INSITU CLEANABLE ALTERNATIVE HEPA FILTER MEDIA

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ABSTRACT

The Westinghouse Savannah River Company, located at the Savannah River Site in Aiken, South Carolina, is currently testing two types of filter media for possible deployment as in situ regenerable/cleanable High Efficiency Particulate Air (HEPA) filters. The filters are being investigated to replace conventional, disposable, glass-fiber, HEPA filters that require frequent removal, replacement, and disposal. This is not only costly and subjects site personnel to radiation exposure, but adds to the ever-growing waste disposal problem. The types of filter media being tested, as part of a National Energy Technology Laboratory procurement, are sintered nickel metal and ceramic monolith membrane. These media were subjected to a hostile environment to simulate conditions that challenge the high-level waste tank ventilation systems. The environment promoted rapid filter plugging to maximize the number of filter loading/cleaning cycles that would occur in a specified period of time. The filters were challenged using non-radioactive simulated high-level waste materials and atmospheric dust; materials that cause filter pluggage in the field. The filters are cleaned in situ using an aqueous solution. The study found that both filter media were insensitive to high humidity or moisture conditions and were easily cleaned in situ. The filters regenerated to approximately clean filter status even after numerous plugging and in situ cleaning cycles. Air Techniques International is conducting particle retention testing on the filter media at the Oak Ridge Filter Test Facility. The filters are challenged using 0.3-μm di-octyl phthalate particles. Both the ceramic and sintered media have a particle retention efficiency $\geq$ 99.97%. The sintered metal and ceramic filters not only can be cleaned in situ, but also hold great potential as a long life alternative to conventional HEPA filters. The Defense Nuclear Facility Safety Board Technical Report, "HEPA Filters Used in the Department of Energy's Hazardous Facilities", found that conventional glass fiber HEPA filters are structurally weak and easily damaged by water or fire. The structurally stronger sintered metal and ceramic filters would reduce the potential of a catastrophic HEPA filter failure due to filter media breakthrough in the process ventilation system. An in situ regenerable system may also find application in recovering nuclear materials, such as plutonium, collected on glove box exhaust HEPA filters. This innovative approach of the in situ

regenerative filtration system may be a significant improvement upon the shortfalls of conventional disposable HEPA filters.

INTRODUCTION

Conventional disposable glass-fiber HEPA filters are used throughout the Department of Energy (DOE) complex in various process systems. The filters must exhibit a particle removal efficiency of 99.97% when challenged by thermally generated di-octyl phthalate (DOP) aerosol with a diameter of 0.3 microns. The pleated glass fiber HEPA filter media has approximately 22.3 m^3 (240 ft^2) of surface area and is typically contained in a 0.6m x 0.6m x 0.3m (2’x 2’x 1’) housing and exhibits a 25 mm of water column (wc) differential pressure across the filter media when clean. A conventional HEPA filter remains in service until the filter media reaches a predetermined maximum pressure drop (approximately 125 mm) or a high source term due to radioactive buildup, and then the filter is replaced.

These filters require routine removal, replacement, and disposal. This process is not only expensive, but also subjects personnel to radiation exposure and adds to an ever-growing waste disposal problem. The conventional HEPA filters also have safety concerns in the areas of filter media strength, water damage, and operation in environments with elevated temperatures. The Defense Nuclear Facility Safety Board (DNFSB) issued a report titled “HEPA Filters used in the Department of Energy Hazardous Facilities”, DNFSB/TECH-23 (1). This technical report documents these and other concerns pertaining to conventional HEPA filters.

To address most of the safety issues associated with the glass fiber filters, the DOE has recently been investing in the development of robust HEPA filters that can be regenerated or cleaned in situ. Previous research has been conducted at other US DOE sites, such as Lawrence Livermore National Laboratory (LLNL) and Oak Ridge National Laboratory, to develop in situ cleanable or regenerative HEPA filters with high media strength. W. Bergman, *et al* conducted research on various filter media, such as steel fibers, ceramic, and sintered metal, using reverse air pulse as the in situ cleaning method (2). The results of these investigations indicate that commercially available filter media could be applied to the development of an in situ cleanable (using reverse air pulse) HEPA filter system that would meet the performance criteria established for a conventional HEPA filter media.

Under funding from the DOE Tanks Focus Area, the National Energy Technology Laboratory (NETL) issued a “Request for Proposals” late in 1999 to identify vendors conducting research in the area of in situ cleanable/regenerative filters or vendors interested in pursuing such technology. A technical evaluation was conducted on the proposals. Based on the proposals reviewed, CeraMem Corporation (Waltham, Massachusetts) and Mott Corporation (Farmington, Connecticut) were selected to support this research program. In the initial phase of the program, CeraMem and Mott developed small test units (lab scale filters) that demonstrated HEPA filter particle retention performance and ability to be regenerated by cleaning in situ using an aqueous solution.

CeraMem provided a ceramic monolith filter and Mott provided a sintered metal filter. Proof of principle for an in situ cleanable HEPA filter was a success with the lab scale filters (3, 4). An American Society of Mechanical Engineers (ASME) Peer Review of the program was completed. The Peer Review Panel was complementary of the technology and the research (5, 6). Testing is now ongoing with ceramic and sintered metal full-scale single elements.

Application of these two alternative media could potentially prevent the buildup of alpha and beta emitters via in situ cleaning. An unknown quantity of radionuclides on a filter media in a process system is a concern of waste management groups, particularly in the case of a catastrophic HEPA filter failure. The in situ cleanable filter could also be used in other applications such as to permit recovery of materials that may collect on HEPA filters during normal process operations. The alternative HEPA filters have other applications such as in the area of bio-terrorism research. Materials used by terrorist such as anthrax can remain in a dormant state for many years. If a facility were conducting research with such materials, it would be advantageous to destroy the organisms in the HEPA filters using high temperatures or antiseptic solutions before the filters are manually handled and/or sent to solid waste.

RESULTS AND DISCUSSION

Full-scale HEPA Filter Elements

Figure 1 depicts the full-scale ceramic (left) and sintered metal (right) filter elements.

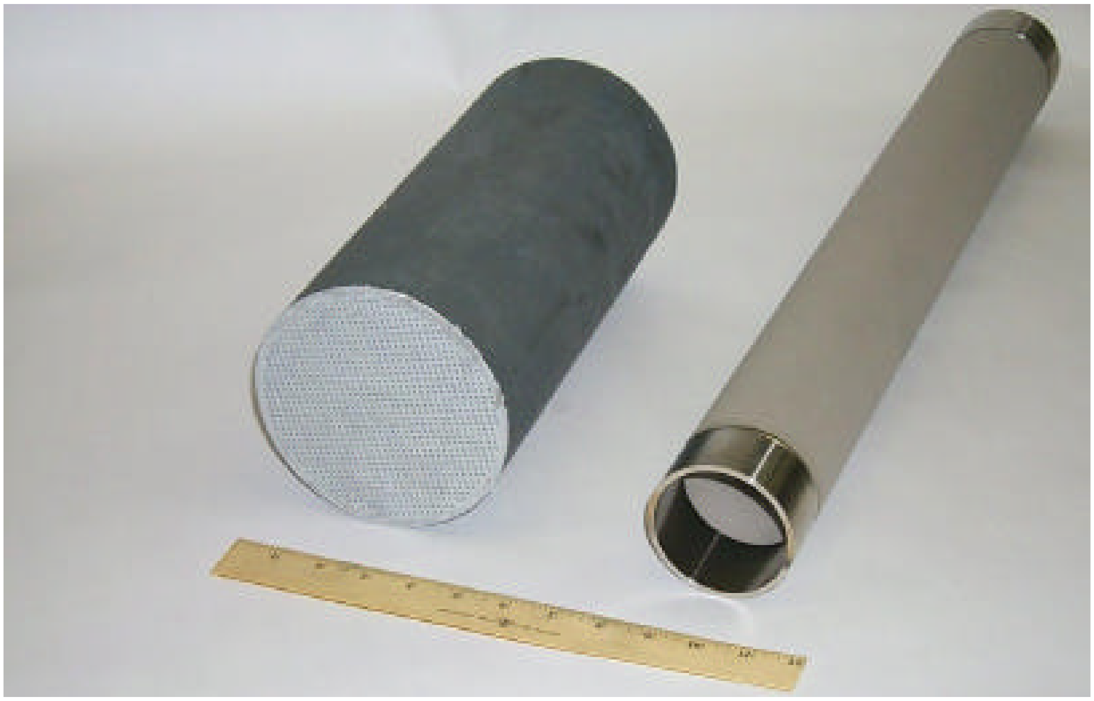

Fig. 1. Full-Size Ceramic and Sintered Metal Filters

The ceramic filter media is a "dead-end" monolith filter. The passageway ends are plugged with ceramic cement in an "alternate, checkerboard pattern". The dirty air with particulate matter enters the filter media and the gas flow is constrained to pass through the monolith walls separating inlet and outlet passageways. The membrane coating covers the passageway walls, and the entrained particles are filtered from the air onto the surface of the microporous membrane. The clean air flows down the outlet passageways and is exhausted from the filter.

Below are the characteristics of the "full-scale" ceramic monolith filters tested in this phase of the program:

- Monolith Membrane Support: Silicon carbide
- Membrane Coating: Glass-frit-bonded zirconium silicate
- Overall Element Dimensions: 144 mm x 305 mm (5.66" diameter x 12" long)
- Monolith Cell Size: 2 mm (0.079")
- Monolith Cell Wall Thickness: 0.8 mm (0.0315")
- Filtration Surface Area: 1.72 m^2 (18.5 ft^2)

Figure 2 shows photomicrographs of a cross-section view of the silicon carbide (SiC) monolith pore structure with a membrane surface coating, with a pore size between 0.2 – 0.5 μm. This ceramic membrane provides a relative low-pressure drop (for a robust media) while obtaining HEPA filter retention efficiency.

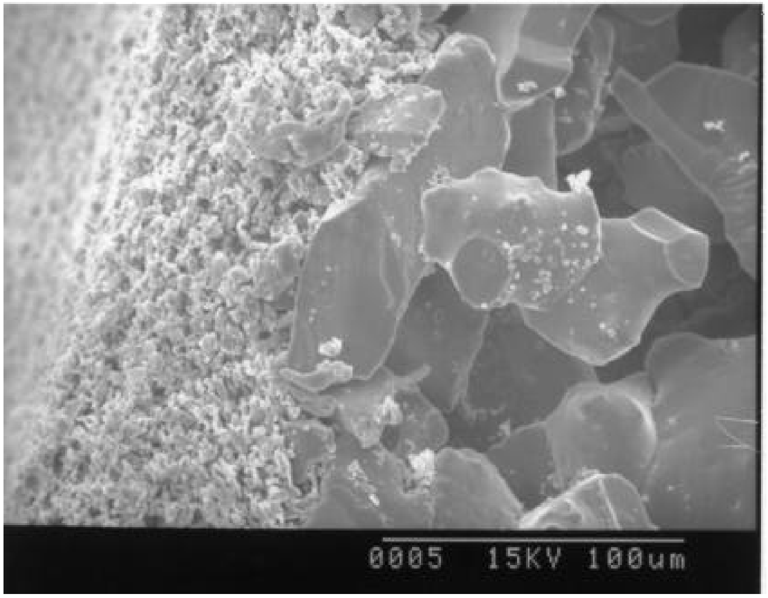

Fig. 2. Cross-Sectional Micrograph of Membrane/Monolith Wall Structure

Below are the characteristics of the “full-scale” sintered metal filters tested in this phase of the program:

- Filter Media Material: Nickel 200
- Ni Particle Size: 2- 4 µm
- Filter Diameter: 76.2 mm (3.0”)
- Media Length: 566.8 mm (22.3”)
- Media Wall Thickness: 2.1 mm (0.085”)
- Filtration Surface Area: 0.13 m^2 (1.36 ft^2)

Figure 3 shows photomicrographs, magnified 1000 times, of the sintered Nickel media. with a pore size between 0.2 – 0.5 µm. The Ni media provides high particle retention efficiencies but has a small surface area in a given geometry resulting in a higher pressure drop than the ceramic filter.

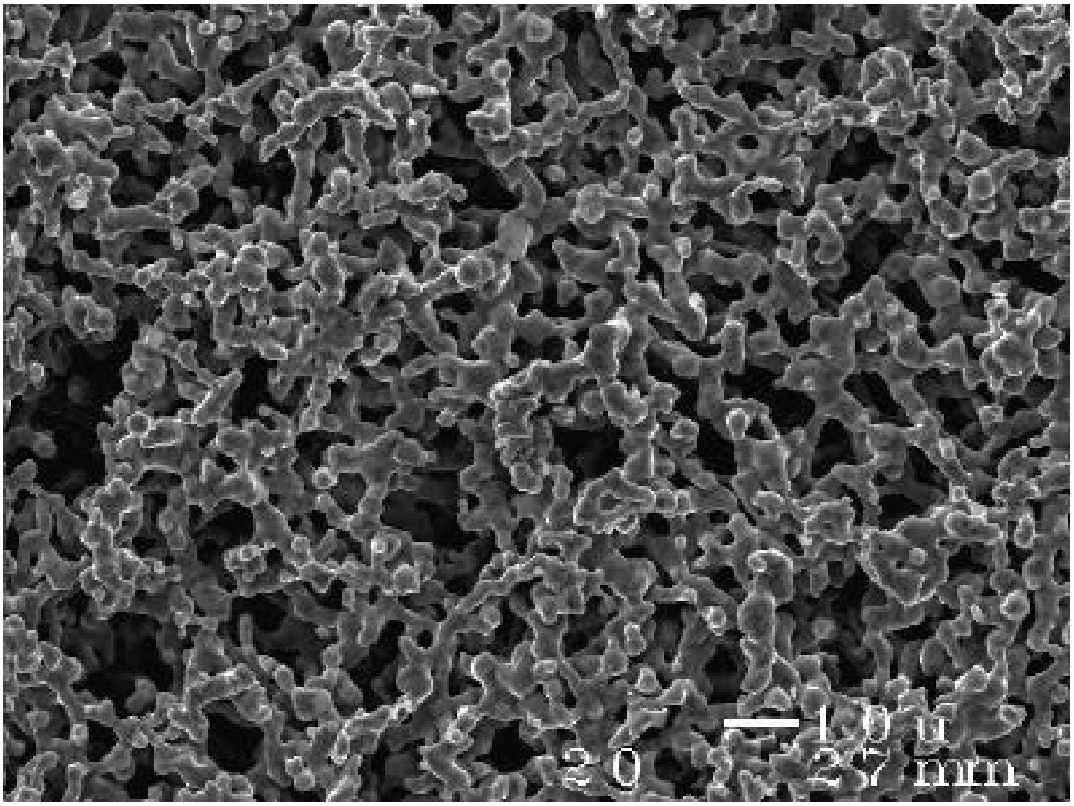

Fig. 3. Micrograph of Sintered Ni Media

Due to the finer metal powder and resulting porous media structure, Nickel 200 media has much higher particle collection efficiency than other sintered metals. The pressure drop of the Ni media is about half that of stainless steel media. Nickel 200 is >99% pure Ni, which has excellent corrosion properties. In many cases nickel is more corrosion resistant than 316L stainless steel. The Ni media is a very good corrosion resistant material for a variety of corrosive environments. Nickel should out perform 316LSS in most applications such as when exposed to normal atmosphere, water, hydrochloric acid and other chlorides, organic acids like acetic acid, caustic soda and other alkalies (except ammonium hydroxide), ammonia, and salt water. Nickel 200 is not good for hot gas service, where sulfur is present.

Particle Retention Testing At ORNL

Particle retention efficiency testing was conducted on the full-scale filter elements at the Oak Ridge Filter Test Facility (FTF). Air Techniques International (ATI) operates the Department of Energy facility under contract. ATI modified their FTF test equipment to conduct efficiency tests on the alternative full-scale filter elements. Filters were supplied to the FTF during FY01 for particle retention test. The vendors were asked to optimize the particle retention vs. the dP and supply approximately 30 filter elements. DOP, which is an organic compound, is a standard in the HEPA filter industry was used in the challenge tests. A total of 28 ceramic and 38 sintered metal full-scale filter elements were supplied to the FTF. Table I shows the results for the ceramic filter. A total of 9 filters passed the particle retention test with greater than 99.97% efficiency. The high number of filters that failed is not seen as a negative, but indicates that the vendor could vary manufacturing techniques to optimize the dP vs. retention that was requested. Each ceramic filter was tested at two different flows. Testing results proved that full-scale ceramic filter elements with HEPA retention could be manufactured. Also varying manufacturing techniques provided critical manufacturing data to the vendor.

Table I. Particle Retention Results Ceramic Full-scale Filters

FILTER SERIAL NUMBER	FLOW THROUGH MEDIA	Resistance Inches w.c.	Penetration %	Efficiency %
H-30	3.54 m^3/min (125 cfm)	21.2	6.8	93.2
	0.71 m^3/min (25 cfm)	8.5	.33	99.67
H-29	3.54 m^3/min (125 cfm)	26.0	4.1	95.9
	0.71 m^3/min (25 cfm)	1.9	1.5	98.5
H-46	3.54 m^3/min (125 cfm)	26.8	2.1	97.9
	0.71 m^3/min (25 cfm)	2.8	.95	99.05
H-44	3.54 m^3/min (125 cfm)	23.2	.014	99.986
	0.71 m^3/min (25 cfm)	1.4	.001	99.999

H-42	3.54 m^3/min (125 cfm)	25.6	.016	99.984
	0.71 m^3/min (25 cfm)	1.4	.001	99.999
H-28	3.54 m^3/min (125 cfm)	26.1	.018	99.982
	0.71 m^3/min (25 cfm)	1.8	.001	99.999
H-33	3.54 m^3/min (125 cfm)	27.2	3.6	96.4
	0.71 m^3/min (25 cfm)	2.1	.72	99.28
H-31	3.54 m^3/min (125 cfm)	22.5	.014	99.986
	0.71 m^3/min (25 cfm)	1.8	.001	99.999
H-40	3.54 m^3/min (125 cfm)	26.5	3.2	96.8
	0.71 m^3/min (25 cfm)	2.1	.56	99.44
H-43	3.54 m^3/min (125 cfm)	25.1	.011	99.989
	0.71 m^3/min (25 cfm)	1.6	.001	99.999
H-39	3.54 m^3/min (125 cfm)	26.8	5.8	94.2
	0.71 m^3/min (25 cfm)	2.2	2.4	97.6
H-47	3.54 m^3/min (125 cfm)	22.6	.008	99.992
	0.71 m^3/min (25 cfm)	1.8	.001	99.999
H-41	3.54 m^3/min (125 cfm)	25.2	.007	99.993
	0.71 m^3/min (25 cfm)	1.6	.001	99.999
14	3.54 m^3/min (125 cfm)	15.0	0.15	99.85
	0.71 m^3/min (25 cfm)	1.2	0.14	99.84
2	3.54 m^3/min (125 cfm)	11.6	4.8	95.2
	0.71 m^3/min (25 cfm)	2.4	4.8	95.2
13	3.54 m^3/min (125 cfm)	18.0	.044	99.956
	0.71 m^3/min (25 cfm)	3.6	.039	99.961
10	3.54 m^3/min (125 cfm)	15.4	0.13	99.87
	0.71 m^3/min (25 cfm)	3.6	0.18	99.82
9	3.54 m^3/min (125 cfm)	18.8	.077	99.923
	0.71 m^3/min (25 cfm)	4.4	0.21	99.79
7	3.54 m^3/min (125 cfm)	21.8	.037	99.963
	0.71 m^3/min (25 cfm)	4.8	.073	99.927

H-26	3.54 m^3/min (125 cfm)	14.2	.10	99.9
	0.71 m^3/min (25 cfm)	1.0	.11	99.89
H-25	3.54 m^3/min (125 cfm)	26.0	.018	99.982
	0.71 m^3/min (25 cfm)	2.0	.016	99.984
H-21	3.54 m^3/min (125 cfm)	28.0	45.0	55.0
	0.71 m^3/min (25 cfm)	7.0	4.8	95.2
H-19	3.54 m^3/min (125 cfm)	17.0	.035	99.965
	0.71 m^3/min (25 cfm)	1.8	.035	99.965
H-22	3.54 m^3/min (125 cfm)	28.0	48.0	52.0
	0.71 m^3/min (25 cfm)	6.4	14.0	86.0
H-20	3.54 m^3/min (125 cfm)	14.8	.028	99.972
	0.71 m^3/min (25 cfm)	1.8	.019	99.981
H-24	3.54 m^3/min (125 cfm)	18.5	21.5	78.5
	0.71 m^3/min (25 cfm)	4.8	4.2	95.8
H-32	Damaged in Shipping	-	-	-
H-34	Damaged in Shipping	-	-	-

As depicted in Table II, 34 of the 35 sintered metal full-scale filters tested, passed the particle retention test with greater than 99.97% efficiency. The sintered metal filters tested have a very high retention. Due to the manufacturing procedures for manufacturing sintered filters, the vendor found it very difficult to optimize dP vs. particle retention. 68% of the filters tested had 99.999% particle retention efficiency, which is over a magnitude higher in filtration than is required for a HEPA filter.

Table II. Particle Retention Result Ni Metal Full-scale Filters

FILTER SERIAL NUMBER	**FLOW THROUGH MEDIA**	**Resistance Inches w.c.**	**Penetration %**	**Efficiency %**
90	0.85 m^3/min (30 cfm)	72	.016	99.984
82	0.85 m^3/min (30 cfm)	90	.022	99.978
115	0.99 m^3/min (35 cfm)	90	.003	99.997
117	0.88 m^3/min (31 cfm)	91	.001	99.999
116	0.90 m^3/min (32 cfm)	88	.001	99.999
114	0.90 m^3/min (32 cfm)	88	.001	99.999

113	0.90 m^3/min (32 cfm)	92	.002	99.998
91-010D	0.90 m^3/min (32 cfm)	91	.008	99.992
91-010-C	0.90 m^3/min (32 cfm)	92	.001	99.999
91-010-B	0.90 m^3/min (32 cfm)	94	.001	99.999
91-010-A	0.90 m^3/min (32 cfm)	94	.001	99.999
120	0.90 m^3/min (32 cfm)	88	.001	99.999
104	0.90 m^3/min (32 cfm)	94	.001	99.999
91-010-F	0.90 m^3/min (32 cfm)	90	.001	99.999
91-010-E	0.96 m^3/min (34 cfm)	90	.001	99.999
85	0.96 m^3/min (34 cfm)	91	.001	99.999
126	0.90 m^3/min (32 cfm)	94	.001	99.999
124	0.99 m^3/min (35 cfm)	90	.001	99.999
122	0.93 m^3/min (33 cfm)	91	.001	99.999
118	1.0 m^3/min (36 cfm)	89	.004	99.996
129	0.90 m^3/min (32 cfm)	92	.001	99.999
119-LB	1.0 m^3/min (36 cfm)	90	.001	99.999
128-LB	0.90 m^3/min (32 cfm)	92	.001	99.999
78-LB	0.85 m^3/min (30 cfm)	92	.001	99.999
79-LB	0.90 m^3/min (32 cfm)	90	.001	99.999
89-LB	0.79 m^3/min (28 cfm)	92	.006	99.994
127-LB	0.90 m^3/min (32 cfm)	90	.001	99.999
105-LB	0.71 m^3/min (25 cfm)	98	.001	99.999
125	0.99 m^3/min (35 cfm)	95	.032	99.968
A-3	0.99 m^3/min (35 cfm)	94	.002	99.998
A-4	0.99 m^3/min (35 cfm)	91	.025	99.975
A-5	0.90 m^3/min (32 cfm)	94	.001	99.999
#1	0.93 m^3/min (33 cfm)	94	.001	99.999
#2	0.93 m^3/min (33 cfm)	99	.001	99.999
5	0.93 m^3/min (33 cfm)	67	.002	99.998
4	Filter Damaged	-	-	-
A-1	Filter Damaged	-	-	-
A-2	Filter Damaged	-	-	-

Full-scale Single Element Simulant Testing

A HEPA filter test apparatus (HFTA) was designed and constructed to test the single element full-scale filters. The HFTA was designed to simulate the conditions that challenge conventional filters on the high-level waste (HLW) tanks at SRS. Figure 4 depicts a photo of the HFTA constructed at the Thermal Fluids Laboratory at SRTC.

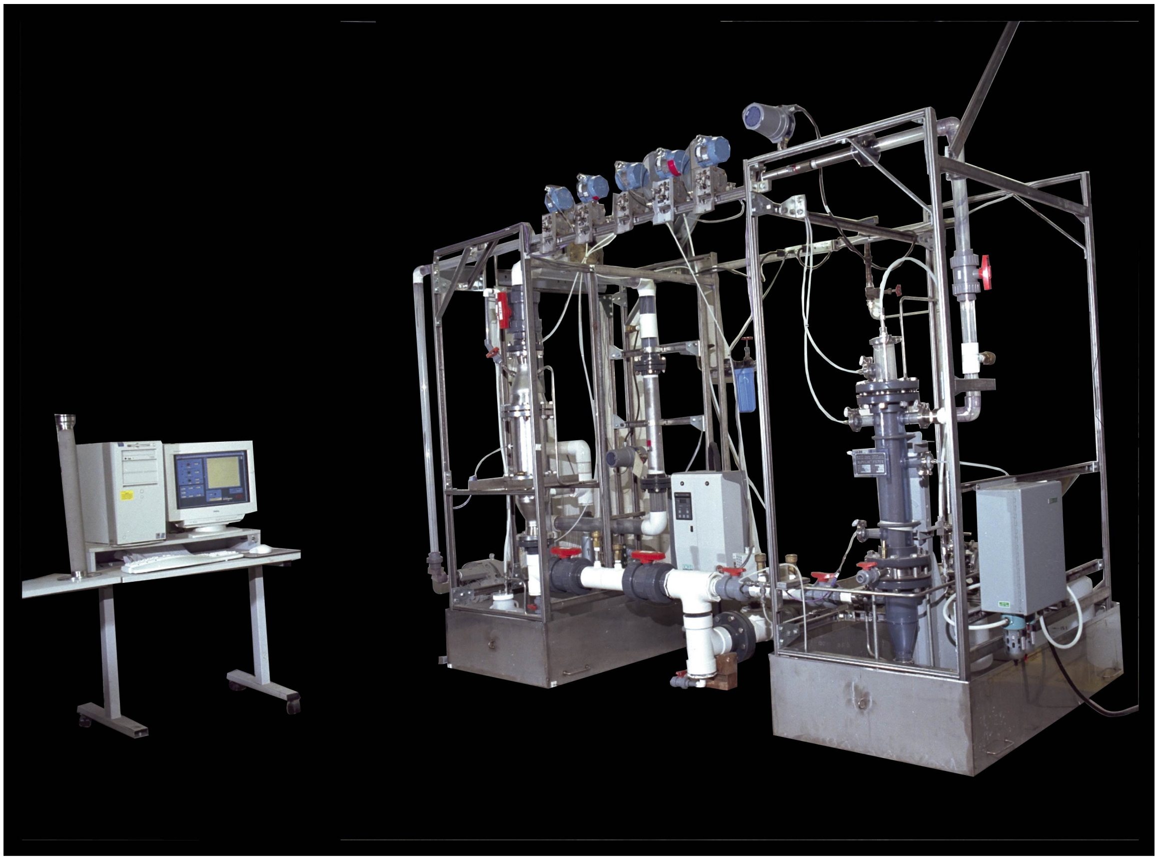

Fig. 4. Full-scale Single Element Test Apparatus

The filters are challenged by entrained particulates of simulated HLW and atmospheric dust. These materials, neglecting the radioactive constituents, are believed to be responsible for plugging the existing HEPA filters in the HLW tanks. Three materials simulants are used; simulated HLW sludge, salt and atmospheric dust. Only one material was used at a time to challenge the filters.

The test was designed for approximately 3.7 m^3/min (130 cfm) of filtered air to flow into the system. The air was split with approximately 2.8 m^3/min (100 cfm) flowing through the ceramic filter and 0.85 m^3/min (30 cfm) through the sintered metal filters. A separate blower or vacuum pump was used to pull the air across each filter. DOP test connectors were designed into the HFTA to conduct in-place leak tests on the filter media.

The HFTA was designed such that one filter could be cleaned while the other remained online for testing. The system operated continuously (24 hours a day, 7 days a week) until the flow across the filter(s) decreased by 20% or more due to particulate matter build-up on the surface of the filter. Once a filter became soiled from filtering simulated HLW particles from the air stream, it was cleaned in situ using an aqueous solution. In situ cleaning was conducted on the sintered metal filter via spraying the inside (dirty side) of the filter with a dilute oxalic acid then rinsed with DI water. The ceramic filter was cleaned in situ by backflushing a dilute nitric acid solution into the dirty side of the filter and rinsed with DI water. A purge of air is allowed to back-flow through the filter to aid in removing water droplets from the media. After the in situ wash cycle, the filters were returned to operation.

After many accelerated plugging and in situ cleaning cycles on the full-scale single elements, the filters continue to return to a clean filter status.

A full-scale ceramic and sintered metal filter that was subjected to such preliminary simulant testing at SRTC was re-tested at the FTF for post test particle retention. The results are positive that there was little or no change in the retention capability after many plugging/ in situ cleaning cycles. This indicates that the filter media is not deteriorating when undergoing repeated plugging/cleaning cycles.

During wild fires, heavy smoke and smoke borne particulates may plug the alternative filter, but test results indicate that the plugged condition will not cause filter failure and/or breakthrough.

Full-scale System Hot Deployment

A full-scale Alternative Filtration System is planned for construction with the hot (radioactive) demonstration of the system being conducted at SRS on a HLW Tank. The HLW tanks are radioactive tanks containing approximately 3.8 million liters of radioactive waste. Before the hot deployment on a HLW tank, the full-scale system will undergo cold testing at SRTC. The sintered metal filter-housing layout being considered for the full-scale demonstration will consist of approximately twenty (20) full-scale elements. The filter elements and filter housing will be an all welded construction, meaning that there will be no seal or gaskets to contend with. As currently conceived, air will be drawn into the open bottom of each filter element and be pulled through the filter wall by vacuum applied to the clean plenum. The dirty side of the filter will be the inter diameter of the cylindrical element. The multiple vertical tubes will be welded into an arrangement resembling a tube and sheet heat exchanger. After the filter becomes plugged with particulate or when the radioactivity from the accumulated particulate approaches area limits, the in situ cleaning system will be initiated. Each element will have a separate spray nozzle(s) and the filter will be cleaned via spraying the inlet side of the filter with an aqueous solution. For the full-scale demonstration of the ceramic media, the housing will consist of approximately seven (7) full-scale filter elements. The current full-scale design requires seals to install the elements in the housing properly. The dirty air will be drawn into the bottom end of the housing and clean air will exit through the top of housing. The elements are cleaned in situ via back flushing an aqueous solution through the media. The spent cleaning solution will be deposited in the HLW tank, thus not creating an additional waste stream.

CONCULSION

Ceramic and sintered metal media holds great promise as an in situ cleanable/regenerative HEPA filter. Testing of the full-scale single element has shown that both ceramic and sintered metal media could be suitable as an alternative HEPA filter media. Data from particle retention testing at the Oak Ridge Filter Test Facility shows that the alternative filters are capable of particle retention greater than 99.97%. Ongoing HLW simulated testing on the full-scale filter elements indicate that the filters regenerate well in situ with a potential for 15 year plus life under actual field conditions of the HLW tanks. In addition to eliminating the costs associated with disposing of and replacing disposable filters, these strong filter media also reduce the potential of a catastrophic HEPA filter failure due to rupture or fire of the media.

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