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Hydraulic fluid power — Filters — Multi-pass method for evaluating filtration performance of a filter element

Transmissions hydrauliques — Filtres — Évaluation des performances par la méthode de filtration en circuit fermé

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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 documents 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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control*.

This third edition cancels and replaces the second edition (ISO 16889:2008), which has been technically revised. It also incorporates the Amendment ISO 16889:2008/Amd 1:2018.

The main changes are as follows:

— deletion of Table 4 (previous references to Table 4 replaced by references to ISO 11943:2021, Table C.2);

— harmonization of conductivity levels with ISO 23369.

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 hydraulic fluid power systems, one of the functions of the hydraulic fluid is to separate and lubricate the moving parts of the components. The presence of solid particulate contamination produces wear, resulting in loss of efficiency, reduced component life and subsequent unreliability.

A hydraulic filter is provided to control the number of particles circulating within the system to a level that is commensurate with the degree of sensitivity of the components to the contaminant and the level of reliability required by the users.

To enable the comparison of the relative performance of filters so that the most appropriate filter can be selected, it is necessary that test procedures be available. The performance characteristics of a filter are a function of the element (its medium and geometry) and the housing (its general configuration and seal design).

In practice, a filter is subjected to a continuous flow of contaminant entrained in the hydraulic fluid until some specified terminal differential pressure (relief-valve cracking pressure or differential-pressure indicator setting) is reached.

Both the length of operating time (prior to reaching terminal pressure) and the contaminant level at any point in the system are functions of the rate of contaminant addition (ingression plus generation rates) and the performance characteristics of the filter.

Therefore, it is necessary that a realistic laboratory test to establish the relative performance of a filter provide the test filter with a continuous supply of ingressed contaminant and allow the periodic monitoring of the filtration performance characteristics of the filter.

It is also necessary that the test provide an acceptable level of repeatability and reproducibility, and that a standard test contaminant, the ISO medium test dust (ISO MTD) in accordance with ISO 12103-1, be featured. This product has been shown to have a consistent particle-size distribution and is available worldwide. The filtration performance of the filter is determined by measurement of the upstream and downstream particle-size distributions using automatic particle counters validated according to ISO International Standards.

This test is intended to differentiate filter elements according to their functional performance but is not intended to represent performance under actual field operating conditions. Test conditions are steady-state, and the dynamic characteristics of industrial hydraulic systems are not represented. Other test protocols exist or are under development to evaluate performance with cyclic flow, high viscosity, flow fatigue, etc.

ISO 23369 (multi-pass testing method for evaluating the performance of hydraulic fluid power filter elements under cyclic-flow conditions) has been developed to supplement the steady-state testing of ISO 16889.

Hydraulic fluid power — Filters — Multi-pass method for evaluating filtration performance of a filter element

1 Scope

This document describes the following:

— a multi-pass filtration performance test with continuous contaminant injection for hydraulic fluid power filter elements;

NOTE 1 For the background interlaboratory study used to verify the test methodology, see Annex D.

— a procedure for determining the contaminant capacity, particulate removal and differential pressure characteristics;

— a test currently applicable to hydraulic fluid power filter elements that exhibit an average filtration ratio greater than or equal to 75 for particle sizes ≥ 25 µm(c), and a final reservoir gravimetric level of less than 200 mg/L;

NOTE 2 It is necessary to determine by validation the range of flow rates and the lower particle size limit that can be used in test facilities.

— a test using ISO medium test dust (ISO MTD) contaminant and a test fluid in accordance with Annex A.

This document is intended to provide a test procedure that yields reproducible test data for appraising the filtration performance of a hydraulic fluid power filter element without influence of electrostatic charge.

This document applies to three test conditions:

— test condition 1, with a base upstream gravimetric level of 3 mg/L;

— test condition 2, with a base upstream gravimetric level of 10 mg/L;

— test condition 3, with a base upstream gravimetric level of 15 mg/L.

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 1219-1, *Fluid power systems and components — Graphical symbols and circuit diagrams — Part 1: Graphical symbols for conventional use and data-processing applications*

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

ISO 3722, *Hydraulic fluid power — Fluid sample containers — Qualifying and controlling cleaning methods*

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 11943:2021, *Hydraulic fluid power — Online automatic particle-counting systems for liquids — Methods of calibration and validation*

ISO 12103-1:2016, *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 General terms

3.1.1
contaminant mass injected
mass of specific particulate contaminant injected into the test circuit to obtain the terminal differential pressure

3.1.2
rest conductivity
electrical conductivity at the initial instant of current measurement after a d.c. 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.

3.1.3
retained capacity
mass of the specific particulate contaminant effectively retained by the filter element when the terminal element differential pressure is reached

3.2 Terms related to differential pressure

3.2.1
differential pressure
difference between the tested component inlet and outlet pressure as measured under the specified conditions

Note 1 to entry: See Figure 1 for a graphical depiction of differential pressure terms.

3.2.2
clean assembly differential pressure
difference between the tested component inlet and outlet pressures as measured with a clean filter housing containing a clean filter element

3.2.3
clean element differential pressure
differential pressure of the clean element calculated as the difference between the clean assembly differential pressure and the housing differential pressure

3.2.4

final assembly differential pressure

assembly differential pressure at the end of a test, equal to the sum of the housing plus the terminal element differential pressures

3.2.5

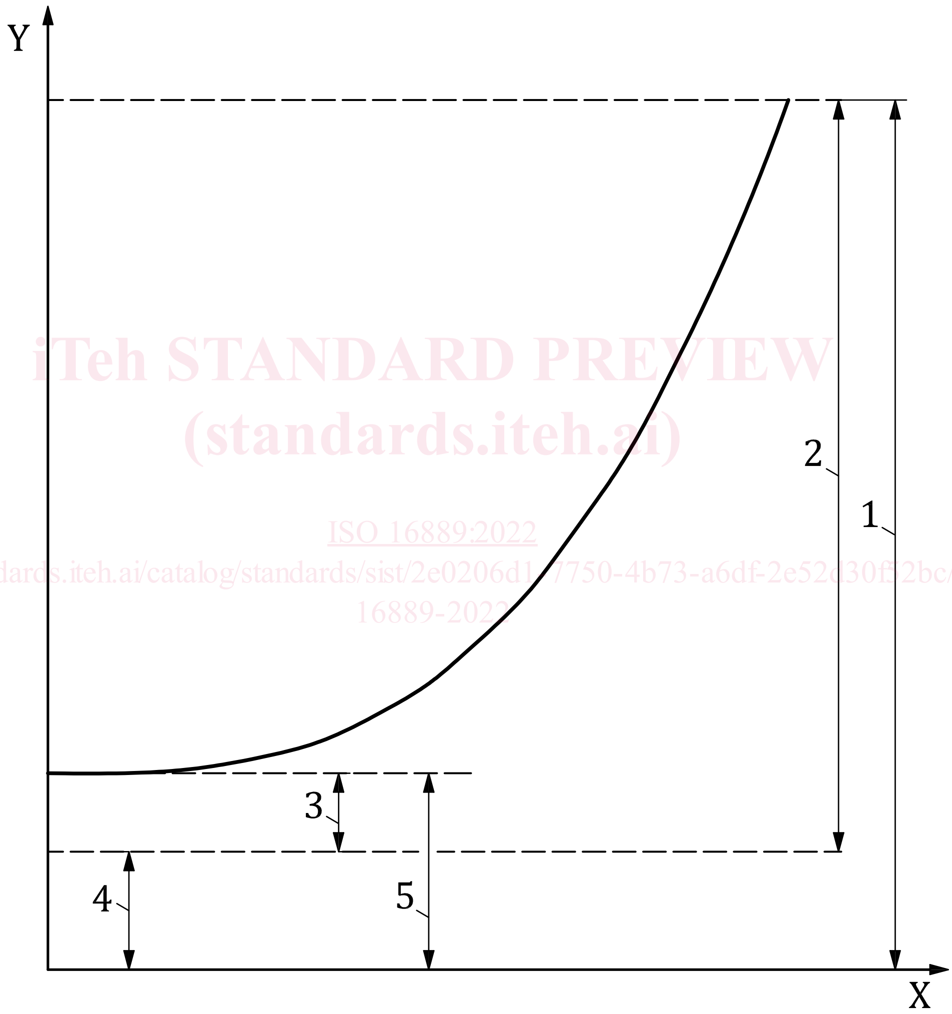
housing differential pressure

differential pressure of the filter housing without an element

3.2.6

terminal element differential pressure

maximum differential pressure across the filter element as designated by the manufacturer to limit useful performance



Key

X test time or mass injected

Y differential pressure

1 final assembly (end of test) differential pressure

2 terminal element differential pressure

3 clean element differential pressure

4 housing differential pressure

5 clean assembly differential pressure

Figure 1 — Differential pressure conventions for multi-pass test

4 Symbols

4.1 The graphical symbols used in this document are in accordance with ISO 1219-1.

4.2 The letter symbols used in this document are shown in Table 1.

Table 1 — Letter symbols

Symbol	Unit	Description or explanation
$\bar{A}_{d,x}$	particles per millilitre	overall average downstream count of particles larger than size x
$\bar{A}_{u,x}$	particles per millilitre	overall average upstream count of particles larger than size x
$\bar{c}_b$	milligrams per litre	average base upstream gravimetric level
$c_b{}'$	milligrams per litre	desired base upstream gravimetric level
$\bar{c}_i$	milligrams per litre	average injection gravimetric level
$c_i{}'$	milligrams per litre	desired injection gravimetric level
c_{80}	milligrams per litre	test reservoir gravimetric level at 80 % assembly differential pressure
k	—	number of the reporting interval corresponding to the time intervals
m	grams	mass of contaminant needed for injection
m_e	grams	estimated filter element contaminant capacity (mass injected)
m_i	grams	contaminant mass injected
m_p	grams	contaminant mass injected at element differential pressure
m_R	grams	retained capacity
n	—	number of counts in specific time period
$N_{d,x,j}$	particles per millilitre	number of downstream particles larger than size x at count j
$\bar{N}_{d,x,t}$	particles per millilitre	average downstream count of particles larger than size x at time interval t
$N_{u,x,j}$	particles per millilitre	number of upstream particles larger than size x at count j
$\bar{N}_{u,x,t}$	particles per millilitre	average upstream count of particles larger than size x at time interval t
p	pascals or kilopascals (bar)[b]	pressure
Δp	pascals or kilopascals (bar)[b]	differential pressure
Δp_f	pascals or kilopascals (bar)[b]	final differential pressure
q	litres per minute	test flow rate
q_d	litres per minute	discarded downstream sample flow rate
$\bar{q}_i$	litres per minute	average injection flow rate
$q_i{}'$	litres per minute	desired injection flow rate
q_u	litres per minute	discarded upstream sample flow rate
t	minute	test time
t_f	minute	final test time
t_{pr}	minute	predicted test time
t_p	minute	test time at element differential pressure
V_{if}	litres	final measured injection system volume
V_{ii}	litres	initial measured injection system volume

[a] The subscript (c) signifies that the filtration ratio, $\beta_{x(c)}$, and the average filtration ratio, $\bar{\beta}_{x(c)}$ are determined in accordance with the method in this document using automatic particle counters calibrated in accordance with ISO 11171.

[b] 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

Table 1 *(continued)*

Symbol	Unit	Description or explanation
V_{min}	litres	minimum required operating injection system volume
V_{tf}	litres	final measured filter test system volume
V_v	litres	minimum validated injection system volume
x_{int}	micrometres	interpolated particle size
x_1, x_2	micrometres	particle sizes
$\beta_{x(c)}$ [a]	—	filtration ratio at particle size x (ISO 11171 calibration)
$\beta_{x,t}$	—	filtration ratio at particle size x and time interval t
$\bar{\beta}_{x(c)}$ [a]	—	average filtration ratio at particle size x (ISO 11171 calibration)

[a] The subscript (c) signifies that the filtration ratio, $\beta_{x(c)}$, and the average filtration ratio, $\bar{\beta}_{x(c)}$ are determined in accordance with the method in this document using automatic particle counters calibrated in accordance with ISO 11171.

[b] 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

5 General procedures

5.1 Set up and maintain apparatus in accordance with Clauses 6 and 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 test data in accordance with Clause 12.

5.5 Present data from Clauses 10, 11 and 12 in accordance with the requirements of Clause 13.

6 Test equipment

6.1 Suitable timer.

6.2 Automatic particle counter(s) (APCs), calibrated in accordance with ISO 11171.

6.3 ISO medium test dust (ISO MTD, ISO 12103-1 — A3), 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.

For quantities greater than 200 g, dry for at least 30 min per additional 100 g. For use in the test system, mix the test dust into the test fluid, mechanically agitate, then disperse ultrasonically with a power density of 3 000 W/m^2 to 10 000 W/m^2.

Ensure that the ISO MTD used conforms to all the requirements of ISO 12103-1 — A3, especially the volume particle size distribution shown in ISO 12103-1:2016, Table 2.

NOTE This dust is commercially available. For availability of ISO MTD, contact the ISO secretariat service or national members of ISO.

6.4 On-line counting system, and dilution system if necessary, validated in accordance with ISO 11943.

6.5 Sample bottles, containing less than 20 particles larger than 6 µm(c) per millilitre of bottle volume, qualified in accordance with ISO 3722, to collect samples for gravimetric analyses.

6.6 Petroleum-based test fluid, in accordance with Annex A.

NOTE 1 The use of this carefully controlled hydraulic fluid assures greater reproducibility of results and is based upon current practices, other accepted filter standards and its worldwide availability.

NOTE 2 The use of an anti-static agent can affect the test results.

6.7 Filter performance test circuit, composed of a filter test system and a contaminant injection system.

6.7.1 Filter test system, consisting of the following:

a) a reservoir, a pump, fluid-conditioning apparatus and instrumentation that are capable of accommodating the range of flow rates, pressures and volumes required by the procedure and capable of meeting the validation requirements of Clause 8;

b) a clean-up filter capable of providing an initial system contamination level as specified in Table 3;

c) a configuration that is insensitive to the intended operative contaminant level;

d) a configuration that does not alter the test contaminant distribution over the anticipated test duration;

e) pressure taps in accordance with ISO 3968;

f) fluid sampling sections upstream and downstream of the test filter in accordance with ISO 4021.

NOTE For typical configurations that have proved satisfactory, refer to Annex B.

6.7.2 Contaminant injection system, consisting of the following:

a) a reservoir, a pump, fluid-conditioning apparatus and instrumentation that are capable of accommodating the range of flow rates, pressures and volumes required by the procedure and capable of meeting the validation requirements of Clause 8;

b) a configuration that is insensitive to the intended operative contaminant level;

c) a configuration that does not alter the test contaminant distribution over the anticipated test duration;

d) a fluid sampling section in accordance with ISO 4021.

NOTE For typical configurations that have proved satisfactory, refer to Annex B.

6.8 Membrane filters and associated laboratory equipment, suitable for conducting the gravimetric method in accordance with ISO 4405.

7 Measuring instrument accuracy and test condition variations

7.1 Use and maintain measuring instrument accuracy and test condition variations within the limits given in Table 2.

Table 2 — Measuring instrument accuracy and test condition variation

Test parameter	SI unit	Instrument reading accuracy	Allowed test condition variation
Conductivity	pS/m	±10 %	1 500 ± 500
Differential pressure	Pa or kPa (bar) [d]	±5 %	—
Base upstream gravimetric level	mg/L	—	±10 %
Injection flow rate	mL/min	±2 %	±5 %
Test flow rate	L/min	±2 %	±5 %
Automatic particle counter (APC) sensor flow rate	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 rate variation is included in the overall 10 % allowed between sensors.

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

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

[d] 1 bar = 0,1 MPa = 10^5 Pa; 1 MPa = 1 N/mm^2.

7.2 Maintain specific test parameters within the limits in Table 3 depending on the test condition being used.

Table 3 — Test condition values

Parameter	Condition 1	Condition 2	Condition 3
Initial contamination level for filter test system	Less than 1 % of the minimum level specified in ISO 11943:2021, Table C.2, measured at the smallest particle size being counted.		
Initial contamination level for injection system	Less than 1 % of the injection gravimetric level.		
Base upstream gravimetric level, mg/L [a]	3 ± 0,3	10 ± 1,0	15 ± 1,5
Recommended particle sizes for counting [b]	Minimum of five sizes, including 30 µm(c), selected to cover the presumed filter performance range from $\beta = 2$ to $\beta = 1\,000$. Typical sizes are 4 µm(c), 5 µm(c), 6 µm(c), 7 µm(c), 8 µm(c), 10 µm(c), 12 µm(c), 14 µm(c), 20 µm(c) and 25 µm(c).		
Sampling and counting method	On-line automatic particle counting.		

[a] When comparing test results between two filters, the base upstream gravimetric levels are expected to be the same.

[b] When a fine filter element is being tested, it might not be possible to count those particle sizes for which filtration ratios are low (for example, $\beta = 2$ or $\beta = 10$), and when a coarser filter element is being tested, it might not be possible to count or determine those particle sizes for which filtration ratios are high (for example, $\beta = 200$ or $\beta = 1\,000$), because this can require measurements that are beyond the limits of the APC or the test conditions specified in this document.

8 Filter performance test circuit validation procedures

8.1 Filter test system validation

8.1.1 Validate the filter test system at the minimum flow rate at which it is operated. Install a conduit in place of filter housing during validation.

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, expressed in litres per minute, with a minimum of 5 L.

It is recommended that the system be validated with a fluid volume numerically equal to 50 % of the minimum test volume flow rate for flow rates less than or equal to 60 L/min, or 25 % of the minimum 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).

8.1.3 Contaminate the system fluid to the base upstream gravimetric level for each test condition (1, 2 or 3) selected as shown in Table 3 using the ISO 12103-1 — A3 test dust.

8.1.4 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 2.

8.1.5 Circulate the fluid in the test system for 60 min, conducting continuous on-line automatic particle counts from the upstream sampling section for a period of 60 min. The sample flow from this section shall not be interrupted for the duration of the validation.

8.1.6 Record the cumulative on-line particle counts at equal time intervals not exceeding 1 min for the duration of the 60 min test at the particle sizes selected from those given in Table 3, including the 30 µm(c) particle size.

8.1.7 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, and

b) the average of all cumulative particle counts per millilitre is within the range of acceptable counts in accordance with ISO 11943:2021, Table C.2.

8.1.8 Validate the on-line particle counting system, and dilution systems if used, in accordance with ISO 11943.

8.2 Validation of contaminant injection system

8.2.1 Validate the contaminant injection system at the maximum gravimetric level, maximum injection system volume, minimum injection flow rate, and for the length of time required to deplete the complete usable volume.

8.2.2 Prepare the contaminant injection system to contain the required amount of test contaminant and required fluid volume consistent with the configuration of that system.

NOTE All ancillary procedures used in the preparation of the contaminant injection system become part of the validation procedure. Alteration of these procedures requires revalidation of the system.

8.2.3 Add dust to the contaminant injection system and circulate for a minimum of 15 min.

8.2.4 Initiate injection flow from the contaminant injection system, collecting this flow externally to the system. Obtain an initial sample at this point and measure the injection flow rate.

8.2.5 Maintain the injection flow rate within ±5 % of the desired injection flow rate.

8.2.6 Obtain samples of the injection flow and measure the injection flow rate at 30 min, 60 min, 90 min and 120 min or at a minimum of four equivalent intervals depending on the system's depletion rate.

8.2.7 Analyse the gravimetric level of each sample obtained in 8.2.6 in accordance with ISO 4405.

8.2.8 Measure the volume of fluid remaining in the injection system at the end of the validation test. This is the minimum validation volume, V_v.

8.2.9 Accept the validation only if:

a) the gravimetric level of each sample obtained in 8.2.6 is within ±10 % of the gravimetric level determined in 8.2.1 and the variation between the samples does not exceed ±5 % of the mean,

b) the injection flow rate at each sample point is within ±5 % of the selected validation flow rate (see 8.2.1) and the variation between sample flow rates does not exceed ±5 % of the average, and

c) the volume of fluid remaining in the injection system, V_v (see 8.2.8), plus the quantity (average injection flow rate [8.2.9 b)] times the total injection time) is within ±10 % of the initial volume (see 8.2.2).

9 Summary of information required prior to testing

Prior to applying the requirements of this document to a particular hydraulic filter element, establish the following:

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

b) filter element test flow rate,

c) terminal element differential pressure,

d) presumed particle size values for specific filtration ratios, and

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

10 Preliminary preparation

10.1 Test filter assembly

10.1.1 Ensure that test fluid cannot bypass the filter element under evaluation.

10.1.2 Subject the test filter element to a fabrication integrity test in accordance with ISO 2942.

NOTE The test fluid specified in 6.6 can be used for conducting the fabrication integrity test.

If the filter 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, it should be appreciated that 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.

Disqualify the filter element from further testing if it fails to meet the designated test pressure.

Allow the fluid to evaporate from the test filter element before installing it in the test filter housing, where applicable.