

*Institute of Environmental Sciences and Technology*

## **IENT-RP-CC007.4**

Contamination Control Division

Recommended Practice 007.4

# Testing HEPA and ULPA Filters



1827 Walden Office Square, Suite 400  
Schaumburg, IL 60173  
Phone: (847) 981-0100 • Fax: (847) 981-4130  
E-mail: [information@iest.org](mailto:information@iest.org) • Web: [www.iest.org](http://www.iest.org)

This Recommended Practice was prepared by and is under the jurisdiction of Working Group 007 of the IEST Contamination Control Division (WG-CC007). The following WG voting members contributed to the development of this edition of this Recommended Practice.

R. Vijayakumar, WG-CC007 Chair, AERFIL

Taguhi Arakelian, Jet Propulsion Laboratory

Eugene Bryan, QVA Test Solutions, LLC

Tony Caughron, TEC Services Inc.

Keith Flyzik, Steris Corporation

Nick Karlowsky, Filtech, Inc.

Donna Kasper, Hollingsworth & Vose

Don Largent, AAF Flanders

Timothy McDiarmid, Air Techniques International

Mark Renn, AAF Flanders

Matt Smyers, Technical Safety Services

Andrew Stillo, Camfil USA, Inc.

The Working Group also wishes to acknowledge the contributions of members who prefer to remain anonymous.

Copyright © 2023 by the Institute of Environmental Sciences and Technology

First printing, June 2023

ISBN: 978-1-937280-58-1 (Electronic format)

ISBN: 978-1-937280-57-4 (Print format)

**PROPOSAL FOR IMPROVEMENT:** The Working Groups of the Institute of Environmental Sciences and Technology are continually working on improvements to their Recommended Practices and Reference Documents. Suggestions from users of these documents are welcome. If you have a suggestion regarding this document, please use the online Proposal for Improvement form found on the IEST website at [www.iest.org](http://www.iest.org).

Institute of Environmental Sciences and Technology  
1827 Walden Office Square, Suite 400  
Schaumburg, IL 60173  
Phone: (847) 981-0100 • Fax: (847) 981-4130  
E-mail: [information@iest.org](mailto:information@iest.org) • Web: [www.iest.org](http://www.iest.org)

**NOTICE AND DISCLAIMER:** This Recommended Practice is published by the Institute of Environmental Sciences and Technology (IEST) to advance the technical and engineering sciences. Use of this document is entirely voluntary, and determination of its applicability and suitability for any particular use is solely the responsibility of the user. Use of this Recommended Practice does not imply any warranty or endorsement by IEST.

The information in this publication was considered technically sound by the consensus of persons engaged in the development and approval of the document at the time it was developed. Consensus does not necessarily mean that there is unanimous agreement among all persons participating in the development of this document.

IEST standards, recommended practices, and guideline publications, of which the document contained herein is one, are developed through a voluntary consensus standards development process. This process brings together volunteers and seeks out the views of persons who have an interest in the topic covered by this publication. While IEST administers the process to promote fairness in the development of consensus, the organization does not write the document and does not independently test, evaluate, or verify the accuracy or completeness of any information or the soundness of any judgments contained in IEST standards, recommended practices, and guideline publications.

IEST disclaims liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this document. IEST disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein, and disclaims and makes no warranty that the information in this document will fulfill any of the particular purposes or needs of users of the document. IEST does not guarantee the performance of any individual manufacturer or seller's products or services by virtue of this standard or guide.

In publishing and making this document available, IEST is not undertaking to render professional or other services for or on behalf of any person or entity, nor is IEST undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. Information and other standards on the topic covered by this publication may be available from other sources, which the user may wish to consult for additional views or information not covered by this publication.

IEST has no power, nor does it undertake to police or enforce compliance with the contents of this document. IEST does not certify, test, or inspect products, designs, or installations for safety or health purposes. Any certification or other statement of compliance with any health or safety-related information in this document shall not be attributable to IEST and is solely the responsibility of the certifier or maker of the statement.

## UPDATES INCLUDED IN THIS PUBLICATION

The text on discharge methods for charged media has been revised. The discussions on charged media and aerosol for discharge have been split for clarity.

The section on efficiency from scan measurements has added clarification on the size range data required. The governing equations have been corrected and/or clarified.

The section on testing filters with media having MPPS <100nm (usually ePTFE) is revised to note that it is valid only for overall efficiency and not scanned efficiency. Explanation on the recommendation to use the alternate size to 0.1-0.2µm has been added since the efficiency in this size range is expected to be lower than the that between 0.2-0.3 µm since it is closer the MPPS of these filters.

# IEST-RP-CC007.4

## CONTENTS

### SECTION

|   |                                           |    |
|---|-------------------------------------------|----|
| 1 | SCOPE AND LIMITATIONS .....               | 6  |
| 2 | REFERENCES.....                           | 7  |
| 3 | TERMS AND DEFINITIONS .....               | 8  |
| 4 | TEST SYSTEM.....                          | 10 |
| 5 | SYSTEM QUALIFICATION AND CALIBRATION..... | 15 |
| 6 | TEST PROCEDURE .....                      | 19 |
| 7 | DATA REDUCTION (SECTION A5) .....         | 21 |
| 8 | REPORTING AND MARKING .....               | 23 |

### FIGURES

|                                                               |    |
|---------------------------------------------------------------|----|
| FIGURE 1—BLOCK DIAGRAM OF A HEPA/ULPA FILTER TEST SYSTEM..... | 11 |
|---------------------------------------------------------------|----|

### TABLES

|                                                                                        |    |
|----------------------------------------------------------------------------------------|----|
| TABLE A1. UPPER AND LOWER CONFIDENCE LIMITS FOR UPSTREAM AND<br>DOWNSTREAM COUNTS..... | 28 |
| TABLE B1. MINIMUM FREQUENCY OF CALIBRATION. ....                                       | 33 |

### APPENDIXES

|                                                                                                                |    |
|----------------------------------------------------------------------------------------------------------------|----|
| APPENDIX A—FACTORS INFLUENCING MEASURED PENETRATION .....                                                      | 24 |
| APPENDIX B—RECOMMENDED CALIBRATION INTERVALS.....                                                              | 33 |
| APPENDIX C—CONSIDERATIONS FOR HEPA/ULPA FILTERS INCORPORATING CHARGED MEDIA .....                              | 34 |
| APPENDIX D—FILTER EFFICIENCY DETERMINATION WHEN FILTER MPPS IS EQUAL<br>OR BELOW 0.1 $\mu\text{M}$ .....       | 36 |
| APPENDIX E—DETERMINING THE FILTER MEAN EFFICIENCY IN THE FACTORY FROM LEAK SCAN<br>DATA PER IEST-RP-CC034..... | 38 |
| APPENDIX F—PARTICLE DETECTION AND PARTICLE SIZE DISTRIBUTION.....                                              | 40 |
| APPENDIX G—BIBLIOGRAPHY .....                                                                                  | 42 |

# Testing HEPA and ULPA Filters

## IENT-RP-CC007.4

### 1 SCOPE AND LIMITATIONS

#### 1.1 Scope

This Recommended Practice (RP) describes the equipment, aerosol properties, processes, and calculations for determining the efficiency of HEPA, ULPA, and super ULPA filters in the factory, using particle counters. The procedure may be applied to production applications. This RP provides guidelines for constructing a suitable test duct and sampling system. Also provided are test criteria for quantifying penetration in the range of 0.030% to 0.00010%, between particles in the size range of 0.1 to 0.3  $\mu\text{m}$ .

#### 1.2 Limitations

Filters tested per IEST-RP-CC007 are typically factory-tested with uniform airflow across the filter. Ducted filters, fan filter units (FFUs), and poorly designed inlet housings for in-line filters may result in non-uniform media air velocity that can possibly reduce the *in situ* filter efficiency.

#### 1.3 Application of Method

Application of this RP is by mutual agreement between the customer and the supplier. To apply this RP, the agreement should also include:

- a) Acceptance criteria for penetration and pressure drop
- b) The test aerosol
- c) The test volume flow rate

Before testing filters, with a penetration level below 0.0005%, according to this RP, the most penetrating particle size (MPPS) should be determined. The determination can be made for the filter medium in flat sheet form, provided that the test is conducted with an aerosol as defined in section 4.2.9.

The test is performed at the same velocity as the average velocity through the medium in the assembled filter at the test volume flow rate.

**CAUTION:** Testing in accordance with this RP may involve hazardous materials, operations, and equipment. This RP does not purport to address the safety problems associated with its use. It is the responsibility of the user to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations before use of this RP.

The methodology described in this RP may be applied for particle-counter testing of filters outside the efficiency and particle size range covered in the document.

## 2 REFERENCES

The following documents are incorporated into this RP to the extent specified herein. Users should apply the most recent editions of the references.

### 2.1 Reference Documents

*ANSI/ASHRAE Standard 52.2-2012: Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*

*Fluid Meters: Their Theory and Application (ASME)*

*ASME-N510: Testing of Nuclear Air-Treatment Systems*

*IEST-RP-CC001: HEPA and ULPA Filters*

*IEST-RP-CC014: Calibration and Characterization of Optical Airborne Particle Counters*

*IEST-RP-CC021: Testing HEPA and ULPA Filter Media*

*IEST-RP-CC031: Method for Characterizing Outgassed Organic Compounds from Cleanroom Materials and Components*

*ISO 21501-4: Light scattering airborne particle counter for clean spaces*

*TAPPI-T1205: Dealing with Suspect (Outlying) Test Determinations*

### 2.5 Sources and Addresses

#### **ASHRAE**

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.  
1791 Tullie Circle, NE  
Atlanta, GA 30329, USA  
Phone: 404-636-8400  
Fax: 404-321-5478  
[www.ashrae.org](http://www.ashrae.org)

#### **ASME International**

American Society of Mechanical Engineers  
Three Park Avenue  
New York, NY 10016-5990, USA  
Phone: 800-843-2763  
Fax: 973-882-1717  
[www.asme.org](http://www.asme.org)

#### **IEST**

Institute of Environmental Sciences and Technology  
1827 Walden Office Square, Suite 400  
Schaumburg, IL 60173, USA  
Phone: 847-981-0100  
Fax: 847-981-4130  
[www.iest.org](http://www.iest.org)

#### **TAPPI**

Technical Association of the Pulp and Paper Industry  
15 Technology Parkway South  
Norcross, GA 30092  
Phone: 770-446-1400  
Fax: 770-446-6947  
[www.tappi.org](http://www.tappi.org)

### 3 TERMS AND DEFINITIONS

The following terms have special meaning in the context of this RP.

#### **aerosol**

A gaseous suspension of fine solid or liquid particles.

#### **airflow**

Airflow refers to volumetric flow rather than mass flow. Tests are run at the manufacturer-rated airflow or other airflow as agreed upon by the customer and supplier.

#### **challenge aerosol**

An aerosol derived from the selected aerosol source material and used as the leak-test challenge for a filter leak test. Challenge aerosols may be produced by a variety of methods, with the choice determined by the aerosol type and the particle size characteristics.

#### **correlation ratio**

The ratio of downstream counts to upstream counts with no filter in the test system.

For *sequential* counting systems, the correlation ratio represents the differences in the upstream and downstream sampling systems, such as:

- particle losses in sample lines and test duct
- diluter (if used)
- sample times

For *simultaneous* counting systems, the correlation ratio represents the same factors as for sequential counting systems, as well as the differences between the different particle counting instruments used upstream and downstream, such as:

- sample flow rate
- counting efficiency

#### **DOP or DEHP**

Diethyl phthalate (DOP) or di(2-ethylhexyl) phthalate (DEHP) ; CAS# 117-81-7.

#### **DOS or DEHS**

Diethyl sebacate (DOS) or di(2-ethylhexyl) sebacate (DEHS) ; CAS# 122-62-3.

#### **electret filter media**

Media made of fibers that carry electrical charge on their surfaces.

#### **HEPA (high-efficiency particulate air) filter**

An extended-medium, dry-type filter in a rigid frame when tested at rated airflow having a minimum particle collection efficiency of 99.97% for 0.3- $\mu$ m mass median diameter particles of DOP when tested in accordance with MIL-STD-282.

**NOTE:** The foregoing is the traditional definition for the HEPA filter. Changes in the filter manufacture, end-user requirements, and testing have introduced products that vary parametrically from filters that have been considered standard according to this definition. Additional information on this topic is given in IEST-RP-CC001.

#### **microspheres (or PSL)**

Monodisperse or polydisperse sized particles usually made of polystyrene latex (PSL). Monodisperse particle size is traceable to the National Institute of Standards and Technology (NIST) or other national standards bodies with respect to the diameter.

**NOTE:** PSL refers to a common type of highly uniform spheres, or a suspension thereof, used to generate a solid aerosol. PSL is useful for leak testing filters where other aerosols may contaminate the filters in an unacceptable manner. The term latex refers to an emulsion in water of finely divided particles of synthetic rubber, plastic, or other elastomer, and is not to be confused with natural rubber latex.

#### **monodisperse aerosol**

An aerosol with a narrow particle size distribution that has a geometric standard deviation less than 1.10. For the procedures in this document, any aerosol with at least 90% of the particles between 0.1 and 0.2  $\mu$ m is considered a monodisperse aerosol.

**most penetrating particle size (MPPS)**

The particle size at which a given filter has its highest penetration (or lowest efficiency); i.e., the worst-case particle size with respect to filtration efficiency. From filtration theory, efficiency is higher for particle sizes smaller or larger than the MPPS. In practice, the MPPS of a filter is considered to be within a measured size range typical in commercial instruments rather than at one unique particle size.

**National Metrology Institute (NMI)**

An organization providing national or international primary test standards used in the unbroken chain of traceability of test equipment.

**NOTE:** Traceability to national metrology institute standards does not always require the use of the NMI of the country in which a calibration laboratory is located.

**optical particle counter (OPC)**

An instrument that measures the number of airborne particles by counting the optical scattering pulses as the particles pass through the sensing volume, and the particle size by scattered light intensity. The optical particle size measured is the light scattering equivalent particle size and not the geometrical size. The device should be capable of measuring and sizing the challenge aerosols over the particle size range of interest. The lowest threshold size of the OPC should be at least half the particle size(s) being measured.

**NOTE:** An OPC may also be referred to as a discrete particle counter (DPC), or per ISO 209, light scattering airborne particle counter (LSAPC).

**PAO (4 cSt poly-alpha-olefin)**

A grade of PAO with a viscosity of 4 centistokes at 100 °C. With reference to filter testing, PAO also refers to a polydisperse aerosol of the described material.

**particle count**

The number of particles detected in a given volume of air (or in a given time period for a stable instrument sample flow rate). The number may be determined by counting discrete particles using a particle counter, or it may be deduced by calibration of a monotonic response (such as the photometric calibration of a condensation nucleus counter) of the instrument to a known concentration standard.

**particle counter**

An instrument capable of resolving responses from individual particles (e.g., an optical particle counter or condensation particle counter).

**particle size**

The apparent maximum linear dimension of a particle in the plane of observation as observed with an optical microscope, or the equivalent diameter of a particle detected by automatic instrumentation. The equivalent diameter is the diameter of a reference sphere having known properties and producing the same response in the sensing instrument as the particle being measured.

**penetration**

The ratio of the number of particles exiting the filter to the number of particles entering the filter, per unit time, expressed as a percentage for a stated particle size range.

**observed penetration**

The penetration calculated from observed counts.

**true mean penetration**

The penetration that would be calculated from the average observed counts, if the tests were repeated indefinitely.

**UCL and LCL penetration**

The 95% upper confidence limit (UCL) penetration and 95% lower confidence limit (LCL) penetration are values statistically calculated from the observed counts. There is a 95% confidence that the true mean penetration is between the UCL and LCL penetrations.

**polydisperse aerosol**

An aerosol that does not meet the definition of a monodisperse aerosol. For the procedures outlined in this document, the statistical mode of a polydisperse aerosol distribution should be between 0.1 and 0.3 µm.

**polystyrene microspheres (PSL) (see microspheres)**

### **sequential counting systems**

Test systems in which particles are counted by the same counter or counters both upstream and downstream of the filter. The counters are sequentially connected to either side of the filter, once or several times. Sequential counting systems are characterized by the need for stable aerosol and by reduced problems in correlating counters.

### **simultaneous counting systems**

Test systems in which particles are counted simultaneously upstream of the filter, with a counter or counters dedicated to upstream counting, and downstream of the filter, with a counter or counters dedicated to downstream counting. Simultaneous counting systems are characterized by reduced need for stable challenge aerosol concentration and by difficulty in correlating counters.

### **subsampler**

A device allowing for a statistically representative sample of a larger sample size or population.

### **super ULPA (ultralow-penetration air) filter**

A throwaway, extended-medium, dry-type filter in a rigid frame, made with filter medium having a minimum particle collection efficiency of >99.9999% (i.e., a maximum particle penetration of <0.00010%) for particles of the most penetrating particle size (MPPS) when tested at the average medium velocity in the filter in accordance with the methods of IEST-RP-CC021.

### **ULPA (ultralow-penetration air) filter**

A throwaway, extended-medium, dry-type filter in a rigid frame, having a minimum particle-collection efficiency of 99.999% (that is, a maximum particle penetration of 0.0010%) when tested in accordance with the methods of IEST-RP-CC007. ULPA filters are defined and described in IEST-RP-CC001.

## **4 TEST SYSTEM**

### **4.1 General**

The basic components of a typical test system are shown in Figure 1. The configuration of components shown provides a test system that operates above ambient pressure. This configuration helps prevent system leaks from affecting the measurement. If the test system is below ambient pressure, small leaks can introduce sufficient particles to interfere with the measurements. In Figure 1, item 13 is a restriction or valve used to regulate the system pressure.

In designing systems, it should be recognized that large volumes, low velocities, and recirculating regions in the flow path lead to long system response times (see section 5.16).

### **4.2 Components**

#### **4.2.1 Inlet filter**

Before mixing with test aerosol, the test air should be cleaned to a level of less than 1% of the challenge aerosol concentration. Filtration with high-efficiency particulate air (HEPA) filters is recommended. (Figure 1, item 1)

#### **4.2.2 Relative humidity measurement and control**

Provisions should be included to maintain the relative humidity of the test airflow in the range of 30% to 70%. (Figure 1, items 3 and 10; section A17)

#### **4.2.3 Temperature measurement and control**

Temperature control is not required if the temperature remains in the range of 10 to 38 °C (50 to 100 °F). However, if the temperature is other than 21 °C (70 °F), appropriate corrections for the flow measurement device should be used to maintain the actual volumetric test flow. In addition, corrections to the measured pressure drop of the filter should be made as per section 7.6. Care should be taken to minimize temperature gradients. (Figure 1, items 3 and 10; section A16)

#### 4.2.4 Blower

A blower of sufficient capacity to provide steady airflow at the test conditions should be used. (Figure 1, item 2)

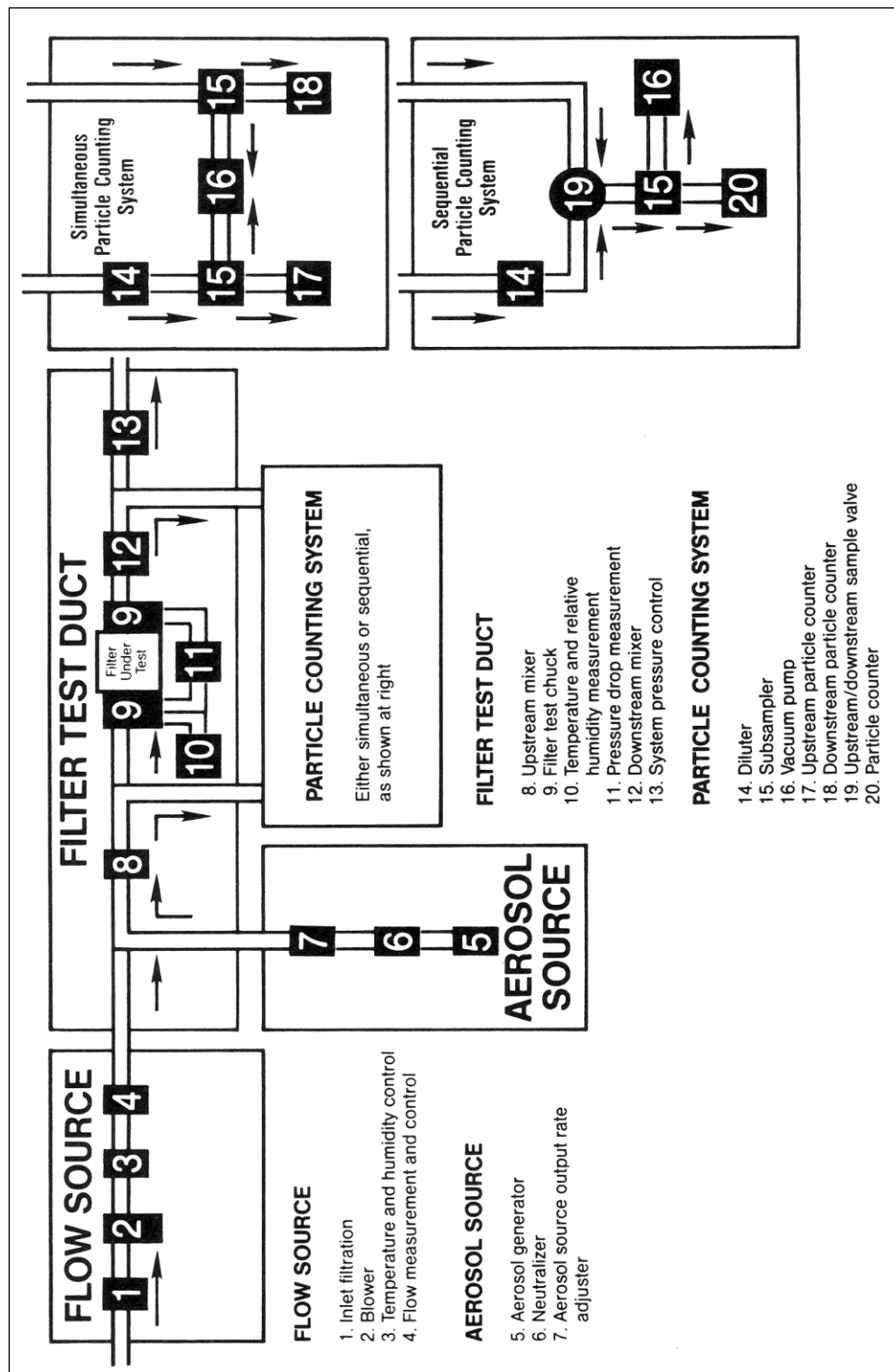


Figure 1—Block diagram of a HEPA/ULPA filter test system.

#### 4.2.5 Flow measurement and control

Equipment used for flow measurement and control should be capable of measuring actual volumetric flow at test conditions within  $\pm 3\%$ . (Figure 1, item 4; sections A3, A16–18)

#### 4.2.6 Filter test duct

All materials for the filter test system that contact the test airstream, including sampling lines, should be cleanable, non-particle-shedding, and electrically conductive and grounded. Two preferred materials are polished stainless steel and aluminum. The test filter should be mounted in a chucking device that completely encapsulates the filter and frame, so the filter frame does not become part of the test duct and leaks in the filter frame are detected. (Figure 1, items 8–13)

#### 4.2.7 Aerosol mixing, upstream and downstream of the filter under test

Upstream of the filter under test, a method should be used to provide for the uniform challenge of the filter (see section 5.13). This may be accomplished with mixing vanes, baffles, multiple aerosol injection points, or other means.

Downstream of the filter under test, a method should be used to confirm that the downstream sample represents the flow through the entire filter (see section 5.14). This may be accomplished with mixing vanes, baffles, multiple sampling points, or other means. (Figure 1, items 8 and 12)

#### 4.2.8 Resistance measurement

The filter resistance should be a measure of the static pressure loss of the airstream as the airstream moves through the test filter at the test flow rate. The airstream should be measured with a differential pressure device connected to pressure taps in the test duct, upstream and downstream of the test filter. The differential pressure device should have an accuracy of at least  $\pm 3\%$  of reading or  $\pm 2.5$  Pa ( $\pm 0.01$  in. w.c.), whichever is larger. (Figure 1, item 11)

Pressure taps in the test duct should be of the static pressure type, at right angles to the airstream. To eliminate the possibility of velocity components in any one reading, several pressure taps appropriately spaced in the test duct are preferred to only one. An average reading can be obtained by plumbing all taps together.

#### 4.2.9 Aerosol material

The particles of the aerosol used for testing, calibrating, and obtaining correlation ratios should be of spherical form and have an index of refraction with a real part between 1.45 and 1.60 and low imaginary part. The vapor pressure should be low enough to ensure that diameter changes through the test system are less than 10%. Possible materials include:

- DOP or DEHP
- PAO
- DOS (DEHS)
- polystyrene microspheres (PSL)
- Mineral oil

**NOTE:** Traditionally, DOP has been the challenge aerosol material for testing filters with photometers. However, due to the potentially adverse health effects of DOP, regulatory health organizations have accepted PAO as a substitute for DOP. Hence, from a practical point of view, PAO is currently the recommended challenge aerosol material for filter tests where DOP has been specified, especially for *in situ* leak testing of filters. It is the user's responsibility to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations before using this RP.

**CAUTION:** (1) For any material used, the Safety Data Sheet (SDS) should be available, and the health risks of using the material in aerosol form should be assessed. As noted in section 1, testing in accordance with this RP may involve hazardous materials, operations, and equipment. This RP does not purport to address the safety problems associated with its use. It is the user's responsibility to consult and establish appropriate safety and health practices and to determine the applicability of regulatory limitations before using this RP. (2) Filter testing will leave a miniscule

amount of the challenge aerosol as a residue that may off-gas. While all of the aerosols identified in this section are adequate for filter testing, determining the effects of offgassing is outside the scope of this RP and is a matter for agreement between the user and supplier. Measurement methods for determining offgassing are given in IEST-RP-CC031.

Use of aerosol materials that do not fit the preceding description may result in penetration measurements that are different from measurements made using the listed aerosols. These restrictions may not apply for other sizing methods.

#### 4.2.10 Aerosol source

Although not shown in Figure 1, use of a method of stopping or bypassing the aerosol flow from the aerosol source is recommended for the purpose of changing the test filter.

#### 4.2.11 Aerosol generator (Figure 1, item 5; sections A1, A10–A14, A19)

The aerosol population may be either polydisperse or monodisperse (see section 4.2.16).

The aerosol generator should be capable of producing a stable aerosol concentration, with the number of particles in the test size range sufficient to allow statistically valid counts downstream of the filter in the desired period. Count statistics are discussed in section A5.

Because the slope of the aerosol size distribution over the particle detector size channels influences the effective size of the channels, the statistical mode of the aerosol count distribution should be within the test size range (0.1 to 0.3  $\mu\text{m}$ ).

For aerosol generators that have output concentration capacities greater than  $10^5$  particles/ $\text{cm}^3$  ( $10^9$  particles/ $\text{ft}^3$ ) or generators that use a solvent, it may be necessary to add dilution air at the outlet of the generator to minimize agglomeration or to evaporate a solvent. Atomizers with integral or subsequent impactors may be used to generate suitable aerosols from a variety of liquids, solutions, and suspensions. Examples of such atomizers include Collison style, Laskin nozzle type, and those described by Scripsick and Soderholm (see Appendix G). Thermal methods of evaporation and condensation similar to those used in MIL-STD-282 may be used if adjustments are made to provide the proper size particles.

#### 4.2.12 Aerosol neutralizer (Figure 1, item 6; sections A10 and A14)

Many aerosol generators produce highly charged aerosols as a result of mechanical shearing of the liquid in the process of making drops. These charges should be neutralized to minimize particle deposition as a result of electric fields. Commercially available radioactive or electrostatic neutralizers produce high numbers of bipolar ions that effectively neutralize the aerosol. These neutralizers should be used immediately after the aerosol is generated and before the aerosol is introduced into the filter test duct.

Electrostatic neutralizers may produce large numbers of ultrafine particles ( $<0.05 \mu\text{m}$ ) that will contribute to the challenge aerosol. This is not important for particle counters that are not sensitive to particles smaller than  $0.05 \mu\text{m}$ . Radioactive neutralizers do not produce such ultrafine particles.

Ionizers of the pulse type, if used, require thorough mixing with the aerosol for effective neutralization. Otherwise, ionizers can charge rather than neutralize the particles and thus be detrimental.

#### 4.2.13 Aerosol source output rate adjuster (Figure 1, item 7)

- a. When testing filters the aerosol challenge upstream of the test filter should be:
  1. Of sufficient concentration to complete the test in a reasonable period of time (see section 6.6)
  2. Of sufficient concentration that the background count rate of the downstream counter does not exceed 5% of the average downstream count
  3. Less than  $10^5$  particles/ $\text{cm}^3$  ( $10^9$  particles/ $\text{ft}^3$ ) to avoid agglomeration

During calibration of the test system, it is necessary to have a substantially lower concentration of the same aerosol to correlate the upstream and downstream sampling systems and counting system (see section 5.9).

- b. The aerosol used for correlation should:

1. Be the same material and size distribution as the test aerosol
2. Have a concentration low enough to limit the error rate resulting from high counting rate in any particle counter to a maximum of 5%
3. Be sufficiently concentrated to accomplish the correlation in a reasonable period

Therefore, a method should be provided to reduce the concentration of aerosol. This reduction can be accomplished either by exhausting a suitable fraction of the aerosol or by filtering a suitable fraction of the aerosol output using a dilution system so the desired concentrations both upstream and downstream are obtained.

#### 4.2.14 Sampling, sample lines (Sections A9 and A15)

The sampling system should be designed to obtain a representative sample. The sampling tubing should be:

- a. Electrically conductive (preferably stainless steel, aluminum, other metal, or other conductive flexible tubing)
- b. Electrically grounded
- c. As short as possible, typically 1 m (39 in.)

To avoid particle losses, use of valves, restrictions, and bends should be minimized.

#### 4.2.15 Diluter (Figure 1, item 14; section A6)

High upstream concentration can result in particle-counting errors. When the high-count-rate error exceeds 5%, a diluter should be used.

Design and operation of diluters for low flow rates may present difficulties such as very small capillary sizes. Hence, for low-flow-rate particle counters, it may be desirable to sample from the test duct at a higher flow rate than the particle counter and then subsample for the particle counter, as shown in Figure 1, item 15.

Diluters should be calibrated per IEST-RP-CC013, equivalent standards, or manufacturer's guidelines and should have at least an accuracy of  $\pm 10\%$  of specified value for the device.

#### 4.2.16 Particle counters (Figure 1, items 17, 18, and 20; sections A1, A6–A8, A11, A19)

The particle-sensing equipment should be one or more particle counters capable of counting particles in the size range of 0.1 to 0.3  $\mu\text{m}$  with set or user-specifiable bin ranges of 0.1 to 0.2  $\mu\text{m}$  and 0.2 to 0.3  $\mu\text{m}$ . Polydisperse particles may be sized with equipment using light scattering, electrical mobility classification, diffusional separation, or other method demonstrated to be of equal or better accuracy.

**CAUTION:** Particle-sensing instruments should be capable of responses independent of particle size in the 0.1  $\mu\text{m}$  to 0.3  $\mu\text{m}$  size range; that is, their count efficiency should be constant in this size range. In general, it is good practice to select particle counters that are capable of detecting and counting particles with at least half the diameter of the size of interest. For example, counters that can measure particles as small as 0.1  $\mu\text{m}$  may be suitable for measurement of filter media performance at 0.2  $\mu\text{m}$ . On the other hand, if the MPPS of the media is 0.2  $\mu\text{m}$  or smaller, it is generally not recommended to use optical particle counters and polydisperse aerosol, since many commercial optical particle counters are not suitable for measuring 0.1  $\mu\text{m}$  or smaller particles.

When using a narrow size distribution of particles, for example, polystyrene latex spheres with 90% of the particles between 0.1 and 0.3  $\mu\text{m}$ , the size distribution should be verified as part of the system qualification and before filter testing. When using particle counters that have sensitivity to a broad range of particle sizes but no particle sizing capability (such as a condensation nucleus counter), it is important to verify that the aerosol generation and neutralization mechanism does not create additional particles of other sizes that may be detected by the particle counters.

The equipment should be able to repeatably and accurately measure the concentration both upstream and downstream of the filter, using a diluter when needed (see 4.2.15). For low concentrations, the zero-count background level of the counter should be less than 5% of the concentration being measured.

#### 4.2.17 System control, data acquisition, and data reduction equipment

To reduce test time and operator errors, automated data acquisition and storage is recommended. Appendix A, sections A6 and A7, discuss reasons to automate the data acquisition and reduction.