Evaluation of Air Filter Test Methods

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There are three generally accepted test methods in current use for determining the
effectiveness of air filters used for the collection of atmospheric dust. These three meth-
ods are (a) weight, (b) dust spot, and (c) DOP, which uses dioctyl-phylate as the aero-
sol. These test methods are discussed briefly and illustrations are used to assist the
reader in visualizing the concentration of dust which will remain in the clean-air stream
for efficiency values reported by each test method.

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Evaluation of Air Filter Test Methods

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At the present time there are two basic methods in general use for determining the effectiveness of air cleaners applied to the removal of atmospheric dust. These two methods are referred to as the "weight method" and the "dust-spot method" and one or the other of these two methods usually forms the basis for reporting air-cleaner performance. It is sometimes difficult, however, to visualize just what performance to expect from an air-cleaner having a given efficiency. What does it mean in terms of air cleanliness when manufacturer's data indicate a weight efficiency of 80 percent or a dust-spot efficiency of 40 percent?

BACKGROUND

In the early 1930's the then American Society of Heating and Ventilating Engineers adopted a code for the testing and rating of unit types of air filters. A specified mixture of synthetic dust was introduced into the air stream passing through the filter under observation and the efficiency of the filter was determined on the basis of the amount of weight of this dust which the filter was able to remove. For a number of years this code was used widely, but it had some shortcomings which became more apparent as new improvements were made in air-cleaning devices. Several years later this code was declared obsolete by the society and was withdrawn from use. A number of years went by during which there was no generally accepted test method for determining air-filter performance by the weight basis. In 1953, the Air Filter Institute, a voluntary organization of air-filter manufacturers adopted Section I of a Code for Testing Air Cleaning Devices of the unit or panel type. This code attempted to eliminate the shortcomings of the previous weight method of testing and is the procedure now in general use for the testing of those types of filters to which this code is intended to apply.

AFI TEST CODE

The AFI test code utilizes a synthetic dust mixture consisting of the following components;
- 72 percent by weight of standard air-cleaner test dust - fine (sometimes referred to as Arizona road dust - fine).
- 25 percent by weight of K-1 carbon black.
- 3 percent by weight of No. 7 cotton linters.

Fig. 1 shows a vertical arrangement of an AFI test duct. The synthetic dust components are mixed thoroughly and introduced into the air stream at a prescribed concentration of 0.625 g per 1000 cu ft of air. Located downstream from the test filter is the final-filter assembly through which all the air passes. The increase in weight of this final filter indicates the amount of dust passing the test filter during each determination. The dust arrestance or efficiency is the percentage relation between the weight of dust fed as compared to the weight of dust passing the test filter.

\[
\text{Efficiency} = \left(1 - \frac{Q_2}{Q_1}\right) \times 100
\]

where
- \(Q_1\) = weight of dust fed
- \(Q_2\) = weight of dust passing test filter

The final filter consists of a nonhygroscopic medium such as a glass-fiber blanket (or the equivalent) and by specification must have an ef-
Fig. 2 Amount of AFI test dust passing the filter for weight efficiencies indicated

Fig. 2 shows the weight of dust passing the test filter and entering the clean-air stream for each efficiency value indicated. Plate No. 1 on the left of the illustration contains 200 g of the AFI synthetic dust mixture and represents the total weight of dust fed into the air stream for each efficiency test. Assume that during the first tests there was no filter in position, then the entire 200 g of dust would remain in the clean-air stream, so Plate No. 1 has been labeled "0% efficiency." Plate No. 2 of Fig. 2 represents a filter with a weight efficiency of 75 percent, and the amount of dust shown on the plate represents the 50 g which would pass through the test filter and enter the clean air stream. Each remaining plate represents the actual amount of test dust which would pass through the filter for the weight efficiency values indicated. In reality, the dust shown on each plate, therefore, represents the inefficiency of the test filter. A comparison of the quantity of dust passing the filter with the original 200 g of dust which was introduced into the air stream will permit one to visualize the weight of dust which the filter was able to remove for each weight efficiency value.

WEIGHT METHOD TEST

The weight method provides an excellent basis for comparing the relative performance of air cleaners in the medium-efficiency range but it has certain shortcomings where high efficiencies are involved. Should a portion of the dust passing the test filter lodge in the ductwork before reaching the final filter, it can be seen that any small amount of dropout would have a significant effect upon the high efficiency values. For this reason, the weight method of testing air-cleaning devices is usually limited to efficiency values of 96 to 97 percent. Weight efficiency values approaching 100 percent become unreliable because they would fall within the limits of experimental error. It is also obvious that it is extremely difficult to compare accurately the performance of experimental filters if the total available spread in efficiencies is only 1 or 2 percentage points.

DUST-SPOT TEST METHOD

As a consequence, a different test procedure is required for the higher efficiency ranges and the method most widely used today is known as the "dust-spot test" which was developed originally by the United States Bureau of Standards. The Air Filter Institute has also published recently its own Dust Spot Test Code which is patterned quite closely after the Bureau of Standards recommendations.

The dust-spot test was developed in order

3 Air Filter Institute, Dust Spot Test Code, 1960.
to determine the ability of an air filter to remove that dust which was likely to discolor the interior of a filtered space and the test equipment required is shown in Fig. 3. In conducting dust-spot efficiency determinations, samples of air are taken upstream and downstream from the filter under observation. These samples are drawn through chemical filter paper, tightly clamped between two pieces of metal called "target holders." The dust removed from each upstream and downstream sample as it passes through the filter paper produces a spot or target. These target holders are inserted in large sections of each sampling tube and a vacuum pump is used for creating the flow of sampled air. In conducting a dust-spot efficiency test, several variables exist, such as the size of the targets formed on the upstream and downstream side of the test filter, the quantity of air being sampled at each position, the length of the sampling period at each position, the density of the dust spots formed, and so on. The standard test procedure is to control the factors producing the upstream and downstream spots so that only one variable exists and this variable can then be evaluated in terms of dust-spot efficiency.

Current practice is to test high-efficiency filters by the dust-spot method when handling atmospheric dust. This means that the test filter is subjected to the concentration of dust present in the atmosphere at the time the test is conducted and the factor which is allowed to vary in dust-spot determinations is generally that of sampling time. The same rate of sampling is maintained upstream and downstream of the test filter, but the upstream sampler is operated for a shorter overall period of time so that the targets formed have equivalent dust densities. The clean filter paper on which the targets are formed is "balanced" prior to each test. With targets of equal dust density, the dust-spot ef-
Dust-spot efficiency is thus a function of the sampling periods as indicated by the following expression

\[
\text{Dust-spot efficiency} = (1 - \frac{T_1}{T_2}) \times 100
\]

where

\[T_1 = \text{sampling time for dirty (upstream) air target}\]

\[T_2 = \text{sampling time for clean (downstream) air target}\]

The average dust-spot efficiency of the test filter is an arithmetical average of the individual dust-spot determinations.

High-efficiency filters tested by the dust-spot method may be loaded with a synthetic dust to determine their comparative operating life. The dust used for loading purposes is generally a mixture of Cottrell flyash and lint which is introduced into the air stream in fixed amounts between efficiency determinations. It is not possible to multiply the total amount of synthetic dust reaching the filter by the average dust-spot efficiency as the units are not compatible. Therefore, in dust-spot tests the reported "dust holding capacity" is actually the weight of dust reaching the test filter. This term should not be confused with the expression for dust holding capacity as determined by the API weight method.

Photo 1 is a photograph of targets formed in a series of actual dust-spot tests and permits a comparison of how much dust remains in the clean air stream for each indicated efficiency value. In addition, the individual efficiency values shown may be compared with the weight efficiency of the corresponding filter by referring to the same column number.

Target No. 1 in Fig. 4 is the upstream or dirty air target for each dust-spot test and was produced by drawing air from the atmosphere through the test target at a rate of 1 cfm for a 40-min period. This upstream target, therefore, is an indication of the amount of dust present in the atmosphere at the time these tests were conducted. If the test filter had been removed from its position, it is obvious that the downstream dust concentration would be the same as the upstream or entering dust concentration and, therefore, this target has been labeled "Of dust spot efficiency." This upstream target should be compared in turn with each of the remaining downstream targets to visualize the relative dust-spot efficiency produced by each test filter. Target No. 2 in Fig. 4 indicates a dust-spot efficiency of 10 percent and applies to the test filter which produced a weight efficiency of 75 percent as shown in Plate No. 2 of Fig. 2.

Target No. 3 indicates a dust-spot efficiency of 30 percent and compares to a weight efficiency of 88 percent as shown in Plate No. 3 of Fig. 2. The relative efficiency values of the remaining columns can be compared on the same basis.

Dust-spot efficiency tests using atmospheric dust are quite severe because the submicron particles, which in themselves represent a small percentage of the total weight of the contaminant, are chiefly responsible for the discoloration or smudging produced in a filtered space.

**DOP Test Method**

There is a third method for testing air filters which is currently used for determining the efficiency of superinterception types of filters. This method uses dioctyl-phylate as the test aerosol and is frequently referred to as the DOP test method. In essence, a DOP test is conducted in the following manner:

Liquid dioctyl-phylate is placed in the vessel referred to commonly as the generator. By the application of heat, a portion of this liquid is vaporized and the DOP vapors are injected into a stream of heated air and conveyed to a mixing chamber. In the mixing chamber, this heated air carrying the DOP vapor is mixed with a stream of cooler air at approximately room temperature and this causes the vapor to condense into very fine droplets or condensation nuclei. The size of the droplets thus formed is controlled by the choice of mixing temperature. In the standard DOP test, the particle size is controlled to produce 0.3-micron particles. These particles are then introduced into the air stream entering the test filter and the concentration of particles upstream and downstream from the filter under observation is measured by a light-scattering device. In effect, the DOP test method is based upon particle count and a comparison of concentration of particles entering and leaving the test filter serves as the basis for determining the DOP efficiency. Most specifications for the superinterception type of filter require a minimum efficiency of 99.97 percent by the DOP method. Extreme care must be exercised in the fabrication of these superinterception filters and each filter must be tested individually for efficiency and pressure drop.

**Summary**

Reference has previously been made to the dust-holding capacity of a filter reported by either the weight or dust-spot methods. This characteristic is related to the anticipated life of the filter or the frequency with which it must be serviced and is useful for comparing

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the performance of one filter to that of another, providing the same basis of comparison is used. Since an air filter loads on the basis of dust volume, it is obvious that the specific gravity or bulk density of the test dust will influence the results. This can best be illustrated by reference to Fig. 5. Each of these graduates contains exactly 200 g of the dust indicated. Since the flasks are all identical in size, the height of the respective columns reflects the relative volume of each type of dust.

Where it is desirable to compare the relative dust-holding capacity of two or more air-cleaning devices, it is important that:

1. The dust-holding capacity is expressed on the same basis.
2. The same identical dust is used for loading purposes.
3. The determinations are based upon the same value of final resistance.

The reported performance of an air filter obviously depends upon the test procedure followed and the type of test dust used. Unfortunately, there is no formula which can be used for converting the results obtained by one test method to that of another. Performance characteristics such as efficiency and dust-holding capacity must be determined empirically for each device, and to be meaningful the procedure involved should follow a prescribed test method. The test procedure as well as the test dust should always be identified.