Air Filtration and the Use of HEPA Filters in Biological Safety Cabinets

Introduction

Air filtration is a topic affecting everyone's lives, whether it is for occupational safety requirements, environmental or home health concerns. Control of airborne particulates in indoor environments is critical to develop quality products, protect employees from contact with hazardous materials, or prevent health problems from prolonged exposure to allergens. How airborne particulates are controlled varies from industry to industry and from an occupational setting to a home environment. To better understand why HEPA filters are used in the biological safety cabinet industry, it is necessary to explore particle sizes, types of filters available for home and occupational use, efficiency and penetration, filter standards and performance testing.

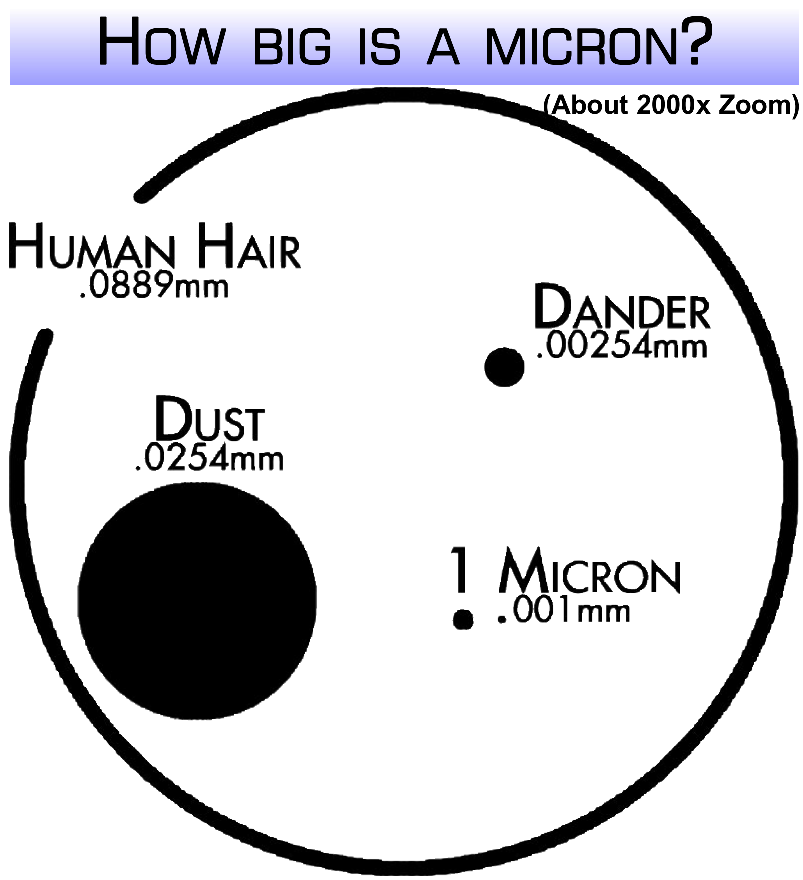
Particles and Relative Micron Size

Particles are generated or become airborne with everyday human activity. Because many people spend the majority of their time indoors at work or home, the quantity of particles floating in the air are of great concern. For example, a sedentary person in a standing or sitting position generates approximately 100,000 particles per cubic foot. Moving from a sitting to a standing position generates 2.5 million particles per cubic foot. Moderate activity generates 30 million particles per cubic foot. Industrial processes in manufacturing or machine shops generate billions of particles per cubic foot.

Airborne particles vary in size depending upon the source. A strand of human hair is a good reference point when considering the relative size of large and small airborne particles. Consider the following common materials and their relative size in microns (millionths of a meter):

- Human Hair: 50-150 microns
- Household dust and lint: 0.01-100 microns
- Pollen: 10-110 microns
- Mold: 1-50 microns
- Pet dander: 0.1-10 microns
- Tobacco Smoke or Soot: 0.01-1 micron
- Viruses and Bacteria: 0.001-10 microns

Why be concerned about the size of the above particles? Solid and liquid particles smaller than 10 microns can aggravate health conditions and cause respiratory problems in humans. A healthy human body can filter out particles as small as the 3-5 micron size via the respiratory system however, it is exposure to smaller sub-micron particulate matter that can present health risks in humans.



Home Consumer Air Filtration Products

Air cleanliness is a trend in the home consumer product market due to increased awareness of health problems caused by allergens. Consumers now have a wide variety of filtration products available to them to help control unwanted allergens including pet dander, dust, pollen, mold spores and lint. While the following filters used in the household product industry are effective to a certain degree at trapping particulate matter suspended in the air flowing through them, note that none are effective at controlling vapors or odors.

Home HVAC systems can be fitted with conventional disposable fiberglass filters to trap large particles such as lint and dust. The primary function of such filters is to protect the heating and cooling unit from large particles prematurely wearing the fan motor and components. Because fiberglass filters are a flat design and the media is relatively porous, such filters are only 2% effective at trapping sub-micron particles.

Disposable, pleated media home furnace filters have folds in the filter media to increase the surface area of the filter in order to trap a wider spectrum of particles. Even with the additional filter media and increased surface area, this type filter will typically trap only 5-10% of smaller sub-micron particles.

Washable fiberglass media filters are also available for home HVAC systems. Despite the fact that these filters are reusable, the filters will retain some particulate after washing, thus reducing the life of the filter with every cleaning and increasing particulate retained in the filter.

Electrostatic charged filter media uses positively and negatively charged filter media to attract opposite charged particles from the air circulation to the filter. This feature is added to a pleated filter design to improve trapping of particles to the 0.3 to 1 micron range. The addition of the electrostatic charge improves trapping efficiency to 20-60% of sub-micron particles.

Electronic air filters are available as units fitted to a home heating and cooling system or as stand-alone filtering systems. These filters employ an electric field to attract and trap charged particles to plates within the system. While effective at trapping smaller particles, routine maintenance involves weekly or monthly cleaning for peak performance.

Ionic filtering systems add negatively charged ions to filter media to cause particles to adhere to one another in the air, creating larger particles that are more easily trapped by air filter media, or these filters cause particles to settle within the room. Ionic systems are commonly sold as stand-alone air purifying units.

Activated carbon filter systems can be added to an HVAC system to help control odors in the home. This type of filter is an absorbent filter that will retain certain vapors passing through it to control odors or chemical smells. Because it does not trap particulates, an activated carbon filter is typically used in tandem with another particulate retention filter.

High efficiency particulate air (HEPA) filters are becoming more commonplace in the household market. In the past these filters where used primarily in the clean room and biosafety technology markets, however, today HEPA filters have become a household name as consumer product manufacturers market HEPA filters to improve home air quality. Vacuum cleaners and HVAC systems are now fitted with HEPA filters. Generally, HEPA filters are 99.97% efficient at the 0.3 micron particle size and are therefore very effective on sub-micron particles. However, as with any media-type filter, the surface area or the size of the filter and the number of air exchanges through the filter will ultimately determine how effective the filter is at retaining particles. For example, although many household vacuum cleaners have HEPA filters attached to the air intake on the vacuum, the diminutive size of the filter and the limited time the vacuum is operating during household cleaning compared to the size of the living space equates to a minimal effect on the overall air quality within the home.

In occupational settings, HEPA filters control particulates to protect the product, personnel, and environment or all three. Depending on the requirements within the industry, various types of HEPA filters are used to achieve the desired effect.

Biological Safety and High Efficiency Particulate Filters

A filter's efficiency rating describes the relationship between particles retained or trapped by the filter to the number of particles entering the filter. For example a 99.97% efficient filter indicates that 99.97% of particles entering the filter are removed from the air by the filter. To further describe efficiency, a filter is also rated by the size of particles at which it is most susceptible to particles passing through it, or its weakest point of particle penetration. Filter penetration is defined as the ratio of particles that pass through the filter media without being trapped to the number of particles that actually enter the filter.

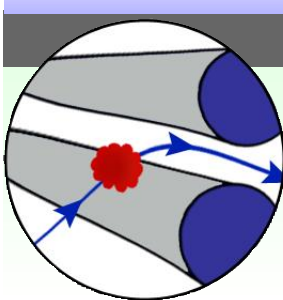
A filter that is 99.97% efficient at 0.3 microns is 99.97% effective at trapping particles at its most vulnerable size of 0.3 microns. For particles that either larger or smaller than 0.3 microns, the filter is actually more efficient than 99.97%. In this example, 0.3 microns is considered the filter's most penetrating particle size (MPPS), in other words, 0.3 microns is the size particle at which penetration of particles through the filter is highest.

In biological applications, laboratory personnel regularly work with microorganisms in biological safety cabinets. HEPA filters used in these cabinets must effectively trap hazardous bacterium and viruses to provide personnel protection. Although an individual virus particle ranges in size from 0.005 to 0.1 micron, viruses generally only survive to travel through the air as part of larger particles (0.3 micron or larger), for example, attached to mucous particles. Because it is difficult to disperse or aerosolize single viral particles and because of the particle collection mechanisms of HEPA filters, particles larger and smaller than a filter's most penetrating size are collected with greater efficiency.

As air passes through a HEPA filter, the air is not simply strained as many presume, rather a number of actions take place. First, as the air comes into contact with the bends and folds of the pleated filter media, the volume of airflow breaks off into numerous smaller air streams as its own velocity and the velocity of the air upstream forces the air through the filter. Some particles become trapped because they are larger than the pores of the filter media, and cannot pass through. This takes place throughout the filter media, not solely at the surface of the filter. For large particles greater than 1.0 micron, the primary collection mechanism is impaction. Impaction occurs when air traveling through the filter and the particles suspended in it encounter a web of randomly placed fibers in the folded filter media through which it must traverse. Although the air can change direction to weave through the filter fiber maze, the tendency of particles is to continue on the same trajectory and to collide with the filter media, resulting in entrapment. For small particle entrapment in the 1.0 micron or smaller particle size range, diffusion is the primary collection mechanism. Small aerosolized particles behave similarly to gases in that they move from an area of higher concentration to an area of lower concentration. Particles are removed from the air stream as they settle in areas of low airstream concentration at the fiber surface where other particles are already trapped. The combination of aforementioned collection mechanisms results in effective removal of particles from a HEPA filtered air stream.

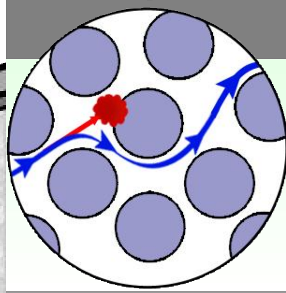
Methods of Collection

Interception



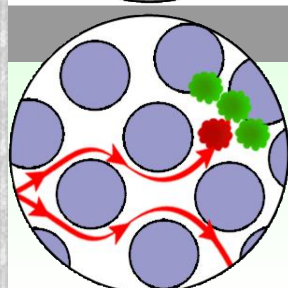
Particles are collected whenver they touch a fiber as they traverse the media.

Inertial Impaction



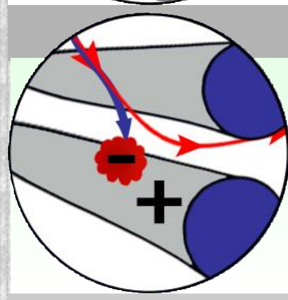
Particles are collected as they travel in a straight path and collide with a fiber. Air continues to flow around the fiber.

Diffusion



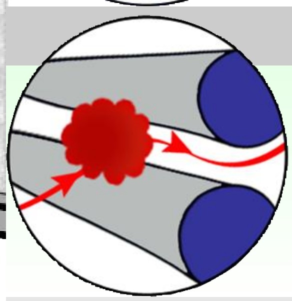
Particles are collected as they travel from areas of high airflow to areas of low airflow, where other particles may already be trapped.

Electrostatics



A negatively charged particle is attracted to a positively charged fiber, causing the particle to attach to the fiber as it traverses the media.

Sieving



Particles are too large to pass between fibers and become trapped against them.

Gravity

Particles naturally fall onto fibers and become trapped as a result.

Filter Performance and Industry Standards

In the United States, the Heating, Ventilating and Air Conditioning (HVAC) industry uses filter efficiency ratings defined by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 52.2 testing. A Minimum Efficiency Reporting Value or MERV rating is assigned to each filter. A higher MERV value indicates better filtration. MERV ratings are used in home consumer products to give an indicator of the product's effectiveness.

In Class II biological safety cabinets, the type of filter required is defined by a standards organization. In the North America, the NSF Standard 49 details the construction and performance requirements of Class II biological safety cabinets. To comply with the NSF standard, Class II cabinets must utilize Type C HEPA filters that are 99.99% efficient at 0.3 microns for the supply and exhaust airflow. The types of HEPA filters available are classified by RP types as defined by the IEST RP-CC-001.3 standard on HEPA and ULPA filters according to the filter's efficiency and penetration at a specific particle size. Although other types of HEPA filters with different efficiencies are classified by the IEST standard, the Type C filter is the standard for use in biological safety cabinets.

HEPA filters are tested by challenging the filters with an aerosolized product of known size to determine the filter's efficiency at that specific size. For example, D.O.P or P.A.O. is forced through the filter using an aerosol generator. The filter is then scanned using a photometer, or aerosol detection device, to measure the mass of the particles in the airflow both upstream and downstream of the HEPA filter and to ultimately calculate the efficiency of the filter at the testing particle size.

In addition to HEPA filters, the IEST standard also classifies ULPA (ultra low penetration filters) and Super ULPA filters by type. Generally ULPA filters have a higher efficiency rating from 99.999 to 99.9999% at a smaller micron size (0.1, 0.2 or MPPS). Although it may seem that more is better, ULPA filters are intended for use in industries such as the semi-conductor industry where the types of particles that are detrimental to semi-conductor manufacturing and development are dispersed at smaller sub-micron sizes. For biological applications, there is no gain in using an ULPA filter compared to a HEPA filter. As explained previously, microorganisms and viruses are not airborne in single particles, but rather are grouped together in larger particles or are attached to other particles in air. Use of an ULPA filter in a biological safety cabinet creates more resistance in the airflow dynamics of the cabinet, requiring a larger blower motor to maintain proper airflows. A larger blower motor will add increased noise level to the cabinet, and potentially increase vibration levels. Additionally, ULPA filters require a different testing protocol with equipment that is generally not maintained by biological safety cabinet certification companies. To test ULPA filters, aerosolized polystyrene latex spheres of specific size are introduced to the air stream. A laser particle counter then measures the size and number of airborne spheres to determine efficiency of the ULPA filter.

In Europe, the EN standard 12469 defines Class II biological safety cabinets and filters that must be used for compliance to the standard. The EN 12469 requires a class H14 HEPA filter as defined by the EN 1822-1 standard classifying HEPA and ULPA filters. An H14 HEPA filter is 99.995% efficient at its most penetrating particle size (MPPS). A specific particle size is not assigned in the classification of H14 filters. Per EN 1822-1, to test the filter for its MPPS, airborne particles are forced through the filter at the flow rate in which the filter will ultimately be used. A five channel particle counter reading particles 0.1, 0.2, 0.3, 0.4 or 0.5 microns in size is used to determine which channel allows the most particles through the filter. The MPPS is determined by choosing the particle size which has most frequently penetrated through the filter. As with the IEST standard for filters, the EN 1822-1 also includes classifications of other types of HEPA and ULPA filters, however, none is required for use in biological safety cabinets.

HEPA Filtration in Biological Safety Cabinets

After discussing particles size, various filter options, particle collection mechanisms and filter performance testing, it is evident why HEPA filters are the industry standard in biological safety cabinets. Particles generated in biological work fall into the spectrum of particles efficiently trapped by HEPA filters. It is a common misconception that ULPA filters given their smaller MPPS rating are somehow better than HEPA filters for biological applications. The known behavior of viruses and bacterium and the tendency of microorganisms to be dispersed in air as part of larger particles support use of HEPA filters for biological work. In addition to utilizing HEPA filters, a properly designed BSC must meet performance standards for airflow velocities, structural requirements and proven product containment capabilities to ensure user safety. HEPA filtration, biological safety cabinet design and user technique combined provide occupational safety in the biological laboratory.

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