# AIR Cleaning Processes and Types of Air Cleaners

**Types of Air Cleaning Processes**

Air cleaners are generally classified according to the technology employed to remove various sized particles and/or gases from the air. The general types of technologies available for use in air cleaners include mechanical filters, electronic air cleaners, and hybrid filters for the capture of particles, and gas phase filters to control odors. Air cleaners which operate by chemical process, such as ozonation, also exist. Information on filtration concepts and background is available in Appendix 2.

The selection of a type of air filter should depend on the intended use of the filter. Air filters' wide applications include: 1) protecting the HVAC equipment and components, 2) protecting the furnishings and decor of occupied spaces, 3) reducing housekeeping and building maintenance,

4) reducing furnace and heating equipment fire hazards, and 5) protecting the general well-being of residents. The first four of these applications can be accomplished with the lower efficiency filters generally used in central HVAC systems. The last, which has to do with health issues, will require much higher performance filtration. It may not always be possible to install this equipment in older existing environmental systems. Thus, self-contained portable room air cleaners must sometimes be used to obtain sufficiently high levels of filtration effectiveness.

***Mechanical Filters***

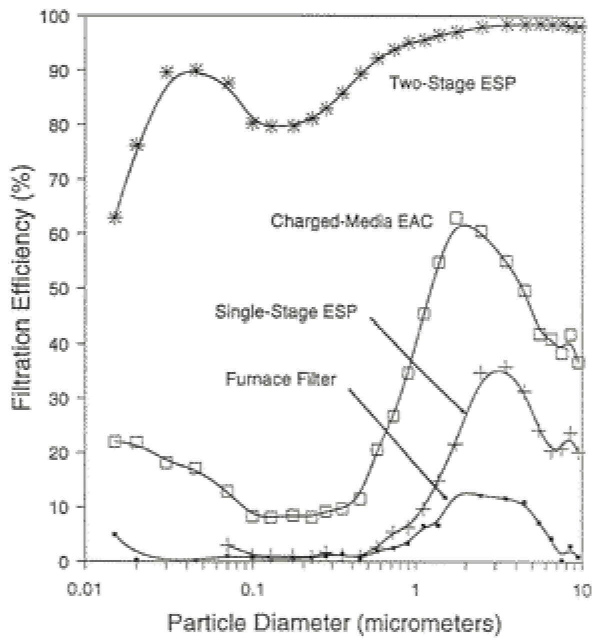
Mechanical filters may be used in central filtration systems as well as in portable units using a fan to force air through the filter. Mechanical filters capture particles by several physical mechanisms. Larger particles such as lint and fibers impact or "impinge" upon the filtration medium. Smaller particles are strained out of the airstream by increasingly smaller openings in the filter pack. Finally, very small submicron-sized particles are captured by diffusion toward the surfaces of the filtration medium (independent of airflow) where they are captured by electrostatic interaction between surface charges of particles and the filtration medium. This latter mechanism is the predominant factor in the effectiveness of the highest efficiency mechanical filters' removal of submicron-sized particles.

Mechanical filters are of three major types:

1. **Flat Filters**

   Flat or panel filters usually contain a low packing density fibrous medium that can be dry or coated with a viscous substance such as oil to increase particle adhesion. Dry-type filter media may consist of open-cell foams, non-woven textile cloths, paper-like mats of glass or cellulose fibers, wood fill, animal hair or synthetic fibers. They may also consist of slit and expanded aluminum. Media filters of various materials are available in a wide range of sizes and thicknesses. The typical, low-efficiency furnace filter in many residential HVAC systems is a flat filter, one-half-inch to one-inch thick, that is efficient in collecting large particles, but removes a negligible percentage of smaller, respirable-size particles. Figure 4 demonstrates how the efficiency of the typical furnace filter over the 0.01 - 10 micron diameter size-range compares to other types of air cleaners which are described.

Figure 4
**Fractional Efficiency of Several Air Cleaners over the 0.01 --10µm Diameter Size Range**



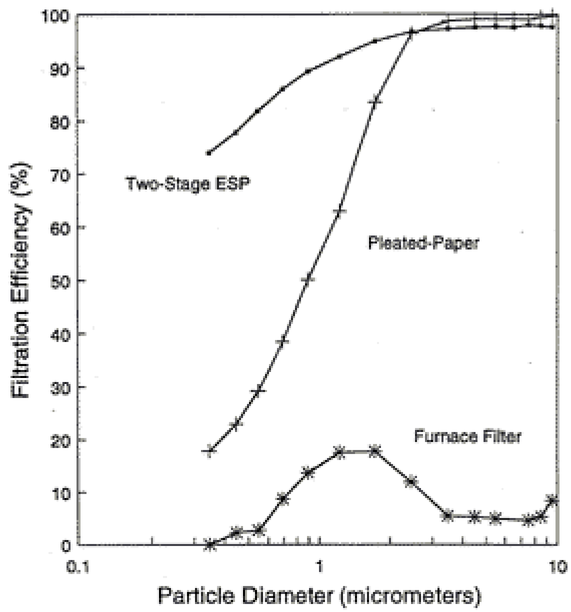

Source: Hanley JT, Ensor DS, Sparks LE,. Aerosol filtration efficiency of in-duct air cleaners

2. **Pleated Filters**

One of the most effective ways to increase the particle collection efficiency of mechanical filters is to increase the filter media density using small denier fibers. This causes smaller media penetrations and increases the screening or straining mesh size. However, any increase in filter density significantly increases resistance to airflow, causing decreased airflow through the filter. The most effective approach to overcoming this problem is to extend the surface area by pleating the filter medium. This lowers the airflow velocity through the filter and decreases overall resistance to airflow such that pressure drop is reduced. Additionally, pleating of filter media increases the total area available for filtration and, thus, extends the useful life of the filter. The efficiency of extended-surface (pleated) media filters is much higher than for other dry-type filters. For example, Figure 5 demonstrates the efficiency of a pleated paper filter over the 0.3 - 10 micron diameter size-range compared to a typical flat furnace filter.

Figure 5

**Fractional Efficiency of Several Air Cleaners Over the 0.3 -- 10 µm Diameter Size Range**




Source: Hanley JT, Ensor DS, Sparks LE,. Aerosol filtration efficiency of in-duct air cleaners

3. **High-Efficiency Particulate Air Filters**

High-efficiency particulate air (HEPA) filters, formerly called high-efficiency particulate arrestors, are a further extension of extended-surface media filters. HEPA filters were originally developed during World War II to prevent discharge of radioactive particles from nuclear reactor facility exhausts. They have since become a vital technology in industrial, medical, and military clean rooms and have grown in popularity for use in portable residential air cleaners.

A HEPA filter has been traditionally defined as an extended-surface dry-type filter having a minimum particle removal efficiency of 99.97% for all particles of 0.3 micron diameter with higher efficiency for both larger and smaller particles. This rating is determined using a test challenge smoke that consists of particles of 0.3 micron average diameter. To qualify as a "true" HEPA, the filter must allow no more than 3 particles out of 10,000 to penetrate the filtration media. The filtering media of a HEPA filter is made of submicronic glass fibers in a thickness and texture very similar to blotter paper. More recently, filters made in the same physical style using less efficient filter paper are being referred to as HEPA filters or "HEPA-type" filters. Their actual efficiency may be 55% or less at 0.3 microns. While still very good filters when compared to conventional panel type and even extended-media pocket filters, these versions of the original HEPA filter have higher airflow, lower efficiency, and lower cost than their original version. The true HEPA has very high pressure drop performance and both versions require prefiltration for maximum life cycle. Also, HEPA filters are generally not applied to residential HVAC systems due to their size and horsepower requirements. A disadvantage of HEPA filters is that the need for a powerful fan leads to increased energy costs compared to less efficient filtration systems, and replacement filters are generally quite expensive (retail prices range from $50 to $100, depending on size). The major advantages of the original HEPA filters, however, include high efficiency, which actually increases with use, and a long maintenance-free life cycle of up to five years when used with a prefilter. Nelson, et al. (1988) state that: "Because the designation of a filter as HEPA ensures a high degree of efficiency, it should be sought if a mechanical filter is to be used." Additionally, the 1990 review of indoor air pollutants and environmental controls published by the American Thoracic Society (1990) concludes that: "High-efficiency particulate filters (HEPA) are highly efficient in removing particles of a wide range of size. A room-size unit will control particles in that room, and a central unit will remove particles from the air of the building when the ventilation system is operating."

***Electronic Air Cleaners***

Electronic filters, generally marketed as electronic air cleaners and formerly referred to as electrostatic precipitators, employ an electrical field to trap particles. Like mechanical filters, they may be installed in central filtration systems as well as in portable units with fans.

The simplest form of electronic air cleaner is the negative ion generator. A variety of negative ion generator-type air cleaners is available. The simplest types use static charges to remove particles from indoor air. They operate by charging the particles in a room, which become attracted to and deposit on walls, floors, table tops, curtains, occupants, etc., where they may cause soiling problems.

More advanced units are theoretically designed to reduce soiling in a room. They generate negative ions within a space through which air flows, causing particles entrained in the air to become charged. The charged particles are then drawn back into the cleaner by a fan, where they are collected on an electrostatically charged panel filter. In other ionizers, a stream of negative ions is generated in pulses, and negatively charged particles are drawn passively back to the ionizer, which contains a positively charged sleeve or cover.

Electrostatic precipitators are the more common type of electronic air cleaner. They employ a one-stage or a two-stage design for particle collection. In the less expensive but less effective single-stage design, a charged medium acts to both charge and collect airborne particles. A two-stage design employs a high-voltage electrode or wire which places a charge on the incoming airborne particles. In the second stage, the charged airborne particles are drawn between a series of oppositely charged metal plates which attract the charged particles from the air causing them to precipitate onto the metal plates. Collection efficiency is a function of the area of the collecting plates, the flow rate, and the strength of the electrical field (Offerman et al., 1985). The airflow remains constant with use, but the particle capture efficiency declines rapidly as the charged collector plates become coated with particles. Cleaning the plates restores the initial efficiency and must be done regularly (at least every few months) to maintain adequate performance (King, 1973).

The advantages of electronic filters are that they generally have low energy costs because of low pressure drop. The airflow through the units remains constant with use, and the precipitating cell is reusable, avoiding long-term filter replacement costs. The major disadvantages are that (1) they become less efficient with use, (2) precipitating cells require frequent cleaning, (3) they can produce ozone, either as a by-product of use or intentionally, and (4) those installed into HVAC systems have a relatively high initial cost including expensive installation because of the size of the unit and its related wiring cost. See "Problems With Ozone Generators" on page 26 for more information on ozone. Additionally, the charged particles produced by negative ion generators can sometimes soil room walls and furnishings.

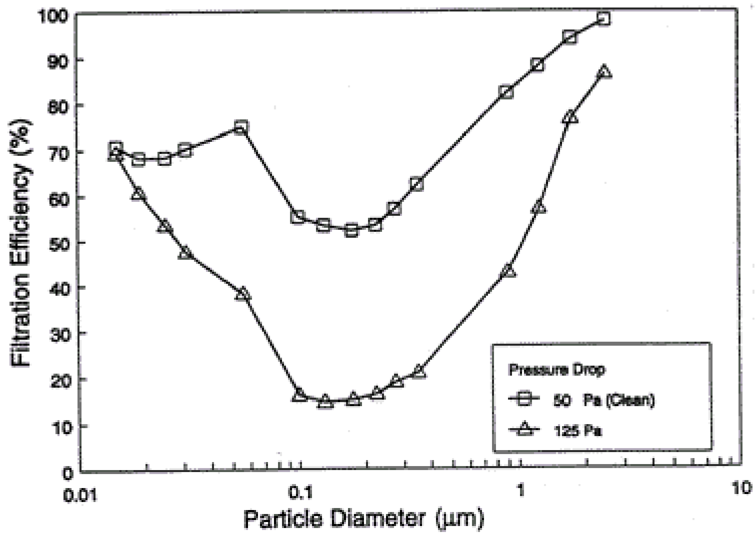
### ***Hybrid Filters***

Hybrid filters incorporate two or more of the filter control technologies discussed above. One such approach uses one or more types of mechanical filters combined with an electrostatic precipitator or an ion generator in an integrated system or single self-contained device.

An example of a hybrid filter is the "electret" media filter which uses permanently charged media fabricated into either flat panel filters or extended media filters. The media filter, made from synthetic fibers, is inherently charged in the manufacturing process and retains a charge which attracts airborne particles that are trapped and retained within the fibers in the conventional methods of impingement and diffusion of other dry-type filters.However, this being a media filter, it presents resistance to airflow which increases as the filter becomes soiled. The filter must, therefore, be replaced periodically. The advantages of an "electret" filter are the filter's relatively low energy cost and their high efficiency when clean. The disadvantages are high maintenance costs due to frequent need to replace filters and efficiency that drops with use. Figure 6 demonstrates the decreased efficiency of an "electret" or charged fiber filter with increased use and dust loading.

Figure 6

**The Effect of Dust Loading on the Fractional Efficiency of a Charged-Fiber Filter**




Source: Hanley JT, Ensor DS, Sparks LE,. Aerosol filtration efficiency of in-duct air cleaners

Ionizing charged-media type filters also exist. In this type of electronic air cleaner, dust in the air is initially charged and then collected on a charged-media filter. Several versions of this type of filter exist. They operate by charging the particles in the air with negative or alternating negative and positive charges, which enhances their deposition in conventional extended-media high-efficiency filters. Theoretically, the ions flow into the occupied space, causing particles to become charged and are then drawn back to the central air handler where they are collected. The claimed advantages of such systems is that they enhance the performance of the particulate filters, reduce particulate counts in the occupied space, and reduce the housekeeping costs of particle soiling in the space. The disadvantage of the technology is that it lacks definitive performance documentation and represents very high initial equipment cost over and above the cost of conventional high-efficiency filters.

Another category of hybrid filters, although not yet available commercially, is electrostatically enhanced filters. In this type of interaction, an electric field is actively superimposed on fibrous, media-based air filters. The principle underlying this technology is electrostatic precipitation superimposed on other capture mechanisms such as impaction, sedimentation, or diffusion. Under experimental conditions, this technology generally leads to increased filtration efficiency, relative to media-based filters alone, especially under low-flow velocity conditions. Experimental data have been obtained for different pollutants such as latex aerosols, dioctylphthalate (DOP) smoke, and two different kinds of laboratory generated dust (Kao, et al., 1987).

***Gas Phase Filters***

Compared to particulate control, gas phase pollution control is a relatively new and complex field. Neither mechanical nor electronic filters effectively remove gases and associated odors. Air cleaning units are often equipped with a chemical filter designed to remove pollutant gases from the air. Two types of gas phase capture and control are physical adsorption and absorption (also called chemisorption). Both are used for removing certain solvent vapors, odors, and low concentrations of gases and vapors in indoor air. Physical adsorption results from the electrostatic interaction between a molecule of gas or vapor and a surface. For example, in the adsorption of air, $N_2$ is physically adsorbed and is easily desorbed without affecting the adsorbent. Solid adsorbents such as activated charcoal and several other materials such as silica gel, activated alumina, zeolites, porous clay minerals, and molecular sieves are useful as adsorbents due to their large internal surface area, stability, and low cost.

Chemisorption, on the other hand, occurs when the sorbent attracts gas molecules onto the surface of the sorbent. Chemisorption involves electron transfer and is essentially a bond-forming chemical reaction between the adsorbing surface and the adsorbed molecule. Chemical reaction can occur when the molecules absorb, or go into solution with elements of the substrate or with other reactive reagents which are manufactured into the sorbate. This enables the sorbent to form chemical bonds with the contaminant molecule which binds it to the sorbent substrate or converts it into more benign chemical compounds. For example, one common chemisorbant employs potassium permanganate as an active oxidating reagent impregnated into an alumina or silica substrate. This chemisorbant will convert formaldehyde, for example, into benign water and carbon dioxide which is desorbed back into the air stream. Other more complex reactions result in compounds that bind to the sorbent substrate. Once bound, the contaminant is chemically altered and cannot escape back into the air stream. Chemisorption is usually slower than physical adsorption because of the complexity of the process. It is also not reversible as the active reagent component is consumed through the chemisorption process.

Activated charcoal is a widely used adsorbent (Noll, et al., 1992). The activation process etches the surface of the carbon to produce submicroscopic pores and channels where adsorption can occur. These pores provide the high surface area-to-volume ratio necessary for a good sorbent. Another advantage of charcoal is that it is non-polar, permitting adsorption of organic gases from air with a high moisture content.

There are several disadvantages to the use of activated charcoal. Although relatively small quantities of activated charcoal have been reported to reduce odors in residences, many pollutants affect health at levels below odor thresholds. Activated carbon adsorbs some gaseous indoor air pollutants, especially volatile organic compounds, sulfur dioxide, and ozone, but it does not efficiently adsorb volatile, low molecular weight gases such as formaldehyde and ammonia (Joffe, 1996). Because the rate of adsorption (i.e., the efficiency) decreases with the amount of pollutant captured, gaseous pollutant air cleaners are generally rated in terms of the adsorption capacity (i.e., the total amount of the chemical that can be captured). All adsorbents have limited adsorption capacities and thus require frequent maintenance. Another problem with the use of traditional adsorption beds is that there is no means to determine the effective residual capacity of activated carbon while it is in use. Additionally, there is concern that sorbent filters, when saturated, may re-emit trapped pollutants.

Recent developments in the gas phase sorbent filter field have yielded advanced products for use in residential HVAC systems as well as in portable air cleaners. This technology utilizes smaller, more active sorbent particles of carbon, permanganate/alumina, or zeolite which are incorporated into a fabric matte. The resulting matrix of fiber and active sorbent particles combines particulate filtration and gas phase filtration into one filter. The particles are situated evenly throughout the fabric containment matrix which assures good airflow and thorough contact with the air stream.

One manufacturer reports substantial sorption capacity increase over a similar weight of larger pelletized charcoal (Kinkead,1990). The whole filter cartridge is disposable to facilitate servicing. Like other gas phase sorbent filters, their useful service life varies according to indoor pollution concentrations. Unlike the more bulky traditional sorbents, they are considerably more economical. Also, because they have particulate arrestance capability comparable to the generic pleated particulate filter, no prefilter is required and the cartridge can be changed based upon static pressure increase.

Most sorbents are manufactured and applied in pellet form. This makes it possible to create gas phase filters which are sorbent mixturesof two or more materials. Usually, compound mixtures more effectively remove odors and gases than charcoal alone. Additionally, filter manufacturers can include in their products specific adsorbents to target particular odors or gases. The recent "hi-tech" matrix-type sorbent can employ mixtures of sorbent types, which allows more effective removal of a much broader range of pollutants than is possible with a single type of sorbent.

### *Ozone Generators*

These air cleaners utilize a chemical modification process instead of mechanical or electronic filters to "clean" the air. Ozone (referred to as trivalent oxygen or saturated oxygen by some manufacturers) has been used in water purification since 1893 (Wickramanayake, 1991). When used in water solutions such as cooling towers, ozone generators have demonstrated good control of reactive contaminants without creating negative side effects. Introducing ozone into the air stream can have beneficial effects under controlled conditions where humans are not exposed. For example, high concentrations of ozone are used to retard microbial growth in meat storage, and to control and counteract microbial growth and odors from fire and flood damaged buildings. However, ozone is of concern when considering spaces for human occupancy. The high concentration levels required for contaminant control are in conflict with potential health effects as established by authorities including the National Institute of Occupational Safety and Health (NIOSH) (Boeniger, 1995), the U.S. EPA (1995), and the U.S. Food and Drug Administration (FDA). Appliance-sized ozone generating units have typically been marketed in the United States and branded as air cleaners by several manufacturers. These air cleaners are marketed with the claim that ozone removes air contaminants from indoor air by oxidizing airborne gases, and even particulates, to carbon dioxide and water vapor. This claim, as well as the health hazards associated with ozone will be reviewed in detail in the section "Problems With Ozone Generators" on page 26.

Additional emerging technologies that employ chemical processes for air cleaning are discussed in Appendix 3.

# Chapter 2: Types of Available Air Cleaners

**Types of Available Air Cleaners**

Air cleaning devices are manufactured by many companies in the United States and they vary widely in design, methods of operation, cost and level of efficiency. Air cleaners can either be incorporated into the central heating, ventilation, and air-conditioning (HVAC) system or moved from room to room as portable units such as small table top units or larger portable room consoles.

### *Table top Units*

Until recently, small, inexpensive, table top appliance-type units have typically been quite popular in terms of unit sales (Clean Air Device Manufacturers Association [CADM], spoken communication). They generally contain small panels of dry, loosely packed, low-density fiber filters upstream of a high-velocity fan. Table top units may also consist of a fan and an electronic or other type of filter. Small table top units generally have limited airflow and inefficient panel filters. Most reviews have shown these table top units to be relatively ineffective (*Consumer Reports*, 1992 and Fox, 1994). The combination of low filter efficiency and low airflow in these units causes them to provide essentially no cleaning when assessed for impact on the air of the entire room (Nelson, et al., 1988).

Performance tests of 12 table top units were reported by *Rodale's New Shelter* magazine (1982). Tests were conducted in a 1200 cu.ft. room in which cigarette smoke was mechanically generated. Nine of 12 units reduced smoke levels by less than 24%, compared to a 17% decline that occurred by settling in the absence of the air cleaners. The researchers concluded that effectiveness of table top units in removing smoke particles was marginal at best and differed little from using no device at all. Similar results were reported by Offerman, et al. (1985).

*Consumer Reports* magazine (1992) also tested nine table top units and found that, because they can move only small amounts of air, they suffice only for a very small room or a portion of a room. Two of the table top units tested were ozone generators. Both of these units were judged "not acceptable" because they produced harmful levels of ozone and did not have automatic controls to limit ozone output.

### *Room Units*

Another major type of residential air cleaner is the larger, yet portable, devices designed to clean the air in a specific size room. Due to their larger and more effective filters or collecting plates, these larger portable room air cleaners are considerably more effective in cleaning the air in a room than the table top units (*oonsumer Reports*, 1992; Fox, 1994) and have become increasingly popular in the past several years, exceeding the table top units in consumer sales (CADM, spoken communication). Room-size air cleaners are generally utilized when continuous, localized air cleaning is necessary (*Consumer Reports*, 1992 and Fox, 1994). Most units may be moved from room to room to reduce pollutant concentration levels as needed. Similarly to the table top units, room units also incorporate a variety of air cleaning technologies.

*Rodale's New Shelter* (1982) reported significantly more effective performances for 15 larger HEPA and/or electronic portable air cleaners. The time required to reduce smoke levels by 95% varied from 26 to 120 minutes.

Offerman, et al. (1985) tested a variety of portable air cleaners using tobacco smoke as a source of particles. The test protocol involved turning cleaners on for a three-to-five hour period following a period of decay and mixing followed by a 6-8 hour period of natural decay. The highest efficiency based on clean air delivery rate (CADR) was observed in the room unit utilizing a HEPA filter.

Room units tested by *Consumer Reports* (1992) all moved more air than table top units. The highest efficiency for smoke and dust removal was observed in a room unit utilizing electrostatic precipitation.

Portable room air cleaners are much more effective in rooms where all doors and windows are closed (AHAM).

### *Central Filtration Systems*

Air cleaning systems can also be installed in the central heating or air-conditioning systems of a residence or in an HVAC system. These units are commonly referred to as "in-duct" units, although this term is actually a misnomer since they are not located in the distribution ductwork, but rather in unducted return air grilles or ducted return air plenums. The term "central filtration system" will be used in this document. This type of unit provides building-wide air cleaning and, by continuously recirculating building air through the unit, can potentially clean the air throughout the entire air handling system, duct work and rooms. However, with these types of units, the HVAC fan must be in constant operation for air cleaning to occur since the airborne contaminants must be captured and carried back to the centralized filter for capture and retention. Thus, central filtration systems must be operated with the fan "on" for constant air movement through the HVAC system. Generally, residential HVAC systems operate only on intermittent fan to maintain a comfortable indoor temperature.

A review by Fox (1992) suggests that a highly efficient room unit will be more effective at removing pollutants in the room where it is located than a central filtration system. *Consumer Reports* (1992) also recommends that for cleaning the air in a room or several rooms, a portable air cleaner is more effective than a central system.

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