Performance Evaluation of AG-1 FC Filters Under Upset Conditions and the Effects of Aging on Filters

Jaime Rickert and John Wilson

Work Described was Underwritten by the Department of Energy Under Cooperative Agreement Number: DE-EM0003163

Introduction

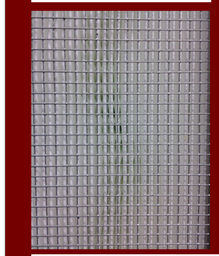
High efficiency particulate air (HEPA) filters are used extensively throughout nearly every operating Department of Energy (DOE) and National Nuclear Security Agency (NNSA) site. These nuclear grade HEPA filters are credited as the final barrier to protect the environment, public, and employees from the accidental release of airborne radioactive materials and therefore must be verified for their performance. These filters must meet the American Society of Mechanical Engineers' (ASME) AG-1 Code on Nuclear Air and Gas Treatment; therefore, they are designed and tested in accordance with the ASME AG-1 Code that establishes design requirements and qualification procedures [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 [3] Standards. 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 differential pressure (dP) of clean filters at their rated flow and 20% of rated flow. Additional information regarding filter performance is provided through research activities at ICET to evaluate new and aged filter performance at upset conditions.

Project Objectives

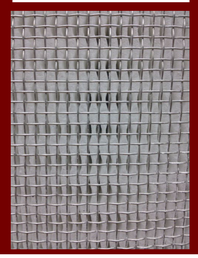
The evaluation of filters in this project allows for the comparison of performance and durability of new filters under upset or design basis conditions with aged filters.

- 24"x24"x11.5" AG-1 Section FC Axial Flow Filters
  - With Separators
  - Without Separators
- 0.4719 m^3/s (1000 cfm)
- Loaded with Alumina Trihydroxide ($Al(OH)_3$) under Ambient Conditions
  - Filters with Separators and W-pack Separatorless Filter are loaded to approximately 995 Pa (4 in. w.c.)
  - U-Pack Separatorless Filters are loaded to approximately 373 Pa (1.5 in. w.c)
- Exposed to Upset Conditions
  - 60 °C (140 °F)
  - 90% Relative Humidity

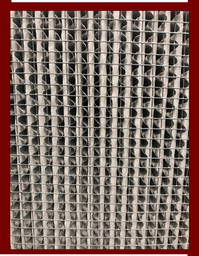
W-Pack(Separatorless)



U-Pack(Separatorless)



Separator Style Filter



References

[1] ASME AG-1-2015, Code on Nuclear Air and Gas Treatment, American Society of Mechanical Engineers. https://www.asme.org/products/codes-standards/ag1-2015-code-nuclear-air-gas-treatment

[2] DOE-STD-3020-2015, DOE Standard Specification for HEPA Filters Used by DOE Contractors. http://energy.gov/ehss/downloads/doe-std-3020-2015

[3] DOE-STD-3025-2007, DOE Standard Quality Assurance Inspection and Testing of HEPA Filters. http://energy.gov/ehss/downloads/doe-std-3025-2007

[4] Separator vs. Separatorless Axial Flow Filter Study Report, 19-REP-DOE-SEP/SEPLESS-FINAL, Rev 0. Institute for Clean Energy Technology. 2019

[5] NSR&D Aged HEPA Filter Study Final Report, 16-REP-DE-EM-0002163-NSRD-FINAL Rev 1. Institute for Clean Energy Technology. 2017

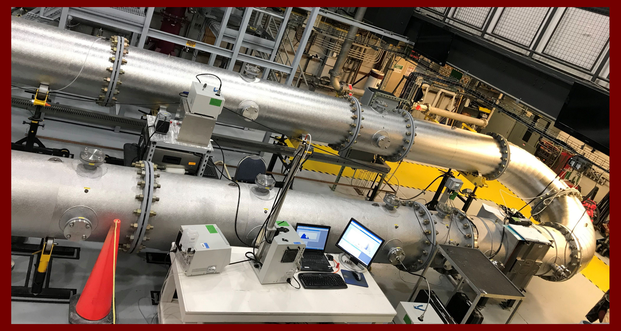
[6] Effects of Aging on Nuclear Grade HEPA Media and Filters Summary Report, 21-REP-DOE-AGING-FINAL, Rev 0. Institute for Clean Energy Technology. 2021

Testing Infrastructure

All filters were tested utilizing ICET's Axial Flow Large Scale 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.

Design Specifications

- Flowrates up to 0.7079 m^3/s (1500 cfm)
- 24,884 Pa (100 in. w.c.)
- Up to approximately 77 °C (170 °F)
- >90% Relative Humidity
- Loading Capability
  - Dioctyl Phthalate (DOP)
  - Alumina Trihydroxide ($Al(OH)_3$)



Aerosol Instrumentation

Scanning Mobility Particle Sizer

- 0.025 – 1 µm
- Uses a DMA to classify particles and a CPC to count the number of particles
- 1 #/cc (min)

Laser Aerosol Spectrometer

- 0.09 – 7.5 µm
- Uses a laser to measure wide angle light scattering intensity
- 0.02 #/cc (min)

Aerodynamic Particle Sizer

- 0.5 – 20 µm
- Accelerates aerosol stream through nozzle and measures time of flight
- 1 #/cc (min)

Rough Handling Test Results [4]

Filter Type / Pack Type	Run ID	Target dP (Pa / in. w.c.)	Target Temp (°C / °F)	Target % RH	Failure (Y/N)
Separator	Man2-RH-1-140-90-1	~249 / 1 (Clean)	60 / 140	90	N
Separator	Man2-RH-4-140-90-1	~995 / 4	60 / 140	90	N
Separator	Man2-RH-4-140-90-2	~995 / 4	60 / 140	90	N
Separator	Man3-RH-1-140-90-1	~249 / 1	60 / 140	90	N
Separator	Man3-RH-4-140-90-1	~995 / 4	60 / 140	90	N
Separator	Man3-RH-4-140-90-2	~995 / 4	60 / 140	90	N
Separator	Man1-RH-1-140-90-1	N/A	N/A	N/A	Y[a]
Separator	Man1-RH-4-140-90-1	~995 / 4	60 / 140	90	Y[b]
Separator	Man1-RH-4-140-90-2	N/A	N/A	N/A	Y[a]
Separator	Man1-RH-4-140-90-3	N/A	N/A	N/A	Y[a]
U-Pack	U-RH-1-140-90-1	~249 / 1 (Clean)	60 / 140	90	N
U-Pack	U-RH-1.5-140-90-1	373 / 1.5	60 / 140	90	N
U-Pack	U-RH-1.5-140-90-2	373 / 1.5	60 / 140	90	N
W-Pack	W-RH-1-140-90-1	~249 / 1 (Clean)	60 / 140	90	N
W-Pack	W-RH-4-140-90-1	~995 / 4	60 / 140	90	N
W-Pack	W-RH-4-140-90-2	~995 / 4	60 / 140	90	Y[c]
W-Pack	W-RH-4-140-90-3	~995 / 4	60 / 140	90	N

Test Stand Testing Process

- Initial dry mass obtained by drying the filters in an oven at approximately 49 °C (120 °F) for four hours and weighing the filter.
- Conditioned in the ALSTS at design flow under ambient air conditions, approximately 16 – 27 °C (60 – 80 °F) and 40 – 60% RH for one hour.
- The filter is removed from the filter housing and weighed to determine the filter tare mass.
- An initial filtering efficiency (FE) is performed to assess the results of the filter's performance from the FTF.
- If applicable, rough handling and post rough handling FE is performed.
- Filter is loaded with alumina trihydroxide ($Al(OH)_3$) to the target dP.
- The filter is removed, and its loaded mass is determined.
- The filter is reinstalled and then exposed to elevated relative humidity and temperature at 0.4719 m^3/s (1000 cfm) for one hour, and all test parameters including filter dP are monitored to determine its stability. All aged elevated conditions were 60 °C (140 °F) and 90% RH.
- 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 mass is determined.
- The filter is dried and weighed to obtain the final dry mass.

Separator/Separatorless Study Test Results [4]

Filter Type / Pack Type	Run ID	Target dP (Pa / in. w.c.)	Target Temp (°C / °F)	Target % RH	Failure (Y/N)
Separator	Man1-1-140-90-1	~249 / 1 (Clean)	60 / 140	90	N
Separator	Man1-4-140-90-1	~995 / 4	60 / 140	90	N
Separator	Man1-4-140-90-2	~995 / 4	60 / 140	90	N
Separator	Man1-4-140-90-3	~995 / 4	60 / 140	90	N
Separator	Man2-1-140-90-1	~249 / 1 (Clean)	60 / 140	90	N
Separator	Man2-4-140-90-1	~995 / 4	60 / 140	90	N
Separator	Man2-4-140-90-2	~995 / 4	60 / 140	90	N
Separator	Man2-4-140-90-3	~995 / 4	60 / 140	90	N
Separator	Man3-1-140-90-1	~249 / 1 (Clean)	60 / 140	90	N
Separator	Man3-4-140-90-1	~995 / 4	60 / 140	90	N
Separator	Man3-4-140-90-2	~995 / 4	60 / 140	90	N
Separator	Man3-4-140-90-3	~995 / 4	60 / 140	90	N
U-Pack	U-1-140-60-1	~249 / 1 (Clean)	60 / 140	60	N
U-Pack	U-1.5-140-90-1	373 / 1.5	60 / 140	90	N
U-Pack	U-1.5-140-90-2	373 / 1.5	60 / 140	90	N
U-Pack	U-1.5-140-90-3	373 / 1.5	60 / 140	90	N
U-Pack	U-2-140-60-1	~498 / 2	60 / 140	60	N
U-Pack	U-2-140-60-2	~498 / 2	60 / 140	60	N
U-Pack	U-2-140-80-1	~498 / 2	60 / 140	80	N
U-Pack	U-2-140-80-2	~498 / 2	60 / 140	80	N
U-Pack	U-2-140-90-2	~498 / 2	60 / 140	90	N
U-Pack	U-2-140-90-3	~498 / 2	60 / 140	90	N
U-Pack	U-2-140-90-1	~498 / 2	60 / 140	90[d]	Y
U-Pack	U-3-140-60-1	~747 / 3	60 / 140	60	Y
U-Pack	U-3-140-60-2	~747 / 3	60 / 140	60	N[e]
U-Pack	U-3-130-60-1	~747 / 3	~54 / 130	60	N
U-Pack	U-3-130-60-2	~747 / 3	~54 / 130[d]	60[d]	Y
U-Pack	U-3-130-60-2B	~747 / 3	~54 / 130	60	N
U-Pack	U-3-130-80-1	~747 / 3	~54 / 130	80	N
U-Pack	U-3-130-80-2	~747 / 3	~54 / 130	80	N
U-Pack	U-3-130-90-1	~747 / 3	~54 / 130	90	Y
U-Pack	U-3-130-90-2	~747 / 3	~54 / 130	90	Y[e]
U-Pack	U-4-140-60-1	~995 / 4	60 / 140	60[d]	Y
U-Pack	U-4-140-60-2	~995 / 4	60 / 140	60	Y[e]
W-Pack	W-1-140-60-1	~249 / 1 (Clean)	60 / 140	60	N
W-Pack	W-4-140-60-1	~995 / 4	60 / 140	60	N
W-Pack	W-4-140-60-2	~995 / 4	60 / 140	60	N
W-Pack	W-4-140-80-1	~995 / 4	60 / 140	80	N
W-Pack	W-4-140-80-2	~995 / 4	60 / 140	80[d]	N
W-Pack	W-4-140-80-2B	~995 / 4	60 / 140	80	N
W-Pack	W-4-140-90-1	~995 / 4	60 / 140	90	N
W-Pack	W-4-140-90-2	~995 / 4	60 / 140	90	N

Aged Study Test Results [5,6]

Utility / Plant Name	Filter Type	Year of Manufacture	Target dP (Pa / in. w.c.)	Failure (Y/N)
EPRI	Separator – Man2	1992*	~995 / 4	N
EPRI	Separator – Man2	1992*	N/A	Y[c]
EPRI	Separator – Man2	1992*	~995 / 4	N
EPRI	Separator – Man1	2009*	~995 / 4	N
EPRI	Separator – Man1	2009*	~995 / 4	N
EPRI	Separator – Man1	2009	~995 / 4	N
EPRI	Separator– Man1	2009	~995 / 4	N
EPRI	Separator – Man1	2009	~995 / 4	N
EPRI	Separator – Man1	2009	~995 / 4	N
EPRI	Separator – Man1	2009	~995 / 4	N
EPRI	Separator – Man1	2009	~995 / 4	N
FTF	Separator – Man3	Test Date 02/1996	~995 / 4	N
FTF	Separator – Man1	2012	~995 / 4	N
FTF	Separator – Man1	2012	~995 / 4	N
FTF	U-pack	2009	~373 / 1.5	N[c]
FTF	U-pack	2009	~373 / 1.5	N
FTF	U-pack	2012	~373 / 1.5	N
FTF	U-pack	2012	~373 / 1.5	N
FTF	W-pack	2003	~995 / 4	N
FTF	W-pack	2004	~995 / 4	N
FTF	W-pack	2008	~995 / 4	N
FERMI	Separator – Man2	1982*	~995 / 4	N
FERMI	Separator – Man2	1982*	~995 / 4	N[c]
Diablo	Separator – Man2	1973*	~995 / 4	N
Diablo	Separator – Man2	1973*	~995 / 4	N
Prairie Island	Separator – Man2	~1980*	N/A	Y[f]
	Separator – Man2	~1980*	N/A	Y[f]
	Separator – Man2	~1980*	N/A	Y[f]
Hanford	Separator – Man1	2004	~995 / 4	N
Hanford	Separator – Man1	2004	~995 / 4	N
Hanford	Separator – Man1	2004	~995 / 4	N
Hanford	Separator – Man1	2004	~995 / 4	N
Hanford	U-pack	2009	~373 / 1.5	N
Hanford	U-pack	2009	~373 / 1.5	N
Hanford	W-pack	1999	~995 / 4	N
Hanford	W-pack	1999	~995 / 4	N
Hanford	W-pack	2000	~995 / 4	N
Hanford	W-pack	2000	~995 / 4	N
Hanford	W-pack	2002	~995 / 4	N
Hanford	W-pack	2002	~995 / 4	N[g]
Hanford	W-pack	2002	~995 / 4	N
Hanford	W-pack	2002	~995 / 4	N
Hanford	W-pack	2002	~995 / 4	N
Hanford	W-pack	2002	~995 / 4	N
Hanford	W-pack	2002	~995 / 4	N
Hanford	W-pack	2003	~995 / 4	N
Hanford	W-pack	2003	~995 / 4	N
Hanford	W-pack	2003	~995 / 4	N
Hanford	W-pack	2003	~995 / 4	N
Hanford	W-pack	2003	~995 / 4	N
Hanford	W-pack	2003	~995 / 4	N
Hanford	W-pack	2004	~995 / 4	N
Hanford	W-pack	2004	~995 / 4	N
Hanford	W-pack	2006	~995 / 4	N
Hanford	W-pack	2006	~995 / 4	N
Hanford	W-pack	2006	~995 / 4	N
Hanford	W-pack	2006	~995 / 4	N
Hanford	W-pack	2007	~995 / 4	N
Hanford	W-pack	2007	~995 / 4	N
Hanford	W-pack	2007	~995 / 4	N

[a] Not challenged to elevated conditions due to rough handling failure
[b] Failed post rough handling FE, tested for information purposes only, and failed final FE.
[c] Filter failed initial FE with original gasket but passed FE after applying new gasket
[d] Target condition was not maintained during elevated condition challenge.
[e] Reduced flow to prevent failure
[f] Failed initial FE, therefore reassigned as Autopsy filters
[g] Failed initial FE but passed final FE
*In-Service Filter
**Testing of EPRI filters occurred in 2016 and all other aged filter testing occurred between 2017 and 2018