

NEW AND NOVEL TECHNOLOGIES IN PARTICULATE FILTRATION

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Particulate air filtration for Collective Protection Systems (CPS) uses high efficiency particulate air (HEPA) filters. These filters are excellent at removing an extremely high percentage of biological and particulate material from the air, with relatively low pressure drop and energy consumption. These filters have been in use for decades and have proven themselves over the years as a valuable tool in protecting personnel and equipment.

The primary issues that are always being pursued with particulate filter improvements are: 1) lower energy consumption, 2) longer filter life, 3) greater dust load capacity, and 4) easier maintenance without compromising filter efficiency. Over the years the Navy has made significant improvements in particulate filters in all of these areas such that the current system is the best operational air filtration system available. However, recent changes in operational requirements have pushed the need for a review of current equipment and its applicability for dealing with new and emerging threats.

This paper will focus on the 200CFM HEPA filter used in CPS systems and present technologies that can potentially improve its capability and performance. The current 200CFM HEPA filter is a round filter design, as shown in Figure 1, where the air flow is from the center outward radially. These filters can be stacked up to provide more air as required. The HEPA filter media is a glass and polymer fiber blend, and is pleated to provide more filter material in a smaller space.

When designing a filter there are several items that must be considered: application, environment, efficiency required, physical geometry constraints, structural requirements, system volumetric flow requirements, system operational pressures, existing air handling equipment and its capabilities, as well as maintenance, ergonomics, cost, and manufacturability. We will not discuss most of these issues since it goes beyond the scope of this article, but they are worth mentioning to provide a fuller understanding of what is required.

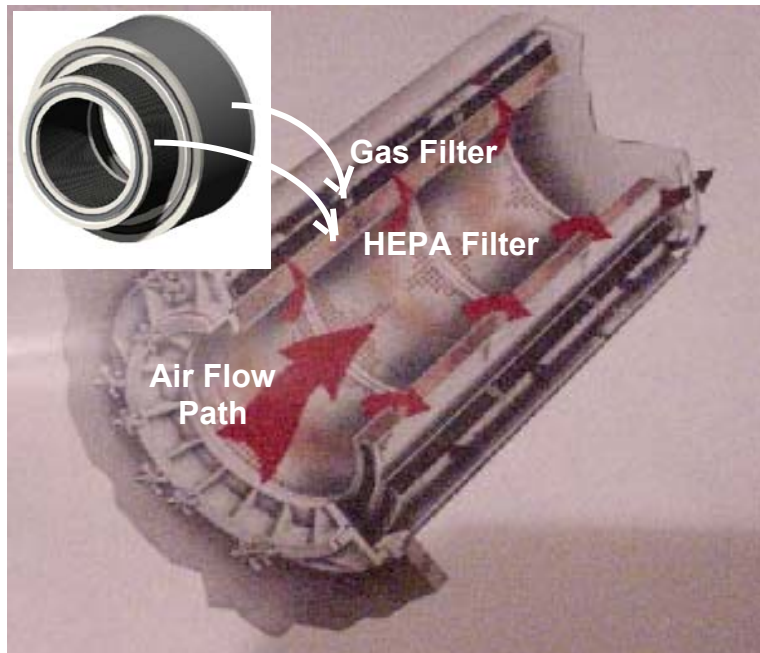


Figure 1.

In order to understand how a fibrous filter works, we need to review the basic physics of filtration theory. A popular misconception regarding how these type filters work is that they act like sieves. Where particles that are too large to pass through the open spaces are trapped, and particles smaller than the open spaces pass through. In reality they seem to defy common sense by actually trapping the smaller particles

as efficiently as the larger ones. This is due to the physics that come in to play in the size range of these open spaces.

There are five ways particles are trapped in fine nonwoven HEPA type filter media, sieve effect, impaction, interception, Brownian diffusion, and static charge effect. The first is the most obvious, sieve effect. This stops large particles that are just too big to fit through the open areas of the filter. For the type filter we are interested in, this would include all particles above 5um in size and larger. As you go smaller in particle size, say between 1um to 5um, occasionally some of these particles get through, but the efficiency for removal is still well into the 99.9999+% range. This is still due primarily to sieve effect and the beginning of inertial impaction effect.

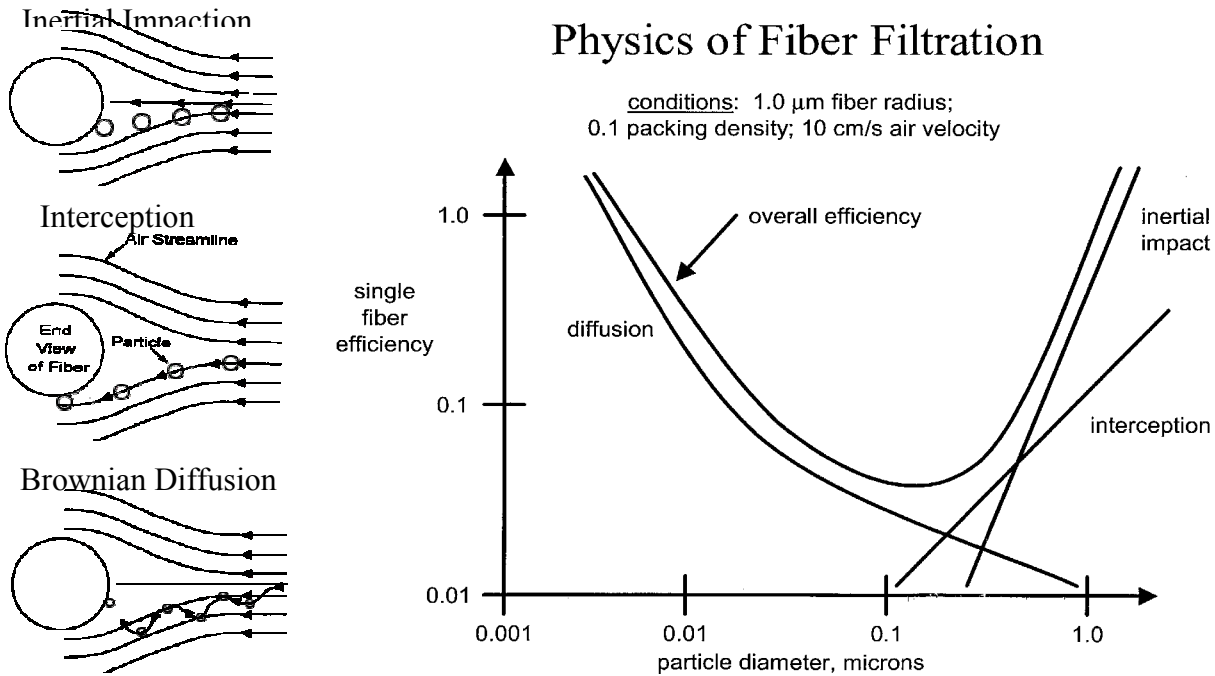


Figure 2.

Inertial impaction occurs when large particles are unable to quickly adjust to changes in the flow stream around fibers. The particle, due to its inertia, impacts a fiber and is captured. Figure 2 above shows how this works. This effect is dominant from around the 0.5um region up to around 5um.

The next effect is interception. Interception occurs when a particle following a gas stream comes within one particle radius of a fiber. When this occurs the particle is trapped by the fiber. Particles that are farther than one particle diameter will not be removed by this process. This is one reason for the high fiber volume density of the 200CFM media. The more dense, the higher the probability of particle capture. This effect is dominant from about 0.1um up to about 1um.

Brownian diffusion is perhaps the most mysterious of the filtering effects since it tends to defy common sense. Very fine particles in the air stream will collide with gas molecules and create a random path through the media. The smaller the particle the longer the particle will zigzag around. This random motion increases the probability of the particle contacting a fiber. This effect is dominant for all particles smaller than 0.1um.

The last effect, which does not get as much notoriety, is electrostatic effect. The reason is that this effect is a function of the type of media used, the environment in which it is used, and the geometry of the fibers. As most of us have experienced, different materials will hold different levels of static

charge. A glass rod when rubbed with fur will build quite a static charge. It will also build a charge if placed in an air stream. In filters, as air passes over the fiber, a charge will build up much the same way, a very small charge certainly but a charge none the less. Additionally the material the fiber is made of will play a part in how much charge will build. Plastic is notorious for holding large static charges. Try pulling a piece of saran wrap quickly and it will try and wrap itself around your arm when you tear it from the roll. The geometry of the fiber will also dictate how much localized electrostatic charge will build on the fiber surface. Humidity in the air will also affect how much charge the fiber will hold, as will the air flow rate through the media. Electrostatic effect is not a dominant effect, but may play some part in particle capture and retention for the previous three effects mentioned.

The particle capture effects mentioned are all subject to how the filter media is made. Fiber diameter, spacing, fiber cross section, and media thickness are big drivers in how effective a filter is. The smaller the fiber, the greater the small particle capture efficiency. The smaller the fiber spacing, the greater filter efficiency. The larger the cross section, the greater the capture capability.

Each of these has tradeoffs that must be considered however, when designing a filter. Glass and polymer fibers are the most common materials used in HEPA filters. Glass fibers can be drawn down to much smaller diameters than can polymers, 0.3um is very possible. This would suggest that an all glass fiber filter would be the best. If your not concerned about space, perhaps this would be correct. However, in order to put a large amount of media into a small space, media pleating is the best solution. Unfortunately glass is very brittle and the small fibers will break if folded too severely. This is one reason why polymer fibers are added to the media matrix. They add a significant amount of structural strength that allows pleating to be effective without significantly impacting filter performance.

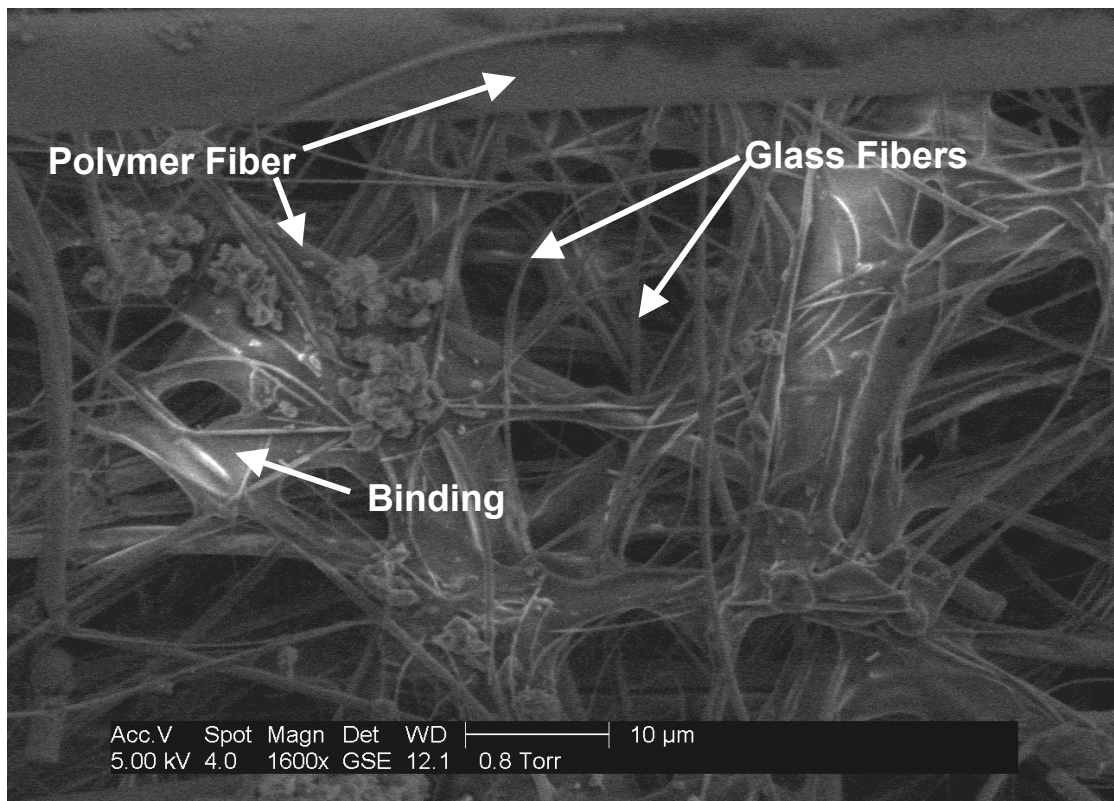


Figure 3.

Above is a micrograph of the HEPA media currently used in 200CFM particulate filters used within the Department of Defense (DoD). As can be seen from the image the glass fibers are extremely small when compared to the 10um polymer fiber in the upper region of the image. The binding agent can

also be seen. The binding agent is a material that helps keep the fibers together and helps to support the nonwoven material in a “fabric” type configuration.

This design is fairly typical of many high performing air filters. The primary issues noted earlier have all been taken into account when designing this media. With recent changes in operational requirements comes the need to identify current capabilities and target technologies that will provide future capabilities.

These requirements are compounded due to the unique requirements the DoD must meet. Most HEPA filters are designed for the specific environment in which they will be used. Filters used in operating room environments must be able to filter out biological organisms. However, they are not subject to high humidity environments, since this would prompt biological growth on the media, and are usually placed within the lower dew point section of the ventilation system. Filters used in semiconductor clean rooms must be able to handle low level exposure to selected acid vapors, typically at temperate conditions.

In typical HEPA filter applications in industry, dust storms in the desert, chemical weapons attacks, and pulse pressures from explosions are not usually considered an issue. DoD CPS HEPA filters however must be able to handle most any chemical, any time, any place, under any humidity condition, under pulse pressure conditions, in temperatures that range from subzero to over 120 degrees, and still provide sufficient protection such that everyone goes home at the end of the day.

Meeting current requirements has been a tall order. Meeting future requirements will be equally challenging. In dealing with emerging threats it may be necessary to develop new media. Adding to this challenge is the fact that the DoD uses less than 50,000 M² of HEPA media a year. There is no economic incentive for industry to invest research and development dollars into a low volume market.

There is however a bright spot in all this. Fiber development technology is moving forward in a number of areas that could meet many of the identified requirement noted above, and which could possibly be transitioned to filter media quite easily. The fabric and carpet industries have developed a number of new technologies that show promise for applicability in air filtration.

Several technologies that could provide improved chemical resistance are microfiber coating, bi-component fibers, and fiber fragmentation. The microfiber coating technology developed by Hills Inc. has produced unique fiber configurations as shown in Figure 4. By extruding one material within another it is possible to provide an exterior coating of one material over another. One application would be to extrude a polymer material coated with Teflon. Teflon is soft, and a thin fiber would not hold up well under the pressure loadings the current HEPA design must meet. However, by selecting a base material that is stronger, but may not have the chemical resistance, and coating it with Teflon, you have a structurally strong fiber with excellent chemical resistance properties. Although Teflon is a good nonstick material, it may still be adequate as a filter due to its high static charge capability.

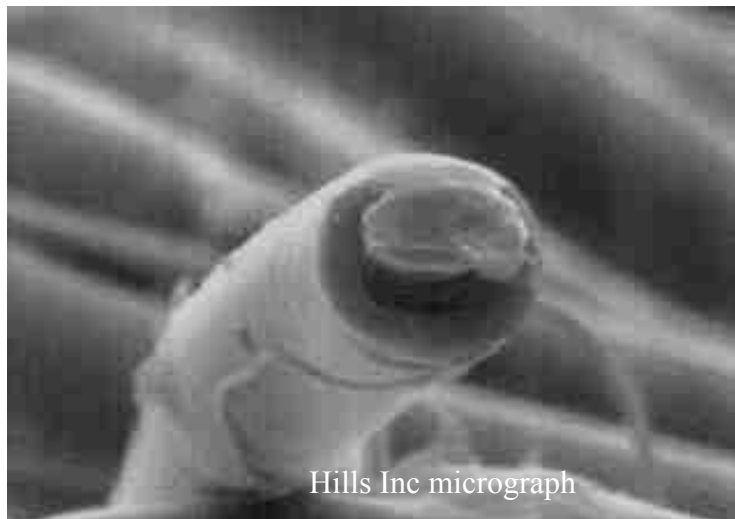


Figure 4.

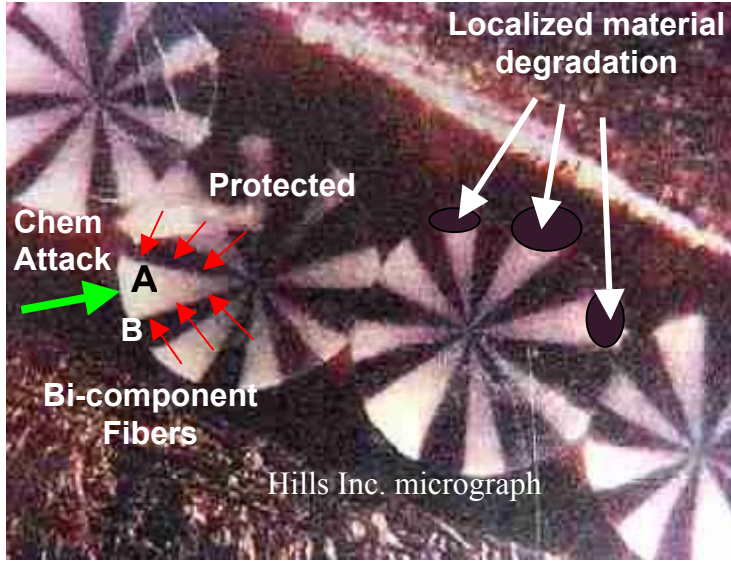


Figure 5.

The second technology is bi-component fibers. By blending different materials together a pie wedge type cross sectional configuration is achieved. This would allow the use of several different materials to be placed into one fiber. If one component is more susceptible to degradation when exposed to a specific chemical than the other, the fiber would remain in tact due to the encapsulating effect of the less reactive adjacent wedges. Figure 5 shows how this type fiber might work. The chemical attack would only occur at the surface of the light material, A. The adjacent darker material, B, with its superior resistance to the chemical, would protect the interior section of the light wedge. Only limited surface

degradation would occur since the effects would not reach as far into the fiber itself. After the attack, the fiber might appear as modified in the lower adjacent fiber.

Another technology development by Hills Inc. is fiber fragmentation. This uses the same extrusion technology but introduces a water-soluble material into the fiber formulation and extrusion process. After the fiber is extruded and blended into the nonwoven structure, the water-soluble interface is washed away, allowing the smaller fibers with irregular surface geometries to spread out within the media matrix increasing the surface area. Figure 6 shows how this might work. This may have an application where a chemically resistant polymer, which cannot normally be drawn down to the fiber diameter required, can be produced.

Fiber Fragmentation Process

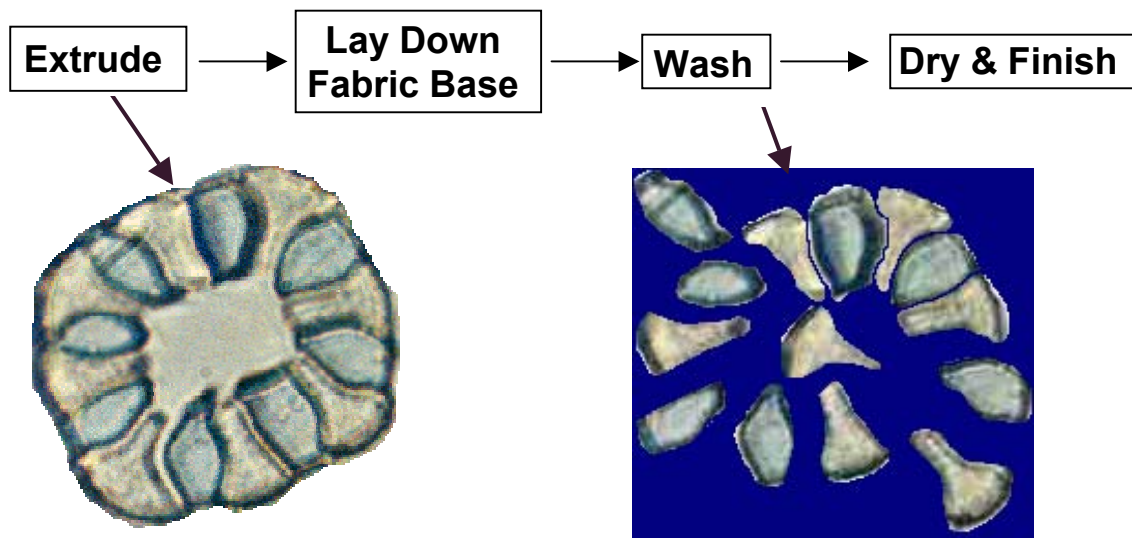
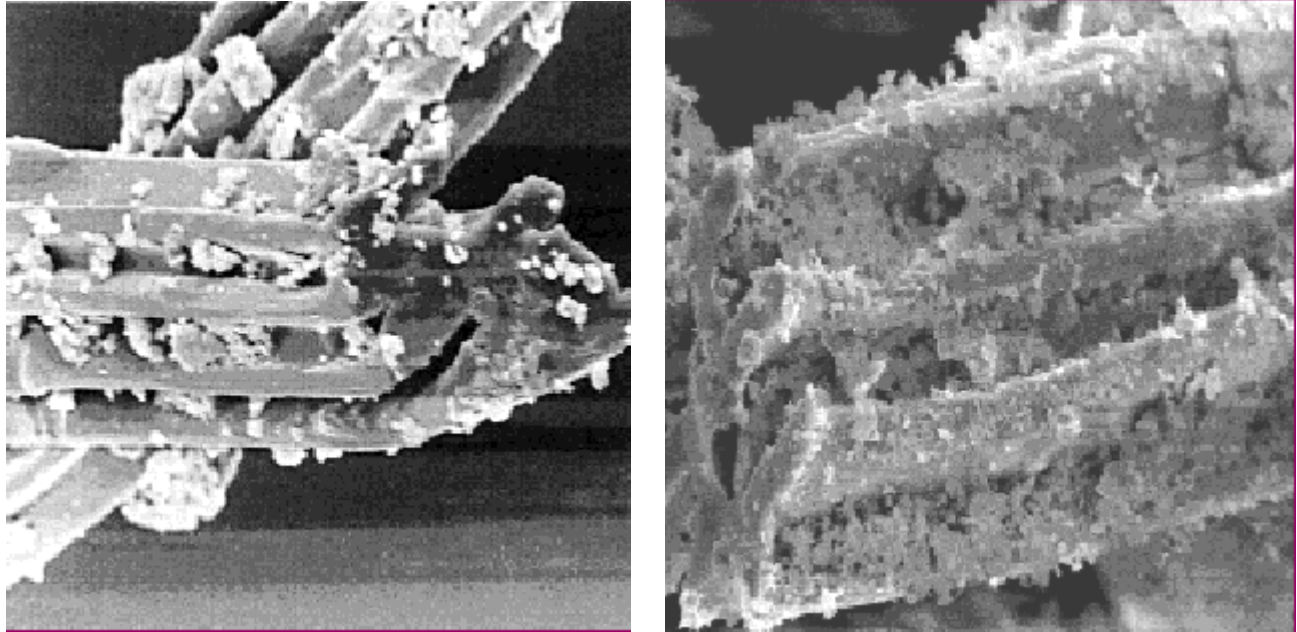


Figure 6.

As noted earlier one aspect of fiber efficiency is surface area. The process outlined above produces irregularly shaped cross sectional fibers. These fibers have much higher surface areas than do typical round extruded fibers. This allows for a greater theoretical particle capture capability. Figure 7 shows extruded fibers with irregular cross section produced by an extrusion process. These fibers were produced for Dr. Edward Vaughn of Clemson University



Used by permission of Dr. Edward Vaughn, Clemson University

Figure 7.

The fibers shown in Figure 7 are 34um by 47um in size. However, they have the same particle capture efficiency as a 7.8um fiber. Eddy currents around the recesses allow for greater dust deposition. Since the fiber is so much larger, structural strength is greater. Additionally the recesses allow for new technologies to be applied. The particles in the grooves in the image to the left are carbon particles placed for odor absorbency.

As noted previously, the smaller the fiber, the greater the surface area, and thus the greater the filter efficiency and capture of small particles. Research conducted by Donaldson Inc. in efforts to increase truck engine filter efficiency have produced a nano fiber web that is laid down over an existing paper fiber base. This nanofiber “spiders web” can be seen in Figure 8. The dendrite formation of salt crystals on the fibers is impressive and suggests a significant amount of dust holding capacity is possible.

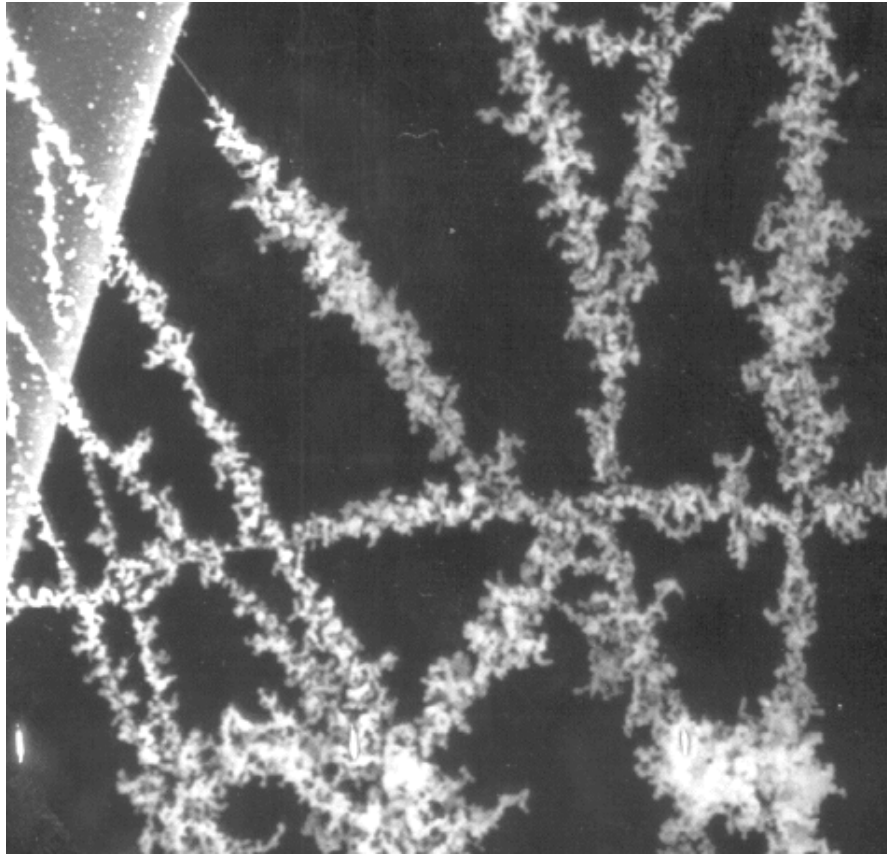


Image Courtesy of Donaldson Company Inc.

Figure 8.

All of the technologies reviewed thus far have looked at improving or modifying the filter media itself. There are technologies that can be applied to existing filter media as well as those noted above that would also increase the capabilities of the particulate filter. As noted earlier localized electrostatic charge effects on fiber surfaces are thought to play some part in the filtration process. Well, by expanding on that thought process it is possible to significantly enhance the filter performance of existing media by applying an electric field or static charge effect.

One technology currently being evaluated is the application of an electric field to the HEPA filter itself. Figure 9 shows how this technology is being applied. This technology is currently being investigated under a Navy funded research effort by New World Associates in Fredericksburg Va. In typical filters when dust collects on a fiber, it tends to deposit on to the leading edge, or side, of the fiber facing the air stream. Through the application of an electric field, it has

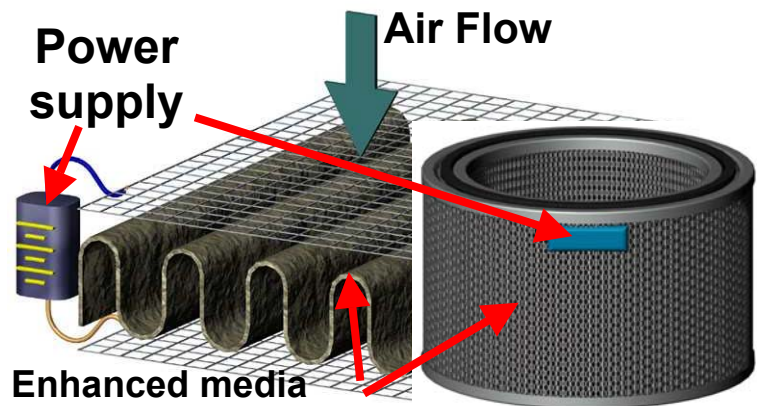


Figure 9.

been noted that there could be a greater loading of dust on the down stream side of the fiber. Testing to date may support this since a significant increase in filter performance as well as dust load capacity has been achieved. However, as yet no micrograph images of dendrite deposition have been obtained to determine this. Through the application of this technology drastic improvements to filter life, dust load capability, performance, and significantly reduced maintenance may be possible.

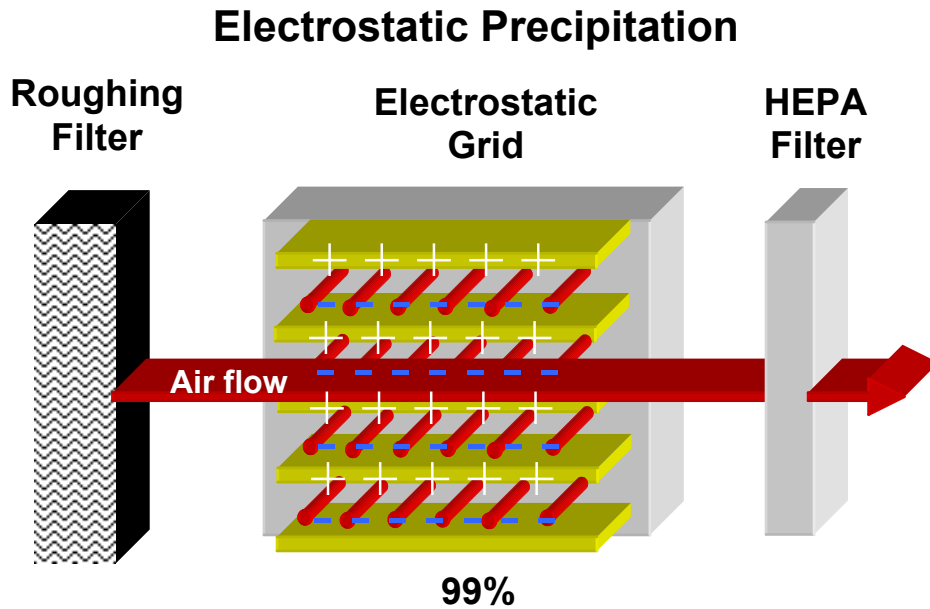


Figure 10.

Following this same line of thinking, static precipitation technology is advancing and is under investigation. At Porton Down in the UK researchers are working with a low voltage system that they believe could drastically improve particulate filtration. The concept, shown in figure 10, uses an electrostatic precipitator backed up by a HEPA filter. The filter Porton Down is using has a 99% efficiency for a single pass. If used in series with a HEPA filter, the life of the HEPA filter

would increase drastically. Current HEPA filters are lasting up to four years in shipboard installations. If this technology were used, it is theoretically possible that the same filters that were installed when the ship was commissioned would be the same filters in use when the ship would be decommissioned. The reason for keeping the HEPA filter in the system is for backup in case the electrostatic filter fails.

For all of the neat and impressive technologies being investigated and developed, there is perhaps a much simpler solution to many of these new requirements and needs. One that has been overlooked due to its simplicity. By developing a cheap and easily replaceable prefilter, it might be possible to meet many of the needs of the CPS community. The prefilter would have to be very inexpensive, light, easy to store, and possibly have a dual function as a storage bag. For meeting the increased chemical resistance requirements, perhaps it could be made of a relatively highly reactive material such that it would sacrifice itself through chemical reactivity with the corrosive gas in order to protect the more valuable HEPA filter further in the system.

This is merely a notional idea. It is mentioned here only to remind us that we should always keep our options open, stay focused on our goals, and that technology development is a tool to get a job done, not an end in itself. The future of CPS filtration is anyone's guess. But it's a sure bet we will be needing it long after our efforts are long forgotten.