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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 Staubbelastung; Übersicht.*

VDI 2066 Blatt 2: 1989, *Messen von Partikeln; Manuelle Staubmessung in strömenden Gasen; Gravimetrische Bestimmung der Staubbelastung; 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.

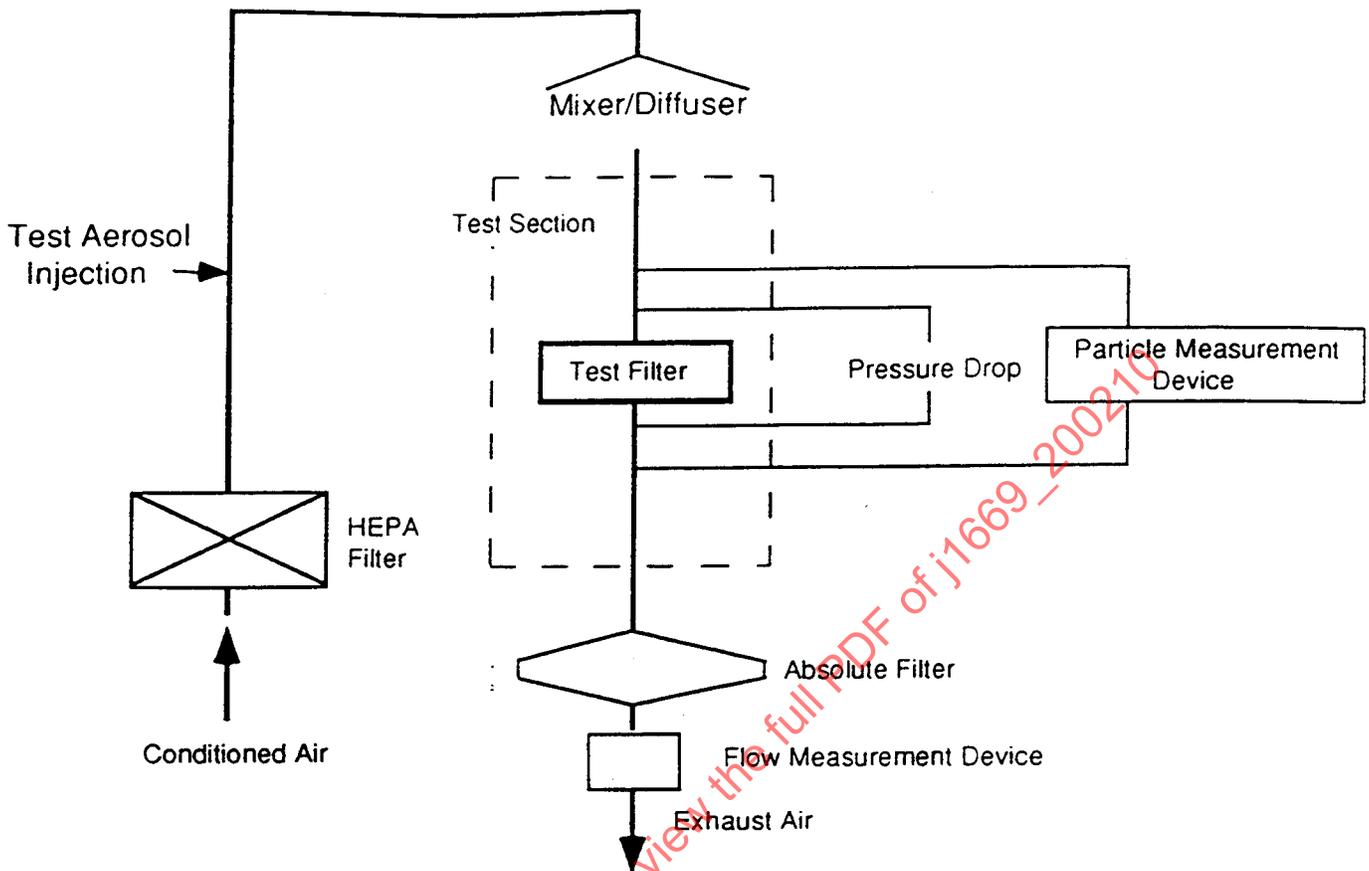


FIGURE 1—TEST-STAND CONFIGURATION

- 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.

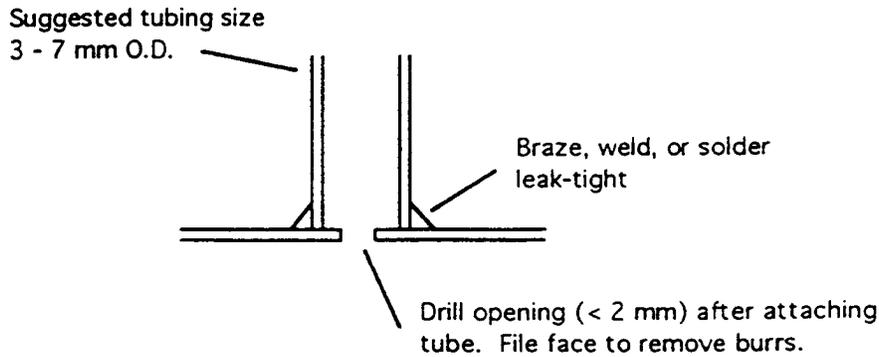
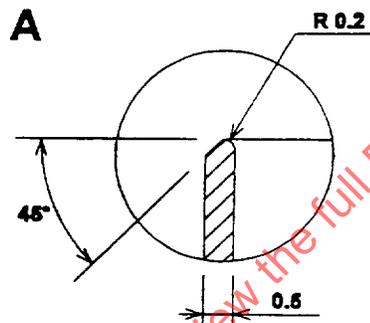
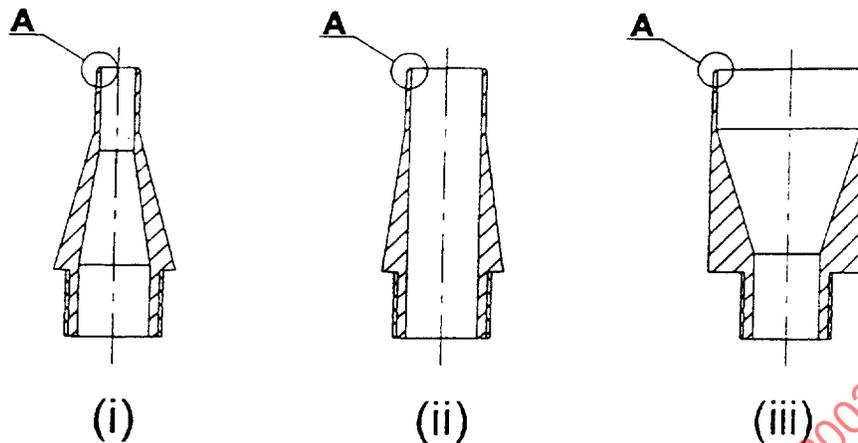


FIGURE 2—PRESSURE TAP CONFIGURATION

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

6.4 Particle Counting and Analyzing Instrument—The airborne particle concentration and size distribution upstream and downstream of the filter shall be measured either by an airborne particle counter or a cascade impactor.

6.4.1 **PARTICLE COUNTERS**—The airborne-particle counter shall be capable of counting airborne particles used in the efficiency tests in the 0.3 to 10 μm geometric or 0.5 to 15 μm aerodynamic diameter range, divided into at least six particle size channels. The last channel shall include particles 10 μm geometric or 15 μm aerodynamic and larger. The particle counter shall be calibrated for both particle size and counting efficiency over the specified range using the same particles used in the efficiency tests. The primary particle size calibration with the test particles shall also be correlated to a secondary calibration with polystyrene latex spheres per ASTM F 328. The polystyrene latex spheres shall be NIST (National Institute of Standards and Technology) traceable. The primary calibration tests, counting efficiency tests, and maximum particle concentration only need to be conducted once for each combination of particle counter and airborne particles.

6.4.1.1 *Primary-Size Calibration*—The airborne-particle counters may be calibrated for geometric size using monodisperse particles of the same composition as used in the efficiency test. For sodium chloride particles, a vibrating orifice generator may be used to generate monodisperse particles having geometric diameters larger than 0.5 μm from a water solution of sodium chloride. A differential mobility analyzer may be used to generate geometric diameters of 0.3 μm and smaller from the sodium chloride generator used in the efficiency test. The same calibration techniques may also be used for other compositions that can be dissolved in solvents. There is not an established method for generating monodisperse test dust.

The airborne-particle counters may also be calibrated for aerodynamic size using heterodisperse particles of the same composition as used in the efficiency test. The technique is based on measuring the fractional aerosol penetration through a series of calibrated impactor stages (see 2.1.5). The 50% cut-off size for the test particles in each impactor stage is used to correlate with the indicated size on the particle counter that is determined with polystyrene latex particles. The particle counters are usually calibrated at the factory with polystyrene latex particles.

6.4.1.2 *Secondary-Size Calibration*—The airborne-particle counters shall have a secondary calibration with polystyrene latex particles prior to system start-up and a minimum of once a year to verify that the primary-size calibration has not changed. If the counter shows a change in the secondary-latex calibration then the primary calibration will also be changed, and the counter should be serviced.

6.4.1.3 *Counting-Efficiency Calibration*—The counting efficiency of the particle counters shall be determined to establish the fraction of particles counted in the different size channels. Channels having less than 50% efficiency may not be used in the filter tests. All counters have a lower size and an upper size limit beyond which they have less than 50% efficiency.

The lower particle size limit is due to the threshold signal approaching background. It can be established by comparing the concentration of different size monodisperse test particles as measured with the particle counter with that obtained with a reference condensation nucleus counter. A differential mobility analyzer is used to generate the different size monodisperse particles.

The upper particle size limit is due to particle losses due to gravity and impaction removing the large particles in the counter-flow system prior to reaching the detector. This size limit can be determined by comparing the concentration of different size monodisperse test particles as measured with the particle counter with that obtained with a reference method. A vibrating orifice generator may be used to generate the monodisperse large particles. The reference method may involve a filter or other device that has a known sampling efficiency for the large particles.

6.4.1.4 **Maximum Concentration**—The maximum total particle concentration shall be established to prevent coincidence counting, i.e., counting more than one particle at a time. A recommended method for establishing this limit is to conduct filter-efficiency tests at a series of different concentrations and compare the results. The maximum concentration is determined at the point where the fractional efficiency at a higher concentration shows a significant deviation from the fractional efficiency at a lower concentration.

6.4.2 **CASCADE IMPACTOR**—A cascade impactor may be used to measure the aerodynamic-size distribution of particles upstream and downstream of the filter. The cascade impactor shall be capable of separating airborne particles by aerodynamic size in the 0.5 to 15 μm diameter range, in a minimum of six particle-size channels.

The impactor measurements consist of determining the mass of particles deposited on each of the different impactor stages representing one of the particle size channels. The mass measurement on each impactor stage may be done manually or electronically based on piezoelectric detection. The collected particle mass shall be determined to an accuracy of $\pm 5\%$. For the manual impactors, two impactors are needed for upstream and downstream measurement. For the electronic impactor, one impactor can be used for both upstream and downstream measurements. Filter clogging must be carefully monitored with the manual impactor because of the longer time required to obtain a measurable weight on the impactor stages. The higher sensitivity of the piezoelectric detectors mitigates this problem.

6.4.2.1 **Aerodynamic-Size Calibration**—The cascade impactor shall be calibrated prior to system start-up using monodisperse particles of oleic acid to which a fluorescent tracer, such as urane, has been added. The calibrating particles shall be generated by the vibrating orifice monodisperse aerosol generator. This calibration is only required once for a given impactor model.

6.4.2.2 **Particle-Sticking Efficiency**—Once the impactor has been calibrated for spherical-oleic particles, the impactor will be calibrated for sticking efficiency of the non-spherical sodium chloride particles. This test is conducted to determine the shift in aerodynamic size due to particle bounce and re-entrainment. Monodisperse particles of sodium chloride that are generated with the vibrating-orifice generator are used in this test. This calibration is only required once for a given impactor model.

6.4.2.3 **Impactor Degradation**—The pressure drop across the impactor shall be monitored to check for signs of nozzle erosion or clogging during each test and from test to test. If there is a measurable change in pressure drop, the impactor shall be serviced and recalibrated.

6.5 **Aerosol Neutralizer**—Generated aerosols often obtain a high level of electrical charge due to mechanical shearing. In the presence of an electric field, highly charged particles readily deposit on the walls of sample tubing and ducts, and can enhance their filtration probability and bias the fractional-efficiency test. To reduce the charge level, an electrostatic or radioactive aerosol neutralizer shall be used immediately following the aerosol generator before injection into the test duct. A neutralizing is required for fractional-efficiency tests and optional for dust-holding capacity tests.

6.6 **Flow Meter**—The air flow meter shall be calibrated annually to ensure a known accuracy of $\pm 2\%$ by using a flow meter conforming to the construction standards set forth in *ASME Fluid Meters*, Sixth Edition.

7. Tests

7.1 The purpose of these tests is to determine flow resistance, gravimetric efficiency, fractional efficiency and dust-holding capacity, rupture or collapse characteristics, and sealing characteristics using the equipment described in Section 6. The test system must be calibrated and qualified per Section 8 prior to testing filters. All daily start up, correlation procedures, and reference filter tests must be done prior to testing filters.

7.2 Air-Flow Restriction and Pressure-Drop Test

- 7.2.1 The purpose of this test is to determine the flow characteristics in dust-free air of a clean air filter.
- 7.2.2 Condition the unit to be tested at least 1 h under temperature and humidity conditions equivalent to those in the test area (5.4).
- 7.2.3 Measure and record the tare-static pressure drop with no filter in the test stand. Measure at nominal flow rates of 10%, 25%, 50%, 75%, 100%, and 110% of the specified maximum air-filter flow rate.
- 7.2.4 Mount the filter to be tested in the test stand. Measure and record the static-pressure drop versus nominal flow rate at rates of 10%, 25%, 50%, 75%, 100%, and 110% of the specified maximum air-filter flow rate.
- 7.2.5 Subtract the tare-pressure drop values from the measured filter pressure drops. Correct the measured pressure drops per Appendix B and report as shown in Section 10.

7.3 Efficiency Tests

- 7.3.1 The purpose of this test is to determine the particulate collection capabilities of the filter. This test is conducted with constant air flow using the aerosol described in 6.3.1.
- 7.3.2 The following types of efficiency tests can be performed:
- 7.3.2.1 Gravimetric efficiency and dust-holding capacity are determined when the specified terminal pressure drop (ΔP_d) is reached at rated flow. This test is done with SAE ultrafine test dust defined in this procedure.
- 7.3.2.2 The initial fractional efficiency as a function of particle size is determined for a clean filter for at least the six standard particle size classes and may be determined for other particle sizes. The standard size class thresholds are 0.3, 0.5, 1.0, 2.0, 5.0, and 10.0 μm . That is, the size ranges are 0.3 to 0.5 μm ; 0.5 to 1.0 μm ; and so on. This test is done with sodium chloride aerosol described in 6.3.1. The initial efficiency should be determined at the user-specified flow.
- 7.3.2.3 The incremental fractional efficiency as a function of particle size is determined at 10, 25, 50, and 100% of filter life (ΔL). This test is done with sodium chloride aerosol described in 6.3.1. The incremental fractional efficiency is determined at the specified flow. The incremental life is determined by pressure drop across the filter as the filter is loaded with SAE ultrafine test dust. The filter pressure drops (ΔP) are calculated from: the initial pressure drop (ΔP_o), the fraction of filter life (ΔL), and the terminal pressure drop (ΔP_d). See Equation 5.

$$\Delta P_i = \Delta P_o + \Delta L * (\Delta P_d - \Delta P_o) \quad (\text{Eq. 5})$$

The incremental fractional efficiency should be determined for at least the six classes of particle sizes specified in 7.3.2.2.

7.3.3 EFFICIENCY TEST PROCEDURES

- 7.3.3.1 Gravimetric efficiency is done using the SAE J726 procedure.

7.3.3.2 Fractional Efficiency Test

- a. Condition a new filter per 5.5.
- b. Measure temperature and relative humidity.
- c. With no filter in the test stand, set the specified volume flow rate and measure the tare pressure drop.
- d. Mount the filter in the test stand.
- e. Set the specified volume air flow.
- f. Measure pressure drop.
- g. Start feeding the efficiency test aerosol as specified in 6.3.1 and wait for the upstream aerosol to become constant.
- h. Determine the fractional efficiencies by particle counting as follows:
- i. For sequential counting systems, wait for the sampling system to equilibrate; then the upstream particles should be counted. Switch to the downstream sample; wait for the sampling system to equilibrate; then the downstream sample should be counted. The upstream-downstream cycle should be repeated twice more for a total of three upstream and three downstream samples. Calculate the filter penetration for each of the three samples. If there is no significant change in the filter penetration from the beginning to the end of these tests, then calculate the initial efficiency by summing the counts in each size range from the three upstream samples for the total upstream count in each size range. Similarly, sum the counts from the three downstream samples. If there is a significant change in filter penetration during the duration of the three samples, then these results may not reflect the true initial efficiency. Refer to 8.2. If the volume of upstream air from which particles are counted is not the same as the volume of downstream air from which particles are counted, then the sample volumes must be recorded for use when calculating the fractional efficiency.
- j. For simultaneous counting systems, the particles for both the upstream and downstream should be counted and recorded. Repeat twice more for a total of three upstream and three downstream samples. Calculate the filter penetration for each of the three samples. If there is no significant change in the filter penetration from the beginning to the end of these tests, then calculate the initial efficiency by summing the counts in each size range from the three upstream samples for the total upstream count in each size range. Similarly, sum the counts from the three downstream samples. If there is a significant change in filter penetration during the duration of the three samples, then these results may not reflect the true initial efficiency. Refer to 8.2. If the volume of upstream air from which particles are counted is not the same as the volume of downstream air from which particles are counted, then the sample volumes must be recorded for use when calculating the fractional efficiency.
- k. If this initial efficiency test is to be followed by an incremental efficiency test, then begin that test immediately upon completion of the initial efficiency test. Do not interrupt the air flow through the filter under test as this can alter the performance of the filter.
- l. Calculate the penetration for each particle size range using the methods in Appendix A. For calculations when the smallest count exceeds 500, then the penetration may be calculated without using the upper and lower confidence limits used in Section 7 of IES-RP-CC007.1. (Counts of 500 or more mean that the 95% confidence limits differ from the calculated value by less than $\pm 9\%$.)
- m. Measure the fractional efficiency with the particle counters as in 7.3.3.2. Protect the particle counters from the high concentration of loading test dust.
- n. Resume feeding the loading dust until the pressure drop across the filter has reached the second incremental pressure drop as calculated in 7.3.2.3.
- o. Repeat the cycle of measuring fractional efficiency and loading until the final pressure drop has been reached and the final fractional efficiency has been measured.
- p. Calculate the fractional efficiencies for each increment of loading in the same manner as initial fractional efficiencies are calculated in 7.3.3.2.

7.4 Capacity Test—This test is done using the SAE J726 procedure. It is done with SAE ultrafine dust as defined in this procedure. This test is frequently done at the same time as the gravimetric efficiency test, per 7.3.3.1.

7.5 Flow Pressure Collapse Test—This test is done using the SAE J726 procedure.

7.6 Seal Effectiveness Test—This test is done using the SAE J726 procedure.

8. Equipment Quantification and Calibration—Documentation

8.1 Air Flow Uniformity—The uniformity of air flow above the filter shall be measured with a calibrated anemometer at the center of each of eight equal-sized areas at a distance of 4 in above the filter. The variation in airflow velocity shall be no more than $\pm 10\%$ from the mean velocity.

8.2 Aerosol Challenge—The uniformity, concentration, and stability of the test aerosol challenges (efficiency and capacity) shall be verified according to this section. Further, the particle size distribution of the capacity challenge shall be verified. These are done to assure that test filters receive a known and repeatable aerosol challenge. If test section of different geometry is used, this verification must be repeated for each test section.

Verification of the aerosol challenge takes into account performance of the aerosol generator, aerosol introduction and mixing method, sampling system, and aerosol-measurement devices.

8.2.1 EFFICIENCY CHALLENGE—For verification of the efficiency challenge, the general procedures and requirements outlined in 6.3.1 and 7.3.3.2 should be followed.

8.2.1.1 Uniformity and Concentration—For verification of uniformity and concentration of the efficiency challenge, a filter shall be installed in the location of the test filter. This may be a flat sheet of filter media (95% ASHRAE grade or better) or a test filter.

The uniformity of distribution and the concentration of the test aerosol used for efficiency tests (see 7.3) shall be verified by use of a particle-sizing instrument that will be used in the test system. This particle-sizing instrument shall draw samples upstream of the filter. Flow shall be passed through the filter at the minimum flow expected for the test system, typically $50 \text{ m}^3/\text{h}$. Samples shall be drawn immediately in front of each of the four quadrants of the filter and at the standard centerline sampling location. A minimum of five samples shall be drawn at each sampling location, and the resulting number distributions averaged. The aerosol number concentration measured in each size range shall meet the criteria outlined in 6.3.1.

The average values for each reported particle-size range shall not vary by more than 10% among the five locations. This indicates that the challenge aerosol is uniformly distributed across the filter, and that the centerline sample is representative of the overall challenge.

To verify that the downstream sample is also representative of the aerosol passing through the filter, this process should be repeated in the plane of the downstream sample-probe location. The five sample locations should be chosen by dividing the duct cross section into quadrants of equal area and sampling from each of those four areas in addition to the centerline location.

8.2.1.2 Stability and Sampling Validity—Verification of aerosol stability shall be combined with verification of the sampling apparatus used in efficiency testing. The stability of the aerosol challenge is evaluated over a period of time equivalent to an efficiency test. The sampling apparatus (including aerosol-measurement equipment) is evaluated for differences between upstream and downstream samples.

The method shall be as follows: The efficiency-test aerosol shall be sampled upstream and downstream of the test-filter location, with filter-mounting framework in place, but with no test filter installed. All sampling apparatus shall be in place as described in 6.2. Samples shall be drawn isokinetically and performance shall be verified at the minimum, midpoint, and maximum rated flows of the test system.

For efficiency tests using particle counters, follow the sampling procedure specified in 7.3.3.2 (i or j). A total of three samples will be taken upstream and three samples downstream of the test-filter location. The count distribution (number of particles in each size class) shall be determined for each sample. The three upstream distributions shall be compared and the number of particles measured in each size class should agree to within 10% among the three distributions. This criteria shall be applied to both the upstream, and the downstream size distributions.

The three upstream distributions shall then be averaged together by size class, likewise the three downstream distributions. The result should be an average upstream and average downstream size distribution. The number of particles in each size class of the average upstream and downstream distributions should agree to within 10%.

Mass-based fractional efficiency-test apparatus shall be evaluated in the same way, except evaluation in each size class shall be made for mass of particles.

Provisions may be made to use the information obtained in this section to create correlation ratios which can be applied to size distributions measured at the downstream-sampling location. This must be done in accordance with 7.3, and with agreement between tester and requester.

8.2.2 **CAPACITY CHALLENGE**—For verification of the capacity challenge, the general procedures and requirements outlined in 6.3.2 and 7.4 should be followed.

8.2.2.1 **Uniformity**—The uniformity of distribution of the test aerosol used for capacity tests (see 7.4) shall be verified by a gravimetric method. The method shall be as follows: A flat sheet of filter media (95% ASHRAE grade or better) shall be weighed and installed in place of a test filter. Flow shall be passed through the filter at the minimum flow expected for the test system, typically 50 m³/h. The filter will be challenged with at least 12.5 mg of test dust per square centimeter of filter area. At the completion of this loading step, the filter paper shall be removed from the test fixture and cut into four equal area parts. Each quadrant shall be weighed and the amount of aerosol captured by each quadrant determined. The weight of aerosol captured shall not vary by more than 10% from quadrant to quadrant.

8.2.2.2 **Size Distribution and Mass Concentration**—The particle-size distribution and mass concentration challenge of the capacity test aerosol may be verified through use of a cascade-type impactor or equivalent device capable of measuring a minimum of six size classes between 0.4 and 15 μm (lower limit of class, aerodynamic diameter). For this evaluation, aerosol should be sampled isokinetically through the sampling apparatus used for efficiency testing. At the end of an appropriate sampling time, an aerodynamic mass-size distribution and mass per unit volume (mass concentration) in mg/m³ shall be calculated. Mass concentration shall be determined by adding mass on each of the stages of the impactor (including after filter), and dividing by total volume of air which has passed through the impactor.

The calculated mass size distribution and mass concentration shall meet the requirements of 6.3.2.

8.3 **Particle Size Calibration**—See 6.4.

8.4 **Coincidence Error**—Since coincidence-counting error can occur when using airborne particle counters, the organization performing the test according to this test code shall demonstrate by experiment that the coincidence-counting error under the actual operating conditions of the system is less than ±5%. Such data shall form part of the certification documentation provided by the test organization.

8.5 **Flow Calibration**—The volumetric flow rate through the filter shall be measured with a calibrated flowmeter to an accuracy of ±2%.

8.6 Repeatability—The organization performing tests in accordance with this test code shall demonstrate by identical tests performed on three separate days of no less than three days apart that both the pressure drop and filter efficiency measured are in agreement with each other to within $\pm 5\%$.

8.7 Documentation—The documentation certifying the performance of a system in accordance to this test code shall include the following:

8.7.1 System diagram and detailed description, including:

8.7.1.1 Particle generator used

8.7.1.2 Particle materials used in the tests

8.7.1.3 Manufacturer and model of the particle counter and/or cascade impactor used

8.7.2 Calibration data for the particle counter and/or cascade impactor

8.7.3 Calibration data for flow

8.7.4 Calibration data for pressure drop

8.7.5 System performance on flow uniformity

8.7.6 System performance on particle-concentration uniformity

8.7.7 Data demonstrating that the coincidence-counting error is less than $\pm 5\%$

8.7.8 Data showing the agreement between upstream and downstream particle counts for a single- or a dual-counter system.

8.7.9 Sample test data

8.7.10 Sample test data showing repeatability of test results

9. Filter Classification—T.B.D.

10. Presentation of Data

Performance Test Report

Report No.	Model	Date:
Requestor	Manufacturer	
Requestor Supplied Conditions		
High Temp. Soak: cycles at °C for hr	Low Temp. Soak: cycles at °C %RH for hr	
Humidity Soak: cycles at °C %RH for hr		
Test Type: <input type="checkbox"/> Initial Fractional Efficiency Only <input type="checkbox"/> Incremental Fractional Efficiency	Test Aerosol:	
Test Dust: <input type="checkbox"/> SAE Fine <input type="checkbox"/> SAE Ultrafine <input type="checkbox"/> Other:		
Rated Flow m ³ /hr	Conditioning Temp. °C	Conditioning RH %
Terminal ΔP Pa	Flow Rate for Eff. m ³ /hr	Dust Concentration mg/m ³

Test Results		Test Rig
Initial Resistance		Pa
Final Resistance		Pa
Fractional Efficiency		
<input type="checkbox"/> Sequential <input type="checkbox"/> Simultaneous		
Particle Size (μm)	Initial (%)	Final (%)
0.3		
0.5		
1.0		
2.0		
5.0		
10.0		
Conf. Level		
Gravimetric Efficiency		%
Dust Holding Capacity		g
Collapse Pressure		Pa

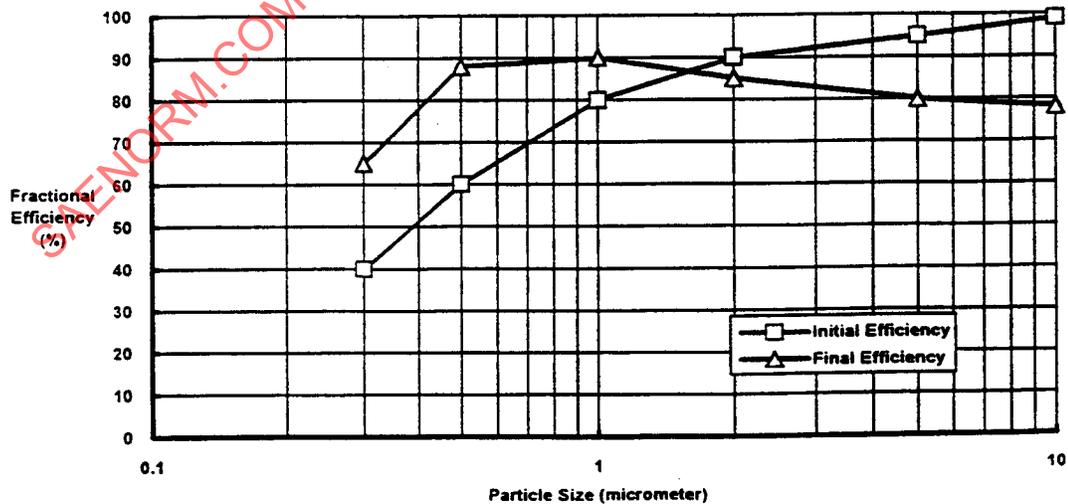
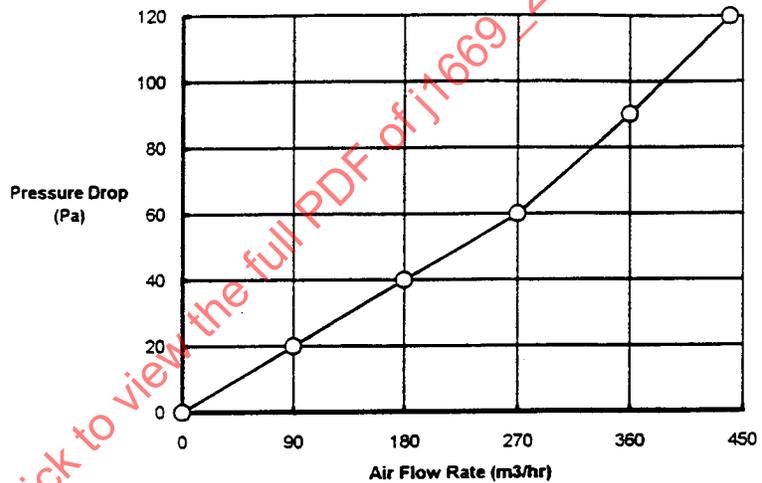
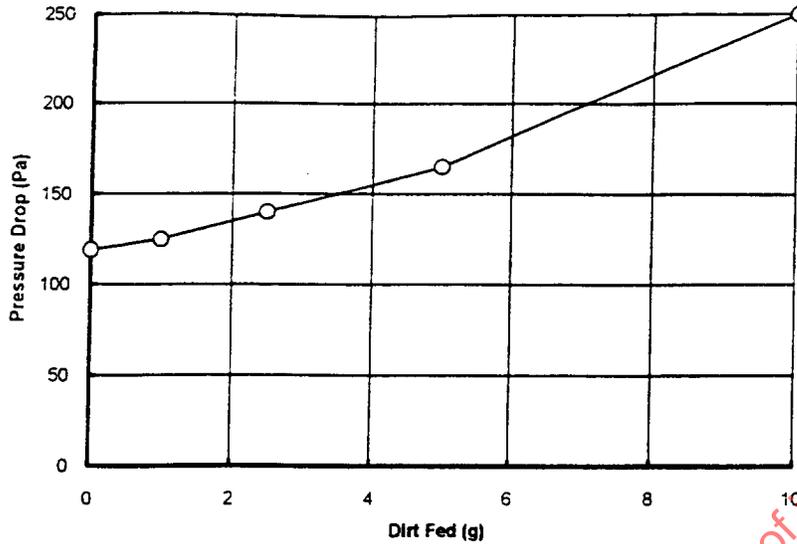


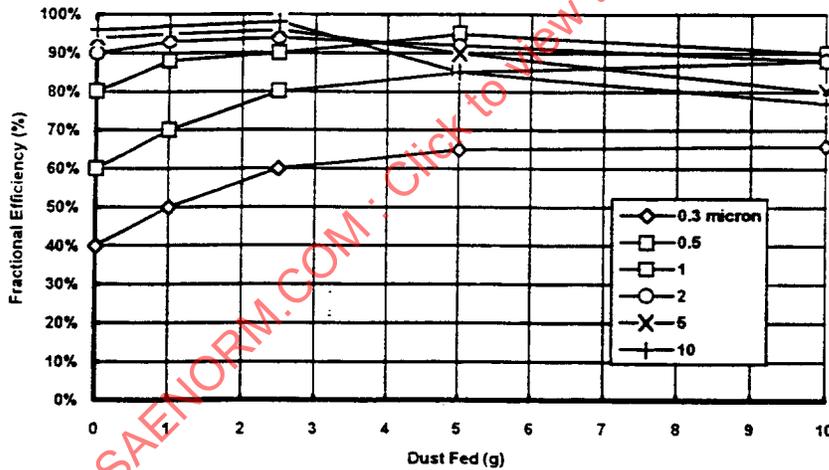
FIGURE 4—PERFORMANCE TEST REPORT

Results of Dust Loading Testing



Test Flow Rate _____ m³/hr Temperature _____ °C RH _____ % Inlet Pressure _____ Pa (abs)
 Total Dust Fed _____ g

Results of Incremental Efficiency Testing



Description of Filter: _____

Description of Collapse: _____

Test Performed by: _____ Date: _____

FIGURE 4—PERFORMANCE TEST REPORT (CONTINUED)

PREPARED BY THE SAE AIR CLEANER TEST CODE STANDARDS COMMITTEE

APPENDIX A

EFFICIENCY DATA REDUCTION

- A.1** The material in this section is adapted from the Institute of Environmental Sciences Recommended Practice IES-RP-CC007.1, "Testing ULPA Filters."

When using particle counters to evaluate fractional filtration efficiency, it is necessary to consider limitations imposed by the method. The efficiency is determined by comparing the particles detected upstream of the filter to the particles detected downstream. Inevitably, there are differences between the upstream and downstream sampling and detection equipment. This section presents a method to calculate correlation ratios to minimize the errors due to the difference between the upstream and downstream equipment. In addition to correcting for small variations between upstream and downstream equipment, the correlation ratio may be used to correct for differences such as using different models of particle counters upstream and downstream or to correct for unequal upstream and downstream sample times.

When the number of particles counted in any size class is low, potential errors may occur as a result of counting a few randomly occurring events. The method to quantify the size of the potential error from counting a few particles is presented.

These data-reduction techniques address only the correlation of upstream and downstream sampling and counting, and the statistics of counting a small number of particles. The confidence intervals calculated with the methods in this appendix do not necessarily reflect the overall test accuracy or precision. The test accuracy and precision cannot be any better than the confidence interval calculated from the counting statistics, but it may be worse because these data-reduction techniques do not address any other sources of error. To minimize the other sources of errors, it is important that the test system be qualified and calibrated as described in the body of this test code.

Sections A.2 through A.5 present "cookbook" calculations. Section A.6 presents more detail, including a sample calculation. The calculations are done in terms of penetration, the ratio of the concentration of particles downstream of the filter to the concentration upstream. The penetrations can be converted to efficiencies after the calculations are completed. The calculations are done for each particle-size class of interest.

A.1.1 Symbols

U	upstream counts
D	downstream counts
R	correlation ratio
P	penetration
T	sampling time
E	efficiency

A.1.2 Subscripts

o	observed
ucl	upper confidence limit
lcl	lower confidence limit
spec	specified performance
c	correlation (i.e., no filter installed)
t	testing a filter
uc	upstream during correlation
dc	downstream during correlation
ut	upstream during test

dt downstream during test

A.2 Correlation Ratio

A.2.1 Observed Value—Correlation Ratio—Using counts obtained with no filter installed, the observed correlation ratio should be calculated for each size class as shown in Equation A1:

$$R_o = D_{o,c}/U_{o,c} \quad (\text{Eq. A1})$$

A.2.2 UCL and LCL Values—Correlation Ratio

- For numbers $n \leq 50$, Table A1 should be used to determine the upper- and lower-confidence limits for each size class for the upstream and downstream counts with no filter installed.
- For numbers $n > 50$, then Equation A2

$$n \pm 2\sqrt{n} \quad (\text{Eq. A2})$$

should be used to determine the upper- and lower-confidence limits for each size class. See Equations A3 through A4.

$$R_{uci} = C_{ucl/c}/U_{lcl,c} \quad (\text{Eq. A3})$$

$$R_{lcl} = D_{lcl,c}/U_{ucl,c} \quad (\text{Eq. A4})$$

A.3 Penetration

A.3.1 Observed—Penetration—With the test filter installed, upstream and downstream counts should be obtained to calculate the observed penetration for each size class. See Equation A5.

$$P_o = D_{o,t}/U_{o,t} R_o \quad (\text{Eq. A5})$$

A.3.2 UCL and LCL Values—Penetration—The UCL and LCL values should be calculated for the upstream and downstream counts for each size class, using Table A1 for numbers $n \leq 50$, or using Equation A2 for $n > 50$. The UCL and LCL of the penetration should be calculated for each size class as shown in Equations A6 and A7:

**TABLE A1—95% CONFIDENCE LIMITS FOR THE
MEAN VALUE OF A POISSON VARIABLE**

Observed Count (n)	Lower	Upper	Observed Count (n)	Lower	Upper
0	0.0	3.7	26	17.0	38.0
1	0.1	5.6	27	17.8	39.2
2	0.2	7.2	28	18.6	40.4
3	0.6	8.8	29	19.4	41.6
4	1.0	10.2	30	20.2	42.8
5	1.6	11.7	31	21.0	44.0
6	2.2	13.1	32	21.8	45.1
7	2.8	14.4	33	22.7	46.3

**TABLE A1—95% CONFIDENCE LIMITS FOR THE
MEAN VALUE OF A POISSON VARIABLE (CONTINUED)**

Observed Count (n)	Lower	Upper	Observed Count (n)	Lower	Upper
8	3.4	15.8	34	23.5	47.5
9	4.0	17.1	35	24.3	48.7
10	4.7	18.4	36	25.1	49.8
11	5.4	19.7	37	26.0	51.0
12	6.2	21.0	38	26.8	52.2
13	6.9	22.3	39	27.7	53.3
14	7.7	23.5	40	28.6	54.5
15	8.4	24.8	41	29.4	55.6
16	9.2	26.0	42	30.3	56.8
17	9.9	27.2	43	31.1	57.9
18	10.7	28.4	44	32.0	59.0
19	11.5	29.6	45	32.8	60.2
20	12.2	30.8	46	33.6	61.3
21	13.0	32.0	47	34.5	62.5
22	13.8	33.2	48	35.3	63.6
23	14.6	34.4	49	36.1	64.8
24	15.4	35.6	50	37.0	65.9
25	16.2	36.8			

$$P_{ucl} = D_{ucl,t} / U_{lcl,t} R_{lcl} \quad (\text{Eq. A6})$$

$$R_{lcl} = D_{lcl,t} / U_{ucl,t} P_{ucl} \quad (\text{Eq. A7})$$

A.4 Calculations for Unequal Sample Times—If

$$T_{uc} / T_{dc} = T_{ut} / T_{dt} \quad (\text{Eq. A8})$$

then no adjustments for sampling time need to be made.

If this condition is not met, then the equation for the observed penetration is as shown in Equation A9:

$$P_o = (T_{ut}/T_{dt})(D_{o,t})/(U_{o,t}(D_{o,c}/U_{o,c})(T_{uc}/T_{dc})) \quad (\text{Eq. A9})$$

The equations for the UCL and LCL values of the penetration are as shown in Equations A10 and A11:

$$P_{ucl} = (T_{ut}/T_{dt})(D_{ucl,t})/(U_{lcl,t}(D_{lcl,c}/U_{ucl,c})(T_{uc}/T_{dc})) \quad (\text{Eq. A10})$$

$$P_{lcl} = (T_{ut}/T_{dt})(D_{lcl,t})/(U_{ucl,c}(D_{lcl,c}/U_{lcl,c})(T_{uc}/T_{dc})) \quad (\text{Eq. A11})$$

A.5 Efficiency—The efficiency for each size class is calculated from the penetration as follows in Equations A12 to A14:

$$E_o = 1 - P_o \quad (\text{Eq. A12})$$

$$E_{lcl} = 1 - P_{ucl} \quad (\text{Eq. A13})$$

$$E_{ucl} = 1 - P_{lcl} \quad (\text{Eq. A14})$$

A.6 Poisson Statistics and Counting

A.6.1 Theory (Poisson Statistics and Counting)—When a well-mixed, stable aerosol penetrates a filter, penetrating particles will appear downstream of the filter (or in a small downstream air sample) randomly, but at some average population density. A particle counter will detect these randomly in time, but at an average rate. For the purpose of calculating penetration, the average rate (particles per unit time or per unit volume) is obtained from the cumulative count measured over the time period of the test or over the volume sampled.

The statistics of particle counting has become increasingly important as the filter penetration and, hence, downstream counts decrease. These variations are described by Poisson statistics. Of primary importance to this type of testing is the relationship between the results of a single test and the results that would be obtained from a test of infinite duration—the true mean result. This relationship between an observed result and the implied confidence limits on the true mean result is described very well in the literature (see Box, et. al. in the Reference Section.)

A.6.2 Practice (Poisson Statistics and Counting)—When top-performance, noise-free particle counters are used in a good duct according to this document, count statistics becomes the largest error on highly efficient filter tests. When testing ULPA filters according to this document, low downstream particle counts are the largest source of uncertainty.

A.6.3 Recommendation (Poisson Statistics and Counting)

A.6.3.1 DETERMINATION OF CONFIDENCE LIMITS ON A COUNT—This procedure uses particle-count data to establish the confidence limits on penetration. Section A.5.3.5 gives the 95% confidence limits on a single-observed particle count from 0 to 50. For a single-observed particle count, n , there is a 95% confidence that the true mean count is between the upper and lower limits given in Table A2. The true mean count is the average count that would be obtained if the tests were repeated indefinitely.

For larger values of counts (n), the Poisson distribution tends toward normality with mean n and variance n . In this case, the 95% confidence levels for a count of n can be expressed as shown in Equation A15:

$$n \pm 2\sqrt{n} \quad (\text{Eq. A15})$$

(See Abramowitz and Stegun in the Reference Section.)

A.6.3.1.1 Example

TABLE A2—EXAMPLE—95% CONFIDENCE LIMITS

Observed Count (n)	Lower	Upper
0	0	3.7
10	4.7	18.4
100	80	120
10 000	9800	10 200

Once the confidence limits on a particle count are established, it is necessary to establish the confidence limits on the correlation ratio and penetration.

In most cases, one number in the ratio is substantially smaller than the other, and it is the uncertainty in the smaller value that dominates the uncertainty in the ratio. In this case, it is reasonable to calculate the confidence limits of the ratio by calculating the ratio with the limits of the smaller value and the observed level of the larger value.

A.6.3.2 CORRELATION RATIO—Statistical uncertainty exists in the ratio of downstream to upstream counts, with no filter in the system. This uncertainty should be established before the penetration is calculated. For example, consider a correlation where the observed counts are 10 000 upstream and 12 000 downstream (see Table A3):

TABLE A3—EXAMPLE—95% CONFIDENCE LIMITS ON CORRELATION RATIO

Observed Value	Lower	Upper
10 000 counts upstream	9 800	10 200
12 000 counts downstream	11 781	12 219

NOTE—In the example shown above, the upstream counts are less than the downstream counts because the upstream sample had been taken through a diluter.

Thus, the confidence limits on the correlation ratio are:

$$\text{Observed: } R_o = 12\,000/10\,000 = 1.20$$

$$\text{Lower: } R_{lcl} = 11\,781/10\,200 = 1.15$$

$$\text{Upper: } R_{ucl} = 12\,219/9800 = 1.25$$

If the uncertainty in the correlation ratio is significantly less than the uncertainty in the penetration of the filter under test, it is reasonable to use the observed value of the correlation ratio. Otherwise, the 95% confidence limits of the correlation ratio should be used.

A.6.3.3 PENETRATION—This correlation example is used to calculate the penetration of a filter test as shown in Table A4:

TABLE A4—EXAMPLE—95% CONFIDENCE LIMITS ON FILTER PENETRATION

Observed Value	Lower	Upper
1000 counts upstream	937	1063
30 counts downstream	20.2	42.8

Using the 95% confidence limits on the correlation ratio results in 95% confidence limits on the penetration of:

$$\text{Observed: } P_o = 30 / (1000 * 1.2) = 0.025 = 2.5\%$$

$$\text{Lower: } P_{lcl} = 20.2 / (1063 * 1.25) = 0.015 = 1.5\%$$

$$\text{Upper: } P_{ucl} = 42.8 / (937 * 1.15) = 0.040 = 4.0\%$$

The efficiency is:

$$\text{Observed: } E_o = 1 - 0.025 = 0.975 = 97.5\%$$

$$\text{Lower: } E_{lcl} = 1 - 0.040 = 0.960 = 96.0\%$$

$$\text{Upper: } E_{ucl} = 1 - 0.015 = 0.985 = 98.5\%$$

In this example, it can be stated that, with 95% confidence, the filter penetration is between 1.5% and 4.0% or the efficiency is between 96.0% and 98.5%.

Note that:

- The particle size range in which the counts were obtained should also be given.
- This confidence level is based on counting statistics only.
- Other error sources may contribute to the uncertainty of the penetration and efficiency measurements.
- For very low penetration filters, the errors due to the counting statistics may be a major factor in determining the overall test precision. For higher penetration filters when it is possible to obtain higher number counts, this error source becomes less important as compared to the other error sources.
- The statistical procedures described here apply only to raw count data. It is improper to apply these methods to data that have been scaled, multiplied by correlation ratios, converted to rates or concentrations, and so forth; to do so will yield erroneous results.

A.6.3.4 TEST PROCEDURES—In a typical testing situation, where the filter should prove to be greater than a specified efficiency, either of two methods may be used.

- The internal test specification written to ensure performance in a pass/fail manner is suitable for manual systems.
- Or, the confidence levels may be calculated continuously as the counts accumulate, until the filter passes or fails.

Method (b) is faster but requires an automated test. The pass/fail testing method can be illustrated by the previous examples. To prove a filter is more than 96% efficient in a particle-size range, it is sufficient to accumulate 1 000 000 counts upstream and require 30 or less downstream.

For the method where the confidence limits are constantly calculated as counts are accumulated, the test is simply continued until the filter is proved to pass or fail the specification. This method requires less time and will not reject good filters as a result of test variability.