condition the filter.
- Initial FE (filter efficiency) is performed 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.
- Filter loaded with aluminum trihydrate (SpaceRite S-3 $Al(H_2O)_3$) until the target filter dP is reached.
- The filter is removed and its loaded is mass determined.
- The air temperature within the test stand is adjusted to upset conditions with the filter removed.

- The filter is then exposed to elevated relative humidity and temperature at 1000 cfm for one hour and all test parameters including filter dP are monitored to determine its stability.
- After one hour, the steam injection is turned off, and the filter is allowed to dry under airflow.
- Final FE measurements are made with the test stand operating under ambient conditions.
- The filter is then removed from the test stand and its mass is determined.
- The filter is dried at 120 °F for four hours and weighed to obtain the final dry mass.

TEST RESULTS

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

The separator vs separatorless testing is in the final stages of the current testing scope. The total number of new separator style filters tested to date includes data for a total of twelve filters. The data collected is representative of four filters from each of the three manufacturers. The summary of the test results are shown in Table 1. The data shown in Table 1 indicates that one separator filter did not pass initial efficiency but passed after being loaded and exposed to conditions. There was no physical damage noted at the time of receipt inspection of this filter. The rest of the separator style filters passed initial FE and all filters passed the final efficiency measurement after being loaded to either 1 in. w. c. or 4 in. w. c. and being exposed to elevated conditions of 140ºF and 90% RH.

Table 1. Summary of Test Results for the Separator Axial Flow Filters

Filter Type	Run ID	dP(in. w. c.)	Temp (°F)	%RH	Failure (Y/N)
Separator	~~Man~~Mfgr1-1-140-90-1	1	140	90	N
Separator	~~Man~~Mfgr1-4-140-90-1	4	140	90	N
Separator	~~Man~~Mfgr1-4-140-90-2	4	140	90	N
Separator	~~Man~~Mfgr1 -4-140-90-3	4	140	90	N
Separator	~~Man~~Mfgr2 -1-140-90-1	1	140	90	N
Separator	~~Man~~Mfgr2 -4-140-90-1	4	140	90	N*
Separator	~~Man~~Mfgr2 -4-140-90-2	4	140	90	N
Separator	~~Man~~Mfgr2 -4-140-90-3	4	140	90	N
Separator	~~Man~~Mfgr3 -1-140-90-1	1	140	90	N
Separator	~~Man~~Mfgr3 -4-140-90-1	4	140	90	N
Separator	~~Man~~Mfgr3 -4-140-90-2	4	140	90	N
Separator	~~Man~~Mfgr3 -4-140-90-3	4	140	90	N

*Failed Initial FE and passed Final FE.

A total of twenty five new separatorless filters (8 W-pack and 17 U-pack) have been tested to date. The test results indicate that all W-pack filters met the percent efficiency of greater than

99.97% when loaded to 1 in. w. c and 4 in. w. c. and exposed to elevated conditions of up to 140ºF and 90% RH.

Twelve of the seventeen U-pack filters met the final FE criteria and five failed. The failure point for the U-pack filters was established as 140º F and 90% loaded to dPs as low as 2 in. w. c. The test results for the U-pack and W-pack filters are shown in Table 2.

Table 2. 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	~~Man~~Mfgr -U-1-140-60-1	1	140	60	N
U-Pack	~~Man~~Mfgr-U-1.5-140-90-1	1.5	140	90	N
U-Pack	~~Man~~Mfgr-U-1.5-140-90-2	1.5	140	90	N
U-Pack	~~Man~~Mfgr-U-1.5-140-90-3	1.5	140	90	N
U-Pack	~~Man~~Mfgr-U-2-140-60-1	2	140	60	N
U-Pack	~~Man~~Mfgr-U-2-140-60-2	2	140	60	N
U-Pack	~~Man~~Mfgr-U-2-140-80-1	2	140	80	N
U-Pack	~~Man~~Mfgr-U-2-140-80-2	2	140	80	N
U-Pack	~~Man~~Mfgr-U-2-140-90-1	2	140	90	Y
U-Pack	~~Man~~Mfgr-U-3-140-60-1	3	140	60	Y
U-Pack	~~Man~~Mfgr-U-3-130-60-1	3	130	60	N
U-Pack	~~Man~~Mfgr-U-3-130-60-2	3	130	60	Y**
U-Pack	~~Man~~Mfgr-U-3-130-60-2B	3	130	60	N
U-Pack	~~Man~~Mfgr-U-3-130-80-1	3	130	80	N
U-Pack	~~Man~~Mfgr-U-3-130-80-2	3	130	80	N
U-Pack	~~Man~~Mfgr-U-3-130-90-1	3	130	90	Y
U-Pack	~~Man~~Mfgr-U-4-140-60-1	4	140	60	Y
W-Pack	~~Man~~Mfgr-W-1-140-60-1	1	140	60	N
W-Pack	~~Man~~Mfgr-W-4-140-60-1	4	140	60	N
W-Pack	~~Man~~Mfgr-W-4-140-60-2	4	140	60	N
W-Pack	~~Man~~Mfgr-W-4-140-80-1	4	140	80	N
W-Pack	~~Man~~Mfgr-W-4-140-80-2	4	140	80	N
W-Pack	~~Man~~Mfgr-W-4-140-80-2B	4	140	80	N
W-Pack	~~Man~~Mfgr-W-4-140-90-1	4	140	90	N
W-Pack	~~Man~~Mfgr-W-4-140-90-2	4	140	90	N

**Temperature and Relative humidity unstable and out of range.

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

The aged filter testing is currently in the early stages and a total number of fifty three aged Section FC axial-flow HEPA filters are reported in this paper. The filters were manufactured by three different filter manufacturers. Twenty one of the filters are of the separator type and thirty two of the separatorless type.

Initially eleven filters along with an additional three filters that were 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 eleven filters, five of these filters were installed in clean ambient environments with one group of three with age of manufacture established as 1992 and a second group of two with an age of manufacture established as 2009. The remaining six filters were taken from the Warehouse Inventory with their age of manufacture established as 2009.

All eleven filters were tested using the previously discussed testing protocol at elevated conditions of 140º F and 90% RH. Eight of the separator style filters were manufactured by Manufacturer 1, and three were manufactured by Manufacturer 2. The data in Table 3 indicates that all eight aged Manufacturer 1 filters (5.5 - 6.5 years from the manufacturing date) passed initial and final FE.

After the initial testing of eleven filters, an additional 42 filters were tested that were provided from multiple sites. Ten filters were supplied from inventory at the FTF with manufactured dates from 2003 to 2012. Two filters removed from service at FERMI with a manufactured date of 1982 were provided. Diablo Canyon Power Plant provided two filters removed from service that were manufactured in 1973. Thus far Hanford has sent two shipments of aged filters from storage, and twenty eight with manufactured dates from 1999 to 2009 have been tested to date. Aged filter manufacture dates range from 1973 to 2012. Additional filters from these sites were also received. Testing of additional filters is either ongoing or the filters have been designated as autopsy filters for media analysis.

The U-pack filters were loaded to 1.5 in. w. c. and all others to 4 in. w. c. based on the operating envelope determined in the separator separatorless study. All filters for the aged study were tested at elevated conditions of 140º F and 90% RH. Table 3 shows the summary of the test results for the aged filters from EPRI, FTF, FERMI, Diablo, and Hanford. One filter failed the initial FE with DOP and was designated as an autopsy only filter. All other filters passed all initial and final FE measurements with DOP.

Table 3. Test results for aged filters.

Utility / Plant Name	**Filter Type**	**Year of Manufacture**	**Loaded dP (in. w. c.)**	**Failure (Y/N)**	**Service/Storage Life**
EPRI	Separator – ~~Man~~Mfgr2	1992	4	N	Removed from ~~In-~~service~~-2009-~~ - Technical Support Center
EPRI	Separator – ~~Man~~Mfgr2	1973	4	N	~~In-~~Removed from ~~S~~service - Not Specified
EPRI	Separator – ~~Man~~Mfgr2	1973	4	N	Removed from ~~In S~~service - Not Specified
EPRI	Separator – ~~Man~~Mfgr2	1982	4	N	Removed from service - TSC HVAC Normal operating 70% RH, 37.5°F to 90°F, 2000 cfm
EPRI	Separator – ~~Man~~Mfgr2	1982	4	N	Removed from service - TSC HVAC Normal operating 70% RH, 37.5°F to 90°F, 2000 cfm
EPRI	Separator – ~~Man~~Mfgr2	1992	4	N/A*	Removed from service - ~~In service 2009~~ Technical Support Center
EPRI	Separator – ~~Man~~Mfgr2	1992	4	N	Removed from service - ~~In service 2009~~ Technical Support Center

Utility / Plant Name	Filter Type	Year of Manufacture	Loaded dP (in. w. c.)	Failure (Y/N)	Service/Storage Life
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Removed from service - ~~In service 2009~~ Technical Support Center
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Removed from service - ~~In service 2009~~ Technical Support Center
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Removed from service - ~~In service 2009~~ Technical Support Center
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Storage Level B
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Storage Level B
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Storage Level B
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Storage Level B
EPRI	Separator – ~~Man~~Mfgr1	2009	4	N	Storage Level B
FTF	Separator – ~~Man~~Mfgr3	Test Date 02/1996	4	N	Level B
FTF	Separator – ~~Man~~Mfgr1	2012	4	N	Level B
FTF	Separator – ~~Man~~Mfgr1	2012	4	N	Level B
FTF	U-pack	2009	1.5	N	Level B
FTF	U-pack	2009	1.5	N	Level B
FTF	U-pack	2012	1.5	N	Level B
FTF	U-pack	2012	1.5	N	Level B
FTF	W-pack	2003	4	N	Level B
FTF	W-pack	2004	4	N	Level B
FTF	W-pack	2008	4	N	Level B
Hanford	Separator – ~~Man~~Mfgr1	2004	4	N	E-C-PK-18B-000
Hanford	Separator – ~~Man~~Mfgr1	2004	4	N	E-C-PK-13B-000
Hanford	Separator – ~~Man~~Mfgr1	2004	4	N	E-C-PK-13B-000
Hanford	W-pack	1999	4	N	E-C-PA-01A-000
Hanford	W-pack	2000	4	N	E-C-PR-05C-000
Hanford	W-pack	2002	4	N	B-E-C-PE-11A & 12A
Hanford	W-pack	2002	4	N	B-E-C-PE-11A & 12A
Hanford	W-pack	2002	4	N	Not Specified
Hanford	W-pack	2002	4	N	B-E-C-PE-11A & 12A
Hanford	W-pack	2002	4	N	Not Specified
Hanford	W-pack	2002	4	N	B-E-C-PE-11A & 12A
Hanford	W-pack	2002	4	N	B-E-C-PE-11A & 12A
Hanford	W-pack	2003	4	N	E-C-PC-10B-000
Hanford	W-pack	2003	4	N	E-C-PC-10B-000

Utility / Plant Name	Filter Type	Year of Manufacture	Loaded dP (in. w. c.)	Failure (Y/N)	Service/Storage Life
Hanford	W-pack	2003	4	N	E-C-PC-10B-000
Hanford	W-pack	2003	4	N	E-C-PR-04C-000
Hanford	W-pack	2003	4	N	E-C-PR-04C-000
Hanford	W-pack	2003	4	N	E-C-PA-01A-000
Hanford	W-pack	2004	4	N	E-C-PP-02B-000
Hanford	W-pack	2006	4	N	E-C-PC-13B-000
Hanford	W-pack	2006	4	N	E-C-PC-13B-000
Hanford	W-pack	2006	4	N	E-C-PC-14B-000
Hanford	W-pack	2006	4	N	E-C-PC-14B-000
Hanford	W-pack	2007	4	N	E-C-PC-15B-000
Hanford	W-pack	2007	4	N	E-C-PC-15B-000
Hanford	W-pack	2007	4	N	E-C-PC-15B-000
Hanford	U-pack	2009	1.5	N	B-E-C-PE-14B
Hanford	U-pack	2009	1.5	N	B-E-C-PE-14B

*Failed initial FE changed to Autopsy Filter.
All Filters from Hanford were in Level B storage.

CONCLUSIONS

The separator vs separatorless study is in the final stages with additional testing being considered to incorporate a suite of data that involves rough handling of the filters before testing. The test data as presented indicate that the new separator style FC axial flow HEPA filters as provided by Manufacturer 1, Manufacturer 3, and the aged FC axial flow HEPA filters passed the minimum efficiency. Five of seven from Manufacturer 2 passed the initial FE. Each filter had a FE of 99.97% or greater when loaded to either 1 in. w. c. or 4 in. w. c. and subjected to the established elevated test conditions of 140ºF and 90% RH. All separator filters passed the final efficiency measurement after being loaded to either 1 in. w. c. or 4 in. w. c.

The W-pack filters passed the efficiency criteria when loaded to 4 in. w. c. and subjected to the elevated conditions upto 140ºF and 90% RH. The U- pack filters data indicated that when subjected to 3 in. w. c. and 4 in. w.c. loading, and then exposed to 140ºF and 60% RH, the filter failed the efficiency requirement. However, when loaded to 3 in. w. c. and subjected to 130ºF and 60% RH, the filters passed the efficiency requirements. At that time, the TWG set the elevated condition bench mark as 140º F and 90% RH. Under these conditions the W-packs passed at 4 in. w. c. of loading and the U-pack filters failed at dPs as low as 2 in. w. c. U-pack filters passed final FE measurements aftering being loaded to 1.5 in. w. c. and exposed to elevated conditions of 140º F and 90% RH. Further testing is scheduled to complete the separator vs separatorless filter study as written in the current test plan.

Aged filter testing utilized the baseline conditions established during the separator vs separatorless testing of 140º F and 90% RH and loading dP of 1.5 in. w. c. for U-Packs and 4 in. w. c. for all other filter types. All filters tested at these conditions have passed the initial and final FEs. Additional filters are being provided from multiple sources to support the aged filter testing.

Additional testing of separatorless filters is needed for older filters and filters removed from service. No separatorless filters that have been removed from service have been made available for testing to date.

In conclusion, separator and W-pack filters have demonstrated more robustness compared to the U-pack filters when it comes to performance after exposure to elevated conditions. Concerns have been voiced from the TWG in regard to the effects of rough handling on the different filters. Additional testing is being planned to address the effects of rough handling on the different filter pack types.

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