

procedures involve an accelerated test using a synthetic test dust. These procedures differ in the type of test dust used and in the method of measuring the dust content of the air entering and leaving the air cleaner. The numerical value of the arrestance, or efficiency, of an air cleaner may vary for each method of test, even if the same test dust is used. However, it generally varies when the same test method is used with different test dust. Caution must be exercised in interpreting published arrestance data, since different test procedures prevent performance comparison of two cleaners of differing designs. The test used may yield results that are considerably different from those obtained in an actual installation.

The two most common methods for evaluating efficiency are: (1) the weight method, in which the weight concentration of dust in the air entering and leaving the cleaner is measured by some suitable means, and (2) the dust spot test in which the dust content of the air entering and leaving is measured in terms of its ability to stain filter paper.

1. *Weight Efficiency.* A weight method in common use today is described in the *Air Filter Institute Code*,² Section I, which specifies a test dust as follows:

"The test dust mixture consists of 72 percent standardized air cleaner test dust, fine (Arizona road dust, fine); 25 percent K-1 carbon black; and 3 percent No. 7 cotton linters ground in a Wiley mill with a 4-mm screen (percentages by weight)."

The entering concentration is determined by feeding a known weight of the prepared test dust at a known and controlled rate. The concentration of dust in the air leaving the filter is determined by passing the entire air flow through a high-efficiency filtering blanket, and measuring the gain in blanket weight. Test data and results are presented on standardized forms made available by the Air Filter Institute.

Atmospheric dust is a heterogeneous mixture of particles ranging in size from a small fraction of a micron up to larger particles tens of microns in diameter. A small percentage of the largest particles in such a mixture always accounts for most of the weight; this is also true of the particle mixture in ambient outdoor atmosphere. The weight efficiency method of rating which employs an artificially generated dust cloud of heterogeneous particle size, is a description only of the ability of a filter to remove the largest dust particles in the mixture and gives little indication of the filter performance in removing the smallest particles. For these reasons, where extremely small particles are objectionable, the weight efficiency method of rating would not adequately differentiate between two filters having approximately equal weight efficiencies on such heterogeneous dust mixtures.

2. *Dust Spot Efficiency.* Recognition of these facts led to development of the dust spot method of testing at the National Bureau of Standards.³ It is based on the idea that, since one objectionable characteristic of the finer airborne dust particles is the capacity to soil walls, ceilings and other interior surfaces, filtration of air through white filter paper would constitute an accelerated simulation of this effect and description of efficiency on the optical density basis would properly reflect this operating characteristic of air-cleaning devices.

The NBS test method is composed of two parts. One (dust spot, atmospheric) employs the normally-occurring particulate matter in the outdoor ambient atmosphere of the testing laboratory as the test aerosol. The second is a fed-dust technique in which a Cottrell precipitator dust from a specified source in combination with standardized lint is dispersed in a horizontal test dust containing the filter undergoing test. In both cases, efficiency is evaluated on the basis of dust spot opacity comparisons, not by weight.

The National Bureau of Standards ordinarily employs

ambient atmospheric dust for its evaluation of electronic air cleaners and other high-efficiency filters, and the fed-dust technique for other types of filters. In evaluating tests by the dust spot method, consideration must be given to the type of contaminant used in the test, since efficiency values are considerably higher when Cottrell dust is used as compared to ambient atmosphere.

The efficiency of many panel filters tested by the dust spot (atmospheric) method is very low (10 to 15 percent or less); this test method is not generally employed for a rating of this type of filter since it fails to differentiate one filter from another, even though on a weight basis the filters in question may exhibit significant differences in performance. Conversely, while the weight efficiency of an electronic air cleaner may be high, the weight method of rating is not adequate to differentiate one device from another.

While the weight method emphasizes the larger particles in a heterogeneous dust mixture, the dust spot method emphasizes the finer particles since the fines have greater staining power than an equivalent weight of coarse particles. This is another reason that not all cleaners can be rated by a single method.

a. *NBS Test Method.* Air samples are drawn at equal flow rates from upstream and downstream of the air cleaner and passed through known areas of filter paper. The optical density of the resulting dust spots on the two filter papers is measured with a photometer and used to determine the arrestance of the air cleaner. Dust spots of approximately the same opacity are developed by successive selection of different upstream and downstream sampling areas or by upstream sampling only a fraction of the time. When unequal areas are employed, Equation 1 is used to evaluate the arrestance E and when part-time upstream sampling is employed, Equation 2 is used to evaluate the arrestance.

$$E = 1 - \frac{A_D}{A_U} \times \frac{Q_D}{Q_U} \quad (1)$$

$$E = 1 - \frac{T}{100} \times \frac{Q_D}{Q_U} \quad (2)$$

where

A_U = upstream dust spot area.

A_D = downstream dust spot area.

Q_U = change in upstream opacity of stain.

Q_D = change in downstream opacity of stain.

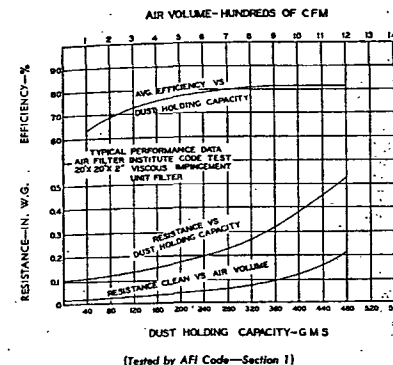
T = percentage of upstream sampling time.

b. *AFI Dust Spot Test.* The Air Filter Institute has adopted a dust spot procedure known as the AFI Dust Spot Test Code,⁴ which is identical with that part of the NBS Test Method which employs ambient atmospheric particulates. The AFI procedure specifies methods and equipment for making dust spot efficiency tests on atmospheric air and specifies procedures and Report Forms for Qualification Tests. Dust Holding Capacity procedures are not included in the AFI Dust Spot Test Code as the purpose of the code is to specify an efficiency measuring technique and procedure. Dust holding capacity procedures are specified in Section I of the AFI Code; this procedure is used to establish that value whether efficiency is measured by the AFI Dust Spot or the AFI Weight method.

3. *Dust-Holding Capacity.*

a. *AFI Method.* The AFI Code, Section I (Weight), specifies procedures for determining dust-holding capacity, the amount of dust which a filter can retain and have a resistance less than some arbitrary value. Under the AFI procedure, dust-holding capacity is defined as the product of the weight of dust reaching the filter and the average efficiency at a specified resistance and air flow. Dust loading and arrestance determinations are made simultaneously; arrestance and resistance are determined for each increment of feed with the results plotted against weight of dust fed. Fig. 1 shows the results of an Air Filter Institute Weight Code test conducted on a typical viscous impingement type filter.

Air Cleaners



(Tested by AFI Code—Section I)

Fig. 1 Typical Unit Filter Performance Data

b. *NBS Method.* Dirt-loading measurements are made at the National Bureau of Standards⁵ by feeding a mixture of 4 percent standardized cotton linters and 96 percent Cottrell precipitate (by weight) to the test filter. The two ingredients are separately dispersed into the air stream by two aspirating type injectors. The measurements show the relationship between the resistance and the weight of dirt mixture received at the filter. In the NBS method, the weight of dust received by the filter is not multiplied by efficiency to obtain dust-holding capacity, and, therefore, the value is frequently referred to as dust received. The curves in Fig. 2 illustrate the difference in the dirt-loading characteristics of two filters: (1) a viscous-impingement type and (2) a dry filter with an extended-surface cellulose-fiber medium, with dust and with lint. This chart shows the different loading effects of lint on the two types of filters as compared to dust without lint. NBS performs loading tests on all filters except electrostatic precipitators, whether the test aerosol be atmospheric air or Cottrell precipitate.

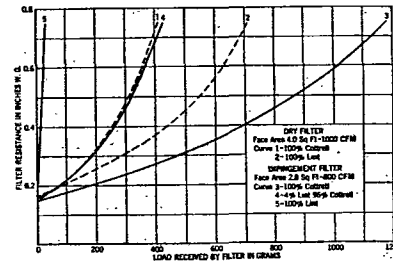
Significance and Limitations of Ratings

The ideal filter test method would simulate the actual performance of the filter when installed at the use site. The desirability of having a widely accepted accelerated test method to determine the operating characteristics of filters is generally recognized, but the variety and variability of airborne particulates⁶⁻⁸ makes the use of a synthetic test dust in any accelerated test automatically violate the principle of simulation of actual performance.

Because the indicated weight efficiency of air filters is highly dependent on the particle size distribution of test dust (and this includes important consideration of its state of deagglomeration) it is universally recognized that testing of filters in this category requires a high degree of standardization of the test dust itself, the dust dispersion apparatus, and other elements of test equipment and of procedures.

It has been established that the concentration, size characteristics and lint content of atmospheric dust vary greatly in different locations.⁴ These inherent limitations of any accelerated test indicate that it is not possible to reproduce exact air filter performance. Test results, therefore, are limited in permitting comparisons between different air cleaners, but are useful in preparing purchase and design specifications.

In loading tests, the dust-holding capacity of a filter as determined in an accelerated test will not permit calculation, from dust concentrations in some locality, of the actual life of



(Tested by NBS—Cottrell Fed-Dust Method)

Fig. 2 Dust and Lint Holding Capacity of Two Filters

a filter. The test results must be restricted to comparisons between different filters.

The accuracy and repeatability of filter tests performed by reputable laboratories is quite good. Sources of differences in reported values lie in the variability of the test aerosols and dusts which is very difficult to control closely. Another source of difference is the nonuniformity of the filter medium. The current trend toward media made of random air or water-laid and spun fibrous materials, introduces the inherent variability of the medium into the performance data. Realization of these unavoidable variations, under even the most closely controlled manufacturing conditions, will prevent misunderstanding and specification of impossibly close performance tolerances.

At present, figures on air cleaner efficiency can not be related quantitatively to the rate of soiling of a space or of mechanical equipment, nor to the intensity of other objectionable effects. Thus, air cleaner efficiency data do not provide the information necessary to design properly air cleaning installations to control wall smudging, deposits on heat transfer surfaces, soiling of furnishings, etc. In other words, in the absence of knowledge of a quantitative relationship between air cleaner efficiency figures and the various objectionable effects, these figures have only the limited value previously indicated. Lacking systematically developed data of this nature, knowledge developed from practical experience must be considered.

Other Filter Test Methods

Different dusts and techniques have been used in various laboratories to determine gravimetric and dust spot efficiency of filters, and opinions on the relative merits of each have been diverse. Questions pertaining to this matter, however, can readily be resolved by reference to the principle, cited above, that present test results must be limited to a comparison between different filters. Any test method can only justify itself if it can report test results on a wide variety of air filters under its particular test conditions. Conversely, test results on a single filter by some *nonstandard* method are valueless because they can not be compared with competing air cleaners.

A test method developed by Whitby⁹ at using a pulverized anthracite coal-carbon black mixture for a test dust, was the basis for an interesting report¹⁰ on the relative performance of a wide variety of air cleaners. While that test method has not gained official recognition, the reported test results