Scroll Filter System Development for Crewed Deep Space Missions

ICES Paper 2019-295

Juan H. Agui – NASA Glenn Research Center

Objectives

Develop a prototype multi-stage filter system to expand filter operational lifetime, and reduce maintenance requirements for spacecraft air revitalization systems.

- Pre-filtration stage(s) with regeneration capability.
- Compatible with the size of the present ISS Bacterial Filter Element (BFE) filter

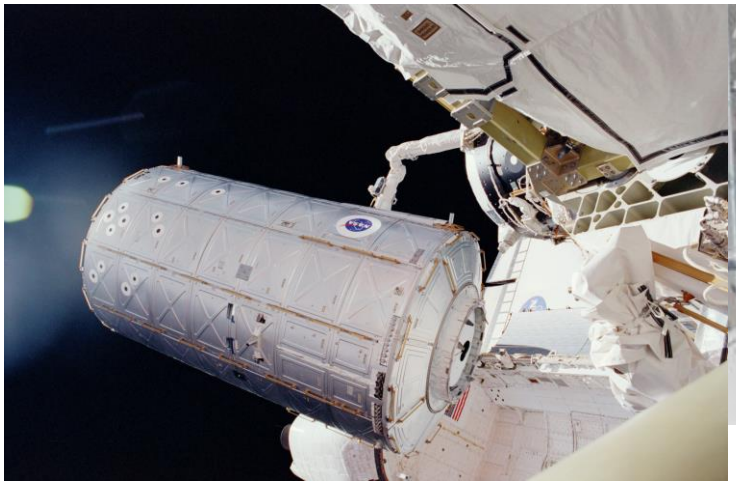
Test according to filtration industry standards.

Provide performance results of this prototype unit for use in future spacecraft air revitalization designs and trade studies.

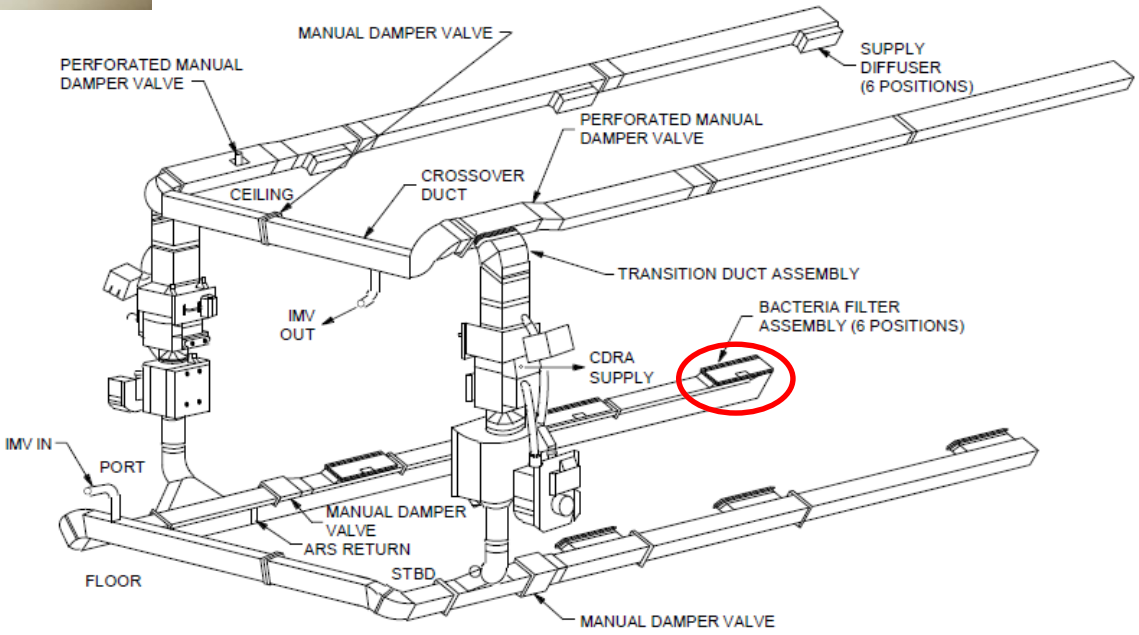
Background/Motivation

- The 15+ years of operational experience on ISS with these state-of-the-art HEPA media filters has provided useful data on replacement intervals and crew time for maintenance.
- The ISS Bacterial Filter Elements (BFEs) are HEPA-grade filters utilized on ISS to control particulates in the pressurized volume of ISS.
- **Filter replacement:** A total of 21 BFEs are installed in US segment. (Columbus and JEM use HEPA filters of a different design.)
    - Original BFE replacement interval was 1 year.
    - Replacement interval was extended to 2-5 years, i.e. replacement interval varies by location.
- **Maintenance:** On-orbit maintenance consists of frequent vacuuming (weekly/biweekly) to remove large particulate loads.

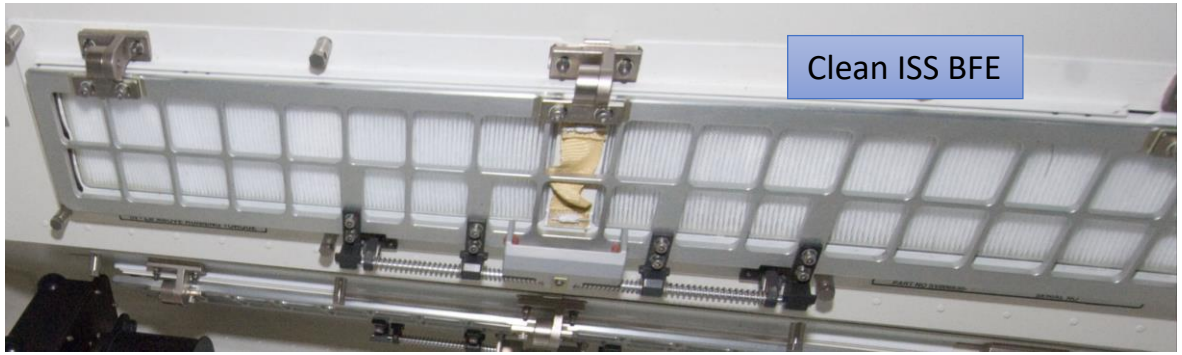
ISS US LAB module ventilation system

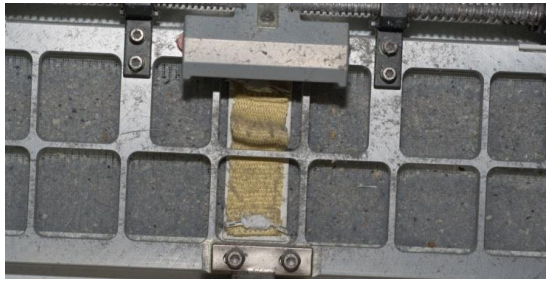


- ISS Lab module volume is 108 m^3 (3834 $ft^{3)}$.
- Required ventilation flow rate is 11.9 m^3/min (400 cfm).
- 6 BFEs installed in ventilation system.



Particulate loading due to lack of sedimentation in ISS microgravity environment





8 days accumulation

12 days accumulation

Node 3
Hygiene & Exercise Location

Inlet to avionics cooling fan

ISS Bacterial Filter Element (BFE)

ISS filters are bacterial filter elements (BFE) and contain pleated borosilicate HEPA media

Rectangular aluminum frame with outside dimensions of 29” x 4” x 4.375”.

Filter media is covered with a 20-mesh (0.84-mm clear opening) prescreen (Nomex™) at the inlet and an aluminum mesh screen at the outlet.

ISS filter efficiency specification:

- Efficiency of 99.9% @ 0.3 microns @ 1.98 m^3/min (70 cfm).

ISS filter pressure drop specification @ flow rate = 1.98 m^3/min

initial: 82.2 Pa (0.33 in H_2O)

end-of-life: 124.5 Pa (0.5 in H_2O)

Previous Scroll BFE

3 stages unit:

1. **Screen Roll Filter:** Mesh screen filter on motorized spooling mechanism.
    - Removes large or asymmetric particulates (hair, cotton fibers, etc.).
2. **Regenerable Impactor Filter:** 2nd stage pre-filter that uses inertial impaction (slits).
    - Removes particulates several microns or larger.
3. **Scroll Media Filter:** Intermediate-stage filter on motorized scrolling mechanism. Utilizes support spindles arranged in pleating pattern to increase filter surface area.
    - Designed to remove sub-micron particulates.

Redesign consideration:

- Prototype is taller in dimension than the ISS BFE filter housing, causing a protrusion and obstacle when installed.
- Required additional latching mechanism
- Not certified as HEPA

New Scroll BFE filter design

Multi-stage filtration system (2 stages) integrated into a single unit:

Stage 1: Screen Roll Filter: Mesh screen filter on motorized spooling mechanism (also known as scrolling mechanism).

- Removes large or asymmetric particulates (hair, cotton fibers, etc.).

Stage 2 HEPA element: Static/replaceable HEPA element

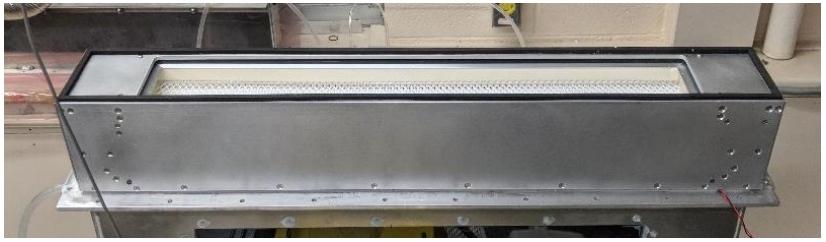
Stage 3: (Optional) Regenerable Impactor Filter: 2nd stage pre-filter that uses inertial impaction (slits).

- Removes particulates several microns or larger.

Scroll BFE filter – Refers to prototype test article in this paper designed to test under ISS BFE conditions.

Scroll Filter System (SFS) – Refers to multi-stage scroll filter system in general.

Scroll BFE filter design



Scroll BFE filter assembly

Cover plate removed showing the motorized take up spool

ISS BFE housing

Scroll BFE filter installed in ISS BFE filter housing

HEPA element used in the Scroll BFE

Scroll Filter Test Objective/Methods

Pressure drop tests:

Measure overall pressure drop at design flow rate.

Investigate extent to each stage's impact to overall pressure drop. Include testing of separate flat sheet tests of filter media used on 3rd stage.

Penetration efficiency tests:

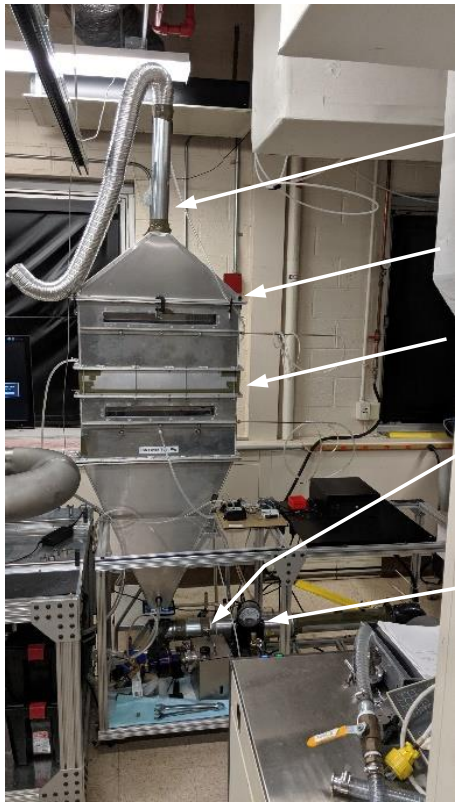
Measure penetration efficiency of scroll filter and investigate individual stages.

- **Liquid aerosol:** Polyalphaolefin (PAO): mass median diameter of 0.303 µm.
- HEPA filter standards (IEST-RP-CC034, MIL-STD-282).

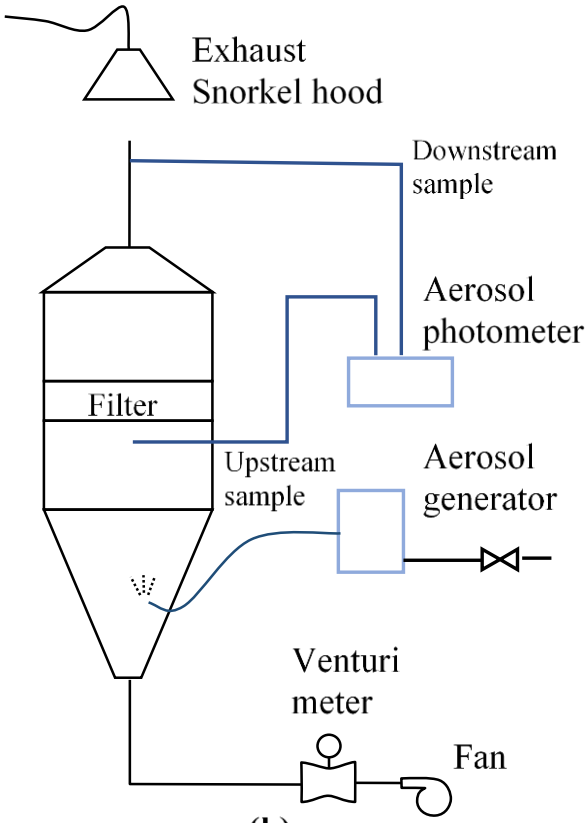
Screen Roll performance test:

- Measure performance of scroll mechanism and roll packing efficiency.

Pressure drop/penetration efficiency testing apparatus



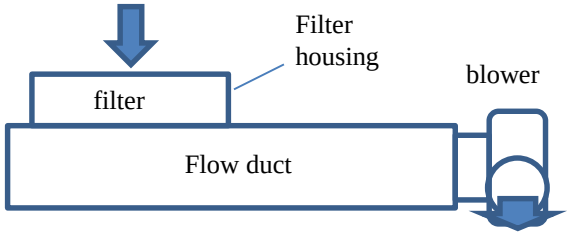
(a)



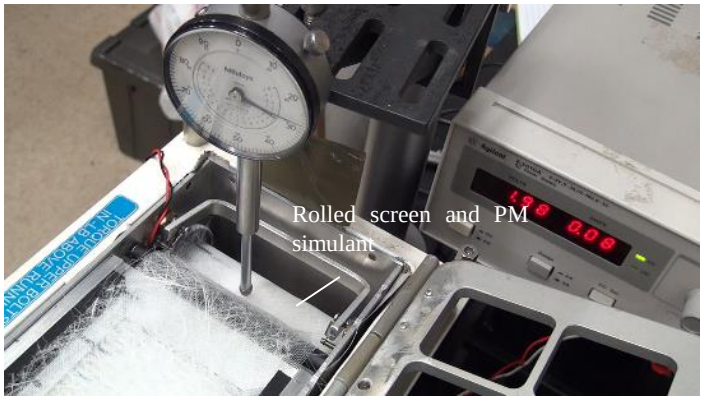
(b)

Bench top testing of Scrolling operation

(a)

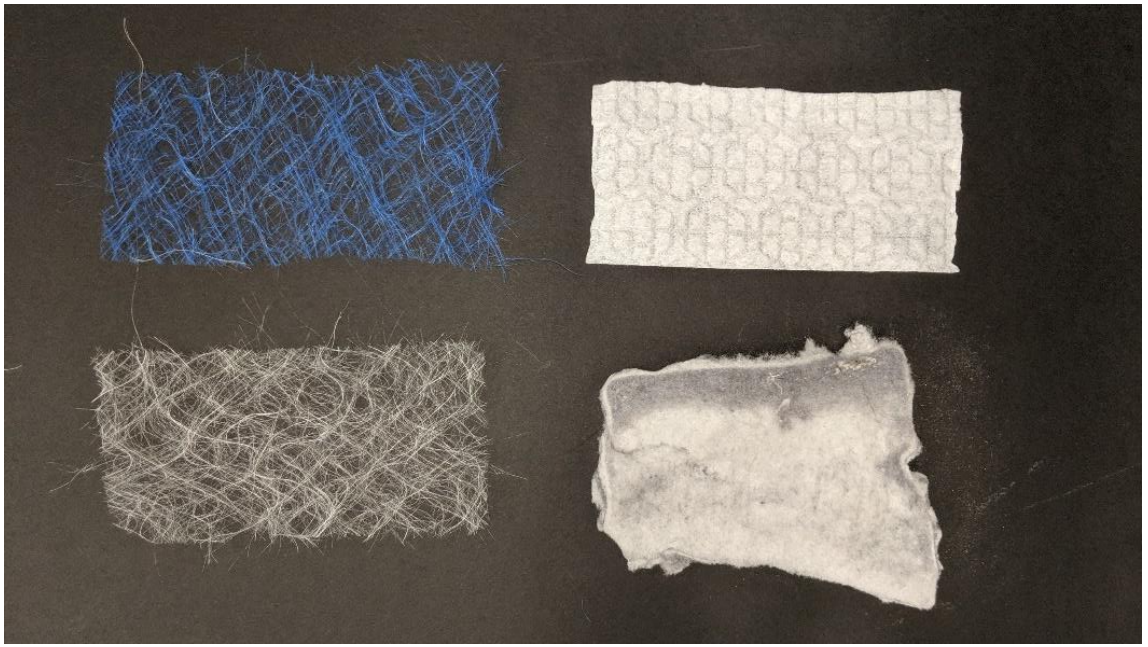


(b)



(c)

Particulate Matter (PM) Simulant materials



Material	thickness (mm)	PM density (mg/mm3)	solid density (mg/mm3)	porosity (%)	Packing ratio (R)
MERV 2 fiberglass	5.84	0.002	1.520	99.861	0.001
MERV 4 fiberglass	3.81	0.007	1.520	99.524	0.005
Cotton pad	1.12	0.049	1.55	96.850	0.031
dryer lint*	2.79	0.014	unknown	unknown	unknown

* limited tests were performed due to significant variation in initial thickness

Packing Ratio Calculations

Original Packing ratio

$$R = \frac{V_{sol}}{V_{PM,0}}$$

Packing ratio after rolling and compaction

$$R' = \frac{\rho_{PM,comp}}{\rho_{sol}}$$

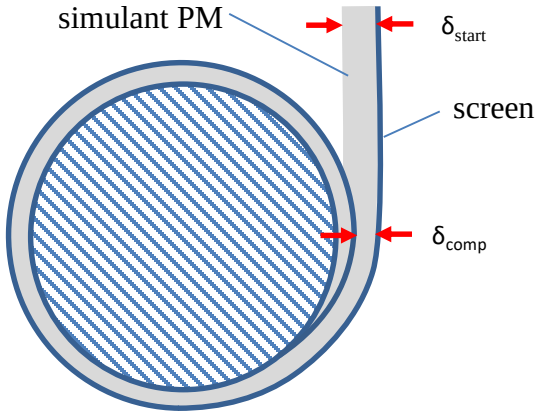
$$V_{PM,0} = w * L_{total} * \delta_0$$

V_{sol} and ρ_{sol} are the volume and density of the solid fibers in the fibrous network

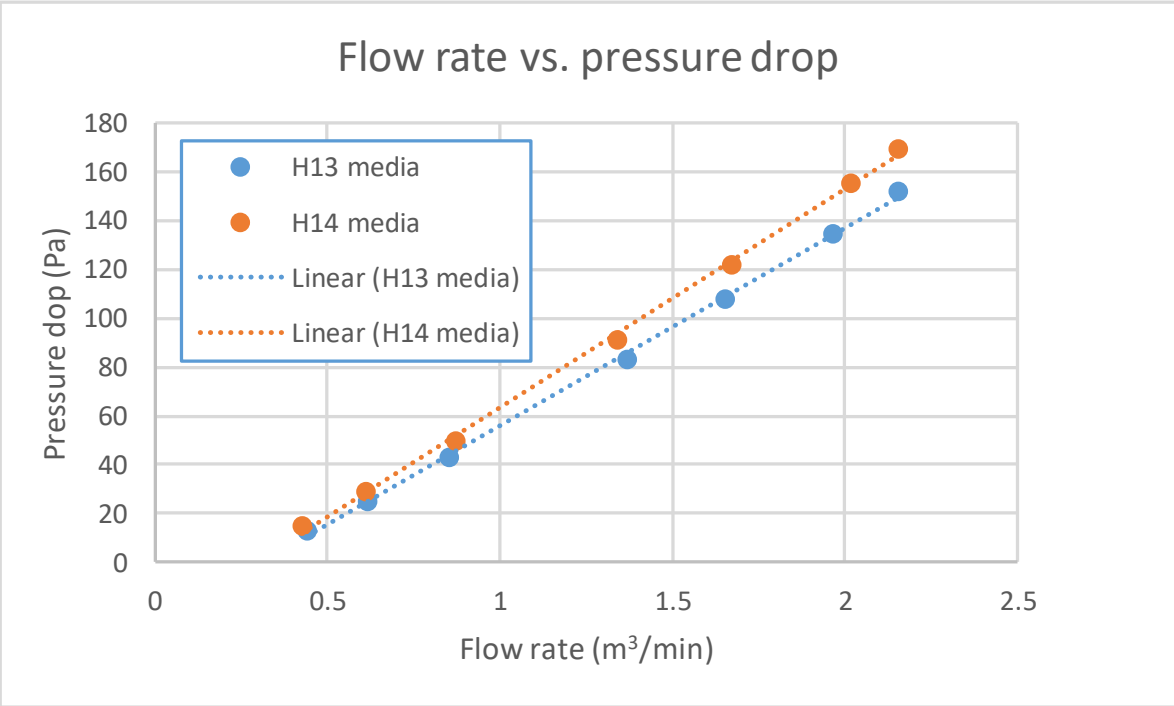
$$V_{PM,comp} = \pi \frac{\left(D_{end}^2 - D_{start}^2\right)}{4} w - L_{total} * \delta_{screeen} * w$$

$$\rho_{PM,comp} = \rho_{PM,0} \frac{V_{PM,0}}{V_{PM,comp}}$$

$$\langle \delta_{comp} \rangle = \delta_0 \frac{\rho_{PM,o}}{\rho_{PM,comp}}$$



Pressure drop



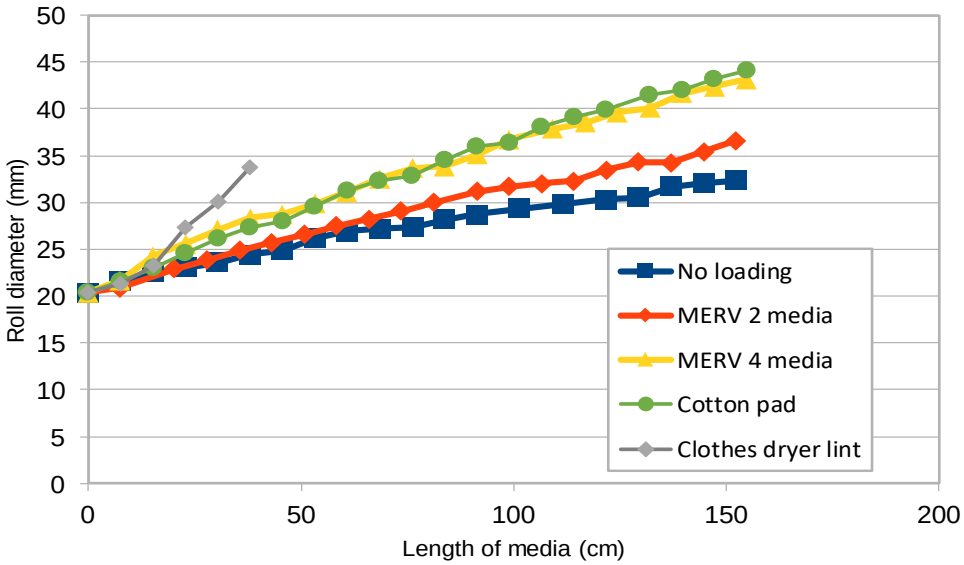
penetration efficiency

Media	Flow rate (m^3/min)	Penetration (%)	Efficiency (%)
H13*	1.94	0.0411	99.9589
H14†	1.94	0.0119	99.9881

*99.95% nominal efficiency

†99.995% nominal efficiency

Packing data



Packing summary

Material	D_{start} (mm)	D_{end} (mm)	δ_{start} (mm)	$\frac{d\,D}{dL}$	Total length (cm)	V_{screen} (cm^3)	$V_{P.M,\,0}$ (cm^3)	$V_{P.M,\,comp}$ (cm^3)	$\langle\delta_{comp}\rangle$ (mm)	ρ_{comp} (mg/mm^3)	R'	ΔR/R	$R'/\left(\frac{dD}{dL}\right)$
MERV 2	20.37	36.63	5.84	0.14	152.40	13.94	452.28	23.03	0.30	0.00	0.00027	18.64	0.001953
MERV 4	20.37	42.39	3.81	0.103	154.94	14.17	299.88	40.98	0.52	0.05	0.03482	6.32	0.338015
Cotton pad	20.42	44.07	1.12	0.153	154.94	14.17	87.97	46.68	0.59	0.09	0.05948	0.88	0.388765
Lint	20.42	33.81	2.79	0.365	38.10	3.48	54.08	25.48	1.32	0.03	NA	NA	NA

Conclusions

- A new prototype of the Scroll BFE being developed at NASA was tested for it performance characteristics. The Scroll BFE features two stages of filtration. A scrolling screen pre-filter stage and a static HEPA stage.
- The test results indicated that the filter is capable of performing at very high efficiency, depending on the filter element used, at the cost of a modest increase in pressure drop.
- The packing efficiency of the PM simulant during the scrolling operation was greater when a thin multi-layer PM layer was scrolled
- The present data and advancements in the development of the Scroll BFE will help to mature the technology towards opportunities on future flight demonstrations and ultimately on a deep space mission.

Future Work

Continue to evaluate other media that could provide greater filtration efficiency while providing low pressure drop.

Components that enhance scroll and regeneration performance, and design and structural options that help achieve further mass savings

- Refinements to track guides and scroll spindle mechanisms to improve sealing and reduce media deformation.

Reference for Mars trade study paper: Agui, J.H. and Perry, J.L., "Life Support Filtration System Trade Study for Deep Space Missions," Proceedings, 47th International Conference on Environmental Systems, Charleston, South Carolina, 16-20 July 2017.

Acknowledgements

This work was funded by the Advance Exploration System's Life Support Systems Project and is gratefully acknowledged.

We would like to thank Dan Gotti (USRA at NASA GRC) for design and fabrication of the BFE scroll filter prototype.

We would like to thank Donna Kasper at Hollingsworth & Vose (H&V) for providing filter media samples and consultation.