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The Condition of High Containment Laboratory HEPA Filters After 13 Years of Service

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Abstract

An assessment was made of the physical state of a high containment laboratory's current HEPA filter population that is approximately 13 years old. Quantitative analyses measured the tensile strength, strain, and organic content characteristics of the filter medium of representative filters. Qualitative analysis was performed on other HEPA filter components.

Both unused stored filters and filters with 13 years of continuous service have lost 40%-45% of their tensile strength with age. Average tensile strength characteristics still exceed the relevant military standard by a factor of 1.8. The strain characteristics of all filters tested exceed the minimum criterion specified in the relevant military standard. Loss of organic content was not identified as an issue, with only one filter exhibiting significant reduction in organic content. Apart from qualitative analysis confirming that neoprene filter face seals degrade with age, no other significant problems were identified.

Introduction

HEPA filters form a primary biocontainment function in a high containment laboratory's microbiological containment regime. Typically, they are fitted to all air handling systems associated with microbiologically secure areas and are used to prevent the escape of infectious aerosols. The vast majority of HEPA filters, both in use and stored, were manufactured during 1983-1984, and most of the filters in service were installed soon after manufacture.

Operating procedures require regular integrity testing of all HEPA filters in service to provide assurance of the facility's ability to contain disease organisms. At the time of installation, the operational life of the HEPA filters was unknown and to date few filters have failed in service (Abraham et al., 1999). However, First (1996) suggests the medium used in HEPA filters loses mechanical strength with age and may suddenly fail without prior warning when subject to pressure pulses induced by fan starting or severe atmospheric wind activity. Other researchers (Bergman et al., 1994; Johnson et al., 1988; Robinson et al., 1985) confirm the loss of medium tensile strength with age.

To assess the physical state of the high containment facility's current HEPA filter population, an analysis of the condition and medium mechanical properties of several unused and used filters was performed.

History of HEPA Filters in Service

Routine integrity testing has found few filters with medium leaks during the past 14 years of service (Abraham et al., 1999). Most problems have occurred with leaks past face sealing gaskets and filters blocking due to dust loading. Relatively few of approximately 1,000 HEPA filters in service have been replaced, and the facility still has a stock of approximately 120 unused filters.

Routine integrity analyses do not address the aging issues (First, 1996) apart from identifying face seal gasket faults, which are a result of the gasket becoming hard and brittle with age. However, any abnormal condition noted when performing routine analysis tasks is reported.

All HEPA filters, whether in service or stored, are exposed continuously to an air-conditioned environment. Typically, filters have been exposed to air maintained at 22°C and variable relative humidity up to 60%.

Exposure to chemicals, apart from formaldehyde and ammonia (for decontamination purposes), is not usual.

Methodology

Eight filters comprised the random sample selected for analysis. Four of these had provided 9 to 13 years of continuous service; the rest had been stored for 13 years. Two Australian manufacturers, e-mail (now AES Environmental, Sydney, New South Wales, Australia) and Gelman (now Clyde Apac, Adelaide, South Australia, Australia), supplied the HEPA filters. The paper manufacturers Flanders Filters Inc. (Washington, North Carolina, USA) and Lydall Inc. (Rochester, New Hampshire, USA) supplied the HEPA media used by e-mail and Gelman, respectively. Table 1 lists the details of each filter that was analyzed. Several medium samples were obtained from each filter and listed with different sample numbers. This was done to separate machine-direction samples from cross-direction samples. The machine direction of the medium is along its longitudinal length; the cross direction is at 90° to the machine direction.

The large (610 x 610 x 292 mm) filters were sampled in the middle of the medium pack and half way between the middle and pack side. An asterisk (*) is used to identify samples taken from the side region of a large medium pack. The small (304 x 304 x 149 mm) filters could be sampled only in the middle of the pack.

The methodology used consisted of physically examining all filter components for condition, followed by removal of the medium pack for further testing. Testing of the medium was done according to the procedures documented in the following standards:

- MIL-F-51079D (1985), "Filter Medium, Fire-Resistant, High-Efficiency"
- TAPPI - T 402 om-93, "Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products"
- TAPPI - T 494 om-88, "Tensile breaking properties of paper and paperboard (using constant rate of elongation apparatus)"

The goal was to determine the tensile stress and strain of the medium samples in the machine and cross directions. Samples were prepared by conditioning the media at 22°C and 50% relative humidity for 24 hours prior to cutting the samples into 25 mm x 150 mm strips. Tensile stress and strain trials were performed on an Instron Corporation (Canton, Massachusetts, USA) tensile test machine (model 1185). To achieve a statistically relevant result per sample group, a minimum of five successful trials was performed per sample group.

Tensile stress is a measure of the force per unit width (N/m) recorded at failure of the medium test strip. The strain indicates the percentage increase in length (%) of the medium test strip at failure.

Table 1

Sample HEPA Filter Details					
Medium Sample Numbers	Manufacturer	Filter Size H x W x D (mm)	Serial #	Date Manufactured	History
9,10,21*,22*	Email	610 x 610 x 292	C110275	09/11/84	Stored
13,14	Email	304 x 304 x 149	C110481	23/08/88	Stored
11,12,23*,24*	Gelman	610 x 610 x 292	003822	24/10/84	Stored
15,16	Gelman	304 x 304 x 149	006278	26/06/86	Stored
1,2,17*,18*	Email	610 x 610 x 292	C110076	19/09/84	Used
5,6	Email	304 x 304 x 149	A118322	28/02/84	Used
3,4,19*,20*	Gelman	610 x 610 x 292	002079	18/02/84	Used
7,8	Gelman	304 x 304 x 149	003073	06/06/84	Used

Advice was obtained from Lydall Technical Papers Division on a procedure to determine the percentage of combustibles present in medium. The procedure followed was:

1. Weigh a sample of medium.
2. Place the sample in an oven for 5 minutes at 540°C.
3. Remove sample and reweigh. The difference in weights represents the organic material content of the sample.

One trial used a 10-minute heating period to determine if 5 minutes was adequate. No further loss of organic matter was identified.

Results

Table 2 provides a summary of the physical condition analysis performed on all filters sampled prior to removal of the filter medium pack. The frame of each filter sampled was intact and within dimensional tolerances.

The results obtained from testing medium samples are displayed in the following six charts. Charts 1 to 4 present the results obtained for medium tensile strength and strain characteristics. To aid comparison the minimum tensile stress and strain values quoted in military specification MIL-F-51079D are indicated. New medium tensile strength, as quoted by medium manufacturers Lydall and Flanders, is also provided for comparison. Charts 5 and 6 indicate the amount of organic material found present in each sampled filter's medium. Comparison is again made to the MIL-F-51079D specification and new medium organic content as quoted by Lydall and Flanders. The standard deviations obtained were small, indicating good agreement between individual medium trials.

Discussion

It is not suggested that the eight filters sampled from the stored and in service filter populations provide statistically relevant results. However, the results do give rise to the following comments.

The visual analysis performed on the sampled filters identified three age-related property changes.

1. The face sealing gaskets on several filters had lost elasticity and become oxidized.
2. The binding compound used between the frame and medium pack had become hard for two sampled filters.
3. Two filters exhibited poor bonding properties between the medium pack ends and the frame.

Of the three problem types identified, only ageing face seal gaskets posed a significant problem as these are known to cause poor sealing when they become hard. However, the gaskets can be easily replaced and the filter returned to service. Other deficiencies identified were isolated problems and to date have not caused problems with filter performance.

The tensile strength of all samples shown in Charts 1 to 4 exceeded the minimum criteria stipulated by military standard MIL-F-51079D. The results obtained for the machine direction were more than twice the value of 0.44 kN/m, as stipulated in the standard. The cross direction values were just under twice the stipulated value of 0.35 kN/m. The tensile strength of all samples had degraded by 40%-45% from the average of the new medium specifications provided by Lydall Technical Papers and Flanders Filters Inc., the medium manufacturers. There is no significant difference in tensile properties between the used and stored medium.

Charts 1 to 4 also contain data on the medium strain characteristics. The standard states that the strain must be no less than 0.5% at sample rupture in either test direction. All samples analyzed exceeded this value. To date no manufacturer's data on new medium strain values have been obtained, making it impossible to perform an age comparison. The strain characteristics between used and stored medium are similar. The Lydall medium tends to exhibit higher strain values than the Flanders medium.

The amount of organic material present in the samples is shown in Charts 5 and 6. The standard states that combustibles cannot exceed 7% by weight. The combustibles are comprised of medium binding compound, mildew inhibiting, water repellent, and fire-retarding chemicals. The organic content of all e-mail samples met this criterion, but one sample exhibited a near total loss of organic compounds. The organic content of the Gelman samples all equalled or exceeded the criterion. It is difficult to determine what has occurred. The Gelman samples that have been in service may have become loaded with dust, thus increasing

Table 2

Observations Made on Physical Condition of Filters				
Filter Type & Serial Number	**Neoprene Face Seal Gasket Condition**	**Separator Condition**	**Frame to Medium Pack Binding Compound**	**Medium Condition**
Email 610 C110275	OK but easy to peel from frame in certain places.	Excellent condition	Excellent condition	Medium clean and physically intact. Bond between medium ends and frame poor, medium could be peeled off.
Email 304 C110481	Gasket OK but easy to peel from frame in places.	Excellent condition	Excellent condition	Medium clean and physically intact. Bond between medium ends and frame poor, medium could be peeled off.
Gelman 610 003822	OK, well adhered to frame.	Excellent condition	Excellent condition	Medium clean and physically intact. Bond to frame good.
Gelman 304 006278	OK, well adhered to frame.	Excellent condition	Excellent condition	Medium clean and physically intact. Bond to frame good.
Email 610 C110076	Gasket deformed to half original thickness, but still elastic. No obvious oxidation. Frame adherence good.	Excellent condition	Still has elastic behaviour but overall harder than stored filters.	Medium clean and physically intact. Bond to frame good.
Email 304 A118322	Compressed and hard, Adherence to frame good.	Excellent condition	Material very hard but bond to components good.	Medium clean and physically intact. Bond to frame good.
Gelman 610 002079	Gasket deformed to half original thickness, but still elastic. No obvious oxidation. Frame adherence good.	Excellent condition	Excellent condition. No noticeable change from stored samples.	Medium evenly discoloured on one face, but physical condition good. Bond to frame good.
Gelman 304 003073	Gasket deformed to half original thickness, also hard and brittle. Surface oxidised. Frame adherence good.	Excellent condition	Excellent condition. No noticeable change from stored samples.	Medium evenly discoloured on one face, but physical condition good. Bond to frame good.

Chart 1

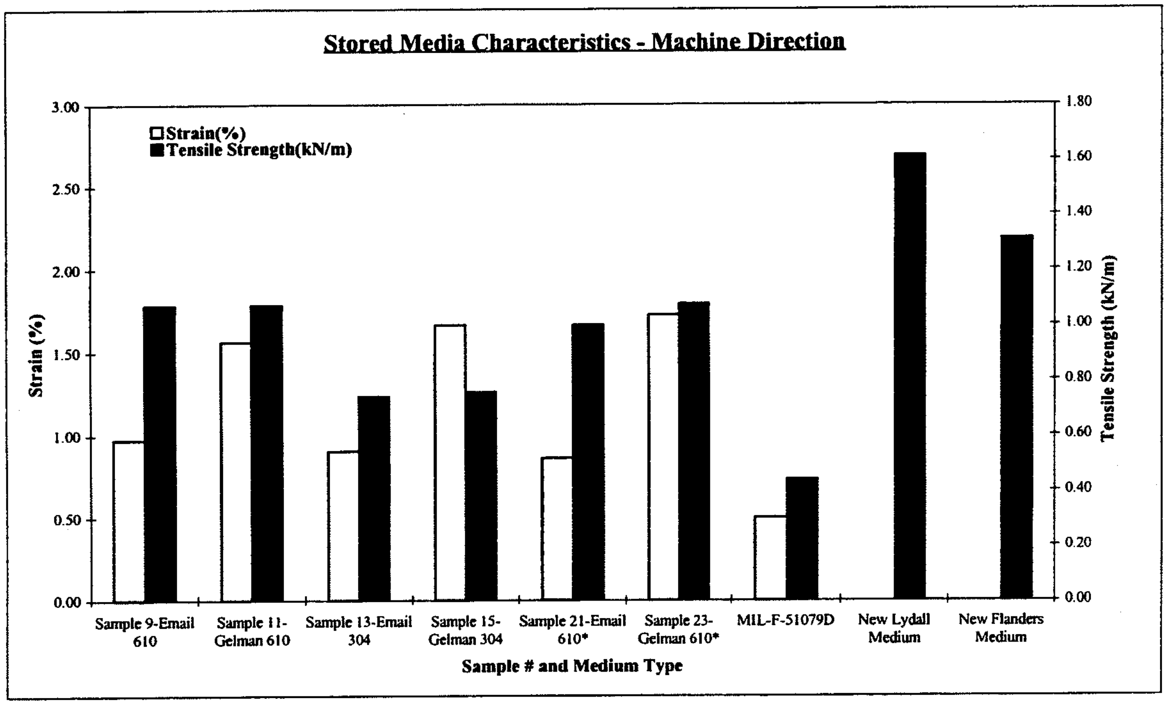


Chart 2

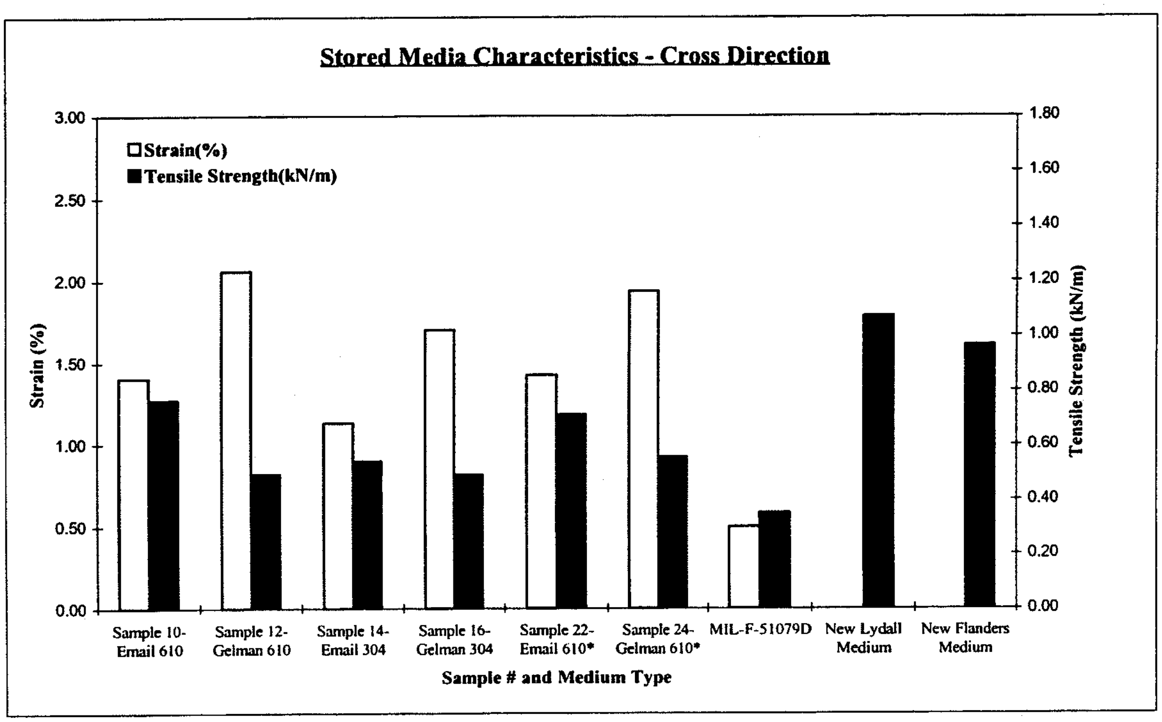


Chart 3

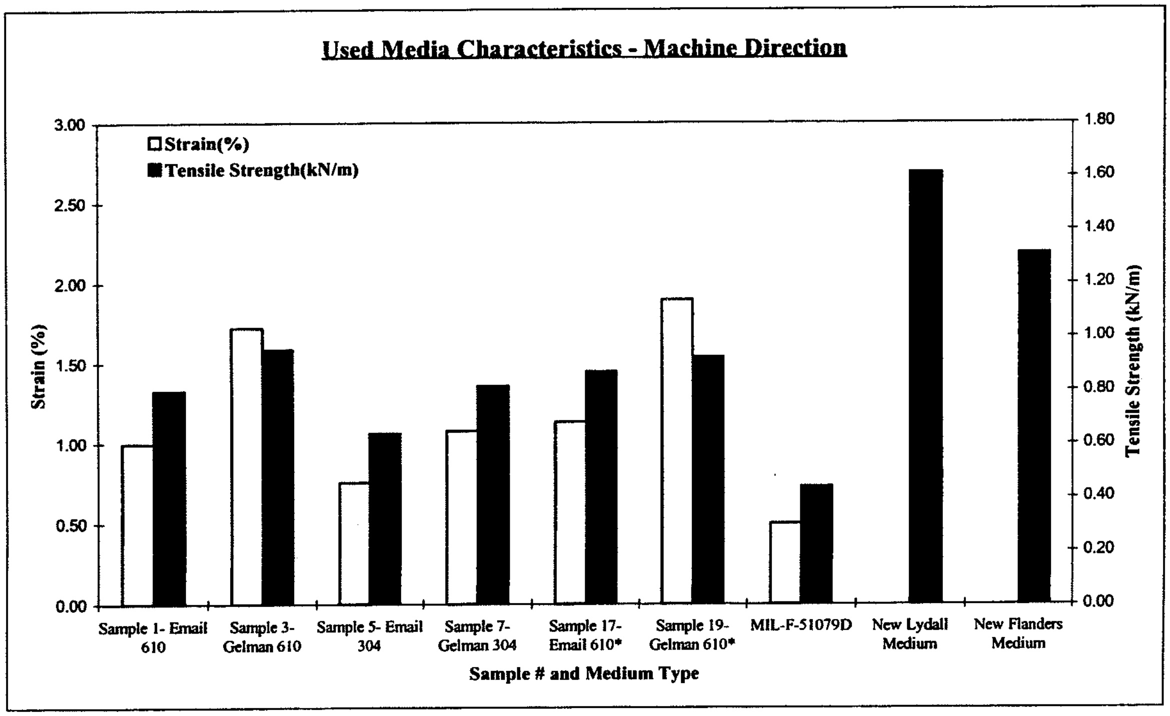


Chart 4

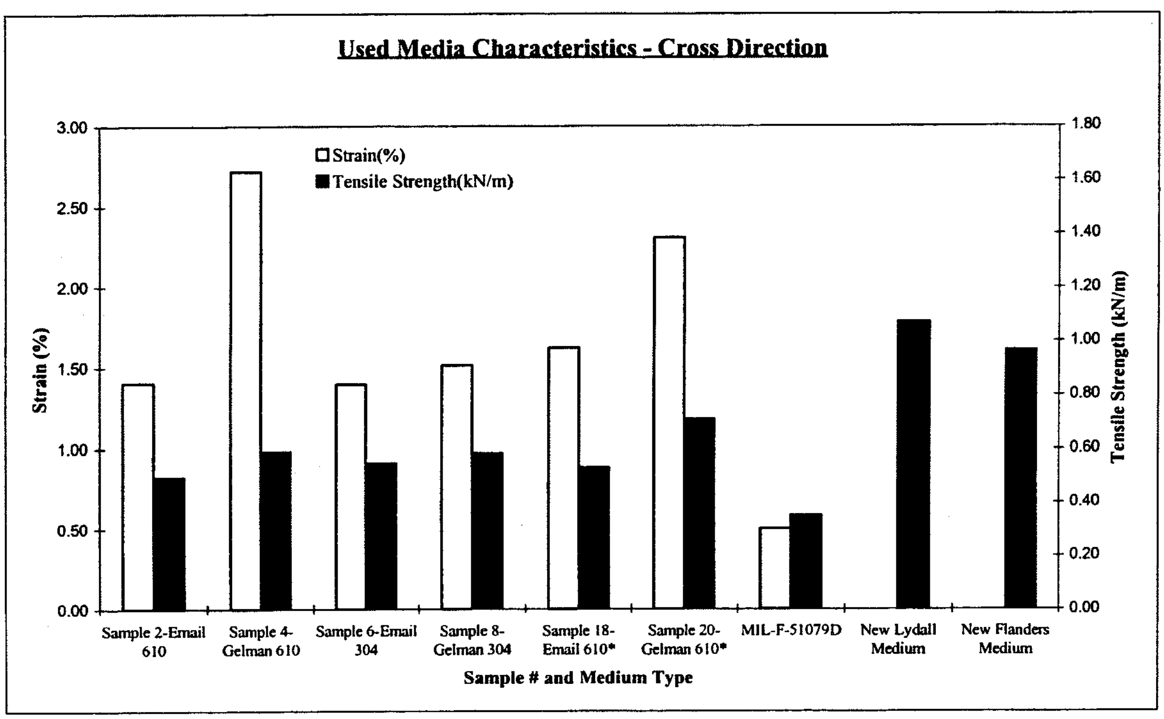


Chart 5

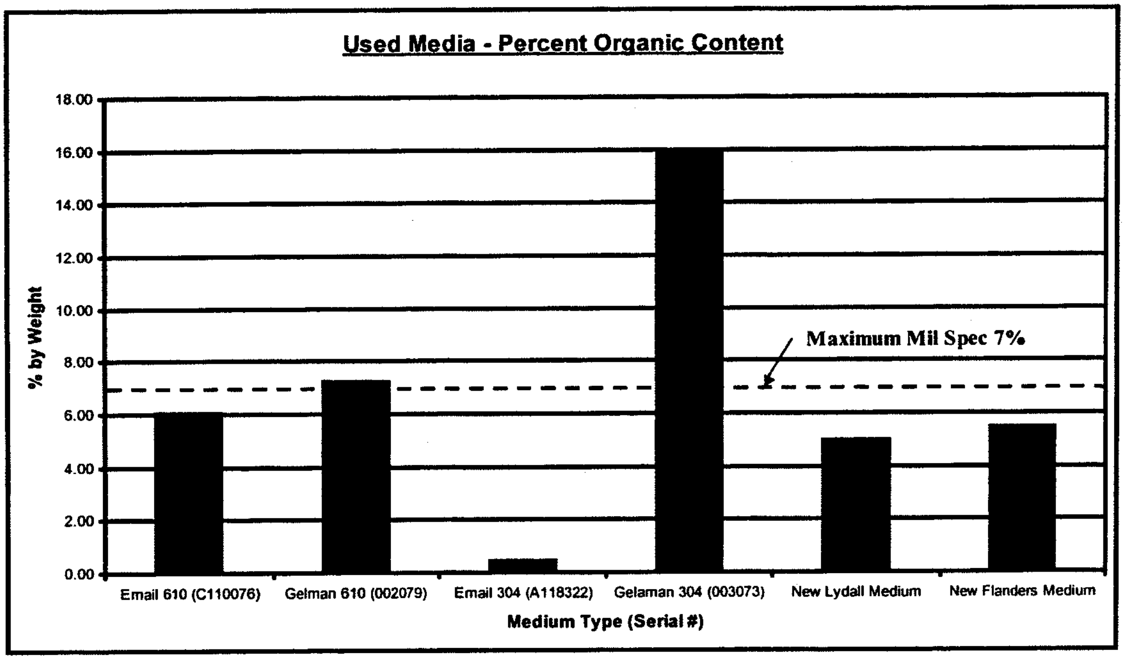
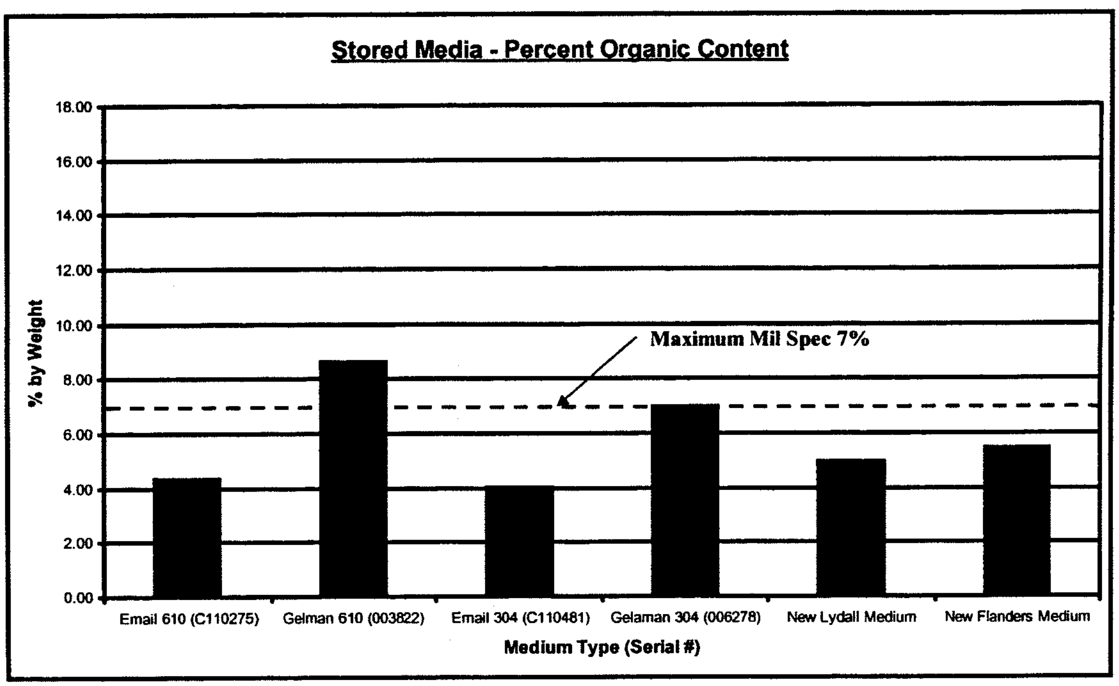


Chart 6



their combustible material weight. However, samples from stored Gelman filters also recorded high values. There is no obvious explanation for this observation; however, one may postulate that the medium batch used in the construction of the Gelman filters had an abnormally high combustible material content from manufacture.

As previously mentioned only one filter recorded a significant reduction in combustible material. This filter may have been exposed to steam vapour that may have reduced the binding compound content in the medium. First (1996) listed loss of binding compound as one of the causes of physical medium failure, but clearly this does not seem to be a significant issue in this analysis.

What is the Risk of Physical Failure of an Aged HEPA Filter?

To answer this question with certainty, two pieces of information are required:

1. What magnitude of pressure pulse is required to physically damage an aged filter?
2. What are the magnitudes of the pressure pulses generated by air handling systems?

Various research (Andrae et al., 1981; Gregory et al., 1979; Johnson et al., 1988; Osaki et al., 1989; Robinson et al., 1985) has demonstrated the behaviour of HEPA filters when subject to long duration pressure pulses or shock pulses. These pulses simulate the effects of a tornado or explosion, respectively, on a HEPA-filtered air handling system. The air handling systems at this laboratory are unlikely to experience either occurrence due to the laboratory's geographical position, the type of work performed (low risk of explosion), and the design of the air handling regime. Realistically, the only significant pressure pulse experienced by the HEPA filters is generated when air handling system fans start or fan swap occurs between an in-service fan and standby fan.

Long Duration Pressure Pulses

Various groups have performed research on HEPA filter structural performance when subject to long duration pressure pulses. Osaki et al. (1989) reported three factors affecting filter structural performance:

1. Rate of pressure increase
2. Pressure differential across filter
3. Airflow rate

Tested filters (Osaki et al., 1989) failed at pressures between 10 to 20 kPa. The failure pressure tended to increase slightly as the pressurization rate (kPa/s) increased. The rate was varied from 1 to 100 kPa/s. Testing was performed at large air flow rates ranging from 110 to 166 l/s. The size of the HEPA filter tested is not clear, but it was either a 610 x 610 x 292 mm or 304 x 304 x 149 mm.

Tornado loading on HEPA filters was simulated using 610 x 610 x 292 mm filters (Gregory et al., 1979). Peak failure pressures of 9.7 to 23.5 kPa were obtained with pressurization rates varying from 19.3 to 9.7 kPa/s, respectively.

Research has also been performed on filter response to tornado transient pressure pulses (Andrae et al., 1981). He reported an average break pressure ± one standard deviation of 16.4 ± 4.9 kPa. The following observation was made: "The parameters that correlate strongly to the HEPA filter static break pressure are the manufacturer, the medium paper tensile strength, the medium paper impact strength, and possibly the medium paper batch. Parameters that did not correlate strongly were tornado pressurisation rate and duration, pack tightness, flow direction, separator type, and particulate loading."

Generally, all papers identified the most common region for medium failure as a rear pleat near the side of the housing. Gregory et al. (1979) theorized that at high flow rates (above 150 l/s) the dominant mechanism causing resistance is momentum exchange and that the majority of airflow is probably passing through the folded ends (pleats) of the filter medium. This may explain why filters typically fail on their rear pleats.

The fact that most medium failures are at the rear of the filter pack when subjected to a pulse or shock wave is not unexpected. The fold (pleat in the medium) is known to reduce medium tensile strength by an amount usually exceeding 50% in most medium samples tested (Robinson et al., 1985).

Since this research on aged filter medium characteristics has shown a 40%-45% reduction in medium tensile strength, it is reasonable to assume that when subjected to long duration pressure pulses, aged filters will fail at lower differential pressures than new HEPA filters.

Johnson et al. (1988) investigated the structural and medium characteristics of aged HEPA filters. The age of the filters analyzed varied from 14 to 19 years, and their operational environment could be described as similar to any large high containment laboratory. The medium tensile tests performed found most filter (aged 14 years) medium did not meet the MIL-F-51079 minimum tensile strength criteria for either machine- or cross-direction samples. This is interesting, as the filters analyzed here, which are the same age, have been found to exceed the MIL-F-51079 tensile strength criteria by a factor of about 1.8 in both directions.

Johnson et al. (1988) tested filters aged between 15 and 19 years of age with long duration pressure pulses (tornado simulation) to determine burst pressures. The average burst result was 9.5 ± 6.5 kPa, which is up to 50% lower than figures quoted for new HEPA filters. Clearly the failure pressure of a HEPA filter reduces with age.

Since it has been demonstrated that HEPA filter medium tensile strength decreases with age (Bergman et al., 1994), at some point in the future HEPA filters installed in air handling systems will become too weak to withstand system-induced pressure pulses and will fail.

Conclusion

The mechanical properties of the tested media have deteriorated, yet they still exceed the requirements of the relevant standard by a significant amount. This confirms research by Bergman et al. (1994) that HEPA filter medium does exhibit a continuous loss of mechanical strength with time. The main risk created by degrading medium mechanical strength is the risk of physical medium failure when subjected to short or long duration shock pulses.

It is essential that HEPA filters used in high containment facilities not be allowed to degrade to the point at which physical failure from air handling system transients may occur. Tensile testing of the media is the only reliable method on which to base any replacement decision since no obvious rule of thumb exists to predict the mechanical state of aged HEPA filter media.

Research has identified little difference in mechanical properties between filters of equivalent specification that have been in service and those that have been in storage for the same length of time. Therefore, filters of equivalent age should be discarded at the same time regardless of whether they have seen in service or not.

Other components of the filter should also be monitored for age-related changes. At present only the neoprene face seal gasket is known to be a significant problem, and this can be renewed easily when required.

Those responsible for the maintenance of high containment facilities need to be aware of the ageing characteristics of HEPA filter media and ensure old HEPA filters are removed prior to the risk of medium failure becoming significant.

References

Abraham, G., Le Blanc Smith, P. M., & McCabe, P. (1999). HEPA filter replacement experience in a biological laboratory. *Journal of the American Biological Safety Association, 3*, 134-142.

Andrae, R. W., Bolstad, J. W., Foster, R. D., Gregory, W. S., Horak, H. L., Idar, E. S., Martin, R. A., Ricketts, C. I., Smith, P. R., & Tang, P. K. (1981). Investigation of air cleaning system response to accident conditions. *Proceedings of the 16th DOE/NRC Nuclear Air Cleaning and Treatment Conference,* CONF-801038. M. W. First (Ed.). Springfield, VA: NTIS, NTIS, p. 1142.

Bergman, W., First, M. W., Anderson, W. L., Gilbert, H., & Jacox, J. W. (1994). Criteria for calculating the efficiency of HEPA filters during and after design basis accidents. *Proceedings of the 23rd DOE/NRC Nuclear Air Cleaning and Treatment Conf.* CONF-940738. M. W. First (Ed.). Springfield, VA: NTIS, NTIS, p. 563.

First, M. W. (1996). Ageing of HEPA filters in service and in storage. *Journal of the American Biological Safety Association, 1*(1), 52-62.

Gregory, W. S., Andrea, R. W., Duerre, K. H., Horak, H. L., Smith, P. R., Ricketts, C. I., & Gill, W. (1979). Air cleaning system analysis and HEPA filter response to simulated tornado loadings. *Proceedings of the 15th DOE/NRC Nuclear Air Cleaning and Treatment Conf.* CONF-780819. M. W. First (Ed.). Springfield, VA: NTIS, NTIS, p. 694.

Johnson, J. S., Beason, D. G.. Smith, P. S., & Gregory, W. S. (1988). The effect of age on the structural integrity of HEPA filters. *Proceedings of the 20th DOE/ NRC Nuclear Air Cleaning and Treatment Conf.* CONF-880822. M. W. First (Ed.). Springfield, VA: NTIS, NTIS, p. 366.

Osaki, M., & Kanagawa, A. (1989). Performance of high-efficiency particulate air filters under severe conditions. *Nuclear Technology, 85,* 274.

Robinson, K. S., Hamblin, C., Hodiere, R. C., & Smith, M. J. S. (1985). In-service aging effects on HEPA filters. *Proceedings of Gaseous Effluent Treatment in Nuclear Installations,* G. Fraser and F. Luykx (Eds). Luxembourg: Committee of the European Commission.

Technical Association of the Pulp and Paper Industry. Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products. *TAPPI Standard,* T 402 om-93, Atlanta: Technical Association of the Pulp and Paper Industry.

Technical Association of the Pulp and Paper Industry. Tensile breaking properties of paper and paperboard (using constant rate of elongation apparatus). *TAPPI Standard,* T 494 om-88, Atlanta: Technical Association of the Pulp and Paper Industry.

U.S. Department of Defense. Military specification for filter medium, fire-resistant, high-efficiency. *U.S. Military Standard,* MIL-F-51079D. Aberdeen Proving Ground, MD: U.S. Department of Defense.