PRACTICAL GUIDE

FILTERS AND FILTRATION

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and

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Air filter products have evolved a great deal in the past few years. Early filtration products were designed to protect the mechanical equipment that conditioned the indoor space. Today the emphasis of filter performance is not only on the mechanical equipment, but also on the inhabitants and the "product" in the conditioned space. This "product" can be people in an office building, patients in a health care setting, semiconductor chips in a manufacturing facility, or artwork in a museum.

Indoor air quality is also a concern today. Air filters generally are not the primary cause of IAQ problems and generally are not the only solution to these problems. However, air filters do play a significant role in IAQ. Air filters also play a role in protecting the "product." Correct filter selection is a critical process in protecting the "product" and in reducing IAQ complaints. In addition, this selection process affects overall mechanical equipment performance.

For example, filter resistance to airflow has an impact on energy costs. Filter efficiency also affects energy cost. A low efficiency filter may have a low resistance to airflow (energy savings), but allows more particulate onto the coil. This particulate acts as an insulator, which reduces heat transfer across the coil, increasing energy use. In addition, with new carbon composite filter products it is possible to bring in less outside air and still maintain an improved indoor environment.

In a recent interview with Warren Young, Director of Engineering Services, Museum of Fine Arts Boston, we discussed particulate and molecular contaminants that are a problem in a museum setting. Warren works in a multi-use facility where art is stored and displayed. There are 800 employees as well as retail and restaurant space. His first priority is employee and visitor comfort followed by the well-being of the artwork.

Because his HVAC systems provide air to all areas of this multi-use facility, high efficiency filters are used. Small respirable particles less than 10 microns in size can cause IAQ problems and create problems in the galleries and art storage. Specifically, carbon black particles generated from internal combustion engines and power plants can stain the artwork. His filtration system removes a good percentage of this particulate.

Another problem is the amount of visitor traffic in the galleries and retail space. This traffic creates a tremendous amount of particulate, which is introduced into the HVAC system through return air ducts. Mold and fungi are a concern where the art is displayed and stored. Mold and fungi can eat the canvas, paper, wood and paint that are present in paintings.

A typical filtration system at the Museum of Fine Arts Boston consists of a 30% pleated filter, 65% synthetic bag filter, followed by a 95% synthetic bag filter. Mr. Young has tried some of the new technologies in the IAQ field. Synthetic media have replaced fiberglass media. In addition, he has recently installed UV-C high output lights downstream of a cooling coil in a prototype unit. The initial results are very good with no microbial growth in this unit and the elimination of odors. He plans to systematically install lights throughout his facility.

The high output UV-C lamps also allow Mr. Young to sterilize his coils and humidification pads without using chemicals. In many cases he cannot use chemicals due to the possibility of a reaction with displayed and stored artwork.

Although the Museum of Fine Arts Boston considers many new technologies, their success is due to the diligent efforts of their maintenance staff. Mr. Young states that maintenance is the key issue. His filter maintenance includes regular reading of filter resistance, visual inspection and a predetermined filter change out. He also looks for a quality filter that will not blow out or fail. A filter failure would create huge problems in his galleries and retail space.

How Filters Work

Since we know that certain size and types of particles are important to remove from museum air, let's look at the different ways mechanical filtration works. There are four methods of filtration. Depending on the type of filter, usually one of the four methods prevails, but all methods are involved in capturing particles on the filter media. The four methods of filtration are:

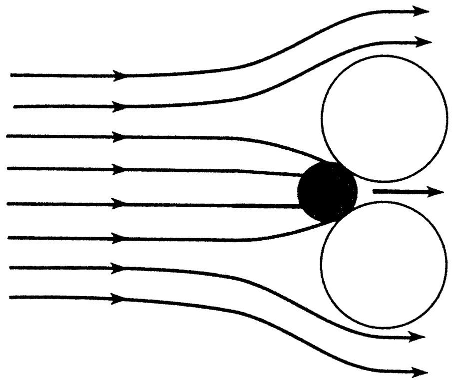

Figure 1: Straining.

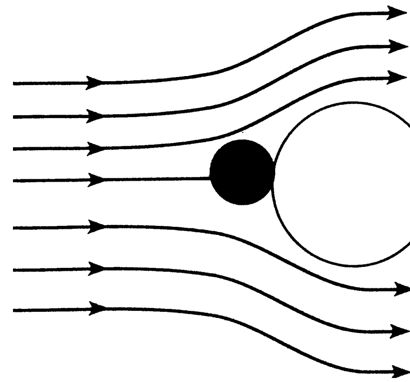

Figure 2: Impingement.

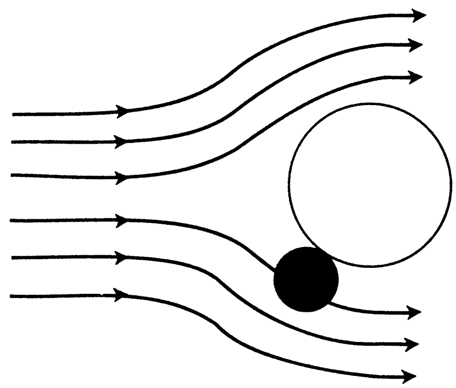

Figure 3: Interception.

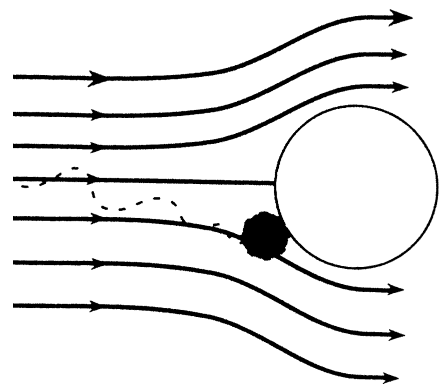

Figure 4: Diffusion.

1. **Straining:** This process occurs when the particle is larger than the opening between media fibers. Straining is the dominant method of particulate removal in low efficiency air filters.
2. **Impingement:** This process occurs when a large, dense particle cannot follow the airstream around media fibers and so collides with the fibers. The particle then attaches to the media. Sometimes the media are coated with an adhesive, which helps keep particles attached to the media. Again, this is the dominant method of particulate removal in low efficiency air filters.
3. **Interception:** This process occurs when a particle moves with the airstream through the filter media. At some point the particle becomes attracted to the media fibers, leaves the airstream and attaches itself to the media fibers. Interception occurs with larger particles and is the primary method of particulate removal in medium efficiency air filters.
4. **Diffusion**: This process occurs with very small particles. Air molecules influence how these small particles move through the filter media. The small particles collide with the air molecules and move in an erratic path (Brownian movement). This path allows for the small particle to come in contact with the media fibers and stay attached. Diffusion is the dominant method of particulate removal in high efficiency air filters.

Filter Testing/Comparison

When considering different types of air filters, it is important to look at the performance of the filter. The three major components to filter performance are:

Efficiency: The percentage of airborne particulate the filter will remove.

Dust-Holding Capacity: The amount of dust the filter will hold before being changed.

Resistance: The resistance to airflow, measured in inches of water gage (Pa), of the filter.

ASHRAE Standard 52.1-1992, *Gravimetric and Dust Spot Procedures for Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter* is the accepted test method for air filters. This test determines efficiency, dust-holding capacity and resistance and is performed in an ASHRAE test duct.

"Efficiency is determined by comparing the discoloration of two targets, one sampling atmospheric air upstream of the filter under test and the other sampling on the downstream side of the filter. Since the filter will remove some of the staining portion of the atmospheric dust, the downstream target will discolor more slowly than the upstream one."[1]

Dust-holding capacity is determined by feeding ASHRAE test dust at a predetermined rate of 2 grams per 1,000 cfm (472 L/s) of air into the test duct and measuring the amount of dust captured in the filter. ASHRAE Standard 52.1-1992 clearly states that the dust-holding capacity of a filter will not necessarily equate to real-life filter performance. This is due in part to the use of ASHRAE dust, not atmospheric dust, and also due to the makeup of particulate in the test location versus where the filter will actually perform.

Initial resistance is of a clean air filter at a rated air velocity, usually 500 fpm (2.5 m/s).

Final resistance is measured on a dirty filter when the test is completed. It is important to note the airflow rate and final resistance for each filter tested. Both the flow rate and final resistance will have an impact on efficiency and dust-holding capacity.

Standard 52.1-1992 is a useful tool in comparing the performance between different filters. Its biggest drawback is that this test method does not give efficiency by particle size for different filters, which is a critical piece of information needed in filter selection.

ASHRAE Standard 52.2P, *Method of Testing General Ventilation Air Cleaning Devices for Removal Efficiency by Particle Size*, Public Review Draft, which is under public review, is the proposed test method that will replace Standard 52.1-1992. Standard 52.2P will report efficiency by particle size and will do so with a high degree of repeatability. This proposed test method addresses two components of filter performance: the ability to remove particles from the air, and the resistance to airflow. The reporting of dust-holding capacity has been dropped from this test.

"This test procedure uses laboratory generated potassium chloride particles dispersed into the airstream as the test aerosol. A particle counter measures and counts the particles in 12 size ranges both upstream and downstream for the efficiency determinations. This standard also defines a method of loading the air cleaner with synthetic dust to simulate field conditions. A set of particle size removal efficiency (PSE) performance curves at incremental dust loading are developed and together with an initial clean performance curve are the basis of a composite curve representing the minimum performance in each size range. Points on the composite curve are averaged and the averages are then used to determine the classification rating of the air cleaner."[2]

The classification of air filter performance is much different in Standard 52.2P than in Standard 52.1-1992. In the past, filters were classified as an average efficiency as reported on the Standard 52.1-1992 test report. The new proposed test method will classify the filter by a minimum efficiency on a particle size. For example a 90% to 95% efficient filter will soon become classified as an H13 filter, where H stands for high efficiency and 13 is an arbitrary classification based on numerical efficiency. Standard 52.2P will enable the end user to select the best filter for an application and will provide a better comparison between different filters.

Filter Types/Filter Construction

As mentioned earlier, all four methods of filtration occur to some extent in different types of filters. These filters can be classified in four groups: low efficiency, medium efficiency, high efficiency and HEPA-type filters.

Most low efficiency filters are pad or panel type filters, with average ASHRAE efficiency reaching 30%. In a museum, these filters would be used as prefilters to remove large particles (10 microns and larger) from the supply air and return air.

Medium efficiency filters can be bag type or box type filters with an ASHRAE efficiency range between 40% and 60%. These filters would be typical of a second stage filter in a museum. These medium efficiency filters effectively remove particles in the 10 to 3 micron range. Removing these particles will greatly enhance the performance and life of high efficiency final filters.

Medium efficiency filters vary in construction with resulting differences in cost and performance. The main cost of the filter is the media. The backer and the frame also affect cost and performance. A welded wire backer costs more than an expanded metal backer but offers a performance advantage. A welded wire backer allows radial (rounded) rather than "v" shaped pleats. The radial pleat allows more air to contact the filter media. A beverage board frame costs more than a cardboard or kraft paper frame. The chemically treated beverage board resists moisture, bowing, and collapsing better than cardboard or kraft paper.

High efficiency filters can be bag type or box type filters with an average ASHRAE efficiency between 80% and 90%. These filters are typically used as the final filter in an HVAC filtration system. These filters will effectively remove over 70% of particles 0.3 micron and larger.

There are many new technologies being used and developed in the air filtration field. New filter media are an important technology being used. Specifically, synthetic media provide high performance in wet or moist conditions and deliver improved overall performance.

Electrostatically-charged media also provide very high performance. This charge enables the filter to have very high initial efficiencies with a low resistance to airflow. This media is electrostatically charged at the factory and then made into either a bag type or box type filter.

New pleating technologies are providing filter media without the use of separators. These separators hold the pleats in position and are often made of corrugated aluminum sheet. Eliminating the need for separators reduces pressure drop, provides more even airflow, and exposes the full media surface to the airflow. These mini pleat box type filters without separators reduce the physical dimensions of the filter. Antimicrobial agents are used to help reduce the colonization and proliferation of microbes on the air filters. Also, heat sealing of the filter during construction is a major advancement. This heat sealing is common in bag type filter construction and is replacing the old stitch construction of fiberglass bag filters.

Synthetic bag filters are replacing fiberglass bag filters. The new synthetic media reduce fiber shedding, provide longer life and lower resistance, and are available with an antimicrobial treatment.

Mini-pleat box filters are replacing separator type box filters used in VAV systems. These new mini-pleat filters have much lower resistance, have a lifespan of between two and three years, provide lower energy costs, and are the lowest cost filters to operate over the filter's life. These filters also reduce the size of the filter and in new applications can reduce the cost and size of the filter housing.

Also new in filtration technology is the development of new carbon composite media, which can provide a significant performance increase over carbon trays or bulk carbon in HVAC applications.

Molecular Filtration

Awareness of the issues and role of molecular contamination on indoor air quality has prompted the development of many new filtration technologies and products. Many sources of molecular contamination exist inside building environments and out. Merely increasing air change rates and outside makeup air does not guarantee chemically pure air. Outside pollution sources include such items as vehicle exhaust and combustion byproducts from industrial processes, as well as industrial and commercial exhaust systems. The volume of chemical contamination in most urban areas is measured in tons per day.

Combustion products contain irritants such as nitrogen dioxide (NO_2) sulfur dioxide (SO_2) as well as formaldehyde (HCHO). Engine exhaust fumes from cars and especially from diesel vehicles and jet engines produce many volatile organic compounds (VOCs) which can be odorous even at very low levels. Ozone (O_3) is a common outdoor pollutant that varies with weather but can reach problematic levels during various seasons. Even buildings in rural areas near farms or factories can see elevated levels of ammonia (NH_3), hydrogen sulfide (H_2S), and hydrogen chloride (HCl). These and many other outdoor pollutant sources can add to rather than dilute the chemical environment inside a building. These odorous and corrosive pollutants can pose a significant problem in critical environments such as semiconductor clean rooms, hospitals and museums.

Indoor sources of molecular contamination can be equally concerning. Human metabolic byproducts include hydrogen sulfide, ammonia and carbon dioxide. Electronic equipment-generated ozone as well as fugitive chemicals from housekeeping activities can rival or exceed pollutants from outdoor sources. Even internally generated VOCs from the off gassing of synthetic materials used in construction contribute to IAQ problems. Unlike outdoor levels of chemical pollution, which are highly variable, inside levels tend to maintain at a more steady state and are cumulative in nature.

Not unlike particles, molecules do have size. However, while particle levels are measured in intuitive units (numbers per unit volume), molecule levels are measured in concentration units such as parts per billion (ppb) or parts per million (ppm). Molecule size is measured in angstroms (1/10,000,000,000 of a meter). They are in general 1000 to 10,000 times smaller than a fine dust particle and so pass through the finest particle filters. Being of this extremely small size and weight, they pose different challenges for collection and removal than do particles. To evaluate many of the new technologies being introduced for gas-phase filtration, it is important to understand the behavior of molecular contaminants and the principle of gas-phase filtration.

Particle contaminants move through the air in air currents. Molecules in contrast move by diffusion. If a chemical contaminant were introduced to one side of a large room with no air movement, it would simply be a matter of time before the chemical would be detected uniformly through the room. The molecules would diffuse through the room from an area of high concentration to areas of lower concentration until we had a homogenous concentration throughout. The speed and force with which the contaminant travels is called diffusion gradient.

Molecular contaminants of low concentrations move with low speed and force. Most if not all applications in the HVAC arena are low concentration in nature. Concentration levels of problematic chemical pollutants will often be in the one to two parts per million ranges. Certain manufacturing environments, such as semiconductor fabrication shops, are concerned with concentration levels of molecular contaminants in the low part per billion ranges.

Two main processes are used in gas-phase air filtration in commercial HVAC applications. One is a reversible physical process known as adsorption condensation. The other involves adsorption and an irreversible chemical reaction known as chemisorption. Adsorption is a surface phenomenon. A vapor or gas will diffuse onto the surface of a sorbent such as activated carbon. Secondary diffusion can take place to move the pollutant further into the sorbent particle's center, fully utilizing all external and internal surface area.

In HVAC applications, concentrations are typically low and so is the diffusion gradient. With low diffusion gradient we will not take advantage of secondary diffusion and the tremendous surface area available within a carbon particle. Adsorption condensation in low level gas-phase filtration is therefore an outside surface phenomenon. Sorbent particle size, not mass, is key to good filter design. This understanding has been the driving force behind many of the new gas-phase filter products.

Adsorption Condensation

Adsorption condensation takes place when molecules of a pollutant diffuse onto the surface of a sorbent. The sorbent surface represents an area of relatively lower concentration of pollutant. The unique properties of the chemical will determine its behavior and the effectiveness of the adsorption process. A chemical's boiling point, vapor pressure, and reactivity all play a role.

In general, materials having a boiling point in excess of 100°C (212°F) lend themselves to adsorption condensation quite readily. The chemical will exist in a vapor but readily convert to its liquid phase when diffused onto a sorbent's surface. These materials will exist as a liquid at room temperatures. Adsorption condensation is a reversible process and pollutants of different molecular weights will compete for the same space on the sorbent surface. Temperature as well as moisture will also affect the adsorption process. Moisture competes for space on a sorbent surface making an adsorption-based filter less effective on a humid day.

Chemisorption

Chemicals or compounds that are highly reactive with low molecular weights and low boiling points exist in a gas state at room temperature. Pollutants of this nature may diffuse onto the surface of a sorbent, but will not convert to a liquid state and will quickly off gas or be displaced by other molecules. To capture these pollutants a process called chemisorption is used. In this process, a chemical reagent is added to the sorbent. The target pollutant reacts with the reagent on the sorbent surface forming a byproduct. To be effective, this byproduct must be highly stable.

For example, if we wished to remove a chemical with a very low boiling point such as hydrochloric acid, we might take a carbon sorbent and impregnate it with potassium iodide. The resulting chemical reaction on the surface of the sorbent would yield potassium chloride, which is a salt.

Salts are highly stable, and unlike hydrochloric acid, safe to handle and landfill. Unlike adsorption condensation, chemisorption is enhanced and in fact needs moisture for a reaction to take place. Many pollutants of concern in indoor air quality are of low molecular weights and require filtration products that utilize this chemisorptive process.

Generally, if you want to remove a pollutant that is a base in nature (pH > 7), the reagent would be an acid. Likewise, if your pollutant were an acid, a reagent in the base family would likely be selected. Chemisorption is a nonreversible process. Filter products using this principle can not be regenerated.

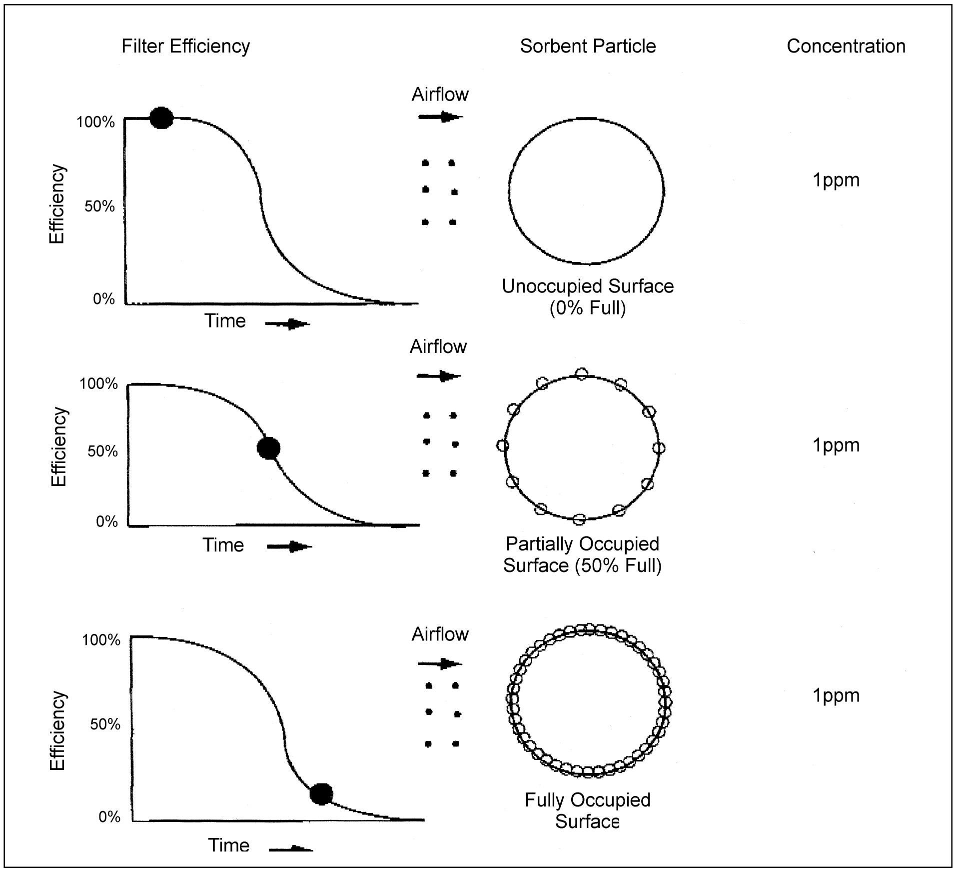

Figure 5: Sorbent filter efficiency over time.

New Products

Gas-phase filters based on adsorption condensation or chemisorption have been around for decades. Refillable charcoal tray systems are perhaps the most popular. These packed bed media filters typically use activated charcoal in the 6–8-mesh range. In some cases potassium permanganate is used if chemisorption is required. These products are typically designed to offer proper surface area and residence time of the pollutant in the media bed. The largest drawback to these products was their physical size and weight, as well as the dust created during servicing. Newer technologies that use smaller geometry activated carbon are emerging. These products offer more outside surface area vs. mass.

Using this smaller geometry carbon in clean media composites offers many advantages. The weight and size of many new gas-phase filters are less than 1/10 that of comparable tray systems. These new products can fit in standard HVAC filter frames and are very clean. There is no dusting in the air stream or mess during change out. With demand for performance in gas-phase filtration, many of these newer products offer reagent treated sorbent as well as standard activated carbon.

Performance charts for common target pollutants are available. Performance data is critical in evaluating many of these new technologies. Carbon impregnated polyester media as well as partial air by-pass filters may have similar construction characteristics but vastly difference performance.

Testing Gas-Phase Filters

Testing gas-phase filters and interpreting the results has always been difficult. Most filters used in HVAC applications see only low level concentrations. Any test using high concentrations of a challenge chemical will not accurately characterize the remaining surface area available for collection of low level contaminants. All sorbent-based filters have a decreasing efficiency curve with service life (see *Figure 5*). Knowing what a threshold efficiency level should be in a particular application is difficult. Certainly, someone wanting to reduce annoying odors in an office building will have different parameters than a museum seeking to protect artwork.

Real-time monitoring or air sampling is the most accurate method. Upstream and downstream concentration levels charted over time yield reliable filter efficiency curves at concentration levels characteristic of that application. With many of the new gas-phase filtration products, sampling the media alone for laboratory testing is not possible.

Conclusion

Increased awareness of indoor air quality has fostered many new filtration technologies. Filters with greatly enhanced performance are available for both particulate and gas-phase filtration. To understand these new technologies often requires understanding the basic filtration principles under which they were designed. Looks can be deceiving, and many new designs may even challenge one's sense of logic. The common characteristic of many of these new products is higher removal efficiencies and lower life cycle cost. Problems can be solved and efficiencies realized by applying many of these newer products.

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