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Superseding AIR1666B

Performance Testing of Lubricant Filter Elements Utilized in Aircraft Power and Propulsion Lubrication Systems

RATIONALE

The proper specification of filtration in aircraft power and propulsion lubrication systems is important in protecting lubrication systems from particulate contamination that could lead to accelerated component wear, system malfunction, and premature component failure. This SAE Aerospace Information Report (AIR) provides information about standard test procedures developed for the evaluation of the performance of lubricant filter elements utilized in aircraft power and propulsion systems. This will allow both manufacturer and customer a common means to specify, control, and evaluate lubricant filter elements to ensure that the filter elements retain their functional characteristics under operating conditions.

The document has been revised to: (1) add the reference for the standard reference material (SRM 2806) used for calibration of automatic particle counters per ISO 11171 and include an update on the current status of the same; (2) move the ranking of the filter elements in Table 3, based on their Bubble Points, to be consistent with the required sequence of tests, and to include a Bubble Point test subsequent to flow fatigue conditioning; (3) add a statement to the end load test to allow for performing the test after cold start conditioning and subsequent Bubble Point determination if significant tensile forces may be experienced at the filter element end caps; (4) link the system(pump) relief valve pressure to the collapse rating differential pressure and delete the statement that the filter element can experience the collapse rating differential pressure under normal conditions since this is unlikely; (5) interchange the gravimetric efficiencies for Media A and B in Figure 3 that were incorrectly reversed; and (6) include numerous editorial changes for clarity.

1. SCOPE

This SAE Aerospace Information Report (AIR) reviews performance testing parameters for non-cleanable (often referred to as disposable) filter elements utilized in aircraft power and propulsion lubrication systems, including gas turbine engines and auxiliary power units (APUs), propulsion and transmission gear boxes, and constant speed drives and integrated drive generators (IDGs).

This document is confined to laboratory testing of filter element performance to qualify the filtration medium and filter element construction as opposed to qualification of the complete filter assembly. The testing discussed here is usually followed by laboratory and on-engine testing of the entire lube filter assembly (including filter element, housing, valving, etc.), which is outside the scope of this AIR.

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1.1 Purpose

Performance testing is necessary to assure that filter elements retain their functional characteristics under operating conditions. Variations in filter element testing methods and requirements make comparison of performance test results difficult. In order to minimize these problems, this AIR describes standard filter element performance test procedures, allowing both manufacturer and customer a common means to specify, control, and evaluate lubricant filter elements. This document highlights recommended tests and the appropriate test sequence. The methodology discussed should be incorporated in filter element specifications.

2. APPLICABLE DOCUMENTS

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

2.1 SAE Publications

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

AIR887	Liquid Filter Ratings, Parameters and Tests
AIR4246	Contaminants for Aircraft Turbine Engine Fuel System Component Testing
AIR5455	Impact of Changes in Test Dust Contaminants and Particle Counter Calibration on Laboratory Filter Element Performance and Fluid Cleanliness Classes
ARP24	Determination of Hydraulic Pressure Drop
ARP901	Bubble-Point Test Method
ARP5454	Multi-Pass Method for Evaluating Filtration Performance of Fine Lube Filter Elements Utilized in Aerospace Power and Propulsion Lubrication Systems

2.2 Military Publications

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

MIL-F-8815	Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems General Specification for
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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 4402 ¹	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 12103-1	Road Vehicles - Test Dust for Filter Evaluation; Part 1: Arizona Test Dust

¹ ISO 4402 has been withdrawn as of December 9, 1999.

2.4 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

3. FILTER ELEMENT INTEGRITY AND PERFORMANCE EVALUATION

Filter element integrity and performance are evaluated by a variety of tests using controlled and reproducible procedures. The more prominent tests, currently in use, are listed in Table 1. In addition, a number of laboratory procedures have been developed, listed in Table 2, which expose filter elements to harsh conditions simulating extreme conditions encountered during service. The generic term for these procedures is "conditioning." Conditioning of filter elements, prior to performance testing, is necessary in order to determine if filter element performance will degrade during actual service.

Table 1 - Filter element integrity and performance tests

Parameter	Test Method	Paragraph
Filter element integrity	Bubble point	5.1
Hardware integrity	End load/Bubble Point	5.2/5.1
Clean pressure drop	Flow versus differential pressure	7.1
Dirt capacity	Pressure build-up versus contaminant added	7.2
Filtration efficiency	Filtration ratios from multi-pass filter element performance test	7.3.1
Collapse rating	Extreme differential pressure	7.4

Table 2 - Filter element conditioning methods

Extreme Environment	Test Method	Paragraph
Exposure to heat, fluid compatibility	Heat soak	6.1
Exposure to cold	Cold soak	6.2
Cold start-up	Cold start	6.2
Flow cycling and pump ripple	Flow fatigue	6.3

4. QUALIFICATION TEST SEQUENCE

Table 3 depicts a model qualification test sequence. Criteria for acceptance or rejection should be defined in the filter element specification. For filter elements experiencing significant flow cycling or pump ripple, flow fatigue testing may be incorporated as discussed in 6.3.

Table 3 - Model qualification test sequence

Filter Element #1	Filter Element #2	Filter Element #3 ¹	Procedure Paragraph
Examination of product (dimensions and weight)	Examination of product (dimensions and weight)	Examination of product (dimensions and weight)	
Bubble point	Bubble point	Bubble Point	5.1
End load	End load	End load	5.2
Bubble point	Bubble point	Bubble point	5.1
Heat soak	Heat soak	Heat soak	6.1
Cold soak	Cold soak	Cold soak	6.2
Cold start	Cold start	Cold start	6.2
Bubble point	Bubble point	Bubble point	5.1
Filter Element with Lowest Bubble Point	Filter Element with Highest Bubble Point	Filter Element with Second Highest Bubble Point	
		Flow fatigue	6.3
		Bubble point	5.1
Clean pressure drop	Clean pressure drop		7.1
Filtration efficiency: filtration ratios			7.3.1
	Dirt capacity		7.2
		Post flow fatigue filtration efficiency: filtration ratios	7.3.1.2
Collapse rating: extreme differential pressure	Collapse rating: extreme differential pressure		7.4

¹ To be incorporated only if high cyclic flow or high pump ripple is encountered in service; see 6.3.

5. INTEGRITY TESTS

5.1 Bubble Point Test

In order to ensure that the filter element has been properly manufactured and handled, an integrity check is performed. The Bubble Point test is an excellent method for detecting punctures and/or tears in the medium, defective sealing, and damage from handling. This procedure is non-destructive.

The Bubble Point test is performed by immersing the filter element horizontally in a bath of appropriate test fluid and allowing the fluid to fully wet the filter element. The filter element is positioned so that the upper edge of the filter element is 1/2 inch below the fluid surface. The inside of the filter element is then slowly pressured with air. After every pressure increase of 1/2 inch of water column, the filter element is rotated by 360 degrees about its horizontal axis and positioned to ensure that any originating air bubbles are from the top surface of the filter element. The pressure at which the first, steady stream of bubbles issues from the top surface of the filter element is defined as the Bubble Point.

The Bubble Point test procedure does not measure the filter element efficiency. A high efficiency filter element constructed with one type of filtration medium can have a lower Bubble Point than a less efficient filter element constructed from a different type of filtration medium. However, the Bubble Point test is an excellent method to check filter element integrity, useful for quality control as well as for qualification testing. A detailed discussion of the theory and procedure is given in ARP901.

5.2 End Load Test

The end load test is used to verify the bonding of the end caps to the filtration medium pack. Typically, a tensile load (in some cases a compressive load) of 50 pounds (or otherwise specified force) is applied to the end caps, along the axis of the filter element. The Bubble Point of the filter element is then determined to ensure that the integrity of the bond between end caps and filter element pack is retained.

Usually, the filter element end caps experience compressive stresses. If there are applications where the filter element end caps may experience significant tensile stresses, the end load test and subsequent Bubble Point test in Table 3 may be performed after cold start conditioning and the subsequent Bubble Point test since the cold start would amplify any deficiencies in the bonding of the end caps.

6. CONDITIONING

6.1 Heat Soak

A primary requirement is that the filter element medium pack, end caps, core, seals, and bonding materials be compatible with the maximum temperature experienced by the filter element in the system, and with the operating fluid(s) of the system at this maximum temperature; incompatibility between component materials and the operating fluid(s) is accelerated by high temperatures. Because of the large surface area of the filter element medium pack exposed to the fluid(s), a compatibility requirement is of major importance. Problems that may occur when operating at high fluid temperature include degradation of the filter element medium pack and the bonding materials used to attach the medium to the support hardware.

Heat soak is performed by immersing the test filter element in the type(s) of lubricant(s) to be used in service, at the highest temperature(s) anticipated in service, typically for a period of 72 hours.

6.2 Cold Soak and Cold Start

Since lubricating fluids have high viscosities at low temperatures, forcing cold fluid through a filter element can produce potentially damaging differential pressures. This occurs during system cold starts. In addition, cold temperature embrittlement can amplify any tendency toward filter element damage. In order to evaluate the effects of low temperature on filter elements, cold soak and cold start tests are employed.

Cold soak is performed by immersing the test filter element in the operating fluid(s) at the anticipated minimum temperature that would be experienced by the filter element during service, usually between -40 °F (-40 °C) and -65 °F (-53.9 °C), typically for a duration of 72 hours.

Cold start testing is performed as a continuation of the cold soak procedure. The filter element is subjected to a predetermined number of flow cycles (often, ten cycles) of cold fluid at the required temperature (or viscosity). The flow rate and flow cycle profile are specified so that the filter element is subjected to the maximum required differential pressure, typically corresponding to the filter element bypass valve full flow differential pressure or the filter element collapse rating differential pressure (7.4) if no bypass valve is present, for a specified duration (usually at least 50% of the cycle time); typical cycle time is 15 seconds $\pm$ 1 second.

6.3 Flow Fatigue

Cyclic flow across a filter element may cause the filtration medium to flex. This movement can result in filter element medium failure. Often, filter element fatigue failures go unnoticed. If the filter element experiences significant flow cycling or potentially damaging pump ripple in service, a flow fatigue test should be considered.

In the flow fatigue test, the test filter element is subjected to a specified number of flow cycles at a series of specified filter element differential pressures, in increasing order of differential pressure. Typically, a total of 100000 cycles are specified. The filter element differential pressure is increased to the required differential pressures by loading the filter element with a specified test contaminant, usually by ingressing the test contaminant in slurry form into the re-circulating test fluid flow in the filter element test circuit at the rated test fluid flow rate and temperature, until the next required differential pressure is achieved.

At each specified differential pressure, the filter element is subjected to the requisite number of flow fatigue cycles (for that differential pressure), each cycle comprised of varying the flow rate from zero flow rate to a flow rate corresponding to the required filter element differential pressure and then decreasing the flow rate to zero flow rate. The frequency of the flow cycles (usually 1 to 3 Hz) and the detailed cycle profile are specified. Typically, peak differential pressure is reached within 25% of the cycle and held for at least 50% of the cycle.

7. FILTER ELEMENT PERFORMANCE TESTS

7.1 Clean Pressure Drop

The clean differential pressure of the filter element is measured in accordance with the procedure in ARP24, typically, as part of the dirt capacity test (7.2) and/or the multi-pass filter element performance test (7.3.1). Where a more comprehensive pressure drop profile is required, the clean differential pressure is determined as a function of increasing fluid flow rate at specified intervals (flow rates) to the maximum specified flow rate. The flow rate is then decreased to zero flow rate and the differential pressures re-determined at the above specified flow rates; this is useful when high flow densities (flow rate per unit filtration area) are involved to determine whether the filtration medium has undergone permanent distortion (compression).

A free-flow dummy element is recommended when determining the differential pressure of the empty filter assembly (i.e., assembly without the filter element) to reduce the impact of any changes in flow patterns on the measured filter element differential pressure. Without the dummy element, the clean filter element differential pressure may actually be determined as a negative number when used in certain filter housings. Typically, the free-flow dummy element is the same as the test filter element without the filtration medium pack. If the test filter element is not constructed with a rigid core, the dummy element is 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.

7.2 Dirt Capacity

There are several versions of this test. All tests are performed utilizing predetermined test parameters: fluid temperature (viscosity), flow rate, and terminal filter element differential pressure. In addition, all methods add a standardized test contaminant (7.2.1) upstream of the filter element until the specified terminal differential pressure across the filter element is attained. The contaminant may be added continuously throughout the test (slurry loading), or in discrete amounts separated by intervals of several minutes (slug loading). Typically, the contaminant is recirculated through the test circuit (multi-pass). The results are reported as the total mass, in grams, of contaminant added to the test system to achieve the terminal filter element differential pressure.

Thus, it should be noted that, in the dirt capacity test, the amount of contaminant retained by a filter element is not determined. By capturing only a small portion of the test contaminant, a coarse filter element may show a higher dirt capacity than a finer filter element which captures most of the test contaminant. Operating with cleaner lubricant significantly reduces the amount of wear debris generated by operating systems. With fewer particles to capture, a high efficiency filter element may even have a longer service life than a coarse filter element. For these reasons, dirt capacity test results should only be compared for filter elements having similar filtration efficiencies.

7.2.1 Test Contaminant

Historically, AC Fine Test Dust or AC Coarse Test Dust, conforming to the specification in AIR4246, were the test contaminants specified for the dirt capacity test. Replacement Test Dusts for the AC Test Dusts, no longer available, were specified by ISO in the late 1990s (ISO 12103-1). The corresponding ISO Test Dusts for AC Fine and Coarse Test Dusts are, respectively, ISO Fine Test Dust (ISO FTD, designated ISO 12103-A2) and ISO Coarse Test Dust (ISO CTD, designated ISO 12103-A4). Dirt capacities with the ISO Test Dusts can differ significantly from the corresponding dirt capacities with AC Test Dusts. This is depicted in Figure 1 for several representative aerospace filter elements.

In general, dirt capacities are reduced with the ISO Test Dusts, by up to ~45 to 50% for finer filter elements rated at 20 μm or less, compared to AC Test Dusts. Users must take this into account in filter element performance specifications and dirt capacity requirements therein. Additional information is provided in AIR5455.

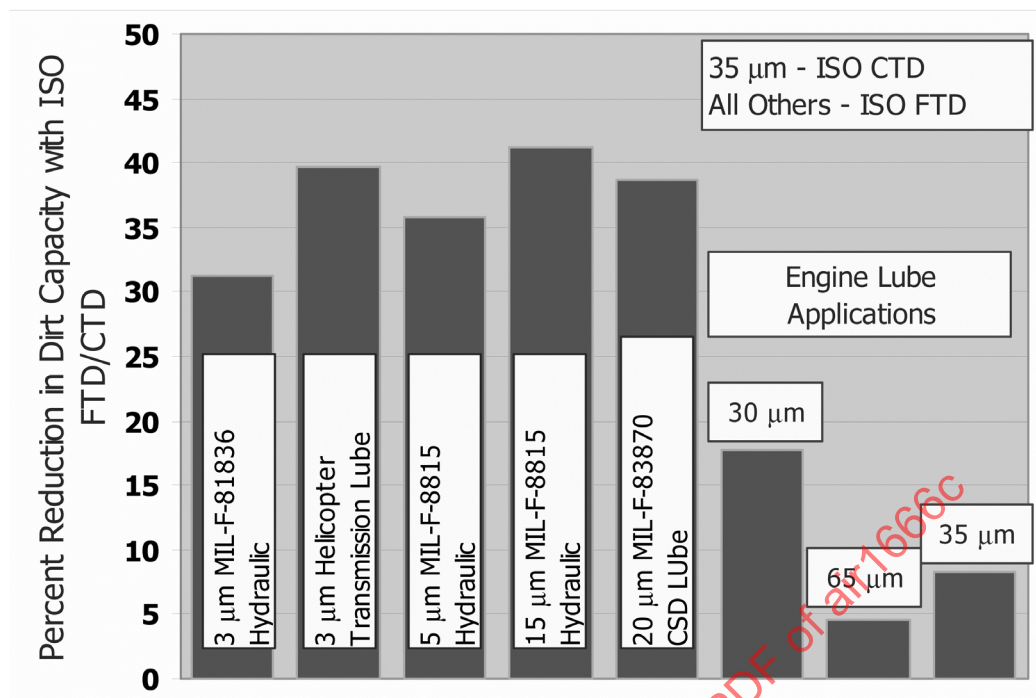


Figure 1 - Reduction in dirt capacity with ISO Fine and Coarse Test Dust contaminants

7.3 Filtration Efficiency

Filtration efficiency is a measure of the ability of a filter element to remove and retain particles from a fluid stream. Most procedures for determination of filtration efficiency involve introducing a specified concentration of standardized particulate contaminant upstream of the filter element, under controlled test conditions to ensure repeatable and reproducible results, and measuring the concentration of contaminant downstream of the test filter element. The particles may be counted individually, utilizing light microscopes or automatic particle counters, or collectively (e.g., gravimetric analysis or turbidity measurement). These tests have generated uniform scales, or ratings, of filter element efficiency, and are convenient yardsticks for comparing the performance of different filter elements (AIR887). The preferred method for measuring filter element efficiency is through filtration ratios determined from a multi-pass filter element performance test.

7.3.1 Filtration Ratios from Multi-Pass Filter Element Performance Test

The multi-pass filter element performance test measures the particle removal efficiencies of filter elements in terms of filtration ratios for the specified particle size ranges under specified test conditions. The numerical concentrations (number of particles per unit volume) of particles upstream and downstream of the test filter element are determined for the specified particle size ranges. The filter element efficiency is reported as filtration ratios, calculated from the numerical particle concentrations. The filtration ratio at a specific size is defined as the ratio of the number of particles upstream of the filter element and the number of particles downstream of the filter element, greater than the specified particle size:

$$\text{Filtration Ratio at particle size } x \mu\text{m} = \frac{\text{Upstream particle concentration } > x \mu\text{m}}{\text{Downstream particle concentration } > x \mu\text{m}} \quad (\text{Eq. 1})$$

The particle removal efficiency, expressed as a percentage, is given by the following equation:

$$\text{Particle Removal Efficiency at } x \mu\text{m} = [1 - 1/(\text{Filtration Ratio at } x \mu\text{m})] \times 100 \quad (\text{Eq. 2})$$

The particle removal efficiencies for several filtration ratios are listed in Table 4.

Table 4 - Filtration ratio versus particle removal efficiency

Filtration Ratio	Particle Removal Efficiency (%)
1	0
2	50
10	90
20	95
50	98
100	99
200	99.5
1000	99.9
5000	99.98

The multi-pass filter element performance test is performed in accordance with the procedure in ARP5454. The test contaminant is introduced into the filter element test circuit in slurry form until the required terminal filter element differential pressure (often corresponding to the filter element bypass valve cracking differential pressure or full-flow differential pressure) is attained. Using on-line sampling techniques, representative portions of upstream and downstream fluid are passed through automatic particle counters throughout the test, and particle counts, corresponding to the size ranges for which filtration ratios are required, are monitored throughout the test. The filtration ratios determined per ARP5454 (designated as Beta Ratios) are computed as average values over the test duration per the procedure in ARP5454.

Obtaining filter element efficiency by the multi-pass filter element performance test provides a more realistic assessment of filtration efficiency:

1. Irregularly shaped test contaminant is employed, which is similar to contaminant in operating systems.
2. Efficiencies are measured over a spectrum of particle sizes.
3. Filter efficiency results are averages of filter element performance from the initial clean filter element to the fully loaded filter element (terminal differential pressure).

7.3.1.1 Test Contaminants

Historically, AC Fine Test Dust was the test contaminant specified for the multi-pass filter element performance test, and the calibration of automatic particle counters was in accordance with ISO 4402 (1991). As stated in 7.2.1, ISO Fine Test Dust (ISO 12103-A2) was selected as the replacement Test Dust for AC Fine Test Dust. In addition, ISO also specified a calibration procedure (ISO 11171) for automatic particle counters to replace the ISO 4402 (1991) calibration procedure which utilized AC Fine Test Dust. The ISO 11171 calibration procedure uses an NIST-certified batch of ISO Medium Test Dust (ISO 12103-A3) as the standard reference material instead of AC Fine Test Dust; the original batches were designated SRM 2806 and SRM 2806a.

The definition of particle sizes per the calibration procedure ISO 11171 differs very significantly from the particle sizes defined in the historic calibration procedure ISO 4402 (1991). In order to distinguish the particle sizes defined in ISO 11171, they were designated as $\mu\text{m(c)}$ or micrometer(c) for the original reference batches SRM 2806 and SRM 2806a. Figure 2 shows the impact of 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 (SRM 2806 and SRM 2806a), on filtration ratios (Beta Ratios) for representative filter elements utilized in aerospace applications.

In general, filtration ratios with the ISO Test Dusts and ISO 11171 particle counter calibration are reduced below $\sim 10 \mu\text{m}$ and increased above $\sim 10 \mu\text{m}$. Users must take this into account in filter element performance specifications and filtration ratio requirements therein. Additional information is provided in AIR5455.

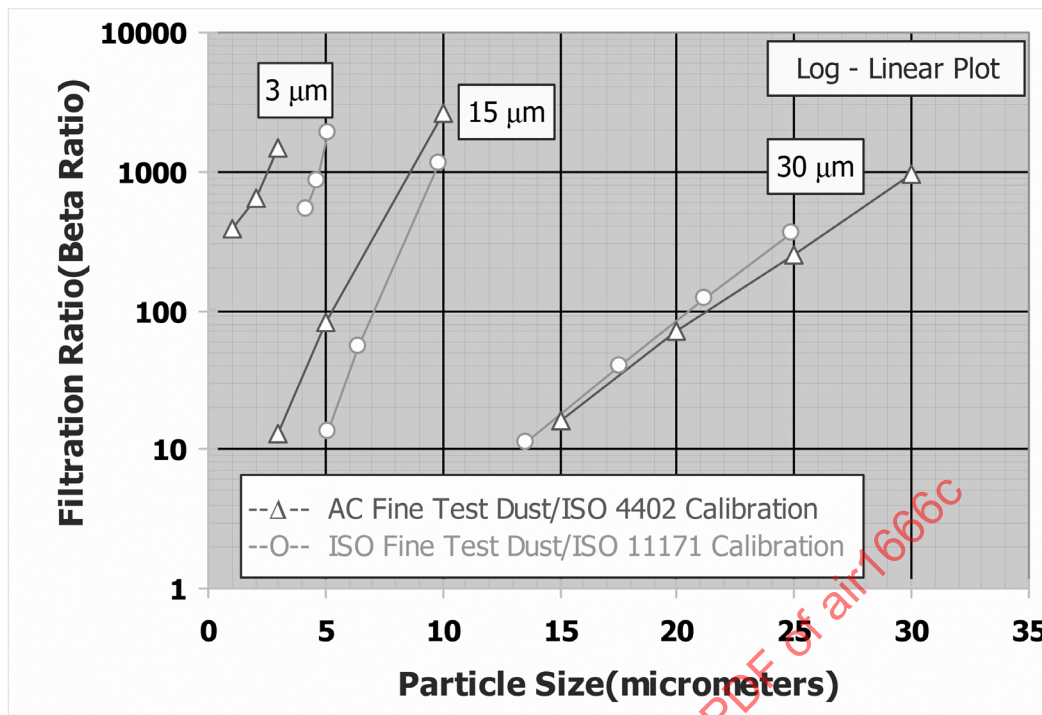


Figure 2 - Comparison of multi-pass filtration ratios (Beta Ratios) with AC Fine Test Dust and ISO Fine Test Dust

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

7.3.1.2 Post Flow Fatigue Filtration Efficiency

The post flow fatigue filtration efficiency test is designed to demonstrate the ability of the filter element to maintain an adequate level of performance when subjected to the stresses associated with the cyclic flow(s)/pressure(s) that may be encountered in service in some applications.

A modified multi-pass filter element performance test is used to determine filter element efficiency. In this test, a reduced flow rate, along with a reduced particulate challenge level, is employed. The reduced flow rate and reduced particulate challenge level allow for an adequate test time to acquire meaningful data since the flow fatigue test requires loading the filter element, significantly, with contaminant in order to achieve the required filter element differential pressures associated with the flow fatigue test cycles.

7.3.2 Historical Methods for Determining Filter Rating

Historically, several alternative methods have been used to measure filter ratings. In comparison to these methods, the multi-pass filter element performance test has several advantages: (1) efficiency is measured more accurately, (2) efficiency is evaluated for a range of particle sizes, and (3) efficiency is measured as the filter element becomes loaded with contaminant over the simulated service life of the filter element.