EPA-452/F-03-023

Air Pollution Cocntrol Technology Fact Sheet

Name of Technology: Paper/Nonwoven Filter - High Efficiency Particle Air (HEPA) Filter
- Ultra Low Penetration Air (ULPA) Filter
(also referred to as Extended Media)

Type of Technology: Control Device - Capture/Disposal

Applicable Pollutants: Submicron Particulate Matter (PM) greater than or equal to 0.3 micrometer (μm) in aerodynamic diameter, and PM greater than or equal to 0.12 μm in aerodynamic diameter that is chemically, biologically, or radioactively toxic; hazardous air pollutants (HAPs) that are in particulate form, such as most metals (mercury is the notable exception, as a significant portion of emissions are in the form of elemental vapor).

Achievable Emission Limits/Reductions:

HEPA and ULPA filters are classified by their minimum collection efficiency. Many international standards and classes currently exist for high efficiency filters (Osborn, 1989). In general, HEPA and ULPA filters are defined as having the following minimum efficiency rating (Heumann, 1997):

HEPA: 99.97% efficiency for the removal of 0.3 μm diameter or larger PM,
ULPA: 99.9995% efficiency for the removal of 0.12 μm diameter or larger PM.

Some extended media filters are capable of much higher efficiencies. Commercially available filters can control PM with 0.01 μm diameter at efficiencies of 99.99+% and PM with 0.1 μm diameter at efficiencies of 99.9999+% (Gaddish, 1989; Osborn, 1989). Several factors determine HEPA and ULPA filter collection efficiency. These include gas filtration, velocity, particle characteristics, and filter media characteristics. In general, the collection efficiency increases with increasing filtration velocity and particle size. In addition, the collection efficiency increases as the dust cake thickness and density increases on the filter (EPA, 1998a).

Testing of the collection efficiency for HEPA and ULPA filters is performed under clean filter conditions. This is in contrast to continuously cleaned-type filters, such as baghouses, which are tested after reaching a steady-state pressure drop. Cleaned-type filters have nearly constant effluent particle concentration, whereas HEPA and ULPA filters have overall efficiencies which vary with particulate loading. (Heumann, 1997)

The efficiency of each filter is tested by the manufacturer before shipping. For nuclear applications, additional tests are required by the Department of Energy (DOE) and by the owner/operator after installation (Burchsted et al, 1979). There are two separate tests for HEPA and ULPA filter collection efficiencies. HEPA efficiency is rated using a thermal dioctyl phthalate (DOP) test. The test dust for HEPA filters is mono-sized, 0.3 μm diameter, DOP particles, generated by vaporization and condensation. Alternative aerosols can also be used as specified or required for given applications. A photometer measures the particle penetration of the HEPA filter by sensing the scattering of light. ULPA efficiency is tested using a particle counter upstream and downstream of the filter. An atomizer injects a solution of DOP, alcohol, and mineral oil in hexane to generate particles ranging from of 0.1 to 0.2 μm in diameter (Heumann, 1997).

Applicable Source Type: Point

Typical Industrial Applications:

HEPA and ULPA filters are best applied in situations where high collection efficiency of submicron PM is required, where toxic and/or hazardous PM cannot be cleaned from the filter, or where the PM is difficult to clean from the filter. HEPA and ULPA filters are typically utilized for applications involving chemical, biological, and radioactive PM. HEPA and ULPA filters are installed as the final component in a PM collection system, downstream from other PM collection devices such as electrostatic precipitators or baghouses. (Heumann, 1997)

Common industrial applications of HEPA and ULPA filters are hospital, low-level nuclear, and mixed waste incinerators and nuclear air ventilation and safety systems. In addition, the filters are used in a number of commercial applications and manufacturing processes such as clean rooms, laboratories, food processing, and the manufacture of pharmaceuticals and microelectronics (Osborn, 1989). The filters can be utilized in any application where dust is generated and can be collected and ducted to a central location.

Emission Stream Characteristics:

a. **Air Flow:** HEPA and ULPA filters are currently limited to low capacity air flow applications. Standard filter packs are factory-built, off the shelf units. They may handle from less than 0.10 up to 1.0 standard cubic meters per second (sm^3/sec) ((“hundreds” to 2,000 standard cubic feet per minute (scfm)) (AAF, 2000; Vokes,1999). HEPA filter systems designed for nuclear applications require higher capacities. For these applications, filter banks, or modules are ducted together in parallel to increase air flow capacity (EPA, 1991). Commercially available modular systems can accommodate air flow rates in the range of 5 to 12 sm^3/sec (5,000 to 40,000 scfm) (AAF, 2000; Vokes, 1999).

   Air flow capacity is a function of the resistance, or pressure drop across the filter and particle loading. As the dust cake forms on the filter, the resistance increases, therefore, the air flow rate decreases. Since the filter is not cleaned, the air flow rate continues to decrease as the system operates. After the pressure drop across the filter reaches a point that prevents adequate air flow, the filter must be replaced and disposed. For these reasons, HEPA and ULPA filters are used in applications that have low air flow rates or have low concentrations of PM (Heumann 1997).

b. **Temperature:** Temperatures are limited by the type of filter media and sealant used in the filter packs. Standard cartridges can accommodate gas temperatures up to about 93°C (200°F). With the appropriate filter media and sealant material, commercial HEPA filters can accept temperatures of up to 200°C (400°F). HEPA filters with ceramic or glass packing mechanical seals can accept temperatures up to 537°C (1000°F). (EPA, 1991)

   Spray coolers or dilution air can be used to lower the temperature of the pollutant stream. This prevents the temperature limits of the filter from being exceeded (EPA, 1998b). Lowering the temperature, however, increases the humidity of the pollutant stream. HEPA and ULPA filters can tolerate some humidity. Humidity higher than 95%, however, can cause the filter media to plug, resulting in failure (EPA, 1991). Therefore, the minimum temperature of the pollutant stream must remain above the dew point of any condensable in the stream. The filter and associated ductwork should be insulated and possibly heated if condensation may occur (EPA, 1998b).

c. **Pollutant Loading:** Typical pollutant loading ranges from 1 to 30 grams per cubic meter (g/m^3) (0.5 to 13 grains per cubic foot (gr/ft^3)) (Novick, et al, 1992). Dust holding capacity compares the weight gain of the filter to the rise in pressure drop during a specific period of time (air flow volume). Typical inlet dust holding capacity range from 500-1000 g/1000 scfm (Gadish, 1989). As discussed above, the pressure drop across the filter is a function of pollutant loading. HEPA and ULPA filters are best used in applications that have low concentrations of PM, or prohibit cleaning of the filter (Heumann, 1997).

d. **Other Considerations:** Moisture and corrosives content are the major gas stream characteristics requiring design consideration. As discussed previously, humidity up to 95% is acceptable with the proper filter media, coatings, and filter construction. Filters are available which can accommodate corrosive gas streams with concentrations up to several percent. These filters are constructed of special materials and are generally more expensive. (EPA, 1991)

HEPA and ULPA filters are monitored for pressure drop across the filter media. Once the pressure drop becomes unacceptable, the filter must be replaced. The typical pressure drop for a clean filter is 25 millimeters (mm) of water column (1 inches (in.) of water column). An increase of the pressure drop in the range of 51 to 102 mm of water column (2 to 4 in. of water column) indicates the end of the service life of the filter (EPA, 1991, Burchsted et al, 1979). Newer filters are available which have clean filter pressure drops in the range of 6 to 13 mm of water column (0.25 to 0.5 in. of water column) (Burchsted et al, 1979).

HEPA and ULPA filters are typically operated under pressure of approximately 203 mm of water column (8 in. of water column) High operating pressures may rupture the filter. HEPA filters utilized in the nuclear industry have seismic requirements in addition to the performance characteristics discussed above. (EPA, 1991)

Emission Stream Pretreatment Requirements:

HEPA and ULPA filters require pre-filtering to remove large PM or for dust concentrations greater 0.03 grams per centimeter squared (g/cm^2) (0.06 pounds per feet squared (lbs/ft^2)). Pre-filtering may be performed in several stages. Mechanical collectors, such as cyclones or venturi scrubbers may be required to reduce large diameter PM. Standard baghouse or cartridge filters are required to filter out PM greater than 2.5 µm in diameter. (EPA, 1991)

In high temperature applications, the cost of high temperature-resistant filter designs must be weighed against the cost of cooling the inlet temperature with spray coolers or dilution air (EPA, 1998b).

Cost Information:

The capital cost for a HEPA filter system is given below. The cost estimate assumes a factory-built, off the shelf modular design under typical operating conditions. The filter system is for a nuclear application and includes one test section and a pair of pressure sensors. Auxiliary equipment, such as fans and ductwork, is not included.

The estimate is based on a manufacturer quote for only the purchased equipment cost in 1999 dollars (AAF, 2000). The vendor did not provide operational and maintenance (O&M) cost, annualized cost, and cost effectiveness because they are application specific. The capital cost for HEPA and ULPA filters are significantly lower than for a baghouse, however, the O&M cost tends to be much higher. Requirements such as the frequency of filter replacement, monitoring and testing procedures, maintenance procedures, and waste profiles impact the O&M cost.

Costs are primarily driven by the waste stream volumetric flow rate and pollutant loading. In general, a small unit controlling a low pollutant loading will not be as cost effective as a large unit controlling a high pollutant loading (EPA, 1998b). HEPA and ULPA filters are currently limited to low flow rate applications. The capital cost range presented is for flow rates of 1.5 m^3/s (3,000, scfm) and 19 m^3/s (40,000 scfm), respectively.

Pollutants that require an unusually high level of control or that require the filter media, adhesives, or the filter unit to be constructed of special materials, such as stainless steel, will increase the costs of the system. The additional costs for controlling more complex waste streams are not reflected in the estimates given below. (EPA, 1991)

a. **Capital Cost:** $6,400 to $8,500 per sm^3/s ($3 to $4 per scfm)

b. **O & M Cost:** Application specific

c. **Annualized Cost:** Application specific

d. **Cost Effectiveness:** Application specific

Theory of Operation:

HEPA and ULPA filters generally contain a paper media. Newer filter designs may contain nonwoven media which utilizes recently developed fine fiber technology (INDA, 2000). Generally, the filter media is fabricated of matted glass fiber such as borosilicate microfiber (EPA, 1991). The small fiber diameter and high packing density of both the paper and nonwoven media allow for the efficient collection of submicrom PM (Gaddish, 1989). The waste gas stream is passed through the fibrous filter media causing PM in the gas stream to be collected on the media by sieving and other mechanisms. The dust cake that forms on the filter media from the collected PM can increase collection efficiency (EPA, 1998a).

The filter media is pleated to provide a larger surface area to volume flow rate. For this reason, HEPA and ULPA filters are often referred to as extended media filters. Close pleating, however, can cause the PM to bridge the pleat bottom, reducing the surface area (EPA, 1998a). Corrugated aluminum separators are often employed to prevent the media from collapsing (Heumann, 1997). The pleat depth can vary from 2.5 centimeters (cm) (1 in.) up to 40 cm (16 in.). Pleat spacing is generally between 12 to 16 pleats per in., with certain conditions requiring fewer pleats, 4 to 8 pleats per in. (EPA, 1998a).

The most common designs are a box filter cell and a cylindrical filter cell. In a box cell, the pleated media is placed in a rigid, square frame constructed of wood or metal. The air flows from the front to the back of the filter. Box packs are approximately 60 cm (24 in.) in height and width and 6 to 30 cm (3 to 12 in.) in length (EPA, 1991). The media in a cylindrical filter cell is supported by inner and outer wire frameworks. A metal cap seals the media at one end. Air flows from the outside to the inside of the filter. This allows a higher air flow rate than a box cell since more surface area is exposed (Vokes, 1999). Typical cylindrical packs are 50 centimeters (cm) (20 in.) in diameter and 35 to 60 cm (14 to 24 in.) in length (Vokes, 1999).

Both the box and cylindrical cells seal the media to the frame or cap using polyurethane, epoxy, or other commercially available adhesive. A metal grill protects the media face from damage. The filter cell is mounted to a holding frame using a gasket or fluid seal. The filter is generally mounted on the clean air plenum (EPA, 1991). The filter can be mounted directly in the duct or in a separate housing. HEPA and ULPA filter systems require pre-filtering for large diameter PM. HEPA and ULPA filter systems are generally the final component in a PM removal system (Heumann, 1997).

The HEPA and ULPA filter cells are generally utilized as a disposable-type filter. As discussed previously, when the filter cake buildup results in unacceptable air flow rates, the filters are replaced. In most designs, replacement of the filter cell takes place at the clean air plenum and outside of the housing unit. This reduces the risk of exposure to PM by the maintenance workers. This feature is especially important for applications were HAPs or toxic PM are being filtered. The Occupational Safety and Health Administration (OSHA) requires special filter replacement procedures, commonly referred to as bag in/bag out procedures, for many HAP or toxic PM applications. (Heumann, 1997)

The operation of the filter may require additional equipment. Pressure sensors at the inlet and outlet may be required to measure the change in the pressure drop across the filter. This not only indicates when the filter should be replaced but also monitors the integrity of the filter system (EPA, 1991). For applications that require a DOP efficiency test to be administered in place, sampling and injection ports and a test apparatus may be required (EPA, 1991). A special fitting may be installed to facilitate bag in/bag out procedures (Vokes, 1999).

Individual HEPA and ULPA filter cells accommodate air flow capacities up to 1.0 sm^3/sec (2,000 scfm) (Vokes, 1999). Larger air flow capacities are required for some applications, such as the nuclear industry. To increase capacity, multiple filters are housed in banks or modules which are ducted together. This allows a standard, off the shelf, filter unit to be utilized for a variety of applications and air flow rates (Osborn, 1998). In this type of design, dampers can be used to seal off a portion of the filters for maintenance (Vokes, 1999).

The number of filter cells utilized in a particular system is determined by the air-to-cloth ratio, or the ratio of volumetric air flow to cloth area. The selection of air-to-cloth ratio is based on the particulate loading characteristics and the pressure drop across the filter media. Practical application of fibrous media filters requires the use of large media areas to minimize the pressure drop across the filter (EPA 1998a). The paper and nonwoven filter media used in HEPA and ULPA filters have a larger pressure drop across the filter than the woven fabrics used in bags. For this reason, HEPA and ULPA filters are utilized at lower airflow rates and lower particulate loadings than baghouse designs. As discussed previously, once the air flow rate through the filter system decreases to an unacceptable point, the filter must be replaced (Heumann, 1997).

Operating conditions are important determinants of the choice of materials used in HEPA and ULPA filter cells. Pollutant streams with high operating temperatures, high humidity, or corrosives require special filter media, sealant, materials, and coatings. These special materials increase the cost of the system. (EPA, 1991).

HEPA and ULPA filters are generally not cleaned. A dynamic cleaning system may result in the filter not maintaining its rated efficiency. Mechanical stresses caused by air impingement and vibration from the cleaning system may cause leakage (Heumann, 1997).

Advantages:

HEPA and ULPA filters are specifically designed for the collection of submicron PM at high collection efficiencies. They are best utilized in applications with a low flow rate and low pollutant concentration. Filter outlet air is very clean and may be recirculated within the plant, in many cases (AWMA, 1992). They are not sensitive to minor fluctuations in gas stream conditions (Heumann, 1997). Corrosion and rusting of components are usually not problems. Operation is relatively simple. Unlike electrostatic precipitators, HEPA and ULPA filter systems do not require the use of high voltage, therefore, flammable dust may be collected with proper care (AWMA, 1992). Filters are available for a range of dimensions and operating conditions. Commercial filter systems and housings are available in several types of configurations to suit a variety of installation and operation requirements. These systems have many built in features such as testing and monitoring equipment (AAF, 2000; Vokes, 1999).

Disadvantages:

The paper and nonwoven media used in HEPA and ULPA filters have a significantly higher resistance than the woven fabrics that are used in bag filters. The high efficiencies of HEPA and ULPA filters require that the integrity of the filter seals be maintained. The filter media is subject to physical damage from mechanical stress (Heumann, 1997). Temperatures in excess of 95°C (200°F) or corrosive pollutant streams require the use of special materials in the filter, which are more expensive (EPA, 1991). Concentrations of some dusts in the filter housing may represent an explosion hazard if a spark is accidentally admitted. Filter media can burn if readily oxidizable dust is being collected (AWMA, 1992). HEPA and ULPA filter systems require high maintenance and frequent filter replacement. Filter life may be shortened in the presence of high temperatures and acid or alkaline particulates or gas constituents. High flow rates or dust loads will also decrease the operational life of the filter. HEPA and ULPA filters cannot be operated in moist environments. Hydroscopic materials, condensation of moisture, or tarry adhesive components may cause plugging of the filter media (EPA, 1991).

A specific disadvantage of HEPA and ULPA units is that they may generate a high volume waste product with a low density of pollutant. For HAP applications and chemical, biological, or radioactive toxic PM applications, the filters must be disposed of as hazardous waste. The waste is composed of the wood or metal frames, organic binders and gaskets, glass fiber media, and hazardous contaminants. (EPA, 1991).

Other Considerations:

HEPA and ULPA filters are useful for collecting particles with resistivities either too low or too high for collection with electrostatic precipitators (AWMA, 1992). Unlike baghouses which require workers to enter the collector to replace bags, HEPA and ULPA filters systems are designed to replace filters outside the collector housing. This makes them ideal for applications involving HAPs or toxic PM. The collected PM is tightly adhered to the filter media for subsequent disposal. Bag in/bag out procedures that may be required by OHSA are easily performed with the filters (Heumann, 1997).

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