

Institute of Environmental Sciences and Technology

IEST-G-CC035.1

Contamination Control Division
Guideline CC035.1

Design Considerations for Airborne Molecular Contamination Filtration Systems in Cleanrooms and Other Controlled Environments



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1 SCOPE AND LIMITATIONS

1.1 Scope

This Guideline describes areas of concern when considering filtration systems that will be effective in eliminating trace amounts of airborne molecular contamination (AMC), here defined as less than 1 part per million by volume (ppmv), from the air supplied to cleanrooms and other controlled environments. This document discusses various applications, potential points of use, filtration methods, materials of construction, performance comparison, and follow-up assessment, secondary impacts of the filters on the rest of the heating, ventilating and air-conditioning (HVAC) system, and exterior impacts on the filtration system (including environmental conditions, upsets, and spills). The Guideline establishes the types of information required to design and implement an effective AMC filtration system. While this document is targeted at cleanroom facilities, it could also provide a framework for other applications such as, but not limited to, laminar flow stations, minienvironments, isolators, and glove boxes.

1.2 Limitations

Because of the large number of combinations of variables, this document does not attempt to recommend specific filtration systems or filtration media for each application. This Guideline does not establish a test standard, although several applicable standards are referenced. This Guideline is not intended to address microbiological issues, radioactive issues, pollution control issues, or emergency response and safety systems. Nor does this Guideline deal with respirators, as accepted test methods and standards exist for these devices.

2 REFERENCES

2.1 Reference documents

The following documents are incorporated into this Guideline to the extent specified herein. Users should apply the most recent editions of the references.

IEST-RP-CC007: Testing ULPA Filters

IEST-RP-CC031: Method for Characterizing Out-gassed Organic Compounds from Cleanroom Materials and Components

2.2 Sources and addresses

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3 TERMS AND DEFINITIONS

Some terms are defined here for the purposes of this Guideline. If definitions are not provided, common usage shall apply.

absorption

The attraction of a contaminant to a sorbent surface and the incorporation of the contaminant into the structure of the sorbent (e.g., water absorbing into a superabsorbent powder).

acid

A corrosive material that reacts chemically as an electron pair acceptor.

activated

Describing an adsorbent whose surface area has been extended through the creation of pores or other internal openings.

adsorption

The attraction of a contaminant to a surface, including inner pore surfaces, of a medium by physical forces (e.g., van der Waals forces), where the contaminant remains on the surface of the sorbent.

airborne molecular contamination (AMC)

Contamination present in the air in a gaseous state, as opposed to a liquid-droplet or solid-particle aerosol. **NOTE:** This definition is specific to this Guideline, which deals with systems designed to remove gaseous contaminants and control odor for the comfort of occupants.

ambient air

Air that is common to the particular environment of interest. For this Guideline, ambient air may be air at atmospheric pressure, uncontrolled, or conditioned and controlled for temperature and humidity.

base

A corrosive material that reacts chemically as an electron pair donor.

breakthrough (see also penetration)

The measurable concentration of a specific contaminant downstream of a filter system, usually expressed in absolute concentration units. The ability to detect breakthrough depends on the detection limit of the measurement technique. A breakthrough curve is a continuous plot of contaminant breakthrough vs. time.

bypass

The deliberate or unintentional diversion of air around the filter medium in a filtration system.

capacity

The cumulative amount of contaminant that is removed by a filter system within a specified time period or at a specified efficiency level.

catalyst

Any substance of which a small proportion notably affects the rate of a chemical reaction without itself being consumed or undergoing a chemical change. **NOTE:** Most catalysts accelerate reactions, but a few retard them (inhibitors).

challenge

The AMC or mixture of AMCs upstream or at the inlet of a filtration system, either introduced intentionally for a test, or present in the actual application.

channeling

The disproportionately greater flow of gas through passages of lower resistance that can occur in fixed beds or columns of granular media due to nonuniform packing, granule segregation, irregular sizes and shapes of the media, gas pockets, wall effects, and other causes.

chemisorption (chemical adsorption)

Chemical bonding of a molecular contaminant to a solid surface or to a chemical on that surface.

cleanroom

A room in which the concentration of airborne particles, molecular contaminants, or both, are controlled to specified limits.

concentration

The quantity of one substance dispersed in a defined amount of another. For AMCs, two common conventions are defined as weight per volume (e.g., $\mu\text{g}/\text{m}^3$) or volume per volume (e.g., ppbv).

condensable

A substance (other than water), typically having a boiling point above room temperature at atmospheric pressure, capable of condensation on a clean surface.

contaminant

Any unwanted substance present in or on a material or any surface within a clean zone.

desorption

The process by which adsorbed materials leave the substrates on which they are adsorbed and reenter the airflow.

diffusion, molecular

A process of spontaneous intermixing of different substances attributable to molecular motion (Brownian motion) and tending to produce uniformity of concentration.

efficiency

The fraction of a specific contaminant that is removed by the filter system, usually expressed as a percentage.

efficiency curve

A continuous plot of contaminant removal efficiency against time.

end point

The occurrence of the maximum permissible concentration of a specific contaminant in the air downstream of a filter system. Also, the time when a predetermined contaminant penetration or efficiency is reached.

face velocity

The speed of the airflow across the cross-sectional area (perpendicular to the airflow) of a filter at the upstream side of the filter.

filter

A device or system used to remove contaminants from a gas flowing through it.

impregnation

Adding one or more chemicals (impregnants) to a surface in order to enhance the removal of selected molecular species from a gas.

medium (plural: media)

The filtering material in a filter; an adsorbent or chemisorbent used to remove airborne molecular contaminants. Alternatively, a material containing an adsorbent or chemisorbent.

minienvironment

An environment that provides localized control of airborne contaminants by means of an enclosure designed to isolate product-handling areas from personnel and the surrounding room environment.

outgassing

The release of any gas-phase compound (e.g., contaminant) from a solid surface; typically accelerated by heating, reducing pressure, or increasing flow.

penetration

The ratio of downstream concentration to challenge concentration of a specific contaminant for a filter system, expressed as a percentage. Related to efficiency by the expression: % Penetration = 100% - % Efficiency.

pressure drop

The difference in pressure between two points in an airflow system upstream and downstream of a filter system.

residence time

The theoretical time that an increment of gas is within the boundaries of the filter's media. Calculated by the following expression: Residence time = Volumetric flow / volume of filter media in the filter system.

shedding

The generation and release of particles from the filter system into an airflow.

volatile organic compound (VOC)

An organic material, such as a solvent, that has a significant vapor pressure at ambient temperature and pressure; i.e., a significant portion of the material is present as a vapor at equilibrium.

Abbreviations

AMC – airborne molecular contamination

FFU – fan-filter unit

HEPA – high efficiency particulate air

HVAC – heating, ventilating, and air-conditioning

MAH – make-up air handler

RAH – recirculation air handler

ppbv – parts per billion (10⁹) by volume (for an ideal gas equivalent to parts per billion molar)

ppmv – parts per million (10⁶) by volume (for an ideal gas equivalent to parts per million molar)

ULPA – ultra-low-penetration air

VOC – volatile organic compound

4 BACKGROUND

4.1 Applications for AMC filtration

The need for AMC control may apply to odor control, safety requirements, process yield improvements, and other situations. The level of required performance will determine the type of filter system acceptable for the application. This Guideline primarily addresses the removal of contaminants that are present in trace amounts (typically << 1 ppmv) in ambient air. Pollution control, which requires different types of intervention, will not be addressed.

AMCs can affect processes in a variety of industries, including, but not limited to, microelectronics, aerospace, pharmaceuticals, medical devices, lasers, optics, and nanotechnology.

4.1.1 Health and safety – toxic contaminants

NOTE: This Guideline does not specifically address health and safety issues. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use of this Guideline.

The sources of toxic contaminants are usually within the facility itself, although extreme external conditions are possible. An AMC filtration system should be considered as only one element of an overall strategy that includes alarms, personal protective equipment, containment, evacuation, and other precautionary measures. A list of hazardous and toxic compounds and their potential sources within a facility should already exist as a result of hazard reviews, Occupational Safety and Health Administration (OSHA) and other regulatory requirements, and industrial guidelines. The AMC

filtration system may be considered as part of the containment system at the source or as a second line of defense, or redundancy, available through the HVAC system.

4.1.2 Product/process protection

The impact of various AMCs on the manufacturing process or finished product will define the types of filters and performance requirements needed for a particular application. The facility process engineer should define the sensitivity of each process component to specific AMCs. These contaminants can originate in the ambient make-up air from outside the facility (air pollution, surrounding industry, loading docks, re-entrainment from exhaust stacks, or even natural sources), in cross-contamination from other process steps, or from employees. Consideration should also be given to protecting the infrastructure and process control equipment especially in corrosive environments.

4.1.3 Comfort and productivity – odors, irritants

These types of problems are caused by compounds that have a detectable unpleasant aroma or may cause allergic reactions. This can be a subjective observation, as what one person considers pleasant can be irritating to another. The perception can also change based on the length of time of exposure to the odor and the potency or concentration of the odor. The sources of these compounds can be internal to the facility (e.g., solvents, cleaning supplies, food preparation, deodorants, and perfumes), generated by the processes or the people, or external, brought in by the ambient make-up air systems from sources such as diesel exhaust and surrounding industries. Once the chemical or mix of chemicals is identified, threshold values for specific odors or irritants can be used to determine the required filtration.

In certain facilities that utilize toxic chemicals in their processes, workers are trained to evacuate the building if they detect any unusual odor. In these cases, the presence of an unidentified odor, even if it is not actually harmful or irritating, can lead to unnecessary plant shutdowns and loss of productivity.

4.2 Locations for AMC filtration

AMC filtration systems are designed to be installed in a wide variety of locations within a facility. Different locations offer varying degrees of flexibility and targeting for specific contaminants or sources of

contaminants. However, space constraints or other interactions with existing HVAC equipment may limit the options available to the facility engineer. The most effective solution may be either a combination of filtration systems in several locations or multiple stages of filtration in a single location. Figure 1 shows some possible locations for AMC filtration (not all locations are available in every facility).

4.2.1 Make-up air handling (MAH) unit

The make-up air handlers are the most direct and effective location to control contaminants from outside the clean facility. These contaminants may include diesel and automotive exhaust fumes from loading docks or highways, emissions from nearby industries or agricultural sites, or air pollution. Filtration systems in the MAH units will not affect contamination sources located inside the facility. High AMC filter efficiencies are required because outside ambient air passes through these filters only once.

In situations where the outside air has high particulate and AMC contaminant levels, it can be advantageous to use an initial filter stage comprised of wet scrubbers or similar technologies to reduce particulate and AMC levels into the building. This setup can increase the life and effectiveness of the indoor AMC filters described within this document.

4.2.2 Recirculation air handling (RAH) unit

When recirculation is used in a facility, the majority of the total airflow usually passes through the recirculation system (see IEST-RP-CC012). Therefore, the RAH may be the best place to handle a contaminant issue that affects a majority of the facility, especially if the sources are widespread (e.g., outgassing of construction materials). These contaminants are often generated within the facility by the manufacturing processes, labs, or other activities. Given the high air-change rates in most clean facilities, ambient air will pass through the filter systems many times, increasing the filtration efficiency of the system under steady-state conditions. The RAH is not the best location to remove outside air contaminants because the contaminated air generally already will have passed through the facility once before contacting the filters. Zones within the return or recirculation system may allow targeting of the filtration to specific needs. If recirculated air is too contaminated, the user may choose to exhaust 100% of that air into less critical areas and bring 100% makeup air into that area (e.g., lithography areas in semiconductor processing).

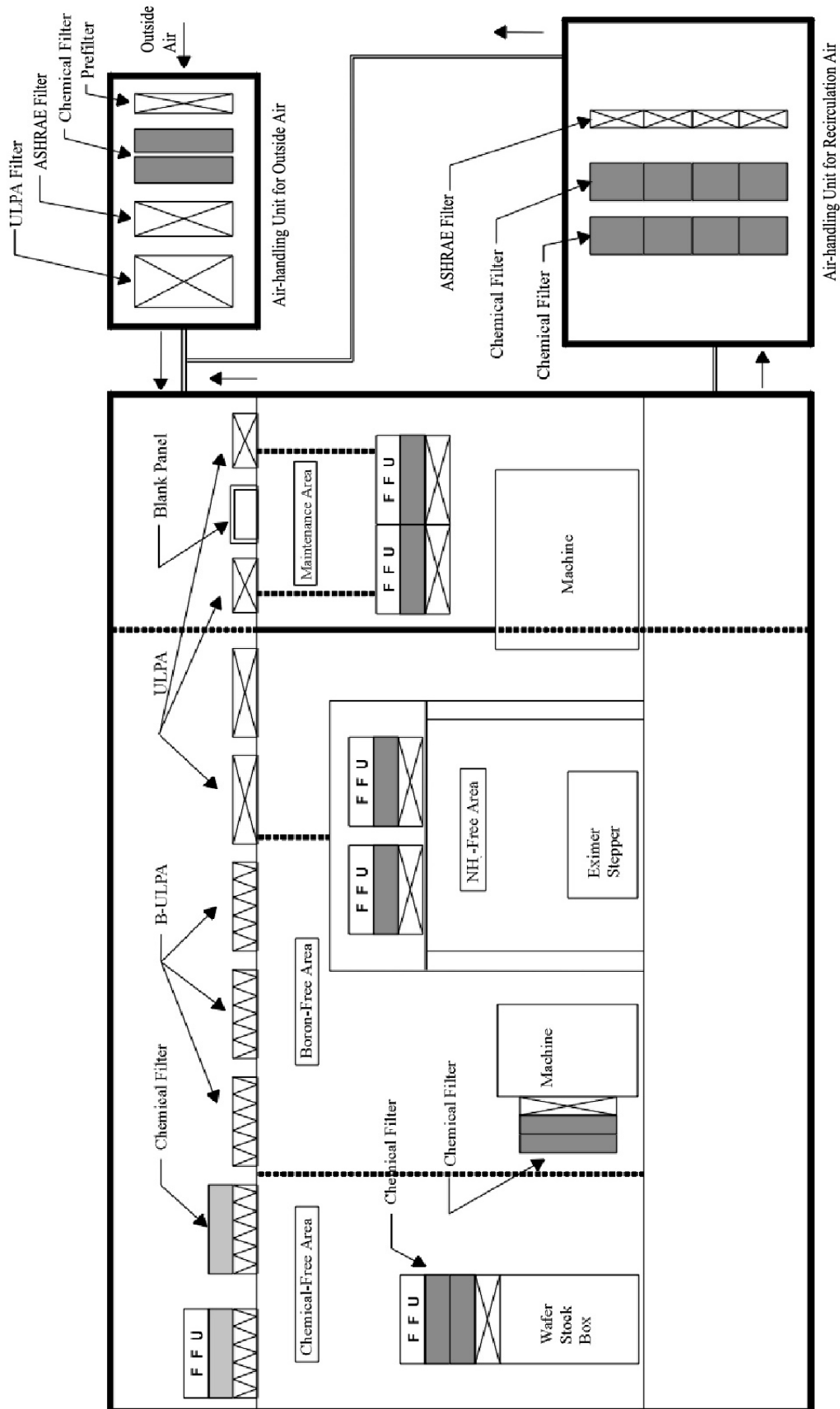


Figure 1—Examples of locations for AMC filtration systems (shown as “chemical filters” in this diagram of a semiconductor facility).

4.2.3 Supply air handling unit

Supply air systems refer to applications where the filtration is placed after the make-up air and recirculated air are blended, thereby treating all of the air that is supplied to the clean space.

4.2.4 Ceiling grids and fan-filter units (FFUs)

Ceiling grids are employed when large remote blowers or fans are used to circulate air through many filters. Fan-filter units incorporate a dedicated fan, motor, and filter into a single housing. The use of AMC filtration in ceiling grids and FFUs offers the opportunity to target the type of filtration to the needs of specific areas of the clean facility. In other words, different filter media or even types of filters could be used to remove condensables in one section of the facility and amines in another, depending on the sensitivities of the process or product. (It should be noted that diffusion of AMC contaminants can occur well beyond the confines of unidirectional airflow, potentially impacting the effectiveness of localized AMC filtration if applied to different sections of a single room). Face velocities are generally lower as well, offering longer residence time in the filter system to achieve removal. Filtration could be used at this location to remove contaminants present in ambient air, both from the outside and from recirculation, and will also achieve multiple passes through the filters. However, this would require a large number of filters if control were needed throughout the facility.

An inherent difficulty with adding AMC filtration to ceiling grids is that partial coverage creates higher pressure-drop zones, diverting airflow to areas without AMC filtration and leading to low airflow through the AMC filters. Serviceability can be more difficult in this location unless proper access is included in the facility design.

4.2.5 Minienvironments

The presence of a minienvironment in the facility offers even greater opportunity to focus solely on the particular contaminants to which a process step is sensitive. Thus, the larger room might have only a general-purpose AMC filter system, while the minienvironment filter system could focus on a specific offending chemical by using highly specialized and customized media. Alternatively, the minienvironment AMC filter could be used to enhance the reduction in contaminants in the larger room. Another advantage is that smaller quantities of ambient air need to be treated. The separate enclosure may also make it possible to use AMC filtration as a source control for contaminants that are generated inside the minienvironment, before they are released to the recirculated ambient air. Gloveboxes and isolators

can be considered as special cases within the category of minienvironments. Some environments are also purged with clean, inert gases such as argon or nitrogen; however, such systems are outside the scope of this Guideline.

4.2.6 Production tools

Most of the information on minienvironments in 4.2.5 may also be applied to the process or inspection tools in the clean space. However, it may be difficult to retrofit a tool that has no provisions for AMC filtration. Modifying a tool to add AMC filtration should be done only in partnership with the tool manufacturer to retain the safety and correct function of the tool. For new tool installations, the tool manufacturer may not have detailed information on the expected levels of AMC contaminants in the clean environment where the tool will be installed. The tool manufacturer, the facility owner, the FFU or minienvironment supplier, and the AMC filtration supplier should work together to select the appropriate AMC filtration system.

4.2.7 Transient source control

Certain types of planned events or activities may generate AMC contamination, such as cleaning of equipment or outgassing from new construction materials. Point-of-use enclosures with the correct filter media can be used to minimize the risk of AMCs entering the ambient air stream. This type of intervention can also be extended to the use of temporary filters on MAH units during pre-planned external events, such as the tarring of a nearby roof or road. In all cases, both the source and the timing of the contaminant release must be known or anticipated.

4.3 Variation of AMC concentration with time

Most applications for AMC filtration do not involve a constant challenge concentration, but rather a concentration that changes with time. Three general types of AMC concentration variation can be identified. Continuous, random variations might be present due to changes in outside ambient air-pollution levels. Periodic or cyclical variations may be caused by external facility activities such as delivery schedules (diesel exhaust at loading docks), lawn mowing or fertilizer applications, or batch production processes (releases of small amounts of chemicals at the end of each cycle). Episodes of high contaminant concentration can occur during equipment cleaning or from accidental releases of chemicals. An understanding of the type and range of variation will determine the appropriate filtration system and help estimate the life of that system.

5 FILTER DESIGNS

5.1 Sorbents

Many different materials are used in AMC filtration systems to remove contaminants. The most common materials are adsorbents; i.e., the contaminants are captured on the surfaces of the materials. These surfaces may be on the outside of the material or associated with internal pores and cracks in the material. Adsorbents are available in various shapes and sizes — powders or granules (irregularly shaped), spherical beads, extruded pellets, and fibers. Adsorbents can be grouped into three general categories: physical adsorbents, chemical adsorbents, and catalysts. Appendix A provides a more complete description of these three mechanisms. Some of the common adsorbents are listed below with general descriptions.

5.1.1 Physical adsorbents

Physical adsorbents use weak molecular forces to hold contaminants on their surfaces. This is usually the most effective means of removing chemically stable compounds. Since only the surfaces are involved, most physical adsorbents are “extended surface” materials. Additional surface area is created by opening pores and cracks that extend from the external surface of the particle to the internal volume of the material. For natural raw materials, these pores are created via a post-activation process. Man-made materials can be created with the pores already present.

The physical adsorption mechanism is an equilibrium process dependent on the environmental conditions (temperature, humidity), the concentration of the contaminant in the air stream, the affinity of the contaminant for the adsorbent material, and the presence of other competing molecules. Changes in any of these aspects may affect how much contaminant can be removed (equilibrium capacity) or may lead to re-entrainment of the contaminant in the air stream (desorption).

a) Activated Carbon – This is the most widely used adsorbent due to its large surface area and thus its broad performance. Surface areas in activated carbons can range from 600 to over 1500 m² per gram, but activity level is usually specified (see ASTM D5742-95) according to the amount of a reference gas that can be held by the carbon as a weight % (e.g., 60 CTC means that 60% by weight of carbon tetrachloride can be held under standardized equilibrium conditions). Activated carbon can be made from almost any organic raw material, including coconut shells, wood, coal, organic fibers (natural or man-made), bone, fruit pits, and nut shells. The original raw-material source affects the pore shape, size, and distribution as well as any impurities that may remain in the carbon (usually referred to as ash content) and the hardness of the resulting adsorbent (resistance to dusting). The pore characteristics will affect the removal and retention of contaminants. Table 1 shows a summary of the characteristics of activated carbons and their directional impacts.

b) Activated Alumina – This is a granular, porous form of aluminum oxide with surface areas of approximately 200-400 m² per gram. Activated alumina has a particular affinity for removing water from air (desiccant). In AMC filtration it is generally used as a substrate for chemical impregnation or as a catalyst support.

c) Zeolite – This is a crystalline, porous, aluminosilicate with a tetrahedral structure. Zeolites can be either natural or man-made and can have an almost infinite variety of internal structures with up to 700 m² of surface area per gram. Natural zeolites are usually mined and have a mixture of chemical compositions and pore structures. They are generally used in liquid absorption and ion exchange applications. Man-made zeolites are produced with controlled compositions and designed pore structures and can be considered molecular sieves. Their designed pore sizes and shapes are tailored to remove or separate certain types of contaminants and can be used as catalysts under the right conditions.

Table 1. Activated Carbon Characteristics

Change	Impact on Activated Carbon/Filter			
	Efficiency	Pressure Drop	Density	Hardness
↑ Activation	↑	= or ↑	↓	↓
↑ Particle Size	↓	↓	=	=
↑ Loading/Depth	↑	↑	N/A	N/A
Impregnation	↑ ¹	= or ↓	↑	=

¹ Increases for target chemical, decreases for non-targeted chemicals.

5.1.2 Chemical adsorbents

Chemical adsorbents use much stronger chemical bonds to capture and remove molecular contaminants. Usually, this is accomplished by impregnating or applying a chemical to a substrate particle to react with certain types of contaminants. The most effective of these impregnations rely on an acid-base reaction that forms a solid salt on the surface and releases water into the air stream as the only by-product. However, oxidation reactions are also effective at removing or destroying certain contaminants. Typically, these reactions are considered irreversible under ambient conditions, eliminating the possibility of desorption. However, reactions with other components of the air can produce unintended by-products or contaminants. As the impregnated chemical is used up by the reaction, the efficiency of the material decreases. Ultimate capacity is determined by the stoichiometry of the reaction equation.

a) Activated Carbons and Aluminas – Extended-surface materials are routinely used as substrates for chemical impregnation. In this use, the large surface area of the activated particle is treated or partially coated with a reactive chemical to form a chemical bond that holds the target contaminant in place. Common impregnations include acids, bases, metals or metal oxides, and permanganates.

b) Ion-exchange Resins (IER) – These are solids with bound ionic groups and free ions that can be displaced by other similarly charged ions (exchange). Most current ion-exchange resins are based on synthetic cross-linked polymers. Though more commonly used in liquid applications, where the carrier liquid swells the polymer to create access to the pores, macromolecular varieties are available that can be used in air applications. Without post-treatment to introduce the exchangeable ions, these macromolecular varieties can be used for physical adsorption.

5.1.3 Catalysts

Very few catalysts are effective in HVAC systems, since most catalysts are effective only at high temperatures. One practical consideration is the catalytic conversion of ozone to oxygen by activated carbon. However, new devices based on photo-catalytic technology are becoming available (see 5.5). The advantage of a catalyst-based system is that the surface is never used up by the reaction that occurs and efficiencies can be maintained for long periods of time. Only poisoning of the catalyst or covering of the surface by physical adsorption reduces performance.

5.2 Media forms/types

The sorbents listed in 5.1, generally referred to as the filtration media, may be present in several different forms within a filtration system. Three general formats are described below, along with variants that are available within each category.

5.2.1 Loose granular

This format consists of a container filled or packed with loose sorbent particles. The container may be a tray, bed, or panel with perforated sides or screens to allow airflow through the depth of material that is formed. Different depths of sorbent are available. When the filter system has reached its end-point, the loose sorbent can be removed and replaced with virgin material. Some systems are designed to be emptied and refilled in place, while others require removal of the trays or panels before refilling. This system also allows changing sorbent particles without changing the entire filter system if the needs of the application change.

Generally, larger granules or extruded pellets (> 2 mm) are used in this format to minimize pressure drop. Care should be taken when filling the container to achieve a tightly packed bed. Otherwise, channeling or bypass of the contaminated air can occur. A variant of this format, the “honeycomb” panel, uses separators within the container to keep sorbent particles from shifting during installation or use. Downstream dust filtration is required to control shedding from attrition of sorbent particles. There is no coverage of the surface area by adhesives or binders, but tight packing of irregularly shaped granules can effectively close off sections from direct contact with the contaminated air stream.

5.2.2 Bonded granular

This format is essentially a loose granular bed where the sorbent granules or pellets have been cemented together to form a solid block or panel. This format makes handling of the sorbent easier than with a loose bed for installation and change-out. No container is necessary and there is essentially no shedding downstream of the filter system. Bonded panels can be brittle and must be handled appropriately during shipping and installation to avoid breakage.

Here again, larger granules or extruded pellets are used to minimize pressure drop, though pressure drop is generally higher for the same type and depth of sorbent than with a loose granular media. Different binding technologies are available, but all will cover some portion of the active surface area of the sorbent. Channeling is not a concern because the granules or pellets are

held in place. Bypass is eliminated by proper sealing at the edges of the panel.

5.2.3 Loaded nonwoven

This is perhaps the most diverse group of filter media. All varieties involve attaching sorbent particles to a nonwoven structure by some means to provide an easy-to-handle media for building a filter. This helps with installation and change-out while avoiding the weight and brittleness of the bonded panels. The two primary differences between the various products are the type of nonwoven technology used and the method of attaching the sorbent particles. Some of the common variants of each are shown in Table 2; there are many possible combinations.

Table 2. Loaded Nonwoven Characteristics

Nonwovens	Sorbent Attachment
Spunbond	Adhesive Powder
Meltblown	Binder Slurry
Carded	Spray Adhesive
Airlaid	Adhesive Webs/Fabrics
Wetlaid	Bicomponent Fiber
Foam	

A variety of sorbent particle sizes and loadings are used. Different attachment methods provide coverage of the active surface area ranging from 1% to 70%. Products can be thick mats designed for use as flat pads, or thin fabrics that can be pleated. Pressure drops for these types of products are generally lower than for loose granular or bonded granular. The active bonding also reduces the shedding from these media. These materials are available with a wide range of sorbent particles, performance levels, and prices.

5.3 Filter construction (deep pleat, V-bank, deep bed, flat pad/panel)

The media forms listed in 5.2 can be incorporated into different types of filters depending on the targeted parameters, including size, weight, filtration performance, pressure drop, and intended location. Some of the common filter structures are described in this section and compared in Table 3. Note that some types of media are limited to certain types of filter construction.

- a) Flat Panel Filters: A flat layer of adsorbent media is supported in a frame perpendicular to the airflow. The adsorbent media can be in any of the forms mentioned in 5.2.
- b) Pleated Filters: A loaded nonwoven is pleated and manufactured into designs similar to particle filters: 1-in. to 6-in. pleated filters, 12-in. deep-pleat “box” or “headered” filters, and pleated panels. These filters can also be produced using an air-permeable medium that is itself an adsorbent (e.g., activated carbon fiber felts).
- c) V-bank Filters: An air filter design where individual panels (flat or pleated) are arranged in ‘V’ configurations, with the mouth of the ‘V’ facing upstream. This design may allow the placement of increased amounts of adsorbent media into a given volume of space within a filter, and can result in higher capacity and lower pressure drop. When used with loose-fill adsorbents these filters are also referred to as tray systems.
- d) Pocket Filters: Individual pockets are formed from a layer of adsorbent-loaded media, sewn, or bonded along the edges. Typically, a number of pockets are sealed together and mounted on a galvanized metal frame and header to form the pocket filter.

Table 3. Filter Construction Comparison

Filter Type	Initial Efficiency	Capacity	Shedding
Loose-fill V-bank (1-in. bed)	High	High	High
Loose-fill V-bank (3-in. bed)	High	Very High	High
Pleated V-bank	High	Medium to High	Low
Pleated Filter (1– 4 in.)	Medium	Low	Low
Bonded Panel	Low	Low	Low
Pleated Panel	High	Medium	Low
Honeycomb Panel	Medium	High	High
Loose-fill Canister	High	High	High
Pleated Filter (6–12 in.)	High	Medium to High	Low
Bag/Pocket	High	Medium	Low

NOTE: Pressure drop is also a significant performance parameter. Consult manufacturers’ literature under comparable airflow or face velocity for a filter of the desired removal efficiency.

e) Canister Filters: Perforated stainless steel, galvanized or plastic inner and outer walls form an annulus that contains a bed of loose-fill adsorbent media. An inlet cone typically contains an integral gasket and bayonet mounts to lock the canister into a holding frame, eliminating bypass and leakage. A solid cap seals the distal end of the canister.

5.4 Materials of construction

For critical applications, filter components including adhesives, sealants, and polymers, should be tested per IEST-RP-CC031 to control outgassing from the filter unit. Some flame retardants can include organophosphates (especially polyurethane), boron (boric acid), and halogenated hydrocarbons (oils) that could cause corrosion, delamination, etc.

Particle shedding should also be controlled for AMC filters so particles do not overload downstream filters.

5.5 Alternative technologies

Alternative technologies such as water wash systems, photocatalytic systems, scrubbers, and purging with inert gas or clean dry air are not covered in this Guideline.

6 SYSTEM DESIGN

6.1 Identifying AMCs

The more that is known about the specific AMCs that are present, namely, where they are present, which ones are causing problems, and the concentration levels, the better the filtration system can be optimized for the application. It is recommended that the facility owner provide average and maximum background chemical measurements to the filter system contractor as early in the specification process as possible.

Monitoring and measurement technologies are available that either provide real-time feedback or require off-line analysis of collected samples. Different technologies have advantages for certain chemical species or concentration ranges (see ISO 14644-8). Ideally, measurements should identify specific AMC contaminants rather than be limited to broad groups (e.g., a filtration supplier can provide a better solution knowing how much toluene and formaldehyde are present as opposed to a total VOC measurement). The technique used should have an appropriate detection limit to ensure accurate results (typically 1 ppbv or less). Measurements indicating how the AMCs and concentrations vary over time (steadily building, cyclical, episodic, etc.) will ensure that AMC filtration is appropriate for the type of variation anticipated (i.e., a

result from a single sample collected over 24 hours will miss a 12-hour cycle).

It is also critical to know the other chemical species that may be present in the air stream because other species could compete with the AMCs of interest for adsorption sites or react with the impregnant and thus decrease the performance or life of the AMC filtration system.

Deductive reasoning can sometimes narrow the extent of monitoring required. A description of an irritating odor can often be used to identify a class of chemicals or the possible source (e.g., "exhaust odors" would suggest both a list of chemicals and probable sources). A list of chemicals and materials used on site may help to identify potential contaminants and sources. The timing of fluctuations could be correlated to other activities to pinpoint the probable source and thus the probable contaminant. In some cases, vapors or aerosols may condense and form particles. In these instances, a real-time particle counting instrument may be useful in tracking to a source. Knowing the source may be enough to help identify the chemical(s) in question but further analysis might be needed to determine specific chemicals and concentrations.

All of this information can be used to formulate an AMC measurement plan that addresses specific areas, chemicals, and times of occurrence.

6.2 AMC performance requirements

The facility engineering department will generally determine the type and level of performance necessary for an AMC filtration system and will communicate these requirements to contractors and suppliers. See Appendix A for descriptions and comparisons of various performance measurements used in the HVAC industry. For any given AMC filtration system, both the efficiency and the capacity may be functions of the challenge concentration. Therefore, it is important to supply the typical and maximum values as part of the performance requirements. In clean facilities, performance specifications (whether time or capacity) should be based on knowledge of baseline AMC levels of concern, and minimum efficiency or maximum breakthrough concentration. Methods to determine appropriate levels and recommended rules of thumb are given in 6.2.1, 6.2.2, and 6.2.3 for different applications.

If capacity is used as the performance measurement, the end point at which the capacity is determined should be specified to provide a valid comparison between filtration systems. For example, "total" capacity often refers to the theoretical capacity of an adsorbent or filter at the point when there is effectively 0% effi-

ciency if measured at specific challenge concentrations that may not represent the application conditions.

AMC filter systems should be performance tested as close as possible to the challenge concentrations present in the location where they are to be installed.

6.2.1 Health and safety

An AMC filtration system should be considered as only one piece of an overall strategy that includes alarms, personal protective equipment, containment, evacuation, and other precautionary measures. If the AMC filtration system is installed to handle releases of hazardous or toxic materials, extremely specific guidelines that are outside the scope of this document must be followed.

6.2.2 Product/process protection

The facility and process engineers can provide the best information regarding the sensitivity of their processes and products to AMCs. This information may be based on known chemical interactions from theoretical and research studies, or on the empirical knowledge and experience generated from day-to-day operations and incidents. AMC monitoring, once in place, can provide a wealth of insight in problem-solving the sources of yield or quality issues. Tool manufacturers and other suppliers may also be able to provide information on the levels of contamination that need to be maintained going to and within their equipment.

University research publications and industry trade groups can also be sources for maximum acceptable levels of AMC in different process steps (e.g., see ITRS Roadmap [www.itrs.net] and SEMI F21-1102 [www.semi.org]).

Once these levels have been determined, they can be compared to the background levels and episodes to calculate the required efficiency of the AMC filtration system and to identify appropriate AMC filtration locations. Note that the acceptable concentration levels determined for the product or process may be significantly higher or lower than those levels determined from a health and safety analysis.

6.2.3 Comfort/productivity

Comfort issues that may affect productivity are typically driven by odors and irritants in the work area. The human nose, eyes, skin, and upper respiratory system are sensitive monitoring devices, able to detect many compounds well below the level at which they are harmful from a safety aspect. Many chemicals and compounds have published "Odor Threshold Levels" that can be used to set maximum concentrations. Individual tolerance to airborne irritants varies greatly.

Depending on the contaminant in question, personal tolerance levels could be lower than the levels required by the process or product. The goal of an AMC system may be to control contaminants to levels below their odor thresholds whenever practical.

Once these levels have been determined, they can be compared to the background levels and episodes to calculate the required efficiency of the filtration system and to identify appropriate locations.

In some cases, contaminants may produce reactions in people even at levels below the odor threshold level. This is a similar phenomenon to "sick building syndrome" (SBS) in office buildings. There is less information currently available on these types of effects than for odors or safety issues, and sources are difficult to identify due to the large number of chemical compounds that may be detected in a work environment. However, the effects are real and improvements have been seen in many situations with the application of broad-spectrum AMC filtration.

6.3 Considerations in choosing locations

The optimum location and type of AMC filtration system will depend on whether the system is being retrofitted into an existing facility or designed into a new facility. Each of these situations will have its own set of possibilities and constraints, but there will usually be more options when designing for a new facility. Following are key items to consider in each location.

6.3.1 Geometry/weight

AMC filtration systems are available in a wide variety of configurations using many different technologies. While most of these systems are designed to fit the cross-section of standard air-handling ducts within the clean facility, they can vary in depth from 1 to 24 in. Some efficiency requirements may dictate the use of multiple filters in series. This situation may impact where the filter system can be used due to equipment and ductwork that is already in place. The engineer should also consider the space required for accessing the filtration system for routine change-outs and maintenance.

In addition, AMC filtration systems can weigh anywhere from a few pounds to a few hundred pounds each (depending on technology, design, and performance requirements). The engineer should verify that the structural components are capable of supporting the additional weight. For example, many existing ceiling grids are not designed to handle the additional load of AMC filters and would need to be reinforced or redesigned.

6.3.2 Pressure drop

Since AMC filtration cannot be achieved by the existing particle filters in a clean facility, at least one additional step in the filtration system design will be required. Thus, the air handling system will need to accommodate additional pressure drop. Many different filtration technologies are available with various combinations of performance, life, pressure drop, and cost. The facility engineer should assess whether the existing fans and motors can meet the demand of the additional pressure drop (and how much additional pressure drop can be tolerated) or if the units will need to be upgraded as part of the design process. Information on available pressure drop within the system can help the AMC filtration system supplier recommend appropriate solutions from its product line.

6.3.3 Shedding

The use of AMC filter systems must not adversely affect the air cleanliness classification (in accordance with ISO 14644-1) of the clean zone as a result of the shedding of particles. Different media technologies produce varying degrees of particle shedding due to types of adsorbents, binding of the adsorbent, or containment strategies. The level of shedding will determine the appropriate installation locations and the degree of downstream particle filtration that is required. For some types of AMC filter systems it may be necessary to install additional downstream filtration so the life of the final HEPA/ULPA filter is not diminished.

6.3.4 Temperature/humidity

Temperature and humidity at the location of the filtration system can have a significant impact on the adsorption process and therefore on the effectiveness of the filter system (see Appendix A). For instance, high humidity (i.e., above 70% relative humidity) will significantly reduce the efficiency and capacity for removal of certain VOCs with activated carbon systems. In the case of physical adsorption of AMCs, a change in temperature or humidity can also impact desorption of AMCs that have already been captured by a filter system. For optimum performance, AMC filters should be located in tightly controlled environments. Preferred locations are downstream of the conditioning of the air to provide a more stable temperature and humidity environment for control of the adsorption process (refer to 5.1.1).

AMC filter systems should be performance-tested at the temperature and humidity levels present in the location where they are to be installed.

6.4 Change-out/disposal

Filter replacement and service considerations include ease of access and frequency of service or change-out. All federal, state, and local regulations for disposal of spent AMC filters should be followed.

6.5 Side reactions/by-products

The goal of AMC filtration is to reduce the unintended impact of chemicals on the facility. AMC filter systems should not produce by-products (through reaction with airborne chemicals) that are as hazardous or more hazardous to the people, processes, or products than the AMCs being removed. To accomplish this, the facility owner should provide the supplier with a complete list of chemicals (contaminant or otherwise) to which the filter system could be exposed. By examining the potential by-products of a filter system from chemical reactions, the facility owner can assess the amount of reduction that is possible for any proposed system.

This assessment should be performed for other components of the facility (in addition to the AMC filtration system) to prevent unanticipated contamination (e.g., a reaction of hydrogen fluoride with borosilicate glass fibers in HEPA filters that releases boron into the air stream).

6.6 Upset conditions

6.6.1 Startup and new construction

Special or sacrificial filters may be installed to control fugitive AMCs or outgassing from construction or new materials.

6.6.2 Spills (concentration spikes)

Spills can produce extremely high levels of AMCs (relative to routine concentrations) that could quickly exhaust or overwhelm the capacity of an AMC filtration system. The ideal solution would be to apply containment or isolation around the spill area and then use source-capture filtration strategies to remove the contaminant from the air. This method is particularly effective in areas that are prone to spills or leaks. If containment is not possible, it may be necessary to consider premature (ahead of scheduled) change-out of the AMC filters that have been exposed to the concentration spike. Otherwise, the filtration system may not be able to achieve the expected performance after the spill or, in severe cases, may desorb AMCs back into the airflow.

If the filtration system is to be designed to handle spills or concentration spikes, the engineer should first esti-

mate the quantity of vapor that would be created by a spill. This estimate can then be used with manufacturer data either to oversize the AMC filtration system for the useful life calculated at typical concentrations or to determine an accelerated change-out schedule (so the system always has the capacity to contain the spill without exceeding the maximum acceptable downstream concentration). The engineer should consider the potential exposure levels and the time or number of passes required for the filtration system to bring the concentration down to acceptable levels. The cost of unused capacity should be compared to the risk and cost impact of the elevated concentrations that might otherwise be generated by a spill.

6.6.3 System shutdown (desorption)

Shutting down the air-handling system for any significant amount of time can expose the AMC filtration system and air-handling components to high temperatures and humidities. This condition can lead to desorption of AMCs from the filtration system and growth of molds and fungi throughout the air-handling system. These situations can cause bursts of AMC or odors when the system is restarted, as well as reduced performance of the filtration system. To prevent such outcomes, filtration components should be changed out before the system is restarted.

7 SYSTEM PERFORMANCE EVALUATION

7.1 AMC efficiency monitoring

AMC monitoring in the field is a complex topic; AMC system efficiency monitoring is even more complex. Published test methods are not yet available for AMC system evaluation. At a minimum, system performance measurement should include valid upstream and downstream concentration measurements.

Real-time monitoring, upstream and downstream of the filter system, would be desirable. However, such

monitoring is not always economical or technically feasible. In some cases, "grab" or "spot" samples may be collected to attempt to assess efficacy of the filter system at a specific point in time.

An alternative is to monitor trends in process yields or contaminant levels on witness substrates to indirectly assess filter system performance.

7.2 Airborne particulate count (shedding)

If relevant, AMC filters should be tested in accordance with IEST-RP-CC007. Acceptable performance is dependent on the filter application and the specific requirements of the facility owner.

7.3 Pressure drop

Adding AMC filters to an existing system increases the demands for fan power. The user should measure the pressure drop across a newly installed bank of AMC filters and compare this measurement to the manufacturer specifications. Significantly lower pressure drop than specified may indicate leakage paths or filter frame bypass during installation, which requires repair. Differential pressure drop is not usable to monitor the condition and state of an operating AMC filter system.

7.4 Outgassing

Chemical filter components should be tested in accordance with IEST-RP-CC031 or as agreed to by the facility owner. Acceptable performance is facility-specific, and therefore should be determined by the facility owner.

7.5 Filter packaging and handling

Filters should not be unsealed until ready for installation. Filters should not be exposed to gases that would compromise the capacity of the filter prior to use.

APPENDIX A—BASICS OF AMC REMOVAL

A1 PHYSICAL ADSORPTION

Physical adsorption is a surface phenomenon similar in many ways to condensation. The forces involved are weak molecular forces such as van der Waals forces. Thus, it is desirable to find adsorbents with large surface areas per unit weight, also known as expanded-surface-area materials. The surfaces of these adsorption media are expanded in two ways to enhance the adsorptive characteristics. First, the media are provided in granular, pelletized, or fibrous form to increase the exterior surface exposed to airflow. Second, the adsorbent media are treated or activated to develop pores of microscopic dimensions throughout the media, greatly increasing the area available for molecular contact. For most adsorbents, the interior surface area represented by the pores accounts for the vast majority of the total surface area available. Pores of various microscopic sizes and shapes provide minute traps that can fill with adsorbed contaminant molecules.

Several steps are necessary for the adsorption of a molecule:

1. The molecule is transported by diffusion from the carrier gas stream across the boundary layer of gas surrounding the adsorbent granule. This process is random, with molecular movement to and from the surface. The net flow of molecules is toward areas of lower concentration in the air.
2. The molecules of the contaminant diffuse into the pores to occupy that portion of the surface. This process is random with net flow toward regions of lower concentration.
3. The contaminant molecules are bound to the surface (adsorbed). This is an equilibrium process dependent on the concentration of the contaminant in the gas and on the surface, and is related to the vapor pressure of the contaminant (i.e., the lower the vapor pressure, the greater the adsorption). The equilibrium varies for different combinations of contaminant and adsorbent, but adsorbed molecular densities can approach those of the liquid or solid form of the compound. Adsorption is typically exothermic, releasing energy.

All of these steps are dependent on the local concentration gradient. The slowest of these steps determines the rate at which adsorption occurs. The speed of transportation across the boundary layer is dependent on the airflow pattern around the granules, because the depth of the boundary layer is determined by the total flow rate and, to a lesser extent, the granule size. The speed of diffusion through the pores is determined primarily

by the granule size, which determines the length of the path for diffusion, and the effective diameter of the pores. In general, the actual adsorption step is fast for physical adsorption.

Note that all of the steps are reversible. This means that some adsorbed molecules can be desorbed at a later time, either when cleaner air passes through the adsorbent bed or when another contaminant arrives that either binds more tightly to the adsorbent surface or is present at a higher concentration. The pore structure of the adsorbent and the characteristics of the contaminant will determine how easily this desorption occurs. Complete desorption usually requires an extremely long time or the addition of thermal energy to the bed.

A2 CHEMICAL ADSORPTION (CHEMISORPTION)

The three physical adsorption steps also apply to chemisorption. However, an additional step occurs after the contaminant is adsorbed onto the surface. A chemical reaction occurs between the contaminant molecule and either the surface of the adsorbent or a chemical on that surface, binding the contaminant to the surface. This additional step leads to several differences from physical adsorption:

1. Chemisorption is highly specific; only certain contaminant compounds will react with a particular chemisorbant.
2. Chemisorption improves as temperature increases (reaction rate increases); physical adsorption improves as temperature decreases (vapor pressure drops).
3. Chemisorption does not always generate heat, but instead may require heat input.
4. Chemisorption is not generally considered reversible at ambient temperatures and pressures. Once the adsorbed contaminant has reacted, it is not desorbed. However, one or more reaction products, different from the original contaminant, may be formed in the process and enter the air as a new contaminant.
5. Water vapor often helps chemisorption or is necessary for it, whereas water vapor can hinder physical adsorption due to competition for space.
6. Chemisorption per se is a monomolecular layer phenomenon; the pore-filling effect that takes place in physical adsorption does not occur in chemisorption, except where adsorbed water that has condensed in the pores forms a reactive liquid.

Most chemisorptive media are formed by coating or impregnating an extended-surface, non-reactive substrate (e.g., activated alumina, zeolite or carbon) with a chemical reactant. The reactant will eventually become exhausted, but the substrate may have physical adsorption ability that remains active when chemisorption ceases. Note that the addition of a chemical to a substrate necessarily uses some of the surface area that would otherwise be available for physical adsorption. Thus, the impregnated media typically has less capacity to remove physically adsorbed contaminants.

A catalyst is a special type of chemisorbant. A catalyst is defined as any substance of which a small proportion notably affects the rate of a chemical reaction without itself being consumed or undergoing a chemical change. Thus, in the ideal case, the amount of catalyst present never changes. The same steps occur (boundary layer transport, pore diffusion, adsorption, reaction), but the catalyst is not exhausted. As with chemisorption, catalysis is considered to be an irreversible phenomenon because the reaction products diffuse away from the surface and cannot participate in the reverse reaction. In addition, catalysis shares the same differences from physical adsorption. In actual application, the catalysts are eventually used up or "poisoned" by other types of reactions that occur besides the reaction of interest.

A3 SPECIFYING AMC FILTRATION PERFORMANCE

This section compares several performance measures used in the HVAC industry with respect to the requirements of a specific application. Figure A1 shows the dynamic response of a hypothetical filtration system when exposed to a constant contaminant concentration. The upstream or challenge concentration in this case is approximately 81 (concentration can be expressed in volumetric or mass units, e.g., ppbv or $\mu\text{g}/\text{m}^3$). This represents the pre-filtered or unfiltered concentration at the location where the filter system will be installed. The downstream concentration, or breakthrough, is expressed in the same units and continuously rises as the filter media are used. The penetration is the ratio of downstream to upstream concentration, expressed as a percentage. Note that in this example there is an initial penetration of about 10%, the best performance that this filter can achieve, followed by a relatively constant breakthrough and then an increasingly rapid rise. Section 5 describes some of the filtration system parameters that can impact the shape of this curve.

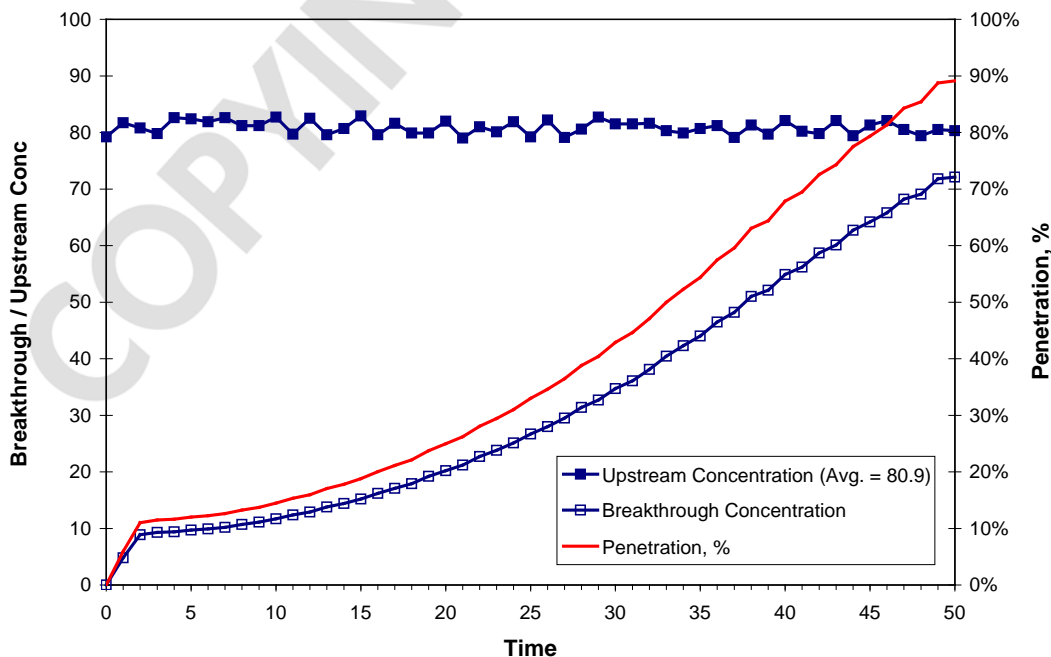


Figure A1—Relationship between challenge, breakthrough, and penetration.

Figure A2 shows the same penetration curve as Figure A1 and the corresponding efficiency curve (efficiency = 100% - penetration). The end point is the event that triggers the change-out of the filter. That event could be a recommended time period (18 months), a maximum breakthrough concentration (from Figure A1), or, as in this case, a minimum efficiency that must be maintained (80% in Figure A2). The capacity, or the amount of contaminant that was removed, is obtained by integrating the area under the efficiency curve from time zero to the point in time when the efficiency drops to this minimum value. One can imagine a series of capacities defined at different efficiencies or times. As shown here, the capacity is a calculated rather than a measured value. Capacity can be measured directly by the weight gain of a filter, but adsorption/desorption of water and possible chemical reactions can lead to misleading results unless properly accounted for.

Using the efficiency-vs.-time curve and successive integrations at each increment of time, one can also create an efficiency-vs.-capacity graph. This alternative presentation of the data can be used to estimate the capacity of an AMC filter system using different minimum efficiency scenarios. It should be noted that these capacity estimates are applicable only to the challenge concentration used to generate the test data.

It is also readily seen that a given capacity (especially if measured at equilibrium or 100% penetration) can be achieved by an infinite number of curve shapes. Some of these curves will meet the minimum efficiency that is required and others will not. That is why efficiency is the recommended performance parameter, with capacity used as a possible tie-breaker between equally performing systems.

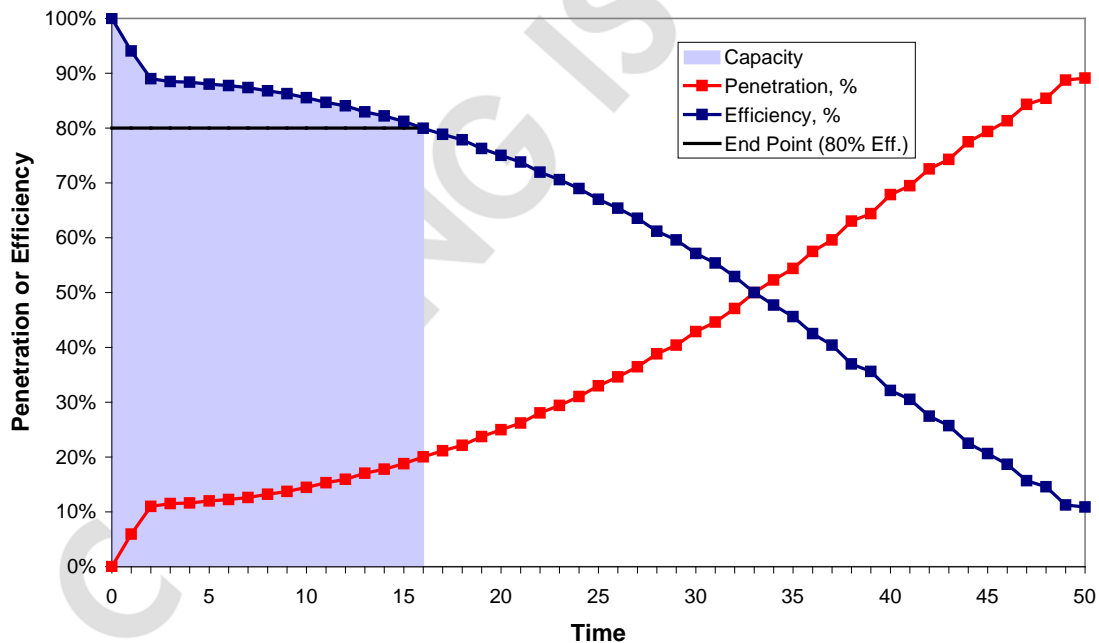


Figure A2—Relationship between penetration, efficiency, end point, and capacity.

APPENDIX B—BIBLIOGRAPHY

IEST RP-CC012: Considerations in Cleanroom Design; Subgroup 1: Cleanroom Design Considerations

ISO 14644-1 Cleanrooms and associated controlled environments—Part 1: Classification of air cleanliness

ISO 14644-8 Cleanrooms and associated controlled environments—Part 8: Classification of molecular contamination

ITRS (International Technology Roadmap for Semiconductors) – relevant sections include: Lithography, Factory Integration, Yield Enhancement. www.itrs.net

SEMI F21-1102: Classification of Airborne Molecular Contaminate Levels in Clean Environments

ASTM D5742-95: Standard Test Method for Determination of Butane Activity of Activated Carbon



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