



AEROSPACE RECOMMENDED PRACTICE

ARP1827

REV. C

Issued 1987-06
Revised 2014-11

Superseding ARP1827B

Measuring Aircraft Gas Turbine Engine Fine Fuel Filter Element Performance

RATIONALE

The document is being revised as follows: (1) Clarification of test fluids in 1.4. (2) Addition of a footnote in references that ISO 4402 has been withdrawn. (3) In 4.1.1, addition of a requirement for test fuel integrity. IFT requirement for test fuel changed to a minimum of 27 dynes/cm which can be more realistically achieved without impacting test results significantly. The IFT requirement has been clarified to be reflective of how the testing is actually performed. (4) In 4.1.1, addition of kinematic viscosity and density measurement, since this is necessary information when comparing the results for different test fluids. (5) Filter element rating in Table 1 changed from 1000 to 200 to be more reflective of filter element efficiency ratings utilized in aerospace. (6) Paragraph 6.5.4 specifies a new level of cleanliness since the reference to the cleanliness level stated in 6.3.5 was not applicable to this step. (7) Validation counts in Table 2 updated based upon the results of the 'ISO Fine Test Dust (ISO FTD) Particle Count Mini-Round Robin' conducted by ISO, which is more representative of recent lots of ISO FTD. (8) Volume changed in 6.6.3.2 from 500 mL to 100 mL since the larger volume is not necessary, given the high gravimetric levels. (9) New 6.6.3.3 inserted which requires a gravimetric analysis be performed on the injection fluid sample collected in 6.6.3.2, prior to performing the multi-pass test, in order to confirm the concentration of the contaminant in the contaminant injection system prior to the test. (10) Volume changed in the newly numbered 6.6.3.10 from 500 mL to 100 mL as the larger volume is not necessary, given the high gravimetric levels. (11) Update of references and addition of references ASTM D445, ASTM D1298, and ASTM D7566. (12) Editorial changes for clarity throughout the document.

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 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 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 fluid.

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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 (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 $\mu\text{m(c)}$ to 25 $\mu\text{m(c)}$, 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, 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.

1.3.2 Filter Efficiency

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 $\mu\text{m(c)}$ or micrometer(c), the (c) indicating NIST certified sizes.

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 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 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 produced by SASOL. 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. In the future, some of these jet fuels may contain synthetic hydrocarbons, i.e., hydrocarbons derived from non-petroleum based feedstocks. For example, fuels produced per ASTM D7566 (which may contain up to a 50% synthetic hydrocarbon component) are permitted to be re-certified as ASTM D1665 or U.K. Defence Standard 91-91 fuels. Once re-certified, the fuels are indistinguishable from fuel 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 fuel 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) and the dispersion of solid contamination and the solubility and dispersion of water in the fluid phase, which are critically dependent on the chemical composition 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 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. 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
AS4059	Aerospace Fluid Power - Contamination Classification for Hydraulic Fluids
AIR5455	Impact of Changes in Test Dust Contaminants and Particle Counter Calibration on Laboratory Filter Element Performance and Fluid Cleanliness Classes

2.2 Military Specifications

2.2.1 U.S. Military Specifications

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6396, <http://quicksearch.dla.mil/>.

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	Performance Specification, Calibrating Fluids, Aircraft Fuel System Components
MIL-PRF-81836	Filter and Disposable Element, Fluid Pressure, Hydraulic, 3 Micron Absolute
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)

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

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.

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 D6304	Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration
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)
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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 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
τ	the predicted test time (minutes) of the filter element efficiency test
τ_A	the actual, recorded test time 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 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 [$\mu\text{m(c)}$] per ISO 11171 calibration

3.2 Conversions

(milligrams per liter) = 0.2642 x (milligrams per gallon)

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

4. GENERAL TEST CONDITIONS

4.1 Test Fluids

- 4.1.1 The fluid 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 six months.

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.

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.

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 $85^{\circ}\text{F} \pm 5^{\circ}\text{F}$ ($29^{\circ}\text{C} \pm 3^{\circ}\text{C}$).
- 4.2.2 The temperature of the test fluid for the filter element efficiency test shall be maintained at $100^{\circ}\text{F} \pm 2^{\circ}\text{F}$ ($38^{\circ}\text{C} \pm 1^{\circ}\text{C}$), 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 $4\text{ }\mu\text{m(c)}$ 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 $\pm 10\%$ 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 $160^{\circ}\text{F} \pm 10^{\circ}\text{F}$ ($71^{\circ}\text{C} \pm 6^{\circ}\text{C}$) and desiccate to room temperature. Determine the mass of the clean-up filter element to an accuracy $\pm 0.1\text{ g}$. 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 $\pm 0.1\text{ g}$ or $\pm 1\%$ 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%.

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 g 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 L (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 W₂ (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 W₃ (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 W₄ (grams).

5.2.12 Calculate percent accountable contaminant using the following formula:

$$C = 100 \times (W_2 + W_3 + W_4) / W_1$$

5.2.13 Validation Requirement

The test setup is considered valid 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.

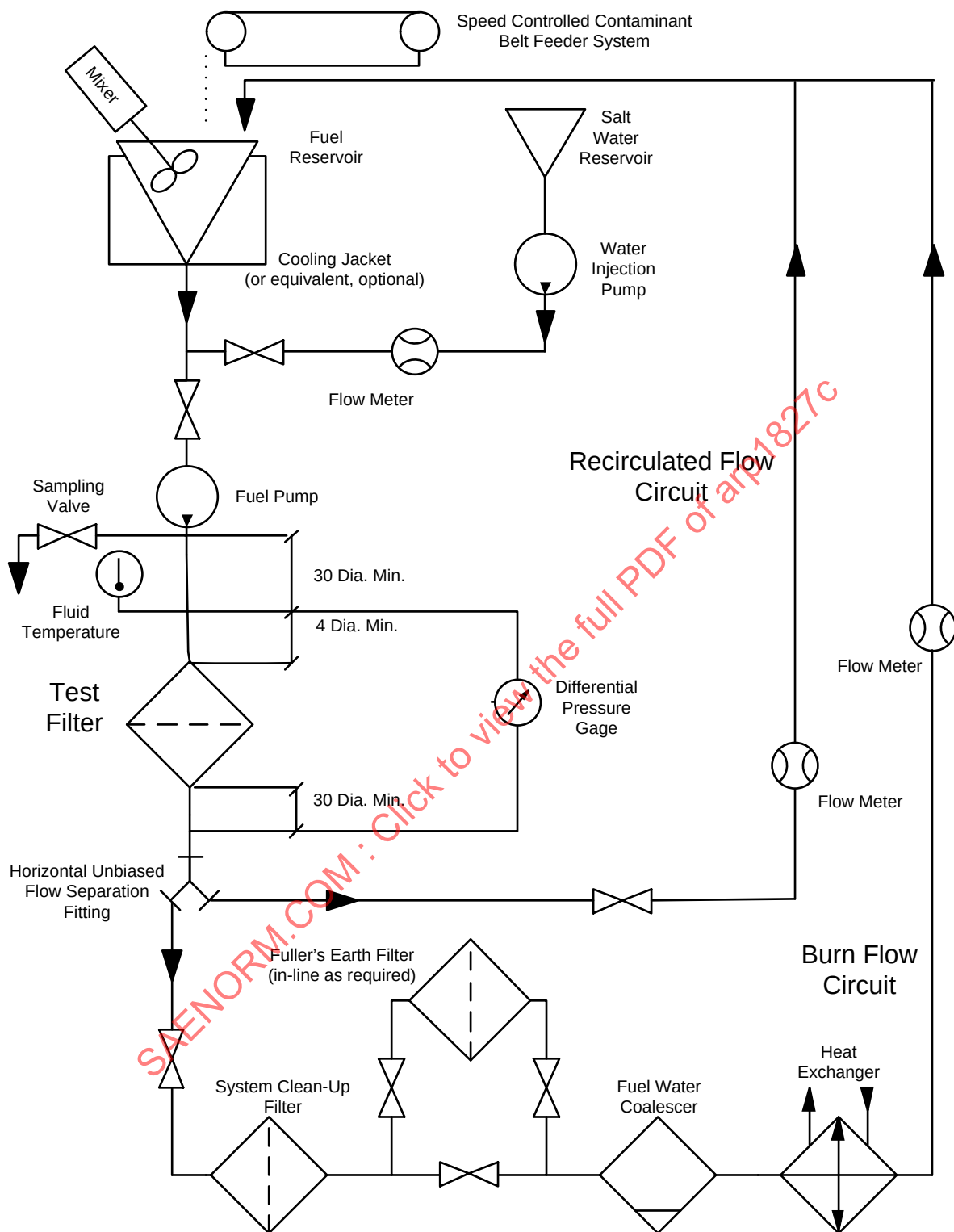


Figure 1 - Test set-up for filter element dirt capacity test

- 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

- Report the clean filter element differential pressure determined in 5.3.4.
- 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.
- 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 (β_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 test contaminant concentration (mass per unit fluid volume) upstream of the test filter element obtained by ingress of the test contaminant from the contaminant injection system in to 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, 3, 5, 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 terminal differential pressure, the base upstream gravimetric level (G_1) selected, and the required test element flow rate (Q_1), per the following equation:

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

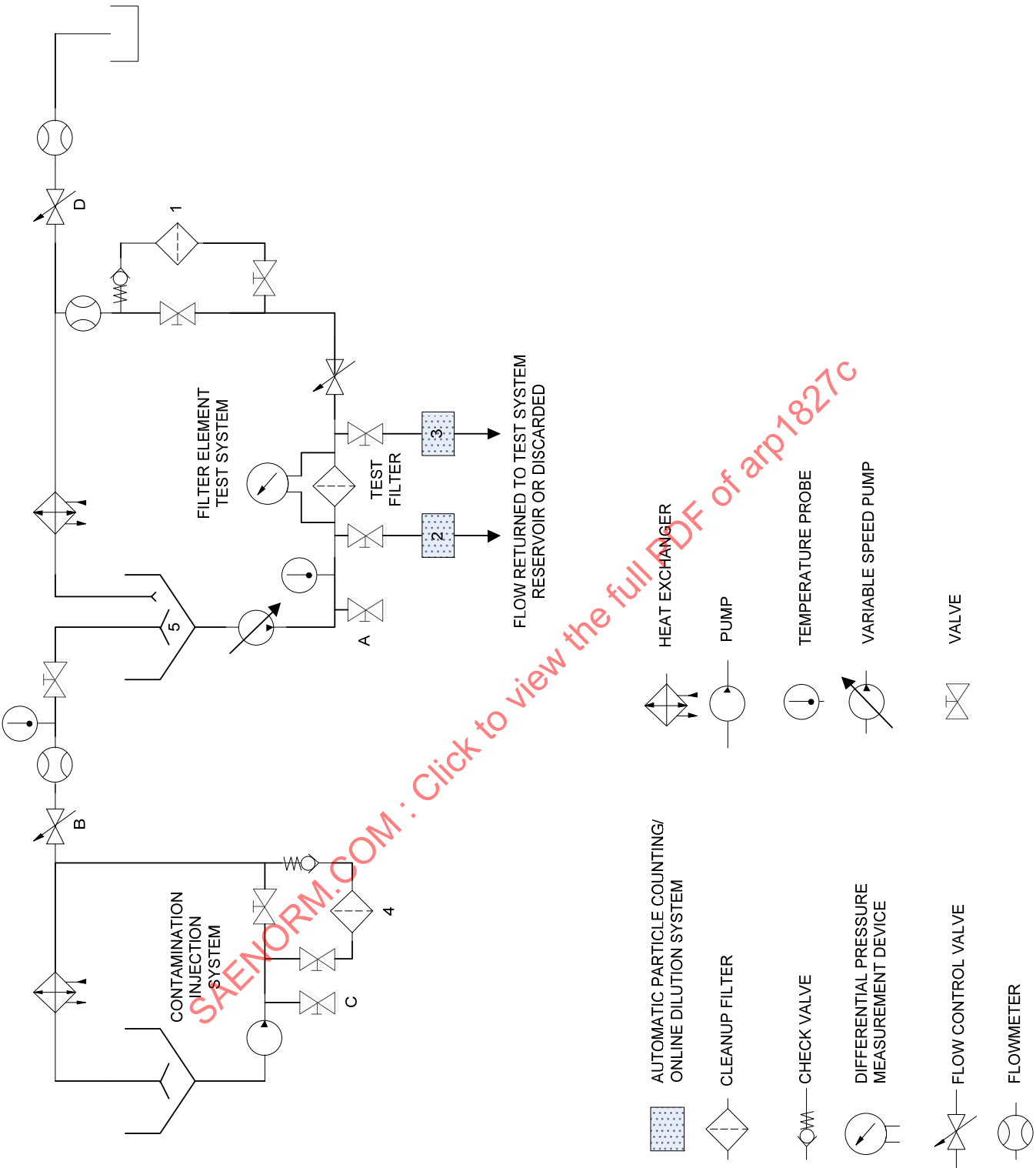


Figure 2 - Test set-up for filter element efficiency test

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 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 $\pm 2\%$) 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 $\pm 5\%$ 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 $\pm 5\%$ of the contaminant injection flow rate (Q_2) in order to maintain a constant filter element test system volume to within $\pm 5\%$ 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 $\pm 5\%$ 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)]				
	4	5	7	10	15
For filter elements rated at Beta Ratios greater than 200 ¹ between 4 μm (c) and 10 μm (c) ² per ISO 11171 calibration					
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 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 $\pm 5\%$ of the average of the injection flow rates, and within $\pm 5\%$ 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) $\times$ (total injection time), is equal, within $\pm 10\%$, 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 $\pm 2\%$). 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, 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 (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/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 $\pm 3\%$. 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 $\pm 10\%$ 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

SO 11171 Particle Size [$\mu\text{m(c)}$]	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	6000	7350	9000	11 000	15 000	18 400	30 000	36 700
5.0	3300	4100	5000	6100	8300	10 200	16 600	20 400
7.0	890	1210	1370	1780	2350	2910	4730	5790
10.0	220	300	330	450	550	750	1160	1440
15.0	60	85	90	125	145	215	300	420
20.0	22	39	38	54	63	90	125	180
25.0 ¹	10	16	15	25	25	40	53	79

NOTE 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 the required weight (W_6) calculated 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 $\pm 2^\circ\text{F}$; $\pm 1^\circ\text{C}$), adjust the injection flow rate at stabilized temperature to within $\pm 5\%$ 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.