INTERNATIONAL

AEROSPACE INFORMATION REPORT

AIR887™	REV. C
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(R) Liquid Filter Ratings, Parameters and Tests

RATIONALE

AIR887C has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE

This SAE Aerospace Information Report (AIR) identifies and explains the meaning of various ratings and terms used to describe the physical characteristics of liquid filter elements. The significance of various filter parameters is discussed. In addition, a number of filter test methods are briefly described. This AIR and the data presented are only applicable where the system liquid wets the filter elements.

2. REFERENCES

2.1 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.

2.1.1 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

ARP598 Aerospace Microscopic Sizing and Counting of Particulate Contamination for Fluid Power Systems

ARP901 Bubble-Point Test Method

ARP1827 Measuring Aircraft Gas Turbine Engine Fine Fuel Filter Element Performance

AS4059 Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids

ARP4205 Aerospace Fluid Power - Hydraulic Filter Elements - Method for Evaluating Dynamic Efficiency with Cyclic Flow

ARP5454 Multi-Pass Method for Evaluating Filtration Performance of Fine Lube Filter Elements Utilized in Aerospace Power and Propulsion Lubrication Systems

AIR5455 Impact of Changes in Test Dust Contaminants and Particle Counter Calibration on Laboratory Filter Element Performance and Fluid Cleanliness Classes

2.1.2 U.S. Government Publications

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

MIL-F-8815 Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems General Specification For

MIL-PRF-5606 Hydraulic Fluid, Petroleum Based

MIL-PRF-83860 Filter Elements, Disposable, Fluid Pressure, Hydraulic Line, 5 Micron Absolute

2.1.3 ISO Publications

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO 12103-1 Road Vehicle - Test Dust for Filter Evaluation - Part 1 - Arizona Test Dust

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

3. GENERAL DATA ON ISO TEST DUSTS

The new International Standard Organization (ISO) test dusts are manufactured from the same Arizona Road Dust as AC fine test dust (ACFTD), but processed with a jet mill and classified into well-controlled particle size distributions. Suspensions of the ISO medium test dust are certified by National Institute of Standards & Technology (NIST) as a reference material for Automatic Particle Counter (APC) calibration. The ISO fine test dust does not have a particle size distribution equivalent to ACFTD. The ISO test dust particles have been measured by projected area using an electron microscope and are not equivalent to the ACFTD particles measured by the longest dimension using ARP598 microscopic examination.

Filter efficiency ratings (see 4.2) and dirt capacity (see 5.2) test results can vary significantly when the new ISO test dusts are used in place of the AC test dusts. The main reason for these variations is the finer distribution and the greater number of small particles in ISO test dusts.

4. FILTER RATINGS

Filter ratings were created to provide a technical method to establish how efficient the filter element is in the removal of particulate from a test system, and to differentiate performance between filter elements. Many factors are considered in establishing a filter rating procedure, such as sensitivity, repeatability between tests and reproducibility between laboratories. While each filter rating measures a parameter, which attempts to correlate with system performance, the rating procedures can only simulate rather than reproduce system conditions.

4.1 Absolute Filtration Rating

The absolute filter rating is defined as the diameter of the largest hard spherical particle, which will pass through the filter element under specified test conditions. This is an indication of the largest opening in the filter element. The Absolute rating is determined by the “Maximum Particle Passed Test” (see 6.2) in which a volume of fluid containing various sizes of spherical particles is passed through the filter element. The effluent is then passed through a membrane analysis filter, which is then examined under a microscope to determine the largest spherical particle which passed through the filter element.

Since contaminants are rarely spherical, the absolute rating cannot be correlated with other efficiency ratings and is usually less significant in defining filter performance than is the efficiency rating. Different types of filter media with the same absolute rating may have a significantly different efficiency at removing system contamination. However, in some systems an absolute filter rating may be applied in an attempt to ensure removal of particles of a size that could block a small orifice or passage.

4.2 Filtration Ratings

Filtration ratings attempt to assess the particulate removal capability of the filter. Several methods of expressing filtration ratings or efficiency that are in use are as follows:

4.2.1 Nominal Rating

The Nominal Rating is an arbitrary value established primarily by filter manufacturers. Generally, “nominal” means a high percentage removal of specific size particles. A 10-micrometer nominal element may be claimed to remove 90% or more of particles of size 10 micrometers or larger.

Since no established removal values or standard test procedures exist, the use of this rating is not recommended.

4.2.2 Filtration Ratio

A filtration ratio test defines the efficiency of a filter element in removing particles at various particle sizes under specified test conditions. The filtration ratio is the ratio of the number of particles larger than a given size flowing into a filter element to the number of particles larger than the same size simultaneously leaving the filter element. In this test, a predetermined mass of test contaminant, of specified characteristics and mixed with the test fluid into a slurry, is introduced into the test system at a steady rate until depleted. The filtration ratio is obtained by dividing the number of upstream particles greater than a given particle size by the number of downstream particles greater than the same particle size.

$$\text{Filtration Ratio } (x) = \frac{\text{No. of Upstream Particles Greater than } (x) \text{ Micrometres}}{\text{No. of Downstream Particles Greater than } (x) \text{ Micrometres}} \quad \text{(Eq. 1)}$$

The filtration ratio can be expressed by the following:

$$FR_x = \frac{N_u}{N_d} \quad \text{(Eq. 2)}$$

where:

FR_x = Filtration ratio for contamination > x µm

N_u = Number of particles greater than size (x µm) per unit volume of fluid upstream of the filter

N_d = Number of particles greater than size (x µm) per unit volume of fluid downstream of the filter

Example: For particles 10 µm and greater in size
$N_u = 3760$
$N_d = 68$

Then:

$$FR_{10} = \frac{3760}{68} = 55$$

Filtration ratio values are obtained throughout the test at designated intervals while the test is in progress. The test must proceed from start to completion without interruption. In this test, a predetermined mass of specified test contaminant is ingressed continuously in slurry form in to the test system. Conditions of fluid temperature, system fluid volume, and flow through the test filter are maintained constant during the test while the filter element pressure differential is monitored. Filtration ratios are determined throughout the test, at designated intervals, by counting particles at specified size ranges from samples of test fluid withdrawn simultaneously upstream and downstream of the element. Since the filtration ratio varies during the filtration ratio test, an average of the measured filtration ratios for particles greater than any size of interest is used rather than the minimum value. The average beta ratio is calculated in accordance with ISO 16889, ARP1827 or ARP5454. The test contaminants, the test system, and method are described under multi-pass test in 6.4.

Different filtration ratio symbols have been assigned to several efficiency tests. The Greek symbol α (alpha) is used to indicate a multi-pass filtration ratio test employing ISO (AC) coarse test dust contaminant. The Greek symbol β (beta) is used to indicate a multipass filtration ratio test employing ISO (AC) medium test dust when testing per ISO 16889 and ISO (AC) fine test dust when testing per ARP1827 or ARP5454. The Greek symbol θ (theta) is used to indicate a single pass filtration ratio test employing ISO (AC) coarse test dust contaminant. The Greek symbol σ (sigma) is used to indicate a dynamic multi-pass efficiency test under a cyclic flow condition and employing ISO (AC) fine test dust when testing per ARP4205.

The filtration ratio can be converted to an Efficiency Rating ("E_x") by the following formula:

$$E_x = 100\% - \frac{100\%}{FR_x} \text{ or } \frac{FR_x - 1}{FR_x}(100\%) \quad \text{(Eq. 3)}$$

where:

E_x = Efficiency, expressed as percent of the filter mediums ability to remove particles at a particles size (x), by count

Example: For an FR_{10} of 55:

$$E_{10} = \frac{55 - 1}{55} \times 100\% = 98.2\%$$

For comparison of filter media, the Efficiency Ratings (E_x) for a number of filtration ratios are indicated in Table 1:

TABLE 1

Filtration Ratio	Efficiency Rating (E_x)
1	0
2	50%
10	90%
20	95%
50	98%
100	99%
1000	99.9%

A filter element with a reported β-Rating of $\beta_3 \geq 50$ would remove a minimum of 98% of all test dust particles greater than 3 µm. Similarly a filter element with a β-Rating of $\beta_{10} \geq 20$ would remove a minimum of 95% of all the particles greater than 10 µm. Obviously the element rated $\beta_3 \geq 50$ will remove many more small particles; especially in the 3 to 10 µm range, than will the element rated β10 ≥ 20.

A number of filtration ratings can be based on the filtration ratio. Some of the more common of these ratings are as follows:

4.2.2.1 Minimum Beta Ratio

The minimum value of the filtration ratio for specified particle sizes during the filtration ratio test.

4.2.2.2 The Average Beta Ratio

Since the filtration ratio may vary with differential pressure and from one sample point to the next, an average of the measured filtration ratios for particles greater than any size of interest is used rather than the minimum value. The average beta ratio is calculated in accordance with ISO 16889.

4.2.2.3 The Time Averaged Beta Ratio

Since there is a time base for the test, a time averaged filtration ratio is sometimes used. Either time averaged beta ratios or time averaged efficiencies can be used, but the results are not the same. Currently, the most favored time average is based on the efficiencies.

4.3 Efficiency by Weight

A number of Military Specifications, such as MIL-F-8815 and MIL-PRF-83860, require that a filter element remove a minimum percentage by weight of a specified contaminant when a certain weight of the contaminant is added on the upstream side of the element. This is known as a Degree of Filtration Test (see 6.3). While the test is very repeatable it has the disadvantage of measuring the efficiency of an element only at the beginning of its life.

5. SIGNIFICANT FILTER TESTS

In addition to the filtration ratings the various tests that are used to further determine the performance of an element are:

a. Clean pressure drop

b. Dirt capacity

c. Collapse pressure

d. Flow fatigue

e. Reverse flow

f. Media migration

g. Material compatibility

h. Cold start capability

i. Contaminant retentivity

5.1 Clean Pressure Drop

Clean pressure drop is the differential pressure across a new filter element at specified flow rates and temperatures with a specified fluid. As a specification requirement, clean pressure drop provides little measure of filter element service life compared to the dirt holding capacity to a specified terminal drop. See 6.5 for the test method.

5.2 Dirt Capacity

The dirt capacity of a filter element relates to the frequency of maintenance, filter element change out intervals, and these relate to the economy of operation. The selection for a required dirt capacity for a filter element for a particular flow-rate and filtration rating must be based on a trade-off study between size and economy.

The Dirt capacity is the amount of contaminant added in a laboratory test to attain a filter element differential pressure corresponding to the change-out differential pressure for a specific application.

The filter element differential pressure, on which dirt capacity is based, is usually the setting at which the differential pressure indicator actuates. In the absence of an indicator, other parameters may be used, as shown below:

a. The pressure drop just below the cracking pressure of the housing bypass valve.

b. An arbitrarily selected value below the collapse strength of the filter element; a typical level being 3 to 9% of system operating pressure. In this case it should be verified that the filter element construction allows for filter performance to the stipulated differential pressure.

In dirt capacity tests, increments of a standard contaminant are added continuously (ISO 16889) or periodically (MIL-F-8815) until a specified differential pressure is reached. See 6.6 for a more detailed description of the procedure. The total contaminant added is called the apparent dirt capacity of the filter element. The retained dirt capacity is the amount of contamination retained by the filter element during the test. The difference between the two dirt capacities is the amount of contaminant that passes through the filter element. Dirt capacity tests are sensitive to several test variables such as contaminant characteristics, rate and amount of contaminant added, fluid, temperature, flow rate and system conditioning (volume, cleanup filter, etc.).

ISO test dusts (per ISO 12103-1), which simulate natural airborne dust, are commonly used for dirt capacity testing. Different contaminants will yield different capacities for the same filter elements. While other contaminants can be used, the ISO dusts provide standardized contaminants at relatively low cost. The ISO 12103-1 test dusts are categorized into four grades based on their particle distributions.

A1: ultrafine
A2: fine
A3: medium
A4: coarse

One basic difference in commonly used dirt capacity tests is whether or not a cleanup filter is permitted downstream of the test filter element during testing. The use of a cleanup filter will increase the apparent dirt capacity. The lower the filtration efficiency of the element, the greater the increase in apparent dirt capacity of the element. However, if use of a cleanup filter is not permitted, the volume and design of the test circuit can have an effect on the apparent dirt capacity and influence the repeatability of the test with different test stands.

In addition to the Dirt Capacity, filter element service life is also related to contamination generation within the system and ingestion rates. Contamination generation is related to filter element efficiency since high efficiency filter elements provide cleaner systems that result in less wear and contamination generation.

5.3 Collapse Pressure

The collapse pressure is the maximum differential pressure that the filter element can withstand without filtration medium or structural failure. The minimum collapse pressure must exceed the filter bypass relief valve setting to allow for full flow pressure drop at cold temperature. For a filter without a bypass relief valve the minimum collapse pressure should be higher than the maximum differential pressure that can be developed across the filter element during system operation; see 6.7 for a collapse pressure test method. For instance, high pressure filter elements designed in accordance with MIL-F-8815 are required to meet a collapse pressure 1.5 times the system operating pressure.

5.4 Flow Fatigue

Flow fatigue tests determine the integrity of the filter element to withstand pulsating flow by subjecting the element to a flow cycle that normally ranges from zero to a specified percentage of rated flow and back to zero. Test dust is added so that cycles are conducted at specified differential pressure(s). The number of flow cycles and differential pressure specified for testing should be dependent upon the expected service life and operating conditions. See 6.8 for test procedure.

5.5 Reverse Flow

In some systems, the filter element may be subjected to reverse flow, i.e., fluid flow through the filter housing is in a direction which is the reverse of the normal flow direction. Reverse flow capability can be designed into a filter element by the use of support screens or mesh on both sides of the medium. Often a better alternative is to design the housing to allow the reverse flow condition to bypass the filter element. Also with an appropriate reverse-flow bypass valve, the housing can be designed so the direction of the flow through the filter element is always the same regardless of direction of flow though the housing. See 6.9 for the test procedure.

5.6 Media Migration

Media migration tests are specified to determine, and hence, limit, the amount of filtration medium or other materials of construction that are released from the filter element during operating conditions. The release is caused by failure of the media to maintain its structural integrity under intended service conditions. Such released material becomes a contaminant in a system. See 6.10 for the test procedure.

5.7 Material Compatibility

Material compatibility tests are specified to determine the integrity of the filter element after artificially aging it in the fluid in which it is to be used at an elevated temperature. See 6.12 for the test procedure.

5.8 Cold Start Capability

This test determines the ability of the filter element to withstand the high differential pressures generated at the start-up of a hydraulic system, especially under cold environmental conditions. See 6.11 for test procedure.

5.9 Contaminant Retentivity

Contaminant retentively is the ability of a filter element to retain the contaminant under various conditions of differential pressure and flow. The dynamic efficiency of a filter element is known to vary and sometimes degrade by sudden releases of contaminant as differential pressure and flow changes. Therefore, conducting dynamic efficiency tests at differential pressures and flow conditions similar to those expected in actual service will better indicate the ability of the filter element to retain contaminants under service conditions.

6. FILTER ELEMENT TEST METHODS

6.1 Bubble Point Test

The bubble point test measures the air pressure when the first steady stream of air bubbles is observed to emit from the top surface of a filter element placed approximately 0.5 inch (12.7 mm) beneath the surface of the bubble point test liquid. The air pressure required to maintain the first stream of bubbles through a pore is inversely proportional, in simplified theoretical models, to the size of the largest pore in the element after appropriate corrections for immersion depth, test liquid surface tension, and a shape correction factor for the type of media.

For simple filtration media, such as simple metal meshes, an approximate correlation can be established between the Bubble Point test and the size of the maximum spherical particle passed in the Maximum Particle Passed test. While this is not the case for more complex filtration media, typically utilized in Aerospace hydraulic systems, the nondestructive bubble point test is an excellent test for qualifying the integrity of filter elements and serves as a quality control test. For a more complete discussion of bubble point testing see ARP901.

6.2 Maximum Particle Passed Test

This test is a measure of the largest spherical contaminant that will pass through a filter element under specified test conditions. The size of this particle is an indication of the largest opening in the filter element. If the filter element is considered non-cleanable the Maximum Particle Passed test is a destructive test and the element should not be used after testing.

The test procedure is in accordance with the procedure in MIL-F-8815. The filter element is installed in a test system provided with a contaminant-mixing chamber and quick opening valve immediately upstream of the filter. The fluid to be used in the test is cleaned until a high degree of cleanliness is obtained. Maximum Particle Passed tests usually require that the test fluid be AS4059 Class 1 or cleaner. Extremely careful cleaning is required to ensure particles from a previous test are not present on the downside of the filter element.

A measured quantity of test contaminant with a known particle size range and distribution, typically spherical glass beads or a mixture of Carbonyl Iron E and glass beads both smaller and larger than the specified rating of the filter element, is injected into the contaminant mixing chamber. After thorough agitation, a measured volume of the resulting mixture is passed through the filter element and collected in a clean beaker. The effluent is then passed through a very fine membrane filter, typically of 0.45-μm pore size. The membrane filter is then examined under a high power microscope fitted with a graduated scale (ocular reticle). By visual observation, the diameter of the largest glass bead or Carbonyl Iron E particle on the membrane is determined. The diameter of this largest bead, expressed in μm, is considered to be the absolute rating of the filter element.

The preferred test contaminants are hard spherical particles. Because of their distinctive shape, they can be differentiated from contaminants, which may be present on the downstream side of a filter element.

6.3 Degree of Filtration Test

This test is a measure of the gravimetric efficiency, expressed as a percentage, of the filter element in removing a specified test contaminant (glass beads, ISO fine, medium or coarse test dusts or some combination of test dust and beads) under specified test conditions. The test procedure is in accordance with MIL-F-8815.

The test system and method are similar to that used for the Maximum Particle Passed test, except that the weight of the test contaminant that passes through the test element, and retained on the analytical membrane filter is determined by gravimetric analysis. The fluid to be used in the test is cleaned until a degree of cleanliness is obtained which will have no significant effect on determination of filter efficiency. Degree of Filtration tests usually require that the test fluid be AS4059 Class 1 or cleaner. Then the degree of filtration or gravimetric efficiency is determined by Equation 6:

$$\text{Eff} = \frac{A - (B - C)}{A} \times 100 \qquad \text{(Eq. 4)}$$

where:

A = Mass of test contaminant passed through the system without a filter element in the filter housing

B = Mass of test contaminant passed through the test filter assembly with the filter element installed

C = blank value; amount of test contaminant attributed to the test system and test filter assembly when no test contaminant is added.

Step-by-step procedures and a detailed schematic for conducting the degree of filtration test can be found in many Military Specifications such as MIL-F-8815.

6.4 Multi-pass Filter Performance Test

The multi-pass filter element performance test is used to determine the filtration ratios for specified particle size ranges for a filter element. The test was developed by the Fluid Power Research Center at Oklahoma State University. A detailed test procedure may be found in ISO 16889 or ARP1827 or ARP5454. See 4.2.2 for explanation of the filtration ratio. In the multi-pass test, new test contaminant is continuously injected into the test system and combines with the contamination in the system not trapped by the filter element under test. Samples of test fluid are withdrawn simultaneously upstream and downstream of the filter element under test. All the referenced test methods currently specify in-line sampling using APC's eliminating errors caused by sample bottle cleanliness. The cumulative particle size distribution per milliliter of fluid is determined at specified particle size ranges. Filtration ratios can then be determined at various levels of filter element loading. In addition, the filtration efficiency can be determined as described in 4.2.2.

In ISO 16889, an anti-static agent is added to the test fluid, MIL-PRF-5606.

The antistatic agent:

a. Minimizes charged particle cohesion

b. Helps disperse the test dust more evenly

c. Minimizes or eliminates the effects of static electricity in the fluid system

In some cases, filtration ratios and dirt capacity may be significantly different (usually higher) when the test is conducted without the antistatic additive. Thus, there may be a significant variance in test results depending on whether or not an antistatic agent is used. It should be noted that multi-pass test procedures that require the use of anti-static agents specify a fluid conductivity limit below which anti-static agent has to be added to obtain the required fluid conductivity. The long term impact of increasing concentration of anti-static agent, especially if the agent degrades with time, is not well characterized, and, potentially, could lead to variations in test results. The multi-pass test can also be used to determine dirt capacity based on the contamination injection rate and the time required to reach a specified differential pressure (see 6.6.1).

6.4.1 Modified Multi-pass Tests

In one modification of the multi-pass test, an on-stream cleanup filter is installed downstream of the downstream sampling port. This filter prevents a build-up of fines in the system, which can overload the automatic particle counters. The resulting filtration ratio is known as the θ (theta) ratio when ISO (AC) coarse test dust is used as the test contaminant.

6.5 Clean Element Pressure Drop Test

The clean filter element pressure drop is the pressure drop across the filter element excluding pressure losses in the housing. In the clean filter element pressure drop test, clean fluid is normally passed first through empty test housing or test housing with a free flow dummy element and then through the housing with the test filter element installed. The difference in pressure drop with and without the filter element installed is the clean element pressure drop. There are occasions where an empty housing has a higher-pressure drop than one with a filter element in it. This unusual occurrence might be due to vortexes, which the filter element breaks up. A negative clean pressure drop is meaningless. To avoid the above, the use of free flow dummy elements is recommended. The free flow dummy elements are, often, the filter element itself without the filtration medium pack. Flow rates, fluid temperature (viscosity) are controlled, measured, and recorded. ARP24 provides guidance on measuring differential pressure. By subtracting the tare value for the filter assembly without the filter element, the pressure drop across the filter element alone can be determined.