SAE Aerospace
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# AEROSPACE RECOMMENDED PRACTICE

SAE ARP5454

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## Multi-Pass Method for Evaluating Filtration Performance of Fine Lube Filter Elements Utilized in Aerospace Power and Propulsion Lubrication Systems



1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) describes the multi-pass method for evaluating the filtration performance of fine lube filter elements, commonly utilized in aerospace power and propulsion lubrication systems: gas turbine engines, auxiliary power units (APUs), helicopter transmissions, constant speed drives (CSDs), and integrated drive generators (IDGs).

1.1 Introduction:

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 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. The filtration ratio at a specified particle size 'x', designated $\beta_x$, 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 1,000 (99.9% particle removal efficiency) for the particle size range 4 µm(c) to 25 µm(c), as defined in ISO 11171.



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1.2.2 Multi-Pass Filter Element Dirt Capacity: The multi-pass filter element dirt capacity is the mass of test contaminant introduced into the filter element test system during the filtration efficiency test to produce the prescribed terminal filter element differential pressure. This value should be used only for comparing filter elements having similar filtration efficiencies

It should be noted that the most commonly specified dirt capacity for lube filter elements utilized in aerospace lubrication systems is the MIL-F-8815 dirt capacity, MIL-F-8815 (paragraph 4.7.2.6). In this dirt capacity test, contaminant is added in discrete increments, 'slugs', each increment consisting of a constant, predetermined mass of test contaminant, immediately upstream of the test filter, via a 'slug' addition valve, at fixed intervals (usually every 4 minutes) during the test. The filter element differential pressure is recorded 2 minutes after each contaminant 'slug' addition. The total mass of contaminant added to achieve the prescribed terminal filter element differential pressure is reported as the dirt capacity.

Due to the extensive experience with the MIL-F-8815 dirt capacity test, and the extensive amount of dirt capacity test data that has been generated with this test, the continued use of the test is recommended for aerospace lubricant filter elements. However, recently, several filter element specifications for helicopter transmission lubrication systems, APU lubrication systems, as well as other aerospace lubrication systems, have specified the multi-pass dirt capacity. In such cases the multi-pass dirt capacity, defined above, should be determined as described in this document. Due to the differences in the two dirt capacity tests, the dirt capacities determined from the two tests will be different.

1.3 Test Contaminant and Particle Counter Calibration:

Historically, AC Fine Test Dust was the test contaminant specified for the multi-pass filter performance test, and the calibration of automatic particle counters was in accordance with ISO 4402. 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).

In addition, ISO has 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 procedure uses ISO Medium Test Dust, designated ISO 12103-A3, instead of AC Fine Test Dust. A reference lot of ISO Medium Test Dust, NIST SRM 2806, is the primary standard for automatic particle counter calibration. The definition of particle sizes per the ISO 11171 calibration procedure differs very significantly from the particle sizes defined in ISO 4402. 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.

1.3 (Continued):

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, have been incorporated in this document.

The change in test contaminant and the particle counter calibration procedure will lead to multi-pass filter performance 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 and dirt capacity test data with data generated per the present procedure, and when comparing filter element efficiency and dirt capacity results from the current procedure to historic specification requirements for filter element efficiency and dirt capacity. AIR5455 discusses the impact of the change in test dusts and automatic particle counter calibration on laboratory filter performance and filter ratings.

1.4 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 lubrication 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, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

| | |
|---|---|
| ARP24 | Determination of Hydraulic Pressure Drop |
| ARP785 | 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 |
| ARP1827 | Measuring Aircraft Gas Turbine Engine Fine Fuel Filter Element Performance |
| 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:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

| | |
|---|---|
| MIL-PRF-23699 | Lubricating Oil, Aircraft Turbine Engine, Synthetic Base |
| MIL-PRF-81836 | Filter and Disposable Element, Fluid Pressure, Hydraulic, 3 Micron Absolute |
| MIL-F-8815 | Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems General Specification for |

2.3 International Organization for Standardization Publications:

Available from International Organization for Standardization, Case Postal 56, CH-1211 Geneva, Switzerland.

| | |
|---|---|
| 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 |

2.3 (Continued):

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 National Institute of Standards and Technology Publications:

Available from National Institute of Standards and Technology, Gaithersburg, MD 20899.

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



3. GLOSSARY OF TERMS:

$\beta$ = the filtration ratio obtained using ISO Fine Test Dust (ISO 12103-A2) under multi-pass test conditions

$Q_1$ = the required flow rate (liters/minute) through the filter element

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

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

$G_1$ = the required upstream gravimetric level (milligrams/liter) of contaminant in the filter element test system

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

$G_2$ = the required gravimetric level (milligrams/liter) of contaminant in the contaminant injection system fluid

3. (Continued):

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

$U_x$ = the total number of particles per unit volume greater than a given particle size 'x' upstream of the filter element

$D_x$ = the total number of particles per unit volume greater than a given particle size 'x' downstream of the filter element

$\tau$ = the predicted test time (minutes) of the test

$\tau_A$ = the actual, recorded test time

$\tau_t$ = the timer value at the end of the test

$V_1$ = the filter element test system fluid volume (liters)

$V_2$ = the contaminant injection system fluid volume (liters)

$V_{2F}$ = the contaminant injection system fluid volume (liters) at the conclusion of the test

$V_{2M}$ = the unusable fluid volume (liters) in the contaminant injection system

$W_1$ = the estimated mass (grams) of contaminant required for the test filter element to reach the terminal filter element differential pressure

$W_2$ = 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

$W_3$ = 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

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

4. CONVERSIONS:

(Liters per minute) = 0.26420 × (Gallons per minute)

5. TEST SET-UP AND HARDWARE:

A schematic diagram of the multi-pass test system is shown in Figure 1.

5.1 General Considerations:

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

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

5.1.3 Reservoirs shall be constructed with smooth conical bottoms that have an included angle of not more than 90 degrees.

5.1.4 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.

5.1.5 Pressure Measurements: Pressure measurements are to be performed in accordance with ARP24.

5.1.6 Cleanup Filter: 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.

5.2 Contaminant Injection System:

5.2.1 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 liters per minute.

5.2.2 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:

$$V_2 = (1200 \times Q_2 \times W_1)/(G_1 \times Q_1) + V_{2M} \qquad \text{(Eq.2)}$$

NOTE: The injection fluid volume may be increased as needed by increasing the amount of test dust proportionately.

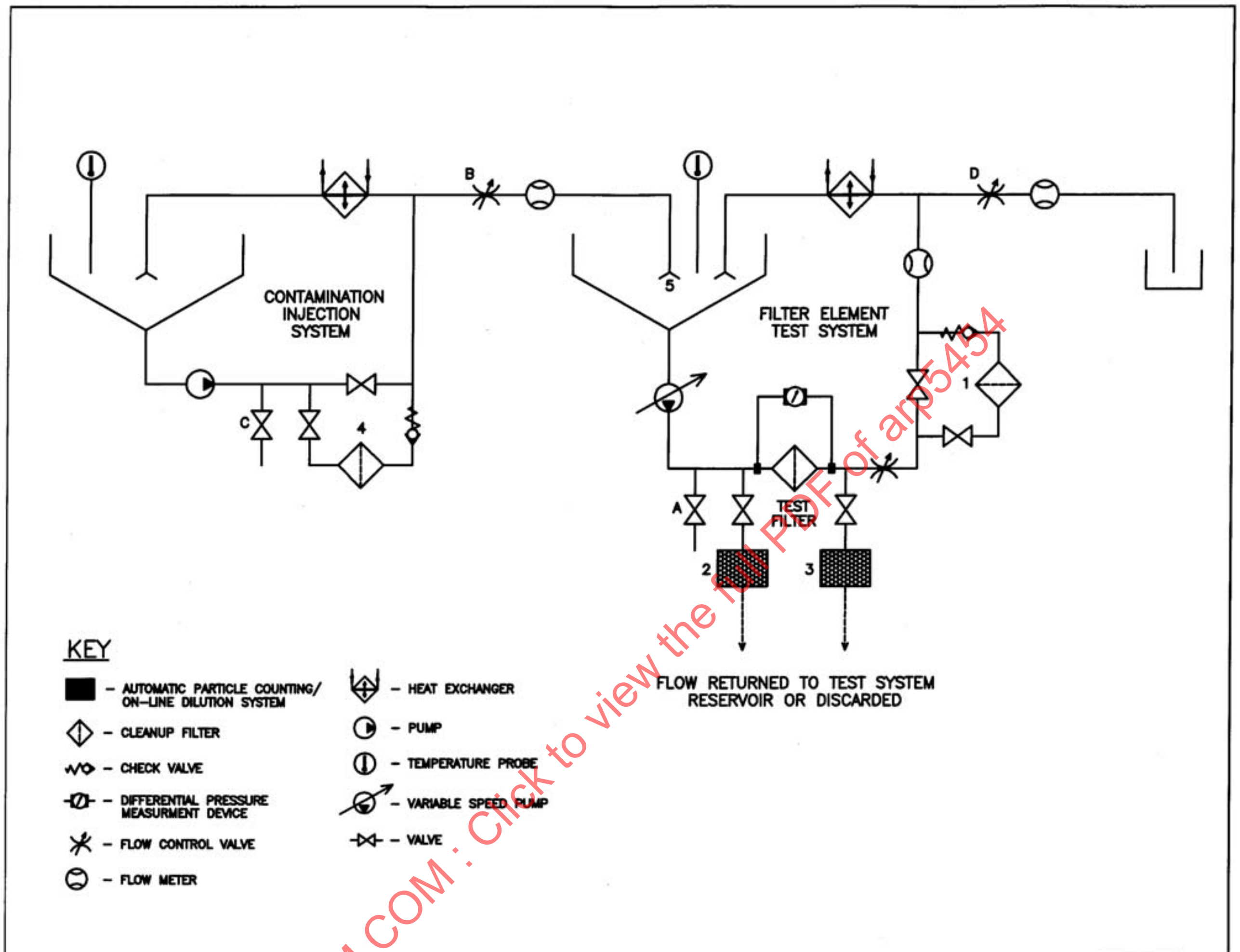


FIGURE 1 - Schematic of Typical Test Set-Up for Multi-Pass Filter Performance Test

5.2.3 Before adding contaminant, the clean-up filter element (Item 4 on Figure 1) per 5.1.6 shall clean the contaminant injection system to the extent that particles greater than 4 micrometers(c) in size do not exceed 200 per milliliter. Gravimetric analysis of fluid samples, taken from valve C (Figure 1), shall be less than 1% of the required gravimetric level ($G_2$) of the contaminant injection system fluid, defined by the following equation:

$$G_2 = (G_1 \times Q_1)/Q_2 \qquad \text{(Eq.3)}$$

5.3 Filter Element Test System:

5.3.1 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 low 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.

5.3.2 The total fluid volume of the filter 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 1. 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 ($V_1$).

5.3.3 Before adding contaminant, the filter element test system shall be sufficiently cleaned, using a clean-up filter (Item 1 on Figure 1) per 5.1.6, so that particles in each size range do not exceed 5% of the expected downstream particle counts during the test.

5.4 Particle Counting:

5.4.1 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. 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.

5.4.2 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 1). 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 filter element test circuit reservoir, or it may be discarded. Do not interrupt sample flow during the test.

5.4.3 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 |

[1] Particle size inclusive.



6. MULTI-PASS TEST PROCEDURE:

6.1 General Considerations:

6.1.1 Test Fluids:The test fluid used shall conform to MIL-PRF-23699 specification, or shall be as specified by the procuring agency.

6.1.2 Test Fluid Temperature: The temperature of the test fluid, during the test, shall be maintained at 131 °F ± 2 °F (55 °C ± 1 °C) for MIL-PRF-23699, unless specified otherwise.

6.1.3 Test Contaminant:

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

6.1.3.2 Test Contaminant Concentration: The target base upstream gravimetric level ($G_1$ milligrams per liter) is defined as the desired test contaminant mass per unit fluid volume ingressed into the filter element test system, 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.

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 ($W_1$) 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:

$$\tau = (1000 \times W_1)/(G_1 \times Q_1) \qquad \text{(Eq.4)}$$

6.1.4 Test Housing and Free-Flow Dummy Element:

6.1.4.1 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.

6.1.4.2 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.

6.1.4.3 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.

6.2 Contaminant Injection System Validation:

6.2.1 Validate at the maximum injection system volume ($V_2$) to be used per 5.2.2, the maximum contaminant injection system gravimetric level ($G_2$) specified per 5.2.3, 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.

6.2.2 Pre-clean the contaminant injection fluid system per 5.2.3., then bypass the cleanup filter system (Item 4 in Figure 1).

6.2.3 Dry the test contaminant, specified in 6.1.3.1, at 275 °F ± 25 °F(135 °C ± 14 °C) for 1 hour and desiccate to room temperature prior to weighing.

6.2.4 Calculate the required amount of contaminant ($W_2$) to be added to the contaminant injection system from the volume ($V_2$) per 5.2.2 and gravimetric level ($G_2$) per 5.2.3, according to the following formula:

$$W_2 = (V_2 \text{ x } G_2)/1000 \quad \text{(Eq.5)}$$

6.2.5 Add the required quantity of contaminant ($W_2$) to the contaminant injection system reservoir fluid and circulate for a minimum of 30 minutes.

6.2.6 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.

6.2.7 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.

6.2.8 Analyze each sample from 6.2.7 gravimetrically in accordance with ARP785.

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

6.2.10 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 6.2.8, shall be within ±5% of the average of the samples, and within ±10% of the required gravimetric level ($G_2$) per 5.2.3.

b. The injection flow rates, measured in 6.2.7, 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) × (total injection time), is equal, within ±10%, to the initial injection system volume ($V_2$).

6.3 Filter Element Test System Validation:

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

6.3.2 Adjust the volume ($V_1$) of fluid in the filter element test system per 5.3.1. Clean the fluid to the level required in 5.3.3 by using the filter element test system clean-up filter (Item 1 in Figure 1).

6.3.3 Adjust the filter element test system to the required flow rate ($Q_1$) (to within ±2%). Adjust the test system fluid temperature per 6.1.2.

6.3.4 Calculate the required amount of contaminant ($W_3$) to be added to the filter element test system reservoir per the following formula:

$$W_3 = (G_1 \times V_1)/1000 \qquad \text{(Eq.6)}$$

6.3.5 Dry the test contaminant (6.1.3.1) per 6.2.3. Add the required quantity of contaminant ($W_3$) per 6.3.4 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 at least fifteen minutes prior to starting the particle counters.

6.3.6 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 one-minute counts for automatic particle counters with operating flow rates of 10 ml/minute.

6.3.6 (Continued):

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.

6.3.7 Circulate the fluid in the test system for 1 hour and record particle counts in each size range (per 6.3.6) for both upstream and downstream particle counters.

6.3.8 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)]** | **Acceptable 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 | 13500 | 16500 | 27000 | 33000 |
| 5.0 | 2900 | 3600 | 4350 | 5350 | 7300 | 8950 | 14600 | 17900 |
| 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 |

[1] Particle size not required if it is not a recommended particle size in Table 1.

6.4 Filter Element Efficiency Test Procedure:

6.4.1 Test Preparation – Contaminant Injection System:

6.4.1.1 Adjust the fluid volume ($V_2$) of the contaminant injection system per 5.2.2.

6.4.1.2 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 1) until the required cleanliness level per 5.2.3 is attained.

6.4.1.3 Bypass the contaminant injection system cleanup filter element (Item 4 on Figure 1).

6.4.1.4 The test contaminant specified in 6.1.3.1 shall be dried per 6.2.3 and weighed per 6.2.4.

6.4.1.5 Add the required amount of contaminant ($W_2$) to the contaminant injection system reservoir and allow mixing for 30 minutes to thoroughly disperse the contaminant.

6.4.1.6 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.

6.4.2 Test Preparation – Filter Element Test System:

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

6.4.2.2 Adjust the fluid volume of the filter element test system to the required volume ($V_1$) per 5.3.1.

6.4.2.3 Start recording particle counts with the automatic particle counters in the filter element test system per 6.3.6.

6.4.2.4 Circulate the fluid in the filter element test system through the cleanup filter element (Item 1 in Figure 1) until the required cleanliness level per 5.3.3 is attained. Stop the particle counters.

6.4.2.5 Establish, and record, the required test flow rate ($Q_1$) and test temperature per 6.3.3 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.

6.4.2.6 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 5.3.1 as required.

6.4.2.7 Restart, adjust, maintain and record the filter element test system flow rate ($Q_1$) and temperature per 6.3.3.

6.4.2.8 Start recording particle counts with the automatic particle counters in the filter element test system per 6.3.6.

6.4.2.9 Continue to circulate until required cleanliness levels per 5.3.3 are once again achieved, then by-pass the filter element test system clean-up filter (Item 1 in Figure 1).

6.4.2.10 Record the differential pressure across the test filter assembly at rated flow ($Q_1$) and temperature (6.3.3).

6.4.3 Filter Element Efficiency Test:

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

6.4.3.2 While the contaminant injection system continues re-circulating, collect approximately 500 ml of injection system fluid sample from Valve C (Figure 1) to determine the initial injection gravimetric level.

6.4.3.3 Measure and verify the contaminant injection flow rate ($Q_2$).

6.4.3.4 Start flow from contaminant injection system to the filter test system and simultaneously start the test recording timer. Record the initial injection flow rate. Monitor and maintain the required injection flow rate ($Q_2$), to within ±5%, throughout the test.

6.4.3.5 Maintain the total volume ($V_1$) of fluid in the filter element test system (to within ±5%) as described in 5.3.2.

6.4.3.6 Record automatic particle counts continuously, throughout the test, per 6.3.6, until the measured differential pressure across the test filter assembly has increased to the required terminal test filter assembly differential pressure calculated in 6.4.2.5.

On-line dilution (5.4.1) should be utilized, if required, to prevent automatic particle counter saturation.

6.4.3.7 Record the differential pressure across the filter assembly in conjunction with the particle counts, throughout the test. Continuous differential pressure measurements using a differential pressure transducer is recommended.