Reference

Selection and uses of HEPA and ULPA filters

New considerations of configuration, media, and methods of testing for HEPA and ULPA filters

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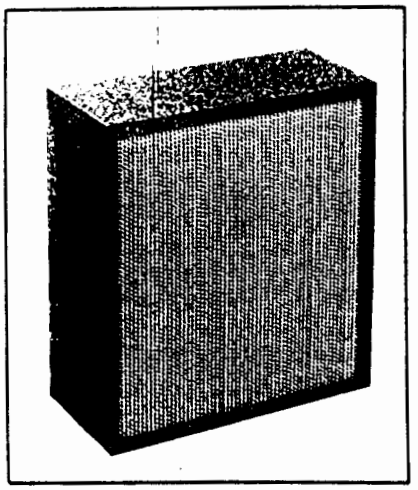
A high efficiency particulate air (HEPA) filter is one that has a minimum efficiency of 99.97 percent by the dioctylphthalate (DOP) test method. An ultra low penetration air (ULPA) filter is one that has a minimum efficiency of 99.999 percent by the same test method. Both filters are identical in appearance.

The significant difference between them is in the media that are used. Frequently there is the added requirement that the clean resistance of a HEPA filter shall not exceed 1.0 in. WG when tested at rated air flow. Despite the fact that almost 40 years have passed since its invention, the HEPA filter continues to be improved in a variety of ways. These include configuration, media, and methods of testing. The purpose of this article is to list current but not necessarily new considerations for one who is specifying HEPA filters.

An extremely valuable document for any user or specifier of HEPA filters is the Institute of Environmental Sciences (IES) publication *HEPA Filters.*[1] The current version of this recommended practice is still classified as "tentative." However, the only known important change to be made in this current version relates to the definition of a fire resistant HEPA filter.



1 Typical HEPA filter.
Courtesy of Cambridge Filter Corp.

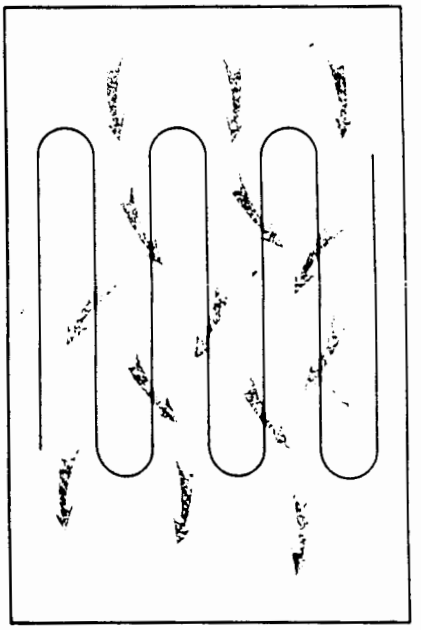
HEPA filter configuration

The earliest commercial configuration of a HEPA filter was developed by pleating medium back and forth over corrugated separators (Fig. 1). This is still the most prevalent configuration. The air flow through the filter is shown in Fig. 2.

The resistance of a HEPA filter is the sum of two losses:

- Resistance of the medium.
- Aerodynamic losses as air passes through the filter. This is referred to as the "configuration loss."

For a filter of any given depth, medium resistance can be decreased by reducing the velocity of air through it by adding more pleats of filter medium. When this is done, the separators will have lower amplitude. The channels through which the air must flow will be reduced in size, increasing the aerodynamic losses. Conversely, if high



2 Air flow pattern through a HEPA filter. Corrugated separators (omitted) retain pleat configuration.

[1] *Superscript numerals refer to numbered references at end of article.*

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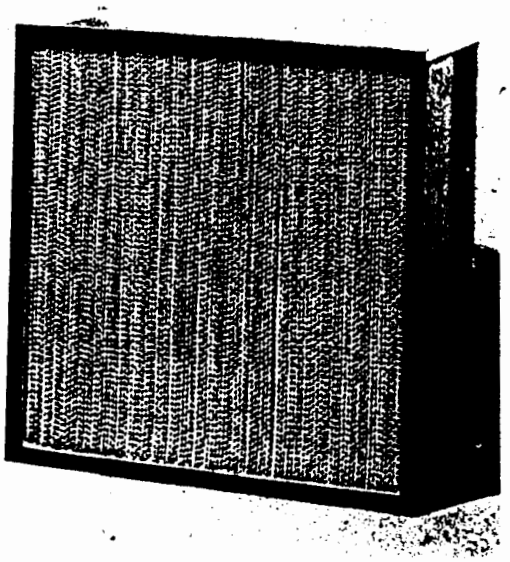
amplitude separators are used to reduce the aerodynamic losses, the medium resistance increases.

From this it can be deduced that for any specific medium, there is an optimized pleat spacing that results in a configuration producing the lowest possible aerodynamic loss for the lowest possible medium pressure drop. There are very few filters made with this optimized configuration. Instead, if the emphasis is on first cost, high amplitude pleats with a minimum of medium are used. (This can also be accomplished by making a "loose pack," although quality filter manufacturers are not inclined to use this method.) However, if long life or high dust holding capacity is the consideration, filters will have more pleats with low amplitude separators. One manufacturer specifically offers a very low amplitude pleated pack for the purpose of attaining long life and high dust-holding capacity (Fig. 3).



3 Low amplitude separators allow the incorporation of more pleats and hence more medium for longer filter life.
Courtesy of Mine Safety Appliance Co.

Separatorless filters

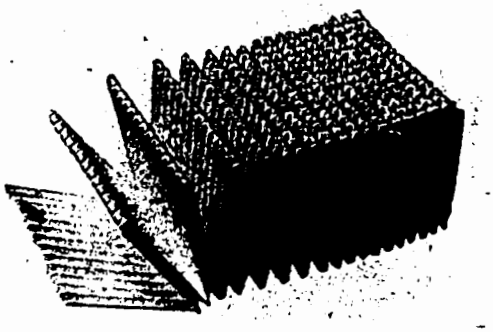
A separatorless filter has been developed by one manufacturer. As the medium is being manufactured, it is corrugated by a proprietary method so that when it is pleated the corrugations abut against one another, creating channels through which air can flow without the need for corrugated separators (Fig. 4). It should be noted that to assure adequate pack strength, metal stiffeners may be installed. In the 24 by 24 by 11½ in. filter, stiffeners are installed every 6 in.

A third style filter pack is referred to as "separatorless," but for the most part this is a misnomer. It is true that no corrugated separators are used; but either before or during pleating, small spacers such as strips of medium or strings are attached to the medium so that when the latter is pleated the strips or strings abut one another, creating channels through which air can flow (Figs. 5 and 6).

Recently one manufacturer introduced a design incorporating medium that has been embossed during manufacture. When the medium is pleated, bosses touch one another, creating the necessary channels for air flow.

These close pleated designs are limited to shallow packs, the depth of which varies with different manufacturers. In close pleated configurations, the shallow pack may be reinforced with struts placed as needed between pleats to prevent collapse.

In one manufacturer's design, the need for struts is eliminated by gluing adjoining strings. This creates a solid pack by, in effect, bonding each pleat to its adjoining one. To match the same cfm capacity as a standard 11½ in. deep HEPA filter, elements can be veed and sealed into a corresponding 11½ in. deep frame (Fig. 7). Some of these veed filters have enough elements that their rated capacity is 2000 cfm.



4 Cutaway of separatorless filter shows how corrugations, formed during the manufacture of medium, create channels through which air can flow.
Courtesy of Flanders Filters Inc.

HEPA filter media

The principal filtering medium used in HEPA filters is all-glass paper. The actual formulation by any manufacturer is a trade secret. Each manufacturer strives to develop an end product that will provide the desired efficiency at the lowest possible pressure drop while getting the greatest yield in sq ft of paper per lb of expensive glass microfibers.

It is never written into specifications, but the "alpha value" of medium is an industry accepted method of defining medium performance. It is given by the formula:

$$\alpha = \frac{[2 - (\log P)]\,100}{R} \qquad (1)$$

where

P = penetration (percent) measured by the DOP test method

R = resistance of medium, mm H_2O

(Both P and R are measured at media velocities of 10.5 fpm.)

The alpha factors for HEPA filter media were usually in the 10 to 11 range. During the last few years, new media have been developed that have lower resistances and/or lower penetrations. For such media, alpha values of 13 or higher can be achieved. The higher the alpha values, the better the overall performances of the media.

Low pressure drop media

During the past year, significant improvements have been made by some manufacturers in reducing the resistances of media and consequently the HEPA filters in which they are used. A filter incorporating a low pressure drop medium commands a premium, but in many in-

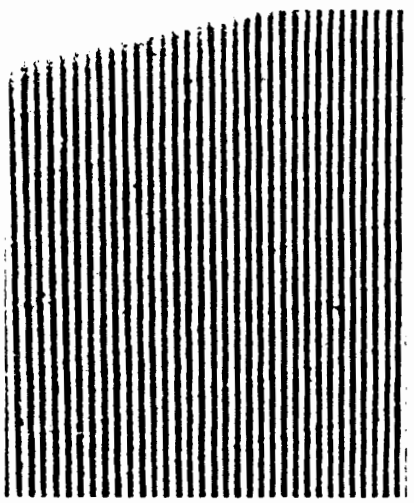
stances it can be determined that the energy saving will result in a quick return on investment. Such a filter therefore represents a saving through the balance of its life.

The calculation of energy saved (in KWH) can be performed using the following formula:

$$KWH_s = \frac{1.174 \times Q \times SP_s \times T \times 10^{-4}}{E} \quad (2)$$

where

KWH_s = kilowatt hours saved for the specified period of time



5 Close up view of close pleated filter illustrating how strings create the channels through which air can flow.
Courtesy of Filtra Corp.

Q = quantity of air filtered, cfm

SP_s = difference in average pressure drop between a filter with low pressure drop medium and standard media

T = time, hr

E = composite of motor, fan, and drive efficiencies expressed as a decimal

As an example, a typical vertical laminar flow clean room ceiling incorporates filters that operate at 90 fpm face velocity (or handle 90 cfm per sq ft of ceiling). The difference in resistance between a "low pressure drop" HEPA filter and a "standard" one will vary, but 0.3 in. WG is not an uncommon value. For one year's operation around the clock 50 weeks per year, total hours are 84,000. System composite efficiencies will vary, but 60 percent is not unreasonable.

For this illustration, the KWH saved per sq ft of ceiling would be calculated as:

$$KWH_s = \frac{1.173 \times 90 \times 0.3 \times 8400 \times 10^{-4}}{0.6} = 44.34$$

If the cost of one KWH is $0.085, the saving is $3.769 per yr per sq ft of filter face area. Vertical laminar flow rooms vary in size, but one that is only 1000 sq ft is relatively small. Still for a room this size, the saving is $3769 per yr.

This saving must be compared to the added cost of the low pressure drop filter. Manufacturers report that the added cost can be recovered in less than a year and a half and thereafter results in the annual saving listed.

Low pressure drop HEPA filters require certain system considerations if they are to be used effectively. If they replace "typical" HEPA filters and no changes are made in the system, the reduced system resistance will cause the fan to deliver more air and thus require more horsepower. If they are used in the original design of a laminar flow clean room, more attention must be paid to the air approach conditions upstream of the filter. In many clean room designs, the resistance of the HEPA filter has been used to create uniform flow across the filter face. When filter resistance is reduced, this benefit is also reduced.

Higher efficiency media

Initially HEPA filters had minimum efficiencies of 99.95 percent by the DOP test method. Early improvements in media allowed minimum efficiencies to be increased to 99.97 percent. The use of the word "minimum" should be noted in both of the cases listed above. Most filters, as individually tested, show efficiencies significantly higher than this minimum value.

As a matter of fact, the filter media themselves had efficiencies considerably higher than those of completed filters. This was due to the fact that the perfect utilization of HEPA filter media by complete sealing of the filter packs within the filter frames was not being accomplished.

When the development of laminar flow clean rooms required that HEPA filters be leak-free, the result was a filter that had a minimum DOP efficiency of 99.99 percent even though it was utilizing the same medium. More than 20 years ago, filter media were developed that allowed a minimum filter efficiency of 99.997 percent. This required an increase of 10 percent in the clean filter pressure drop.

Advances made by the microelectronics industry in crowding more capacity onto silicon chips has resulted in less space between components. There is a general rule that the maximum allowable particle size for any contaminant should not exceed 10 percent of the distance between components or connectors. The latest generation of devices classified as VLSI (very large scale integrated) have clearances as close as one micrometer (1×10^{-4} cm or 3.39×10^{-5} in.). As a result, the maximum allowable size of contamination in the processing of VLSI chips is 0.1 micrometer.

To meet this VLSI requirement, filters incorporating ULPA media with a minimum DOP efficiency of 99.999 percent are available.

DOP filter testing

In the United States whenever DOP efficiency is referenced, it should, and usually does, mean the measurement of DOP penetration through the filter by using the basic method outlined in MIL-STD-282. This consists of the generation of an essentially uniform aerosol of DOP. This is used as a challenge for the HEPA filter. A properly calibrated photometer reads the penetration of this aerosol through the filter.

While a filter is being tested, it is encapsulated in such a way that the penetration represents all the aerosol passing through the filter from any of the following sources: through the medium, through pinholes in the medium, leaks in sealing the pack to the frame, and leaks through the frame and gasket leakage.

The DOP test has been under assault for a variety of reasons. Objections to DOP itself have come from two sources. The industrial hygienists point to literature suggesting that DOP is a potential mutagen. Assemblers of scientific satellites, especially the OAO (Orbiting Astronomical Observatory), are opposed to all phthalates because of concern that they might off-gas from items in a clean room such as HEPA filters tested with DOP. It is contended that even a single molecular layer of DOP on the optics of these satellites could significantly impair their performances.

Early styles of airborne counters could only accurately count and size particles that were 0.5 micrometers and larger. The development of the laser spectrometer has allowed particles as small as 0.12 micrometer to be counted with accuracy. In one instance when the laser spectrometer was used to measure the size of DOP particles generated in accordance with MIL-STD-282, it was found that the aerosol was not completely uniform in size. However, it has a preponderance of 0.189 micrometer particles and not 0.3 micrometer as had been thought.[3] Studies of HEPA filter performances using the laser photometer as the research instrument have been reported in several recent DOE Nuclear Cleaning Conferences.[4]

Despite these apparent shortcomings in the DOP test method, it is still the *current standard method* for testing HEPA filters in the United States. If any other method is used, reliability, repeatability, and reasonable correlation with the DOP test method are necessary if the results are to be meaningful.

Leak testing

Whatever is not captured by a HEPA filter has either passed through intact medium or has gone around it. The adjective *intact* is used to preclude pinholes or tears in the medium that are equivalent to going around it. If there were no bypass of any type, the efficiency of the filter would be the efficiency of the medium. The influence of the medium penetration vs. bypass can be determined by DOP testing a filter at its rated air flow capacity and at 20 percent of capacity. If there is a significant amount of leakage, the penetration of DOP will be higher at the lower flow than at the rated flow. The explanation of this has been reported elsewhere.[5] Many HEPA filter specifications require that penetration at both 100 and 20 percent rated capacity shall not exceed 0.03 percent.

The elimination of leaks is important for all filters that are to be used in laminar flow clean rooms because every leak represents a stream of unfiltered air that could contaminate the critical product or process in the clean room. It does not take a challenge of particles all the same size to identify a hole. Any aerosol quantity will work if 0.01 percent of its upstream concentration can be measured downstream. DOP is still used, but instead of thermal generation, compressed air is forced through a container of liquid DOP using Laskin nozzles, which create a heavy mist of polydispersed particles of the liquid.

Whereas monodispersed thermally generated DOP consists mostly of 0.18 micrometer particles, the specification for polydispersed "cold" DOP allows for only 10 percent or more to be less than 0.4, 50 percent or more to be less than 0.7, and 99 percent or more to be less than 3.0 micrometers. Other liquids that are reported to work equally well for the generation of polydispersed particles are ethylene glycol, corn oil, and DOS (dioctylsebacate).

There is a precise method for leak testing a HEPA filter outlined in the IES publication *Laminar Flow Clean Air Devices.*[6]

There is no standard procedure for determining the efficiency of HEPA filters using polydispersed DOP or any other "cold" aerosol used for leak testing.

ULPA filter testing

As previously mentioned, the basic method for testing HEPA filters is in accordance with MIL-STD-282. Over the years, refinements have been made in the DOP tested. These refinements, generated by both the manufacturers of DOP machines and the users, have been directed toward methods of improving accuracy and reproducibility. This has been accomplished in the methods of generating the DOP aerosol and in the operation of the photometer used to detect it.

It is important to remember that in a DOP tester, performance is determined by measuring the amount of light scattering generated by samples taken upstream and downstream of the filter. The scattering effect of the heavily DOP-laden air upstream is set at 100 on the photometer. The downstream concentration is measured as a *percent of upstream concentration.*

The optics and electronics of the current DOP testers allow the downstream concentration (penetration) to be measured to the nearest 0.001 percent. Since HEPA filters must have penetrations of less than 0.03 percent, the DOP tested is capable of measuring concentrations one-thirtieth of the maximum allowable. On the other hand, ULPA filters have maximum penetrations of 0.001 percent for this same smoke. The minimum downstream concentration that current DOP testers can now measure is the maximum allowable penetration for an ULPA filter.

The penetration measurement is limited by the concentration of DOP particles in the downstream air. For a filter of a specific effi-

ciency, the number of downstream particles will increase as the upstream particle concentration increases. For this reason, one effort to extend the performance of the DOP tester has focused on procedures for increasing the upstream concentration of DOP. This is not as easily accomplished as might be expected.

Laser spectrometer

As mentioned previously, the laser spectrometer can count airborne particles as small as 0.12 micrometer. This ability to measure smaller particles is due in part to the use of a laser as a light source, creating a high intensity beam of monochromatic coherent light. Since one of the constraints of any particle counter is the smallest particle from which light of sufficient intensity can be reflected to trigger a photodetector, the use of a laser allows smaller particles to be detected and counted. Improvements have also been made in the detecting system to permit more accurate sizing and counting of small particles.

While the laser spectrometer is intended primarily as a laboratory device, filter manufacturers use it to measure the performances of the ULPA filters that they manufacture. There is no agreed upon standard performance method for production testing of ULPA filters with a laser spectrometer.

There are some problems facing the industry, which user representatives are trying to counter with industrywide standards. Among these for ULPA filter testing are:

- Low sampling rate. The laser spectrometer samples at the rate of 10 cc per sec. The DOP tester samples at the rate of 1 cfm or 471 times greater than the laser spectrometer.
- Long testing time. The laser photometer requires 2 to 3 min to take a suitable sample. The DOP tester takes a minute or less. One observer noted that it would require seven laser spectrometers to test filters at the same rate as one DOP tester.

6 Ribbons of filter medium spaced every 1¼ in. apart form the separators that hold the pleats apart.
Courtesy of American Air Filter Co.

7 Panels made from close pleated filter elements can be veed and sealed inside an 11½ in. deep frame.
Courtesy of Filtra Corp.

- Standardization of challenge. There is a problem in finding a standardized aerosol with a sufficient quantity of 0.12 micrometer particles to get a reliable sample in the time frame noted.

Despite this problem, technical societies such as the IES have committees hard at work trying to establish a recommended practice that will allow the laser spectrometer (or some other device) to be used under conditions that will allow the generation of correct and reproducible test data for ULPA filters.

Conclusions

- Despite its existence for more than 40 years, the HEPA filter continues to be improved.
- The vast selection of combinations of materials of construction and configurations makes the HEPA filter suitable for more and more applications.
- In writing a filter specification, media performance should not be overlooked since it relates to desired efficiency and energy usage.
- The only standardized method for testing HEPA filters in the United States is the DOP test method per MIL-STD-282, which uses an essentially monodispersed aerosol. The particle size was presumed to be 0.3 micrometer, but a recent measurement using the laser spectrometer indicates that the size is 0.19 micrometer. This is frequently referred to as "hot DOP."
- A polydispersed aerosol of DOP can be used for leak testing. Such an aerosol incorporates a wide range of sizes, only a few of which are as small as a monodispersed aerosol. This is frequently referred to as "cold DOP."
- ULPA filters, the higher efficiency category of HEPA filters, are available.
- In the absence of a standard method for testing ULPA filters, a specific procedure acceptable to all qualified manufacturers should be specified. Ω

References

1) *HEPA Filters*, IES recommended practice IES-RP-CC-001-83T. Available from the Institute of Environmental Sciences, 940 East Northwest Highway, Mt. Prospect, Ill. 60056.

2) Avery, R. H., "Air Filtration: Resistance, Energy, and Service Life," *Heating/Piping/Air Conditioning*, December 1973.

3) "Absolute Filter Testing," (Bulletin 12-106), Cambridge Filter Corporation, Syracuse, N.Y. 13221.

4) Burchsted, C. A., *An Index of the 1st through 16th AEC/ERDA/DOE Nuclear Air Cleaning Conferences*, Publication No. DOE/TIC-11405. Available from NTIS, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, Va. 22161.

5) Avery, R. H., "New Techniques in the Testing of HEPA Filters," *Air Engineering*, January 1968.

6) *Laminar Flow Clean Air Devices*, IES recommended practice IES RP-CC-002-83T.