**Proceedings of The ASME 2011 14th International Conference on Environmental Remediation and Radioactive Waste Management**
**ICEM2011**
**September 25-29, 2011, Reims, France**

**59170**

# LIFETIME PERFORMANCE OF ASME AG-1 SECTION FK RADIAL FLOW FILTERS

**Paxton Giffin**
Institute for Clean Energy Technology
Mississippi State University
205 Research Blvd
Starkville, MS, 39759 USA

**Jaime Rickert**
Institute for Clean Energy Technology
Mississippi State University
205 Research Blvd
Starkville, MS, 39759 USA

**Michael Parsons**
Institute for Clean Energy Technology
Mississippi State University
205 Research Blvd
Starkville, MS, 39759 USA

**Charles Waggoner**
Institute for Clean Energy Technology
Mississippi State University
205 Research Blvd
Starkville, MS, 39759 USA

## ABSTRACT

The American Society of Mechanical Engineers AG-1 Standard has added section FK for specialty HEPA filters. The Institute of Clean Energy Technology has performed as series of lifetime performance evaluations for a set of radial flow HEPA filters developed under guidelines of AG-1 Section FK.

A series of 18 filters Section FK HEPA filters have been tested. This included testing two different configurations of 56.6 $m^3$/min (2000 cfm) filters, 12 remote change filters and 6 safe change filters. Testing consisted of lifetime performance evaluations using three different aerosol challenges and two different relative humidity/temperature conditions. Challenge aerosols ranged in mass median diameter (MMD) size from 500 nm (alumina) to 3000 nm (Arizona road dust). All testing was conducted consistent with NQA-1 standards. Test data were continuously collected for volumetric airflow, air temperature, relative humidity, up and downstream particle size distribution, up and downstream particle count, and filter differential pressure.

Data provided in this paper include the mass versus differential pressure (dP) loading curves demonstrating loading capacity as a function of particle size. Results of mass loading are shown to follow current models for smaller aerosols, but large particle challenges demonstrated higher loading capacities than expected. Data will also be provided to demonstrate changes in the filter pack geometry during latter stages of loading (at differential pressures greater than 2986-3484 Pa (12-14 in. w.c.) dP). This change in pleat geometry (pleat collapse) leads to a threshold dP at which the differential pressure will continue to increase even if aerosols are no longer added to the air flow. Data will be presented to demonstrate that reducing the airflow by 25 percent will counteract this runaway increase in dP, even if reduction of airflow is done as late as 6221+ Pa (25+ in. w.c.). Filter failure for the units tested ranged from 7465 to 12442 Pa (30 to 50 in. w.c.).

Video of filters collected inside the filter housing while loading indicated little flutter of pleats, however, ballooning of pleats was shown to occur during latter stages of the testing protocol. Photographs of the filter annulus prior to discontinuing airflow do not show evidence of bridging between pleats, even for very high filter loading. Additional photos of filters post-failure demonstrate the tendency of the filter pack to remain somewhat distorted with physical failure of the medium occurring at the medium-potting material interface.

## INTRODUCTION

This paper is intended to use data collected for evaluating the performance of a new design of nuclear grade HEPA filters to emphasize the need of users to adequately characterize their applications and evaluate filter performance under those conditions. Data presented in this paper will point out a highly unusual instance where qualification testing may not represent the ability of a filter to withstand conditions within the operating envelope called for by the standard. It must be emphasized from the outset that this is a rare occurrence, however, it is not at all a rare occurrence for newly designed containment filtration systems to perform below expectations. Owners/operators of nuclear facilities should always base expectations of how new systems will function on the best possible data and, if possible, on empirically derived information from testing. This paper is intended to demonstrate the benefits of full-scale, lifetime testing of filters under use conditions.

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

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

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

Radial flow or circular filters have been used in Europe for some time. Two manufacturers, Vokes [2] and MC Air Filtration [3], produce filters basically equivalent to the AG-1 FK units. Use of radial flow filters for containment ventilation systems was introduced to US Department of Energy (DOE) operations by British Nuclear Fuels Ltd. (BNFL) first at the Idaho National Laboratory (INL) and then at the Hanford facility in Washington State. Radial flow filters have a variety of advantages for some applications, particularly when they have to be changed remotely. There are also advantages to the footprint of radial flow filter housings.

Radial flow filters have different considerations for filter pack stability due to the geometry of fan folded filter medium secured in a circular pack. The wedge shape of the individual pleats and the pleat width to length ratio require a different approach in use of separators and stabilizing radial displacement of the pleats. Two variants (remote change and safe change) of a 56.6 $m^3$/min (2000 cfm) AG-1 radial flow filter were included in tests reported in this paper. Table II provides comparative information for filter packs in the two versions of filters tested. Figure 1 provides pictures displaying additional structural differences in the two designs.

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

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

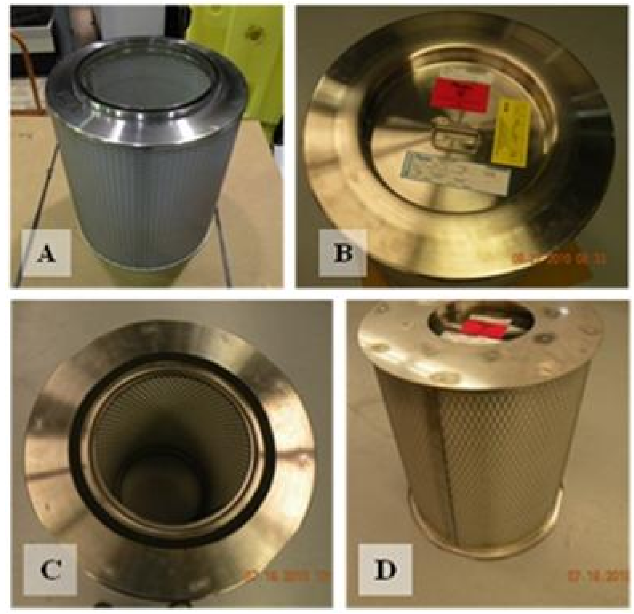


Figure 1. A: Safe Change Filter Top, B: Safe Change Filter Bottom, C: Remote Change Filter Top, D: Remote Change Filter Bottom Displaying Remote Grab Rings.

Testing of the radial flow filters was accomplished in accordance with a test plan developed by a technical working group comprised of representatives from a variety of DOE Office of Environmental Management entities including the Headquarters, the Office of River Protection, National Nuclear Safety Administration, DOE site contractors, and Mississippi State University (MSU).[4] Pre-testing activities in addition to development of a formal test plan included a technical peer review of MSU filter testing infrastructure and procedures. The MSU facility also was the subject of an ASME NQA-1 [5] quality audit and all testing activities were compliant with that standard.

Instrumentation used up and downstream of the filter to make aerosol measurements are shown in Table III along with their maximum and minimum particle concentration limits and particle size distribution ranges.

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

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

Both variants of the FK design (safe and remote change) were evaluated using three different particle size aerosols: NIST utlrafine Arizona road dust, alumina, and carbon black. Figure 2 gives the particle size distributions for each of these three aerosols.

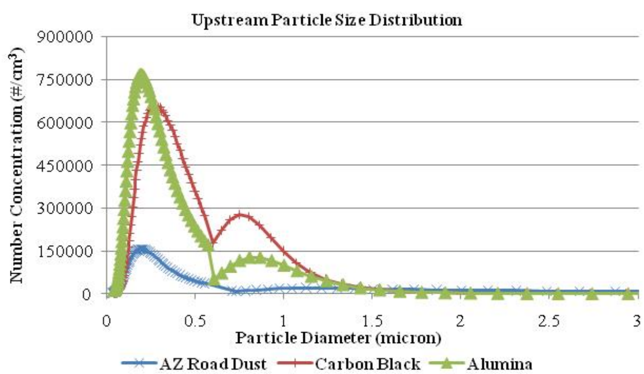


Figure 2. Particle size distributions for the three aerosols used to evaluate the lifecycle performance of both the safe change and remote change radial flow filters of this study.

**Testing Infrastructure and Testing Results**

A test stand was designed and fabricated to accomplish the evaluations called for in the test plan. The MSU test stand is capable of 113.3 $m^3$/min (4000 cfm) airflows at filter differential pressures up to 12442 Pa (50 inches w.c.). It is currently equipped with a two-position radial flow filter housing manufactured by Flanders [6]. Figure 3 shows a photo of the test stand used to generate data provided in this paper.


Figure 3. Photo of the MSU large scale HEPA filter test stand equipped with a housing capable of testing two 2000 cfm radial flow HEPA filters.

The test plan for this effort called for testing each type of filter to failure or to 12442 Pa (50 in. w.c.). using each of the three test aerosols. Additionally, each type of filter/aerosol combination would be evaluated under two sets of temperature/relative humidity conditions. A summary of the test matrix is provided in Table IV. Ambient test conditons consisted of 21.1 $^0$C (70 $^0$F) and 40-60 % relative humidity, and elevated test conditions called for 54.4 $^0$C (130 $^0$F) and 85-100% relative humdity. The test stand is located in the high bay of the Institute for Clean Energy Technology at Mississippi State University. The test stand configuration for ambient testing consisted of the portion of the test stand located within the high bay while the configuration employed for elevated conditions included connection to an additional segment located outside of the building.

Table IV. Testing Matrix for lifecycle evaluation of Section FK Radial Flow Filters under the MSU test plan

| **Test Parameters and Guidelines:** | | | Aerosol #1 0.25 µm (Alumina) | Aerosol #2 2.0 µm (Carbon Black) | Aerosol #3 5 µm (AZ Road Dust) |
|---|---|---|---|---|---|
| Remote Change HEPA Filter | Data Set 1 | Test Set 1. Inlet air controlled to 40-50% RH. Test until Max dP and/or failure is reached | Filter 1 | Filter 2 | Filter 3 |
| | | Run ID Number | RC-DS1-001 | RC-DS1-002 | RC-DS1-003 |
| | | Test Set 2. Inlet air controlled to 40-50% RH until filter reaches 4 in. w.g., then add air at 74-77$^0$C and 95-100% RH for maximum duration. Test until max dP and/or failure is reached | Filter 4 | Filter 5 | Filter 6 |
| | | Run ID Number | RC-DS1-004 | RC-DS1-005 | RC-DS1-006 |
| Remote Change HEPA Filter | Data Set 2 | Test Set 1. Inlet air controlled to 40-50% RH. Test until Max dP and/or failure is reached | Filter 7 | Filter 8 | Filter 9 |
| | | Run ID Number | RC-DS2-007 | RC-DS2-008 | RC-DS2-009 |
| | | Test Set 2. Inlet air controlled to 40-50% RH until filter reaches 4 in. w.g., then add air at 74-77$^0$C and 95-100% RH for maximum duration. Test until max dP and/or failure is reached | Filter 10 | Filter 11 | Filter 12 |
| | | Run ID Number | RC-DS2-010 | RC-DS2-011 | RC-DS2-012 |

Figure 4 provides loading curves for filters evaluated under ambient conditions. The test plan called for testing two remote change and one safe change filter under the ambient conditions. Two remote change filters were evaluated under each set of conditions because these units were anticipated to be more succeptable to failure due to the smaller filter pack and less surface area of medium. The three sets of loading curves provide information about the performance of each version of flter. Several things are clear from these curves. First, it is clear that the remote change filters had higher loading capacities than the safe change version. Next, the rapid change in loading curve slope indicates a change in filter pack geometry. This rapid increase in differential pressure provides less than 30 minutes for facility operators to take actions to reduce airflow and prevent physical failure of the filter. The final observation that can be made from these plots is the strong dependence of the loading curve on particle size.

High temperature and relative humidity testing involved connecting the interior portion of the test stand to an outside segment that includes a natural gas burner, ductwork, and hot water induction nozzles to increase relative humidity. The photo in Figure 5 shows this segment of the test stand. The 90$^0$ elbows needed to locate the outside segment of the test stand (due to existence of other permanently located equipment) necessitates an air straighter that is located immediately upstream of the portion of the test stand housed in the high bay and employed for testing under ambient conditions.

Testing under elevated temperature and relative humidity conditions involved use of a single aerosol, alumina. This testing was intended to simulate an upset condition that occurs when the filter reaches its normally maximum differential pressure. The test protocol included loading the filter to 995 Pa (4 in. w.c.). under ambient conditions, reconfiguring the test stand, increasing temperature/relative humidity, and challenging the filter under the elevated conditions without additional aerosol (alumina) challenge.

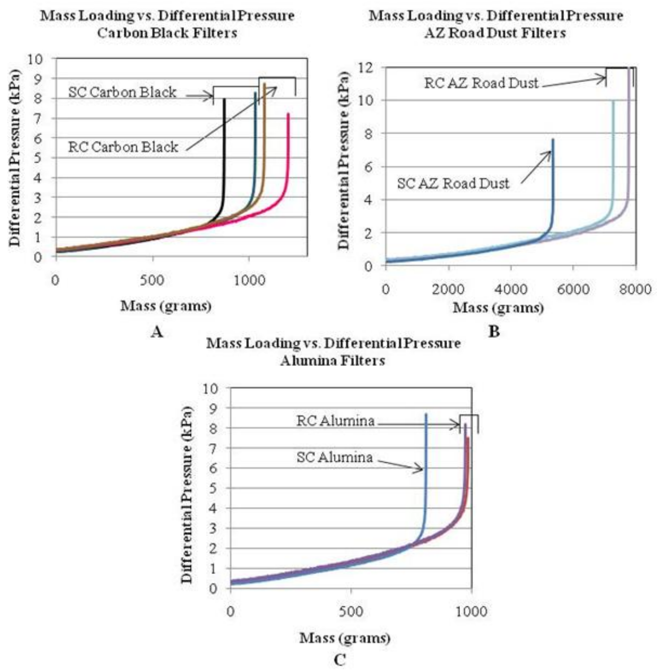


Figure 4. Plots of loading curves for the 10 filters tested under ambient conditions

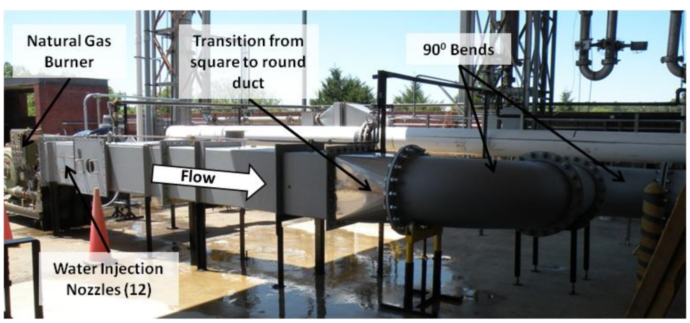


Figure 5. Heated section of the test stand showing the natural gas burner, hot water injection segment, transition from rectangular to round duct, and elbows. Not shown is an air straighter segment downstream of the last elbow.

Figure 6 provides a plot of differential pressure versus time for the first evaluation of a safe change filter under the elevated temperature and relative humidity protocol. This plot has been annotated to identify portions correlating to the time that heat and humidity are being increased. The initial segment of the dP curve demonstrates that the filter has been loaded to four inches with alumina under ambient conditions. Aerosol challenge is suspended before increasing the temperature/relative humidity conditions. It must be pointed out that this filter failed before achieving the test conditions of 54.4 $^0$C (130 $^0$F) and 85% RH. This was a totally unexpected result. AG-1 filters are qualified by testing that includes a wet overpressure test where the filters are completely wetted at 2488 Pa (10 in. w.c.) for 30 minutes. The test conditions represented by Figure 6 appear to be much less aggressive than the wet overpressure qualification test.

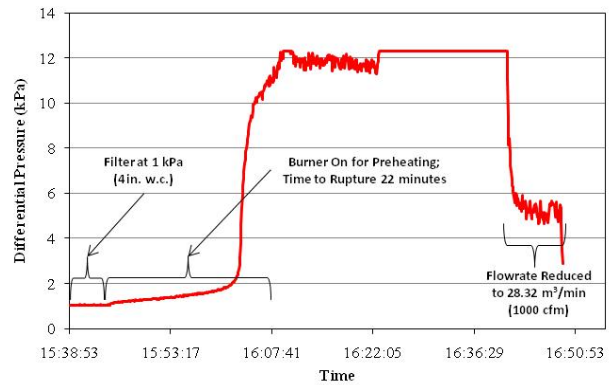


Figure 6. Plot of differential pressure vs. time for testing of a safe change filter at elevated temperature and relative humidity.

The last segment of the Figure 6 dP curve shows where the volumetric flow rate has been reduced from 56.6 to 28.3 $m^3$/min (2000 to 1000 cfm). There has been a corresponding decrease in dP from greater than 12442 Pa to 4977 Pa (50 in. w.c. to 20 in. w.c.). This represents a significant difference between the test protocol used under the current test plan and the wet overpressure qualification test. Qualification testing is at 10 in. dP, so the volumetric flow rate can be reduced preventing the runaway increase in dP leading to failure.

The failure mechanism for both versions of these filters has consistently involved ballooning of pleats and rupture at the interface between potting material and media. Figure 7 displays photographs of ballooned pleats of two filters that have failed.

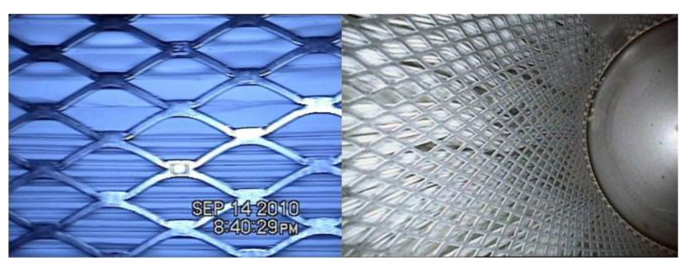


Figure 7. photos of pleat ballooning of filters that have failed during testing. The photo on the left was taken inside the filter housing while the filter was under test flow conditions. The photo on the right shows the more catastrophic pleat distortion for a filter that failed during elevated temperature and relative humidity conditions.

## CONCLUSIONS

Data presented in this paper represents the first evaluation of AG-1 Section FK radial flow HEPA filters that employ dimple-pleated medium. Testing conducted under ambient conditions demonstrated that both versions of the filters tested are capable of withstanding 7465 to 12442 Pa (30 to 50 in. w.c.) before failing from pleat ballooning. Unexpected results included the significant changes in filter pack geometry at differential pressures at or below 2488 Pa (10 in. w.c.).

It was expected that the safe change filters would perform better than the remote change version. This proved to be a false assumption. The relatively mild test conditions of 54.4 $^{0}$C (130 $^{0}$F) and 85% relative humidity were not expected to cause rapid failure. This also proved to be a false assumption.

The filter pack for the AG-1 Section FK radial flow filters covered in this study is currently being redesigned. This demonstrates one aspect of the value of this effort; unexpected failures have been averted and a more robust filter design is expected.

## ACKNOWLEDGMENTS

We acknowledge the support of this work under DOE Cooperative Agreement DE-FC01-06EW07040.

## REFERENCES

[1] ASME AG-1-2009, Code on Nuclear Air and Gas Treatment, American Society of Mechanical Engineers, http://catalog.asme.org/Codes/PrintBook/AG1_2009_Code_Nuclear_Air_Gas.cfm (2009)

[2] http://www.vokesair.com/

[3] http://www.mcaf.co.uk/

[4] *Test Plan for Evaluating WTP Representative Radial Flow Filters for Loading and Rupture at ICET*, May 12, 2010 (Ver. 17); Institute for Clean Energy Technology, Mississippi State University; Dr. Charles Waggoner, Principal Investigator

[5] ASME NQA-1-2008 *Quality Assurance Requirements for Nuclear Facility Applications*; The American Society of Mechanical Engineers, Three Park Avenue, New York, NY

[6] http://www.flanderscorp.com/