

ASME AG-1 Section FC Qualified HEPA Filters; a Particle Loading Comparison - 13435

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ABSTRACT

High Efficiency Particulate Air (HEPA) Filters used to protect personnel, the public and the environment from airborne radioactive materials are designed, manufactured and qualified in accordance with ASME AG-1 Code section FC (HEPA FILTERS) [1]. The qualification process requires that filters manufactured in accordance with this ASME AG-1 code section must meet several performance requirements. These requirements include performance specifications for resistance to airflow, aerosol penetration, resistance to rough handling, resistance to pressure (includes high humidity and water droplet exposure), resistance to heated air, spot flame resistance and a visual/dimensional inspection. None of these requirements evaluate the particle loading capacity of a HEPA filter design.

Concerns, over the particle loading capacity, of the different designs included within the ASME AG-1 section FC code[1], have been voiced in the recent past. Additionally, the ability of a filter to maintain its integrity, if subjected to severe operating conditions such as elevated relative humidity, fog conditions or elevated temperature, after loading in use over long service intervals is also a major concern. Although currently qualified HEPA filter media are likely to have similar loading characteristics when evaluated independently, filter pleat geometry can have a significant impact on the *in-situ* particle loading capacity of filter packs. Aerosol particle characteristics, such as size and composition, may also have a significant impact on filter loading capacity.

Test results comparing filter loading capacities for three different aerosol particles and three different filter pack configurations are reviewed. The information presented represents an empirical performance comparison among the filter designs tested. The results may serve as a basis for further discussion toward the possible development of a particle loading test to be included in the qualification requirements of ASME AG-1 Code sections FC and FK[1].

INTRODUCTION

Industrial air cleaning systems both process and ventilation related, are often critical to the protection of plant personnel and the environment. These types of systems provide for the containment of toxic and radioactive materials within nuclear facilities. Critical components of these systems are the nuclear-grade HEPA filter units. These filters are manufactured and qualified in accordance with the American Society of Mechanical Engineers (ASME) AG-1 Code on Nuclear Air and Gas Treatment sections FC or FK[1].

The evaluation of the particle loading capacities of HEPA filters, utilized in the nuclear industry, has been an ongoing topic of concern. In recent years, opinions have been circulated indicating that an ASME AG-1 Section FC Size-8 (mini-pleat 3400 m³/hr (2000 CFM)) filter[1] would have substantially less loading capacity than an ASME AG-1 Section FC Size-5 (1700 m³/hr (1000 CFM)) filter[1], due to the tighter pleat spacing of the design. With more than one major filter manufacturer offering a qualified ASME AG-1 Section FC Size-8 filter, it is considered important to either verify or refute such claims upon the basis of relevant data. The potential benefits of the higher flow capacity of Size-8 HEPA filters include but are not limited to, a reduced number of filters required to satisfy a system design flow rate, or an extension in filter life due to expected higher loading capacity. Either could help substantially reduce operating costs by reducing waste disposal costs.

Moreover, a recent study on the particle loading characteristics of a prototype radial-flow HEPA filter design[2], manufactured in accordance with ASME AG-1 Section FK[1], that demonstrated an inherent weakness and the potential for failure of the filter pack raises substantial concern. This pack construction is not unique to radial-flow filters and is also currently an acceptable option within the ASME AG-1 Code Section FC[1]. The specific construction utilized, does not have a pleat separator like other constructions. It relies on the media itself being dimpled to provide the pleat spacing. Even though this construction passed all qualification requirements for new, clean Section FC style filters, questions exist with regard to the stability of the pack during and after particle loading, particularly following possible subsequent exposure to filter adverse operating conditions.

As an initial step, to compare the loading capacity of qualified ASME AG-1 Section FC[1] filters, particle loading tests were conducted on half-high qualified Size-5, Size-7, and Size-8 filter designs. Since it was not clear, that a qualified ASME AG-1 section FC Size 8 (“V”-bed) style filter was ever included in any prior particle loading studies, it was important to conduct tests on this filter in comparison to traditional style qualified filters.

Half-high filters were utilized for two reasons;

1. One of the test systems utilized to particle load filters had limitations in blower capacity, thereby making it impossible to test full size-filters and achieve a substantive increase in filter pressure drop.
2. Full-size filters would have very long loading times, making it impractical for this evaluation.

Filters were exposed to aerosols of varying particle size distributions. The aerosol particles utilized were Polyalphaolefin (referred to as PAO for the balance of this paper); an oil-droplet aerosol generated using both vapor condensation (thermal) and nebulized (Laskin nozzle) methods and a JIS Z8901 Class 11 test dust. Further details of the aerosols/dust are included in the “Selection of Loading Particles” section of this paper. The plan was to load all filters to a final pressure drop of 1245-1495 Pa (5-6 inches w.g.). For this loading comparison, all filters were loaded at the same flow rate to simplify the testing. The flow-rate utilized was 1156 m³/hr (680 CFM), the rated flow capacity of the half-high Size 7 filter. This was near the middle of the range between the Size 5 and Size 8 filters. The filter medium utilized in all test filters was the same grade and from the same manufacturing lot.

FILTER CONFIGURATION DETAILS

The allowable pack designs, specified within the ASME AG-1 Code Section FC[1], are a primary filter attribute that can potentially affect filter particle loading capacity. The current code for nuclear-grade HEPA filters defines four specific pack types as being acceptable in the construction of qualified HEPA filters. The difference between these is the method utilized to separate the pleats, and in one case includes the actual configuration of the filter. The four pack types are summarized below;

- (a) Type A filter packs are constructed by folding the media to the required depth. Corrugated aluminum separators are then inserted between the pleats (folds) to both support and separate the media. This type of filter pack construction is utilized in all filter sizes except for Size 8. (See Fig. 1(a) below for a photograph of a Type A filter pack)
- (b) Type B filter packs are constructed by arranging a series shallow pleated media panels approximately 1 inch deep) in a “V” configuration within the filter case. Pleats are separated and supported by either ribbons of glass fiber media, or noncombustible threads bonded to the filter media. This pack type is the only one currently utilized for Size 8 filters. (See Fig. 1(b) below for a photograph of a Type B filter pack).
- (c) Type C filters packs are fabricated by corrugating or embossing a continuous sheet of filter media and folding the media to the required depth to make the filter pack. (See Fig. 1(c) below for a photograph of a Type C filter pack).

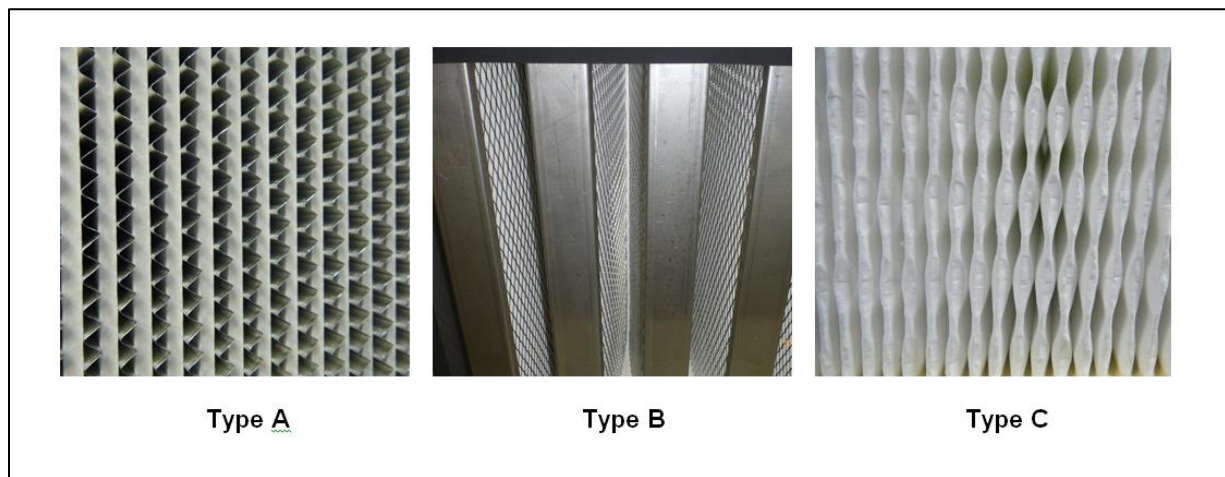


Figure 1: Photographs of pack Types A, B and C as defined in ASME AG-1 Section FC.

- (d) Type D filter packs are made by folding the media to the required depth. The folded filter media is separated and supported by ribbons of glass-fiber media or noncombustible threads, glued to the filter media. (See Fig. 2 below for photographs of typical Type D filter packs).

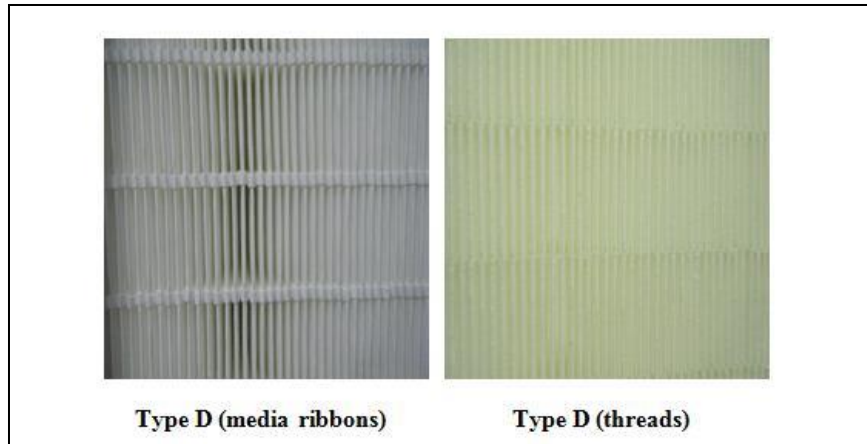


Fig. 2: Photographs of pack Type D as defined in ASME AG-1 Section FC.

As previously indicated, this study utilized half-high ASME AG-1 Section FC[1] Size 5, Size 7 and Size 8 filters. Both the half-high Size 5 and 7 filters, represented by the test data in this paper, utilized a Type A pack. The difference between the half-high Size 5 and 7 Type A packs was the amplitude and configuration of the corrugated aluminum separator. This difference results in a change in the number of pleats within the filter. The separator configuration of the half-high Size 7 filters is configured to yield more pleats as compared to the half-high Size 5 filters. This results in a higher rated flow capacity for the half-high Size 7 filters. Since the pleat height remained constant, the half-high Size 7 filter had 43% more useable media surface area as compared to the half-high Size 5 filters.

The pack type utilized in the half-high Size 8 filters was a Type B. In this case, the pleats were separated using noncombustible threads bonded to the filter media. This filter configuration contains 44% and 106 % more useable media surface than the half-high Size 7 and Size 5 filters respectively. Based on this alone, the half-high Size 8 filter design would be expected to have higher particle loading capacity than both the half-high Size 7 and Size 5 filters.

PAST LOADING STUDIES REVIEW

Although concern over the loading capacity has been recently voiced, this concern has a historical background. During the late 1970's and early 1980's, many studies were conducted that compared different loading dusts and filter configurations. An overview of these studies including basic conclusions is summarized below for reference.

1. In 1986, R.P. Pratt & B.L. Stewart authored a paper that evaluated the loading of deep pleat HEPA filters in comparison to mini-pleat filters [3]. It compares loading capacities of these filters when loaded with BS 2831No. 2, an alumina test dust, having a noted mean particle size of 5 μm and carbon black having a noted particle size less than 1 μm . In addition, a sub-micron sodium chloride aerosol (0.14 μm) was also utilized since, as noted, the main challenge to HEPA filters was likely to be sub-micron. The filters utilized for this study were of commercial grade. Some uncertainties were indicated based on the typical agglomeration issues associated with carbon black. This study concluded;

- a. When tested with the sub-micron sodium chloride aerosol, the mini-pleat design shows increased loading capacity as the loading capacity is purely a function of the media area utilized in this case.
 - b. There is no clear advantage to the mini-pleat design when compared using the BS 2831 No. 2 test dust.
 - c. Testing with carbon black indicated that the deep pleat filters hold considerably more particles than the mini-pleat filters. This is likely the result of agglomeration of the carbon black resulting in a larger particle size and premature bridging of flow channels by aerosol particles deposited on the upstream side of the pleats.
2. A study represented by a series of papers authored by M. W. First, J. M. Price and S. N. Rudnick, was published from 1979 thru 1982, on loading with atmospheric dust[4,5,6] and compares atmospheric loading results of traditional 1700 m³/hr (1000-cfm) US design nuclear grade HEPA filters to 3060 m³/hr (1800-cfm) European “V”-Bed type filters. This study compared these filters when the European design was operated at both 3060 m³/hr and an under-rated flow of 1700 m³/hr. The 1700 m³/hr flow would provide a direct comparison to the 1700 m³/hr (1000CFM) US design. A comparison of loading with and without a pre-filter was also included. This study concluded that
- a. The European design filter, when operated at 1700 m³/hr, does not reach the projected theoretical increase in service life. Since this filter pack design has nearly twice the media area as the 1700 m³/hr US design, if operated at half its design flow rate, it should yield four times the service life of the US design. The service life was found to be only half of that predicted, or roughly 1.6 times that of the 1700 m³/hr (1000 CFM) US design.
 - b. The pre-filters utilized in the study did not appear to offer any substantial improvement in service life.

The plots in Fig. 3 from the last paper in the series show loading comparisons for three filter designs, tested at different times. It indicates a temporal variability in performance, which is likely the result of changing ambient atmospheric dust size distributions.

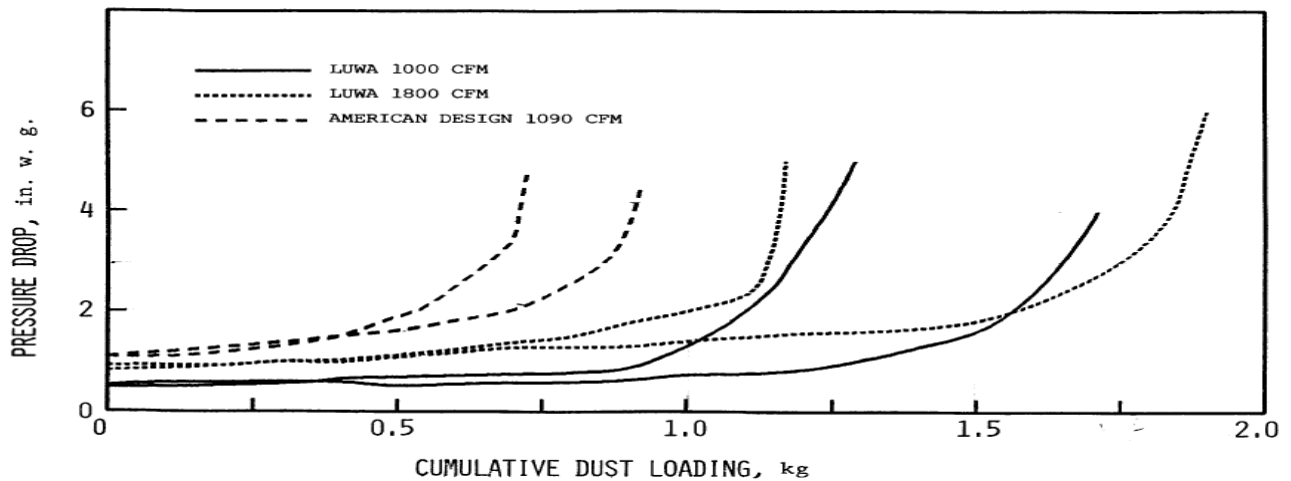


Fig. 3: Variability in Loading Data [6]

3. Another study by R.P. Pratt [7] published in 1981 deals with the loading characteristics of high capacity (“V”-bed, mini-pleat) HEPA filters. This study evaluated the dust loading of the mini-pleat filters using both ASHRAE and BS 2831 No. 2 test dusts at both the rated flow of 3400 m³/hr (2000 cfm) and at 1700 m³/hr (1000 cfm). As a baseline, conventional deep-pleat design filters were also loaded at 1700 m³/hr (1000 cfm) for comparison. The initial results of this study indicate that the high capacity filter could be used to the advantage of plant designers in one of two ways.
 - a. Since a significantly greater dust loading capacity can be attained by operating at half the rated flow capacity, the filters would last significantly longer in service, resulting in substantial savings in disposal costs.
 - b. The higher rated flow capacity could be utilized to reduce the size of a given filter installation. This would, however, also work to reduce the life of the filters.

4. A study that looked at the impact of varying media area on the dust holding capacity of deep pleat HEPA filters[8] was authored by J. Dymont and D. Loughborough in 1996. It evaluated the loading capacity of deep pleat HEPA filters constructed with different pleat counts to vary the total media area. Both carbon black and sodium chloride aerosol in the size range of 0.15-0.40 μm were utilized. The results indicated that
 - a. An optimal pleat count can be determined for the case of carbon black as the loading dust.
 - b. For the sodium chloride aerosol, the loading capacity continued to rise with increasing area, up to the maximum filter area tested.

These results are summarized in Fig. 4.

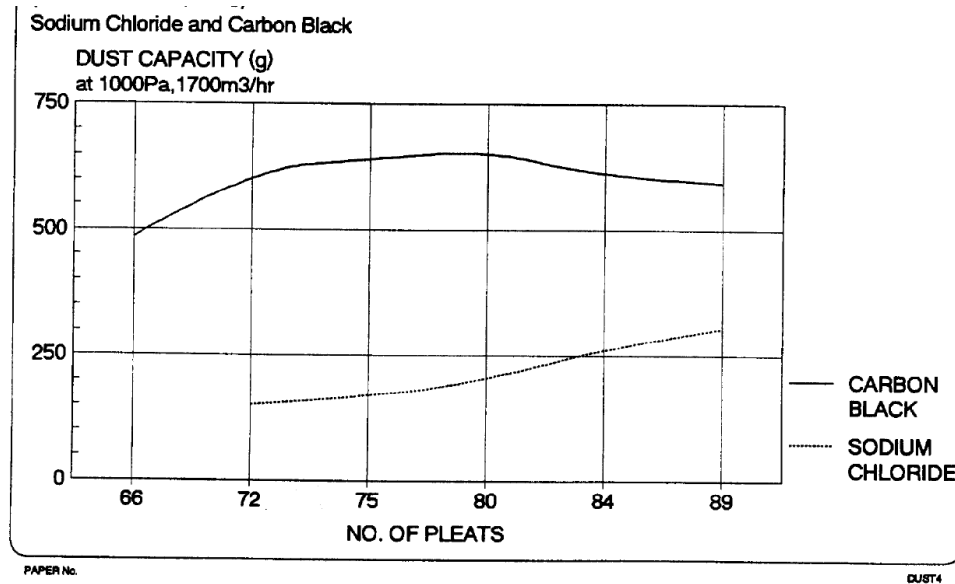


Fig. 4: Dust Capacity vs. No. of Pleats (Deep-Pleat Units) [8]

5. C.A. Gun and J.B. McDonough published a paper in 1981 that evaluated the atmospheric loading performance of various industrial grade HEPA filters[9]. It should be noted that not all filters tested were of nuclear grade. The study evaluated a “European style” ”V”-bed filter, a standard U.S. nuclear grade filter, a “Super-Pak” or deep mini-pleat design and a “Super-Flow” or deep-pleat separatorless pack using corrugated media. All filters were operated at a media velocity of 5 fpm to a final pressure drop of 747 Pa (3.0 inches w.g.). The results of this study are summarized in Table I.

Table I: Atmospheric Dust loading test results[9].

Filter Type	Flow (m ³ /hr)	Media Area (m ²)	Media Velocity (cm/s)	Dust Load (Grams)
Standard US	1835	20.1	2.54	1026
“Super-Pak”	2633	28.8	2.54	1140
“Super-Flow”	2124	23.2	2.54	840
European v-bed	3313	36.2	2.54	1500

The following observations were also documented based on visual examination of the loaded filters;

- a. The Standard US and Super-Pak appeared to be structurally sound.
- b. The Super-Flow showed pleat deformation with some sagging, nesting of filter folds, and sections of pleats adhering together. This resulted in the loss of effective media area and is the likely cause of it demonstrating the lowest dust holding capacity.
- c. The European “V”-bed showed pleat and panel deformations on the downstream side. The pleats and panels had ballooned out which would also cause a reduction in filter media area.

Some key observations made among all these studies, to be considered when developing a particle loading test as part of the qualification requirements for nuclear grade filters are;

1. For a submicron aerosol, the loading capacity is directly related to the available (effective) media area within the filter pack.
2. As the aerosol size increases, the advantages of a mini-pleat style filter begin to diminish at some point.
3. An optimal pleat count can be determined for deep pleat HEPA filters when loaded with aerosol particles that are greater than 1 μm in size.
4. “V”-bed style mini-pleat filters can have a significantly higher dust holding capacity than conventional 1700 m^3/hr (1000 CFM) HEPA filters, when operated at 1700 m^3/hr (1000 CFM- half the rated flow capacity).
5. Deep pleat separatorless packs (Type C pack style) tend to have less dust holding capacity than the other styles, due to premature pleat deformation, sagging and nesting of pleats.

SELECTION OF LOADING PARTICLES

The loading of nuclear-grade HEPA filters with smoke and soot is a major concern. The ability of the filter to maintain its integrity during such an event is of primary interest. A review of typical particle size ranges of smoke, as presented by G. W. Mulholland[10] , for burning plastics like PVC, polyurethane, polystyrene and polypropylene are in the range of 0.3 -1.6 μm , as measured optically. Additionally, as indicated by J.R. Gaskill, N.J. Alvares, D.G. Beason, and H.W. Ford, Jr.[13], the varying conditions and materials evaluated during multiple tests yielded particle sizes within the range of 50% greater than 1 μm , to 80% greater than 3 μm . With this in mind, an attempt was made to load the test filters with aerosol particles encompassing this range. Table II provides the aerosols/dust selected to load filters within this particle size range.

Table II: Loading Aerosol/Dust Characteristics.

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

- a. 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”.
- b. See appendix II & III for JIS Z8901 Class 11 certification and composition.
- c. Assumes aerosol generated during this testing is within the range measured by Air Techniques International.
- d. Assumes perfectly dispersed dust.

PAO TEST SET-UP AND MEASUREMENT METHOD

A manual leak (scanning) test system was utilized to load with PAO aerosols. This type of manual test system is typical of that utilized by manufacturers to leak-test small batch sizes, or odd configurations, along with the repair of mini-pleat clean-room filters. These systems typically include a blower, variable frequency drive (to control blower speed and thus airflow through the filter), flow measurement, aerosol injection, a plenum box, a means of clamping the filter to the plenum box and a particle-size or concentration measuring device. A simplified schematic of the test arrangement is included in Fig. 5.

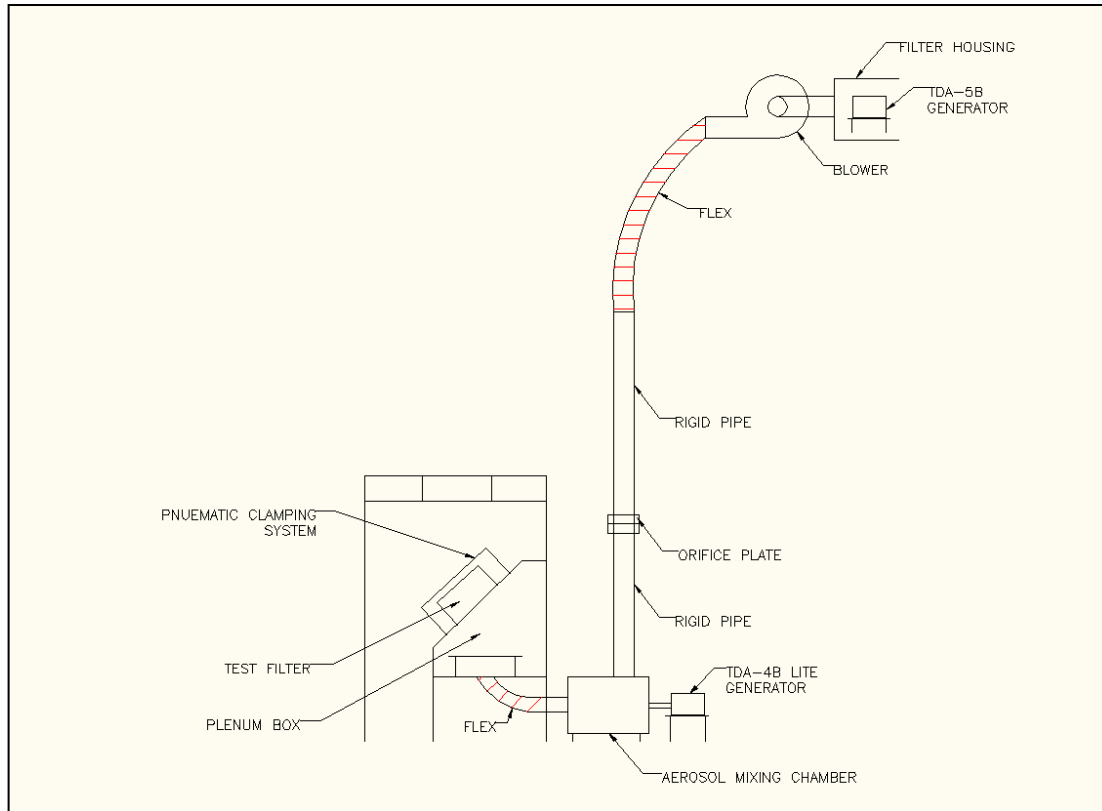


Fig. 5: PAO Test Arrangement

The intention was to particle load all filters to a final pressure drop of 1245-1495 Pa (5-6 inches w.g.). In this case, due to the limited capability of the pneumatic clamping system, a final pressure drop in the range of 747-996 Pa (3-4-in w.g.) was achieved. Pressure drops higher than this range resulted in filter bypass.

The procedure utilized during the two PAO particle loading tests consisted of maintaining a constant flow of 1156 m³/hr (680 ACFM), recording the average aerosol concentration per time period in µg/liter from an ATI Aerosol photometer model 2H, along with the filter pressure drop at the end of each time period.

JIS Z8901 CLASS 11 TEST SET-UP AND METHOD

A custom low-efficiency filter test duct utilized for both loading research and water spray exposure was utilized to load with the JIS Z8901 Class 11 test dust. This test duct is shorter than a typical ASHRAE 52.2 test duct. However, it has been found to yield stable and representative loading data. A simplified schematic of the test arrangement is included in Fig. 6.

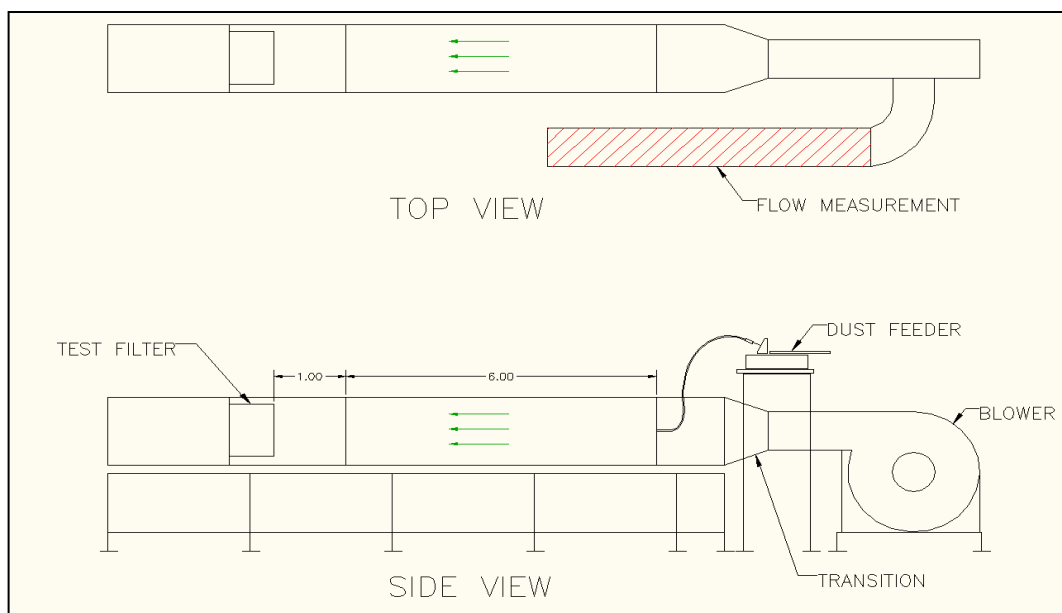


Fig. 6: JIS Z8901 Class 11 Test Arrangement.

The mechanical clamping system utilized on this system allowed all filters to be loaded to a final pressure drop of 1245-1495 Pa (5-6 inches w.g.).

The procedure utilized during the JIS Z8901 Class 11 loading tests consisted of maintaining a constant air flow of 1156 m³/hr (680 ACFM), feeding the test dust at a rate of 7.14 grams/minute in multiple 50 gram segments per loading increment and recording the filter pressure drop. The loading was divided into five equal pressure drop increase increments, based on the difference in the initial pressure drop and the target final pressure drop of 1469 Pa (5.9-in w.g.). An initial “conditioning” load of approximately 29 grams was also included.

TEST RESULTS

The data collected during the PAO aerosol tests were utilized to calculate the mass (in grams) of PAO particles loaded into the filter using;

$$ML = (C_A) \times (Q) \times (\Delta t) \times (1 \times 10^{-6}), \quad (\text{Eq. 1})$$

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.)

The term 1 x 10⁻⁶ is simply a conversion from µ-grams to grams.

No calculation of ML was required for the JIS Z8901 Class 11 dust, as the actual mass being injected was measured.

The Mass Loading values were then utilized to calculate the mass loading per unit area of available media surface for filtration. This was calculated using;

$$ML_A = ML/UA/(1 \times 10^{-6}), \quad (\text{Eq. 2})$$

where:

ML = Mass Loading (grams) and

UA = Useable media Area for filtering (cm²)

The term 1×10^{-6} is simply a conversion from grams to μ -grams.

The ML_A values were calculated, as they may provide insight into the effective utilization of the media surface for the different configurations

The raw data collected during both the thermal condensation and Laskin nozzle PAO aerosol loading tests and the JIS Z8901 Class 11 were first plotted using total mass loading versus filter pressure drop. The following observations were made;

1. The loading curves for half-high Size 5 filters are linear to the final pressure drops tested, for all loading particles
2. The loading curves for the half-high Size 7 filters are linear for both the JIS Z8901 Class 11 and the Laskin PAO aerosol. The curve for the thermal PAO aerosol is linear up to 622-747 Pa (2.5-3.0 inches w.g.), however there appears to be a slight increase in the slope of the loading curve above this point.
3. The loading curve for the half-high Size 8 filters is linear for the JIS Z8901 Class 11. The curves for both PAO aerosols are linear up to 622-747 Pa (2.5-3.0 inches w.g.), however there is an increase in the slope of the loading curve above this point.
4. The smaller the filter surface area, the steeper the loading curve slope, except for the JIS Z8901 Class 11 loading dust. In this case, the half-high size 7 and 8 filters had nearly the same loading curve slope.

The curves described above are depicted in Fig.'s 7-9.

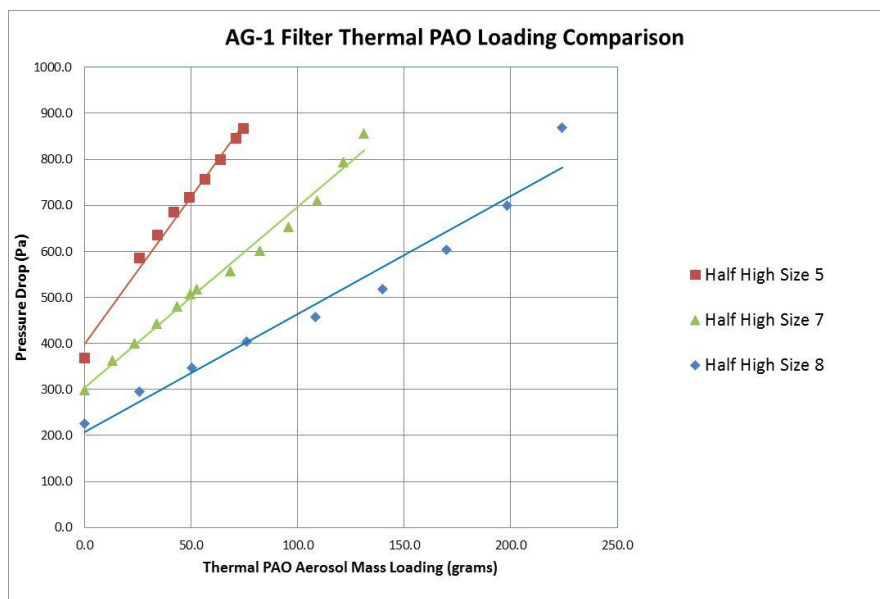


Fig. 7: Thermal PAO Loading Curves

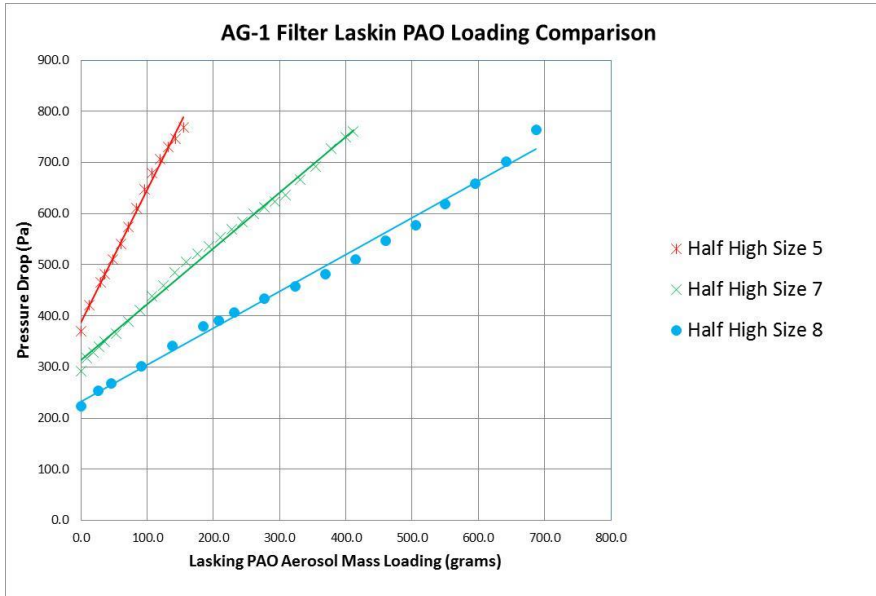


Fig. 8: Laskin PAO Loading Curves



Fig. 9: JIS Z8901 Class 11 Dust Loading Curves

These same data were also plotted for mass loading per unit area versus filter pressure drop. The following observations were made;

1. The loading curves for the Thermal PAO aerosol for all filters have nearly the same slope. This means that the filters are utilizing surface area at essentially the same effectiveness.
2. The Laskin PAO loading curves for the half-high Size 7 and 8 filters are of nearly the same slope, indicating that they are using surface area almost equally. The half-high Size 5 filter has a much steeper slope than the others, indicating that its smaller surface area is affecting its loading characteristics with the larger particle size.
3. The JIS Z8901 Class 11 dust loading curve for the half-high Size 8 filter has nearly the same slope as the half-high Size 5 filter and both are much steeper than that for the half-high Size 7 filter. The curve for the half-high Size 8 filter actually crosses that of the half-high Size 7 filter indicating that the media surface area of half-high Size 7 filter is being used more effectively when exposed to this larger particle size.

The curves based on mass loading per unit area are depicted in Fig.'s 10-12.

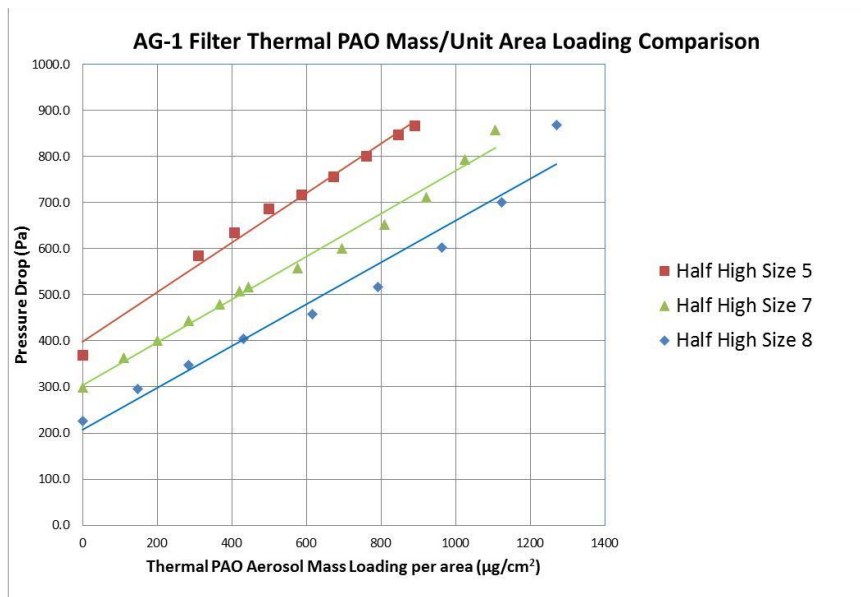


Fig. 10: Thermal PAO Mass/Unit Area Aerosol Loading Curves.

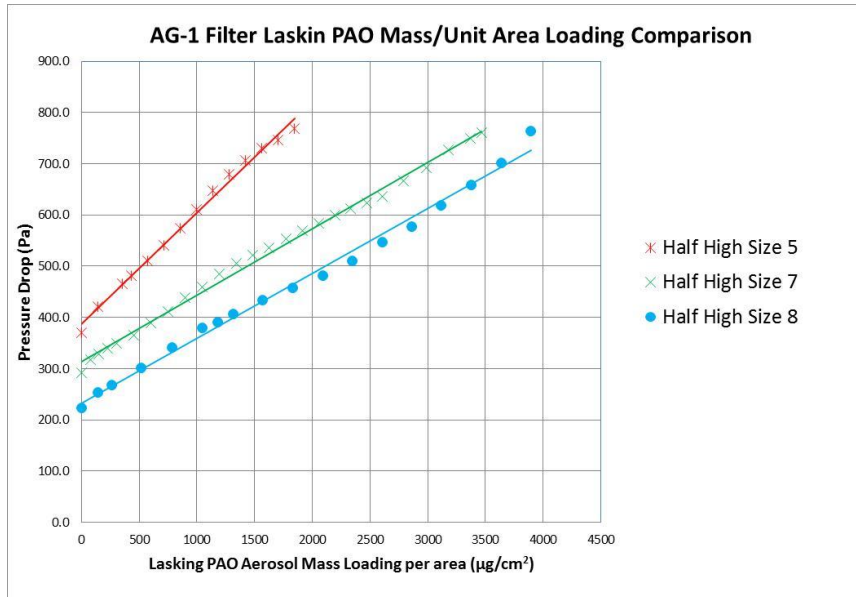


Fig. 11: Laskin PAO Mass/Unit Area Aerosol Loading Curves.



Fig. 12: JIS Z8901 Class 11 Mass/Unit Area Dust Loading Curves.

A linear regression was performed on the mass loading curves to determine the mass loading for each filter type and aerosol/dust at 747 Pa (3 inches w.g.). These data were plotted against the calculated, useable media area available for filtration. The following observations were made;

1. Both the thermal and Laskin PAO aerosol droplets exhibited linear loading characteristics relative to filter area. This is likely the result of more depth loading with these smaller liquid particles.

2. The JIS Z8901 Class 11 loading dust exhibited non-linear loading characteristics relative to filter area. This is likely the result of;
 - a. Surface loading having a larger impact as both media area and particle size increase. Increased area corresponds to a tighter pleat spacing that results in bridging of the upstream pleat channels by particle deposition.
 - b. With tighter pleat spacing, as the pressure drop increases, deformation of the media (swelling or “ballooning” of the pleats) can restrict airflow and possibly block surface area. This would cause the increase in pressure drop to accelerate with time and become over-proportional to the mass loading.

The curves resulting from this analysis are depicted in Fig. 13. Additionally, Fig. 14 shows the face loading characteristics that occurred during the JIS Z8901 Class 11 loading of the half-high Size 7 and Size 8 filters. A photograph of the half-high Size 5 filter was not included as it was identical in appearance to that of the half-high Size 7 filter.

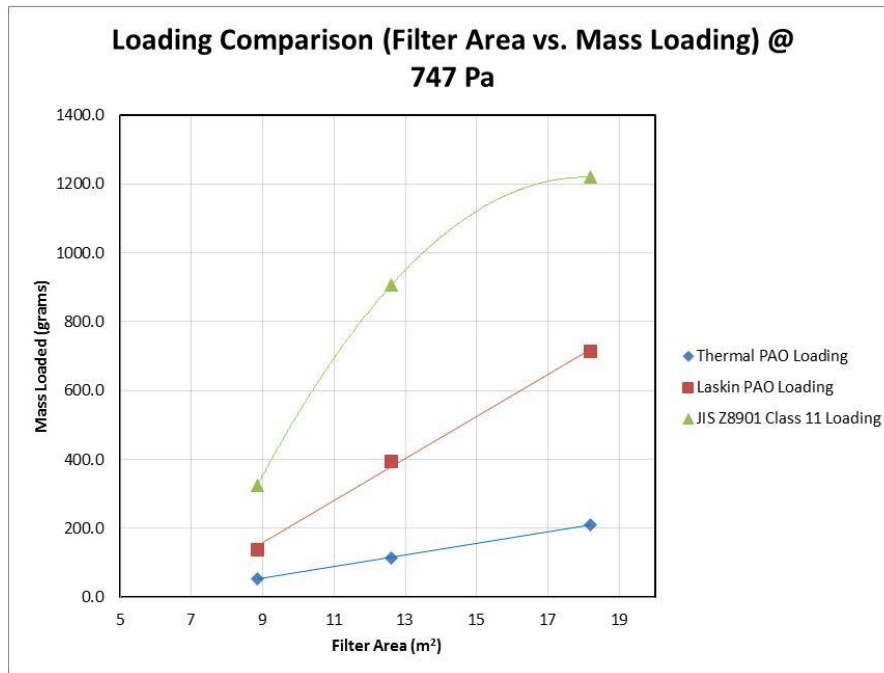


Fig. 13. Loading Comparison (Filter Area vs. Mass Loading) @ 747 Pa

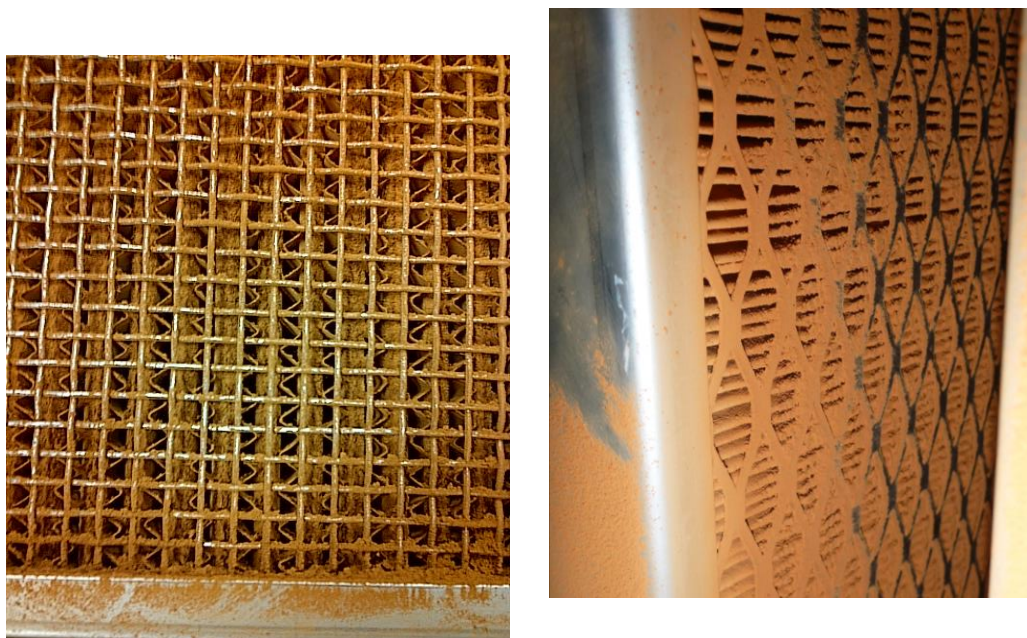


Figure 14: Photograph of half-high Size 7 and 8 filters after JIS Z8901 Class 1 dust loading.

A comparison of the mass loading to increase of media surface area for all aerosol particles relative to the half-high Size 5 filters was also performed. This comparison utilized the data from the previous analysis at 750 Pa (3-inches w.g.) but also included data calculated at 1370 Pa (5.5-inches w.g.) for the JIS Z8901 Class 11 dust. This analysis is summarized in Table III. It shows that the multiple of mass loading relative to the half-high Size 5 filters is consistently higher than the multiple of media area. It should also be noted that the mass loading multiple, for the half-high Size 8 filter, is lowest for the JIS Z8901 Class 11 dust at 1370 Pa (5.5-inches w.g.). This is likely the result of more surface loading, bridging of pleat channels by particle deposition, and the deformation of pleats due to the higher pressure drops that reduce available filtration surface area.

Table III: Comparison of area multiple to Loading multiple.

	Media Area (m ²)	Area Multiple	Loading to 747 Pa Calculated						Loading to 1370 Pa Calculated	
			Thermal PAO		Laskin PAO		JIS Z8901 Clas 11		JIS Z8901 Clas 11	
			Mass (g)	Loading Multiple	Mass (g)	Loading Multiple	Mass (g)	Loading Multiple	Mass (g)	Loading Multiple
Half High Size 5	8.84	1.0	54.6	1.0	139.2	1.0	324.3	1.0	824.3	1.0
Half High Size 7	12.62	1.4	113.0	2.1	395.7	2.8	907.9	2.8	2223.7	2.7
Half High Size 8	18.19	2.1	210.3	3.9	712.9	5.1	1219.6	3.8	2608.4	3.2

CONCLUSIONS

The test results reported here are mostly consistent with prior loading studies. It is clear, that though the loading capacities are not directly proportional to the media surface area; for all particle size distributions, the half-high Size 8 filter had the highest loading capacity for the aerosols particles and dusts used in this study. In general, the loading capacity was found to be nearly two times the area multiple of the baseline filter configuration. These results also support the discussion by Bergman[11] that the pressure drop in HEPA filter media increases at a greater rate when loading with smaller particles, as compared to larger particles.

The loading characteristics of AG-1 qualified filters using other pack types should also be considered. Specifically, based on the findings by Gun and McDonough[9] as well as Griffin, Parsons and Waggoner[2] for a prototypical separatorless radial-flow design, filters using deep-pleat AG-1 Section FC Type C packs should be evaluated for their loading characteristics. This would provide some insight into the possible need for developing a particle loading test, as part of the qualification requirements of ASME AG-1 for nuclear-grade filters. The determination of a loading aerosol particle or dust that is reasonably representative of that which would be present *in-situ* might then also become an issue for future consideration.

An interim solution to the implementation of a particle loading test, as suggested by Dr. Werner Bergman, is to set a minimum flow requirement to the resistance-to-pressure test which is currently part of the AG-1 qualification requirements. At present, this test does not have any flow requirement at all. If a filter pack type or construction is not stable under both wet conditions and elevated pressure drop, it is likely that this would result in a significant reduction in the flow required to maintain the current test requirement of 2490 Pa (10 inches w.g.). Implementation of this option would involve setting a minimum flow requirement; equal to some multiple of the filter's rated flow capacity, for example. If the airflow drops below this value during the resistance-to-pressure test, it would be an indication that the filter pack construction may be unstable under these conditions and thus represent cause for concern with respect to long-term filter reliability in service.

It may also be appropriate - if an actual particle loading capacity value is not adopted - to consider combining a particle preloading of the filter with a minimum flow requirement for the resistance-to-pressure test. Under this concept, filters would first be loaded with hygroscopic submicron-size particles to a pressure drop of 249 Pa (1-inch w.g.) and then be exposed to the water droplets of the resistance-to-pressure test under a to-be-determined minimum flow requirement. This option may be one for early evaluation, based upon results from a research team in Germany that sought to limit Δp increases of HEPA filters under fog conditions via enhanced drainage of intercepted water from the pleat surfaces [12]. It was found that particle loading of even small amounts of fine-dust appeared to counteract water drainage improvements observed for new, clean HEPA filters exposed to airstream laden with 2-10- μm dia. water droplets. This hybrid option could conceivably facilitate the resistance-to-pressure test being updated toward somewhat simulating the challenges that fatigued, dust-loaded filter packs might be exposed to in service under adverse operating conditions involving elevated temperatures and air humidities.

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TDA-4Blite (Type III-A Laskin Nozzle)

UNIT 1		5 PSI		10 PSI		20 PSI		30 PSI	
		MMD	Sigma G	MMD	Sigma G	MMD	Sigma G	MMD	Sigma G
1 Nozzle	Test 1	0.582	1.54	0.565	1.55	0.579	1.54	0.627	1.52
	Test 2	0.559	1.51	0.550	1.51	0.557	1.51	0.566	1.52
	Test 3	0.482	1.46	0.491	1.42	0.451	1.53	0.491	1.44
2 Nozzle	Test 1	0.586	1.55	0.484	1.58	0.585	1.54	0.594	1.55
	Test 2	0.560	1.52	0.545	1.53	0.561	1.52	0.539	1.51
	Test 3	0.482	1.46	0.483	1.44	0.491	1.42	0.491	1.43
3 Nozzle	Test 1	0.596	1.54	0.566	1.56	-	-	0.590	1.56
	Test 2	0.565	1.52	0.539	1.52	0.564	1.51	0.559	1.50
	Test 3	0.492	1.46	0.486	1.44	0.503	1.41	0.499	1.42

TDA-5B (Thermal Condensation Generator)

		10 mg/m3		50 mg/m3		100 mg/m3		200 mg/m3	
		MMD	Sigma G	MMD	Sigma G	MMD	Sigma G	MMD	Sigma G
Unit 1	Test 1	0.299	1.32	0.306	1.29	0.364	1.35	0.387	1.33
	Test 2	0.301	1.32	0.314	1.30	0.365	1.31	0.408	1.32
	Test 3	0.255	1.30	0.324	1.37	0.357	1.31	0.408	1.34

TDA-5B (Thermal Condensation Generator)

		Percentage of Full Output Capacity					
		25%		50%		100%	
		MMD	Sigma G	MMD	Sigma G	MMD	Sigma G
Unit 1	Test 1	.311	1.30	.306	1.29	.439	1.30
	Test 2	.312	1.31	.314	1.30	.372	1.30
	Test 3	.317	1.39	.324	1.37	.375	1.33

Appendix I

報告書番号 309318
Report No.
2011年3月31日

粒子径分布測定結果報告書
Particle Size Distribution Report

ホソカワミクロン株式会社
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測定者 Measured by	崔 靈 Cui Ling		検印 Approved by	
依頼先 Requested by	ホソカワミクロン株式会社 受託加工事業部 HOSOKAWA MICRON CORPORATION, Toll processing division			
試料名 Sample name	JIS 試験用粉体 I-11種 Lot No. P1111001 JIS test powders I, No.11 (社)日本粉体工業技術協会 The Association of Powder Process Industry & Engineering, Japan			

粒子密度 Particle density	測定法 Measurement method	ピクノメーター法 Pycnometer method	測定結果 Result	3.0 g/cm ³
	浸漬液 Immersion liquid	イソプロピルアルコール Isopropyl alcohol		

粒子径分布 Particle size distribution	測定法 Measurement method	沈降天秤法 Sedimentation balance method		
	分散液 Dispersion liquid	ヘキサメタリン酸ナトリウム水溶液 0.2 wt% Sodium hexametaphosphate water solution (0.2 wt%)		

粒子径分布測定結果
Particle size distribution result

粒子径 [μm] Particle size	8	6	4	2	1	
オーバーサイズ% (質量基準) % Over size (Mass base)	5.8	9.3	19.3	47.9	69.5	
備考 Remarks						

ホソカワミクロン株式会社 受託加工事業本部 2011年4月5日 後重幸 
HOSOKAWA MICRON CORPORATION, Toll processing division Shigeruki Ushiro

**JIS Z8901 Classes 7, 8 & 11
KANTO (JAPANESE) LOAM TEST DUSTS**

TYPICAL CHEMICAL ANALYSIS JIS Z8901 CLASS 7, 8 & 11			
<i>Chemical</i>	<i>% Of Weight</i>	<i>Chemical</i>	<i>% Of Weight</i>
SiO ₂	34.0 – 40.0	Fe ₂ O ₃	17.0 – 23.0
Al ₂ O ₃	26.0 – 32.0	CaO	0.0 – 3.0
MgO	3.0 – 7.0	TiO ₂	0.0 – 4.0

Appendix III