SAE INTERNATIONAL

AEROSPACE RECOMMENDED PRACTICE

ARP1827™ REV. D

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Superseding ARP1827C

(R) Measuring Aircraft Gas Turbine Engine Fine Fuel Filter Element Performance

RATIONALE

The proper performance of the engine fuel filter element is important in protecting engine fuel system components from particulate contamination that could lead to accelerated component wear, fuel system malfunction, and premature component failure. This SAE Aerospace Recommended Practice (ARP) provides a standard test method for determining the filtration efficiency and dirt capacity of engine main fuel filter elements. This will allow both manufacturer and customer a common means to evaluate the performance of engine main fuel filter elements.

The standard has been revised to: (1) clarify the scope in terms of the applicability of the procedure to fuel filter elements rated at 25 µm(c) or finer, (2) include an update on the current status of the standard reference material (SRM) used for calibration of automatic particle counters per ISO 11171, (3) update the dirt capacity test setup validation procedure for clarity and to include the option of using a suitable validation filter element, (4) specify periodic determination of the water content in the jet fuel during the dirt capacity test, and (5) include editorial changes for clarity.

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) delineates two complementary filter element performance parameters: (1) dirt capacity, and (2) filtration efficiency, and corresponding test procedures. It is intended for non-cleanable (disposable), fine fuel filter elements, rated at 25 µm(c) or finer, used in aviation gas turbine engine fuel systems.

1.1 Purpose

Variation in fuel filter element testing methods and requirements make comparison of performance results difficult. In order to minimize these problems, this document describes standard filtration ratings and test procedures. Both manufacturer and customer will have a common means to evaluate fuel filter elements.

1.2 Filter Element Performance Ratings

1.2.1 Filter Element Dirt Capacity

The mass of test contaminant added to the filter element test system, under the test conditions specified herein, to produce a prescribed terminal filter element differential pressure. The dirt capacity is determined in a specified test fluid.

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For more information on this standard, visit
https://www.sae.org/standards/content/ARP1827D/

1.2.2 Filter Element Efficiency

Filter element efficiency is the ability of a filter element to remove (and retain) contaminant particles from the fluid stream. This procedure determines the particle removal efficiency of the filter element as a function of particle size. The particle removal efficiencies for the various particle size ranges (“x”) are expressed as filtration ratios, termed beta ratios (β_x). The filtration ratio at a specified particle size is the ratio of the number of particles larger than the specified size entering the filter element (U_x) to the number of particles larger than the same size leaving the filter element (D_x).

$$\text{Filtration ratio at particle size “x”} = \beta_x = U_x/D_x \quad \text{(Eq. 1)}$$

The techniques specified in this document allow measurement of filtration ratios up to 1000 (99.9% particle removal efficiency) for the particle size range 4 to 25 µm(c), as defined in ISO 11171.

1.3 Test Contaminant and Particle Counter Calibration

1.3.1 Dirt Capacity

Historically, AC Test Dusts (AC Fine Test Dust and AC Coarse Test Dust) were specified, either as a component of the test contaminant for the Dirt Capacity test or, in some applications, as the principal test contaminant.

Replacement test dusts for the AC Test Dusts, no longer available, were specified by ISO (ISO 12103-1) in the late 1990s. The corresponding ISO Test Dust for AC Fine Test Dust is ISO Fine Test Dust (designated ISO 12103-A2) and the corresponding ISO Test Dust for AC Coarse Test Dust is ISO Coarse Test Dust (designated ISO 12103-A4).

The change to ISO Test Dusts can result in dirt capacity test results that may differ from test results obtained with the corresponding AC Test Dusts. It is necessary for users to take this into account when comparing historic dirt capacity test data generated per ARP1827 with data generated per subsequent revisions, and when comparing dirt capacity test results to historic specification requirements for dirt capacity. Additional information may be found in AIR5455.

1.3.2 Filtration Efficiency

Historically, AC Fine Test Dust was the test contaminant specified for the filtration efficiency test, and the calibration of automatic particle counters was in accordance with ISO 4402 (1991). As stated in 1.3.1, ISO Fine Test Dust (ISO 12103-A2) was selected as the replacement test dust for AC Fine Test Dust. In addition, ISO also specified a calibration procedure, ISO 11171, for automatic particle counters to replace the ISO 4402 (1991) calibration procedure which utilized AC Fine Test Dust. The ISO 11171 calibration procedure uses a batch of ISO Medium Test Dust (ISO 12103-A3), certified by the National Institute of Standards and Technology (NIST), as the standard reference material (SRM) instead of AC Fine Test Dust; the original NIST certified batches were designated SRM 2806 and SRM 2806a.

The definition of particle sizes per the calibration procedure ISO 11171 differs very significantly from the particle sizes defined in the historic calibration procedure ISO 4402 (1991). In order to distinguish the particle sizes defined in ISO 11171, they were designated as µm(c) or micrometer(c) for the original reference batches SRM 2806 and SRM 2806a.

The change in test contaminant and the automatic particle counter calibration procedure has resulted in filter element efficiency test results that are significantly different from test results obtained previously with AC Fine Test Dust and ISO 4402 calibration. It is necessary for users to take this into account when comparing historic filter element efficiency test data generated per ARP1827, Rev. None, with data generated per subsequent revisions, and when comparing filter element efficiency test results to historic specification requirements for filter element efficiency. AIR5455 discusses the impact of the change in test dusts and automatic particle counter calibration on laboratory filter performance and filter ratings.

Around 2016, NIST certified a new reference batch of ISO Medium Test Dust, SRM 2806b, for particle counter calibration since the original reference batches, SRM 2806 and SRM 2806a, were depleted. The size distribution of SRM 2806b determined by NIST differed from the original reference batches of ISO Medium Test Dust (SRM 2806 and SRM 2806a) resulting in a redefinition of particle sizes. Industry designated the particle sizes as μm(b) to coincide with the reference batch SRM 2806b. However, there is consensus in the industry that redefining particle sizes with each certified reference batch of ISO Medium Test Dust leads to confusion in the industry in setting specification requirements and complicates comparison of data determined with particle counters calibrated with different reference batches. In order to alleviate this, going forward, all particle sizes will be expressed in terms of the original particle sizes μm(c) defined for SRM 2806 and SRM 2806a. At the time of this publication, NIST was completing certification of a new batch of ISO Medium Test Dust as the new standard reference material (SRM 2806d) due to the depletion of SRM 2806b.

1.4 Test Fluids (Dirt Capacity)

Historically, test fluids have included MIL-PRF-7024 calibration fluid and petroleum based jet fuels. For commercial applications, fuels such as ASTM D1655 Grades Jet A and Jet A-1 have been used and, more recently, fuels complying to Russian and Chinese national standards and semi and fully synthetic fuels. For military applications, fuels such as MIL-DTL-5624, Grades JP-4 and JP-5, and MIL-DTL-83133, Grade JP-8, have been used. Fuels containing synthetic hydrocarbons, i.e., hydrocarbons derived from non-petroleum based feedstocks, are also being approved. For example, fuels produced per ASTM D7566 are permitted to be re-certified as ASTM D1655 or UK Defence Standard 91-91 fuels in the proper admixture with petroleum based jet fuels. Once re-certified, the fuels are indistinguishable from fuels produced solely from petroleum based feedstocks. Other national standards allow synthetic hydrocarbons complying with one or more of the annexes of approved synthesized paraffinic kerosene within ASTM D7566 to be blended with petroleum based jet fuels up to 50% by volume as long as the final blend meets the requirements of the national standard.

The dirt capacity is dependent on test fluid properties (such as viscosity), the dispersion of solid contamination and the solubility and dispersion of water in the fluid phase, which are dependent on the chemical composition (including additives) and chemical/physical properties of the test fluid. The above should be kept in mind when comparing dirt capacities of filter elements in different test fluids.

1.5 Filter Element Conditioning

Filter element performance ratings can be adversely affected by harsh operating environments. Filter elements should, therefore, be subjected to procedures simulating these harsh operating conditions prior to performance testing. Conditioning is the term covering these procedures. This document does not cover conditioning requirements. They should be determined by the user and reported by the testing agency. AIR1666 discusses recommended filter element conditioning methods for gas turbine engine lubrication filter elements. The methods discussed in AIR1666 can also be applied to filter elements utilized in other aerospace fluid systems.

2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR1666	Performance Testing of Lubricant Filter Elements Utilized in Aircraft Power and Propulsion Lubrication Systems
AIR5455	Impact of Changes in Test Dust Contaminants and Particle Counter Calibration on Laboratory Filter Element Performance and Fluid Cleanliness Classes
ARP24	Determination of Hydraulic Pressure Drop

ARP785 Procedure for the Determination of Particulate Contamination in Hydraulic Fluids by the Control Filter Gravimetric Procedure

AS4059 Aerospace Fluid Power - Contamination Classification for Hydraulic Fluids

MAP749 Aircraft Turbine Engine Fuel System Component Endurance Test Procedure (Room Temperature Contaminated Fuel)

2.2 Military Specifications

2.2.1 U.S. Military Specifications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-DTL-5624 Turbine Fuel, Aviation, Grades JP-4 and JP-5

MIL-DTL-83133 Turbine Fuels, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-27)

MIL-E-5007[1] Engines, Aircraft, Turbojet and Turbofan, General Specification for

MIL-PRF-56061 Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance

MIL-PRF-7024 Performance Specification, Calibrating Fluids, Aircraft Fuel System Components

MIL-PRF-81836 Filter and Disposable Element, Fluid Pressure, Hydraulic, 3 Micron Absolute

2.2.2 UK Military Specifications

Available from Defence Equipment and Support, UK Defence Standardization, Kentigern House, 65 Brown Street, Glasgow G2 8EX, United Kingdom, Tel: +0141 224 2531/2, Fax: +0141 224 2503, http://www.dstan.mod.uk.

Defence Standard 91-91 Turbine Fuel, Aviation Kerosene Type, Jet A-1, NATO Code: F-35, Joint Service Designation: AVTUR

2.3 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

ISO 4021 Hydraulic Fluid Power - Particulate Contamination Analysis - Extraction of Fluid Samples from Lines of an Operating System

ISO 4402[2] Hydraulic Fluid Power - Calibration of Automatic-Count Instruments for Particles Suspended in Liquids - Method Using Classified AC Fine Test Dust Contaminant

ISO 11171 Hydraulic Fluid Power - Calibration of Automatic Particle Counters for Liquids

ISO 11943 Hydraulic Fluid Power - On-Line Automatic Particle-Counting Systems for Liquids - Methods of Calibration and Validation

[1] MIL-E-5007 is inactive for new design as of January 1997. MIL-PRF-5606 is inactive for new design as of March 1996.
[2] ISO 4402 has been withdrawn as of December 9, 1999.

ISO 12103-1 Road Vehicles - Test Dust for Filter Evaluation - Part I: Arizona Test Dust

ISO 16889 Hydraulic Fluid Power Filters - Multi-Pass Method for Evaluating Filtration Performance of a Filter Element

2.4 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

ASTM D971 Standard Test Method for Interfacial Tension of Oil against Water by the Ring Method

ASTM D1298 Standard Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

ASTM D1655 Standard Specification for Aviation Turbine Fuels

ASTM D3240 Standard Test Method for Undissolved Water in Aviation Turbine Fuels

ASTM D7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons

2.5 NIST Publications

Available from NIST, 100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, Tel: 301-975-6478, www.nist.gov.

NIST SRM 2806 National Institute of Standards and Technology - Standard Reference Material 2806 - Medium Test Dust (MTD) in Hydraulic Fluid, (1997)

3. GLOSSARY

3.1 Terms

β the filtration ratio obtained using ISO Fine Test Dust (ISO 12103-A2) under multi-pass test conditions

C the percent of accountable contaminant obtained in the dirt capacity test validation

Q_T the total flow rate (liters/minute) through the test filter element for the dirt capacity test

Q_R the recirculated flow rate (liters/minute) for the dirt capacity test

Q_V the flow rate (liters/minute) for validation of the dirt capacity test setup; this is the lowest flow rate that the test setup is rated for.

Q_1 the required flow rate (liters/minute) through the test filter element for the filter element efficiency test

Q_2 the required flow rate (liters/minute) of injection flow from the contaminant injection system to the filter element test system for the filter element efficiency test

Q_{2A} the calculated average rate of injection flow from the contaminant injection system to the filter element test system in the filter element efficiency test

G_1 the required base upstream gravimetric level (milligrams/liter) of contaminant in the filter element test system for the filter element efficiency test

G_{1A} the actual, average base upstream gravimetric level (milligrams/liter) of contaminant in the filter element test system in the filter element efficiency test

G_2 the required gravimetric level (milligrams/liter) of contaminant in the contaminant injection system fluid for the filter element efficiency test

G_{2A} the calculated average gravimetric level (milligrams/liter) of contaminant in the contaminant injection system fluid in the filter element efficiency test

U_x the total number of particles per unit volume greater than a given particle size “x” upstream of the filter element in the filter element efficiency test

D_x the total number of particles per unit volume greater than a given particle size “x” downstream of the filter element in the filter element efficiency test

τ the predicted test time (minutes) of the filter element efficiency test

τ_A the actual, recorded test time (minutes) of the filter element efficiency test

τ_t the timer value at the end of the test

V_1 the filter element test system fluid volume (liters) in the filter element efficiency test

V_2 the initial contaminant injection system fluid volume (liters) in the filter element efficiency test

V_{2F} the final contaminant injection system fluid volume (liters) at the conclusion of the filter element efficiency test

V_{2M} the unusable fluid volume (liters) in the contaminant injection system for the filter element efficiency test

W_1 the total mass (grams) of contaminant added to the test system in the dirt capacity validation procedure

W_2 the mass (grams) of contaminant collected on the validation filter element in the dirt capacity validation procedure

W_3 the mass (grams) of contaminant washed from the validation filter element during degreasing, plus the mass (grams) of contaminant remaining in the validation filter element housing, in the dirt capacity validation procedure

W_4 the mass (grams) of remaining suspended contaminant in the test fluid in the dirt capacity validation procedure

W_5 the estimated mass (grams) of contaminant required for the test filter element to reach the terminal filter element differential pressure in the filter element efficiency test

W_6 the required amount of contaminant (grams) to be added to the contaminant injection system to achieve the desired base upstream gravimetric level (G_1) in the filter element test system for the filter element efficiency test

W_7 the required amount of contaminant (grams) to be added to the filter element test system to achieve the target base upstream gravimetric level required to validate the filter element test system in the filter element efficiency test

x contaminant particle size [µm(c)] per ISO 11171 calibration

3.2 Conversions

(milligrams per liter) = 0.2642 x (milligrams per U.S. gallon)

(liters per minute) = 3.785 x (U.S. gallons per minute)

4. GENERAL TEST CONDITIONS

4.1 Test Fluids

4.1.1 The fuel used for dirt capacity testing shall conform either to ASTM D1655 Jet A or Jet A-1 specification, MIL-PRF-7024 Type II calibration fluid, or to other test fuels specified by the procuring agency (see discussion in 1.4). In order to ensure integrity of the test fluid, the equivalent of a fluid change-out to new fluid should occur once in 24 months (either by topping off with new fluid or by changing out the test fluid) and testing of the fluid for critical properties should occur every 6 months.

4.1.1.1 The interfacial tension (IFT) of the test fluid, determined per ASTM D971, shall be a minimum of 27 dynes/cm if it is Jet A or Jet A-1 fuel, or it shall be as specified by the procuring agency. It is recommended that a Fuller's Earth filter be utilized for achieving the required interfacial surface tension since this has been shown to give reproducible results. The IFT of the fuel shall be recorded prior to and at the end of the test.

4.1.1.2 The kinematic viscosity and density of the test fluid shall be determined. A number of ASTM and other standards are referenced in fuel specifications for determination of viscosity and density. Two standards, ASTM D445 for kinematic viscosity and ASTM D1298 for relative density, are referenced in this ARP. Other standards that are applicable to the test fluid, or as specified by the procuring agency, may be used. The standards used should be indicated.

4.1.1.3 The test fluid shall contain no more than 20 ppm of free water per ASTM D3240.

4.1.2 The fluid used for filter element efficiency testing shall conform to MIL-PRF-5606.

4.2 Test Fluid Temperature

4.2.1 The temperature of the test fluid for the dirt capacity test shall be maintained at 85 °F ± 5 °F (29 °C ± 3 °C), unless specified otherwise.

4.2.2 The temperature of the test fluid for the filter element efficiency test shall be maintained at 100 °F ± 2 °F (38 °C ± 1 °C), unless specified otherwise.

4.3 Cleanup Filter and Water Removal Coalescer

4.3.1 The efficiency of cleanup filter elements used during testing and for initial cleaning of test fluids shall conform to MIL-PRF-81836 specification, or equivalent. Filter elements meeting this efficiency will control particles in the 4 µm(c) size range which can affect both the particle counts and the filter element dirt capacity. The clean-up filter shall have no by-pass valve, and the filter element shall be sized to ensure that there is adequate dirt capacity for the anticipated test duration.

4.3.2 The efficiency of coalescers for removing free water from the test fuel should be such that the maximum concentration of free water exiting the coalescer does not exceed 20 ppm when tested per ASTM D3240.

NOTE: ASTM D3240 is used with current petroleum based aviation turbine fuels. If other fuel types having differing chemical compositions are used, it should be verified that ASTM D3240 can be used to determine the free water concentration in such fuels.

4.4 Pressure Measurements

Pressure measurements are to be performed in accordance with ARP24.

4.5 Test Housing and Free-Flow Dummy Element

4.5.1 The service filter housing shall be used whenever possible, and it shall be installed in a normal service attitude. If this housing contains a by-pass valve, it should be blocked and tested for zero leakage at twice the normal cracking pressure.

4.5.2 If a service filter housing is not available, the test housing shall duplicate the inside configuration, including size, direction, and location of the inlet and outlet flow ports used in the service filter housing. The volume beyond the ends of the filter element can vary up to ±10% of the corresponding volumes of the actual housing.

4.5.3 It is recommended that a free-flow dummy element be installed in the filter housing when determining the differential pressure of the empty filter assembly (i.e., without the filter element installed) to reduce the impact of any changes in flow patterns on the measured filter element differential pressure. The free-flow dummy element shall be the same as the test element without the filtration medium pack. If the test filter element is not constructed with a rigid core, the dummy element shall be provided with a core having a minimum open area equal to twice the filter element outlet area and a diameter approximating the inside diameter of the media pack.

4.6 Test Hardware

4.6.1 Vessels, conduits, reservoirs, and fittings shall be selected with smooth contours, no pockets, and shall be properly oriented to prevent contaminant entrapment.

4.6.2 All lines shall be sized to maximize turbulent flow throughout the system.

4.6.3 Reservoirs shall be constructed with smooth conical bottoms that have an included angle of not more than 90 degrees. For the dirt capacity test, there should be sufficient turbulence/agitation to prevent settling of the contaminant. A mechanical stirrer may be used to accomplish this.

4.6.4 Fluids entering the reservoir shall be diffused. Diffusion should take place below the reservoir fluid surface in order to eliminate the formation of air bubbles. These air bubbles could adversely affect automatic particle counter readings. Reservoir diffusion can also aide contaminant dispersion.

4.6.5 All component parts of the dirt capacity test stand shall be electrically grounded to ensure static electricity is discharged to earth. National and local fire and explosion safety standards should be observed when using fuel for testing.

4.6.6 The bifurcation of the by-pass and burn flow loops in the dirt capacity test stand should be in the form of a Y-junction with both forks in the same horizontal plane to prevent water or contaminant settling at the junction (see Figure 1).

4.7 Particle Counting

On-line automatic particle counting systems and dilution systems (if required), per ISO 11943, shall be used to determine the number and size distribution of the contaminant particles in the fluid for the filter element efficiency test. The on-line dilution system may be required to ensure that the particulate concentration in the fluid sampled by the automatic particle counters does not exceed the saturation limits specified by the automatic particle counter manufacturer.

The automatic particle counters, including the on-line dilution system, should be validated for on-line counting in accordance with ISO 11943.

4.8 Clean-up Filter Element Weighing

Dry the clean-up filter element in an oven for 1 hour at 160 °F ± 10 °F (71 °C ± 6 °C) and desiccate to room temperature. Determine the mass of the clean-up filter element to an accuracy of ±0.1 g. Place the filter element in the oven at 160 °F for an additional 15 minutes, desiccate to room temperature, and re-determine the mass. Repeat this procedure until two successive values are within ±0.1 g or ±1% of the mass of the total contaminant added, whichever is greater.

5. DIRT CAPACITY TEST

5.1 General

5.1.1 A diagram of the major components of the dirt capacity test setup is depicted in Figure 1.

5.1.2 The contaminant used shall be in accordance with Table X of MIL-E-5007, or as otherwise specified by the procuring agency.

5.1.3 In order to ensure repeatable results, the ratio of the test filter element flow rate to the contaminant reservoir (and recirculated flow circuit) volume must be greater than 0.2 for a 20 minute, or longer, test. This will ensure that the maximum error for dirt capacity measurement is limited to 2%.

5.2 Dirt Capacity Test System Validation Procedure

The dirt capacity test system validation is typically conducted at the lowest flow rate that the test system is rated for. It may also be conducted at the test filter element flow rate and recirculated flow rate; see 5.2.7.

5.2.1 Determine the viscosity, density and IFT of the test fuel as specified in 4.1.1 and ensure that the IFT is greater than 27 dynes/cm. If required, the fuel should be treated with Fullers Earth to increase the IFT to the required level.

5.2.2 Determine the water content of the test fuel per ASTM D3240 and ensure that it meets the requirement of less than 20 ppm free water.

5.2.3 Preclean the test fluid, using the system clean-up filter, to a minimum cleanliness level corresponding to AS4059 Class 1 or better.

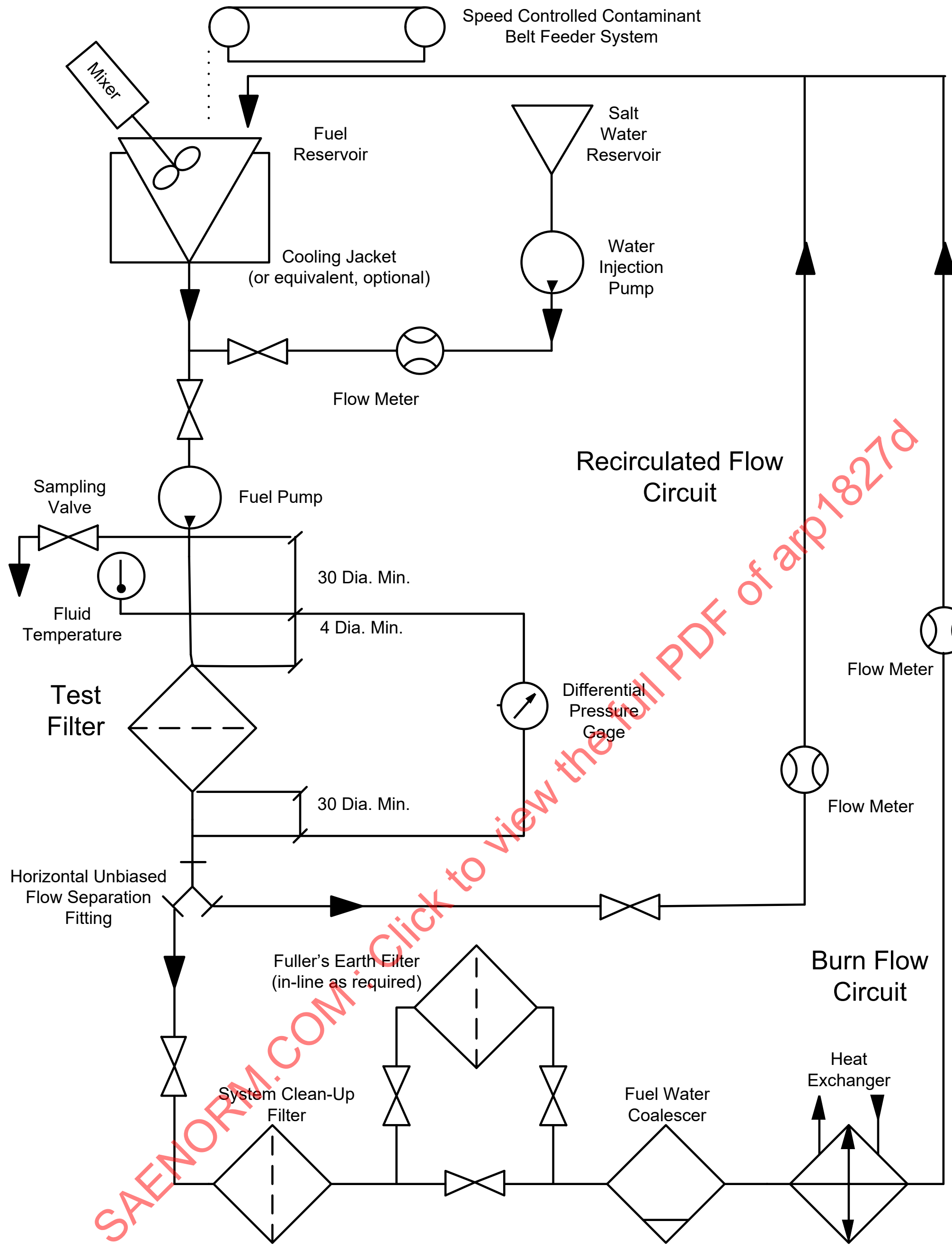

Figure 1 - Test setup for filter element dirt capacity test

5.2.4 Choose a fine filter element, with filtration efficiency as specified in 4.3.1, suitably sized for the flow rate and which can conveniently be weighed, along with a suitable non-by-pass housing. The dirt capacity of the filter element, with contaminant per 5.1.2, should be sufficient to produce a minimum test time between 60 to 120 minutes. This filter element is referred to as the validation filter element.

5.2.5 Determine the mass of the validation filter element in 5.2.4 per 4.8.

5.2.6 Install the validation filter element in the non-by-pass housing to obtain the validation filter assembly. Install the validation filter assembly at the same location as the test filter assembly.

5.2.7 Stabilize the test setup at the test temperature (4.2.1), validation flow rate Q_V through the test housing, a recirculation flow rate (Q_R) of 0.75 x Q_V and a burn flow rate of 0.25 x Q_V (see Figure 1). Alternately, the test filter element flow rate Q_T and the recirculating flow rate Q_R, along with a burn flow rate of (Q_T - Q_R), may be used if the validation filter element is sized for the test filter element flow rate.

5.2.8 Start timer and start addition of test contaminant per 5.1.2 to the reservoir using a belt feed system per MAP749 at the specified rate. The required contaminant addition rate (grams per minute) equals the specified contaminant concentration level (grams per liter) times the required flow rate (Q_V or Q_T in liters per minute) through the filter.

NOTE: In MIL-E-5007 and many other specifications, the required contamnant concentartions are given in grams per 1000 gallons which is the same as milligrams per gallon. This can be convetred to grams per liter for the above calculation using the conversion parameter in 3.2 for converting from miiligrams per gallon to milligrams per liter.

5.2.9 Allow contaminant addition for the requisite time period to attain the terminal filter element differential pressure. Stop contaminant addition and the timer. Allow flow to continue for an additional 10 minutes. Obtain a 1 L (approximate) sample of fluid from the sampling valve (Figure 1) and then stop flow through the validation filter element. Determine and record the IFT of the test fuel to ensure that it is within the required limit (5.2.1).

5.2.10 Calculate the total contaminant addition for the validation time period using the contamination addition rate (grams per minute) in 5.2.8 and the validation time period recorded in 5.2.9. This is denoted W_1 (grams).

5.2.11 Remove the validation filter element, thoroughly rinse with pre-filtered degreasing solvent, collecting the rinsings in a suitable clean container, and dry the validation filter element to a constant mass per 4.8. The difference between this mass and the original dry mass of the validation filter element per 5.2.5 is denoted W_2 (grams).

5.2.12 Determine the mass of all contaminant washed off the validation filter element during degreasing (5.2.11), as well as any contaminant remaining in the validation filter element housing, per ARP785. This contaminant mass is identified as W_3 (grams).

5.2.13 Obtain a gravimetric analysis of the fluid sample taken in step 5.2.9 per ARP785. Convert this result into grams/liter. Multiply by the volume of the test system fluid less the volume of the burn flow circuit fluid and recirculated flow circuit fluid, expressed in liters, to obtain W_4 (grams).

5.2.14 Calculate percent accountable contaminant using the following formula:

$$C = 100 \times (W_2 + W_3 + W_4)/W_1 \quad \text{(Eq. 2)}$$

5.2.15 Validation Requirement

The test setup is considered validated if the percent of accountable contaminant (C) is between 95% and 100%.

5.3 Dirt Capacity Test Procedure

5.3.1 Pre-clean the test fluid, using the system clean-up filter, to a minimum cleanliness level corresponding to AS4059 Class 3.

NOTE: For filter elements rated at 5 µm(c) or finer, it may be necessary to pre-clean the test fluid to AS4059 Class 1.

5.3.2 Determine the viscosity, density and IFT of the test fuel as specified in 4.1.1 and ensure that the IFT is greater than 27 dynes/cm. If required, the fuel should be treated with Fullers Earth to increase the IFT to the required level.

5.3.3 Determine the water content of the test fuel per ASTM D3240 and ensure that it meets the requirement of less than 20 ppm free water.

5.3.4 Install the test filter housing with the free-flow dummy element in it to determine the tare value.

5.3.5 Stabilize the test setup at the required flow rates: filter element flow rate of Q_T, recirculating flow rate of Q_R, burn flow rate of (Q_T - Q_R), through the filter assembly at the required test temperature (4.2.1). Record the filter assembly (test filter housing + free-flow dummy element) differential pressure as the tare.

5.3.6 Terminate flow, remove the free-flow dummy element from the filter housing and install the test filter element in the test filter element housing.

5.3.7 Attain the required system flow rates: filter element flow rate of Q_T, recirculating flow rate of Q_R, burn flow rate of (Q_T - Q_R), through the filter assembly at the required test temperature (4.2.1). Record the filter assembly(test filter housing + test filter element) differential pressure. Calculate the initial test filter element differential pressure by subtracting the tare value, determined in 5.3.5, from the test filter assembly differential pressure.

5.3.8 If the contaminant (5.1.2) includes water/salt water, start the water/salt water injection (Figure 1). Take fuel samples every 15 minutes via the sampling valve and determine the fee water content per ASTM D3240. Adjust the water/salt water injection until the water content in the fuel stabilizes at the required concentration in 5.1.2. Continue to extract fuel samples and monitor the water content every 30 minutes during the test, and adjust the water/salt water injection, as required, to maintain the concentration specified in 5.1.2.

5.3.9 Add solid test contaminant per 5.1.2 to the reservoir using a belt feed system per MAP749 at the specified rate and start timer. The required contaminant addition rate (grams per minute) equals the specified contaminant concentration level (grams per liter) times the burn flow rate Q_B (liters per minute).

NOTE: In MIL-E-5007 and many other specifications, the required contamnant concentartions are given in grams per 1000 gallons which is the same as milligrams per gallon. This can be convetred to grams per liter for the above calculation using the conversion parameter in 3.2 for converting milligrams per gallon to milligrams per liter.

5.3.10 Record the test time (minutes) at 20%, 40%, 60%, 80%, and 100% of the terminal filter element differential pressure for the dirt capacity test. Additionally, as a minimum, record test filter element differential pressure and time (minutes) at 30-minute intervals.

NOTE: The test filter assembly differential pressures corresponding to 20%, 40%, 60%, 80%, and 100% of the terminal filter element differential pressure may be obtained by adding the tare value, determined in 5.3.5, to the required percentage of the terminal filter element differential pressure.

5.3.11 Conclude the test when the required filter element differential pressure is attained. Stop timer and record the total test time. Also determine and record the IFT of the test fuel to ensure that it is within the required limit (5.2.1).

5.3.12 Test Data Reporting

5.3.12.1 Report the viscosity, density, and pre-test and post-test IFTs.

5.3.12.2 Report the tare differential pressure, the filter assembly differential pressure with the test filter element installed, and clean filter element differential pressure determined in 5.3.7.

5.3.12.3 Report the “dirt capacity” as the total amount of contaminant (grams) added to reach the terminal test filter element differential pressure, along with the recorded total time.

5.3.12.4 The results of the dirt capacity test should be presented as a graphical plot of contaminant mass added (x-axis) versus filter element differential pressure (y-axis) using the clean filter element differential pressure from 5.3.7 and the data from 5.3.10.

6. FILTER ELEMENT EFFICIENCY TEST

6.1 General

6.1.1 A schematic diagram of the filter element efficiency test setup is shown in Figure 2.

6.1.2 The test contaminant used shall be ISO Fine Test Dust per ISO 12103-A2, unless specified otherwise.

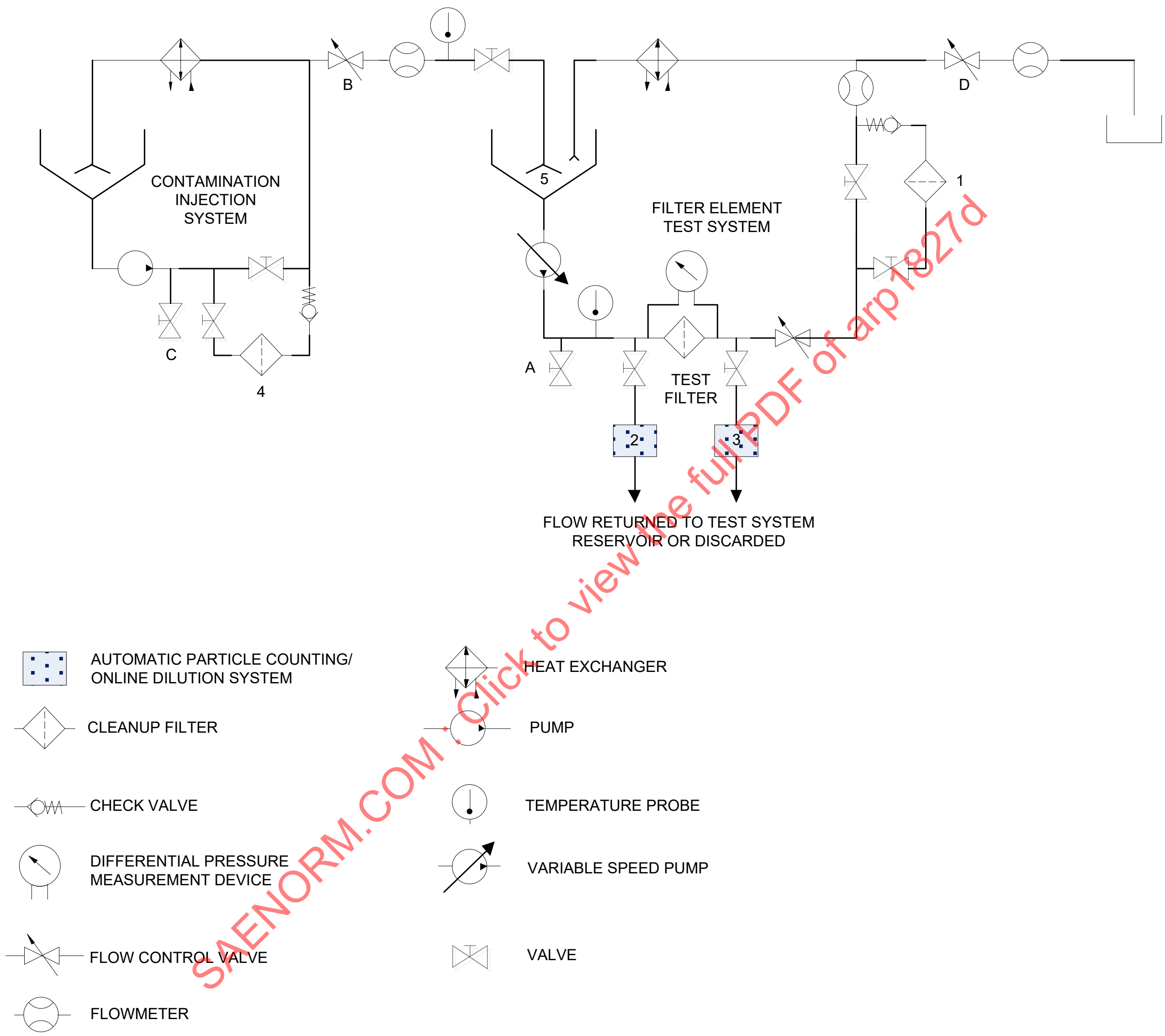

Figure 2 - Test setup for filter element efficiency test

6.1.3 The target base upstream gravimetric level (G_1 milligrams per liter) is defined as the desired test contaminant concentration (mass per unit fluid volume), upstream of the test filter element, obtained by ingression of the test contaminant from the contaminant injection system into the filter element test system. The target base upstream gravimetric level shall not normally be less than 2 mg/L nor more than 10 mg/L in order to achieve a sufficient number of particles challenging the filter while minimizing saturation and dilution errors for the automatic particle counters.

6.1.4 The target base upstream gravimetric level shall be selected from 2 mg/L, 3 mg/L, 5 mg/L, or 10 mg/L to obtain (if possible) a test time of 30 to 120 minutes. The predicted test time (τ) can be calculated from the estimated mass of test contaminant (W_5) required to achieve the terminal filter element differential pressure, the base upstream gravimetric level (G_1) selected, and the required test element flow rate (Q_1), per the following equation:

$$\tau = (1000 \times W_5)/(G_1 \times Q_1) \quad \text{(Eq. 3)}$$

6.2 Contaminant Injection System

6.2.1 A turbulent means should be provided for transferring fluid from the contaminant injection system to the filter element test system to yield a flow rate (Q_2) of at least 0.25 L/min.

6.2.2 The total fluid volume (V_2) of the contaminant injection system may be adjusted by varying the level of the fluid in the reservoir and shall be sufficient to contain the fluid volume required by the following equation:

$$V_2 = (1200 \times Q_2 \times W_5)/(G_1 \times Q_1) + V_{2M} \quad \text{(Eq. 4)}$$

NOTE: The injection fluid volume may be increased as needed by increasing the amount of test dust proportionately. The factor of 1200 in Equation 4 is a composite of converting milligrams to grams (factor of 1000) and including a safety margin of 20% in slurry volume (factor of 1.2).

6.2.3 Before adding contaminant, the clean-up filter element (Item 4 in Figure 2) per 4.3 shall clean the contaminant injection system to the extent that gravimetric analysis of fluid samples, taken from valve C (Figure 2), shall be less than 1% of the required gravimetric level (G_2) of the contaminant injection system fluid, defined by the following equation:

$$G_2 = (G_1 \times Q_1)/Q_2 \quad \text{(Eq. 5)}$$

6.3 Filter Element Test System

6.3.1 The total fluid volume (V_1) of the filter element test system (exclusive of the clean-up filter system) shall be numerically equal (to within ±2%) to one-fourth the required filter element flow rate (Q_1). This volume may be attained by adjusting the reservoir fluid level. In some instances, where the filter element flow rate is low, this may be impractical, and a larger fluid volume may be utilized provided supporting test data is available to show that: (1) there is no settling of test contaminant within the test system due to the lower fluid turnover rate, and (2) the test results are not materially affected due to the lower fluid turnover rate. In general, a total fluid volume (V_1) of more than one-half of the required test flow rate (Q_1) is not recommended.

6.3.2 The total fluid volume of the filter element test system should be maintained to within ±5% of the initial volume (V_1) during the filter element efficiency test. This can be accomplished by discarding fluid at a regulated flow rate via Valve D in Figure 2. The flow rate of fluid discarded via Valve D should be adjusted to be within ±5% of the contaminant injection flow rate (Q_2) in order to maintain a constant filter element test system volume to within ±5% of the initial volume (V_1), unless portions of the upstream or downstream sample flow, including any on-line dilution, to the automatic particle counters, are discarded, or fluid is introduced into the system from external sources during on-line dilution. In this case, the flow rate of the discarded fluid via Valve D should be suitably adjusted so as to maintain a constant filter element test system volume to within ±5% of the initial volume (V_1).

6.3.3 Turbulent sampling means, in accordance with ISO 4021, shall be located upstream and downstream of the test filter element in order to provide fluid sample flow to the automatic particle counters (Items 2 and 3 in Figure 2). The design of the sampling system shall be such as to minimize lag time in fluid flow to the automatic particle counters. The portion of the sampling flow not passing through the automatic particle counters may be returned to the filter element test circuit reservoir via a by-pass line. Flow through the automatic particle counters may also be returned to the reservoir, or it may be discarded. Do not interrupt sample flow during the test.

6.3.4 Automatic particle counters should be calibrated in accordance with ISO 11171 for the appropriate particle sizes. The recommended particle sizes are given in Table 1.

Table 1 - Recommended particle sizes to be counted

Filter Rating	Recommended ISO 11171 Particle Sizes [μm(c)]				
For filter elements rated at beta ratios greater than 200[1] between 4 μm(c) and 10 μm(c)[2] per ISO 11171 calibration	4	5	7	10	15
For filter elements rated at beta ratios greater than 200[1] between 10 μm(c) and 25 μm(c)[2] per ISO 11171 calibration	7	10	15	20	25

NOTES:
[1] A beta ratio of 200 corresponds to 99.5% particle removal efficiency.
[2] Particle size inclusive.

6.3.5 Before adding contaminant, the filter element test system shall be sufficiently cleaned, using a clean-up filter (Item 1 in Figure 2) per 4.3, so that particles in each size range do not exceed 1% of the expected downstream particle counts during the test.

6.4 Contaminant Injection System Validation

6.4.1 Validate at the maximum injection system volume (V_2) to be used per 6.2.2, the maximum contaminant injection system gravimetric level (G_2) specified per 6.2.3, the minimum contaminant injection flow rate (Q_2), and for a length of time required to deplete the complete usable volume ($V_2 - V_{2M}$) of the contaminant injection reservoir.

6.4.2 Preclean the contaminant injection fluid system per 6.2.3, then bypass the cleanup filter system (Item 4 in Figure 2).

6.4.3 Dry the test contaminant, specified in 6.1.2, at 275 °F ± 25 °F (135 °C ± 14 °C) for 1 hour and desiccate to room temperature prior to weighing.

6.4.4 Calculate the required amount of contaminant (W_6) to be added to the contaminant injection system per the following formula:

$$W_6 = (V_2 \times G_2)/1000 \quad \text{(Eq. 6)}$$

6.4.5 Add the required quantity of contaminant (W_6) to the contaminant injection system reservoir fluid and circulate for a minimum of 30 minutes.

6.4.6 Initiate injection flow from the contaminant injection system, once the temperature has stabilized (within ±2 °F; ±1 °C), collecting this flow externally from the system. Maintain the injection flow rate at the stabilized temperature to within ±5% of the desired injection flow rate (Q_2) for the duration of the validation. Obtain an initial sample at this point and measure the injection flow rate by collecting the fluid in a calibrated measuring cylinder for a measured duration of time not less than 0.5 minute.

6.4.7 Obtain samples of the injection flow and measure the injection flow rate at 30 minutes, 60 minutes, 90 minutes, and 120 minutes or at four equal intervals, depending upon the depletion rate of the system.

6.4.8 Analyze each sample from 6.4.7 gravimetrically in accordance with ARP785.

6.4.9 Measure the volume of the injection system at the end of the validation test (V_{2F}).

6.4.10 Validation Requirements

The contaminant injection system shall be considered validated only if the criteria listed below are met.

a. The gravimetric level of each sample, analyzed in 6.4.8, shall be within ±5% of the average of the samples, and within ±10% of the required gravimetric level (G_2) per 6.2.3.

b. The injection flow rates, measured in 6.4.6 and 6.4.7, shall be within ±5% of the average of the injection flow rates, and within ±5% of the required injection flow rate (Q_2).

c. The volume remaining in the injection system (V_{2F}) plus the volume of fluid expelled during the validation, calculated as: (average injection flow rate) x (total injection time), is equal, within ±10%, to the initial injection system volume (V_2).

6.5 Filter Element Test System Validation

6.5.1 Install a straight pipe in place of the filter element test housing.

6.5.2 Adjust the volume (V_1) of fluid in the filter element test system per 6.3.1.

6.5.3 Adjust the filter element test system to the required flow rate (Q_1) (to within ±2%). Adjust the test system fluid temperature per 4.2.2.

6.5.4 Clean the fluid to a level where the particles in each size range do not exceed 1% of the expected particle count during the validation by using the filter element test system clean-up filter (Item 1 in Figure 2), then by-pass the test system clean-up filter.

6.5.5 Calculate the required amount of contaminant (W_7) to be added to the filter element test system reservoir per the following formula:

$$W_7 = (G_1 \times V_1)/1000 \quad \text{(Eq. 7)}$$

6.5.6 Dry the test contaminant (6.1.2) per 6.4.3. Add the required quantity of contaminant (W_7) per 6.5.5 to the filter element test system reservoir to yield the target base upstream gravimetric level (2 mg/L, 3 mg/L, 5 mg/L, or 10 mg/L) of the test system (G_1). Circulate the contaminant through the filter element test system for 15 minutes prior to starting the particle counters.

6.5.7 With the automatic particle counters connected on-line, set the particle sizes to the required particle size ranges to be counted; recommended particle size ranges to be counted are given in Table 1. Set the particle counter to count for either 30-second or 60-second intervals depending on the estimated test time (τ) so as to obtain at least 35 particle counts during the filter efficiency test. However, the minimum volume of fluid counted during each count should not be less than 10 mL. This will necessitate 1-minute counts for automatic particle counters with operating flow rates of 10 mL/min.

6.5.8 Monitor and verify that the flow rate through each automatic particle counter is equal to the value used for the automatic particle counter calibration (ISO 11171) to within ±3%. Synchronize the counting periods of the two automatic particle counters as closely as possible.

6.5.9 Circulate the fluid in the test system for 1 hour and record particle counts in each size range (per 6.5.7) for both upstream and downstream particle counters.

6.5.10 Validation Requirements

The filter element test system shall be considered validated only if the criteria listed below are met.

a. The cumulative particle count obtained for a given particle size for each counting interval does not deviate by more than ±10% from the average cumulative particle count over the validation duration for that particle size, for each automatic particle counter.

b. There is less than a 10% difference between the cumulative particle count obtained from the upstream automatic particle counter at each counting interval in each particle size range and the cumulative particle count obtained from the downstream automatic particle counter for the same particle size during the corresponding count interval.

c. The average particle count over the validation duration for each particle size range, for each automatic particle counter, is within the acceptable range given in Table 2.

NOTE: The validation counts in Table 2 are based on particle counter calibration per ISO 11171 using the original NIST certified ISO Medium Test Dust reference batches SRM 2806 and 2806a. As discussed in 1.3.2, NIST subsequently certified another batch of ISO Medium Test Dust, SRM 2806b, which has been depleted., NIST is now completing certification of yet another reference batch SRM 2806d. The validation counts in Table 2 will be revised to reflect this once the reference batch SRM 2806d is available for particle counter calibration.