32nd Nuclear Air Cleaning Conference
Denver, CO.
June 18-19, 2012

ASME AG-1 Qualified HEPA Filters, A Particle Loading Comparison

Andrew Stillo Jr.
Camfil Farr
Riverdale, NJ 07457

Dr. Craig Ricketts
New Mexico State University
Las Cruces, NM 88003

Outline

1. Background (The Case for more loading tests).
2. Review of filter pack options and what pack types were tested.
3. Aerosol Particles used for Loading.
4. Test Set-ups used for Loading.
5. Results and Analysis.
6. Conclusions.
7. Acknowledgements.

Background

- The availability of qualified Size 8 (mini-pleat "V"-bed design) filters has sparked speculative claims like;
  - "Our gut feeling is that these filters would hold only about 25% of the amount of particulate that a standard separator type would."
  - "They simply can't have the same rugged strength as standard pleated HEPA filters".

Background (cont.)

- Size 8 filters meet the same requirements as all ASME AG-1 Section FC qualified filters meaning;
  - They are manufactured using ASME AG-1 appendix FC-I qualified media.
  - They are qualification tested and meet the same qualification requirements and hence meet the robustness level indicated by these tests.

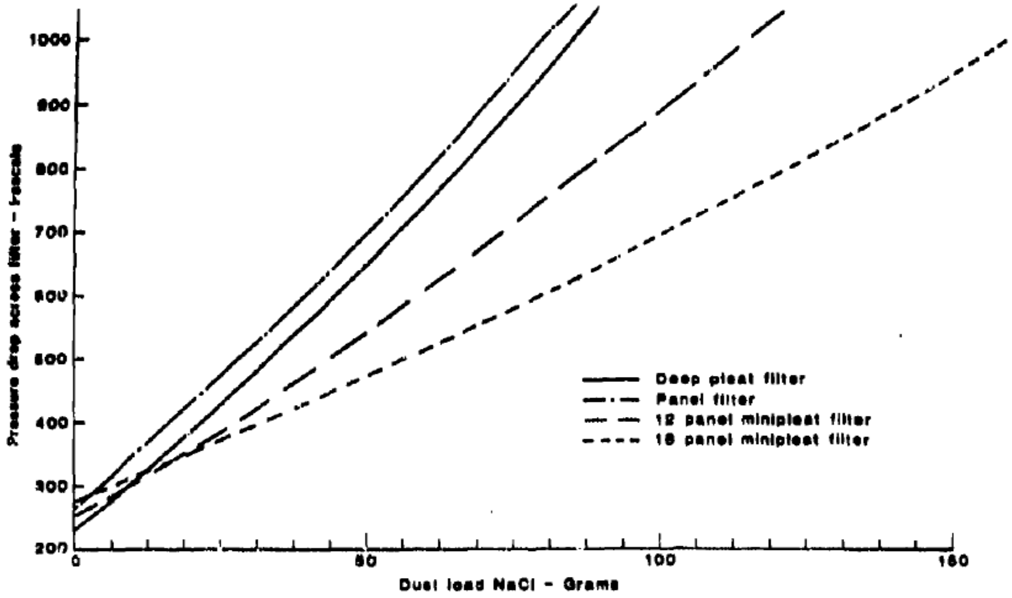
Background (Cont.)

- A series of loading studies[1-7] were conducted during late 70's into early 80's.
  - Why
    - Increasing disposal cost of radioactive materials.
    - Plugging of filters due to smoke and soot?
  - What was a significant focus?
    - Many tests performed compared commercial grade mini-pleat "V"-bed filters from Europe to conventional US nuclear grade filters.

Background (Cont.)

Loading Curve from;

R.P. Pratt and B.L. Stewart, “Collection of aerosols in HEPA filters”



AERE R 12323 Fig. 7

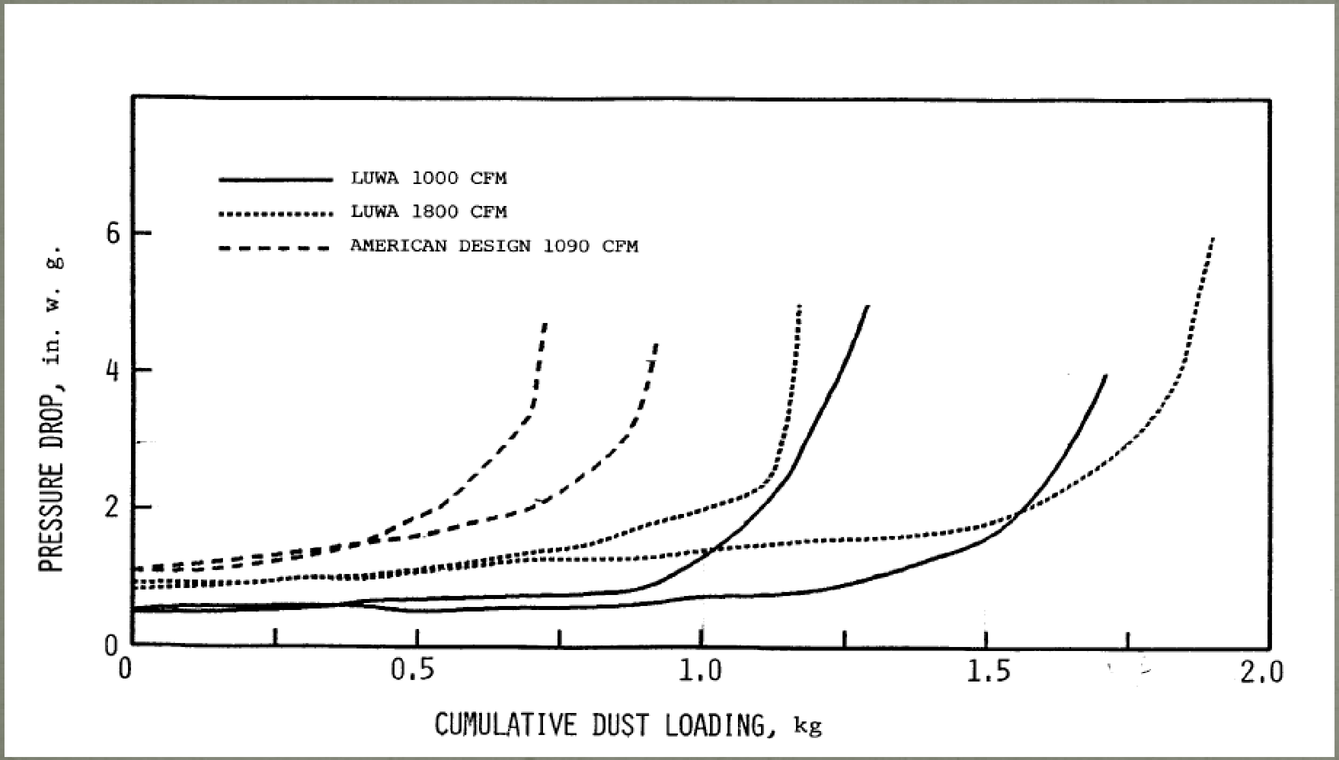
Dust load v pressure drop NaCl test dust at 1.5m/min face velocity

Demonstrates linear loading for sub-micron aerosols for the different filter types

Background (Cont.)

Loading Curve from;

M. W. First , J. M. Price, S. N. Rudnick; “PERFORMANCE OF 1,000- AND 1800- CFM HEPA FILTERS ON LONG EXPOSURE TO LOW ATMOSPHERIC DUST LOADINGS.



Demonstrates both higher loading capacity for “V-Bed” style filter and performance variability for all.

Background (Cont.)

Loading Data Table from;
C.A. Gunn and J.B. McDonough, "SURVEY OF LOADING PERFORMANCE OF CURRENTLY AVAILABLE TYPES HEPA FILTERS UNDER IN-SERVICE CONDITIONS

Filter Type	Flow (CFM)	Media Area (ft^2)	Media Velocity (FPM)	Dust Load (Grams)
Standard US	1080	216	5	1026
"Super-Pak"	1550	310	5	1140
"Super-Flow"	1250	250	5	840
European v-bed	1950	390	5	1500

Shows increasing loading capacity with increasing area except for the "Super-Flow"

Background (Cont.)

- A summary of key observations/findings from these past studies are;
  - Particle loading is related to filter effective media area for most cases.
  - "V"-bed style mini-pleat filters can have a significantly higher particle holding capacity than conventional 1000 CFM HEPA filters.
  - Deep pleat separatorless packs (dimple pleat) tend to have less dust holding capacity than the other styles, due to premature pleat deformation, sagging and nesting of pleats.

Background (Cont.)

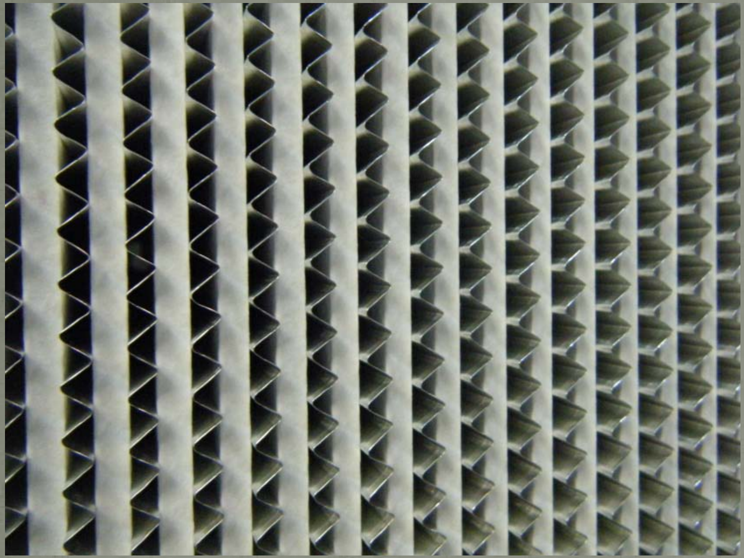
- A recent study[8] on the particle loading characteristics of a prototype radial-flow HEPA filter raises additional concern;
  - Demonstrates an inherent weakness and potential for failure of dimple pleat construction in radial-flow filters.
  - This pack construction is not unique to radial-flow filters and is also utilized in standard axial flow nuclear grade filters (ASME AG-1 Section FC).

Background (Cont.)

- Why perform more particle loading tests?
  - Validate or disprove the recently voiced speculative loading claims with data.
  - Past test results were not of US nuclear grade mini-pleat “V”-bed construction.
  - Optimization has occurred relative to the original “V”-bed designs of the 70’s & 80’s.
  - Support the potential development of a particle loading qualification test based on past and present findings concerning separator-less packs.

Filter Configurations Tested
Allowable Pack Types

- There are four distinct pack types allowed within the AG-1section FC code[9].



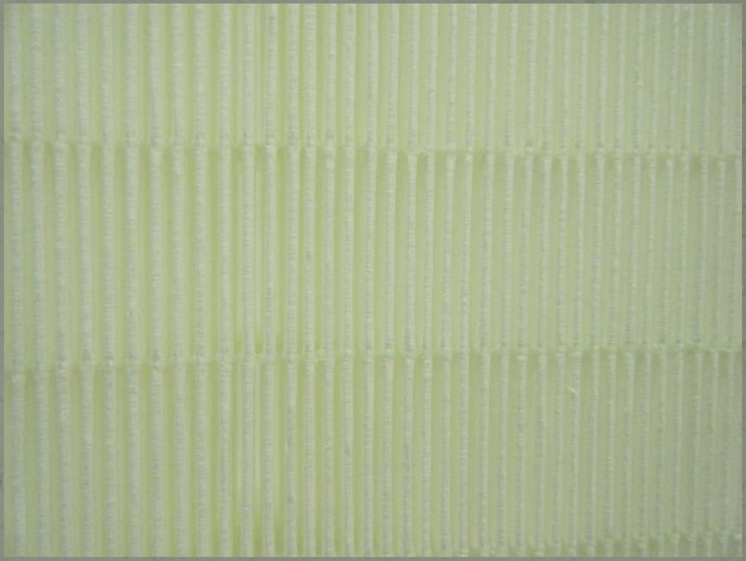
Type A : Pleats separated by corrugated aluminum separators

Type B : Individual pleated panels (using thread or media ribbon separators) arranged in a “V” form.

Filter Configurations Tested
Allowable Pack Types

- (Cont)

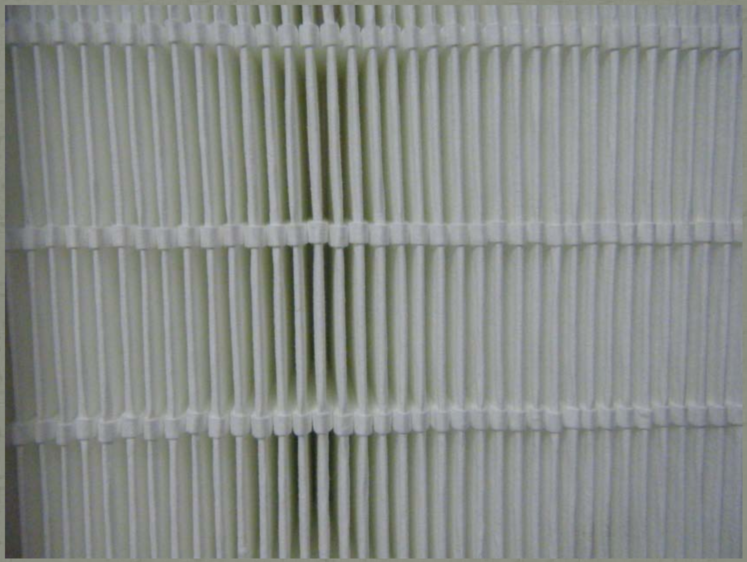
Type C : Corrugated or embossed media.



Type D : Pleats separated by threads

Filter Configurations Tested
Allowable Pack Types

- (Cont)



Type D : Pleats separated by ribbons of media

Filter Configurations Tested

Half-High Size 8

Half-High Size 7

Half-High Size 5

Why Half-high filters ;

- Flow limitation of one of the test systems.
- Longer test times associated with Full-size filters.

Aerosol Particles used for Loading

- Loading of Nuclear Grade HEPA filters with smoke and soot is a major concern.
  - G. W. Mulholland[10] indicates that the typical size range of burning plastics like PVC, polyurethane, polystyrene and polypropylene are in the range of 0.3-1.6 µm.
  - J.R. Gaskill, N.J. Alvares, D.G. Beason, and H.W. Ford [11] performed studies using the Full Scale Fire Test Facility at Lawrence Livermore Laboratory under varying conditions.
    - They found that the particle size were in the range of 50% > 1 µm to 80% > 3 µm.

Aerosol Particles used for Loading(cont.)

Table II: Loading Aerosol/Dust Characteristics.

Aerosol Type	*Generation Method*	*Typical Concentration or Feed Rate*	*Mass Media Particle Size (µm)*	*Geometric Standard Deviation*
PAO (Polyalphaolefin)	TDA-5B[1] (vapor condensation generator <25% capacity)	50 µg/liter	< 0.31[3]	1.3
PAO (Polyalphaolefin)	TDA-4Blite[1] (Laskin nozzle generator -2 nozzles @ 20psig)	40 µg/liter	0.491-0.585[3]	1.5
JIS Z8901 Class 11[2] (test dust)	Standard dust feeder	7.14 g/min (370.8 µg/liter)	2.8[4]	1.6

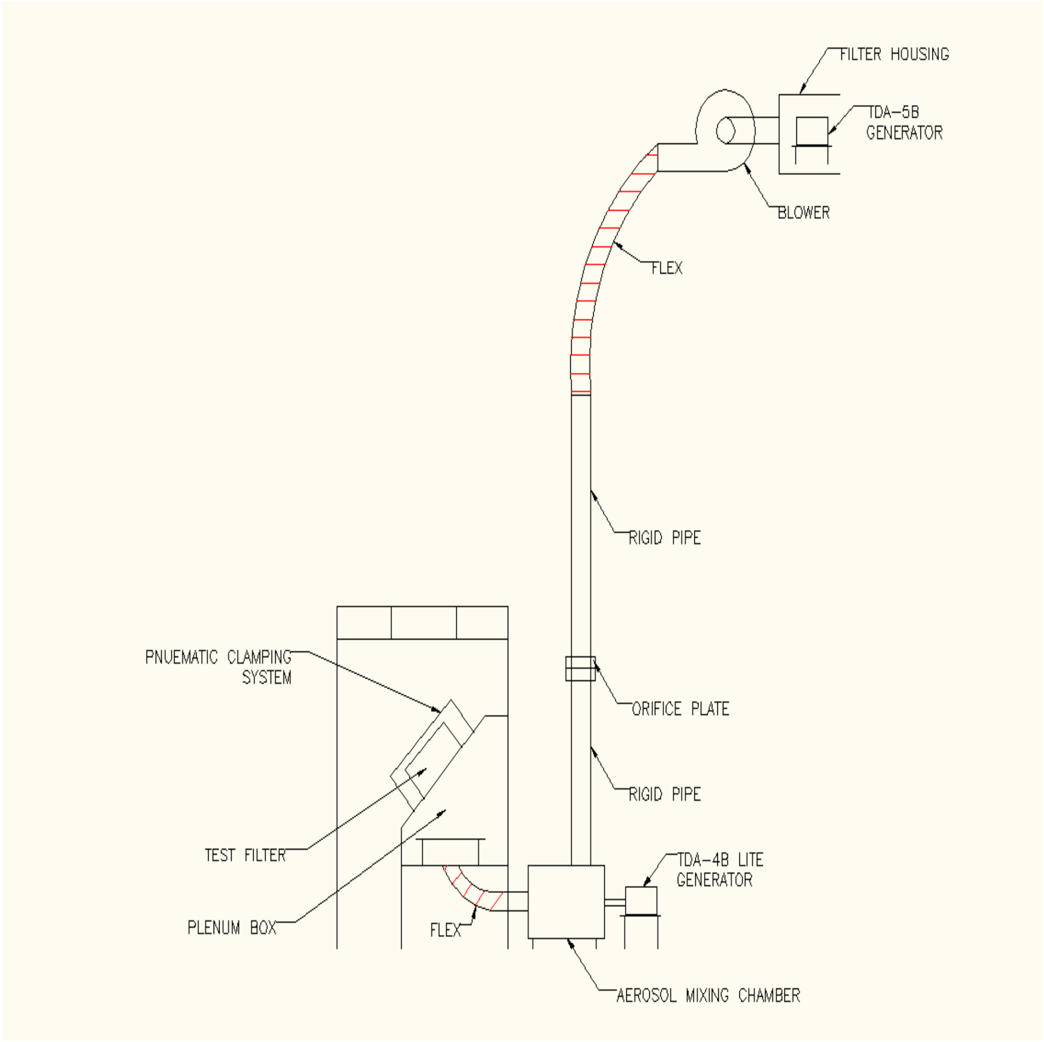
1 See appendix I for particle size information provided by Air Techniques International from data collected for the CETA (Controlled Environment Testing Association) "Bleed Thru study".

2 See appendix II & III for JIS Z8901 Class 11 certification and composition.

3 Assumes aerosol generated during this testing is within the range measured by Air Techniques International.

4 Assumes perfectly dispersed dust.

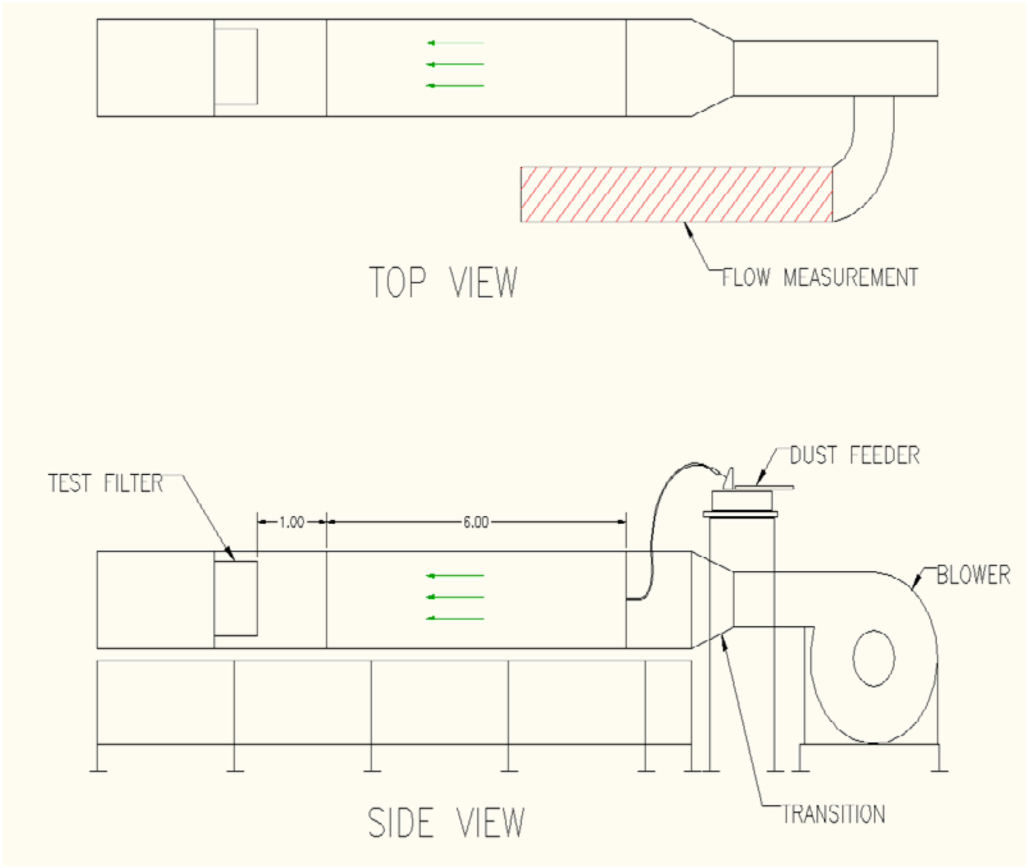
Test Set-up
Laskin & Thermal PAO



Loading procedure;

- Maintain a constant flow of 680 ACFM.
- Record the average aerosol concentration per time period in µg/liter from an ATI Aerosol photometer model 2H.
- Record the filter pressure drop at the end of each time period.

Test Set-up (cont.) JIS Z8901 Class 11



Loading Procedure;

- The loading was divided into five equal pressure drop increase increments
- Maintain a constant air flow of 680 ACFM.
- Feeding the test dust at a rate of 7.14 grams/minute in multiple 50 gram segments per loading increment.
- Recording the total dust.
- Recording the filter pressure drop at the end of each loading.

Test Results

$$ML = (C_A) \times (Q) \times (\Delta t) \times (1 \times 10^{-6}),$$ For PAO Loading

where:

ML = Mass Loading (grams),
C_A = Concentration Average for time period (µg/liter),
Q = Volume flow rate passing through the filter (liters/min), and
Δt = time interval (minutes.)

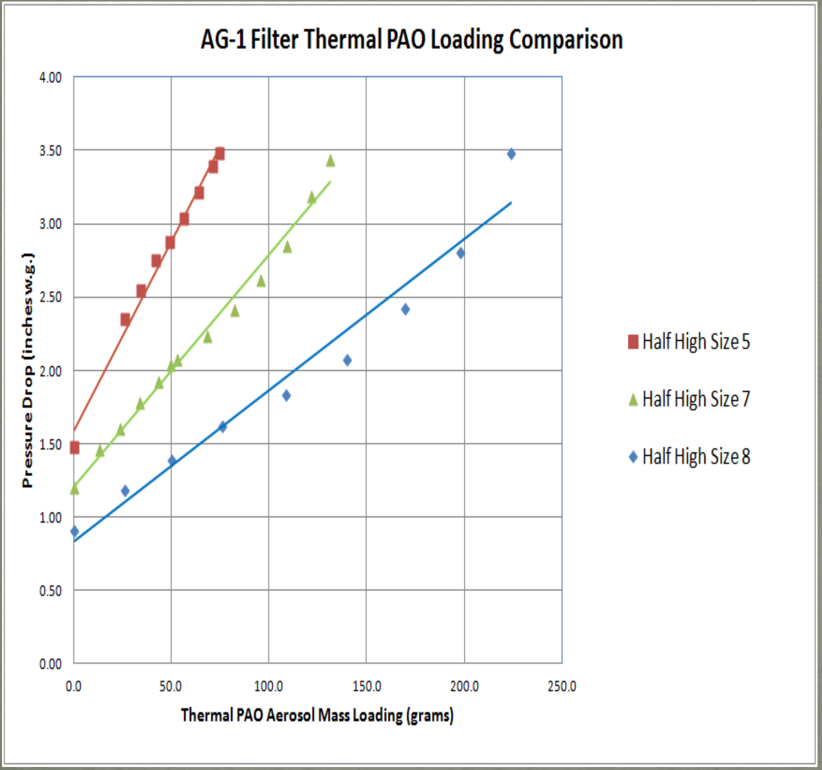
$$ML_A = ML/UA/(1 \times 10^{-6}),$$

where:

ML = Mass Loading (grams) and
UA= Useable media Area for filtering (cm^2)

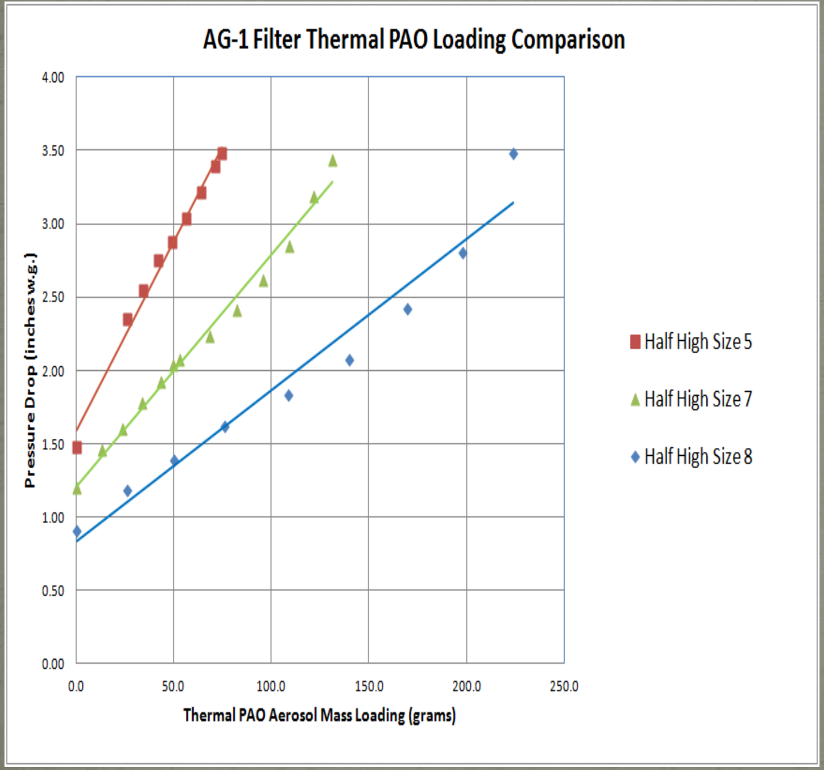
Test Results
Loading Curve Analysis

Mass loaded vs. Filter Resistance

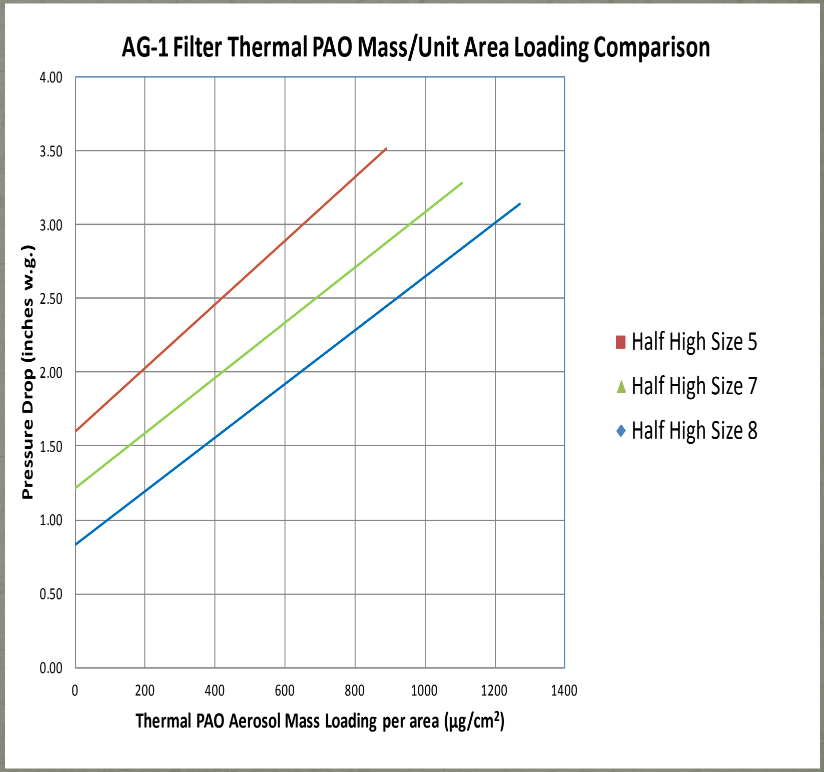


Test Results
Loading Curve Analysis

Mass loaded vs. Filter Resistance

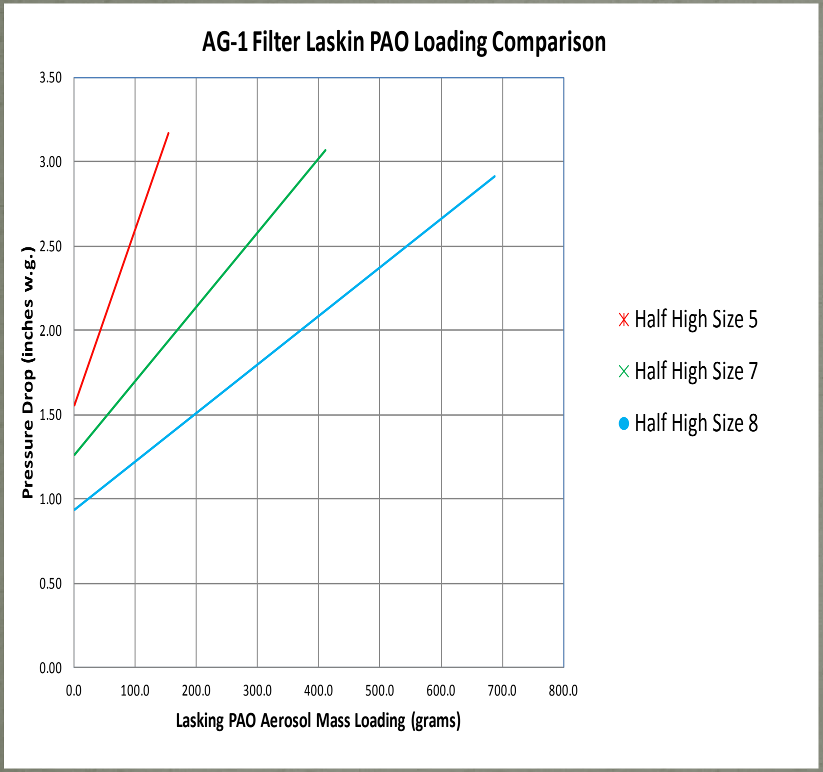


Mass loaded/unit area vs. Filter Resistance



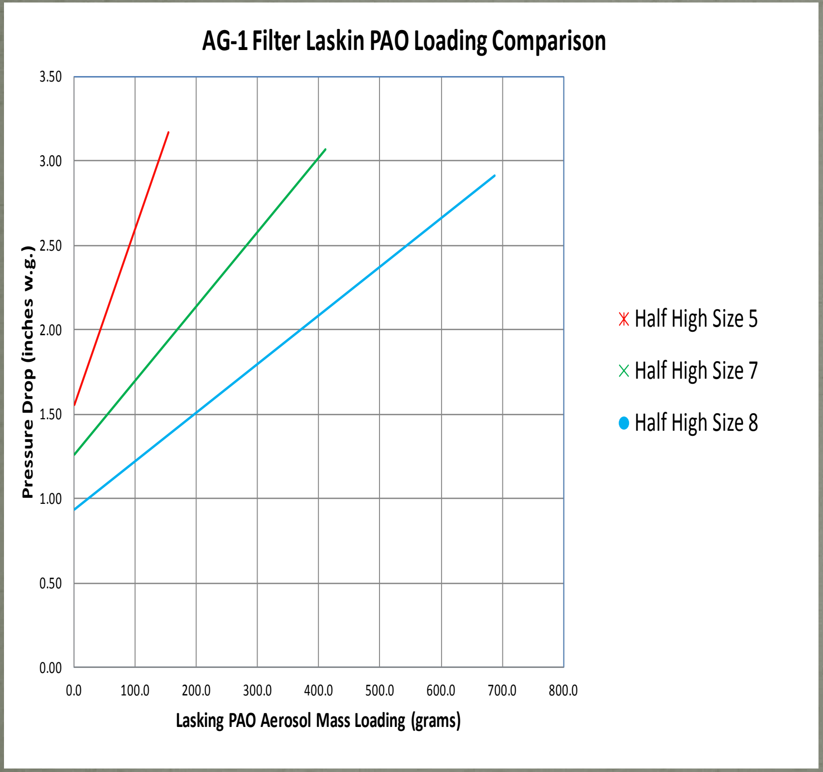
Test Results
Loading Curve Analysis

Mass loaded vs. Filter Resistance



Test Results
Loading Curve Analysis

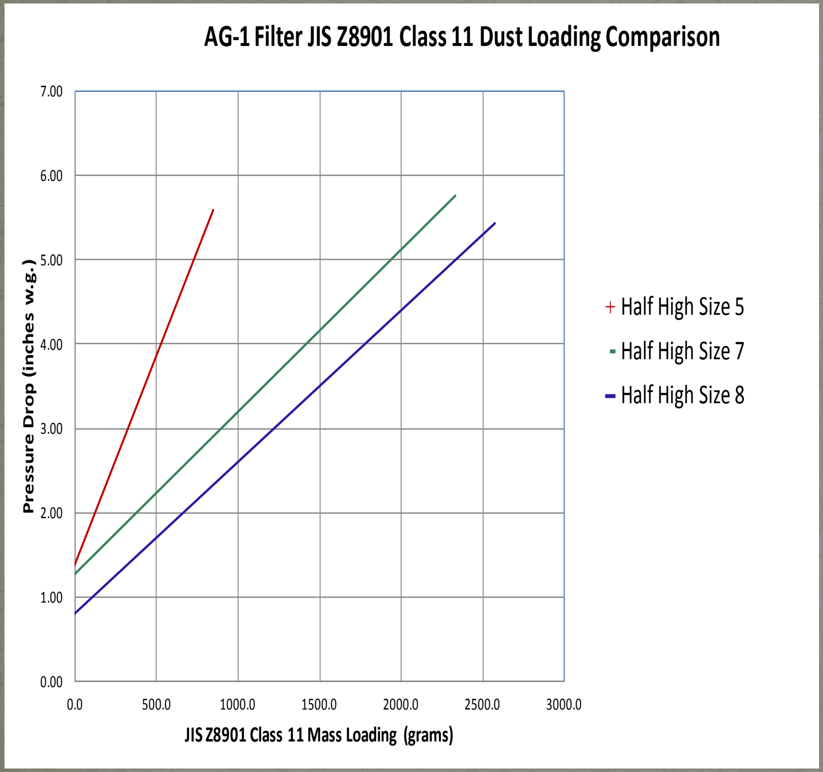
Mass loaded vs. Filter Resistance



Mass loaded/unit area vs. Filter Resistance

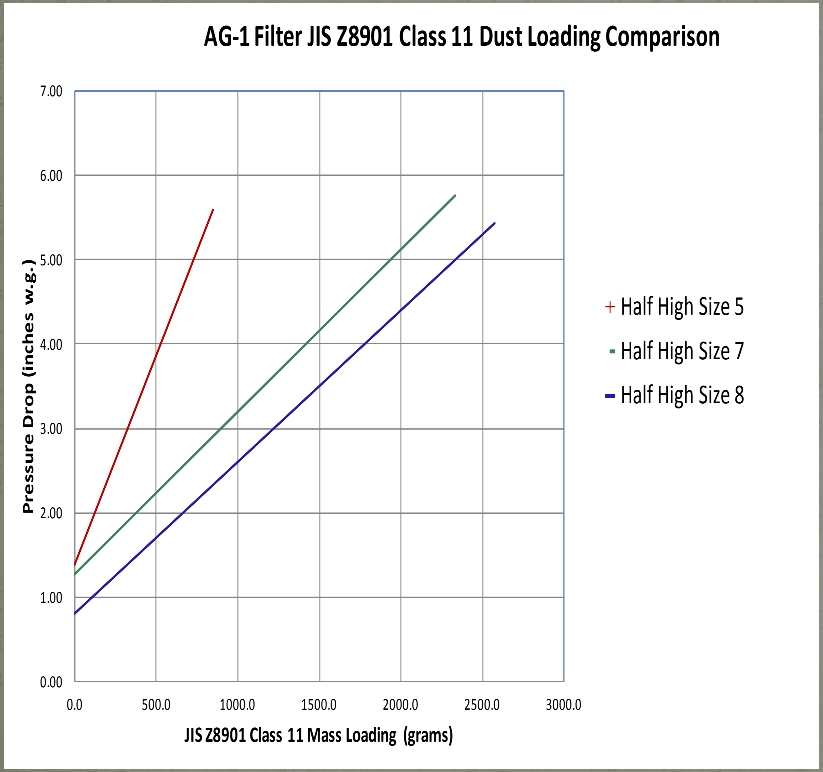
Test Results
Loading Curve Analysis

Mass loaded vs. Filter Resistance

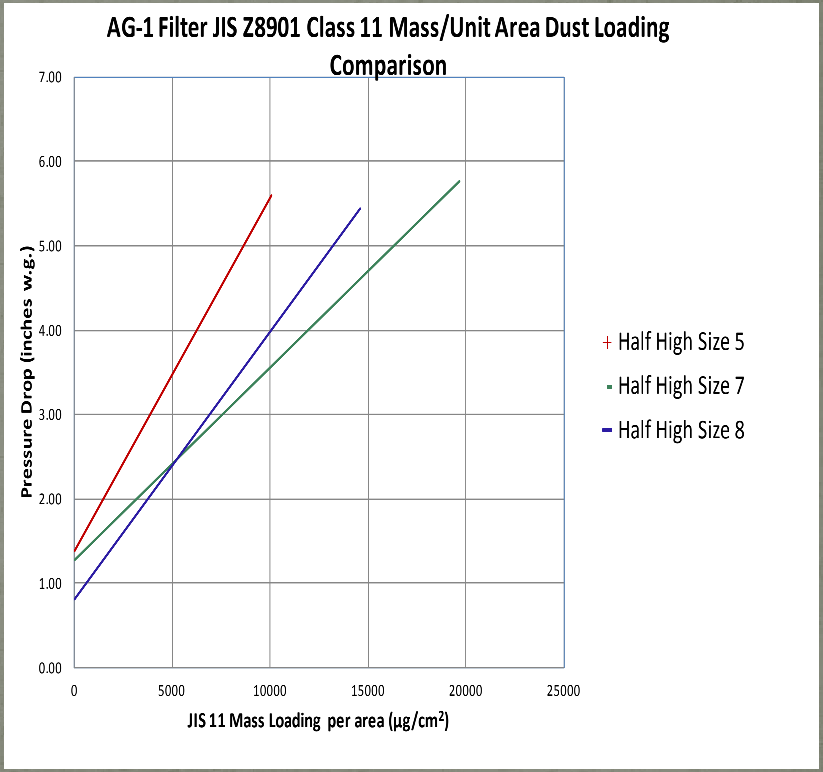


Test Results
Loading Curve Analysis

Mass loaded vs. Filter Resistance



Mass loaded/unit area vs. Filter Resistance

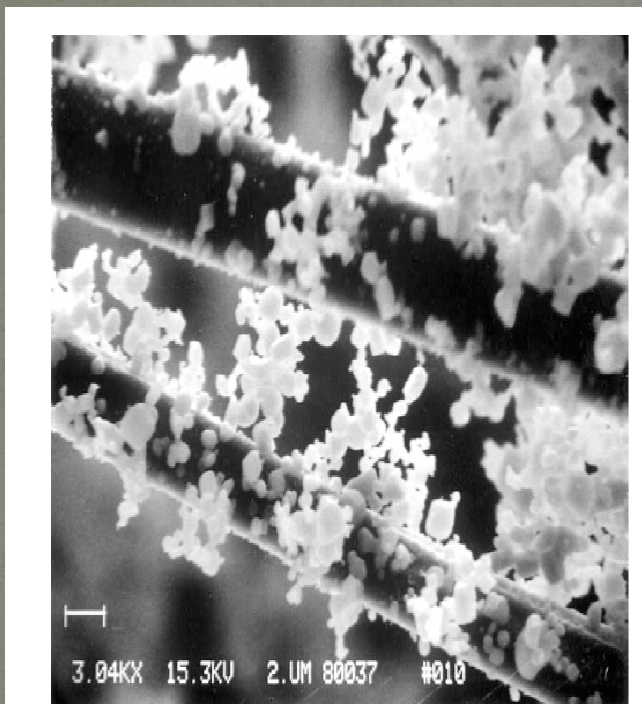


Test Results:
Area multiple/Loading Multiple Comparison

			Loading to 3 " W.G. Calculated						Loading to 5.5" W.G.	
			Thermal PAO		Laskin PAO		JIS Z8901 Clas 11		JIS Z8901 Clas 11	
	Media Area (ft^2)	Area Multiple	Mass (g)	Loading Multiple	Mass (g)	Loading Multiple	Mass (g)	Loading Multiple	Mass (g)	Loading Multiple
Half High Size 5	95.2	1.0	54.6	1.0	139.2	1.0	324.3	1.0	824.3	1.0
Half High Size 7	135.8	1.4	113.0	2.1	395.7	2.8	907.9	2.8	2223.7	2.7
Half High Size 8	195.8	2.1	210.3	3.9	712.9	5.1	1219.6	3.8	2608.4	3.2

Test Results
Dendrite model comparison [12]

- Dendritic particle deposits pictured to bottom left are approximated as fiber elements.



Photograph from: W. Bergman, “HEPA Filter Loading” [12]

$$\left(\Delta P_m - \Delta P_{m0}\right)\frac{\rho_{pD} D_p^n}{V_m} = k\frac{M}{A}$$

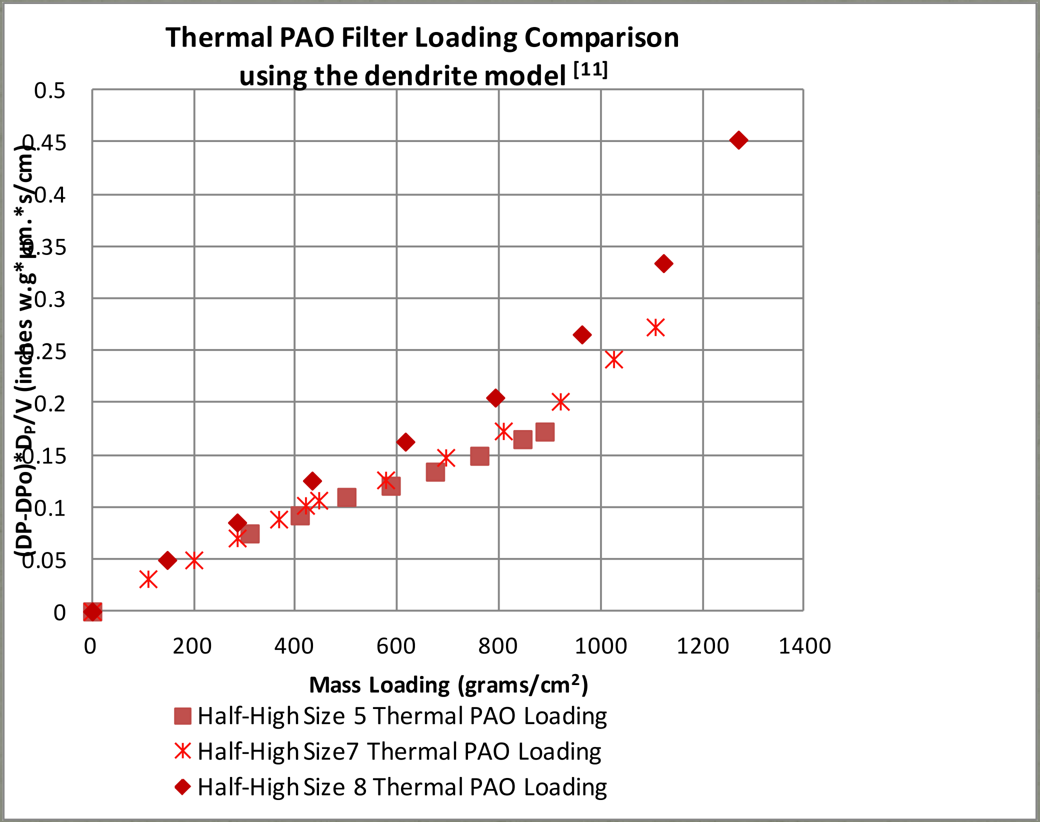
Where:

n = constant between 1 and 2

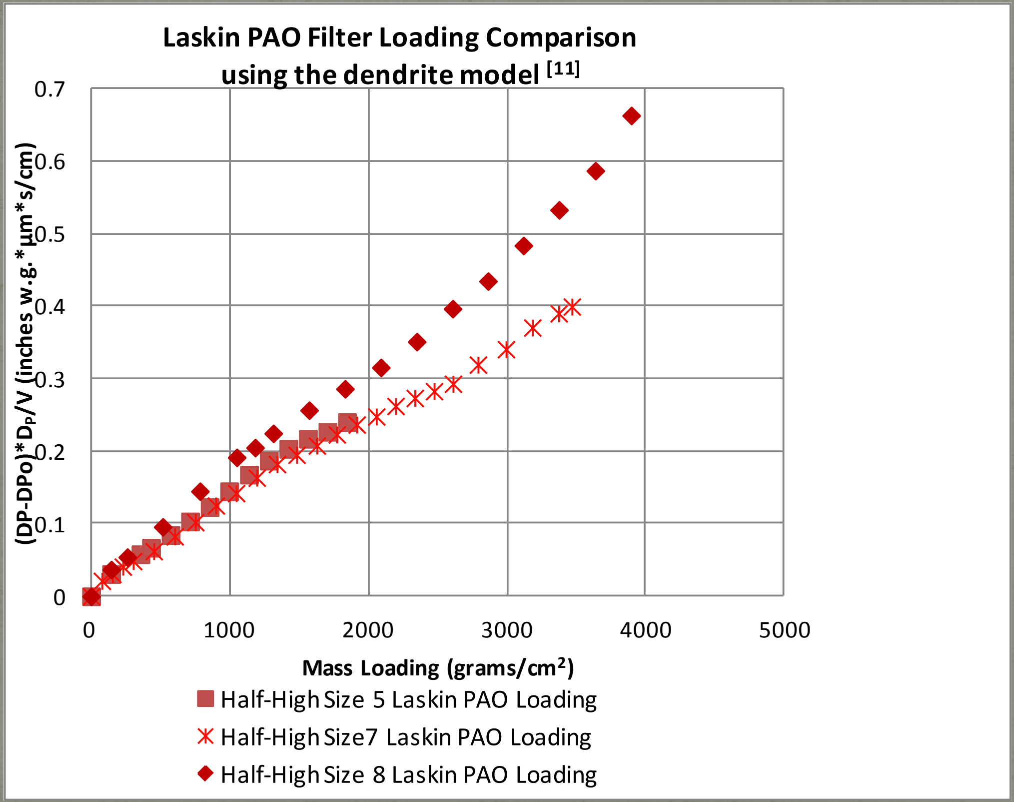
k = constant

Combined pack bed and particle fiber model

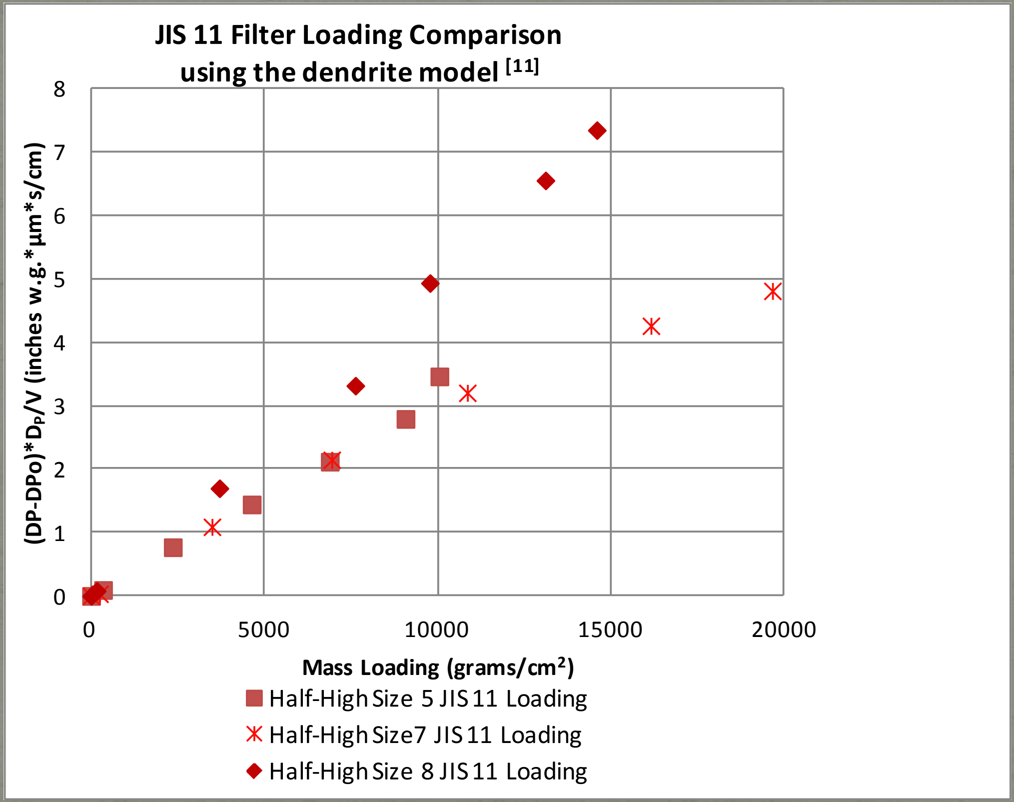
Test Results
Dendrite model comparison [12]



Test Results
Dendrite model comparison [12]



Test Results
Dendrite model comparison [12]



Conclusions

- Results reported here are mostly consistent with prior studies.
- The Half-high Size 8 filter has the highest loading capacity and the loading capacity multiple is higher than the multiple of increased media area (nearly 2X).
- It appears that the effective utilization of filtering surface area diminishes as particle size increases for the Size 8 filter design.
- The Dendrite model presented by Bergman[12] appears to hold true for filters of similar pack configuration.

Conclusions

- Deep pleat separatorless packs "Type-C" should be evaluated further for particle loading capacity.
- A particle loading test should be considered as an additional qualification requirement;
  - An interim solution in lieu of a loading test may be to set a minimum flow requirement for the resistance-to-pressure test.
  - An ultimate solution, based on capillary condensation of even lightly loaded filters[13] may be the combination of a particle preloading and resistance-to-pressure test with minimum flow requirement.

Acknowledgements

- Dr. Craig Ricketts for his support and mentoring.
- Dr. Werner Bergman for his review of the paper and valuable comments.
- Camfil Farr-Riverdale, NJ operations and R&D Laboratory personnel for their support.
- CETA & Dave Crosby for PAO particle size data.

Questions??

References

1. R.P. Pratt and B.L. Stewart, “Collection of aerosols in HEPA filters”, *United Kingdom Atomic Energy Authority, HARWELL, DTIC, Selected Jan 11, 1988, AERE R 12323.*
2. M. W. First and J. M. Price, “PERFORMANCE OF 1,000- AND 1800- CFM HEPA FILTERS ON LONG EXPOSURE TO LOW ATMOSPHERIC DUST LOADINGS, *”, *Proceedings of the 15th DOE Nuclear Air Cleaning Conference, pp 1185-1190.*
3. M. W. First and S. N. Rudnick, “PERFORMANCE OF 1000- AND 1800- CFM HEPA FILTERS ON LONG EXPOSURE TO LOW ATMOSPHERIC DUST LOADINGS, II”, *Proceedings of the 16th DOE Nuclear Air Cleaning Conference, pp 682-696.*
4. M. W. First and J. M. Price, “PERFORMANCE OF 1000- AND 1800- CFM HEPA FILTERS ON LONG EXPOSURE TO LOW ATMOSPHERIC DUST LOADINGS, III”, *Proceedings of the 17th DOE Nuclear Air Cleaning Conference, pp 909-918.*
5. R.P. Pratt, “A PRELIMINARY ASSESSMENT OF THE DUST LOADING VERSUS PRESSURE DROP CHARACTERISTIC OF HIGH CAPACITY HEPA FILTERS”, *Proceedings of the 16th DOE Nuclear Air Cleaning Conference, pp 697-707.*
6. J. Dyment and D. Loughborough, “THE EFFECT OF MEDIA AREA ON THE DUST HOLDING CAPACITY OF DEEP PLEAT HEPA FILTERS”, *Proceedings of the 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference, pp 743-751.*
7. C.A. Gunn and J.B. McDonough, “SURVEY OF LOADING PERFORMANCE OF CURRENTLY AVAILABLE TYPES HEPA FILTERS UNDER IN-SERVICE CONDITIONS”, *Proceedings of the 16th DOE Nuclear Air Cleaning Conference, pp 667-681.*

References

8. P. Griffin, M. Parsons and C. Waggoner, “Results from Evaluation of Representative ASME AG-1 Section FK Radial Flow Dimple Pleated HEPA Filters Under Elevated Conditions”, Proceedings of the 2012 Waste Management Symposia Session 10 titled “Filtration Issues for Waste Treatment”.
9. ASME AG-1-2009 “Code on Nuclear Air and Gas Treatment”, pp 358-362.
10. G. W. Mulholland, “SMOKE PRODUCTION AND PROPERTIES”, *SFPE Handbook of Fire Protection Engineering, 2nd Edition, Chapter 15, Section 2, pp 217-227.*
11. J.R. Gaskill, N.J. Alvares, D.G. Beason, and H.W. Ford, Jr. “Preliminary Results of HEPA-Filter Smoke Plugging Tests Using the LLL Full-Scale Fire Test Facility”, Proceedings of the 14th ERDA Air Cleaning Conference, p. 134 ff.
12. W. Bergman, “HEPA Filter Loading”, *Proceedings of the 29th Nuclear Air Cleaning Conference.*
13. C.I. Ricketts, V. Ruedinger, and J.G. Wilhelm, “The Flow Resistance of HEPA Filters in Supersaturated Airstreams”, Proceedings of the 20th DOE/NRC Nuclear Air Cleaning Conference, *pp 668-694*.