are nevertheless valid and significant because all were subject to identical standardized procedures.

Test methods of the National Bureau of Standards have validity for similar reasons, but because the testing is performed for government departments and on the basis of confidential reporting, the test value is largely restricted to government personnel and contractors doing government work.

Dioctyl-phthalate (DOP) smoke, a homogeneous aerosol of 0.3-micron particle size, is used to test a special class of extremely high efficiency filters, used principally to control particulate matter of extreme toxicity, and for supply systems to areas requiring exceptional cleanliness. Since the test aerosol and procedures are standardized, results on this family of air filters can be compared in a valid manner.

Research on the operating characteristics of air filters continues, and techniques are in use and under development. However, these are beyond the scope of this chapter.

TYPES OF AIR CLEANERS

All the common types of air cleaners fall into two broad categories: (1) filters proper, wherein the accumulating dust load results in a pressure drop increase continuously to the end of an operating period determined by maximum permissible pressure drop, generally 0.5 to 1.0 in. of water; at the end of this period filters are either replaced or washed for re-use; and (2) the ionizing type electronic cleaner in which deposits are removed at the end of an operating cycle, usually by washing, automatically or manually, or by automatically moving the plates through an oil bath. Pressure drop is essentially constant throughout the operating cycle.

This classification of air cleaners is set forth as follows:

Air Filters

1. Viscous Impingement
   (a) Frame, panel or unit types
   (b) Moving curtain type
2. Dry Type (Extended Surface, Deep Folded)
   (a) Thick beds of fibers, porous sponge, etc.
   (b) Thin nonwoven mats
3. Charged Media, Electronic (Dry)

Electronic, Air Cleaner, Ionizer-Plate Type

1. Stationary plate type, washable
2. Rotating plate type.

Viscous Impingement Filters

Viscous impingement filters are flat, shallow assemblies in which the approach velocity of the air stream equals the velocity through the filter media. Thus, the air velocity through the filter media is high (250 to 520 fpm). The filter media is commonly composed of relatively coarse fibers in a bed of high porosity and, in the case of thicker beds, of relatively high dust-holding capacity. These filters are characterized by relatively low efficiency on dust, good efficiency on lint, and low cost.

Viscous-impingement types of filters derive their name from the fact that the medium is treated with a viscous substance frequently referred to as oil or as adhesive. In the operation of the filter, the air stream is broken up into many small columns, and these individual columns of air are made to change direction many times during the course of passage through the filter. At each change of direction, momentum carries the larger dust particles in a straight line, until they impinge against the elements or fibers of the medium and are held by the adhesive surface.[11,12,13]

The filter may be of the unit or panel type: (1) the permanent type which is manually cleaned and replaced, (2) the disposable type which is replaced after it has accumulated its dirt load, or (3) the automatic moving-curtain type.

Unit or Panel Type. A number of different materials are used as the filtering medium in unit filters of the viscous-impingement type. These include animal hair, vegetable fibers, metallic wools, fibers of glass, and various configurations of metal screens and mesh material, crimped wire, screen, woven mesh, metal stampings or plates, or sometimes a combination of these. The arrangement of the medium in this type of filter actually involves two basic configurations:

1. The *high-velocity type* in which the filtering medium is placed on edge to offer a low resistance to the flow of air. This type of filter design generally does not have any recommended direction of air flow. Filters in this category carry a nominal face velocity rating of from 480 to 520 fpm. Due to the possibility of face loading, these high-velocity viscous-impingement filters are apt to be adversely affected if there are excessive amounts of lint in the air being handled.

2. The *progressive pack* or *progressive density design*, in which the medium is packed more densely on the leaving air side than on the entering air side. Such an arrangement permits the accumulation of dirt throughout the depth of the media, with the larger particles being removed near the air entering face of the filter, and selective removal taking place throughout the depth of medium. Filters of this design generally are rated at a face velocity of 300 to 350 fpm.

The adhesive or oil used on a viscous-impingement type filter requires careful selection. In general, it is good practice to follow the filter manufacturer's recommendations. Desirable characteristics of a suitable adhesive are: (a) a low percentage of volatiles to prevent excessive evaporation, (b) a viscosity that varies only slightly with normal changes of temperature, (c) ability to inhibit growth of bacteria and mold spores, (d) high capillarity, or the ability to wet and retain the dust particles, (e) a high flash point and fire point, and (f) freedom from odor.

Unit types of viscous-impingement filters are usually produced in nominal thicknesses of 1 and 2 in. and in several standard sizes. The initial resistance of typical filters of this category usually ranges from 0.08 to 0.15 in. of water. The resistance of any air filter increases with an increase in the rate of air flow. In the case of unit types of viscous filters, the initial resistance at other than normal rating can be approximated from Equation 3:

$$R_2 = R_1(V_2/V_1)^{1.7} \qquad (3)$$

where

R_1 = resistance at normal rating, inches water.
R_2 = resistance at air velocity, V_2, inches water.
V_1 = face velocity at normal rating, feet per minute.
V_2 = face velocity at other than normal rating, feet per minute.

Unit filters generally fit into metal frames which are riveted or bolted together to form a filter bank or section. The rate of loading of the filter obviously depends upon the type and concentration of the dirt in the air being handled and upon the operating cycle of the system. For this reason, periods between maintenance cannot be predicted with certainty. Manometers or draft gages are often installed to measure the pressure drop across the filter bank and thereby indicate when the filter requires servicing. The final allowable pressure drop may vary from one installation to another; but in general, unit filters are serviced when their operating resistance reaches 0.5 in. of water. With certain types of media a decline in efficiency may be the limiting factor in operating life rather than the increased resistance due to diet load.

The manner of servicing unit filters depends upon their construction. Disposable types of filters are constructed of inexpensive materials and are designed to be discarded after one period of use. The cell sides of this design are usually a combination of cardboard and metal stiffeners. The permanent type of unit filters are generally constructed of metal in order to withstand repeated handlings. Various cleaning methods have been recommended for filters of this design, but the most widely used procedure involves washing the filter with steam or water (frequently using a detergent) and then dipping or spraying the filter with its recommended adhesive. The excessive adhesive should be allowed to drain from the filter before it is put back into service. In order to provide as uniform an operating resistance as possible, it is sometimes advisable to use the *rotation* system of filter maintenance where large banks are involved. In this procedure, a portion of the filter bank (20 – 25 percent) is reconditioned on an established schedule. Certain arrangements of unit types of viscous filters are designed to have the filters washed in place. Cleaning is generally accomplished by means of hot water sprayed from a hose or by the use of fixed nozzles. At the completion of the washing cycle, the necessary adhesive is applied. Where filters are washed in place, provision should be made to collect and drain the water so as to prevent leakage from the filter housing.

Moving-Curtain Viscous Filters. Automatic moving-curtain viscous filters are available in two main types. In one design the filter medium is installed on a travelling curtain which intermittently passes through an adhesive reservoir where the media gives up its dust load, and at the same time takes on a new coating of adhesive. The medium used in this design generally consists of metal panels or sections made up of screen wire, stamped plates or baffles, or reinforced mesh which are attached to a pair of chains, and these in turn are mounted on sprockets located in the top and bottom of the filter housing. The media thus forms a continuous curtain which moves up one face and down the other face of the filter. Arrangement of media is such that the air is caused to change direction many times in its passage through the curtain and thus provides the impingement effect for the collection of dust particles.

Automatic filters of this design generally utilize a timer for periodically moving the filter curtain. This timer is so set that the curtain makes one complete revolution in 24 to 48 hr. Periodically the precipitated dirt must be removed from the adhesive reservoir. This is generally done by scraping the dirt into a tray which can conveniently be suspended from the reservoir lip. The frequency of dirt removal is a variable; but in normal operation this type of filter will require attention approximately once every three months. Where it is desirable to eliminate the maintenance associated with removing the precipitated dirt from the reservoir, the adhesive may be pumped through oil clarifiers or can be allowed to circulate through large capacity settling tanks.

Automatic viscous-impingement filters are also available in which the media is furnished in roll form so that it is fed automatically across the face of the filter, while the dirty media is being rewound into a roll at the bottom. Most designs of this type have the media automatically fed across the face of the filter by means of a timer control or pressure switch control. The timer control appears to be preferable because the media can be replenished in small increments, and this results in a more uniform operating resistance. Filters of this design are generally constructed to be *fail safe* by having a signal that indicates when the roll of media is about to become exhausted. At the same time the drive motor is de-energized so that the filter cannot run out of media. The normal service requirements involve insertion of a clean roll of media at the top of the filter and disposing of the loaded dirty roll. Automatic filters of this design are not limited in application to the vertical position. Horizontal arrangements are available for use in connection with make-up air units, air conditioning units, etc.

Most automatic types of viscous filters are equipped with a fractional horsepower motor operating the drive mechanism through a gear reducer. The operating period is adjustable so that the media travel can be adjusted for changes in dust concentration. In operation, the resistance of an automatic filter will remain approximately constant as long as proper operation is obtained. A resistance of 0.4 to 0.5 in. of water at a face velocity of 500 fpm is typical of this class.

Dry Type Air Filters

The media used in dry types of air filters are usually fabric-like or blanket-like materials of varying thicknesses. Media of cellulose fibers, bonded glass, wool felt, asbestos, synthetics and other materials have been used commercially. The medium in filters of this class is frequently supported by a wire frame in the form of pockets or V-shaped pleats. In other designs the media may be self-supporting. Pleating of the media provides a high ratio of media area to face area.

The efficiency of dry type air filters is usually higher than that of viscous impingement type filters, and the variety of media available makes it possible to furnish almost any degree of cleaning efficiency desired. Modern dry type filter media and configurations give dust-holding capacity equal to or better than many viscous impingement filters and efficiencies that are much higher. The high efficiency dry type filters do not generally need prefilters to obtain good service life. Exceptions to this, however, are the filters rated at 99.9 percent efficiency on the DOP test aerosol.

Where highly efficient filtration is required, the DOP rated dry filter, the electrostatic precipitator, and a second group of dry filters cover the field. The first group are rated by the 0.3 micron DOP smoke method only and show 99.9+ percent efficiency. The electrostatic precipitator, usually rated by atmospheric dust spot method of NBS or AFI, show efficiencies from 90 to 98 percent. The higher efficiency dry filters that are usually rated by either NBS or AFI atmospheric dust spot, show performance up to about 95 percent.

The DOP rated filters are made in an extended surface configuration of deep, spaced folds of all glass fiber paper-like material, or one made of a glass-asbestos mix. The NBS or AFI rated higher efficiency filters are usually made of a mat of fine glass fiber in thicknesses from about $\frac{1}{4}$ to 1 in. The use of the higher efficiency dry filters is expanding. The choice between electrostatic precipitators and the applicable type of dry filter depends on the technical requirements and an economic study of maintenance and replacement costs.

In some designs of dry type air filters, the filter media is replaceable and is held in position in permanent metal cell sides. In other designs the entire cell is disposed of after it has accumulated its dirt load.

Mention should be made that the absence of an adhesive on the filter medium does not necessarily qualify it as a *dry type* air filter. The distinguishing characteristics are generally the high efficiency produced by the smaller size fibers and the fact that the fibers are spaced close together to obtain a dense mat or pad. A low resistance pad consisting of large fibers having no adhesive coating would be a *dry* filter but would be less effective than a typical viscous-impingement filter.

The initial resistance of a dry type filter will vary with the choice of medium. A number of commercial designs have an initial resistance of approximately 0.1 in. of water. It is customary to replace the media when a final resistance of 0.5 in. of water is reached. Other types of dry media providing higher orders of cleaning efficiency will offer a higher resistance to air flow. The overall operating resistance must be considered in the system design since that is the resistance against which the fan will be called upon to operate.