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AEROSPACE INFORMATION REPORT

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LIQUID FILTER RATINGS, PARAMETERS AND TESTS

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 is briefly described. This AIR and the data presented are only applicable to filters in which the system liquid wets the filter elements. This document includes equivalent metric units (in parentheses) as referenced information.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other documents shall be the issue in effect on the date of the purchase order.

- 2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP24 Determination of Hydraulic Pressure Drop
ARP901 Bubble Point Test Method

- 2.1.2 U.S. Government Publications: Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-F-8815 Filter and Filter Elements, Fluid Pressure, Hydraulic Line
MIL-F-24402 Filters (Hydraulic), Filter Elements (High Efficiency)

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2.1.3 NFPA Publications: Available from National Fluid Power Association, 3333 N. Mayfair Road, Milwaukee, WI 53222-3219.

ANSI/(NFPA) T3.10.8.8 Hydraulic Fluid Power - Filters - Multi-pass Method for Evaluation Filter Performance (Revision and redesignation of ANSI/B93.31)

NFPA T3.10.8.18 Multi-pass Method for Evaluating the Filtration Performance of Coarse Hydraulic Filter Element

3. FILTER RATINGS:

Filter ratings are arbitrary yardsticks which have been selected to differentiate performance between filter elements. Many factors are considered in establishing a filter rating procedure, such as sensitivity, reproducibility from test to test and between laboratories, and speed of performance. 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.

3.1 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 5.2) in which a volume of fluid containing various size spherical particles is passed through the filter element. The effluent fluid 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 the efficiency rating 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. The primary significance of the absolute rating determined by the "Maximum Particle Passed Test" is that it is often correlated with the "Bubble Point Test" (see 5.1) which can then be used to provide a quality conformance test for production elements. However, in some systems an absolute filter rating may be applied in an attempt to insure removal of particles of a size that could block a small orifice or passage.

3.2 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:

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3.2.1 Nominal Filtration Rating: The nominal filtration rating is a measure of the retention by weight of a specified artificial contaminant of a given concentration under specified test conditions. "Nominal" ratings are usually based on a 90, 95, or 98% retention by weight when tested in a degree of filtration test similar to that described in 5.3 under filtration test methods. Due to many variations in test procedures and lack of uniformity in percentage removal, "nominal" ratings are primarily an arbitrary value established by the manufacturer.

Figure 1 indicates the distribution by weight of some artificial contaminants commonly used for filter efficiency tests. As shown in Table 1 the "nominal" filtration rating is dependent upon the percentage retention by weight.

TABLE 1

Contaminant	Nominal Micrometer Rating At 90% Retention	Nominal Micrometer Rating At 95% Retention	Nominal Micrometer Rating At 98% Retention
F-12 glass beads	15	13	12
10-20 μ m glass beads	12	11	9
F-9 glass beads	8	6	4
AC Fine test dust	2	1	0.5

Therefore, to have meaning, the percentage of test contaminant retained by the filter should accompany the "nominal" rating. Identifying the test contaminant and percentage of contaminants retained is preferred to the arbitrary nominal rating often used. The nominal rating, because of its vagueness, is losing favor to the more modern and sophisticated filtration ratio described.

3.2.2 Filtration Ratio: A filtration ratio test defines the dynamic efficiency of a filter to a discrete micrometer size under specified test conditions. The filtration ratio relates the number of particles larger than a given size flowing into a filter to the number of particles larger than the same size simultaneously leaving the filter. 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.

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

Filtration ratio values are obtained at designated intervals while the test is in progress. The test must proceed from start to completion without interruption. In this test, a predetermined weight of a specified contaminant is continuously added 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 pressure differential is

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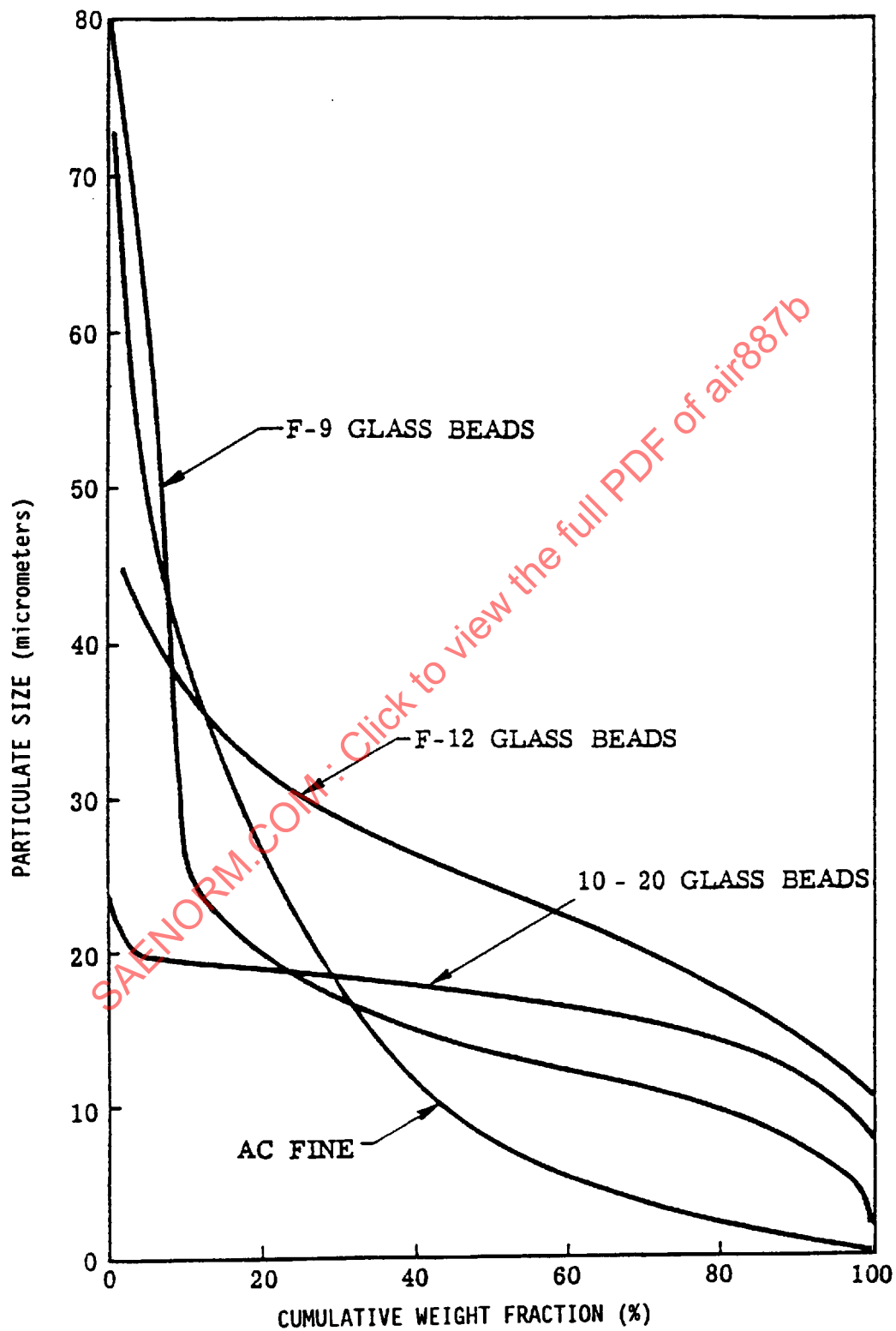


FIGURE 1 - Distribution of Contaminants for Testing Filter Efficiency

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3.2.2 (Continued):

monitored. Filtration ratios are determined at various predetermined levels of differential pressure across the filter by counting particles above a specific size from samples of test fluid withdrawn simultaneously upstream and downstream of the filter element. The test contaminants, the test system, and method are described under multipass test in 5.4.

Different filtration ratio symbols have been assigned to several dynamic efficiency tests. The Greek symbol α (alpha) is used to indicate a multipass filtration ratio test employing air cleaner coarse test dust (ACCTD) contaminant. The Greek symbol β (beta) is used to indicate a multipass filtration ratio test employing air cleaner fine test dust (ACFTD) contaminant. The Greek symbol θ (theta) is used to indicate a single pass filtration ratio test employing air cleaner coarse test dust (ACCTD).

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 $> x \mu\text{m}$

N_u = Number of particles greater than size ($x \mu\text{m}$) per unit volume of fluid upstream of the filter

N_d = Number of particles greater than size ($x \mu\text{m}$) per unit volume of fluid downstream of the filter

Example: For particles $10 \mu\text{m}$ and greater in size

$N_u = 3760$

$N_d = 68$

Then

$$FR_{10} = \frac{3760}{68} = 55 \quad (\text{Eq.3})$$

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

$$E_x = 100\% - \frac{100\%}{FR_x} \text{ or } \frac{FR_x - 1}{FR_x} (100\%) \quad (\text{Eq.4})$$

where:

E_x = Efficiency, expressed as percent, of the filter medium's ability to remove particles over a particle size (x), by count.

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3.2.2 (Continued):

$$FR_{10} = 55 \quad (\text{Eq.5})$$

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

For comparison of filter media, the Efficiency Ratings (E_x) for a number of filtration ratios are indicated in Table 2:

TABLE 2

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 air cleaner fine test dust particles greater than $3 \mu\text{m}$. 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 $10 \mu\text{m}$. Obviously the element rated $\beta_3 \geq 50$ will remove many more small particles; especially in the 3 to $10 \mu\text{m}$ range, than will the element rated $\beta_{10} \geq 20$.

For filtration ratios over 100, a difference of one particle downstream will change the filtration ratio significantly. Therefore, it is recommended that the filtration ratio be based on a smaller size particle when the filtration ratio exceeds 100.

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

- 3.2.2.1 Minimum Beta: The minimum value of the filtration ratio for particles greater than a specified size observed at any of the required measurement points. The current version of ANSI B93.31 requires a minimum beta for particles greater than $10 \mu\text{m}$. Obviously, minimum beta ratings can be identified for particle sizes other than $10 \mu\text{m}$. For fine filters as used in many aerospace systems, β_5 and β_3 ratings are more appropriate.
- 3.2.2.2 The Average Beta: Since the filtration ratio may vary with differential pressure and from one sample point to the next, an arithmetic average of the measured filtration ratio for particles greater than any size of interest is often used rather than the minimum value.
- 3.2.2.3 The Time Averaged Beta: 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.

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3.3 Efficiency by Weight:

A number of Military Specifications, such as MIL-F-8815 and MIL-F-24402, 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 5.3). While the test is very repeatable it has the disadvantage of measuring the efficiency of an element only at the beginning of its life.

4. SIGNIFICANT FILTER PARAMETERS:

In addition to the filtration ratings the various parameters 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. Containment retentivity

4.1 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 element performance compared to the dirt holding capacity at a specified terminal pressure drop. See 5.5 for test method.

4.2 Dirt Capacity:

Dirt capacity is a measure of the "life" of the element, i.e., the amount of contaminant added in a laboratory test before the differential pressure due to clogging becomes so high that the element must be replaced or cleaned.

The element differential pressure on which dirt capacity is based, may be selected on the basis of:

- a. Pressure drop just below the cracking pressure of the housing bypass valve, or
- b. The setting at which the differential pressure indicator actuates, or
- c. An arbitrarily selected value below the collapse strength of the element; a typical level being 3 to 9% of system operating pressure

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

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4.2 (Continued):

Dirt capacity is an important factor in evaluating elements of comparable filtration efficiency. However, dirt capacity is only one factor in determination of element service life. Service life is also related to contamination generation and ingestion rates. Contamination generation is related to filter efficiency since high efficiency filters provide cleaner systems which result in less wear and contamination generation.

In dirt capacity tests, increments of a standard contaminant are added continuously or periodically until a specified differential pressure is reached. See 5.6 for a more detailed description of the procedure. The total contaminant added is called the apparent dirt capacity of the element. The retained dirt capacity is the amount of contamination retained by the filter during the test. The difference between the two dirt capacities is the amount of containment that passes through the filters. Dirt capacity tests are sensitive to several test variables such as contaminant characteristics, rate and amount of contaminant add, fluid, temperature, flow rate and system conditioning (volume, cleanup filter, etc.).

Standardized air cleaner fine test dust, which simulates natural airborne dust, is commonly used for dirt capacity testing. Different contaminants will yield different capacities for the same filters. Another contaminant often used is standardized air cleaner coarse test dust. While other contaminants can be used, the air cleaner test dusts provide standardized contaminants at relatively low cost. Dirt capacity and efficiency are greater at lower flow rates and less at higher flow rates.

One basic difference in commonly used dirt capacity tests is whether or not a cleanup filter is permitted downstream of the test 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.

4.3 Collapse Pressure:

The collapse pressure is the minimum differential pressure across the element for which the element must not collapse, cause permanent degradation of filtration efficiency or fail in any other manner. The minimum collapse pressure must be somewhat higher than the filter bypass relief full flow pressure drop at cold temperature. For filters without bypass reliefs, the minimum collapse pressure should be higher than the maximum differential pressure which can be developed across the filter when installed in the system. See 5.7 for a collapse pressure test method. This pressure can be somewhat higher than the normal peak operating pressure of the system.

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4.4 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 conditions. See 5.8 for test procedure.

4.5 Reverse Flow:

In some systems, the filter element may be subject to reverse flow, i.e., fluid flow through the filter housing is in a direction the reverse of normal. Reverse flow capability can be designed into an element by the use of support screens or mesh on both sides of the medium. Often a better alternative is to design the housing with valving to allow reverse flow to bypass the element. Also with appropriate valving, a housing can be designed so that flow through the element is always the same regardless of direction of flow through the housing. See 5.9 for test procedure.

4.6 Media Migration:

Media migration tests are specified to determine and limit the amount of material that a filter releases from its own media and materials of construction. 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 5.10 for test procedure.

4.7 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 5.12 for test procedure.

4.8 Cold Start Capability:

This parameter determines the ability of the element to withstand the high differentials generated at the start-up of a hydraulic system, especially under cold environmental conditions. See 5.11 for test procedure.

4.9 Containment Retentivity:

Containment retentivity is the ability of an element to retain the contaminant under various conditions of differential pressure and flow. The dynamic efficiency of elements is known to vary and sometimes degrade by sudden releases of contaminant as differential pressures 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 element to retain contaminants under service conditions.

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5. FILTER TEST METHODS:

5.1 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 which is approximately 1/2 in 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 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 a given filter medium, an approximate correlation can be established between the bubble pressure test and the size of the maximum spherical particle passed in the maximum particle passed test. Using this correlation, the bubble pressure test can be used in production testing of filter elements as a quality control test. Even for elements without absolute ratings, the nondestructive bubble point test is often conducted on each element to assure quality.

Depth and semidepth type media have a higher efficiency and absolute rating than mesh filters with the same bubble point. For a more complete discussion of bubble point testing see ARP901.

5.2 Maximum Particle Passed Test:

This test is a measure of the largest standard contaminant that will pass through a filter under specified test conditions. The size of this particle is an indication of the largest pore in the filter element and thus determines the absolute rating of the element. The maximum particle passed test is a destructive test and the element should not be used after testing.

The 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.

A measured quantity of artificial contaminant of 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 absolute rating of the filter - is injected into the contaminant mixing chamber. After thorough agitation, a measured volume of the resulting mixture is passed through the filter and caught in a clean beaker. The effluent is then passed through a very fine membrane filter, typically of .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 on the membrane is determined. The diameter of this largest bead, expressed in μm , is considered to be the absolute rating of the 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 an element.

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5.3 Degree of Filtration Test:

This test is a measure of the efficiency, expressed as a percentage, of the filter element in removing a specified artificial contaminant (glass beads, AC fine or coarse test dust or some combination of test dust and beads) under specified test conditions.

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. Then the degree of filtration or gravimetric efficiency is determined by Equation 6:

$$Eff = \frac{A-M}{A} \times 100\% \quad (\text{Eq.6})$$

where:

A = weight of test contaminant added

M = weight of test contaminant retained by membrane filter

Step-by-step procedures and a detailed schematic for conducting the degree of filtration test can be found in many Military Specifications including MIL-F-8815 and MIL-F-24402.

5.4 Multipass Test:

The multipass test is used to determine the filtration ratio of a filter element. The test was developed by the Fluid Power Research Center at Oklahoma State University. Detailed test procedures may be found in ANSI/(NFPA) T3.10.8.8 and NFPA T3.10.8.18. The two tests listed are similar except AC fine test dust is used to evaluate fine filters and AC coarse test dust is used to evaluate coarse filters. When AC coarse dust is used the resulting filtration ratio is known as the Alpha (α) ratio. With the more commonly used AC fine test dust, the filtration ratio is known as the Beta (β) ratio. See 3.2.2 for explanation of this ratio.

In the multipass test, fresh contamination is continuously injected into the test system and combines with the contamination in the system not trapped by the filter under test. Samples of test fluid are withdrawn simultaneously upstream and downstream of the element under test. ANSI/(NFPA) T3.10.8.8 currently specifies bottle sampling but in-line sampling is often used when evaluating very efficient filters to eliminate the error caused by sample bottle cleanliness. The cumulative particle size distribution per milliliter of fluid is determined, usually at particles sizes of 10, 20, 30, and 40 μm although counts are often obtained for sizes down to 2 μm with automatic particle counters. Filtration ratios can then be determined at various levels of element loading. In addition, the filtration efficiency can be determined as described in 3.2.2.

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5.4 (Continued):

In some cases an antistatic agent is added to the test fluid for the multipass test. 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 several times 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. ANSI/(NFPA) T3.10.8.8 requires the use of an antistatic agent.

The multipass 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.

- 5.4.1 Modified Multipass Tests: In one modification of the multipass 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.

Another variation developed by the Fluid Power Research Center, Oklahoma State University determines a filtration ratio solely from downstream particle concentrations at predetermined increments equal to the time for the fluids to make a complete pass. Usually, at least four circulating cycles are required. This procedure was developed for evaluating low flow, high Beta filters. The filtration ratio is designated as a Beta Prime (β') or Beta Bar rating. Unlike the typical multipass test, there is no additional ingress of contamination throughout the test.

5.5 Clean Element Pressure Drop Test:

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