

RECENT IMPROVEMENTS IN THE 200 CFM HEPA FILTER

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ABSTRACT

Data from recent tests on filters having Lydall 3282, 4350, and 4450 media are shown and compared. Results for the 3282 media show the promise of additional dust capacity increases. In addition to changes in the media type and pleat geometry, electrical enhancement may dramatically increase filter efficiency and dust capacity without raising the pressure drop. A new project to investigate electrical enhancement of the filters is described and includes further refinements to filter test stand. To increase filter reliability and decrease cost, other changes are being proposed, including a corrosion-resistant liner material and a new “short-term” packaging design for filters used in Navy applications.

1. INTRODUCTION

The 200 cfm cylindrical HEPA filter in the M56A1 CBR filter set is a mainstay for shipboard, fixed-site, and temporary shelter collective protection systems. The last few years have seen dramatic improvements in performance and service life as a result of new media and improved pleat configurations. The dust capacity (and therefore service life) of the filter has more than doubled with the addition of glue bead separators in the pleat pack, a change from Lydall 3255 to Lydall 3242 media, and the use of bag prefilters in Navy installations and.

To more fully study HEPA filter performance a computerized test stand (built to SAE J726 specifications) that measures the dust capacity and efficiency of the 200 cfm filters was developed and is described in the paper. Data from recent tests on filters having Lydall 3282, 4350, and 4450 media¹ are shown and compared in Section 2. Improvements in the test stand to allow precise measurement of filter efficiency curves are reported in Section 3. A new project to investigate electrical enhancement of the

filters is described in Section 4. To increase filter reliability and decrease cost, other changes are being proposed, including a corrosion-resistant liner material² and a new “short-term” packaging design³ (described in Section 5) for filters used in Navy applications. In Section 6 we give conclusions based on the work described in this paper. Please note that, since this paper describes extensive development effort that has been described extensively elsewhere, significant content has been excerpted from other reports.^{1,2,3,4} While every effort has been made to properly cite those sources at some point in this paper, they are not cited in every case in order to avoid an excess of clutter.

2. DUST CAPACITY TESTS

This effort was focused on evaluating several new Lydall non-woven filter media for possible use in the 200 cfm HEPA filter. The goal was to see if Lydall 3282, 4350, and 4450 media can be used to increase the dust capacity relative to the current Lydall 3242 media. An increased dust capacity would indicate that the media should have a longer service life. This evaluation included the building of a dust load test stand conforming to SAE J726 and procuring prototype filters using the new media. The test stand was configured to deliver a known amount of dust at a constant rate to the test filter while measuring the pressure drop through the filter. Using data from this test the pressure drop vs. dust load curves for different filter media could be compared. New World used previously collected data as a benchmark in evaluating the accuracy of its test data.⁴

2.1 Description of Filter Media and Test Filters

Figure 1 shows a typical M56A1 HEPA filter. The characteristics of the five media tested for this effort are described in Table 1. The physical characteristics of the HEPA filters containing each media are described in Table 2 and Figure 2. Because the liner was not the same for each media type, one could expect some initial pressure drop variation due to the liner rather than the media. Based on measurements of other filters we believe that the difference in pressure drop between the two expanded metal liners is insignificant. The perforated metal liner used with the Lydall 3255 media may give a slightly higher initial pressure drop.



Figure 1. 200 cfm HEPA filter from M56A1 filter set.

Table 1. Typical Properties of Lydall HEPA Filter Media (Courtesy of Lydall, Inc.).

Characteristic	Grade 3242*	Grade 3255	Grade 3282**	Grade 4350	Grade 4450
Pressure Drop, mm @ 32 lpm/100 cm ²	33	35.7	28	26.5	29
DOP Penetration 0.3 Microns @ 32 lpm/100 cm ²	.015	.015	.045	.03	.017
Basis Weight, lb/3000 ft ²	48	53.9	42	48	48
Caliper, in.	.016	.016	.015	.016	.016
Tensile, MD, g/in.	>4,000	>3,000	>3,500	>3,000	>3,000
Tensile, CD, g/in.	>1,700	>1,800	>1,700	>1,500	>1,500

* Grade 3242 is the HEPA media used in the current filter

** Grade 3282 subsequently renamed to grade 3333 by Lydall, Inc.

Table 2. Summary of HEPA filter configurations.

Filtration Medium	Manufacturer	Pleat Density	Media Area*	Pleat Separator	Liner Type
Lydall 3255 with backing	Hunter Manufacturing	6 per inch	55 ft ²	none	perforated metal
Lydall 3242	Hunter Protective	9 per inch	82 ft ²	glue bead	expanded metal
Lydall 3282	Airguard Industries	7 ³ / ₄ per inch	71 ft ²	glue bead	expanded metal
Lydall 4350	Airguard Industries	7 ³ / ₄ per inch	71 ft ²	glue bead	expanded metal
Lydall 4450	Airguard Industries	7 ³ / ₄ per inch	71 ft ²	glue bead	expanded metal

* Based on nominal pleat dimension of 1.85 in. x 9.00 in. and pleat density shown.



Figure 2. Liner configurations: a) is a perforated metal liner with 0.25” holes and was used only on the filters with Lydall 3255; b) is an expanded metal liner with 0.26” by 0.50” openings and was used for filters with the Lydall 3242 media; c) is an expanded metal liner with 0.47” by 0.80” openings and was used for filters with the Lydall 3282, 4350, and 4450 media.

2.2 Description of Dust-Loading Test Stand

The test stand developed to evaluate the dust capacity of the filters is shown in Figure 3 and Figure 4. A primary focus during development of the teststand was to deliver a uniform dust cake to the test filter. The first attempts saw tremendous clumps and piling of dust on the filter, which in our opinion indicated that the dust was not being separated into fine enough particles after being dropped from the feeder. After experimenting with different techniques to de-agglomerate the dust, we settled on a mesh screen placed across the pipe leading to the test filter. As is shown in Figure 5, this solved the problems with uneven dust delivery.



Figure 3. Filter efficiency and dust capacity test stand.

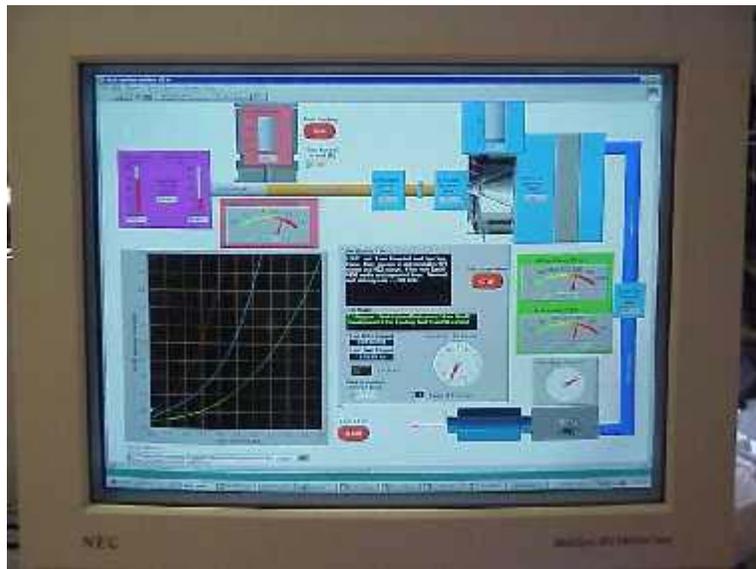


Figure 4. Labview panel / user interface.



Figure 5. Uniformly applied dust after dust.

2.2 Dust Capacity Results

Results of dust capacity tests on the filter configurations are shown in Figure 6, Figure 7, and Figure 8. Note that not all media were tested at all conditions. The results show that for all test conditions the filters using the Lydall 3282 media outperformed the filters with the current media (Lydall 3242), the original media (Lydall 3255) and the two additional media selected for evaluation (Lydall 4350 and 4450). While the results for the Lydall 3282 media are encouraging, initial efficiency tests show the filters with this media to be somewhat below HEPA quality (estimated efficiency is 99.92% to 99.96% at 0.3 microns compared to the required 99.97%). Changes in the pleat configuration used for the filters with the Lydall 3282 media may result in increased efficiency.

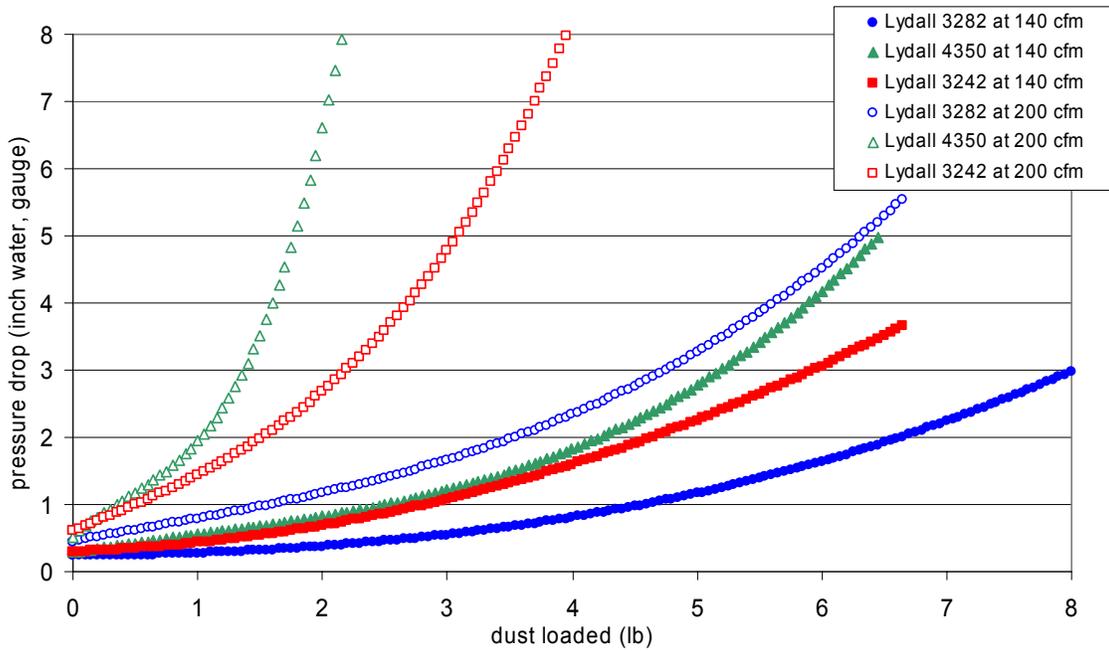


Figure 6. Dust load performance (measured at New World) 140 cfm and 200 cfm.

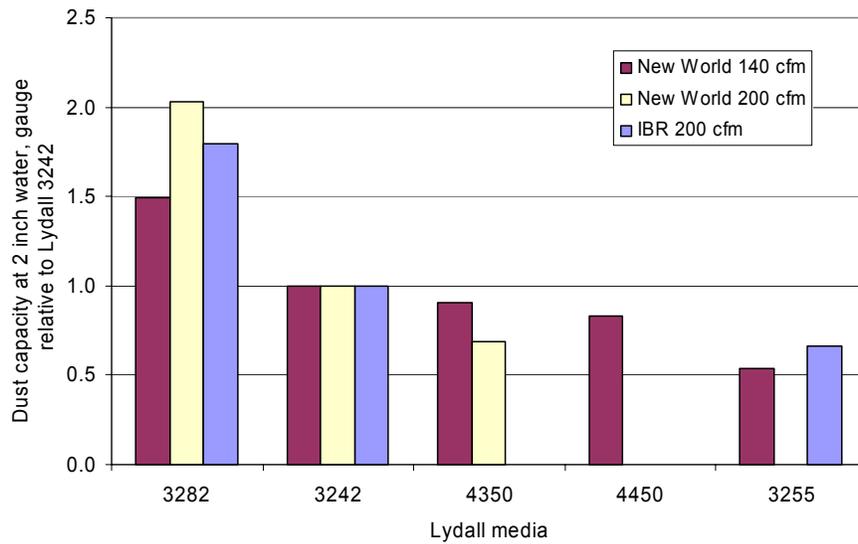


Figure 7. Dust capacity at 2 inches of water, gauge normalized by the capacity of the Lydall 3242 media used in current M56A1 HEPA filters.

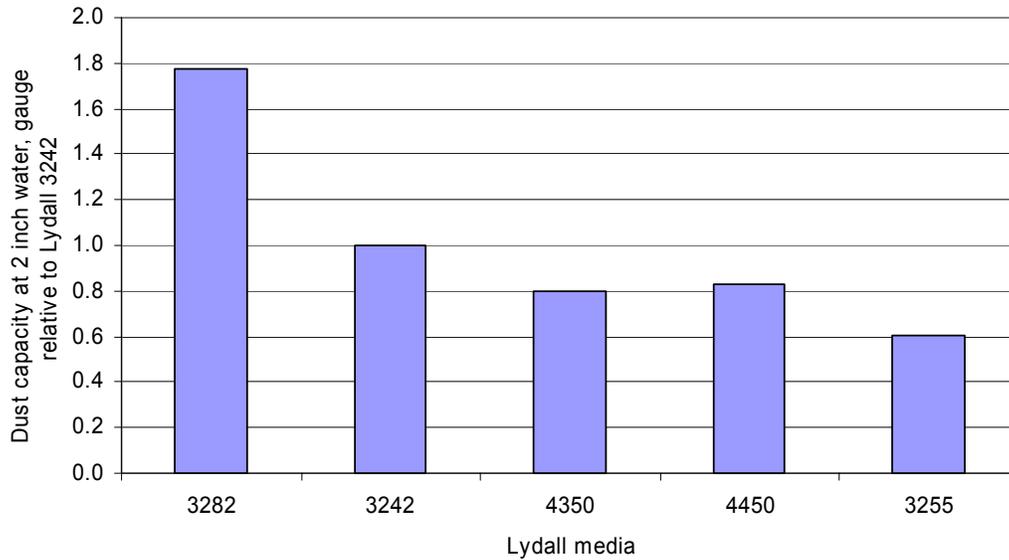


Figure 8. Relative dust capacity of media based on average of New World (140 cfm and 200 cfm) and IBR data.

3. EFFICIENCY TESTING

Since the dust capacity tests described in the previous section were completed, the test stand shown in Figure 3 has been modified to allow efficiency tests over the range of 0.1 to 10 micron (nominal) particle sizes. The test stand uses Particle Measuring Systems' Lasair 101 (0.1 to 2.0 microns) and Lasair 510 (0.5 to 10.0 microns) laser particle counters to measure filter penetration such as that shown in Figure 9 for the M56A1 HEPA filter. From the penetration curves the efficiency is calculated as shown in Figure 10. The instrumentation system has been developed to allow testing over an extremely wide efficiency range, including HEPA filters as shown in Figure 10 and much lower efficiency filters such as the bag prefilter (see Figure 12) tested for Figure 11.

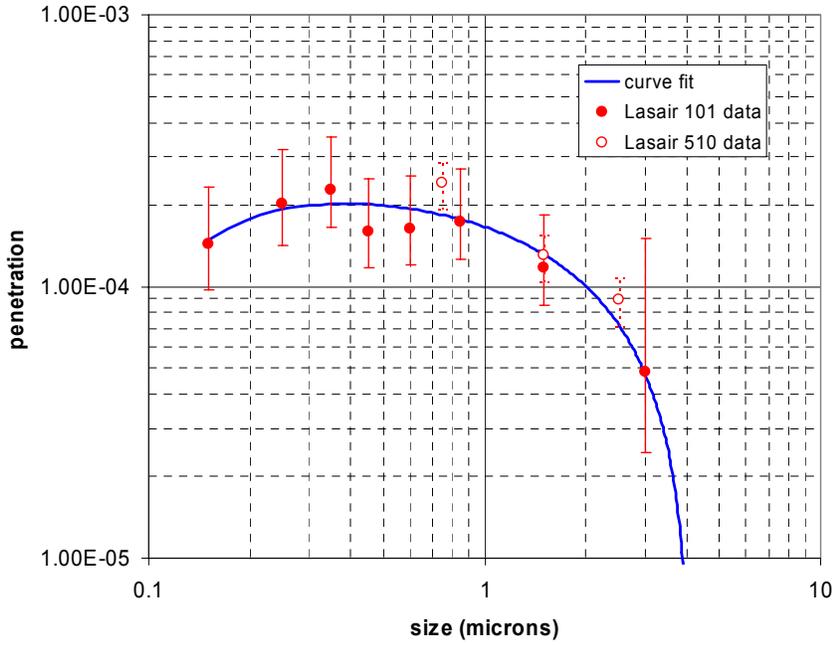


Figure 9. Particle penetration for 200 cfm cylindrical HEPA filter using Lydall 3242 media.

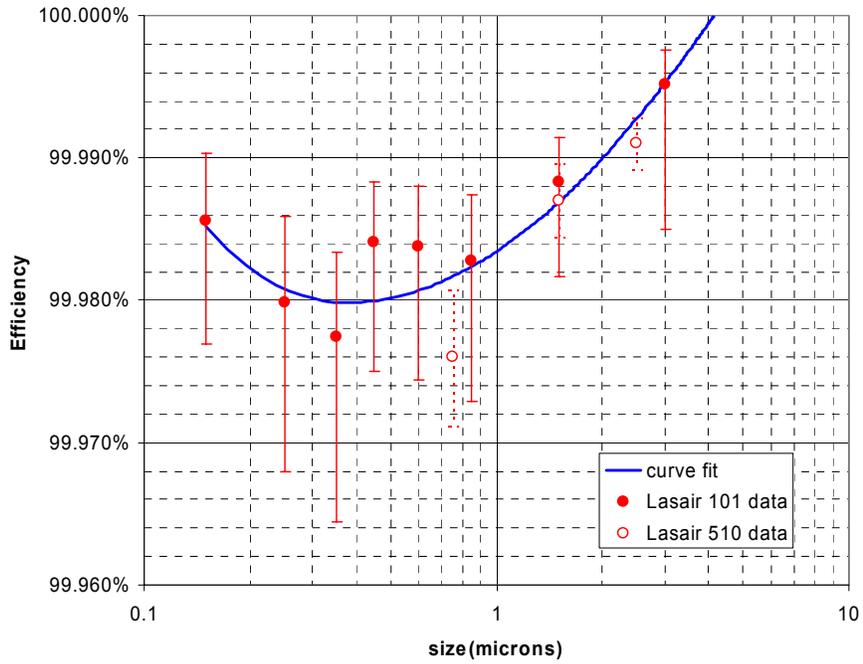


Figure 10. Filtration efficiency of 200 cfm cylindrical HEPA filter.

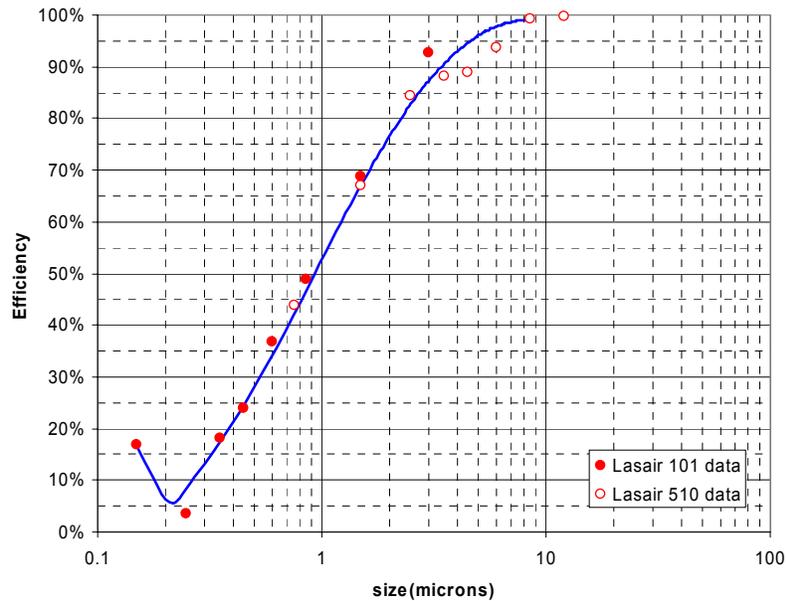


Figure 11. Filtration efficiency of US Navy-style bag prefilter for M56A1 filter set.



Figure 12. Bag prefilter used with M56A1 filter set in US Navy applications.

4. ELECTRICALLY-ENHANCED FOLTER MEDIA

The upgrades to the test stand to allow filter efficiency testing (described in the previous section) were made to allow evaluation of electrically-enhanced filter media (see Figure 13). This type of filter uses either unpleated or pleated fibrous media placed in an electric field of up to 10 kV/cm to polarize the media fibers and enhance filtration efficiency.⁷ Electrically-enhanced fibrous filter media offer the opportunity to:

- Enhance non-HEPA-grade filter media to HEPA-like efficiency while increasing dust-load capacity and maintaining low pressure drop.

- Enhance HEPA-grade filter media to ULPA-grade efficiency without increasing pressure drop or reducing dust load capacity.

Technologies use fibrous filter media combined with two or three electrodes. The electric field continuously charges the media, creating an “electret-like” effect to enhance capture efficiency. This type of media can use relatively low voltage (7 to 9 kV) that does not create ionized particles or ozone.

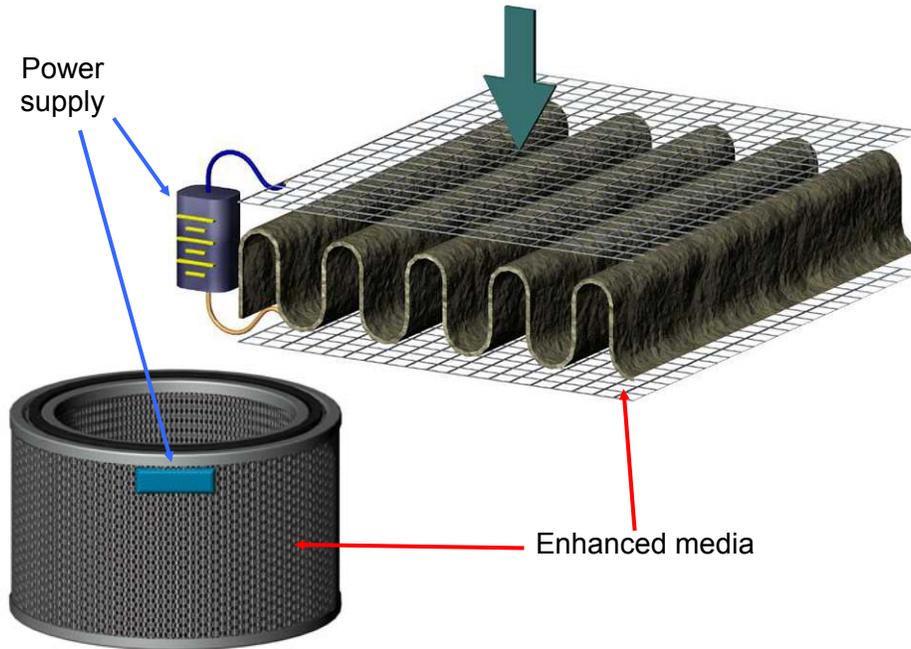


Figure 13. Electrically-enhanced filter.

The increase in efficiency due to the application of an external electric field has been known for many years. A simple model for the penetration for charge-neutral particles is given by Brown⁵

$$\begin{aligned}
 \text{Penetration} &= \exp^{- (\gamma * t)} \\
 \gamma &= (4\alpha * E_{\text{TOTAL}}) / (\pi * d_f) \\
 E_{\text{TOTAL}} &= 1 - [(1 - E_{\text{interception}}) * (1 - E_{\text{impaction}}) * \\
 &\quad (1 - E_{\text{diffusion}}) * (1 - E_{\text{interaction}}) * \\
 &\quad (1 - E_{\text{gravity}}) * (1 - E_{\text{electrostatic}})]
 \end{aligned}$$

where

- d_p = particle diameter, m
- d_f = fiber diameter, m
- α = packing fraction (= 1-porosity)
- U_o = face velocity of filter, m/s
- G = $(\rho_g d_p^2 C_c g) / (18 \eta U_o)$
- D_p = dielectric constant of the particle
- D_f = dielectric constant of the filter media
- E = strength of electrostatic field, V/m
- ϵ_o = permittivity in free space
- η = coefficient of dynamic viscosity
- t = filter thickness, m

and

$$E_{\text{electrostatic}} = 1/3 (D_p-1)/(D_p+2) * (D_f-1)/(D_f+1) * (d_p^2 \epsilon_o E^2) / (U \eta d_f)$$

In addition to the theoretical model given by Brown, Bergman *et al.* developed both theoretical descriptions of the effect and measured the performance increases.⁷ Figure 14 shows the improvement in capture efficiency from for a clean filter. Figure 15 shows that, not only is the initial capture efficiency of the filter increased, but that the efficiency improvement is maintained as the filter is loaded with particles, and that the electrically-enhanced filter can hold more than double the quantity of contaminant when compared to the uncharged filter. Note that the ability to maintain the capture efficiency for the electrically-enhanced filter is much different that the behavior of filters with permanently charged fibers (e.g. electret fibers), where the efficiency enhancement is short-lived.⁶

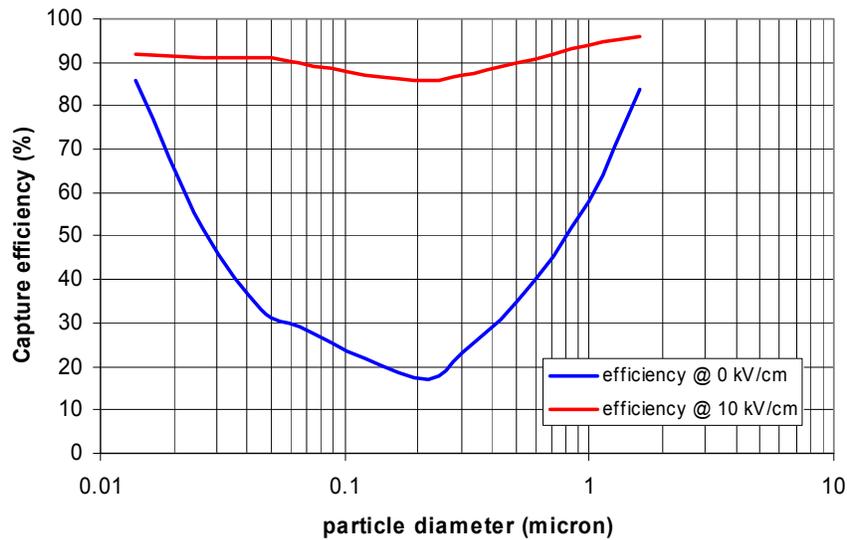


Figure 14. Electrical enhancement efficiency improvement measured at LLNL.⁷

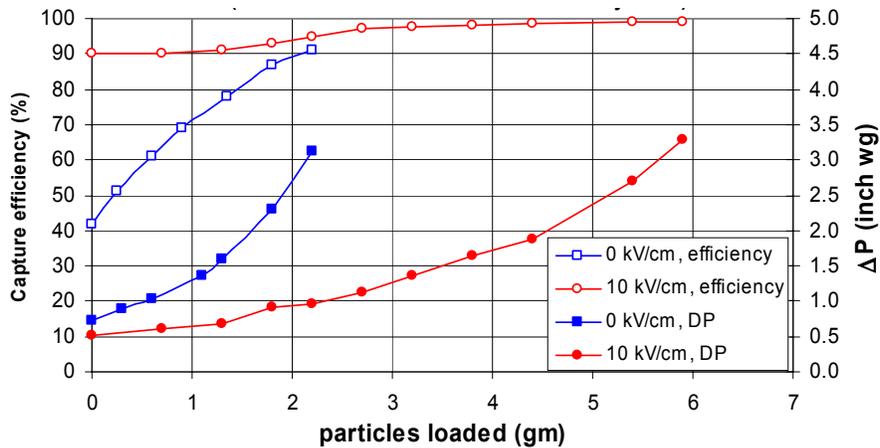


Figure 15. Electrical enhancement dust capacity improvement measured at LLNL.⁷

The ultimate goal of the electrically-enhanced filter media study described in this section is to evaluate the technology for both low efficiency filters (such as described above) and for HEPA filters. Currently HEPA filters using a number of different media and electrode configurations are being fabricated. The expected physical characteristics are shown in Table 3.

Table 3.

Expected characteristics of 200 CFM filter w/ electrically enhanced media	
power consumption	< 1 watt (0.07 mA @ 9 kV)
size/form factor	identical to current M56A1 200 CFM CPS filter
ozone production	none
sensitivity to humidity	TBD

Evaluations of a low-efficiency filter using unpleated one-inch-thick fiberglass media similar to that found in a typical home furnace filter have been performed at New World. This electrically-enhanced filter was tested

- with and without 5 kV/cm electric field,
- at a face velocity of 85 ft/min, which is the same as that for the bag prefilter described in the previous section of this report,
- at a face velocity of 253 ft/min,
- with and without charge(electrical)-neutralized particles (Arizona Road Dust).

The experimental results shown in Figure 16 through Figure 18 show the efficiency changes for various experimental conditions. The experiments show that

- the efficiency improvement due to electrical enhancement decreases with face velocity, consistent with the equation shown earlier in this section, and
- the efficiency improvement due to electrical enhancement is more significant with charged particles challenging the filter.

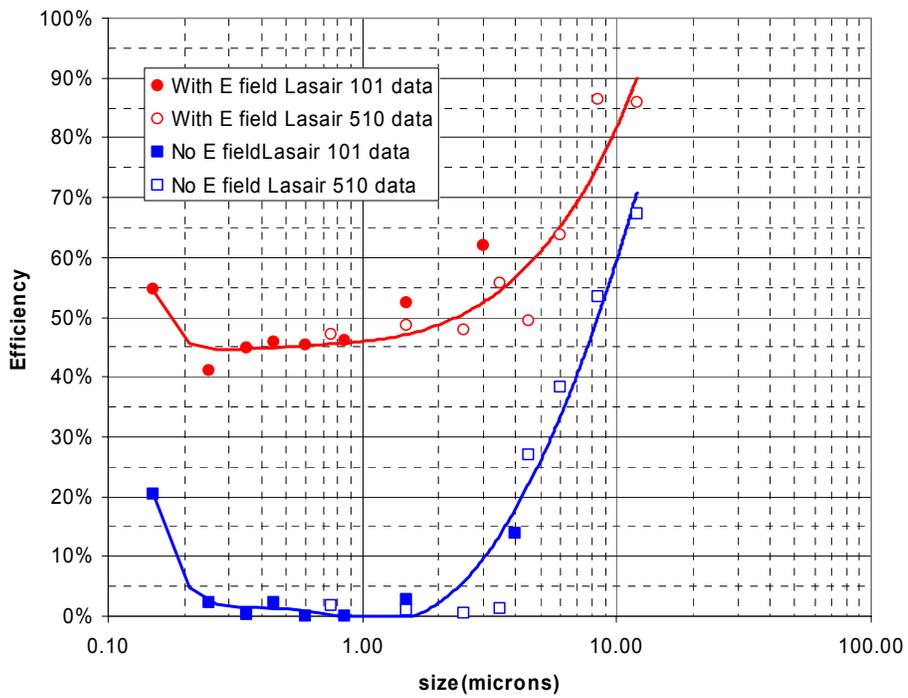


Figure 16. Measured performance enhancement of flat panel filter with electrical enhancement. Face velocity was 0.43 m/s (85 ft/min). Particles were not charge-neutralized.

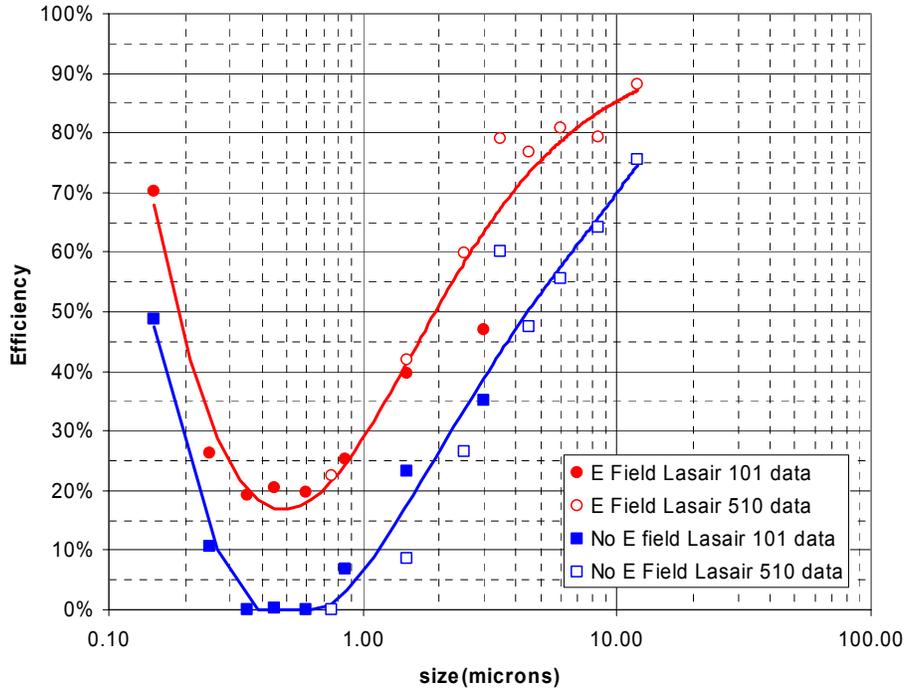


Figure 17. Measured performance enhancement of flat panel filter with electrical enhancement. Face velocity was 1.32 m/s (253 ft/min). Particles were not charge neutralized.

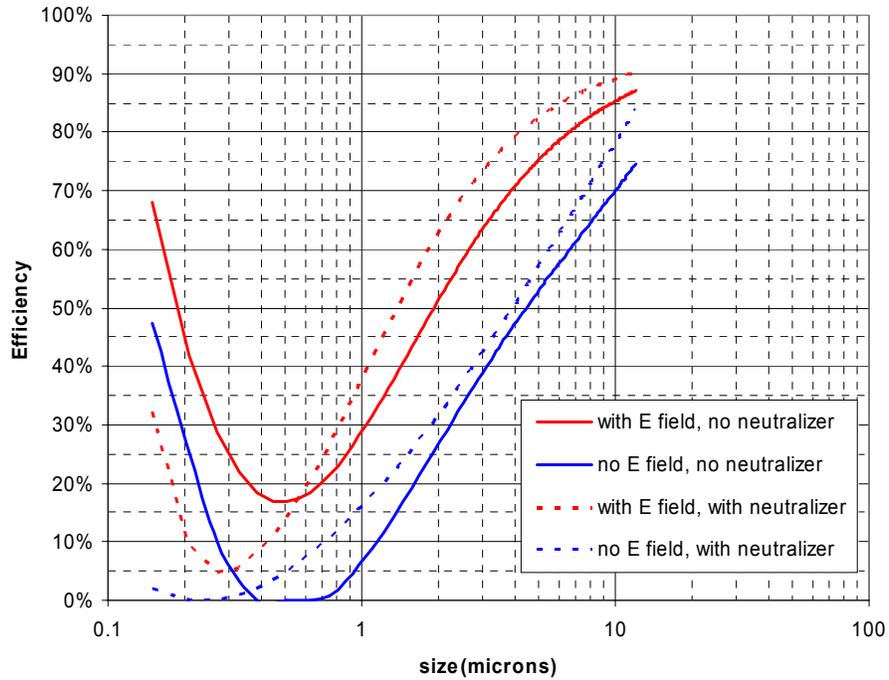


Figure 18. Flat panel filter efficiency with and without electrical enhancement, and with and without charge-neutralized challenge particles.

Figure 19 shows a comparison between the capture efficiency of the bag prefilter described in the previous section and the flat panel filter. Note the difference in the pressure drop for each filter. Note that the capture efficiency of the panel filter would drop somewhat if it were challenged with charge-neutralized particles (as was the case for the bag prefilter measurement). Even so, multiple layers of the electrically enhance media could be used to increase efficiency while still maintaining a significantly lower pressure drop than the bag prefilter media.

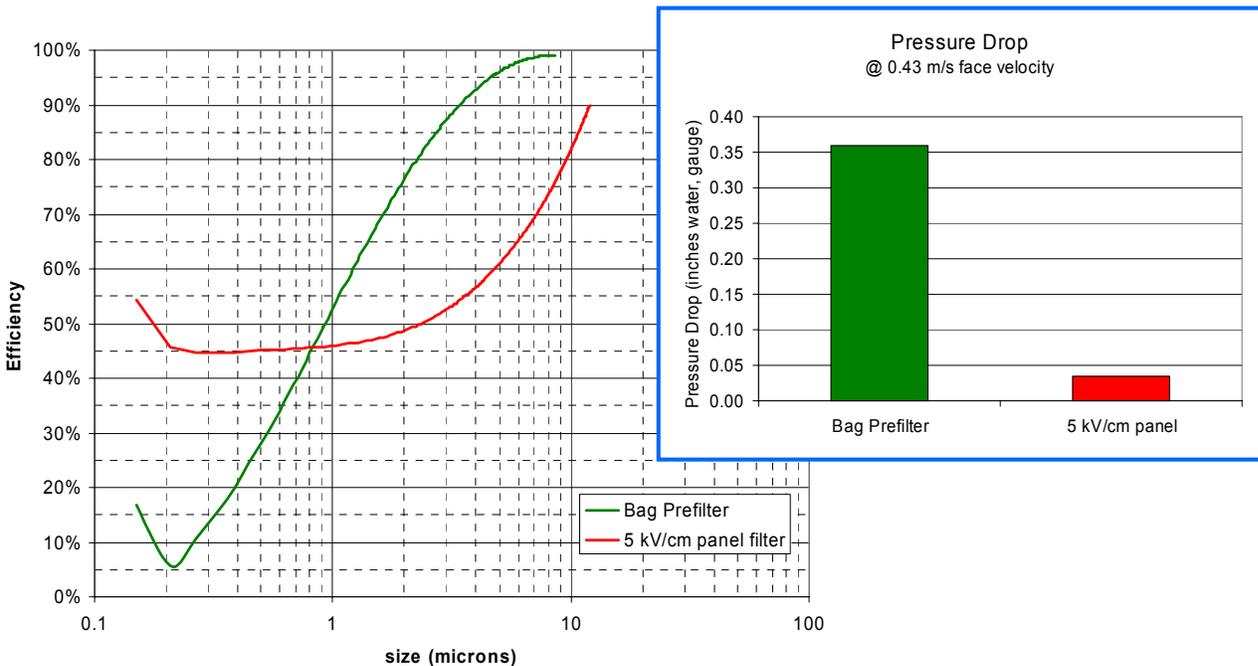


Figure 19. Comparison of bag prefilter efficiency and pressure drop with electrically-enhanced flat panel filter efficiency and pressure drop. Note that particles were charge-neutralized for the test of the flat panel but were not for the bag prefilter.

The next steps in the electrically-enhanced filter media evaluation are to

- Test electrically enhanced HEPA filters.
- Test dust capacity for low- and high-efficiency electrically-enhanced filters to confirm previous results.⁷
- Test effects of humidity, salt spray, etc. (note that some evaluations have been made that show minimal effects⁷ due to salt and humidity but these need to be verified).
- Design practical filters that can be used in military environments.

5. M56A1 FILTER SET PACKAGING

In order to reduce procurement costs, a new low-cost package for the M56A1 filter set was developed that can be used for filters that will be stored for a relatively short time.³ Figure 20 shows the current aluminum can package and Figure 21 shows the newly developed Mylar bag/cardboard box packaging configuration. It is estimated that the new package results in cost savings of \$60 and weight savings in excess of 10 lbs compared to the aluminum can. Figure 22 through Figure 26 show rough-handling performance tests passed by the new filter package.

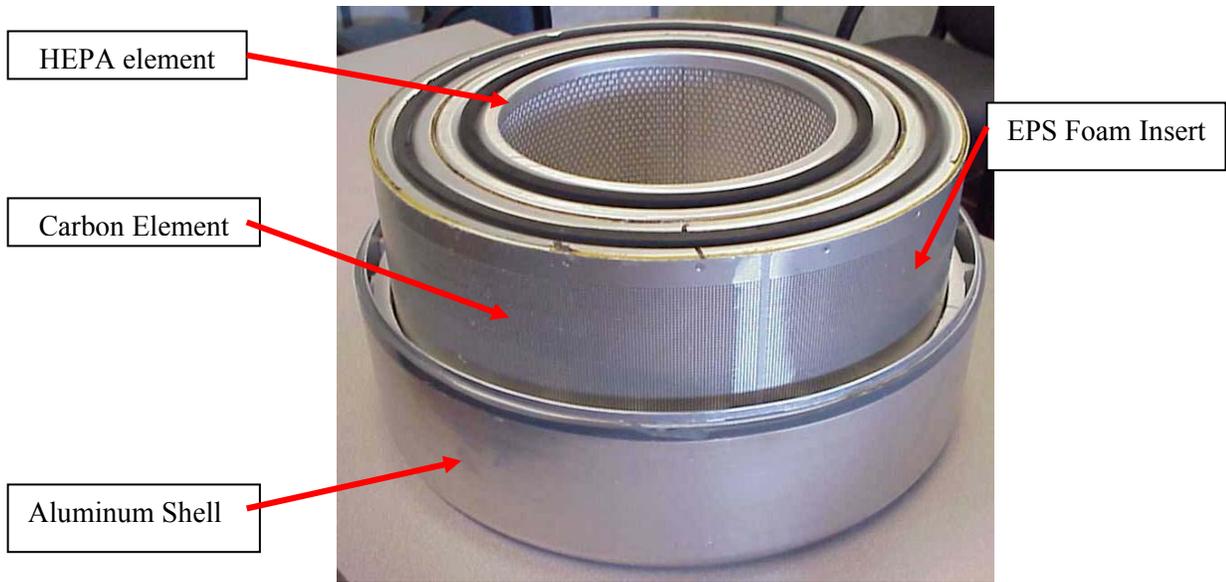


Figure 20. Exploded view of the current filter packaging

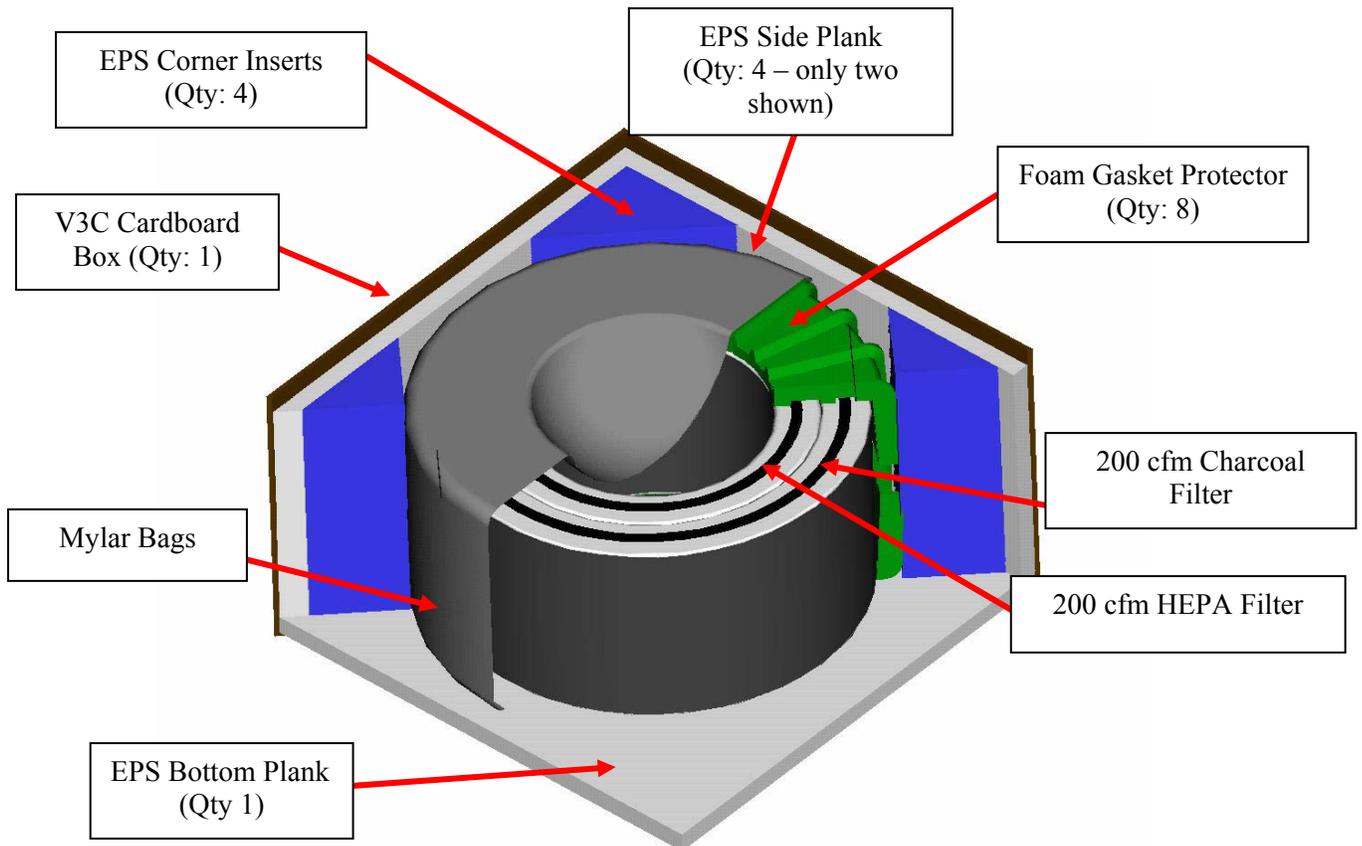


Figure 21. Cut away of revised package with 1- inch foam EPS side planks. Note: Top EPS plank not shown for clarity.



Figure 22. Close-up of packaging after testing.



Figure 23. Figure 22: Close-up of immersed filter set.

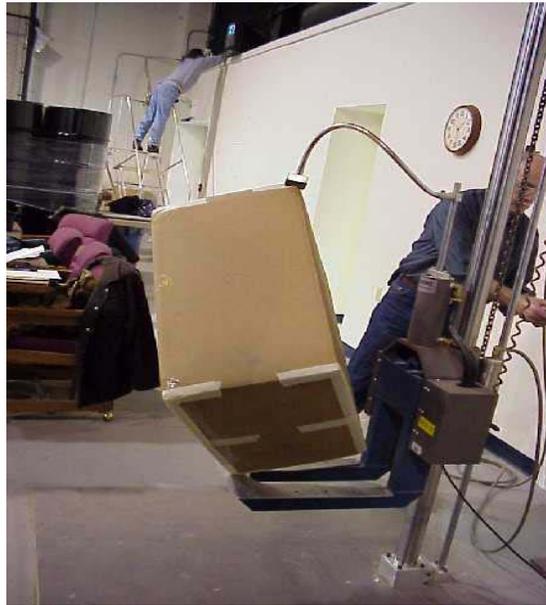


Figure 24. Manual handling sequence (corner drop).



Figure 25. Sequence 1 Climate hazard (Conditioning).



Figure 26. Manual handling sequence (face drop).

CONCLUSIONS

Dust capacity tests have been performed on several alternate media for the HEPA filter in the M56A1 filter set. Lydall 3282 media shows promising dust capacity (better than twice the current Lydall 3242 media), but the efficiency of the Lydall 3282 will need to be improved to meet requirements.

An aerosol penetration testing capability has been developed and will allow detailed efficiency evaluations of new filter media, including electrically-enhanced media. Measurements taken to date for

electrically-enhanced media confirm previous results reported in the literature.^{5,6,7} Conclusions on electrically-enhanced filter media based on results to date are as follows:

- The electrical enhancement effect exists and offers significant performance improvements.
- Electrical enhancement is inversely proportional to face velocity and is probably more appropriate for low face velocity filters such as the M56A1 HEPA than for 2' by 2' commercial filters rated at 2000 cfm.
- The best application of electrically-enhanced media is probably in combination with other technologies. Examples include
 - application to either 200 cfm HEPA or bag prefilter to increase system efficiency from current 99.97% to 99.997% with increased service life and no increase in pressure drop, and
 - application to low base-efficiency filter (90%) electrically enhanced to 99% efficiency plus UV with 99% kill rate. This would give a low-pressure-drop 99.99% efficient system that could be used for HVAC recirculation loops.

Finally, a new low-cost, lightweight package for the M56A1 filter set has been developed. This package is appropriate for short-term storage of the filter sets.

ACKNOWLEDGMENTS

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