# Measuring Aircraft Gas Turbine Engine Fine Fuel Filter Element Performance

RATIONALE

The document is being revised for: (1) addition of references to jet fuels, (2) correction of one error in conversion units of gpm to lpm in para, 4., (3) clarification of some definitions in glossary of terms, (4) deletion of NIST SRM 2806 reference dust lot in para.1.3 since this is no longer the only reference lot. and deletion ofr references to Revision A, (5) revision of the test set-up for dirt capacity determination in fuel to include fuel recirculation (by-pass) loop, (6) revision of the test set-up to ensure homogeneous suspension of the test contaminant and minimize contaminant settling and variation in test results due to variations in test fuel, (7) improved definition of the system clean-up filter efficiency and coalescer water removal efficiency, (8) clarification of the amount of test contaminant to be used for validation of the dirt capacity test circuit, (9) editorial changes in para. 6.7.1.2, 6.7.1.5, 7.6(deleted), 7.10 for clarification of procedure.



## 1. SCOPE

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

### 1.1 Purpose

Variation in filter element testing methods and requirements make comparison of 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 specify, control, and evaluate 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 fuel. This value should be used only for comparing filter elements having similar filtration efficiencies.

#### 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 are expressed as filtration ratios, termed Beta Ratios ($\beta_x$). 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 ($D_x$).

$$\text{Filtration Ratio at particle size 'x'} = \beta_x = U_x / D_x \qquad \text{(Eq. 1)}$$

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 μm(c) to 25 μm(c), as defined in ISO 11171.

1.3 Test Contaminant and Particle Counter Calibration

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, have been specified by ISO (ISO 12103-1). 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 the present procedure, and when comparing dirt capacity test results from the current procedure to historic specification requirements for dirt capacity.

Historically, AC Fine Test Dust was the test contaminant specified for the filter efficiency test, and the calibration of automatic particle counters was in accordance with ISO 4402 (1991). In addition to the change in test contaminant to ISO Fine Test Dust (ISO 12103-A2), ISO has also specified a calibration procedure ISO 11171 for automatic particle counters to replace the ISO 4402 calibration procedure which utilized AC Fine Test Dust. The ISO 11171 procedure uses ISO Medium Test Dust, designated ISO 12103-A3, instead of AC Fine Test Dust. The definition of particle sizes per the ISO 11171 calibration procedure differs very significantly from the particle sizes defined in ISO 4402 (1991). In order to distinguish the particle sizes defined in ISO 11171, they are designated as μm(c) or micrometer(c), the (c) indicating NIST certified sizes.

Both the change in test contaminant, from AC Fine Test Dust to ISO Fine Test Dust (ISO 12103-A2), and the change in automatic particle counter calibration, from ISO 4402 to ISO 11171, are incorporated in this revision of ARP1827.

The change in test contaminant and the automatic particle counter calibration procedure will lead to 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 (Revision 0) with data generated per the present procedure, and when comparing filter element efficiency test results from the current procedure 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.

1.4 Test Fuels

Historically, test fuels have included petroleum based fuels: fuels for commercial operation such as Jet A and Jet A-1, specified in ASTM D1655, or fuels for military operation such as JP5 and JP8, specified in MIL-DTL5624 or MIL-DTL-83133. Recently, synthetic fuels manufactured by the Fischer Tropsch (FT) process have also been specified in the form of 50 % mixtures with standard, petroleum based jet fuels, and 100 % FT fuel is also now being specified for aviation turbine operation in the U.K. Defence Standard 91-91, Issue 6. In addition, bio-fuels are being investigated as potential future fuels for aviation turbine engines.

The dispersion of solid contamination as well as the solubility of water and dispersion of free water in the fuel phase are critically dependent on the chemical composition and chemical/physical properties of the test fuel, which would have a significant impact on the dirt capacity of fuel filter elements. This is expected to become even more significant with the introduction of FT fuels or bio-fuels in the future, which could have very different chemical compositions from petroleum based aviation turbine fuels. Thus, it is essential that fuel filter element dirt capacities only be compared for the same fuel type.

1.5 Filter Element Conditioning

Filter element performance ratings can be adversely effected 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. SAE 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 724-776-4970 (outside USA), www.sae.org.

ARP24 Determination of Hydraulic Pressure Drop

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

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

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

AS4059 Aerospace Fluid Power – Cleanliness Classification for Hydraulic Fluids

### 2.2 Military Specifications

#### 2.2.1 U. S. Military Specifications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

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

MIL-PRF-5606[1] Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance

MIL-PRF-7024 Turbine Fuel, Aviation, Grades JP-4 and JP-5

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

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

[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.

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|---|---|
| MIL-DTL-83133E | Turbine Fuels, Aviation, Kerosene Types, Nato F-34 (JP-8), Nato F-35, And JP-8 + 100 |

2.2.2 U. K. Military Specifications

Available from Defence Equipment and Support, U. K. 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, Issue 6 | Turbine Fuel, Aviation Kerosine Type, Jet A-1, NATO Code: F-35, Joint Service Designation: AVTUR |

2.3 ISO Publications

Available from International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland, Tel: +44-22-749-01-11, www.iso.org.

| | |
|---|---|
| ISO 4021 | Hydraulic fluid power – Particulate contamination analysis – Extraction of fluid samples from lines of an operating system |
| ISO 4402 | 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 |
| 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 D971 | Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method |
| ASTM D6304 | Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration |
| ASTM D1655 | Standard Specification for Aviation Turbine Fuels |
| ASTM D3240 | Standard Test Method for Undissolved Water in Aviation Turbine Fuels |

2.5 NIST Publications

Available from National Institute of Standards and Technology, 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

$\beta$ 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

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

$Q_2$ the required 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 filter element efficiency test

$G_{2A}$ the calculated average gravimetric level (milligrams/liter) of contaminant in the contaminant injection 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

$\tau$ the predicted test time (minutes) of the filter element efficiency test

$\tau_A$ the actual, recorded test time of the filter element efficiency test

$\tau_t$ 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 cleanup filter element in the dirt capacity validation procedure

$W_3$ the mass (grams) of contaminant washed from the cleanup filter element during degreasing, plus the mass (grams) of contaminant remaining in the cleanup filter 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 Gallon)

(Liters per minute) = 3.785 x (Gallons per minute)

# 4. GENERAL TEST CONDITIONS

## 4.1 Test Fluids

4.1.1 The fluid used for dirt capacity testing shall conform to ASTM D1655, Jet A specification, or to other test fuels specified by the procuring agency(see para. 1.4). The interfacial tension (IFT) of the test fluid, determined per ASTM D 971, shall be 30 dynes/centimeter ± 3 dynes/centimeter if it is Jet A fuel, or it shall be as specified by the procuring agency. The fuel interfacial tension shall be maintained throughout the test. IFT testing should occur at the beginning and end of each test and at other times not to exceed 2 hours. It is recommended that a Fuller's Earth filter be utilized for maintaining interfacial surface tension, since this has been shown to give reproducible results. The fuel shall be saturated but contain no free water as determined by the Karl Fischer method per ASTM D 6304.

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).

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. 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.

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 filter media. 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.

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 insure 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 system and dilution system, 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 is 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 ±0.1 gram 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 gram or ±1% the mass of the total contaminant added, whichever is greater.

## 5. DIRT CAPACITY TEST

### 5.1 General

5.1.1 The dirt capacity test is to be performed according to MAP749 with several modifications. A diagram of the major components of the dirt capacity test set-up 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.

5.1.3 In order to insure repeatable results, the ratio of the test 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 insure that the maximum error for Dirt Capacity measurement is limited to 2%.

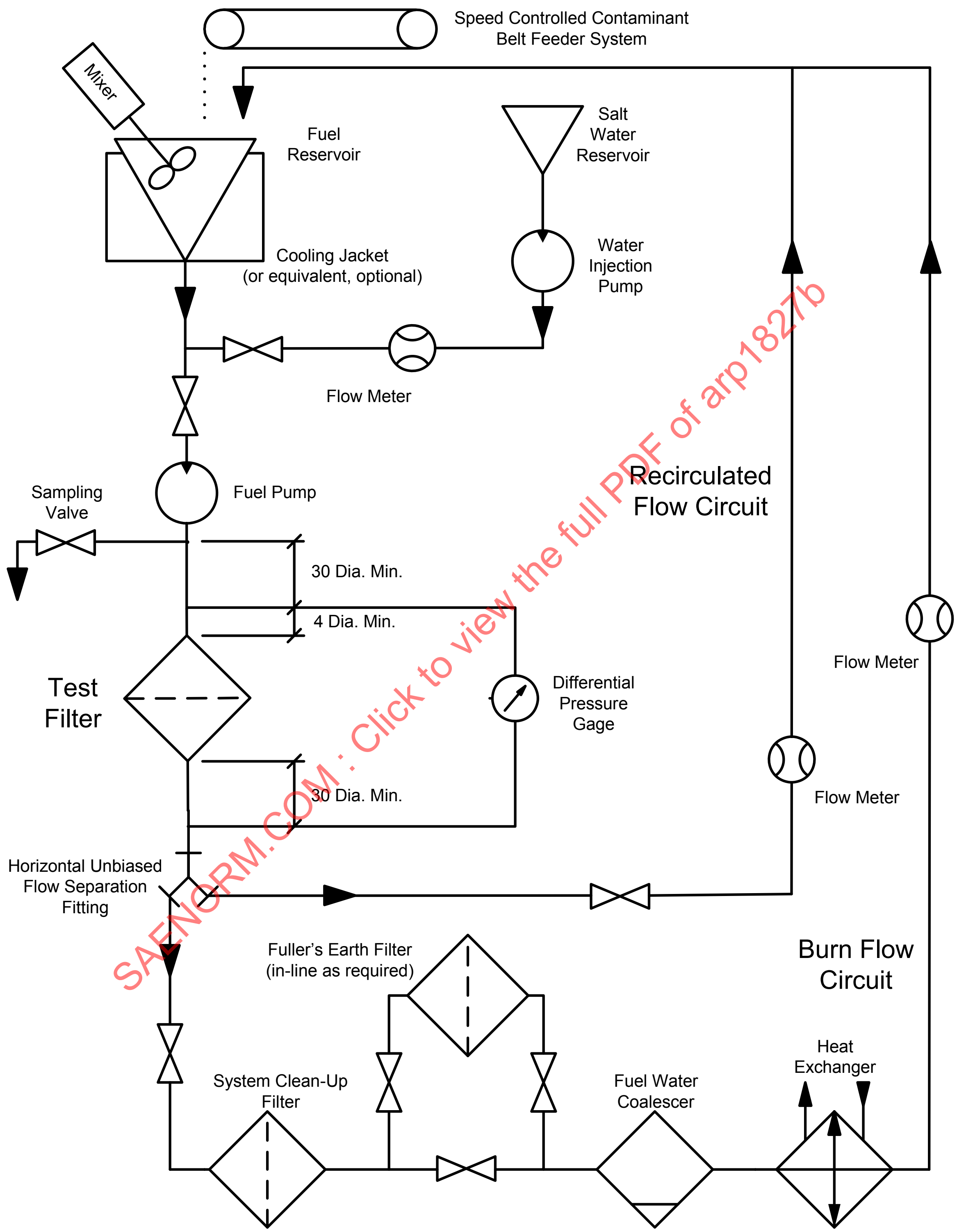




FIGURE 1 - TEST SET-UP FOR FILTER ELEMENT DIRT CAPACITY TEST

5.2 Dirt Capacity Test System Validation Procedure

5.2.1 Preclean 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 preclean the test fluid to AS4059 Class 1.

5.2.2 Install a free-flow dummy element into the test housing per 4.5.

5.2.3 Determine the mass of a new clean-up filter element (4.3) per 4.8.

5.2.4 Install the clean-up filter element in the system.

5.2.5 Attain required system flow rate and temperature (4.2.1).

5.2.6 Add required amount of test contaminant (W1) per 5.1.2 to the reservoir using a belt feed system per MAP749 at the rate of 1 gram per minute of contaminant per GPM of test system flow.

5.2.7 Allow flow to continue for an additional 10 minutes after contaminant feed has been completed.

5.2.8 Obtain a 1 liter (approximate) sample of fluid from the sampling valve (Figure 1).

5.2.9 Stop flow through the clean-up filter element. Remove clean-up filter element, thoroughly rinse with prefiltered degreasing solvent, collecting the rinsings in a suitable clean container, and dry the clean-up filter element to a constant mass per 4.8. The difference between this mass and the original dry mass of the clean-up filter element per 5.2.3 is denoted $W_2$ (grams).

5.2.10 Determine the mass of all contaminant washed off the clean-up filter element during degreasing (5.2.9) as well as any contaminant remaining in the clean-up filter housing per ARP785. This contaminant mass is identified as $W_3$ (grams).

5.2.11 Obtain a gravimetric analysis of the sample taken in step 5.2.8 per ARP785. Convert this result into grams/liter. Multiply by the volume of the test system fluid, expressed in liters, to obtain $W_4$ (grams).

5.2.12 Calculate percent accountable contaminant using the following formula:

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

5.2.13 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 Preclean the fluid as described in 5.2.1.

5.3.2 Stabilize at rated flow and temperature (4.2.1) through the test housing with the free-flow dummy element installed. Record the differential pressure across the test housing with the free-flow dummy element as the tare value. Terminate flow, remove the free-flow dummy element from the filter housing and install the test filter element in the test housing.

5.3.3 Install a new clean-up filter (4.3).

5.3.4 Open valves upstream and downstream of the filter and stabilize at rated test flow and temperature (4.2.1) through the test filter. Measure and record the test filter assembly differential pressure. Calculate the initial test filter element differential pressure at rated flow and temperature by subtracting the tare value, determined in 5.3.2, from the test filter assembly differential pressure.

5.3.5 Add test contaminant per 5.1.2 at the appropriate rate per MAP749 and start timer. For example, the required contaminant addition rate (grams per minute) equals the specified contaminant concentration level (grams per gallon) times the required flow rate through the filter (gallons per minute).

5.3.6 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, 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 5.3.2, to the required percentage of the terminal filter element differential pressure

5.3.7 Test Data Reporting

(a) Report the clean filter element differential pressure determined in 5.3.4, (b) Report the "Dirt Capacity" as the total amount of contaminant (grams) added to reach the terminal test filter element differential pressure, along with the total time to reach terminal differential pressure, (c) 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).

## 6. FILTER ELEMENT EFFICIENCY TEST

### 6.1 General

6.1.1 This procedure determines filtration ratios at selected particle size ranges, designated Beta Ratios ($\beta_x$). A schematic diagram of the filter element efficiency test system 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.

6.1.3 The target base upstream gravimetric level ($G_1$ milligrams per liter) is defined as the desired ingressed test contaminant concentration (contaminant mass per unit fluid volume) upstream of the test filter element. 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, 3, 5, or 10 mg/l to obtain (if possible) a test time of 30 to 120 minutes. The predicted test time ($\tau$) can be calculated from the estimated mass of test contaminant ($W_5$) required to achieve terminal 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 lpm.

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 Eq. 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)

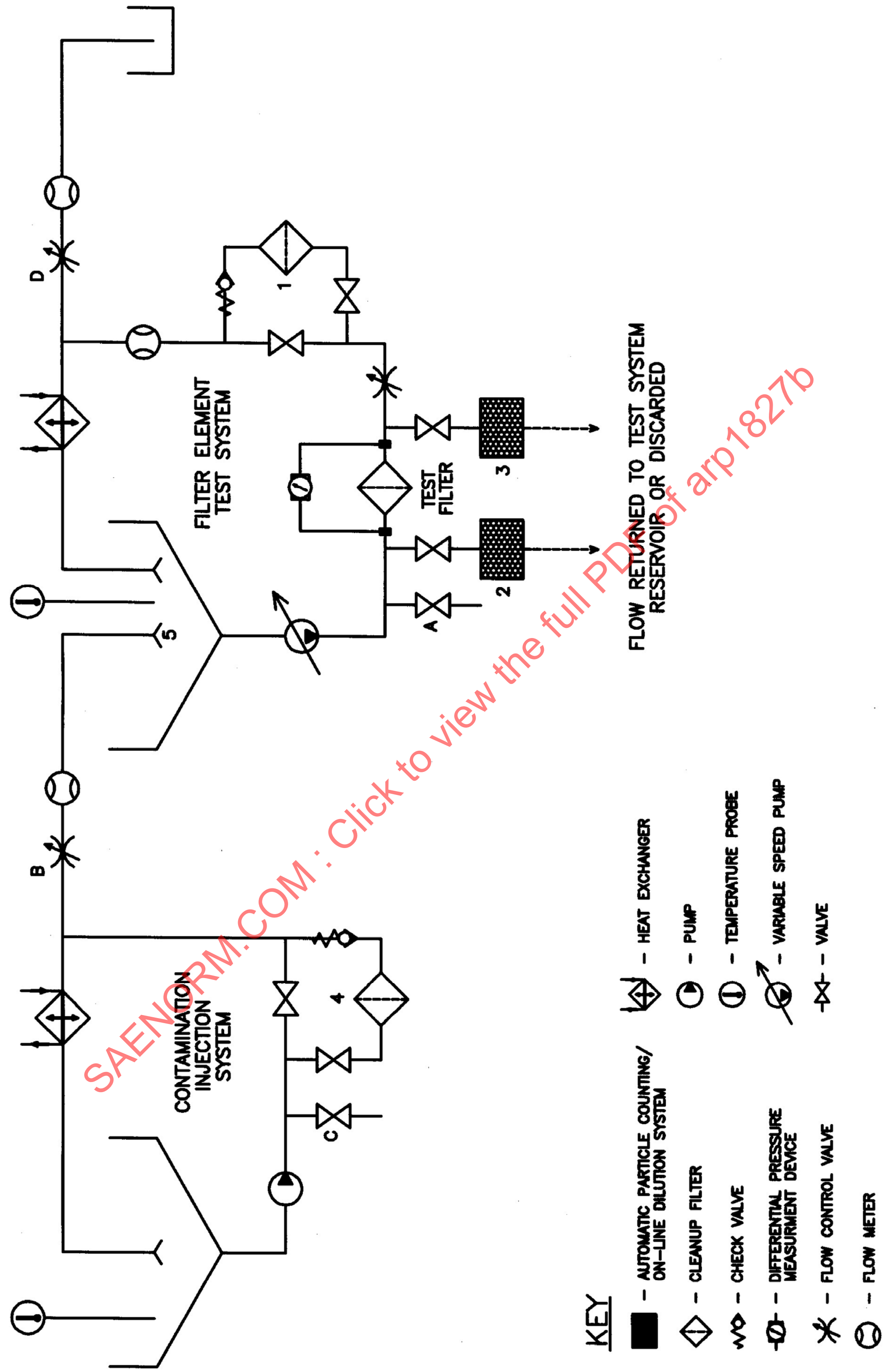




FIGURE 2 - TEST SET-UP FOR FILTER ELEMENT EFFICIENCY TEST

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:

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

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 1000 between 4 micrometers(c) and 10 micrometers(c)[1] per ISO 11171 calibration | 4 | 5 | 7 | 10 | 15 |
| For filter elements rated at Beta Ratios greater than 1000 between 10 micrometers(c) and 25 micrometers(c)[1] per ISO 11171 calibration | 7 | 10 | 15 | 20 | 25 |

Notes: 1. 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 5% 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:

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

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 one-half minute.

6.4.7 Obtain samples of the injection flow and measure the injection flow rate at 30, 60, 90 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 the level required in 6.3.5 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, 3, 5, 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 ($\tau$) 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/minute.

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.

6.5.8 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.

6.5.9 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.



TABLE 2 - VALIDATION COUNTS

| ISO 11171 Particle Size [µm(c)] | Acceptance range of particle counts/ml greater than indicated particle size for ISO Fine Test Dust (ISO 12103-A2) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 mg/l | | 3 mg/l | | 5 mg/l | | 10 mg/l | |
| | From | To | From | To | From | To | From | To |
| 4.0[1] | 5400 | 6600 | 8100 | 9900 | 13 500 | 16 500 | 27 000 | 33 000 |
| 5.0 | 2900 | 3600 | 4350 | 5350 | 7300 | 8950 | 14 600 | 17 900 |
| 7.0 | 880 | 1190 | 1350 | 1750 | 2300 | 2850 | 4650 | 5700 |
| 10.0 | 240 | 320 | 360 | 480 | 590 | 810 | 1250 | 1550 |
| 15.0 | 65 | 95 | 100 | 140 | 160 | 240 | 340 | 470 |
| 20.0 | 20 | 35 | 35 | 50 | 60 | 85 | 120 | 170 |
| 25.0[1] | 9 | 15 | 15 | 25 | 25 | 40 | 50 | 75 |

**Notes: 1.** Particle size not required if it is not a recommended particle size in Table 1.

6.6 Filter Element Efficiency Test Procedure

6.6.1 Test Preparation – Contaminant Injection System

6.6.1.1 Adjust the fluid volume ($V_2$) of the contaminant injection system per 6.2.2.

6.6.1.2 Circulate the fluid in the contaminant injection system, without any contaminant injection flow to the filter element test system reservoir, through the cleanup filter element (Item 4 in Figure 2) until the required cleanliness level per 6.2.3 is attained.

6.6.1.3 Bypass the contaminant injection system cleanup filter element (Item 4 on Figure 2).

6.6.1.4 The test contaminant specified in 6.1.2 shall be dried per 6.4.3 and weighed per 6.4.4.

6.6.1.5 Add the required amount of contaminant ($W_6$) to the contaminant injection system reservoir and allow mixing for 30 minutes to thoroughly disperse the contaminant.

6.6.1.6 Once the contaminant injection system temperature has stabilized (within ±2 °F; ±1°C), adjust the injection flow rate at stabilized temperature to within ±5% of the selected value ($Q_2$), returning the injection flow directly to the injection system reservoir during test set-up.

6.6.2 Test Preparation – Filter Element Test System

6.6.2.1 Install the filter element test housing with a free-flow dummy element in the filter element test system.

6.6.2.2 Adjust the fluid volume of the filter element test system to the required volume ($V_1$) per 6.3.1.

6.6.2.3 Start recording particle counts with the automatic particle counters in the filter element test system per 6.5.7.

6.6.2.4 Circulate the fluid in the filter element test system through the cleanup filter element (Item 1 in Figure 2) until the required cleanliness level per 6.3.5 is attained. Stop the particle counters.

6.6.2.5 Establish, and record, the required test flow rate ($Q_1$) and test temperature per 6.5.3 in the filter element test system. Record the differential pressure drop across the test housing with the free-flow dummy element installed at the above test conditions.

Calculate the terminal test filter assembly differential pressure as the sum of the required terminal filter element differential pressure and the pressure drop across the test housing with the free-flow dummy element installed, recorded above.

6.6.2.6 Stop filter element test system flow. Install the filter element to be tested in the test housing in place of the free-flow dummy element. Readjust filter element test system volume ($V_1$) per 6.3.1 as required.

6.6.2.7 Restart, adjust, maintain and record the filter element test system flow rate ($Q_1$) and temperature per 6.5.3.

6.6.2.8 Start recording particle counts with the automatic particle counters in the filter element test system per 6.5.7.

6.6.2.9 Continue to circulate until required cleanliness levels per 6.3.5 are once again achieved, then bypass the filter element test system clean-up filter (Item 1 in Figure 2).

6.6.2.10 Record the differential pressure across the test filter assembly at rated flow ($Q_1$) and temperature per 6.5.3.

6.6.3 Filter Element Efficiency Test

6.6.3.1 Record five stabilized upstream and downstream particle counts at each particle size range. These are the blank (control) counts.