

Passenger Compartment Air Filter Test Code

Foreword—The following Passenger Compartment Air Filter Test Code has been established to cover particulate air filters used in automotive interior ventilation systems.

The objective of this procedure is to maintain a uniform test method for evaluating filter performance characteristics of particulate air filters on specified laboratory test stands.

The performance characteristics of greatest interest are pressure drop (or airflow restriction), overall and fractional efficiencies, and holding capacity for airborne particles.

The data collected according to this test code can be used to establish performance characteristics for filters tested in this manner. The actual field operating conditions, including contaminants, humidity, temperature, mechanical vibration, flow pulsation, etc., are difficult to duplicate; however, with the procedure and equipment set forth, comparison of air filter performance may be made with a high degree of confidence.

1. Scope—This SAE Recommended Practice describes laboratory test methods to measure filter performance. Performance includes, but is not limited to, air flow restriction or pressure drop, overall and fractional efficiency, holding capacity for airborne particles, and air filter structural integrity.

1.1 Purpose—The purpose of this test code is to establish and specify consistent test procedures, conditions, equipment, and performance reports to enable comparison of filter performance of particulate air filters used in automotive interior ventilation systems.

2. References

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated, the latest revision of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J726—Air Cleaner Test Code

NOTE—SAE J726 the volume flow that would exist if the temperature and pressure were standard. If the only characteristic to be measured is the filter resistance, then it may be convenient to use the methods of SAE J726.

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SAE WEB ADDRESS:

2.1.2 ASME PUBLICATION—Available from ASME, 345 East 47 Street, New York, NY 10017-2330.

ASME Fluid Meters, Sixth Edition

2.1.3 ASTM PUBLICATION—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM F 328—Practice for Determining Counting and Sizing Accuracy of an Airborne Particle Counter Using Near-Monodispersed Spherical Particulate Materials, *Annual Book of ASTM Standards*, Vol. 10.05, 1989

2.1.4 IES PUBLICATION—Available from Institute of Environmental Sciences, 940 East Northwest Highway, Mt. Prospect, IL 60056.

IES-R-P-CC007.1—Testing ULPA Filters

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

V. A. Marple, K. L. Rubow, and S. M. Behm, "A Micro-orifice Uniform Deposit Impactor (MOUDI): Description, Calibration, and Use," *Aerosol Sci. Technol.*, Vol. 14, pp. 434–446, 1991

VDI 2066 Blatt1:1975, *Messen von Partikeln; Staubmessungen in strömenden Gasen; Gravimetrische Bestimmung der Staubbelaugung; Übersicht.*

VDI 2066 Blatt 2: 1989, *Messen von Partikeln; Manuelle Staubmessung in strömenden Gasen; Gravimetrische Bestimmung der Staubbelaugung; Filterkopfgeräte (4m³/h, 12 m³/h).*

A. van Santen and E.J. Gannon, "In-Duct Measurement of Particulates," *Filtration and Separation*, Sept/Oct, 1987, pp. 328–336.

G.E.P. Box, W.G. Hunter and J.S. Hunter, *Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building*, John Wiley & Sons, NY, 1978.

M. Abramowitz and I.A. Stegun, *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables*, Dover Publications, Inc., NY, 1972.

2.3 Other Publications

V. A. Marple and K. L. Rubow, "Aerodynamic Particle Size Calibration of Optical Particle Counters," *J. Aerosol Sci.*, Vol. 7, pp. 425–433, 1976.

3. Definitions

3.1 Test Air Flow Rate—A measure of the quantity of volume of air drawn through the air filter per unit time. The flow rate shall be expressed in actual cubic meters per hour.

3.2 Pressure Loss—Permanent pressure drop due to decrease of flow energy caused by the air filter (kPa).

3.3 Pressure Drop—Difference in static pressure measured immediately upstream and downstream of the air filter (Pa at standard conditions).

3.4 Fractional Efficiency, E_F—The ability of the air filter to remove airborne particles of a specified size. See Equation 1.

$$E_{Fi}\% = \frac{C_{1i} - C_{2i}}{C_{1i}} \cdot 100 \quad (\text{Eq. 1})$$

C_{1i} = concentration of particles of specified size, i, in the influent

C_{2i} = concentration of particles of specified size, i, in the effluent

- 3.5 Gravimetric Efficiency**—The ability of the air filter to remove contaminant. As used in this test code, it is the cumulative mass efficiency during the life of the filter from the initially clean filter to the specified maximum filter pressure drop as it is loaded with SAE ultrafine test dust. This is expressed by Equation 2:

$$\text{Gravimetric efficiency, \%} = \frac{\text{Increase of weight of air filter under test}}{\text{Increase of weight of air filter under test} + \text{increase of weight of absolute filter}} \times 100 \quad (\text{Eq. 2})$$

- 3.6 Initial Fractional Efficiency**—The initial fractional efficiency of a clean air filter under test to remove particles from air flowing through it. As used in this test code, it refers to the efficiency before the collected aerosol has any measurable effect on the efficiency of the filter under test. The collected aerosol can affect the measured filter efficiency before enough aerosol is collected to affect the filter pressure drop.

- 3.7 Penetration, P**—The ratio of the number of particles or mass of particles of specified size exiting the filter per unit time to the number of particles or the mass of particles of specified size entering the filter per unit time expressed in a percentage as shown in Equation 3:

$$P = 1 - E \quad (\text{Eq. 3})$$

where:

E = Efficiency

- 3.8 Dust-holding Capacity**—The mass of dust collected by the filter at the specified terminal pressure drop in grams.

- 3.9 Hydraulic Diameter (D_h)**— $4 \times (\text{area of cross-flow section})/(\text{duct perimeter})$

- 3.10 Particle Counter**—A particle sizing and counting device.

- 3.11 Test Aerosol**—Particles suspended in air, used for filter efficiency or capacity evaluation.

- 3.12 Aerosol**—Particles suspended in air.

- 3.13 Sampling Apparatus**—Sampling probes, sampling lines, and any valves, fittings, or other devices which may be installed between the sampling probes and the aerosol measuring device.

- 3.14 Correlation Ratio**—The ratio of the number or mass of aerosol observed at the downstream sampling location to the number or mass of aerosol at the upstream sampling location. This number may be greater or less than 1.0. Correlation ratio may be used in the calculation of filter efficiency as per Appendix A and is defined according to Equation 4:

$$R_o = D_{o,c}/U_{o,c} \quad (\text{Eq. 4})$$

where:

R_o = observed (calculated) correlation ratio

$D_{o,c}$ = quantity of aerosol observed downstream with no filter installed

$U_{o,c}$ = quantity of aerosol observed upstream with no filter installed

4. **Measurement Accuracy**

- 4.1 Air flow rate and air velocity, within 2% and 5%, respectively, of the specified value.
- 4.2 Pressure drop and restriction within 2% of the reading.
- 4.3 Temperature within 2 °C of the specified value.
- 4.4 Weight within 0.1% of the actual value, except where noted.
- 4.5 Absolute filter to 0.01 g.
- 4.6 Relative humidity within 2%.
- 4.7 Barometric pressure within 300 Pa.
- 4.8 Aerosol concentration upstream of the test filter within 10% of specified value.
- 4.9 Aerosol uniformity in the mixing chamber during fraction efficiency test within 10% of the actual value.

5. **Test Materials and Conditions**

- 5.1 Test dust for dust-holding capacity and gravimetric efficiency, shall be SAE "Ultrafine." The following chemical analysis (Table 1) is typical:

TABLE 1—CHEMICAL ANALYSIS OF TEST DUST

Chemical	% of Weight
SiO ₂	65–76
Al ₂ O ₃	11–17
Fe ₂ O ₃	2.5–5.0
Na ₂ O	2–4
CaO	3–6
MgO	0.5–1.5
TiO ₂	0.5–1.0
V ₂ O ₃	0.10
ZrO	0.10
BaO	0.10
Loss on Ignition	2–4

Before a test, the test dust shall be mixed in a specified container for a minimum of 15 min. This test dust shall be dried to a constant mass at a temperature of 105 °C ± 15 °C. The test dust shall then be allowed to become acclimatized to a constant mass under the prevailing test conditions.

NOTE—To ensure a constant rate of dust feed with some dust feeders, it may be necessary to heat the dust prior to its being fed to the injector.

The particle size distribution by volume as specified by SAE J726 shall be as follows in Table 2.

TABLE 2—PARTICLE SIZE DISTRIBUTION BY VOLUME, %

Size (microns)	Ultrafine Grade (% greater than)
2.0	85–88
3.2	65–71
5.0	26–34
10	0–2

- 5.2 Aerosol for Special Tests**—Mono- or polydisperse latex or lycopodium and other aerosols may be used for tests performed on the filter on user request.
- 5.3 Absolute Filter**—A high-efficiency particulate air (HEPA) type filter downstream of the filter under test to retain the particulate passed by the test filter. A HEPA-type filter is also used to clean air provided to the test stand during the test with submicron particles using particle counters. Maximum penetration for this filter shall be less than or equal to 0.03% for 0.3 μm particles.
- 5.4 Temperature and Humidity**—All tests shall be conducted with air entering the air filter at a temperature of $20\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ and a relative humidity of $55\% \pm 15\%$.
- 5.5 Air-Filter Conditioning**—Prior to the test, test filters shall be subjected to a temperature of $80\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ for 8 h, $38\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ and humidity of $90\% \pm 5\%$ for 8 h, and $-40\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ for 8 h. The filters under the test are to adjust to room temperature between cycles. After the final cycle, the filter shall be stabilized to test conditions not less than 5 h.

6. Test Equipment

6.1 Test Stand

- 6.1.1 TEST-STAND CONFIGURATION**—The test stand shall meet the performance requirements of 6.1.2. The test stand shall consist of a conductive and grounded vertical test section with test-filter mounting framework, and shall be designed to minimize particle loss. It shall include equipment or apparatus for air conditioning and supply, flow measurement, pressure-drop measurement, and aerosol introduction and sampling. Each test stand which is configured in accordance with Figure 1 and meets the requirements of 6.1.2 shall be acceptable for this test standard. In all cases, any deviations must be arranged between the tester and the requester.
- 6.1.2 TEST-STAND PERFORMANCE**—Test-stand performance must meet the requirements of this section and shall be validated as part of the overall test system (test stand and associated equipment) as detailed as follows and in 8.2. Validation information shall be recorded in a standard format and made available to requesters. System validation shall be performed at least once per year.
- 6.1.2.1 Air Conditioning and Supply**—Provisions should be made to maintain temperature and humidity of the test air in accordance with 5.4. Prior to mixing with test aerosol, air should be cleaned to a level of less than 5% of the challenge aerosol concentration at all particle sizes. Use of HEPA filtration is recommended. The system shall demonstrate the ability to maintain these conditions over the period of time required to complete a filter evaluation.

The system must be capable of delivering the user-specified flow, $\pm 10\%$. Further, it must be capable of maintaining this flow for the duration of a test. This flow typically will be in the range of 50 to 680 m^3/h with filter pressure drop up to 1000 Pa. The system may operate at either positive or negative pressure, provided it meets the requirements of 6.1.2.

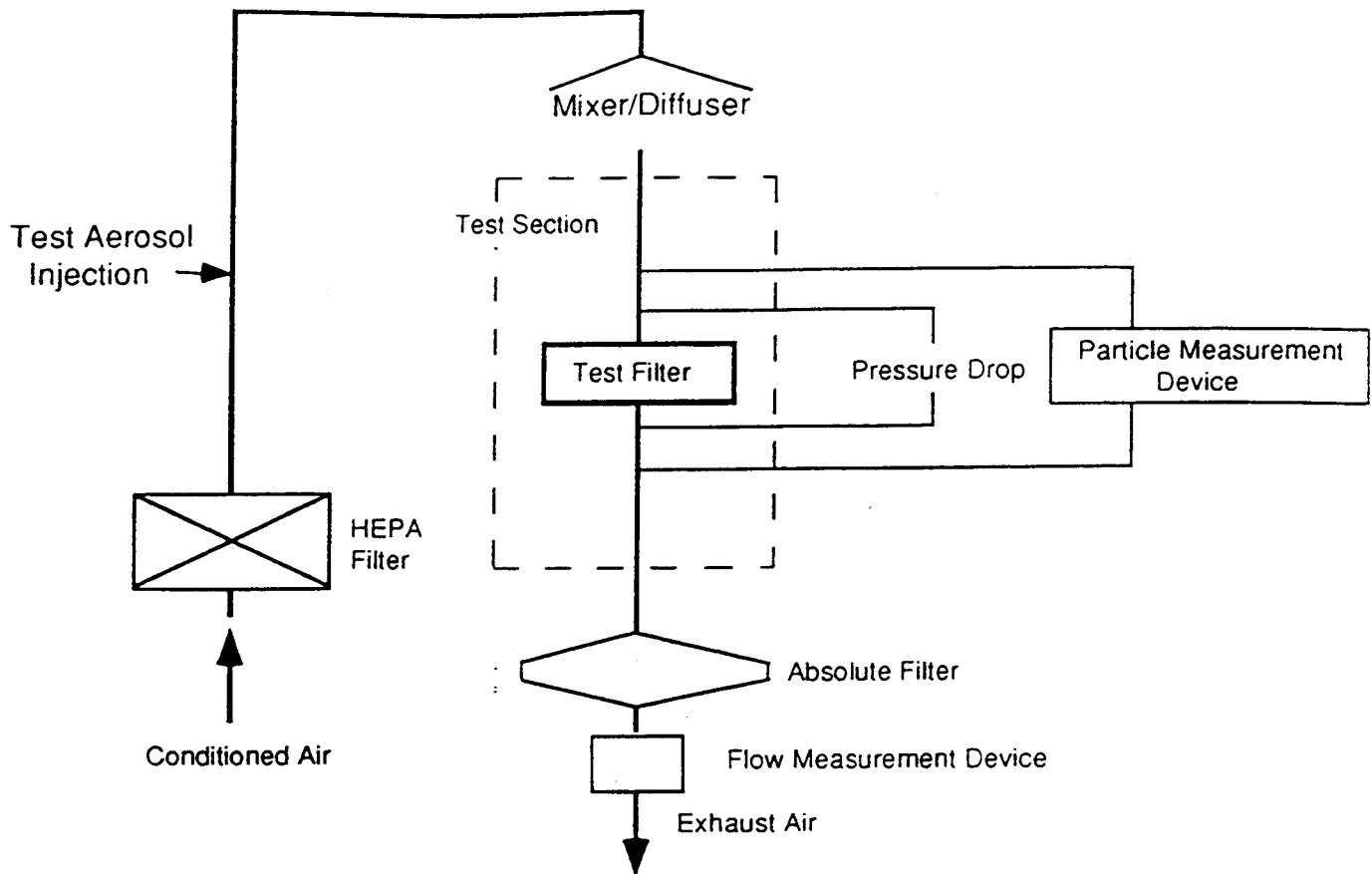


FIGURE 1—TEST-STAND CONFIGURATION

- 6.1.2.2 *Flow Measurement*—Flow shall be measured in accordance with 6.8 across the range of flow as specified in 6.1.2.1. Flow-measurement devices may be certified out of the test duct, provided that they are installed in exact accordance with the manufacturer's requirements. If no manufacturer's installation instructions are available or if the flow-measurement devices are not installed according to them, they shall be calibrated in place in the test rig and be traceable once removed to a standard calibrating source.
- 6.1.2.3 *Pressure-Drop Measurement*—Pressure drop (differential pressure) across the test filter shall be measured with a differential pressure device connected to pressure taps in the test duct. These taps shall be located in a straight-sided test section which includes the filter under test and be positioned not more than one duct diameter (hydraulic) upstream and downstream of the test filter. The pressure taps shall be of the static-pressure type and configured as in Figure 2.

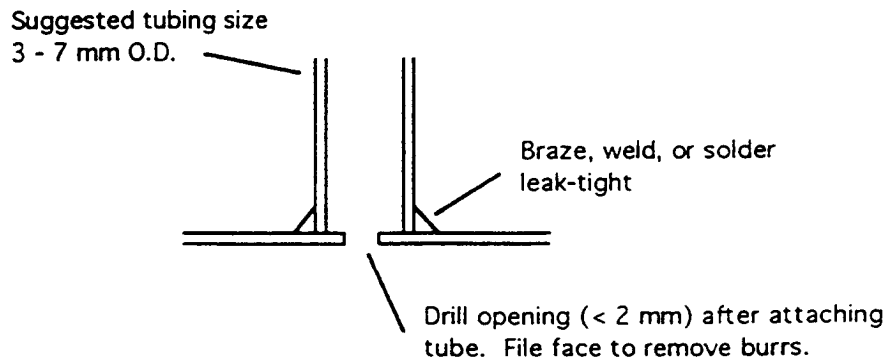
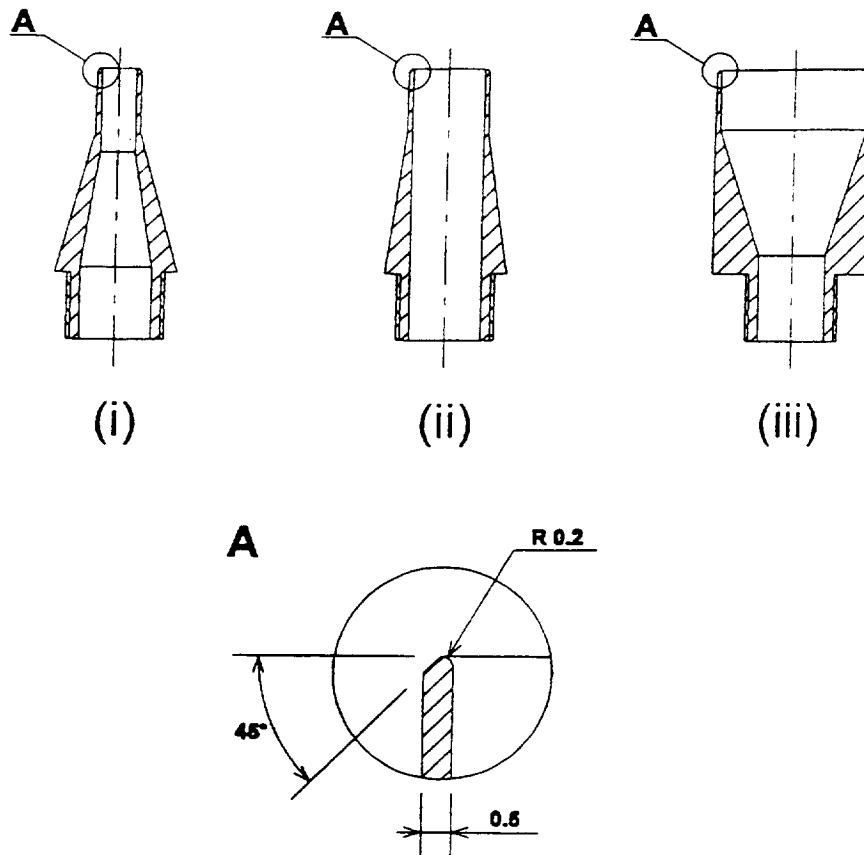


FIGURE 2—PRESSURE TAP CONFIGURATION

The pressure-drop instrumentation shall be capable of measuring the full range of pressure drops expected for the test, plus 10%. Accuracy of measurement over this range shall be in accordance with 4.2.

- 6.1.2.4 Aerosol Introduction and Mixing**—Aerosol shall be introduced into the duct and subsequently mixed in such a way that a uniform mixture of test aerosol will be delivered to the filter under test. Aerosol uniformity shall be verified in accordance with 8.2. In certifying the test system, the uniformity, concentration, and stability of the efficiency challenge shall be measured in accordance with 8.2.1. In addition, uniformity, concentration, and size distribution of the capacity challenge shall be verified in accordance with 8.2.2.
- 6.1.3 TEST-FILTER MOUNTING**—The test filter shall be mounted in the horizontal position with the geometric center of the filter coincident with the centerline of the duct. The test filter shall be mounted in a frame that approximates the actual holding frame for the application which shall be specified by the requester. Where available, the filter shall utilize gasketing identical to the production gasketing.
- 6.2 Aerosol Sampling Apparatus**—Test aerosol shall be sampled upstream and downstream of the filter under test. The aerosol may be drawn through the sampling apparatus into a particle counter or other device. The performance of the sampling apparatus shall be evaluated as part of the test system in accordance with 8.2.
- 6.2.1 SAMPLING PROBES**—Sampling probes shall be isokinetic (local velocity of duct and probe equal) to within 20% and positioned as defined in 6.2.1.1. Examples of isokinetic sampling probes are shown in Figure 3. Typically, different sized probes will be required to match the velocity in duct at different test conditions. The same probe design should be used before and after the filter.
- 6.2.1.1 Sample Probe Location**—Sampling probes shall be located on the centerline of the test duct. The upstream probe shall be located as close as possible to the filter under test. The downstream probe shall be located such that a representative sample of test aerosol is obtained and that the requirements of 8.2 are met.
- 6.2.2 SAMPLING LINES**—Tubing leading to particle counters shall be as short as possible and minimize number of bends and static buildup to avoid particle losses. The last may be accomplished by using electrically conductive, grounded materials or choosing another material that has demonstrated good performance in this area. The use of valves and other restrictions should be avoided.



Dimensions are in millimeters

The internal diameter of the sampling probe should be selected with regard to the local velocity in the duct, and the sampling flow rate of the measuring equipment used. In the three examples shown, (i) shows a probe which has had its cross-section reduced at the sampling point in order to increase probe sampling velocity; (ii) shows a probe of constant cross-section design; and (iii) shows a probe with increased cross-section to decrease probe sampling velocity. In reducing or increasing probe cross-section, interior and exterior angles of the probe should be small, and overall design should minimize particle losses. (VDI 2066, 1975; VDI 2066, 1989, and Van Santen & Gannon, 1987—see Reference Section.)

FIGURE 3—EXAMPLES OF ISOKINETIC PROBES

6.3 Particle Generator—The aerosol generator is used for fractional-efficiency tests and shall be capable of producing a stable aerosol concentration and size distribution. The number of particles in each size range must be sufficient for justifiable statistical evaluation. The aerosol generator shall meet the performance requirements of 6.3.1.

A dust-feeding system consisting of a dust feeder and dust injector shall be used in dust-holding capacity tests. The dust feeder shall feed dust at a continuous and uniform rate, with a stable-size distribution. The dust injector is used to disperse dust into the test system and shall not change the airborne particle size distribution. The dust feeder shall meet the performance requirements of 6.3.2.

- 6.3.1 AEROSOL GENERATOR FOR FRACTIONAL EFFICIENCY TESTS—Sodium chloride aerosol shall be used to determine fractional efficiency. Other aerosols can be used as specified by the requester. One should expect different results with different aerosols due to changes in particle-counter response to particle refractive index, density, and shape.

The aerosol generator shall nebulize a saline solution to produce a homogeneous mist aerosol with stable concentration and size distribution. The droplets must be dried to form solid salt particles using dry dilution air, heat, or desiccant. The aerosol must be charge-neutralized according to 6.5 prior to introduction into the test duct. The size distribution of the aerosol shall have sufficient particles in the range of 0.3 to 10 μm for statistical evaluation within each size class. Typically, this will be a minimum of 1000 particles per size class per sample. The total concentration of the aerosol in the test duct shall not exceed the limit of the particle counter. A maximum 5% coincidence error is allowed in particle counter according to 8.4. The aerosol concentration and size distribution shall be verified according to 8.2.1.

- 6.3.2 DUST DISPERSER AND INJECTOR FOR DUST-HOLDING CAPACITY AND GRAVIMETRIC EFFICIENCY TESTS—A dust-feeding system consisting of a dust disperser and dust injector shall be used for dust-holding capacity and gravimetric efficiency tests. The dust-feeding system shall produce an aerosol of SAE Ultrafine dust with a stable concentration ($\pm 20\%$ variation over time). The feed rate of the dust feeder shall produce a dust concentration in the test duct between 50 to 100 mg/m^3 . The dust injector shall deflocculate the dust particles prior to introduction into the test duct. If the dust disperser is capable of deflocculating the dust particles, a dust-injector nozzle is optional. The aerosol shall be charge-neutralized according to 6.5 prior to introduction into the test duct.

The size distribution of the dust in the test duct immediately upstream of the test filter shall be specified in Table 3. The aerosol-size distribution in the test duct shall be verified according to the procedure in 8.2.2.

The dust disperser shall be an open-tray or turntable venturi-suction feeder, a rotary-brush feeder, a fluidized-bed feeder, or other dust feeder capable of producing the required test dust.

**TABLE 3—PARTICLE-SIZE DISTRIBUTION BY MASS %
OF THE TEST DUST IN THE TEST DUCT**

Size (μm)	Mass (% greater than)
0.3	TBD
0.5	TBD
1.0	TBD
2.0	TBD
5.0	TBD
10	TBD