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Second edition
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Aerospace series — Test methods for hydraulic filter elements —

Part 3: Filtration efficiency and retention capacity

Série aérospatiale — Méthodes d'essais pour les éléments filtrants hydrauliques —

Partie 3: Efficacité de filtration et capacité de rétention

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 10, *Aerospace fluid systems and components*.

This second edition cancels and replaces the first edition (ISO 14085-3:2015), which has been technically revised.

The main changes are as follows:

— Table 3 has been revised;

— 10.3.2 has been revised;

— Figure 4 has been converted to Table 4 and Table 5.

A list of all parts in the ISO 14085 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In aerospace hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure. The liquid is both a lubricant and power-transmitting medium. The presence of solid contaminant particles in the liquid interferes with the ability of the hydraulic fluid to lubricate, and causes wear and malfunction of the components. The extent of contamination in the fluid has a direct bearing on the performance, reliability, and safety of the system, and should be controlled to levels that are considered appropriate for the system concerned.

Different principles are used to control the contamination level of the fluid by removing solid contaminant particles; one of them uses a filter element enclosed in a filter housing. The filter element is the porous device that performs the actual process of filtration. The complete assembly is designated as a filter.

The performance characteristics of a filter are a function of the filter element (its medium and geometry) and the housing (its general configuration and seal design). For a given filter, the actual performance is a function of the characteristics of the liquid (viscosity, temperature, conductivity, etc.), the particles in suspension (size, shape, hardness, etc.), and the flow conditions.

A standard multi-pass method for evaluating the performance of hydraulic fluid filter elements under steady state conditions has been developed and used for several years, and is referred to in several aircraft hydraulic systems specifications.

Most aircraft hydraulic systems are subjected to unsteady flow with flow cycles caused by such conditions as actuator movement. Such flow variations can have a significant impact on filter performance. The relative performance of hydraulic filters is compared in order to select the most appropriate filter. To ensure the reliability of such comparisons, it is necessary to perform testing with the same standard operating conditions.

This document describes two test methods and the equipment required to measure hydraulic filter element performance with multi-pass flow in both steady and cyclic conditions.

The influence of other stressful operating conditions, such as heat, cold, and vibration, are not measured with this procedure alone. The influence of such conditions is determined with pre-conditioning performed on the test filter element prior to efficiency testing (refer to ISO 14085-1 for descriptions of such tests and when they are applied).

The stabilized contamination level measured while testing with cyclic flow gives an indication of the average contamination level maintained by the filter in a dynamic operating system. The average system contamination level is important in establishing wear rates and reliability levels.

The measurements are made with precise control over the operating conditions, in particular the test fluid and test contaminant, to ensure repeatability and reproducibility. However, because the test parameters and test contaminant do not exactly replicate actual operating conditions which significantly differ from one system to another, the measurements cannot be expected to duplicate the actual performance in an operating system.

Aerospace series — Test methods for hydraulic filter elements —

Part 3: Filtration efficiency and retention capacity

1 Scope

This document describes two methods to measure in repeatable conditions the filtration efficiency of filter elements used in aviation and aerospace hydraulic fluid systems. It can be applied when evaluating the overall characteristics of a filter element according to ISO 14085-1, or separately.

Since the filtration efficiency of a filter element can change during its service life as it is clogging, this test method specifies its continuous measurement by using on-line particle counters with continuous injection of test contaminant and recirculation of particles not retained by the test filter element until the differential pressure across the element reaches a given final or "terminal" value.

This document allows the efficiency to be measured under both steady or cyclic flow conditions. It is also applicable to measuring the stabilized contamination levels that are produced by the filter element while testing with cyclic flow.

This document is not applicable to qualifying a filter element under replicate conditions of service; this can only be done by a specific test protocol developed for the purpose, including actual conditions of use, e.g. the operating fluid or contamination.

The test data resulting from application of this document can be used to compare the performance of aerospace hydraulic filter elements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2942, *Hydraulic fluid power — Filter elements — Verification of fabrication integrity and determination of the first bubble point*

ISO 3968, *Hydraulic fluid power — Filters — Evaluation of differential pressure versus flow*

ISO 4021, *Hydraulic fluid power — Particulate contamination analysis — Extraction of fluid samples from lines of an operating system*

ISO 4405, *Hydraulic fluid power — Fluid contamination — Determination of particulate contamination by the gravimetric method*

ISO 5598, *Fluid power systems and components — Vocabulary*

ISO 11171, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*

ISO 11218, *Aerospace — Cleanliness classification for hydraulic fluids*

ISO 11943, *Hydraulic fluid power — Online automatic particle-counting systems for liquids — Methods of calibration and validation*

ISO 12103-1:2024, *Road vehicles — Test contaminants for filter evaluation — Part 1: Arizona test dust*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

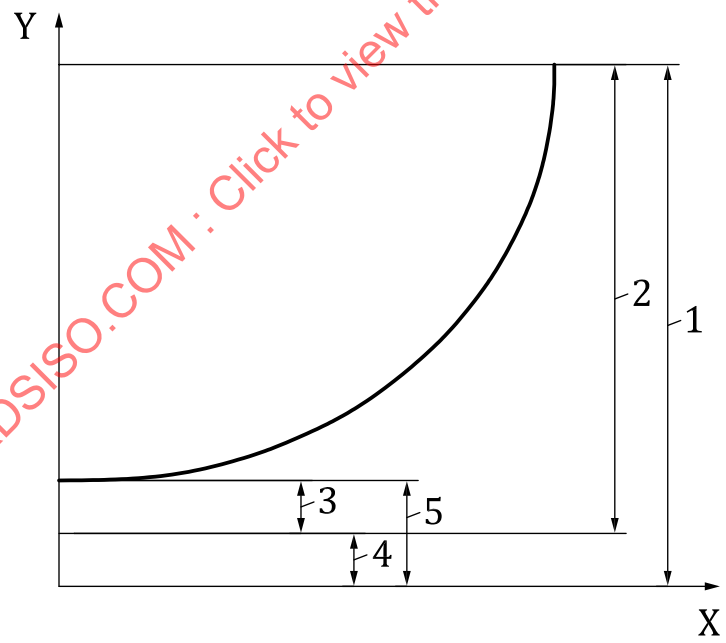
— IEC Electropedia: available at https://www.electropedia.org/

3.1
contaminant mass injected
mass of a specific particulate contaminant injected into the test circuit to obtain the terminal differential pressure

3.2
cyclic flow
change of flow from the specified rated flow rate to 25 % of the rated flow rate at a specified frequency and waveform

3.3
differential pressure
Δp
difference between the inlet and outlet pressures of the component under test, as measured under specified conditions

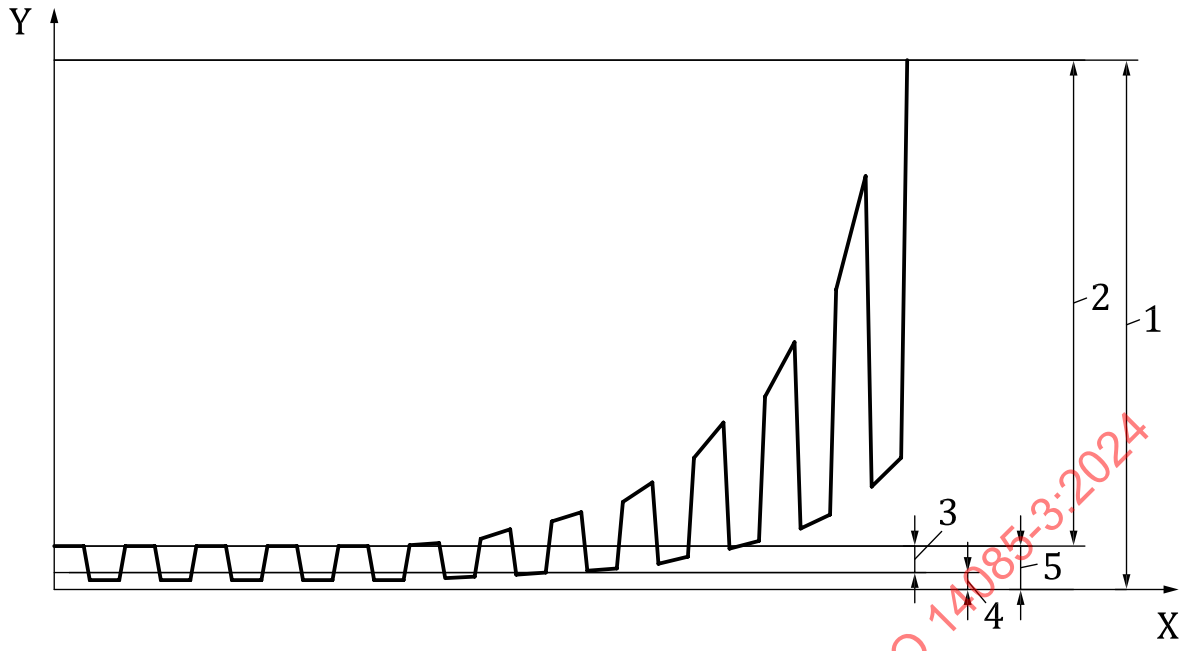
Note 1 to entry: See Figure 1 and Figure 2 for graphical depiction of *differential pressure* (3.3) terms.



Key

X	test time or mass injected	3	clean element differential pressure
Y	differential pressure	4	housing differential pressure
1	final assembly (end of test) differential pressure	5	clean assembly differential pressure
2	terminal element differential pressure		

Figure 1 — Differential pressure conventions for multi-pass test with steady flow



Key

X	test time or mass injected	3	clean element differential pressure at test flow rate (q_f)
Y	differential pressure	4	housing differential pressure at test flow rate (q_f)
1	final assembly (end of test) differential pressure	5	clean assembly differential pressure at test flow rate (q_f)
2	terminal element differential pressure at test flow rate (q_f)		

Figure 2 — Differential pressure conventions for multi-pass test with cyclic flow

3.3.1
clean assembly differential pressure
difference between the tested component inlet and outlet pressure as measured with a clean filter housing containing a clean filter element

3.3.2
clean element differential pressure
differential pressure (3.3) of the clean element calculated as the difference between the *clean assembly differential pressure* (3.3.1) and the *housing differential pressure* (3.3.4)

3.3.3
final assembly differential pressure
assembly *differential pressure* (3.3) at end of test equal to sum of housing plus *terminal element differential pressures* (3.3.5)

3.3.4
housing differential pressure
differential pressure (3.3) of the filter housing without an element

3.3.5
terminal element differential pressure
maximum *differential pressure* (3.3) across the filter element as designated by the manufacturer or specification to limit useful performance

3.4
filtration ratio
ratio of the number of particles larger than a specified size per unit volume in the influent fluid to the number of particles larger than the same size per unit volume in the effluent fluid

Note 1 to entry: For steady flow testing, the filtration ratios are designated with the Greek letter beta, *ß*.

Note 2 to entry: For *cyclic flow* (3.2) testing, the filtration ratios are designated with the Greek letter sigma, *σ*.

3.5
free-flow dummy element
duplicate test filter element with its media layers removed to replicate the flow pattern in the housing generated by the test filter element

3.6
rest conductivity
electrical conductivity at the initial instant of current measurement after a DC voltage is impressed between electrodes

Note 1 to entry: It is the reciprocal of the resistance of uncharged fluid in the absence of ionic depletion or polarization.

3.7
retention capacity
mass of specific particulate contaminant effectively retained by the filter element when *terminal element differential pressure* (3.3.5) is reached

4 Symbols

Symbol	Unit	Description or explanation
$\overline{A}_{u,x}$	particles per millilitre	Overall average upstream count greater than size, x
$\overline{A}_{d,x}$	particles per millilitre	Overall average downstream count greater than size, x
$\overline{c}_b$	mg/l	Average base upstream gravimetric level
c_b'	mg/l	Desired base upstream gravimetric level
$\overline{c}_i$	mg/l	Average injection gravimetric level
c_i'	mg/l	Desired injection gravimetric level
c_{80}	mg/l	Test reservoir gravimetric level at 80 % assembly Δp
m	G	Mass of contaminant needed for injection
m_e	G	Estimated filter element capacity (mass injected)
m_i	G	Contaminant mass injected
m_p	G	Contaminant mass injected at element differential pressure
m_R	G	Retained capacity
n	None	Number of counts in specific time period
$N_{u,x,j}$	particles per millilitre	Number of upstream particles greater than size, x, at count, j
$N_{d,x,j}$	particles per millilitre	Number of downstream particles greater than size, x, at count, j
$\overline{N}_{u,x,t}$	particles per millilitre	Average upstream count greater than size, x, at time interval, t
$\overline{N}_{d,x,t}$	particles per millilitre	Average downstream count greater than size, x, at time interval, t
Δp	Pa or kPa (bar)	Differential pressure
Δp_f	Pa or kPa (bar)	Final assembly differential pressure

Symbol	Unit	Description or explanation
Δp_n	Pa or kPa (bar)	Net assembly differential pressure
$\Delta p_{2,5\ \%}$	Pa or kPa (bar)	Assembly differential pressure after increase of 2,5 % net Δp
$\Delta p_{80\ \%}$	Pa or kPa (bar)	Assembly differential pressure after increase of 80 % net Δp
$\bar{q}_f$	l/min	Average filter test flow rate
q_d	l/min	Discarded downstream sample flow rate
q_f	l/min	Filter rated flow (maximum flow for cyclic conditions)
q_i'	l/min	Desired injection flow rate
$\bar{q}_i$	l/min	Average injection flow rate
q_u	l/min	Discarded upstream sample flow rate
t	min	Test time
t'	min	Predicted test time
t_f	min	Final test time
t_i	min	Total injection time
t_p	min	Test time at element differential pressure
$t_{2,5\ \%}$	min	Test time at beginning of 2,5 % stabilization period
$t_{80\ \%}$	min	Test time at beginning of 80 % stabilization period
V_{if}	l	Final measured injection system volume
V_{ii}	l	Initial measured injection system volume
V_{min}	l	Minimum required operating injection system volume
V_{tf}	l	Final measured filter test system volume
V_v	l	Minimum validated injection system volume
x, x_1, x_2	µm(c)	Particle sizes
β_x	None	Filtration ratio at particle size, x (steady flow)
$\beta_{x,t}$	None	Filtration ratio at particle size, x, and time interval, t (steady flow)
$\bar{\beta}_x$	None	Average filtration ratio at particle size x (steady flow)
σ_x	None	Filtration ratio at particle size, x (cyclic flow)
$\sigma_{x,t}$	None	Filtration ratio at particle size, x, and time interval, t (cyclic flow)
$\bar{\sigma}_x$	None	Average filtration ratio at particle size, x (cyclic flow)

5 Test procedure overview

5.1 Set up and maintain apparatus in accordance with Clause 6 and Clause 7.

5.2 Validate equipment in accordance with Clause 8.

5.3 Run all tests in accordance with Clauses 9, 10, and 11.

5.4 Analyse and present data from Clause 11 in accordance with Clause 12.

6 Test apparatus

6.1 Suitable timer

6.2 Sample bottles, use applicable sample bottles containing less than 100 particles greater than 6 µm(c) per millilitre of bottle volume, as qualified in accordance with ISO 3722, to collect samples for gravimetric analyses.

6.3 Membrane filters and associated equipment, suitable for conducting gravimetric contamination analysis in accordance with ISO 4405.

6.4 Test contaminant, use ISO fine test dust (ISO FTD), grade A2 in accordance with ISO 12103-1, dried at 110 °C to 150 °C for not less than 1 h for quantities less than 200 g.

Ensure that the ISO FTD used conforms to all the requirements of ISO 12103-1 grade A2, especially the volume particle size distribution shown in ISO 12103-1:2024, Table 2.

NOTE If the total quantity of ISO FTD needed is greater than 200 g, batches not exceeding 200 g can be prepared to make up the amount required.

For use in the test system the test dust should be mixed into the test fluid, mechanically agitated, then dispersed ultrasonically in an ultrasonic bath that has a power density of 3 000 W/m^2 to 10 000 W/m^2 provided it has been demonstrated that ultrasonic energy used does not affect the fluid viscosity.

6.5 Test fluid, petroleum base test fluid which shall have the properties as detailed in Annex A.

Another standard test fluid shall be used provided there is agreement between parties. Only filter test results obtained with the same fluid shall be compared.

The temperature of the test fluid, during the test, shall be controlled at a value to result in a test fluid kinematic viscosity of 15 mm^2/s ± 1 mm^2/s.

NOTE 1 The use of this hydraulic fluid ensures greater reproducibility of results and is based upon current practices, other accepted filter standards, and its world-wide availability.

NOTE 2 The addition of an anti-static agent to this test fluid can affect the test results.

6.6 Particle counting systems

6.6.1 An online automatic particle counting system, in accordance with ISO 11943, shall be used to determine the number and size distribution of the contaminant particles in the fluid. An online dilution system may be 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, if applicable, should be validated for on-line counting in accordance with ISO 11943.

6.6.2 A 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. 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 can be returned to the filter element test circuit reservoir via a by-pass line. Flow through the automatic particle counters can also be returned to the filter element test circuit reservoir provided it has not been diluted, or it can be discarded. Do not interrupt sample flow during the test.

6.6.3 Automatic particle counters shall be calibrated in accordance with ISO 11171 for the appropriate particle sizes. Use the recommended particle sizes given in Table 2 unless otherwise agreed.

6.7 Test housing and free flow dummy element

6.7.1 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 shall be blocked and tested for zero leakage at twice the normal cracking pressure.

6.7.2 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.

6.7.3 Install a free flow dummy element 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 (the internal cross-sectional area of the filter assembly outlet tube) and a diameter approximating the inside diameter of the media pack.

6.8 Filter performance test circuits

The filter performance test requires two separate circuits: a filter element test circuit, and a contaminant injection circuit. Schematic diagrams of typical filter performance test set-ups used to measure filtration efficiency in steady and cyclic flow conditions are shown in Annex B.

6.8.1 Filter element test circuit, consisting of the following.

6.8.1.1 A reservoir with a smooth conical bottom that has an included angle of not more than 90°, pump, fluid conditioning apparatus, and instrumentation that are capable of accommodating the range of flow rates, pressures, temperatures, and volumes required by the procedure, and is capable of meeting the validation requirements of Clause 8.

6.8.1.2 A clean-up filter capable of providing an initial system contamination level as specified in Table 2.

6.8.1.3 A configuration that is insensitive to the intended operative contaminant level.

6.8.1.4 A configuration that does not alter the test contaminant distribution over the anticipated test duration.

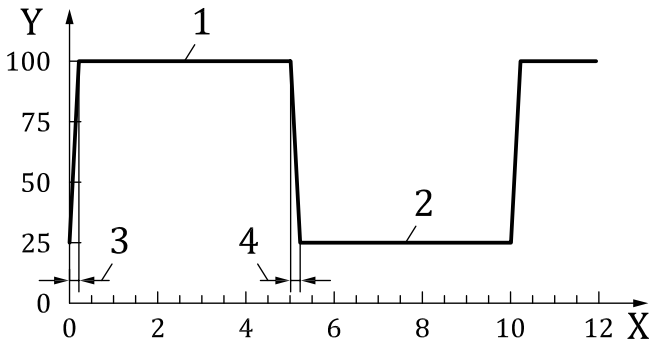
6.8.1.5 Pressure taps in accordance with ISO 3968.

6.8.1.6 Fluid sampling sections upstream and downstream of the test filter in accordance with ISO 4021.

6.8.1.7 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.

6.8.1.8 For cyclic flow testing, a cyclic flow by-pass line equipped with an automatically controlled shut-off valve (e.g. an electrically-actuated ball valve or poppet type valve, which has been shown to be satisfactory for this application) or other method capable of producing the required flow rate cycle at the test frequency shall be used.

The flow cycling set-up shall be capable of cycling at 0,1 Hz. Each 10 s cycle shall consist of two equal parts, the first including a flow rise period (25 % to 100 % of the test flow rate, q_f) and a constant 100 % flow period, followed by the second part including a flow decay back to 25 % q_f and a constant 25 % flow period. This is accomplished via the solenoid operated shut-off valve and the flow control valve in the by-pass circuit shown in Figure B.2 or using an alternate acceptable method. The set-up should be such that the flow cycle falls within the limits set forth in Figure 3.



key

X	time after start of flow cycle	2	25 % of filter rated flow, 0,25 q_f
Y	differential pressure	3	rise time = 0,1 s to 0,2 s
1	filter rated flow, q_f	4	fall time = 0,1 s to 0,2 s

Figure 3 — Flow cycle waveform

Alternatively, any other specified frequency or cycle waveform (minimum or maximum flow, and rise and fall times) can be used for the test provided there is agreement between parties. However, a validation shall be successfully performed at these alternate conditions in accordance with 8.2; and the cyclic conditions shall be clearly delineated in the test report.

Alternative cyclic conditions can affect the test results, both in efficiency and stabilized cleanliness; therefore, when making comparisons between filters, only one condition should be used.

NOTE The solenoid operated shut-off valve and the flow control valve in the by-pass circuit are the primary differences in the cyclic flow test circuit and that of steady flow multi-pass test equipment.

6.8.2 Contaminant injection test circuit, consisting of the following.

6.8.2.1 A reservoir with a smooth conical bottom that has an included angle of no more than 90°, pump, fluid conditioning apparatus, and instrumentation that are capable of accommodating the range of flow rates, pressures, temperatures, and volumes required by the procedure, and is capable of meeting the validation requirements of Clause 8.

6.8.2.2 A configuration that is relatively insensitive to the intended contaminant level.

6.8.2.3 A configuration that does not alter the test contaminant particle size distribution over the anticipated test duration.

6.8.2.4 A fluid sampling section in accordance with the requirements of ISO 4021.

6.8.2.5 A clean-up filter capable of providing an initial injection system contamination level as specified in Table 2.

6.8.2.6 A turbulent means for transferring fluid from the contaminant injection system to the filter element test system reservoir to yield an injection flow rate up to 0,25 l/min.

6.8.2.7 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.

From a general point of view, the injection flow should be set as low as possible to minimize any influence of contaminant removed by the downstream fluid discarded. The injection system shall be validated at the minimum flow rate (see 8.3).

Turbulence is not always possible or guaranteed by calculation. Long straight lines should not be used. A validation ensures that the system is satisfactory.

NOTE The injection fluid volume can be increased, which requires an increase in the amount of test dust proportionately.

7 Instrument accuracy and allowable test condition variation

7.1 Utilize and maintain instrument accuracy and test condition variations within the limits in Table 1.

7.2 Maintain specific test parameters within the limits in Table 2 depending on the test condition being conducted.

Table 1 — Instruments accuracy and test conditions variations

Test parameter	Unit	Instrument accuracy (±) of reading	Allowed test condition variation (±)
Electrical conductivity	pS/m	10 %	—
Differential pressure	Pa, kPa or bar	5 %	—
Base upstream gravimetric	mg/l	—	10 %
Flow:			
Injection flow	ml/min	2 %	5 %
Test flow	l/min	2 %	5 %
APC sensor and dilution flow rates	l/min	1,5 %	3 % [a]
Kinematic viscosity	mm^2/s [b]	2 %	1 mm^2/s
Mass	g	0,1 mg	—
Temperature	°C	1 °C	2 °C [c]
Time	s	1 s	—
Injection system volume	l	2 %	—
Filter test system volume	l	2 %	5 %

[a] Sensor flow variation to be included in the overall 10 % allowed between sensors.

[b] 1 mm^2/s = 1 cSt (centistoke).

[c] Or as required to conform to the viscosity tolerance.

Table 2 — Test conditions values

Initial contamination level for filter test systems	Less than 1 % of the minimum number specified in Table 3 measured at the minimum particle size to be counted.
Initial contamination level for injection system	Less than 1 % of injection gravimetric level.
Base upstream gravimetric level, mg/l [a]	1 ± 0,1 or 3 ± 0,3 or 10 ± 1,0
Recommended particle counting sizes [b]	Minimum of five sizes selected to cover the presumed filter performance range from β or σ = 2 to β or σ = 1 000. Typical sizes are: (4, 5, 6, 7, 8, 10, 12, 14, 20, 25) µm(c).

[a] When comparing test results between two filters, the base upstream gravimetric level should be the same.

[b] Particle sizes where filtration ratios are low (β or σ = 2, 10...) can be unobtainable for fine filters and particle sizes where betas are high (β or σ = ..., 200, 1 000) can be unobtainable for coarser filters.

8 Test equipment validation

8.1 Steady flow filter test system validation

8.1.1 Validate the filter test system at the minimum flow rate at which it is to be operated. Install a pipe in place of filter housing during validation. The main clean-up filter shall not be by-passed.

8.1.2 Adjust the total fluid volume of the filter test system (exclusive of the clean-up filter circuit) such that it is numerically within the range of 25 % to 50 % of the minimum volume flow rate (l/min) value, with a minimum volume of 5 l.

NOTE 1 This is the ratio of volume to flow rate required by the filter test.

The fluid volume should be numerically equal to 50 % of the maximum flow rate for flow rates less than or equal to 60 l/min with a minimum volume of 5 l. For flow rates greater than 60 l/min, the fluid volume should be numerically equal to 25 % of the flow rate greater than 60 l/min.

8.1.3 Clean up the contents of the reservoir until the cleanliness conforms to the level stated in Table 2.

8.1.4 Contaminate the system fluid to the lowest base upstream gravimetric level to be used in testing as shown in Table 2 using ISO FTD and circulate for 15 min. The circuit should be contaminated by continuous injection of the test dust into the main circuit which has been configured into a single pass way (i.e. with continuous recirculation through a clean-up filter).

8.1.5 Verify that the flow rate through each particle counting sensor is equal to the value used for the particle counter calibration within the limits of Table 1.

8.1.6 Circulate the fluid in the test system for an additional 60 min, conducting continuous online automatic particle counts from the upstream sampling section for the 60 min period. Sample flow from this section shall not be interrupted for the duration of the validation.

8.1.7 Record cumulative online particle counts at equal time intervals not to exceed 1 min for the duration of the 60 min test at the particle sizes selected from those given in Table 2, including the 25 µm(c) particle size.

8.1.8 Accept the validation test only if:

a) the particle count obtained for a given size at each sample interval does not deviate more than 15 % from the average particle count from all sample intervals for that size;

b) the average of all cumulative particle counts per millilitre is within the range of acceptable counts shown in Table 3; and

c) 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.

NOTE Validation is required only at particle sizes to be used in the filter performance test.

Table 3 — Validation counts for ISO FTD (for information)

Particle size	Acceptable cumulative particle counts per millilitre [a]					
	Base upstream gravimetric 1 mg/l		Base upstream gravimetric 3 mg/l		Base upstream gravimetric 10 mg/l	
µm(c)	minimum	maximum	minimum	maximum	minimum	maximum
4	2 401	2 980	7 204	8 939	24 015	29 797
5	1 323	1 626	3 968	4 876	13 225	16 255
6	712	961	2 136	2 882	7 119	9 608
7	438	642	1 314	1 925	4 379	6 417
10	89	212	268	634	895	2 116
14	31	70	94	211	312	701
15	26	58	78	175	259	582
20	11	23	34	70	114	235
22	8	17	24	51	81	169

[a] The minimum and maximum values are based on particle counts determined by an interlaboratory comparison conducted with automatic particle counters calibrated in accordance with ISO 11171, with a calculated variation based on the Poisson distribution.

8.1.9 Validate the online particle counting system, and dilution systems if used, in accordance with ISO 11943.

NOTE Validation is required only at particle sizes to be used in the filter performance test.

8.2 Cyclic flow filter test system validation

8.2.1 Validate the ability of the cyclic flow system to achieve the required flow waveform shown in Figure 3 at the minimum and maximum filter rated flows for which the test stand is intended for use.

8.2.2 Validate the cyclic flow filter test system at the minimum flow rate at which it is to be operated.

8.2.3 Validation shall be performed while cycling at the minimum filter flow rate, q_f, at which the filter test system is to be operated.

8.2.4 Validate the cyclic flow at 0,1 Hz (6 cycles per minute), using the waveform shown in Figure 3.

8.2.5 Install a pipe and valve in place of the filter housing during validation. The pipe and valve shall be selected so that they produce the maximum differential pressure expected during testing at the maximum flow rate. The main clean up filter shall not be by-passed.

8.2.6 Adjust the total fluid volume of the filter test system (exclusive of the clean-up filter circuit) such that it is numerically equal to 50 % of the maximum volume flow rate, with a minimum volume of 5 l for flow rates less than or equal to 60 l/min or equal to 25 % of the maximum test volume flow rate for flow rates greater than 60 l/min.

NOTE This is the ratio of volume to flow rate required by the filter test procedure (see 10.3.4).

8.2.7 Validate the online particle counting system and dilution systems, if used, in accordance with ISO 11943 while the filter test system is under cyclic flow conditions.

8.2.8 Establish a background fluid contamination level that is less than that specified in Table 2.

8.2.9 Contaminate the system fluid at the minimum base upstream gravimetric level to be used as shown in Table 2, using ISO FTD test dust, and circulate for 15 min. The circuit should be contaminated by continuous injection of the test dust into the main circuit which has been configured into a single pass way (i.e. with continuous recirculation through a clean-up filter).

8.2.10 Verify that the flow rate through each particle counting sensor is equal to the value used for the particle counter calibration and is within the limits of Table 1.

8.2.11 Circulate the fluid in the test system for an additional 60 min, conducting continuous online automatic particle counts from the upstream sampling section for the 60 min period. Sample flow from this section shall not be interrupted for the duration of the validation. If dilution is used, the fluid that has passed through the sensor shall not be returned to the reservoir.

8.2.12 Record cumulative online particle counts at equal time intervals not to exceed 1 min for the duration of the 60 min test at the particle sizes shown in Table 2.

8.2.13 Accept the validation only if

a) the on-line particle counting system and dilution system were successfully validated in accordance with ISO 11943;

b) the particle count obtained for a given size at each sample interval does not deviate more than 15 % from the average particle count from all sample intervals for that size;

c) the average of all cumulative particle counts per millilitre are within the range of acceptable counts shown in Table 3; and

d) 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.

8.3 Contaminant injection system validation

8.3.1 Validate at the maximum initial injection system volume (V_{ii}) to be used in accordance with 10.2.3, the maximum contaminant injection system gravimetric level (c_i') specified in accordance with 10.2.4, the minimum contaminant injection flow rate (q_i'), and for a length of time required to deplete the complete usable volume (V_{ii} V_{min}) of the contaminant injection reservoir.

8.3.2 Pre-clean the contaminant injection fluid system to achieve the fluid cleanliness given in Table 2, then by-pass the clean-up filter system.

8.3.3 Calculate the required amount of contaminant (m) to be added to the contaminant injection system from the volume (V_{ii}) and gravimetric level (c_i') in accordance with 8.3.1, according to the Formula (1):

$$m = \frac{(V_{ii} \times c_i')}{1\,000} \tag{1}$$

8.3.4 Add the required quantity of contaminant (m) to the contaminant injection system reservoir fluid and circulate for a minimum of 30 min.

8.3.5 Start the timer and initiate injection flow from the contaminant injection system, once the temperature has stabilized, 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_i') 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 30 s.

8.3.6 Obtain samples of the injection flow and measure the injection flow rate at 30 min, 60 min, 90 min, and 120 min or at four equal intervals, depending upon the depletion rate of the system.

8.3.7 Analyse each sample from 8.3.6 gravimetrically in accordance with ISO 4405.

8.3.8 Measure the volume of the injection system at the end of the validation test. This is the minimum validated volume, V_v.

8.3.9 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, analysed in 8.3.7, shall be within ±5 % of the average of the samples, and within ±10 % of the desired gravimetric level (c_i') in accordance with 8.3.1.

b) The injection flow rates, measured in 8.3.6, shall be within ±5 % of the average of the injection flow rates, and within ±5 % of the desired injection flow rate (q_i').

c) The volume remaining in the injection system (V_v) plus the volume of fluid expelled during the validation, calculated as: $\bar{q}_i \times t_i$, is equal, within ±10 %, to the initial injection system volume (V_{ii}).

9 Summary of information required prior to testing

The following information shall be available prior to applying this document to a particular filter element:

a) fabrication integrity test pressure (see ISO 2942);

b) filter element test flow for steady flow test and maximum test flow (q_f) for cyclic flow test;

c) terminal element differential pressure;

d) presumed micrometre values for specific filtration ratios;

e) presumed value, m_e, of the filter element capacity (mass injected);

f) fluid;

g) fluid temperature;

h) fluid viscosity.

10 Preliminary test preparation

10.1 Test filter assembly

10.1.1 Ensure that test fluid cannot by-pass the filter element in the housing to be evaluated.

10.1.2 Subject the test filter element to a fabrication integrity test in accordance with ISO 2942. The element shall be disqualified from further testing if it fails to exhibit at least the designated test pressure.

10.1.3 Unless the test fluid was used for fabrication integrity testing, allow the fluid to evaporate from the test filter element before installing it in the test filter housing.

NOTE 1 The test fluid specified in 6.5 can be used for fabrication integrity testing.

NOTE 2 If the element is not readily accessible, as in the case of a spin-on configuration, the fabrication integrity test can be conducted following the multi-pass test, with the element removed. However, a low and, perhaps, unacceptable first bubble point value determined in such a case does not mean that such a value would have been obtained if the fabrication integrity test had been conducted before the multi-pass test.

Unless the test fluid was used for fabrication integrity testing, allow the fluid to evaporate from the test filter element before installing it in the test filter housing.

10.2 Contaminant injection system

10.2.1 Calculate the average test flow rate ($\bar{q}_f$) using Formula (2) or Formula (3):

for steady flow tests:

$$\bar{q}_f = q_f \tag{2}$$

for cyclic flow tests:

$$\bar{q}_f = \frac{(q_f + 0{,}25 \times q_f)}{2} = 0{,}625 \times q_f \tag{3}$$

10.2.2 Select a desired base upstream gravimetric level (c_i') from Table 2 so that the predicted test time (t') calculated using Formula (4) is preferably in the range of 1 h to 3 h, based on the simple average test flow rate, $\bar{q}_f$, calculated using Formula (2) or Formula (3):

$$t' = \frac{1\,000 \times m_e}{c_b' \times \bar{q}_f} \tag{4}$$

NOTE 1 A second filter element can be tested for capacity analysis if the value of the estimated capacity (m_e) of the test element is not supplied by the filter manufacturer.

NOTE 2 Predicted test times of less than 1 h or longer than 3 h are acceptable as long as the base upstream gravimetric level chosen is maintained.

10.2.3 Calculate the minimum required operating injection system volume that is compatible with the predicted test time, t', and a desired value for the injection flow using Formula (5):

$$V_{min} = (1{,}2 \times t' \times q_i') + V_v \tag{5}$$

NOTE The volume calculated using Formula (5) ensures a sufficient quantity of contaminated fluid to load the test filter element plus 20 % for adequate circulation throughout the test. Larger injection system volumes can be used.

A value for the injection flow rate (q_i') of 0,25 l/min is commonly used and ensures that the downstream sample flow expelled from the filter test system does not significantly influence the test results. Lower or higher injection flow rates can be used provided that the base upstream gravimetric level is maintained. The injection flow rate should equal or exceed the value used for injection system validation in 8.3.1.

10.2.4 Calculate the desired gravimetric level (c_i') of the injection system fluid using Formula (6):

$$c_i' = \frac{c_b' \times \bar{q}_f}{q_i'} \tag{6}$$

10.2.5 Adjust the total initial volume, V_{ii}, of the contaminant injection system (measured at the test temperature) to the value determined in 10.2.3; and record the result on the report sheet given in Table 4 and Table 5 issued from Clause 13.

10.2.6 Calculate the mass of contaminant needed for the contaminant injection system (m) using Formula (7):

$$m = \frac{c_{\mathrm{i}}' \times V_{\mathrm{ii}}}{1\,000} \tag{7}$$

10.2.7 Prior to the addition of the test dust to the contaminant injection system, verify that the background fluid contamination level is less than specified in Table 2.

10.2.8 Prepare the contaminant injection system to contain the quantity of fluid, V_{iii}, and quantity of ISO FTD, m, (see 10.2.6) using the same procedure that was used for the contamination injection system validation (see 8.3).

10.2.9 Adjust the injection flow rate at stabilized temperature to within ±5 % of the value selected in 10.2.3 and maintain that value throughout the test. Record the injection flow rate on the report sheet given in Table 4 and Table 5 issued from Clause 13. During setup, return the injection flow directly to the injection reservoir.

10.3 Steady flow filter test system

10.3.1 Install the filter housing with a free-flow dummy element in the filter test system and thoroughly bleed of air.

10.3.2 Verify that the rest conductivity of the test fluid is maintained in the range of 1 000 pS/m to 2 000 pS/m, when measured at test temperature. If it is outside this range, either add anti-static agent to increase the conductivity or more new fluid to reduce it.

WARNING — The addition of an anti-static agent can affect the test results.

10.3.3 Circulate the fluid in the filter test system at the average filter test flow, $\bar{q}_{\mathrm{f}}$, (see 10.2.1), and at a test temperature such that the fluid viscosity is maintained at 15 mm^2/s. Measure and record the temperature and the differential pressure of the filter housing containing the free flow dummy element in accordance with ISO 3968.

10.3.4 Adjust the total fluid volume of the filter test system (exclusive of the clean-up filter circuit) such that its value in litres is numerically between 25 % to 50 % of the average filter test volume flow rate, $\bar{q}_{\mathrm{f}}$, in l/min, with a minimum value of 5 l.

In case the designated test volume flow rate is greater than 60 l/min filter test system fluid volume should be numerically equal to 25 % of the test volume flow rate.

NOTE Repeatable results require that the system volume be maintained constant. The specified range of ratios between the test system fluid volume and the test volume flow rate from 1:4 to 1:2 minimizes the physical size of the system reservoir as well as the quantity of test fluid required, while maximizing the mixing conditions in the reservoir.

10.3.5 Adjust the particle counter thresholds corresponding to the particle sizes selected from Table 2.

10.3.6 Initiate online automatic particle counting by using the following procedure.

a) Set the particle counters to count for either 30 s or 60 s intervals depending on the estimated test time, t', with the goal to obtain at least 35 data sets during the cyclic flow segment of the filter efficiency test. However, the minimum volume of fluid counted during each count should not be less than 10 ml. This necessitates 1 min counts for automatic particle counters with operating flow rates of 10 ml/min.

b) Adjust the upstream and downstream sampling flow rates to an initial upstream value compatible with the sampling procedure and particle counting sensors used; and adjust the downstream flow rate to within ±5 % of the injection flow rate and maintain uninterrupted flow from both sampling points during the entire test.

c) Adjust the upstream and downstream dilution flow rates if required for automatic particle counting, so that at the end of testing, the flow rates and concentrations at the particle counters are compatible with the instrument requirements.

The upstream and downstream sensor flow rates should be set and maintained at these values, and within the limits specified in 8.1.5 and Table 1.

Synchronize the counting periods of the two automatic particle counters as closely as possible.

d) Return the undiluted and unfiltered sampling flow upstream of the test filter directly to the test reservoir.

If the upstream sample is diluted or filtered for online automatic particle counting, the diluted or filtered fluid should be collected outside of the filter test system.

If the upstream sample flow is diluted or filtered, the downstream sample flow rate to be discarded should be reduced by a value equal to the upstream sample flow that is collected outside the system. This is to assist in maintaining a constant system volume that should be kept within ±5 % of the initial system volume.

10.3.7 Establish a fluid background contamination level less than that specified in Table 2.

10.3.8 Stop the test flow and particle counters.

10.4 Cyclic flow filter test system

10.4.1 Perform the tasks in 10.3.1 through 10.3.5.

10.4.2 Start cyclic flow in accordance with the waveform in Figure 2.

10.4.3 Start recording particle counts with the automatic particle counters in the filter element test system in accordance with 10.3.6.

10.4.4 Establish a fluid background contamination level less than that specified in Table 2.

10.4.5 Stop the test flow and particle counters.

11 Filter element efficiency test

11.1 Steady flow test

11.1.1 Install the test filter element into its housing and subject the assembly to the specified test condition (test flow rate and test temperature established in 10.3.3 to maintain viscosity at 15 mm^2/s ± 1,0 mm^2/s), and reaffirm fluid level.

11.1.2 Measure and record the clean assembly differential pressure. Calculate and record the clean element differential pressure by subtracting the housing differential pressure measured in 10.3.3 from the clean assembly differential pressure.

11.1.3 Calculate the final assembly differential pressure, Δp_f, by adding the terminal element differential pressure to the housing differential pressure.

11.1.4 Measure and record the initial system contamination level using online particle counting from upstream of the test filter element.

11.1.5 By-pass the system clean-up filter if the upstream contamination level is less than that specified in Table 2, otherwise continue clean-up until the required cleanliness level is achieved.

11.1.6 Obtain a sample from the contaminant injection system. Label it "Initial injection gravimetric sample".

11.1.7 Measure and verify the injection flow rate. The injection flow rate shall be continuously measured to ensure that the flow rate is maintained within the specified tolerances.

11.1.8 Initiate the filter test by:

a) allowing the injection flow to enter the filter test system reservoir;

b) starting the timer; and

c) diverting the downstream sample flow from the test system to maintain a constant system volume within a tolerance of ±5 %.

11.1.9 Initiate online automatic particle counting by using the procedures given in 10.3.6.

11.1.10 Record upstream and downstream particle counts at equal time intervals until the differential pressure across the filter assembly has increased to the terminal value calculated in 11.1.3.

11.1.10.1 Maintain the upstream and downstream sensor flow rates equal to the values chosen in 10.3.6 b), within the limits specified in Table 1.

11.1.10.2 Monitor and record the particle counter sensor flow rates throughout the test and maintain within the limits specified in Table 1.

11.1.10.3 Use online dilution only when required to avoid exceeding the coincidence limit of the automatic particle counters, as determined in accordance with ISO 11171.

The sensor flow rate and dilution ratios should be controlled and recorded throughout the test to calculate the exact amount of test fluid that is passed through the sensor for each count.

11.1.11 Record the assembly differential pressure at the beginning of each particle count throughout the test.

Continuous differential pressure measurements using a differential pressure transducer should be used for this purpose.

11.1.12 Extract a bottle sample for gravimetric analysis from upstream of the test filter when the assembly differential pressure has reached 80 % of the final assembly differential pressure.

11.1.13 Conclude the test at the final assembly differential pressure by the following:

a) recording the final test time, t_f;

b) diverting the injection flow from the filter test system;

c) stopping the flow to the test filter.

11.1.14 Measure and record the final volume in the filter test system as V_{tf}.

11.1.15 Measure and record the final injection system volume as V_{if}.

11.1.16 Obtain a fluid sample for determining final injection gravimetric level from the contaminant injection system.

11.1.17 Remove the filter element and check that no visual evidence of filter element damage has occurred as a result of performing this test; and report any observations accordingly.

Although the installation and test procedures are checked for qualification prior to testing, it should be checked when interpreting the results that the test has been performed satisfactorily.

11.2 Cyclic flow test

11.2.1 Install the test filter element into its housing and subject the assembly to the maximum flow rate for cyclic conditions (q_t), and to the test temperature established in 10.3.3 to maintain viscosity at 15 mm^2/s ± 1,0 mm^2/s, and reaffirm fluid level.

11.2.2 Measure and record the clean assembly differential pressure. Calculate and record the clean element differential pressure by subtracting the housing differential pressure measured in 10.3.3 from the clean assembly differential pressure.

11.2.3 Calculate the final assembly differential pressure, Δp_f, by adding the terminal element differential pressure to the housing differential pressure.

11.2.4 Calculate the net assembly differential pressure, Δp_n, by subtracting the clean element differential pressure (see 11.2.2) from the terminal element differential pressure [see Clause 9 c)].

11.2.5 Calculate the filter assembly differential pressures corresponding to increases of 2,5 % and 80 % of the filter element net differential pressure as shown in Formulae (8) and (9), and record:

$$\Delta p_{2,5\,\%} = \Delta p_f + 0{,}025 \times (\Delta p_n) \quad (8)$$

$$\Delta p_{80\,\%} = \Delta p_f + 0{,}8 \times (\Delta p_n) \quad (9)$$

11.2.6 Restart cyclic flow in accordance with 10.4.2. Record five upstream and downstream particle counts at each particle size range. These are the blank counts. If the upstream contamination level is less than that specified in Table 2, by-pass the system clean-up filter, otherwise continue flowing the oil through the clean-up filter, and collecting blank counts, until the required cleanliness level is achieved.

11.2.7 Obtain a sample from the contaminant injection system. Label it “Initial injection gravimetric sample”.

11.2.8 Measure and verify the injection flow rate. The injection flow rate shall be continuously measured to ensure that the flow rate is maintained within the specified tolerances given in Table 1.

11.2.9 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, c_i', to within ±5 %, throughout the cyclic flow segments of the test.

11.2.10 Maintain the total volume of fluid in the filter element test system to within ±5 %, as described in 10.3.4.

11.2.11 Record automatic particle counts throughout the test in accordance with 10.3.6.

11.2.12 Record the maximum differential pressure across the filter assembly during flow cycling throughout the test. Continuous differential pressure measurements using a differential pressure transducer shall be used.

11.2.13 When the differential pressure across the filter assembly at maximum test flow increases to $\Delta p_{2,5\ \%}$, as calculated with Formula (8), perform the following steps:

a) stop contaminant injection;

b) stop the test-recording timer; record the timer value as $t_{2,5\ \%}$; start a secondary timer;

c) divert all APC sensor flow to the test reservoir and close the discard valve, if open.

11.2.14 Continue recording particle counts for the stabilization time period of 30 min, measured with the secondary timer.

NOTE The stabilization time of 30 min is the time duration during the test when contaminant injection is halted and fluid is circulated through the test filter element, allowing it to clean up the fluid. The fluid contamination level during this period is recorded so that the stabilized contamination level can be determined. The test procedure requires determination of the stabilized fluid contamination levels at filter element differential pressures corresponding to increases of 2,5 % and 80 % of the net differential pressure.

11.2.15 At the end of the 30 min stabilization time period, reset the secondary timer, start contaminant injection, the external flow discard, and the test-recording timer, and continue with the cyclic flow testing until the filter assembly differential pressure has increased to 80 % of the net differential pressure.

11.2.16 When the differential pressure across the filter assembly increases to $\Delta p_{80\ \%}$, as calculated with Formula (9), perform the following steps:

a) extract a bottle sample for gravimetric analysis from upstream of the test filter;

b) stop contaminant injection;

c) stop the test-recording timer; record the timer value as $t_{80\ \%}$; start the secondary timer;

d) divert all APC sensor flow to the test reservoir and close the discard valve, if open.

11.2.17 Continue recording particle counts for the stabilization time period of 30 min, measured with the secondary timer.

11.2.18 At the end of the second stabilization time period, reset the secondary timer, start contaminant injection, the external flow discard, and the test-recording timer, and continue with the cyclic flow testing until the terminal filter assembly differential pressure is attained.

For filter elements with efficient filtration medium, and/or small filtration areas, the terminal element differential pressure can be achieved during the 30 min stabilization period. The 80 % test time should then be used for the 100 % point.

11.2.19 When the required terminal test filter assembly differential pressure is reached, perform the following:

a) record final test time, t_f, as the test-recording timer value;

NOTE This time represents the total time that contaminant was injected into the filter test system.

b) determine and record the final injection flow rate, then stop injection flow from the contaminant injection system and stop the test-recording timer; record the final contaminant injection system volume, V_{if};

c) stop fluid sampling flow;

d) stop flow through the test filter element system.

11.2.20 Collect another sample of the injection system fluid to determine the final injection gravimetric level at completion of test.

12 Calculation and data reporting

12.1 Filtration ratio and retention capacity

12.1.1 Establish 10 reporting times equal to 10 %, 20 %, 30 % . . . 100 % of the final test time (see 11.1.13 or 11.2.19) and record these times on the report sheet given in Table 4 and Table 5.

12.1.2 Calculate the assembly differential pressure corresponding to each reporting time by conducting a linear interpolation between the nearest measured differential pressures prior to and after that time. For the 100 % time point, use the final assembly differential pressure.

12.1.3 Calculate and record on the report sheet given in Table 4 and Table 5 the element differential pressures corresponding to each of the reporting times by subtracting the housing differential pressure from each respective assembly differential pressure.

12.1.4 For each particle count obtained during the test, calculate the cumulative particle count in accordance with millilitre at each particle size by dividing the raw counts obtained in the counted volume and adjusting for any dilution, if used.

12.1.5 Calculate the average upstream and downstream particle counts at each particle size, x, for each of the 10 reporting times, t, by using Formulae (10) and (11) and the specific instructions in 12.1.5 a) to d).

$$\overline{N}_{\mathrm{u},x,t} = \frac{\sum_{j=1}^{n} N_{\mathrm{u},x,j}}{n} \tag{10}$$

$$\overline{N}_{\mathrm{d},x,t} = \frac{\sum_{j=1}^{n} N_{\mathrm{d},x,j}}{n} \tag{11}$$

where n is the number of particle counts started in the specific reporting time period.

Use only the particle count data collected during the cyclic flow portions of the test when contaminant injection was being performed. Do not include the data collected during the two stabilization periods.

a) Delete the particle counts corresponding to test times of 1 min, 2 min and 3 min. Additionally, delete the particle counts corresponding to the test times of 1 min, 2 min, and 3 min after the two stabilization periods.

NOTE These data deletions are to eliminate potentially erroneous particle counts obtained prior to contaminant dispersion.

b) For the first reporting time (10 %), using Formulae (10) and (11), average the upstream and downstream counts calculated in 12.1.4 for all the particle counts that were started before the first reporting time

[with the exception of the first three deleted in 12.1.5 a)]. Record these average counts on the report sheet given in Table 4 and Table 5.

For a total test time less than 30 min, there may be no data for the 10 % reporting; in this case, the entries should be left blank.

c) For the second reporting time (20 %), average the upstream and downstream counts calculated in 12.1.4 for all the particle counts that were started after the first reporting time and before the second reporting time. Record these average counts on the report sheet given in Table 4 and Table 5.

d) For the third through tenth reporting times (30 % to 100 %), repeat 12.1.5 c) in a similar manner using only the counts that were started in each reporting interval. Record these average counts on the report sheet given in Table 4 and Table 5.

12.1.6 Using Formula (12) or (13), calculate the filtration ratios ($\beta_{x,t}$ or $\sigma_{x,t}$) corresponding to each of the 10 reporting times by dividing the average upstream particle count by the average downstream particle count at each size, x, corresponding to that respective reporting time. Round the results to three digits of precision (e.g., 1,75; 20,1; 300), and record on the report sheet given in Table 4 and Table 5.

For steady flow tests:

$$\beta_{x,t} = \frac{\overline{N}_{u,x,t}}{\overline{N}_{d,x,t}} \tag{12}$$

For cyclic flow tests:

$$\sigma_{x,t} = \frac{\overline{N}_{u,x,t}}{\overline{N}_{d,x,t}} \tag{13}$$

Particle counts shall be averaged, and average filtration ratios shall be calculated from these average counts. Under no circumstances shall filtration ratio, β or σ, values be averaged.

12.1.7 Using Formulae (14) and (15), calculate the overall test average upstream and downstream particle counts by numerically averaging the 10 average counts from 12.1.5 corresponding to each of the 10 reporting times. Record the results on the report sheet given in Table 4 and Table 5.

$$\overline{A}_{u,x} = \sum_{k=1}^{10} \overline{N}_{u,x,t} \tag{14}$$

$$\overline{A}_{d,x} = \sum_{k=1}^{10} \overline{N}_{d,x,t} \tag{15}$$

where k represents the number of reporting interval (1, 2, 3, … 10) corresponding to the time intervals (10 %, 20 %, 30 % … 100 %) of t_f.

12.1.8 Using Formula (16) or (17), calculate the overall average filtration ratios, $\overline{\beta}_x$ or $\overline{\sigma}_x$, by dividing the overall test average upstream by the downstream cumulative particle counts at each size, x µm(c). Record the results, to three digits of precision, on the report sheet given in Table 4 and Table 5.

$$\overline{\beta}_x = \frac{\overline{A}_{u,x}}{\overline{A}_{d,x}} \tag{16}$$

$$\overline{\sigma}_x = \frac{\overline{A}_{u,x}}{\overline{A}_{d,x}} \tag{17}$$

12.1.9 Conduct a gravimetric analysis in accordance with ISO 4405 on the two samples extracted from the contaminant injections system (11.1.6 and 11.1.16 for steady flow tests or 11.2.7 and 11.2.20 for cyclic flow

tests). Report the gravimetric contamination results to the nearest 0,1 mg/l on the report sheet given in Table 4 and Table 5. Calculate the average injection gravimetric level ($\overline{c}_i$) of the gravimetric levels of the two injection system samples, and accept the test only if the gravimetric level of each injection system sample is within ±5 % of $\overline{c}_i$.

If $\overline{c}_i$ differs from the selected value c_i' (from 10.2.4) by more than 5 %, repeat the gravimetric analyses. If the recheck differs more than 5 %, the contaminant injection system validation procedure in 8.3 should be repeated.

12.1.10 Conduct a gravimetric analysis in accordance with ISO 4405 on the 80 % upstream sample [from 11.1.12 for steady flow tests or 11.2.16 a) for cyclic flow tests], and record the result of this analysis as the final system gravimetric level. Report the gravimetric contamination results to the nearest 0,1 mg/l on the report sheet given in Table 4 and Table 5.

NOTE The final sample is taken at the 80 % point because it often overlaps the end of the test.

12.1.11 Using Formula (18), calculate and record on the report sheet given in Table 4 and Table 5 the average injection flow rate ($\overline{q}_i$), by subtracting the final injection system volume from the initial injection system volume and dividing the result by the final test time.

$$\overline{q}_i = \frac{V_{ii} - V_{if}}{t_f} \tag{18}$$

Accept the test only if this value is within ±5 % of the value selected in 10.2.3.

12.1.12 Using Formula (19), calculate and record on the report sheet given in Table 4 and Table 5 the average base upstream gravimetric level (c_b').

$$\overline{c}_b = \frac{\overline{c}_i \times q_i}{\overline{q}_f} \tag{19}$$

Accept the test only if this value is equal to the base upstream gravimetric level chosen from Table 2.

12.1.13 Report the following minimum information for filter elements evaluated in accordance with this document. Present all test and calculation results as included in the report sheet given in Table 4 and Table 5. The layout of the report sheet should be used as shown.

12.1.14 Using the actual final test time to reach the terminal element differential pressure (t_f), the average gravimetric level of the injection system (c_i'), and the average injection flow rate ($\overline{q}_i$), calculate the mass of ISO FTD injected (m_i) using Formula (20).

$$m_i = \frac{\overline{c}_i \times \overline{q}_i \times t_f}{1000} \tag{20}$$

Calculate and report on the test sheet given in Table 4 and Table 5 the ISO FTD retained capacity using Formula (21) and round the result to two digits of precision.

$$m_R = m_i - \frac{c_{80} \times V_f}{1000} - \frac{q_d \times t_f \times \left(c_{80} - \overline{c_b}\right)}{1000} - \frac{q_u \times t_f \times \left[\left(c_{80} + \overline{c_b}\right)/2\right]}{1000} \tag{21}$$

NOTE Formula (21) subtracts from the mass of ISO FTD injected:

a) the mass of contaminant remaining in the test system at the end of the test;

b) an estimate of the amount of contaminant permanently extracted from the system through the filter downstream sampling point [the term ($c_{80} - c_b'$) is a conservative estimate of the gravimetric contamination level downstream of the test filter];

c) an estimate of the amount of contaminant extracted from the upstream sample flow (q_u) that is permanently discarded from the test system [the term (c_{80} + c_b′)/2 is an estimate of the average upstream gravimetric contamination level]; if the upstream sample flow is recycled and not discarded, Formula (21) is applied without the final term.

12.1.15 Record the values of the gravimetric levels obtained in 12.1.9 and 12.1.10 on the report sheet given in Table 4 and Table 5.

12.1.16 Calculate, record on the report sheet given in Table 4 and Table 5, and plot on linear coordinates element differential pressure versus ISO FTD contaminant added by using Formula (22).

$$m_p = \frac{\bar{c}_i \times \bar{q}_i \times t_p}{1\,000} \tag{22}$$

where m_p is the mass of the contaminant added at differential pressure Δp, and time t_p.

12.1.17 Plot on semi-log coordinates average β or σ versus particle size, β or σ values being on the log scale with β or σ = 100 000 as the highest value plotted.

When β_x or σ_x equals infinity values (zero downstream particle count) are recorded, they should be plotted as β_x or σ_x = 100 000.

12.1.18 Using Formula (23) or (24), calculate and record on the report sheet given in Table 4 and Table 5 the particle size values corresponding to average filtration ratios of 2, 10, 75, 100, 200 and 1 000, using interpolation of straight-line segments connecting points on the semi-log filtration ratio versus particle size plot. The interpolated particle size for a specified filtration ratio is a value that falls between two of the points from the plot in 12.1.17 (corresponding to filtration ratios β_{x1} or σ_{x1} and particle size x_1 and β_{x2} or σ_{x2} and particle size x_2). Do not extrapolate.

For steady flow tests:

$$x = \frac{(x_1 - x_2) \times \log\left(\frac{\beta_x}{\beta_{x_1}}\right)}{\log\left(\frac{\beta_{x_1}}{\beta_{x_2}}\right)} + x_1 \tag{23}$$

For cyclic flow tests:

$$x = \frac{(x_1 - x_2) \times \log\left(\frac{\sigma_x}{\sigma_{x_1}}\right)}{\log\left(\frac{\sigma_{x_1}}{\sigma_{x_2}}\right)} + x_1 \tag{24}$$

For many filters, particle size values for each of the above filtration ratios values cannot be obtained by interpolation. In these cases, the unobtainable values should be noted as either less than the minimum particle size counted or greater than the maximum particle size counted, whichever is appropriate. Values should be reported for at least two or more consecutive filtration ratios from the above recommended values.

For filtration ratio values greater than 100 000, use the value of 100 000 in Formula (23) or (24).

12.1.19 Plot on semi-log coordinates average filtration ratio values for each particle size versus percent test time, with the filtration ratio values on the log scale.

12.1.20 Plot on $\log_{10}$ coordinates average filtration ratio values for each particle size versus element differential pressure, with the filtration ratio values on the ordinate.

12.1.21 Have available a record of all physical values pertaining to the test.

12.2 Calculation of stabilized particle counts for cyclic flow test

12.2.1 Using the particle counts recorded during the first 30 min stabilization period (see 11.2.14), calculate the 2,5 % stabilized downstream particle counts for the size ranges 4 µm(c), 6 µm(c), and 14 µm(c) by averaging the recorded particle counts for the last 1 min of the 30 min stabilization time. Record in the report sheet given in Table 4 and Table 5.

If 1 min particle counting intervals are being used, report only the last particle count.

12.2.2 Determine the 2,5 % stabilized ISO 11218 cleanliness classes for the above size ranges from the averaged stabilized downstream particle counts and record in the report sheet given in Table 4 and Table 5.

12.2.3 Calculate and record the corresponding filter element differential pressure, obtained by subtracting the housing differential pressure from the 2,5 % filter assembly differential pressure, $\Delta p_{2,5\,\%}$, calculated in 11.2.5.

12.2.4 Calculate and record in the report sheet given in Table 4 and Table 5 the contaminant injected to $\Delta p_{2,5\,\%}$, using the time, $t_{2,5\,\%}$, from 11.2.13, by using Formula (25):

$$c_{2,5\,\%} = \frac{\left(t_{2,5\,\%} \times \bar{c}_{\mathrm{i}} \times \bar{q}_{\mathrm{i}}\right)}{1\,000} \tag{25}$$

12.2.5 Using the particle counts recorded during the second 30 min stabilization period (see 11.2.17), calculate the 80 % stabilized downstream particle counts for the size ranges 4 µm(c), 6 µm(c), and 14 µm(c) by averaging the recorded particle counts for the last 1 min of the 30 min stabilization time. Record in the report sheet given in Table 4 and Table 5.

If 1 min particle counting intervals are being used, report only the last particle count.

Table 4 — Steady flow filter element multi-pass report sheet

Test laboratory: _____			Test date: _____	Operator: _____
Filter and element identification				
Element ID: _____			Housing ID: _____	
Spin-on: YES / NO			Minimum element bubble point (Pa): _____	
Operating conditions				
Test fluid				
Type: _____		Ref.: _____		Batch no.: _____
Viscosity at the test temperature (mm^2/s): _____			Temperature (°C): _____	
Antistatic: Yes _____ No _____		Type: _____	Conductivity (pS/m): _____	
Test contaminant				
Type: ISO 12103-1 A2 test dust (ISO FTD)		Batch no.: _____		
Test system				
Flow rate, q_f (l/min): _____			Initial volume (l): _____	
Average base upstream gravimetric level, $\bar{c}_{\mathrm{b}}$ (mg/l): _____			Final volume (l): _____	
Injection system				
Injection parameters	Initial	Final	Average injection parameters	
System volume (l)			Injection flow $\bar{q}_{\mathrm{i}}$ (l/min)	
Gravimetric level (mg/l)			Gravimetric level, $\bar{c}_{\mathrm{i}}$ (mg/l)	
Counting system				

Table 4 *(continued)*

Location	Counter and sensor ref.	Flow rate (ml/min)	Dilution ratio
Upstream			
Downstream			
Counter calibration:	Method: _____		Date: _____

Test results

Element integrity

Bubble point to ISO 2942 (Pa): _____ Test fluid: _____ Surface tension: _____

Differential pressure

Filter housing (kPa): _____ Clean assembly (kPa): _____

Clean element (kPa): _____ Final element (kPa): _____

Differential pressure versus contaminant added

Time interval	Test time (min)	Element Δp (kPa)	Injected mass (g)	Time interval	Test time (min)	Element Δp (kPa)	Injected mass (g)
10 %				60 %			
20 %				70 %			
30 %				80 %			
40 %				90 %			
50 %				100 %			

Retention capacity

ISO FTD mass injected m_i (g): _____ ISO FTD retained capacity m_R (g): _____

80 % upstream gravimetric level c_{80} (mg/l): _____

Filtration ratio β_x

Average filtration ratio	2	10	75	100	200	1 000
Particle size, x, µm(c)						

Particle counts per mL and filtration ratio

Time interval		$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β
Initial up													
10 %	Up												
	Down												
20 %	Up												
	Down												
30 %	Up												
	Down												
40 %	Up												
	Down												
50 %	Up												
	Down												
60 %	Up												
	Down												
70 %	Up												
	Down												
80 %	Up												
	Down												
90 %	Up												

Table 4 *(continued)*

	Down												
100 %	Up												
	Down												
Avg.	Up												
Avg.	Down												

Table 5 — Cyclic flow filter element multi-pass report sheet

Test laboratory: _____ Test date: _____ Operator: _____

Filter and element identification

Element ID: _____ Housing ID: _____

Spin-on: YES / NO Minimum element bubble point (Pa): _____

Operating conditions

Test fluid

Type: _____ Ref.: _____ Batch no.: _____

Viscosity at the test temperature (mm^2/s): _____ Temperature (°C): _____

Antistatic: Yes _____ No _____ Type: _____ Conductivity (pS/m): _____

Test contaminant

Type: ISO 12103-1 A2 test dust (ISO FTD) Batch no.: _____

Test system

Flow rates, (l/min): Max, q_f: _____ Average, $\bar{q}$:_____ Cycle rate: _____ cycles/min
(for user specified cyclic conditions, attach a complete description of the flow waveform)

Initial volume (l): _____ Final volume (l): _____ Average base upstream gravimetric level, $\bar{c}_b$ (mg/l): _____

Injection system

Injection parameters	Initial	Final	Average injection parameters	
System volume (l)			Injection flow $\bar{q}_i$ (l/min)	
Gravimetric level (mg/l)			Gravimetric level, $\bar{c}_i$ (mg/l)	

Counting system

Location	Counter and sensor ref.	Flow rate (ml/min)	Dilution ratio
Upstream			
Downstream			

Counter calibration: Method: _____ Date: _____

Test results

Element integrity

Bubble point to ISO 2942 (Pa): _____ Test fluid: _____

Differential pressure

Filter housing (kPa): _____ Clean assembly (kPa):_____

Clean element (kPa): _____ Final element (kPa): _____

Differential pressure versus contaminant added

Time interval	Test time (min)	Element Δp (kPa)	Injected mass (g)	Time interval	Test time (min)	Element Δp (kPa)	Injected mass (g)
10 %				60 %			
20 %				70 %			
30 %				80 %			
40 %				90 %			
50 %				100 %			

Table 5 *(continued)*

Retention capacity												
ISO FTD mass injected m_i (g): _____ ISO FTD retained capacity m_R (g): _____												
80 % upstream gravimetric level c_{80} (mg/l): _____												
Filtration ratio σ_x												
Average filtration ratio		2		10		75		100		200		1 000
Particle size, *x*, µm(c)												
Stabilized downstream test results												
Δ*p* point	Filter element Δ*p* (kPa)	ISO FTD injected, g	Stabilized ISO 11218 cleanliness classes									
			4 µm(c)		6 µm(c)		14 µm(c)					
2,5 %												
80 %												
Particle counts per mL and filtration ratio												
Time interval	*d* > µm(c)	σ	*d* > µm(c)	σ	*d* > µm(c)	σ	*d* > µm(c)	σ	*d* > µm(c)	σ	*d* > µm(c)	σ
Initial up												
10 % Up												
Down												
20 % Up												
Down												
30 % Up												
Down												
40 % Up												
Down												
50 % Up												
Down												
60 % Up												
Down												
70 % Up												
Down												
80 % Up												
Down												
90 % Up												
Down												
100 % Up												
Down												
Avg. Up												
Avg. Down												
Stabilization test results (downstream particle counts)												
Δ*p* point												
2,5 %												
80 %												

12.2.6 Determine the 80 % stabilized ISO 11218 cleanliness classes for the above size ranges from the averaged stabilized downstream particle counts and record in the report sheet given in Table 4 and Table 5.

12.2.7 Calculate and record the corresponding filter element differential pressure, obtained by subtracting the housing differential pressure from the 80 % filter assembly differential pressure, $\Delta p_{80\,\%}$, calculated in 11.2.5.

12.2.8 Calculate and record in the report sheet given in Table 4 and Table 5 the contaminant injected to $\Delta p_{80\,\%}$, using the time, $t_{80\,\%}$, from 11.2.16, using Formula (26):

$$c_{80\,\%} = \frac{\left(t_{80\,\%} \times \bar{c}_{\mathrm{i}} \times \bar{q}_{\mathrm{i}}\right)}{1\,000} \tag{26}$$

13 Identification statement (reference to this document)

Use the following statement in test reports, catalogues and sales literature when electing to conform to this document:

"Method for determining filtration performance data in accordance with ISO 14085-3, *Aerospace series — Hydraulic Filter elements — Test methods — Part 3: Filtration efficiency and retention capacity.*"

Annex A
(normative)

Properties of test fluid to evaluate performance of hydraulic fluid systems filter elements

A.1 Properties of mineral oil stock

— pour point (max.) -60 °C;

— pour point (max.) 82 °C;

— acid or base number, mg KOH/g (max.) 0,10.

A.2 Additive materials

— viscosity/temperature coefficient improvers: not to exceed 20 % (by mass);

— oxidation inhibitors: not to exceed 2 % (by mass);

— anti-wear agent such as tricresyl phosphate: (0,5 ± 0,1) % (by mass);

When TCP is used, limit the ortho-isomer content to a maximum of 1 % (by mass).

A.3 Properties of finished oil

— viscosity:

1) at 40 °C (min.) 13,2 mm^2/s;
2) at 100 °C (min.) 4,9 mm^2/s;
3) at – 40 °C (max.) 600 mm^2/s;
4) at – 54 °C (max.) 2 500 mm^2/s;

— pour point (max.) – 60 °C;

— flash point with closed cup (min.) 82 °C;

— acid or base number, mg KOH/g (max.) 0,20;

— rubber swell, standard synthetic rubber l 19 % to 30 %;

— evaporation loss (max.) 20 %;

— copper strip corrosion (ASTM standard, max.) No. 2e;

— water content (max., parts per million by mass) 100;

— steel-on-steel wear (average wear scar, max. dia.) 1 mm;

— chlorine (max., parts per million by mass) 50.