Designation: F 1977 – 99

An American National Standard

Standard Test Method for Determining Initial, Fractional, Filtration Efficiency of a Vacuum Cleaner System[1]

This standard is issued under the fixed designation F 1977; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method may be used to determine the initial, fractional, filtration efficiency of household and commercial canister (tank-type), stick, hand-held, upright, and utility vacuum cleaner systems.

1.1.1 Water-filtration vacuum cleaners which do not utilize a replaceable dry media filter located between the water-based filter and cleaning air exhaust are not included in this test method. It has been determined that the exhaust of these vacuum cleaners is not compatible with the specified discrete particle counter (DPC) procedure.

1.2 The initial, fractional, filtration efficiencies of the entire vacuum cleaner system, at four discrete particle sizes (0.3, 0.5, 1.0, and 2.5 µm), is derived by counting upstream challenge particles and the constituent of downstream particles while the vacuum cleaner system is being operated in a stationary test condition.

1.3 The vacuum cleaner system is tested at the nozzle under a normal airflow rate equivalent to 150 % of the airflow rate produced at the maximum air power point as determined in accordance with Test Method F 558.

1.4 The vacuum cleaner system is tested with a new filter(s) installed, and with no preliminary dust loading. The fractional efficiencies determined by this test method shall be considered initial system filtration efficiencies.

1.5 Neutralized potassium chloride (KCl) is used as the challenge media in this test method.

1.6 One or two particle counters may be used to satisfy the requirements of this test method. Both require flow control means to switch between sampling the upstream and downstream air sampling probes.

1.7 To efficiently utilize this test method, automated test equipment and computer automation is recommended.

1.8 Different sampling parameters, flow rates, and so forth, for the specific applications of the equipment and test procedure may provide equivalent results. It is beyond the scope of this test method to define those various possibilities.

1.9 This test method is limited to the test apparatus, or its equivalent, as described in this document.

1.10 This test method is not intended or designed to provide any measure of the health effects or medical aspects of vacuum cleaning.

1.11 This test method is not intended or designed to determine the integrity of HEPA filtration assemblies used in vacuum cleaner systems employed in nuclear and defense facilities.

1.12 The inch-pound system of units is used in this test method, except for the common usage of the micrometer, µm, for the description of particle size which is a SI unit.

1.13 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water[2]

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[3]

D 2986 Practice for Evaluation of Air Assay Media by the Monodisperse DOP (Dioctyl Phthalate) Smoke Test[3]

D 3154 Test Method for Average Velocity in a Duct (Pitot Tube Method)[3]

F 50 Practice for Continuous Sizing and Counting of Airborne Particles in Dust-Controlled Areas and Clean Rooms Using Instruments Capable of Detecting Single Sub-Micrometre and Larger Particles[4]

F 395 Terminology Relating to Vacuum Cleaners[5]

F 558 Test Method for Measuring Air Performance Characteristics of Vacuum Cleaners[5]

2.2 *Other Documents:*

IES Recommended Practice CC021.1—Testing HEPA and ULPA Filter Media[6]

IES Recommended Practice CC001.3—HEPA and ULPA Filters[6]

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[1] This test method is under the jurisdiction of ASTM Committee F-11 on Vacuum Cleaners and is the direct responsibility of Subcommittee F11.23 on Filtration.

Current edition approved May 10, 1999. Published August 1999.

[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] *Annual Book of ASTM Standards*, Vol 11.03.

[4] *Annual Book of ASTM Standards*, Vol 15.03.

[5] *Annual Book of ASTM Standards*, Vol 15.07.

[6] Available from the Institute of Environmental Sciences, 940 E. Northwest Highway, Mount Prospect, IL 60056.

ISO Guide 25—General Requirements for the Competence of Calibration and Testing Laboratories[7]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *challenge*, *n*—aerosolized media introduced upstream of the test unit and used to determine the filtration characteristics of the test unit.

3.1.1.1 *Discussion*—Also known as test aerosol. The term "contaminant" shall not be used to describe the media or aerosol used to challenge the filtration system in this test method. The term "contaminant" is defined in Terminology D 1356 and does not meet the needs of this test method.

3.1.2 *chamber airflow*, *n*—the sum of all airflows measured at a point near the downstream probe.

3.1.3 *filter*, *n*—the entity consisting of the converted filter media and other items required to be employed in a vacuum cleaner for the purpose of arresting and collecting particulate matter from the dirt-laden air stream; sometimes referred to as a filter element, filter assembly, cartridge, or bag.

3.1.4 *normal airflow*, *n*—that airflow, determined to be 150 % of the airflow occurring at the point of maximum air power of the system's nozzle as determined in accordance with Test Method F 558.

3.1.5 *nozzle adaptor*, *n*—a plenum chamber, fabricated to mount to the inlet nozzle of the test unit in a sealable manner and shown in Fig. 1.

3.1.5.1 *Discussion*—Construction specifications are discussed in the Apparatus section.

3.1.6 *particle count*, *n*—the numeric sum of particles per cubic foot.

3.1.6.1 *Discussion*—Throughout this test method, the units of measure for this term, generally, do not accompany the term "particle count" and are assumed to be understood by the reader.

3.1.7 *primary motor*, *n*—the motor which drives the blower, producing airflow through the vacuum cleaner.

3.1.8 *secondary motor*, *n*—any motor in the vacuum cleaner system, not employed for the generation of airflow.

3.1.9 *sheath air*, *n*—the air flowing over and around the test unit that is mounted in the test chamber.

3.1.10 *stabilization*, *n*—those conditions of operation which produce results having a total variation of less than 3 % and at least 1000 total count in all size ranges for challenge and less than 15 counts per cubic foot in the 0.3-µm channel for the background count.

3.1.10.1 *Discussion*—Total variation is calculated as the maximum data point minus the minimum data point divided by the maximum data point times 100.

3.1.10.2 *Discussion*—The assurance of statistical control is not a simple matter and needs to be addressed. A process is in a state of statistical control if the variations between the observed test results vary in a predictable manner and show no unassignable trends, cyclical characteristics, abrupt changes, excess scatter, or other unpredictable variations.

3.1.11 *system filtration efficiency*, *n*—a numerical value based on the ratio of a discrete size, particle count emerging from the vacuum cleaner, relative to the upstream challenge, particle count of the same size.

3.1.12 *test chamber*, *n*—the enclosed space surrounding the vacuum cleaner being tested, used to maintain the controlled environmental conditions required during the test procedure.

3.1.13 *test run*, *n*—the definitive procedure that produces a singular measured result.

3.1.13.1 *Discussion*—A test run is the period of time during which one complete set of upstream or downstream air sample data, or both, is acquired.

3.2 *Definitions:*

3.2.1 *aerosol*, *n*—a suspension of solid or liquid particles in a gas.

3.2.2 *background particles*, *n*—extraneous particles in the air stream prior to the start of the test.

3.2.2.1 *Discussion*—Under conditions required of this test method, extraneous particles will be found to pass through the test chamber (for example, particles penetrating the test chamber's HEPA filters or being abraded or released from the surfaces of tubing and test equipment). Operating under stabilized conditions, these particles shall be counted in the downstream flow and subsequently subtracted from the test data to determine the initial, fractional, filtration efficiency of the test unit (see Note 3).

3.2.3 *channel*, *n—in particle analyzers*, a group of particle sizes having a definitive range; the lower end of the range identifies the channel, for example, a range of particle sizes from 0.3 to 0.4 µm is identified as the 0.3-µm channel.

3.2.4 *coincidence error*, *n—in particle analyzers*, errors occurring at concentration levels near or above the design limits of the instrument being used because two or more particles are simultaneously being sensed.

3.2.5 *diffusion dryer*, *n—in aerosol technology*, a device containing desiccant, surrounding the aerosol flow path, that removes excess moisture by diffusion capture.

3.2.6 *diluter*, *n—in aerosol technology*, a device used to reduce the concentration of particles in an aerosol.

3.2.7 *downstream*, *adv*—signifies the position of any object or condition that is physically in or part of the airflow stream occurring after the referenced item.

3.2.8 *DPC*, *n*—an acronym for discrete particle counter.

3.2.8.1 *Discussion*—The IES Recommended Practice CC001.3 and Practice F 50 describe a discrete particle counter as a instrument that utilizes light-scattering or other suitable

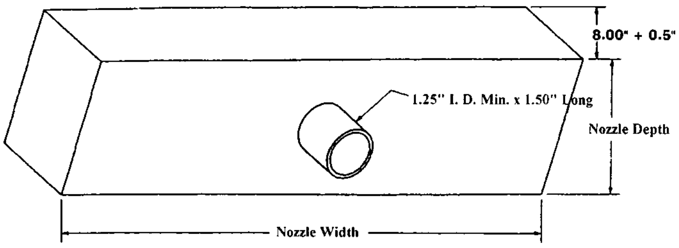

FIG. 1 Nozzle Adapter

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[7] Available from the International Organization for Standardization, Case Postale 56, CH-1211 Geneva 20, Switzerland.

principle to count and size discrete particles in air, and that displays or records the results. The discrete particle counter is also known as a single-particle counter or simply as a particle counter.

3.2.9 *fractional efficiency*, *n*—a numerical value based on the ratio of the number of emergent, downstream particles of a discrete size, relative to the number of incident, upstream particles of the same size.

3.2.9.1 *Discussion*—In practice, a single particle size is reported, having an understood or assumed size range equal to the channel size. This value is also known as the differential size efficiency or particle size efficiency, or both.

3.2.10 *fractional efficiency curve*, *n*—the fractional efficiency plotted as a function of the particle size.

3.2.11 *HEPA*, *adj*—an acronym for high-efficiency particulate air.

3.2.11.1 *Discussion*—Additional information pertaining to HEPA may be found in Practice D 2986 and IES-RP-CC021.1.[8]

3.2.12 *laminar*, *adj*—in pneumatics, nonturbulent, laminar flow through a pipe is considered laminar when the Reynolds number is less than approximately 2000 and turbulent for a Reynolds number greater than approximately 4000.

3.2.12.1 *Discussion*—Laminar flow in a pipe is characterized by a smooth symmetrical pattern of streamlines. The Reynolds number is a nondimensional unit of measure proportional to the ratio of the inertial force of the gas to the frictional forces acting on each element of the fluid.[9,10]

3.2.13 *neutralizer*, *n*—*in aerosol technology*, a device used to minimize losses and coagulation caused by electrostatic charges, and to counteract high charge levels in aerosols generated by nebulization, combustion, or dispersion by neutralizing the particle charge level to the Boltzmann distribution level.

3.2.13.1 *Discussion*—Neutralizers generally use radioactive Krypton gas, Kr-85, sealed in a stainless steel tube shielded by an outer metal housing.

3.2.14 *particle*, *n*—a small, discrete object.

3.2.15 *particulate*, *adj*—indicates that the material in question has particle-like properties.

3.2.16 *population*, *n*—the total of all the units of a particular model vacuum cleaner being tested.

3.2.17 *sample*, *n*—a small, representative group of vacuum cleaners, taken from a large collection (population) of vacuum cleaners of one particular model, which serve to provide information that may be used as a basis for making a determination concerning the larger collection.

3.2.18 *submicrometer*, *adj*—describes the range of particles having a mean diameter of less than 1 µm (1×10^{-6} m).

3.2.19 *unit or test unit*, *n*—a single vacuum cleaner system of the model being tested.

3.2.20 *upstream*, *adv*—signifies the position of any object or condition that is physically in or part of the airflow stream occurring before the referenced item.

3.2.21 *vacuum cleaner*, *n*—as defined in Terminology F 395.

3.3 *Symbols:*

cfm = cubic feet/minute.
D = diameter, in.
ft = feet.
°F = degrees Fahrenheit.
Hz = frequency, Hertz.
H_2O = water, column.
in. = inch.
psi = pound-force per square inch.
Q = airflow rate, cubic feet/minute.
RH = relative humidity.
RMS = root mean square.
s = second.
$\bar{X}$ = population mean.
X_i = test unit average.
µm = micrometre (10^{-6} m).
% = percent.

4. Summary of Test Method

4.1 This test method provides a procedure to determine the initial, fractional, filtration efficiency of a vacuum cleaner system (system filtration efficiency). The effects of the downstream concentration of particles that may be caused by various factors including the electric motor(s) used in the vacuum cleaner are mathematically removed in the determination of the initial fractional efficiency.

4.2 In determining a vacuum cleaner system's initial, fractional, filtration efficiency, the test unit is placed in a test chamber, and sealed from ambient conditions. In this test chamber, a large, controlled volume of HEPA filtered air (meeting HEPA standards as defined by IES-RC-CC021.1) is passed over and around the test unit. A controlled aerosol challenge is introduced into the vacuum cleaner system. Upstream and downstream, air sampling measurements of the number and size of particles, within four particular ranges (channels), are acquired on a near, real time basis. The initial, fractional, filtration efficiency values at four incremental sizes are then calculated.

5. Significance and Use

5.1 It is well known that modern electrical appliances, incorporating electric motors that use carbon brushes for commutation, may emit aerosolized, particles into the surrounding environment. This test method determines the initial, fractional, filtration efficiency of a vacuum cleaner system, taking those emissions into consideration.

5.2 For all vacuum cleaner systems tested, the total emissions of the unit, whatever the source(s), will be counted at each of the four particle size levels identified in the test procedure. This test method determines the initial, fractional filtration efficiency of a vacuum cleaner system, with this motor emission mathematically removed in the calculation of efficiency.

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[8] "High Efficiency Particulate Air Filters (HEPA and ULPA)," European Committee for Standardization (CEN), prEN 1822-1:1995, January 1995.

[9] Hinds, William C., *Aerosol Technology—Properties, Behavior, and Measurement of Airborne Particles*, John Wiley & Sons, 1982, ISBN 0-471-08726-2.

[10] Willeke, Klaus, and Baron, Paul A., *Aerosol Measurement—Principles, Techniques, and Applications*, John Wiley & Sons, formerly Van Nostrand Reinhold, 1993, ISBN 0-442-004486-9.

6. Apparatus

6.1 The information provided in this test method is intended to enable a laboratory to design, fabricate, and qualify the various components utilized in this procedure. Detailed and specific information regarding the components, a set of construction drawings, photos, vendor information, assembly, calibration, qualification testing instructions, and so forth, are not provided.

6.2 *Laboratory Filtration Test Room*:

6.2.1 The laboratory shall be maintained at 70 ± 5°F and 35 to 55 % RH.

6.2.2 To maintain the required ambient conditions within the laboratory and the test chamber, the test chamber airflow may be recirculated through the laboratory, in a closed-loop fashion. The air should pass through a HEPA filtration system before exhausting into the laboratory.

6.3 *Main Test Chamber*—The test chamber is mounted in a vertical attitude and shall be capable of enclosing the vacuum cleaner which is to be mounted in a horizontally, centralized position that will allow the test chamber sheath air to flow over and around it. Shown diagrammatically in Fig. 2, the body of the chamber is between approximately 2.5 and 3 ft in diameter (a rectangular chamber may be used) by approximately 4 to 5 ft in height, which is considered adequate for testing household and commercial vacuum cleaners as identified in the scope. The test chamber is fabricated from aluminum or stainless steel and shall be electrically connected to an earth ground. A large access panel or door shall be provided to accommodate the installation of the test unit. This door shall have a peripheral seal to ensure against the loss of aerosolized, challenge particles during testing. A removable wire form grill, capable of supporting the test unit, shall be placed at or near the bottom

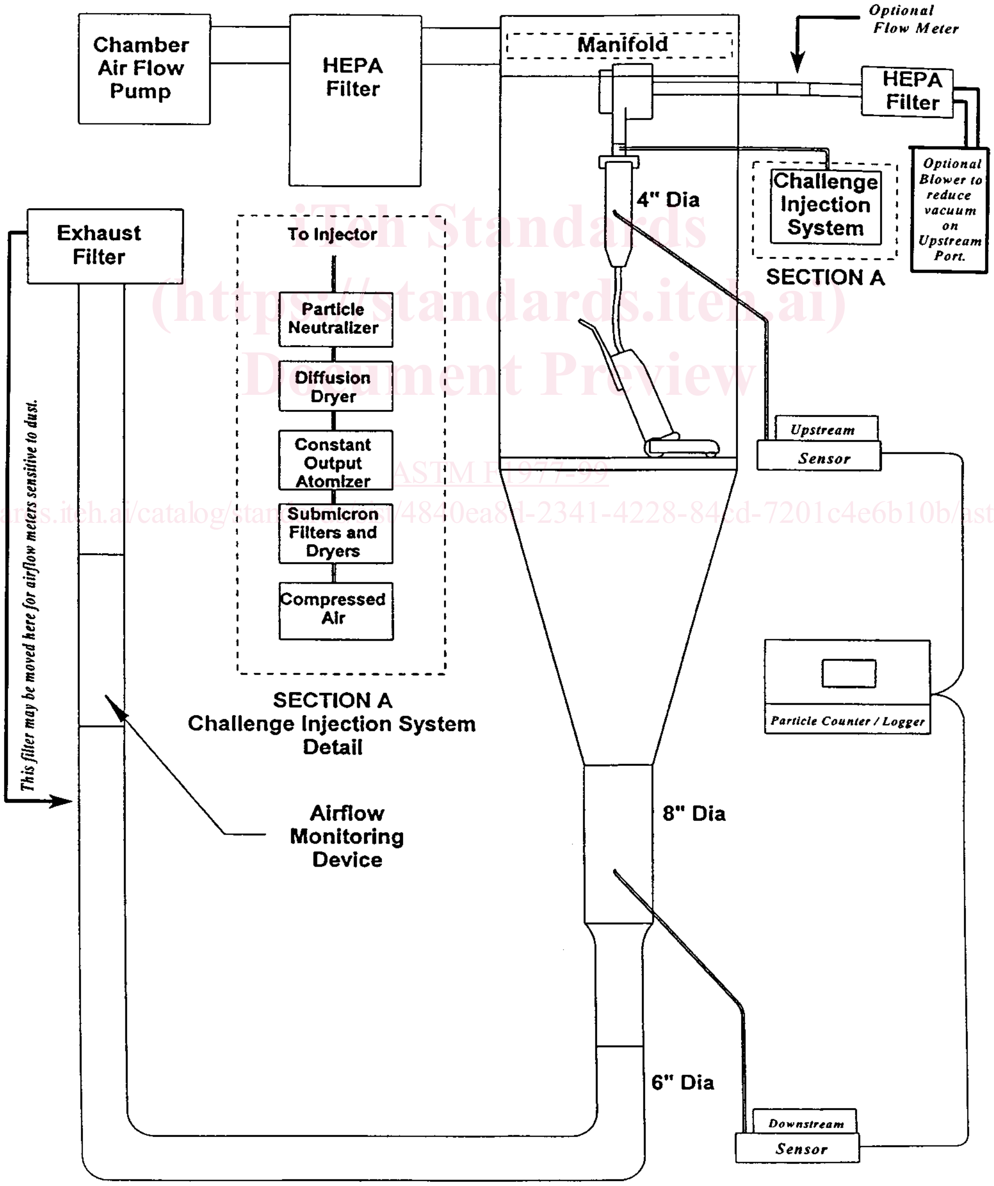

FIG. 2 Filtration Test Chamber and Supporting Equipment

of the test chamber (opening space 2 in. or greater; 0.2-in. diameter rod or less; open area 80 % or greater).

6.4 *Sheath Air Supply*—The test chamber's sheath airflow shall be produced by a positive pressure blower system. The sheath air is introduced into the top of the test chamber through a manifold and diffuser section in a manner to ensure a velocity profile across a horizontal plane, at the middle of the chamber, that is within 10 % of the maximum velocity measured at any point on that plane, when measured at chamber flow rates of 100 and 1000 cfm; in accordance with the procedure described in Test Method D 3154.

6.4.1 The HEPA-rated filtration section and the test chamber's air supply, blower system shall be sized to provide a minimum airflow of 1000 cfm at the load previously described.

6.5 *Challenge Injection System*—Air entering the test chamber at any point or for any purpose, unless specifically stated otherwise, shall initially pass through a HEPA filter. (HEPA filtration specifications are found in IES-RP-CC021.1.)

6.5.1 An atomizing system (challenge feeder) is required to inject the challenge at a constant rate equal to ±5 % of the concentration level required during the data acquisition period. This system is supported with equipment and components to supply the required concentration level of aerosol at a maximum 20 % relative humidity.

6.5.2 The atomizer shall be designed to generate polydisperse aerosols (in particular potassium chloride (KCl)) with the ability to generate sufficient particles in the 0.3 to 3.75-µm ranges as specified in 12.3.2.

6.5.3 A source of high pressure, HEPA-filtered, clean dry air is provided to the challenge feed system. This air supply shall be regulated to ±1 psi and operator controlled between 0 and 80 psi.

6.5.4 Control of the challenge concentration level shall be provided to ensure that the upstream air sampling concentration level does not produce coincidence errors in the upstream DPC. Any control means that does not introduce extraneous contaminants or change the characteristics of the challenge, or the air stream which is transporting it, may be used. A procedure to determine the maximum concentration limit is provided in Annex A4.

6.5.5 The challenge passes through a dryer prior to entering the neutralizer. A dryer providing a maximum 20 % relative humidity at its exit is required. The humidity probe is located in the dryer; therefore, the air velocity will not affect the humidity measurement.

6.5.6 After drying, the challenge aerosol shall pass through a krypton-85, gas-charged neutralizer to neutralize or discharge the aerosol to Boltzmann equilibrium.

6.5.7 All air sampling and air handling tubes, positioned downstream of the neutralizer and upstream of the air sampling DPC, shall be metallic or elastomeric tubes with metallic liners. In either case, these tubes shall be earth grounded.

6.5.8 A metallic injector tube with a smooth interior wall is mounted vertically inside the test chamber so that the outlet is positioned above and in close proximity to the inlet point of the test vacuum cleaner. The challenge aerosol is injected into the top of the injector tube, through a dispersion means, to ensure a particle concentration profile, across the diameter of the tube at the position of the probe, that shall be within ±3 % of the measured, maximum particle concentration when the injector tube is operating at steady state conditions of 50 and 100-cfm flow rates. This section of pipe will support the thin-walled sampling probe which shall be mounted in a position to ensure its proper function.[9,10]

6.5.8.1 Operating at the specified, normal airflow rate, the injector tube shall be sized to produce turbulent flow. The thin-walled probe and airflow metering device shall be mounted within this tube section in positions to ensure their proper functioning.

(1) The injector tube should be approximately 2-in. diameter and 24 in. long; fabricated from aluminum, stainless steel, or steel with a rust-preventative coating; and shall be earth-grounded.

(2) The airflow metering device shall have an accuracy of ±2 % with a full-scale reading of not more than two times the normal airflow, and readability to 1 cfm.

NOTE 1—This recommended configuration will satisfy the normal airflow requirements for most known vacuum cleaners and is considered a practical size for mounting within the test chamber. However, a laboratory may require several injector tubes, configured differently, to satisfy the entire range of testing conditions it could experience.

6.5.8.2 The HEPA-filtered air enters the top of the injector tube. Depending upon the testing conditions, this airflow may be produced by the DPC vacuum pump, the vacuum cleaner, by an auxiliary air blower, or any combination of those elements.

6.5.8.3 The flexible tube, transporting the challenge aerosol from the outlet of the injector tube to the vacuum cleaner, by means of a nozzle adaptor, shall not be longer than 2 times the distance between the end of the injector tube and the inlet to the nozzle adaptor. An elastomeric tube having an earth-grounded, metallic liner shall be used. The inside diameter of this tubing shall not be less than 1 in.; the wall of the tubing shall not be less than ⅛ in. The tubing shall not be allowed to kink between the end of the injector tube and the inlet to the nozzle adaptor. The interfacing connections of this tube, to the outlet of the injector tube and the inlet of the nozzle adaptor, are to be sealed and constructed to ensure no loss of challenge particles or dilution of the challenge concentration.

NOTE 2—Because the tubing and connections may be operating under negative or positive pressure depending upon the testing conditions, aerosol losses could occur from mechanical means due to improper construction of the joints, and dilution could occur from leaks.

(*1*) The injector tube's blower system shall be sized to minimally provide any additional airflow required to make up for the losses caused by the injector tube, plastic tubing, and the nozzle adaptor (discussed as follows), when the test unit is to be operating at normal airflow. A blower system with the following performance characteristics should be expected to satisfy most test conditions: sealed suction in excess 100 in. H_2O and airflow in excess of 100 cfm at a 2-in. orifice as determined in accordance with Test Method F 558.

NOTE 3—During the sequence of determining the background particle counts, normal airflow through the injector tube is not required. Any background particle counts in the injector tube are insignificant and will be counted with the challenge.

6.5.9 The nozzle adaptor (a rectangular-shaped box acting as a plenum chamber; see Fig. 1) is securely attached and sealed to the vacuum cleaner's nozzle. The nozzle adaptor may be fabricated from wood or other suitable construction materials. The seal between the nozzle and the nozzle adaptor shall be leak-free. The nozzle adaptor shall not interfere with the operation of any mechanisms that may be present in the test unit's nozzle, for example, a rotating agitator, bristle brush. The inside, cross-sectional shape and size of the nozzle adaptor is to conform to the inside, perimeter dimensions of the test unit's nozzle. The nozzle adaptor's inside height, in a direction perpendicular from the face of the nozzle, is to be 4 ± ½ in. The flexible tube from the injector tube, is to enter the nozzle adaptor through the center of any one of the three larger surfaces and shall not extend inside the chamber by more than ½ in. (see 12.2 to 12.2.8.5).

6.6 *Lower Chamber*:

6.6.1 The truncated extension at the bottom of the test chamber reduces the test chamber's horizontal cross section, perpendicular to the direction of airflow, resulting in an increase in the air stream velocity through the metallic, lower pipe section placed at the bottom of this truncated section.

6.6.2 The diameter of the lower pipe section should be approximately 6 to 8 in. This will produce a desirable, turbulent flow without greatly restricting the test chamber airflow. This section of pipe will support the downstream, air sampling, thin-walled probe which shall be mounted in a position to ensure its proper function.[9,10] The minimum length for this pipe section shall be no less than 2 ft. Aerosol passing through this pipe at the location of the probe, shall have a concentration profile across the pipe diameter that does not vary by more than 3 % from the maximum measured concentration level when the test chamber is operating under steady-state flow conditions of 100 and 1000 cfm.

6.6.3 The air duct system, downstream from the lower pipe section, may be of any appropriate material and may include air straighteners, filters, and so forth, to accommodate airflow measurement devices placed in this duct section to measure and monitor the test chamber's airflow. A minimum, 6-in. diameter pipe should be used.

6.7 *Discrete Particle Counters(s)*:

6.7.1 At least one discrete particle counter (DPC), supported by computer equipment, software, and other peripherals, is required.

6.7.1.1 The three possible test conditions, described in this test method, may utilize either a one- or two-DPC system.

6.7.1.2 The DPC system may acquire air samples through a switching valve system.

NOTE 4—When using either DPC system, the total operational times of the test unit during the test run will be identical to ensure that the unit is subjected to the same operating conditions in both situations. This will result in different test run times; see 12.13.1 and its sub-paragraphs.

(1) In a system using two DPCs, capable of simultaneously switching from sampling one probe to the other, the need to develop a correlation ratio between the two DPCs and apply it when determining the initial, fractional, filtration efficiency is discussed in Annex A5. When a correlation ratio is required, it shall be used in the determination of the fractional efficiency. In most cases, it can be expected that the need will be negated because any difference between the two DPCs and the sampling lines would be canceled out in the switching process.

(2) For the switching process, an electrical mechanical valve system should be used in both DPC systems.

6.7.1.3 The minimal requirements of the DPC system to be used for this procedure are as follows:

Sizing sensitivity	≥0.3 µm
Sample flow rate	≤1.0 cfm nominal; user adjustable within± 20 %
Concentration limit	≥ a minimum 1 000 000 particles/ft^3 with less than 10 % coincidence error at the concentration limit
Operating principle	Laser optics
Sizing information	≥8 channels, user selective

6.8 *Dilution System*:

6.8.1 A dilution system in the downstream sampling line may be required to maintain the DPC concentration level below the limit established in this test method.

6.8.1.1 If the dilution system reduces particle concentration by injecting air into the sampling line, this air shall be filtered through a HEPA filter.

6.8.1.2 An airflow meter that is at least equivalent in accuracy and readability to that used in the DPC shall be used to monitor the dilution airflow.

NOTE 5—Development of a large, upstream particle count is highly desirable so that meaningful downstream counts are established. When testing units which have a high motor emissions count, overconcentrating the downstream DPC may dictate the use of a dilution system. The use of any dilution means will sacrifice precision in the calculation of efficiency. In those cases where high motor emissions are present, the number of test runs required to reach 95 % confidence may become high.

6.9 *Other Equipment*:

6.9.1 *Digital Display Humidity Meter*, used for qualification and verification of the various air supplies. Accuracy: minimum ±3 % at 78°F between 20 and 90 % of range. Display resolution: ±1 % RH. Response time: 15 s for a 60 % step change in moving air.

6.9.2 *Voltmeter*, to measure rated input volts to the vacuum cleaner; capable of providing measurements accurate within ±1 % of the vacuum cleaner's rated input voltage.

6.9.3 *Voltage Regulator System*, to control the input voltage to the vacuum cleaner. The regulator system shall be capable of maintaining the vacuum cleaner's rated voltage ±1 % and rated frequency having a wave form that is essentially sinusoidal with± 3 % maximum harmonic distortion for the duration of the test.

6.9.4 *Thin-Walled Probes* of various sizes may be required to accommodate the flow requirements of the DPC(s). The probes shall be sized to meet the performance requirements of 12.4 and its depending, sub-paragraphs.

6.9.4.1 Probes are to be located and properly mounted in the middle of the airstream of their respective ducts.[9]

6.9.4.2 The output of each probe shall be channeled to the DPC through earth-grounded, smooth bore, metallic tubing. Electrically conductive, plastic tubing with the conductive layer being earth-grounded may also be used. The tubing shall convey the aerosol sample to the DPC through the shortest practical distance. In all cases, the inlet to the DPC shall be physically positioned below the probes outlet and not more than 2 ft from the vertical center line of the test chamber. All