Introduction to HEPA filtration systems

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Industries everywhere are discovering benefits to both product quality and human safety by using HEPA filters in their HVAC systems or in laminar flow applications.

High efficiency particulate air (HEPA) filters, once known as absolute filters, were originally developed as the particulate stage of a chemical, biological, radiological filtration and adsorber unit for use by the U. S. Armed Services. In the late 1940s, the U. S. Atomic Energy Commission (AEC) adopted them for use for the containment of airborne radioactive particulates in the exhaust systems of experimental reactors as well as for use in other phases of nuclear research.

In the years immediately following World War II, there was little market for HEPA filters beyond the needs of the military and the AEC. Probably the first major commercial user was Eastman Kodak, whose engineers evidently discovered the benefits of improving the quality of plant air relative to product quality and yield. Subsequently, an emerging aerospace industry followed the leadership of a group of engineers working at Sandia Laboratories in Albuquerque, N.M., who developed and patented laminar flow clean devices and rooms. Together, manufacturers and users have further developed and refined this important discovery.

In clean rooms, HEPA filters are used both to remove small particles and to straighten air flow.

Mechanisms of filtration

The HEPA filter is designed to be most economical at removing particles of about 2 μm or smaller in size. Much less expensive filters can be used to remove particles larger than that. HEPA filter paper, or medium, is made of glass fibers of very small diameter. These fibers crisscross randomly throughout the depth of the filter media. HEPA filter media do not have a controlled pore size. In fact, the spaces between fibers are quite often much larger than the particles captured. As an aerosol moves through the filter media, the entrained particles collide with the fibers or into other particles that are already stuck to the fibers. When this occurs, a variety of strong forces are established between the captured particle and the fiber or particle that has captured it.

Three mechanisms—impaction, diffusion, and interception—are believed to cause the small particles to arrive at a capture point. In capture by impaction, particles large enough (i.e., with enough mass) to have sufficient momentum leave the gas stream as the gas turns to move around a fiber. The particles then strike the fiber. In capture by diffusion, the small particles (i.e., those without sufficient mass to leave the gas stream on their own) move about randomly because they are being constantly bombarded by other small particles and molecules of the gas in which they are suspended. That random motion causes the smaller particles to touch the capture points. Finally, interception occurs when the particle strikes the capture point on a bias.

A fourth mechanism of filtration, screening or straining, can occur in a HEPA filter but, because of the prefiltration normally employed in air-handling systems, is not usually a significant factor. Straining means that the spaces between the fibers are smaller than the particles that are being captured.

Filter production

The media

The production of HEPA filter media begins with borosilicate glass microfibers. Fibers of various diameter size designations are blended together to make media of different characteristics. As a general rule, the greater the concentration of fine fibers, the higher the filter's efficiency and the greater its resistance to airflow.

The fibers are first weighed out and then blended in a slurry or pulp stock containing water and acid. The acid lowers the pH balance and helps achieve uniform distribution. The stock is transferred to a series of machine chests. These chests, equipped with agitation, eventually release the stock into a headbox through the approach flow located at the front end of a fourdrinier papermaking machine.

The pulp suspension is wet laid onto a fine mesh screen moving on a conveyor. Immediately, the water in the solution begins to fall free through the screen. A few feet further down, a series of vacuums is pulled on the paper machine wire to draw off the rest of the water. Water repelling chemicals and binding chemicals are applied just before the final vacuum, which pulls them through the entire depth of the paper as it is being formed.

The finished filter media are rolled in flat-sheet form. Filter paper in this form is used to make conventional separator-type filters.

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Separator type

In constructing a separator-type filter pack, the flat sheet is fed into a machine which pleats it back and forth as the operator inserts the separators. The separators, which are usually made of aluminum or kraft paper, are designed to keep adjacent folds of the filter media apart so that air flows evenly through the depth of the pack.

Separatorless type

At one time, all HEPA filters were made with separators. Flanders invented a process by which the paper could be molded to be self-supporting and self-separating. The purpose in developing this process was to overcome some of the problems that had been observed in the use of separators.

Experience had shown that in some applications, aluminum separators (the most common type) can tend to oxidize and generate particles in some environments. It was also discovered that separators caused an uneven loading of particulate across the filter media because of the obstruction in the filter pack.

The manufacture of separatorless media begins with the conventional flat sheet. A pattern of raised impressions, or "dimples," is formed in the flat sheet medium during the process. When the medium is pleated into pack form, these dimples align against each other to hold adjacent folds of the pack apart while giving it shape and stability. The result is a self-supporting, self-separating filter pack that avoids all of the problems associated with separator materials.

The frame

With or without separators, the HEPA filter pack is a delicate component that needs a rigid frame for support and protection. The choice of frame materials depends on the filter's application. Fire-resistant wood, for example, is used extensively in containment application, but almost never in clean room applications, where aluminum is most often specified. Each frame material dictates its own method of assembly, but the objective in framing the filter pack is always to create a leak-free seal between the rigid frame and the soft filter media.

Sealing techniques

The diverse applications for HEPA filters have fostered the development of a wide range of specialized devices to house the filters. Since any leakage between the filter and its holding device can be a source of contamination, the method of sealing them together is an important consideration in the filter's design.

Gasket seal

A standard gasket seal is adequate for some applications. The neoprene gasket material is bonded to the filter frame with an adhesive. Usually, some sort of clamping device or special mating flange is needed to compress the gasket once it is mounted.

A gasketed filter may not be adequate in other applications. Experiments with many different types of gasket materials have shown that it is virtually impossible to create a long-lasting, leak-free seal with them because gaskets will take a set after being clamped for extended periods. This creates voids in the seal and allows unfiltered air to emerge on the downstream side.

Fluid seal

In 1968, Flanders Filters, Inc. patented two fluid seal concepts and introduced them to the market as an alternative to standard sealing methods using neoprene gasket materials and the attendant hardware, clamping devices, compression springs, etc.

The first fluid seal patent was issued for a HEPA filter ceiling system constructed of extruded aluminum U-channels and (at the junctions) die-cast aluminum connectors. The net effect was a grid of channels or canals, all interconnecting, which could be filled with a heated petroleum liquid which, when cooled to ambient temperatures, became highly viscous. Filters were constructed with a simple "knife edge" on the downstream side which, when the filters were installed, was immersed into the fluid to effect the filter-to-grid seal. There were no clamp arms required, since gravity and positive plenum pressure held the filters in place.

Testing

What distinguishes a HEPA filter from any other filter used in ventilation systems? Certainly, the efficiency is of paramount importance. Properly constructed and tested, a HEPA filter is remarkably efficient in removing extremely small particulate from the airstream passing through it. Current technology has enabled the development of filters which are reportedly 99.999995% efficient in removing particles 0.12 μm in size. Consequently, the test used to determine the efficiency of a HEPA filter is very different from the more familiar ASHRAE test used for most nonspecialized filters in HVAC systems.

The ASHRAE test is a destructive test, wherein a manufacturer submits a sample of his product to an independent laboratory. There, a test is performed in which prescribed amounts of dust are fed onto the filter in a test duct until a certain pressure drop is reached. The amount of arrestance (vs. the amount which escapes arrestance) over the life of the filter determines the efficiency rating. Since a filter's efficiency tends to increase during its life, it is the average lifetime efficiency of the filter that is assigned to an ASHRAE filter. Hence, a filter whose efficiency begins at 70% and ends at 90% might have a rating of 80%.

The hot DOP test

By comparison, the rating given a HEPA filter emanates from a much more stringent test called the "hot" DOP test. The DOP test is also a test of the filter's average efficiency, but in a different sense from the ASHRAE test. It is a test of the average initial efficiency rather than the average lifetime efficiency of the filter. It is also a non-destructive test that should be performed on every HEPA filter and not upon a production sample, as in the ASHRAE test.

In the DOP test, which lasts about 20 s, the filter is challenged with a thermally generated ("hot") dioctylphthalate (DOP) aerosol having a homogenous particle size of 0.3 μm. A sample is taken upstream of the filter, and that value is accepted at 100%. Another sample is taken downstream to determine the percentage of penetration of the challenge aerosol.

Two values are taken and recorded during the hot DOP test: penetration and pressure drop. Because a HEPA filter must by definition have a minimum removal efficiency of 99.97% upon 0.3 μm particle size and larger, the penetration value cannot exceed 0.03% (100 - 99.97 = 0.03%). Pressure drop cannot exceed 1.0-in. wg at rated or test flow. If one accepts the premise that a filter becomes more efficient as it accumulates material in service, then the filter has been tested during its most vulnerable period.

The scan test

The necessity of scan testing HEPA filters used in critical applications arises from an important limitation of the DOP test: the inability to locate minuscule leak points that frequently occur in the filter media. A HEPA filter having a penetration reading of 0.03% would indicate the passage of at least some of the challenge aerosol through the filter medium. Indeed, a fair percentage of HEPA filters which pass the DOP test can still have some identifiable areas of higher penetration. These are usually termed "pinhole" leaks and cannot be found by the hot DOP test. They occur simply because the effluent from the filter passes through a series of baffles designed to mix the penetrating particulates with clean air prior to the second test sample being taken.

Sandia Laboratories' early researchers into clean room techniques developed a procedure to scan or probe the downstream face of a bank of filters in a laminar flow system, not only to locate pinhole leaks in the filter element, but to determine whether the filters were sealed to their mounting frames. A challenge aerosol, usually a cold DOP with a particle size range from 0.1 to 3.0 μm (polydispersed), is generated and introduced upstream of the filter bank while the system is in operation. The downstream side is probed with a portable forward light-scattering photometer. Pinhole leaks and filter-to-frame leaks are identified and patched.

Any leak greater than 0.01% of the challenge is repaired. Simply stated, then, the scan test is a defect test. Most filter manufacturers now routinely sell scan tested filters for laminar flow applications (vs. unscanned filters for nuclear or industrial uses).

The laser test

One of the most recent advances in HEPA filter testing is the laser efficiency test. The single particle size spectrometer operates much like the DOP test instrument except that it uses laser as its light source.

The highest reliable reading that can be obtained on the DOP test instrument is just under 99.99% on 0.3 μm. This upper limit of sensitivity was not a problem until the late 1970s, when the production of integrated circuits began to require unprecedented levels of air cleanliness. Although it was known that higher efficiency filter media could be manufactured, the production of higher efficiency filters was hindered because there was no way to verify their performance on a production scale. The problem was solved in 1979 by the development of the dual laser spectrometer, which accurately detects and measures particles as small as 0.1 μm.

A cold DOP challenge is introduced into the system while the dual laser spectrometer samples simultaneously on the upstream and downstream sides of the filter. A computer printer produces a histogram which presents the efficiency data in both tabulated form and as a graph. This sophisticated test system provides the operator with the filter's efficiency at 31 slightly overlapping levels of particle size.

The dual laser spectrometer test method has been adopted by major filter manufacturers. Although there is not yet a written standard published for its use, it promises to supplant the hot DOP test.□

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