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Hydraulic fluid power — Multi-pass method of evaluating filtration performance of a filter element under cyclic flow conditions

Transmissions hydrauliques — Évaluation des performances d'un élément filtrant par la méthode de filtration multi-passe sous débit cyclique

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Foreword

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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).

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

This second edition cancels and replaces the first edition (ISO 23369:2021), which has been technically revised.

The main changes are as follows:

— calculation of ramp time.

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.

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Introduction

In hydraulic fluid power systems, one of the functions of the hydraulic fluid is to separate and lubricate the moving parts of 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 contaminants and the level of reliability required by the users.

Test procedures enable the comparison of the relative performance of filters so that the most appropriate filter can be selected. 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 of 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, a realistic laboratory test establishes the relative performance of a filter by providing the test filter with a continuous supply of ingressed contaminant and allowing the periodic monitoring of the filtration performance characteristics of the filter. A standard multi-pass method for evaluating the performance of hydraulic fluid power filter elements under steady-state flow conditions has been developed as ISO 16889. That test procedure provides a basis for the comparison of the relative performance characteristics of various filter elements. The results from such a test, however, might not be directly applicable to most actual operating conditions.

In actual operation, a hydraulic fluid power filter is generally not subjected to steady-state flow but to varying degrees of cyclic flow. Tests have shown that, in many instances, the filtration capabilities of an element are severely reduced when subjected to varying cyclic flow conditions. It is therefore important to evaluate the filtration performance of a filter for applications under cyclic flow conditions.

The cyclic flow multi-pass test procedure for hydraulic filters specified in this document has been developed to supplement the basic steady-state flow test (ISO 16889) for filter elements that are expected to be placed in service with cyclic flow. The recommended flow cycle rate of 0,1 Hz is a result of an industry survey and a broad range of test results. If much higher cycle rates are expected in actual service, the test should be conducted at that frequency to produce more meaningful results. The procedure specified in this document may be applied at a cycle rate other than 0,1 Hz, if agreed upon between the supplier and user. However, only values resulting from testing at the 0,1 Hz cycle rate may be reported as having been determined in accordance with this document.

Fluid samples are extracted from the test system to evaluate the filter element's particulate removal characteristics. To prevent this sampling from adversely affecting the test results, a lower limit is placed upon the rated flow rate of filter elements that should be tested with this procedure.

The current maximum flow rate specified in this document is based upon the maximum gravimetric level of injection systems that have been qualified to date.

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Hydraulic fluid power — Multi-pass method of evaluating filtration performance of a filter element under cyclic flow conditions

1 Scope

This document specifies:

a) A multi-pass filtration performance test under cyclic flow conditions with continuous contaminant injection for hydraulic fluid power filter elements.

b) A procedure for determining the contaminant capacity, particulate removal and differential pressure characteristics.

c) 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 test system reservoir gravimetric level of less than 200 mg/L. 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.

d) A test using ISO 12103-1 A3 medium test dust contaminant and a test fluid.

This document provides 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 is applicable to three test conditions:

1) Base upstream gravimetric level of 3 mg/L.

2) Base upstream gravimetric level of 10 mg/L.

3) 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 2160, *Petroleum products — Corrosiveness to copper — Copper strip test*

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

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

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
m_i
mass of specific particulate contaminant injected into the test circuit to obtain the terminal differential pressure

3.2
differential pressure
difference between the tested component inlet and outlet pressures as measured under the specified conditions

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

3.3
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

3.4
clean element differential pressure
differential pressure of the clean element calculated as the difference between the *clean assembly differential pressure* (3.3) and the *housing differential pressure* (3.6)

3.5
final assembly differential pressure
assembly differential pressure at the end of a test, equal to the sum of the housing differential pressure and the terminal element differential pressure

3.6
housing differential pressure
differential pressure of the filter housing without an element

3.7
terminal element differential pressure
maximum differential pressure across the filter element as designated by the manufacturer to limit useful performance

3.8
rest conductivity
electrical conductivity at the initial instant of current measurement after a DC voltage is impressed between electrodes

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

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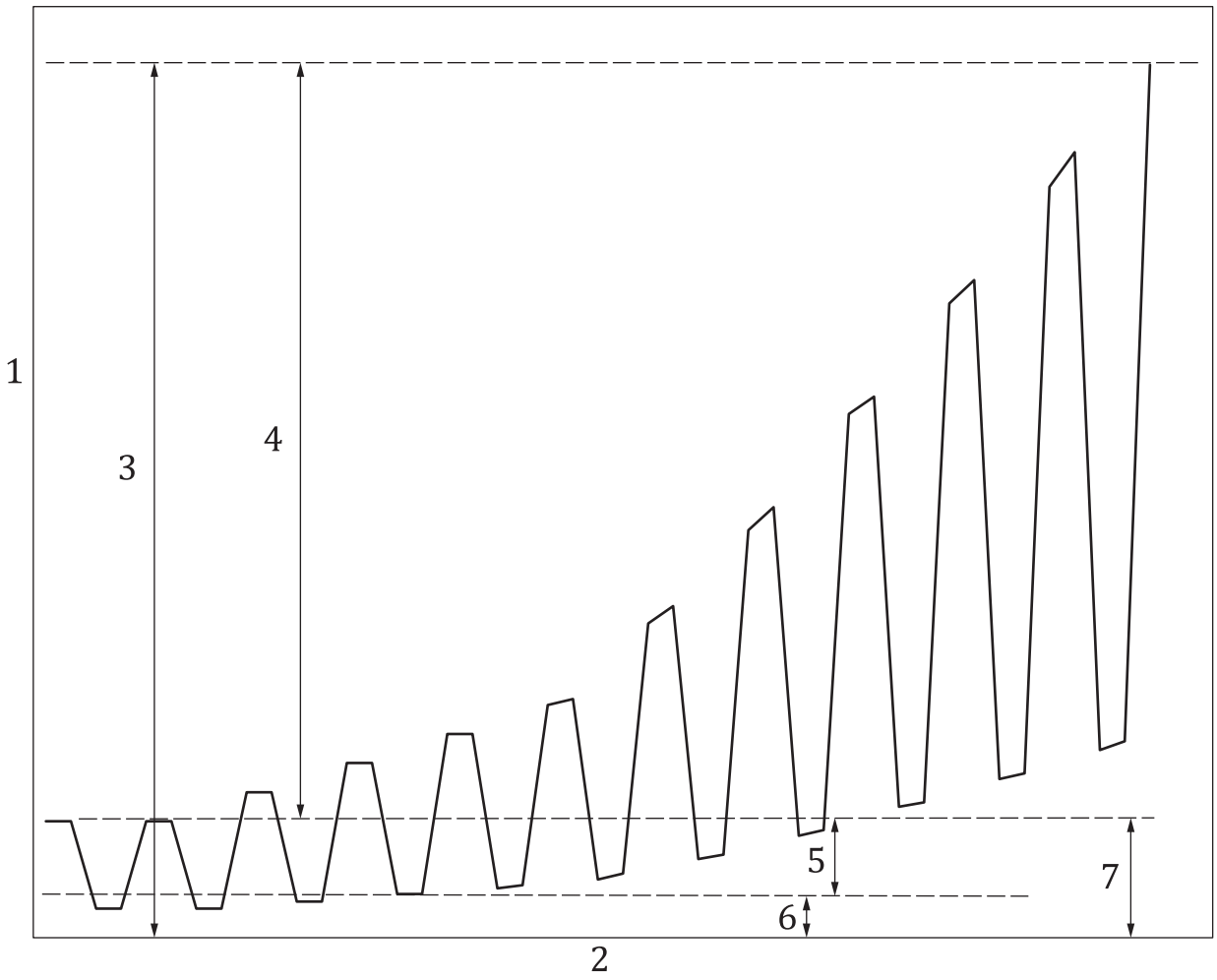
3.9
retained capacity
m_R
mass of specific particulate contaminant effectively retained by the filter element when terminal element differential pressure is reached

3.10
cyclic flow
change of flow from the specified rated flow rate to 25 % of rated flow rate at a specified frequency and waveform



Key

1 differential pressure (ΔP))
2 test time or contaminant mass injected
3 final assembly differential pressure (end of test)
4 terminal element differential pressure
5 clean element differential pressure at q_{max}
6 housing differential pressure at q_{max}
7 clean assembly differential pressure at q_{max}

Figure 1 — Differential pressure conventions for multi-pass test under cyclic flow conditions

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4 Symbols

Table 1 — Symbols

Symbol	Unit	Description
$\bar{A}_{u,x}$	particles per millilitre	overall average upstream count of particles larger than size x
$\bar{A}_{d,x}$	particles per millilitre	overall average downstream count of particles larger than size x
$\alpha_{x(c)}$ [a]	–	filtration ratio at particle size x (ISO 11171 calibration)
$\alpha_{x,t}$	–	filtration ratio at particle size x and time interval t
$\bar{\alpha}_{x(c)}$	–	average filtration ratio at particle size x (ISO 11171 calibration)
a	litres per second squared	rise and fall ramp flow rate acceleration
$\bar{c}_b$	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
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
$N_{u,x,i}$	particles per millilitre	number of upstream particles larger than size x at count i
$N_{d,x,i}$	particles per millilitre	number of downstream particles larger than size x at count i
$\bar{N}_{u,x,t}$	particles per millilitre	average upstream count of particles larger than size x at time interval t
$\bar{N}_{d,x,t}$	particles per millilitre	average downstream count of particles larger than size x at time interval t
p	Pa or kPa (bar)	Pressure
ΔP	Pa or kPa (bar)	differential pressure
q	litres per minute	test flow rate
$\bar{q}$	litres per minute	average test flow rate
q_{min}	litres per minute	minimum test flow rate (25 % of q_{max})
q_{max}	litres per minute	maximum 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	minutes	test time
t_{pr}	minutes	predicted test time
t_f	minutes	final test time

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

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Table 1 *(continued)*

Symbol	Unit	Description
t_P	minutes	test time at element differential pressure
t_F	seconds	fall ramp time
t_R	seconds	rise ramp time
t'	seconds	predicted test time
V_{if}	litres	final measured injection system volume
V_{ii}	litres	initial measured injection system volume
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_1 , x_2	micrometres	particle sizes
x_{int}	micrometres	interpolated particle size

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

5 General procedure

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 Calibrated timer, a digital or mechanical stopwatch calibrated by a facility meeting the requirements of ISO/IEC 17025.

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

6.3 ISO medium test dust (**ISO MTD**) (in accordance with ISO 12103-1, A3 medium test dust), dried at 110 °C to 150 °C for not less than 1 h for quantities less than 200 g. For use in the test system, mix the test dust into the test fluid, mechanically agitate, then disperse ultrasonically in an ultrasonic bath that has a power density of 3 000 W/m^2 to 10 000 W/m^2.

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.

NOTE 1 This dust is commercially available. For availability of ISO medium test dust, contact the ISO Central Secretariat or member bodies of ISO.

6.4 Online particle counting system (if necessary) with optional dilution system that has been validated in accordance with ISO 11943.

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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 base test fluid, with properties as specified in Annex A.

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.

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

6.7.1 Filter test system, consisting of:

a) a reservoir, 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 relatively insensitive to the intended contaminant level and capable of meeting the validation requirements of Clause 8;

d) a configuration that does not alter the test contaminant particle size distribution over the anticipated test duration and that is capable of meeting the validation requirements of Clause 8;

e) pressure taps in accordance with the requirements of ISO 3968;

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

g) cyclic flow bypass line equipped with an automatically controlled shut-off valve (e.g., an electrically-actuated ball valve or poppet type valve or alternative system (e.g., direct drive), which have been shown to be satisfactory for this application) capable of producing the required flow rate cycle at the designated frequency.

NOTE For typical configurations that have proved to be satisfactory, see the filter test system design guide in Annex B.

6.7.2 Contaminant injection system, consisting of:

a) a reservoir, 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 relatively insensitive to the intended contaminant level and capable of meeting the validation requirements of Clause 8;

c) a configuration that does not alter the test contaminant particle size distribution over the anticipated test duration and capable of meeting the validation requirements of Clause 8;

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

NOTE For typical configurations that have proved to be satisfactory, see the contaminant injection system design guide in Annex B.

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

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7 Measurement accuracy and test condition variation

7.1 Use and maintain instrument accuracy and test conditions within the limits given in Table 2.

Table 2 — Instrument accuracy and test condition variation

Test parameter	SI unit	Instrument accuracy (±) of reading	Allowed test condition variation (±)
Conductivity	pS/m	10 %	1 500 pS/m ± 500 pS/m
Differential pressure	Pa or kPa (bar)	5 %	—
Base upstream gravimetric level	mg/L	—	10 %
Injection flow rate	mL/min	2 %	5 %
Test flow rate	L/min	2 %	5 %
APC sensor and dilution flow rates	mL/min	1,5 %	3 % [a]
Kinematic viscosity [b]	mm^2/s	2 %	1 mm^2/s
Mass	g	0,1 mg	—
Temperature	°C	1 °C	2 °C [c]
Time	s	0,1 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

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

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

Table 3 — Test condition values

Parameter	Filter test condition		
	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 to be counted.		
Initial contamination level for injection system	Less than 1 % of injection gravimetric level.		
Base upstream gravimetric level, based on the average test flow rate while cycling, $\bar{q}$ [a]	(3 ± 0,3) mg/L	(10 ± 1,0) mg/L	(15 ± 1,5) mg/L
Recommended particle sizes to be counted [b]	Minimum of five sizes selected to cover the presumed filter performance range from $\alpha_{x(c)}$ = 2 to $\alpha_{x(c)}$ = 1 000. Typical sizes are: (4, 5, 6, 7, 8, 10, 12, 14, 20, 25, 30) µm(c).		
Sampling and counting method	Online automatic particle counting		
Cyclic flow rate conditions	From q_{max} to q_{min} at a frequency of 0,1 Hz (6 cycles/min) in accordance with the waveform specified in Figure 2.		

[a] When comparing test results between two filters, the base upstream gravimetric level and the wave form shall be the same.

[b] Particle sizes where α is low (α = 2, 10...) can be unobtainable for fine filters, and particle sizes where α is high (α = 200, 1 000) can be unobtainable for coarser filters.

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8 Filter performance test circuit validation procedures

8.1 General

These validation procedures reveal the effectiveness of the filter performance test circuit to maintain contaminant entrainment and prevent contaminant size modification.

8.2 Filter test system validation

8.2.1 Install a conduit in place of the filter housing during validation. The conduit shall be selected so that is produces the maximum differential pressure expected during testing.

NOTE An orifice with a 60° inlet and outlet is recommended.

8.2.2 Validation shall be performed at the cyclic flow rate that includes the lowest minimum test flow rate (q_{min}) and highest maximum test flow rate (q_{max}) at which the filter test system is to be operated. The minimum test flow rate shall be 25 % of the maximum test flow rate.

8.2.3 Validate the cyclic flow at 0,1 Hz (6 cycles/min), unless otherwise specified.

8.2.4 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 maximum volume flow rate, with a minimum of 5 L.

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

8.2.5 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.

8.2.6 Establish a background fluid contamination level that is less than that specified in Table 3.

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

8.2.8 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 2.

8.2.9 Circulate the fluid in the test system for 60 min, conducting continuous online automatic particle counts from the upstream sampling section for a period of 60 min. 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.

8.2.10 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 3.

8.2.11 Accept the validation only if:

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

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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; and

c) the average of all cumulative particle counts per millilitre are within the range of acceptable counts shown in ISO 11943.

8.3 Contaminant injection system validation

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

8.3.2 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 preparation of the contaminant injection system become part of the validation procedure. Alteration of these procedures requires revalidation of the system.

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

8.3.4 Start the timer and initiate injection flow from the contaminant injection system, collecting this flow externally from the system. Obtain an initial sample at this point and measure the injection flow rate.

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

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

8.3.7 Analyse the gravimetric level of each sample obtained in 8.3.6 in accordance with ISO 4405.

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

8.3.9 Accept the validation only if:

a) the gravimetric level of each sample obtained in 8.3.6 is within ±10 % of the gravimetric level determined in 8.3.1 and the variation between samples does not exceed ±5 % of the mean; and

b) the injection flow rate at each sample point is within ±5% of the selected validation flow rate (8.3.1), 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 (8.3.8) plus the quantity [average injection flow rate (12.11) times total injection time (8.3.6)] is within ±10 % of the initial volume (8.3.2).

9 Summary of information required prior to testing a filter element

The following information shall be established before submitting a particular filter element to the test specified in this document:

a) fabrication integrity test pressure (in accordance with ISO 2942);

b) filter element maximum test flow (q_{max}) as determined by the manufacturer;

c) terminal element differential pressure;

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d) presumed particle size values for specific filtration ratios;

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

10 Preliminary test preparation

10.1 Test filter assembly

10.1.1 Ensure that test fluid cannot bypass 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 Where applicable, 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 Annex A 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.

NOTE 3 If the tested element fails the fabrication integrity test, then the corresponding cyclic flow results should be considered invalid, since there is no evidence that the element would have initially passed the test.

10.2 Contaminant injection system

10.2.1 Calculate the average test flow rate ($\bar{q}$) using Formula (1):

$$\bar{q} = \left(\frac{q_{max} + q_{min}}{2} \right) \tag{1}$$

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

10.2.3 Predicted test times of less than 1 h or longer than 3 h are acceptable as long as the selected test condition 1, 2, or 3 is maintained.

$$t' = \frac{1\,000 \times m_e}{c'_b \times \bar{q}} \tag{2}$$

where $\bar{q}$ (flow rate) is calculated using Formula (1).

NOTE A second filter element is tested for capacity analysis if the value of the estimated capacity of the test element is not supplied by the filter manufacturer.

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10.2.4 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 (3):

$$V_{\min} = \left(1{,}2 \times t' \times q_{\mathrm{i}}^{'}\right) + V_{\mathrm{v}} \tag{3}$$

The volume calculated using Formula (3) 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 may be used.

A value for the injection flow rate ($q_{\mathrm{i}}^{'}$) 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 may be used provided that the base upstream gravimetric level is maintained.

10.2.5 Calculate the desired gravimetric level ($c_{\mathrm{i}}^{'}$) of the injection system fluid using Formula (4):

$$c_{\mathrm{i}}^{'} = \frac{c_{\mathrm{b}}^{'} \times \bar{q}}{q_{\mathrm{i}}^{'}} \tag{4}$$

10.2.6 Adjust the total initial volume, V_{ii}, of the contaminant injection system (measured at the test temperature) to the value calculated in 10.2.4 and record the result on the report sheet given in Table C.3.

10.2.7 Calculate the mass of contaminant needed for the contaminant injection system (m) using Formula (5):

$$m = \frac{c_{\mathrm{i}}^{'} \times V_{\mathrm{ii}}}{1\,000} \tag{5}$$

10.2.8 Prior to the addition of the ISO 12103-1, A3 medium test dust to the contaminant injection system, verify that the background fluid contamination level is less than specified in Table 3.

10.2.9 Prepare the contaminant injection system to contain the quantity of fluid, V_{ii}, and ISO 12103-1, A3 medium test dust (m) (see 10.2.7) using the same procedure that was used for the contamination injection system validation (see 8.2).

10.2.10 Adjust the injection flow rate at a 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 C.3. During setup, return the injection system sampling flow directly to the injection reservoir.

10.3 Filter test system

10.3.1 Install the filter housing (without test element) in the filter test system and thoroughly bleed off air.

10.3.2 It is recommended that the rest conductivity of the test fluid should be checked and maintained in the range of 1 500 pS/m ± 500 pS/m (see ASTM D-4308). This can be accomplished by the addition of an anti-static agent. The addition of an anti-static agent can affect the test results. Use of an anti-static agent that has a date code older than 18 months is not recommended.

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10.3.3 Circulate the fluid in the filter test system at maximum test flow rate and at a test temperature such that the fluid viscosity is maintained at 15 mm^2/s ± 1,0 mm^2/s; record the temperature and differential pressure of the empty filter housing 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 % and 50 % of the designated maximum test flow rate through the filter, in L/min, with a minimum of 5 L.

10.3.5 If the designated maximum test volume flow rate is less than or equal to 60 L/min, it is recommended that the filter test system fluid volume be numerically equal to 50 % of the maximum test volume flow rate. If the designated maximum test volume flow rate is greater than 60 L/min, it is recommended that the filter test system fluid volume be numerically equal to 25 % of the maximum test volume flow rate.

10.3.6 Repeatable test 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.

10.3.7 Establish a fluid background contamination level less than that specified in Table 3.

10.3.8 Effectuate online automatic particle counting by:

a) Adjusting the upstream sampling flow rate to a value compatible with the sampling procedure used and the downstream sampling flow rate to within ±5 % of the injection flow rate. Maintain uninterrupted flow from both sampling points during the entire test.

b) Adjusting the upstream and downstream dilution flow rates if required for online 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; and the upstream and downstream sensor flow rates should be set and maintained at the values, and within the limits, specified in 8.2.8 and Table 2.

c) Returning 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.

d) The upstream and downstream dilution flow rates should be equal to the values chosen in 10.3.8 b within the limits shown in Table 2.

e) Sensor flow rates should be monitored and recorded throughout the test and maintained within the limits shown in Table 2.

10.3.9 Adjust the particle counter thresholds to the values selected from Table 3.

11 Filter performance test

11.1 Install the filter element into its housing and subject the assembly to the specified test condition and reaffirm the fluid level.

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11.2 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.

11.3 Calculate the final assembly differential pressure corresponding to the final element differential pressure plus the housing differential pressure.

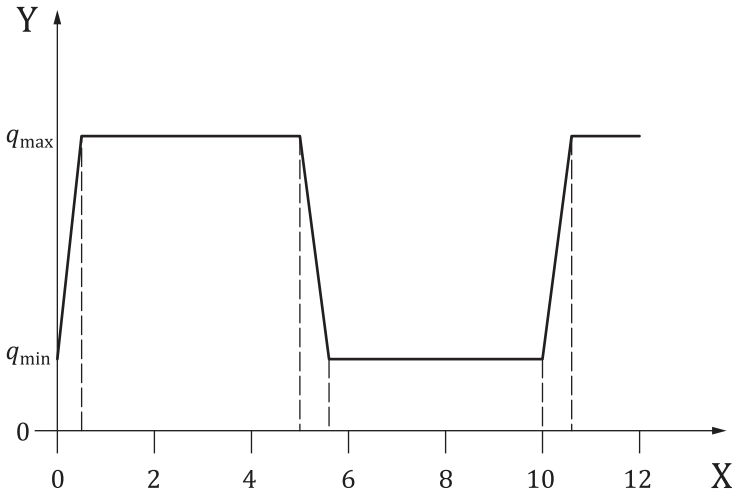
11.4 Measure and record the initial system contamination level using online particle counting from upstream of the test filter element.

11.5 Bypass the system clean-up filter if the upstream contamination level is less than that specified in Table 3. If the upstream contamination level is not less than specified in Table 3 then continue to utilize the clean-up filter until the upstream contamination level is less than that specified in Table 3.

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

11.7 Measure and verify the injection flow rate. Continuous measurement of the injection flow rate is required throughout the test to ensure the flow rate is maintained within the specified tolerances.

11.8 Operate the cycling valve in the test system to generate and repeat the flow rate cycle shown in Figure 2.



Key

X test time (t')

Y test flow rate (q)

Figure 2 — Waveform for multi-pass test under cyclic flow conditions

Up to $q_{max} \leq 120$ L/min the rise and fall ramp time should be ≤0,2 s. From $q_{max} > 120$ L/min the rise and fall ramp flow rate acceleration (a) should be ≥ 7,5 L/s^2. Ramp time should be calculated using Formula (6)

$$t_{R,F} = \frac{q_{max} - q_{min}}{60 \times a} \quad (6)$$

NOTE During validation of the test stand, a pressure reading can be used to confirm rise and fall timing as measured by the flow meters.

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11.9 Initiate the filter test as follows:

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

b) start the timer;

c) divert the downstream sample flow from the test system to maintain a constant system volume within a tolerance of ±5 % [see 10.3.8, a)].

11.10 Conduct and record online particle counts on the upstream and downstream fluid at equal time intervals of either 30 s, 40 s, 50 s or 60 s (not to exceed 60 s) until the differential pressure across the filter assembly at maximum test flow rate has increased to the terminal value calculated in 11.3. In addition:

a) the flow rate and dilution ratio shall be controlled and recorded to calculate the exact amount of test fluid that is passed through the sensor for each count;

b) a minimum counting volume of 10 mL shall be used to obtain statistically significant data. Care should be taken to use online dilution as required to avoid exceeding the coincidence limit of the automatic particle counter as determined in accordance with ISO 11171.

11.11 Record the assembly differential pressure twice per flow cycle: once just before the flow rate rises and again just before the flow rate falls. Continuous differential pressure measurements using a differential pressure transducer are recommended for this purpose.

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

11.13 Conclude the test at the final assembly differential pressure at the maximum test flow rate as follows:

a) record the final test time;

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

c) stop the flow rate cycle;

d) stop flow to the test filter.

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

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

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

11.17 Check that no visual evidence of filter element damage has occurred as a result of performing this test. Although the installation and test procedures are checked for qualification prior to testing, it is advisable to check when interpreting the results that the test has been performed satisfactorily.

12 Calculations

12.1 Establish 10 reporting times equal to 10 %, 20 %, 30 %... 100 % of the final test time and record these times on the report sheet in Table C.3.

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12.2 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.

12.3 Calculate and record on the report sheet in Table C.3 the element differential pressures corresponding to each of the reporting times by subtracting the housing differential pressure from each respective assembly differential pressure.

12.4 For each particle count obtained during the test (11.10), calculate the cumulative particle count per millilitre at each size by dividing the raw counts obtained by the counted volume and adjusting for any dilution, if used.

12.5 Calculate average upstream and downstream particle counts at each particle size, x, for each of the 10 reporting times, t, using Formulae (7) and (8) and the specific instructions in this subclause, a) through d).

$$\bar{N}_{\mathrm{u},x,t} = \frac{\sum_{i=1}^{n} N_{\mathrm{u},x,i}}{n} \tag{7}$$

$$\bar{N}_{\mathrm{d},x,t} = \frac{\sum_{i=1}^{n} N_{\mathrm{d},x,i}}{n} \tag{8}$$

where

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

a) Delete the first three (3) particle counts corresponding to test times of 1 min, 2 min and 3 min.

NOTE 1 These data deletions are to eliminate potentially erroneous particle counts obtained prior to system stabilization.

b) For the first reporting time (10 %), using Formulae (7) and (8), average the upstream and downstream particle counts obtained in 12.4 for all the particle counts that were started before the first reporting time [with the exception of the first three deleted in 12.5 a)]. Record these average values on the report sheet in Table C.3.

NOTE 2 If the total test time is less than 30 min, it is possible to have no data for the 10 % reporting time; in this case, the entries are left blank.

c) For the second reporting time (20 %), average the upstream and downstream counts obtained in 12.4 for all the particle counts that were started after the first reporting time and before the second reporting time. Record these average values on the report sheet in Table C.3.

d) For the third through tenth reporting times (30 % to 100 %), repeat 12,5 °C) in a similar manner using only the counts that were started in each reporting interval. Record these average values on the report sheet in Table C.3.

12.6 Calculate the filtration ratios ($\alpha_{x,t}$), using Formula (9), corresponding to each of the 10 reporting times by dividing the average upstream particle count by the average downstream particle count at

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each particle size, x, corresponding to that respective reporting time. Record the results on the report sheet in Table C.3 to three significant digits (i.e.; 1,75; 20,1; 324; 45 600).

$$\alpha_{x,t} = \frac{\bar{N}_{u,x,t}}{\bar{N}_{d,x,t}} \tag{9}$$

Particle counts shall be averaged, and average filtration ratios (α values) are to be calculated from these average counts. Under no circumstances shall the α values be averaged.

12.7 Calculate the overall test average upstream and downstream particle counts, using Formulae (10) and (11), by numerically averaging the 10 average counts from 12.6 corresponding to each of the 10 reporting times. Record the results on the report sheet in Table C.3.

$$\bar{A}_{u,x} = \sum_{t=10}^{100} \bar{N}_{u,x,t} \tag{10}$$

$$\bar{A}_{d,x} = \sum_{t=10}^{100} \bar{N}_{d,x,t} \tag{11}$$

where

t is the 10 reporting time intervals from 10 % to 100 %.

12.8 Calculate the overall average filtration ratios, $\bar{\alpha}_{x(c)}$, using Formula (12), at each particle size, $x_{(c)}$, by dividing the overall test average upstream particle counts by the overall test average downstream particle counts at each particle size. Record the results on the report sheet in Table C.3 to three significant digits.

$$\bar{\alpha}_{x(c)} = \frac{\bar{A}_{u,x}}{\bar{A}_{d,x}} \tag{12}$$

NOTE The subscript (c) signifies that the filtration ratio, $\bar{\alpha}_{x(c)}$, was determined in accordance with this document, using particle counters calibrated in accordance with ISO 11171. Particle counts shall be averaged, then average filtration ratios (α values) are to be calculated from these average counts. Under no circumstances shall the α values be averaged.

12.9 Conduct a gravimetric analysis in accordance with ISO 4405 on the two samples extracted from the contaminant injection system (11.6 and 11.15). Report the gravimetric contamination results to the nearest 0,1 mg/L on the report sheet in Table C.3. Calculate the average injection gravimetric level, $\bar{c}_i$, 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 $\bar{c}_i$.

If $\bar{c}_i$ differs from the selected value c'_b (from 10.2.5) by more than 5 %, repeat the gravimetric analyses. If the recheck differs more than 5 %, it is recommended that the contaminant injection system validation procedure in 8.3 be repeated.

12.10 Conduct three gravimetric analyses in accordance with ISO 4405 on the 80 % upstream sample (see 11.12) and record the average of these analyses as the final system gravimetric level. Report the gravimetric contamination results to the nearest 0,1 mg/L on the report sheet in Table C.3.

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

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12.11 Calculate and record on the report sheet in Table C.3, using Formula (13), the average injection flow rate ($\bar{q}_i$):

$$\bar{q}_i = \frac{V_{ii} - V_{if}}{t_f} \tag{13}$$

Accept the test only if this value is within ±5 % of the value selected in 10.2.2.

12.12 Calculate and record on the report sheet in Table C.3, using Formula (14), the average base upstream gravimetric level, $\bar{c}_b$:

$$\bar{c}_b = \frac{\bar{c}_i \times \bar{q}_i}{\bar{q}} \tag{14}$$

Accept the test only if this value is equal to the base upstream gravimetric level chosen from Table 3.

13 Data presentation

13.1 Report the minimum information for filter elements evaluated in accordance with this document. Present all test and calculation results as outlined in Annex C and included in the report sheet in Table C.3. It is recommended that the layout of the report sheet be used as shown. Have available a record of all physical values pertaining to the test.

13.2 Using Formula (15), calculate the filter element contaminant mass injected (m_i), and report the value obtained on the report sheet in Table C.3.

$$m_i = \frac{\bar{c}_i \times \bar{q}_i \times t_f}{1\,000} \tag{15}$$

13.3 Using Formula (16), calculate the filter element contaminant retained capacity (m_R), round the result to the nearest two significant digits and report the value obtained on the report sheet in Table C.3.

$$m_R = m_i - \frac{c_{80} \times V_{if}}{1\,000} - \frac{q_d \times t_f \times (c_{80} - \bar{c}_b)}{1\,000} - \frac{q_u \times t_f \times \left(\frac{c_{80} + \bar{c}_b}{2}\right)}{1\,000} \tag{16}$$

Formula (16) subtracts from the mass of ISO medium test dust injected (in accordance with ISO 12103-1, A3 medium test dust):

1) the weight of contaminant remaining in the test system at the end of the test;
2) an estimate of the amount of contaminant permanently extracted from the system through the filter downstream sampling tap (the term $[c_{80} - \bar{c}_b]$ is a conservative estimate of the gravimetric level downstream of the test filter); and
3) 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 $\left(\frac{c_{80} + \bar{c}_b}{2}\right)$ is an estimate of the average upstream gravimetric level. If the upstream sample flow is recycled and not discarded, the formula is applied without the final term.

13.4 Report the values of the gravimetric levels obtained in 12.9 and 12.10 on the report sheet in Table C.3.

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13.5 Using Formula (17), calculate the contaminant mass injected at the element differential pressure (m_P), record the value on the report sheet in Table C.3 and plot on linear coordinates (see Figure C.1) for the element differential pressure versus ISO 12103-1, A3 medium test dust contaminant mass added.

$$m_P = \frac{\overline{c_i} \times \overline{q_i} \times t_f}{1\,000} \tag{17}$$

13.6 Plot using semi-log (log linear) coordinates the average α value versus particle size, x, with α values on the log scale with α = 100 000 as the highest value plotted (see the example in Figure C.2).

NOTE When $\alpha_{x(c)}$ values equal to infinity (i.e. zero downstream particle count) are recorded, they are plotted as $\alpha_{x(c)}$ = 100 000.

13.7 Calculate and record on the report sheet in Table C.3 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 α versus particle size plot. Do not extrapolate.

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

To calculate the interpolated particle size, x µm(c), for a specified filtration ratio, $\alpha_{x(c)}$, where the value falls between two of the points from the plot in 13.6 (corresponding to filtration ratios and particle sizes α_{x1} and α_{x2} and particle sizes x_1 and x_2 respectively), use Formula (18). For α values greater than 100 000, use the value of 100 000 for α in Formula (18):

$$x = \frac{(x_1 - x_2) \times \log(\alpha_{x(c)} / \alpha_{x_1})}{\log(\alpha_{x_1} / \alpha_{x_2})} + x_1 \tag{18}$$

Plot on semi-log (log linear) coordinates average α values, $\overline{\alpha}$, for each particle size versus percent test time, with the values on the log scale (see the example in Figure C.3).

13.8 Plot on log-log coordinates average α values, $\overline{\alpha}$, for each particle size versus element differential pressure, with the α values on the ordinate (see the example in Figure C.4).

14 Identification statement (reference to this document)

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

"Method for determining filtration performance of a hydraulic filter element under cyclic flow conditions conforms to ISO 23369, *Hydraulic fluid power — Multi-pass method of evaluating filtration performance of a filter element under cyclic flow conditions*".

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Annex A
(normative)

Base test fluid properties

A.1 Properties of mineral oil stock (Table A.1)

Table A.1 — Mineral oil stock properties

Parameter	Value
Pour point	–60 °C max.
Flash point with closed cup	82 °C min.
Acid or base number	0,10 mg KOH/g max.

A.2 Additive materials (Table A.2)

Table A.2 — Additive materials

Material	Value
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) [a]
[a] When tricresyl phosphate is used, limit the ortho-isomer content to a maximum of 1 % (by mass).	

A.3 Finished base test fluid properties (Table A.3)

Table A.3 — Finished base test fluid properties

Parameter	Value
Viscosity at 40 °C (minimum)	13,2 mm^2/s
Viscosity at 100 °C (minimum)	4,9 mm^2/s
Viscosity at –50 °C (maximum)	2 500 mm^2/s
Viscosity at –40 °C (maximum)	600 mm^2/s
Pour point (maximum)	–60 °C
Flash point with closed cup (minimum)	82 °C
Acid or base number (maximum)	0,20 mg KOH/g
Rubber swell, standard synthetic rubber I	19 % to 30 %
Evaporation loss (maximum)	20 %
Copper strip corrosion (in accordance with ISO 2160)	No. 2e
Water content (maximum)	100 µg/g
Steel-on-steel wear (average wear scar, maximum diameter)	1 mm
Chlorine (maximum)	50 µg/g

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Table A.3 *(continued)*

Parameter	Value
Colour	Clear and transparent; the fluid shall contain red dye in a proportion not greater than one part of dye per 10 000 parts of fluid (by mass) (used for identification only).

A.4 Qualified test fluids

The following fluids fulfil the requirements of A.3:

— MIL-PRF-5606

— AIR 3520

— NATO Code H-515/520

— DEF STAN 91-48.

A.5 Rest conductivity

It is recommended that the test fluid rest conductivity be checked and maintained in the range of 1 500 pS/m ± 500 pS/m (see ASTM D4308 or ISO equivalent). This can be accomplished by the addition of an anti-static additive.

The use of anti-static additive having a date code of older than 18 months is not recommended.

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Annex B
(informative)

Test system design guide

B.1 General

The procedure described in this document requires a pre-test validation procedure to determine the acceptability of the equipment to perform the desired test.

This annex provides basic guidance in constructing equipment that meets the validation requirements of this document.

This annex provides only guidelines for construction and in no way guarantees successful validation of the equipment.

B.2 Basic test system

B.2.1 General guidelines

B.2.1.1 Circuit diagram

A circuit diagram of the basic test system, which consists of the filter test system and the contaminant injection system, is shown in Figure B.1.

B.2.1.2 Lines

All lines should be sized to ensure turbulent mixing flow, and long straight runs should be avoided.

B.2.1.3 Connectors

Connectors should not have internally exposed threads or lips that can trap contaminants.

B.2.1.4 Lines and connectors

Lines and connectors should be arranged to eliminate dead flow zones. Where possible, vertical runs are preferable to horizontal.

B.2.1.5 Valves

Ball valves are preferable to other types of valves as they do not trap contaminants and have a self-cleaning action.

B.2.2 Filter test system

B.2.2.1 General

The filter test system consists of the elements described in B.2.2.2 through B.2.2.8.

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B.2.2.2 Reservoir

A reservoir constructed with a conical bottom displaying an included angle of not more than 90 with the entering oil diffused below the fluid surface. This construction technique eliminates horizontal surfaces that promote contaminant settling.

The reservoir design pictured in Figure B.2 is a full cone and is useful for containing a desired fluid volume in a system where height is critical. The reservoir design pictured in Figure B.3 is a cylinder with a conical bottom and is useful for containing a desired fluid volume in a system where reservoir diameter is critical.

Reservoir included angles of between 60° and 90° offer the best balance of ease of construction and the ability to discriminate between the various fluid levels.

A device for monitoring the level of clean fluid in the test reservoir is used to check that the level remains constant.

B.2.2.3 System pump and drive

The system pump should be selected from a pump family that is relatively insensitive to contaminant at the desired operating pressures.

The system pump should exhibit a relatively low flow-pulsation characteristic (less than 10 %) so as not to cause erroneous test results.

The system pump should not cause alteration of the test contaminant distribution as a result of its pumping mechanism.

NOTE 1 Gear pumps and some types of piston pumps have demonstrated capability in these respects. Centrifugal and progressive cavity pumps have resulted in difficulties in complying with validation.

The pump drive should be of the variable speed type to provide the capability of adjusting the test flow rate. The pump drive should be relatively insensitive to changes in load so as to maintain a constant speed.

NOTE 2 Variable frequency AC drives and DC drives exhibit these desirable characteristics.

B.2.2.4 Clean-up filter

The system clean-up filter should be capable of providing an initial system contamination level as shown in Table 2.

To promote rapid clean-up, the filter should typically be finer than the filter to be tested and be sized for at least the maximum system flow rate.

To promote economy, the filter should also possess a high contaminant capacity. The use of multiple or large filters to achieve a low flow rate per unit area is desirable.

B.2.2.5 Heat exchanger or heater

B.2.2.5.1 General

Depending upon system power capabilities, cooling or heating of the system fluid might be required:

B.2.2.5.2 Heat exchangers

A conventional shell and tube heat exchanger may be used. It is recommended that a vertical mounting configuration with the oil entering the tube side from the bottom be used. This is to reduce the possibility of particle sedimentation or capture in the heat exchanger.

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Either single or multi-pass heat exchangers have been successfully used.

Some data indicate that up to a 65 % loss in thermal transfer can occur when operating with the oil on the tube side. Care should be taken to size the heat exchanger accordingly.

B.2.2.5.3 Other fluid cooling methods

Other cooling methods (e.g. double wall conduits and coils wrapped on the external surface of reservoirs and pipes) have also proved satisfactory.

B.2.2.5.4 Fluid heating

If required, fluid heating can be accomplished by the use of heating tapes on external surfaces or by using a second heat exchanger with a high temperature fluid on the shell side.

B.2.2.6 Regulation valves

B.2.2.6.1 Bypass valve

It is often convenient to incorporate a test filter bypass section (including a bypass valve) upstream of the filter returning directly to the reservoir. This section allows the system pump to be operated at a higher speed for low flow tests eliminating high flow ripples and drive overheating. Diaphragm, weir or pinch valves have proved suitable for bypassing the filter.

If a filter bypass section is used, it should be included in and active during the test system validation and be measured as part of the system volume.

B.2.2.6.2 Counter pressure regulation valve

This optional downstream valve allows the test filter to be tested under pressure that is generally required for online automatic particle counting. Ball, diaphragm, weir or pinch valves are suitable for this purpose.

B.2.2.7 Cyclic flow bypass valve

This cyclic flow bypass valve section is the key to performing the cyclic flow multi-pass test. The valve is required to regulate the flow bypassing the test filter. This valve controls the bypass of fluid around the test filter at the specified cycle rate. Upstream of the test filter it should be connected between the pump and the APC sampling port. The return pipe of the by-pass should go directly to the tank. Ball, diaphragm, weir or pinch valves with automatic actuation are suitable for this purpose.

B.2.2.8 Flowmeter

The flowmeter should be located between the test filter and the downstream sampling port to read the true flow rate in the test section and to provide the maximum protection for the flowmeter from abrasive contaminant. Flowmeters in other locations can require correction for sampling flows that may not be measured. Turbine flow meters using sealed bearings have proven suitable.

B.2.3 Contaminant injection system

B.2.3.1 General

The contaminant injection system consists of the elements described in B.2.3.2 through B.2.3.6.

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B.2.3.2 Reservoir

Construction and design precautions are the same as for the test system reservoir described in B.2.2.2.

NOTE Due to the large volume and high contaminant concentrations encountered, an auxiliary agitation system for the contaminant injection reservoir is desirable, for example, stirrers, auxiliary circulation loops or similar high energy input devices.

B.2.3.3 Pump

The high concentration of contamination in the test circuit makes the choice of the pump limited to those with a complete insensitivity to abrasive slurries. Centrifugal and progressive cavity pumps have been shown to be acceptable. When using centrifugal pumps, vertical mounting with the inlet down or horizontal mounting with the discharge at the bottom have proven successful.

B.2.3.4 Clean-up filter

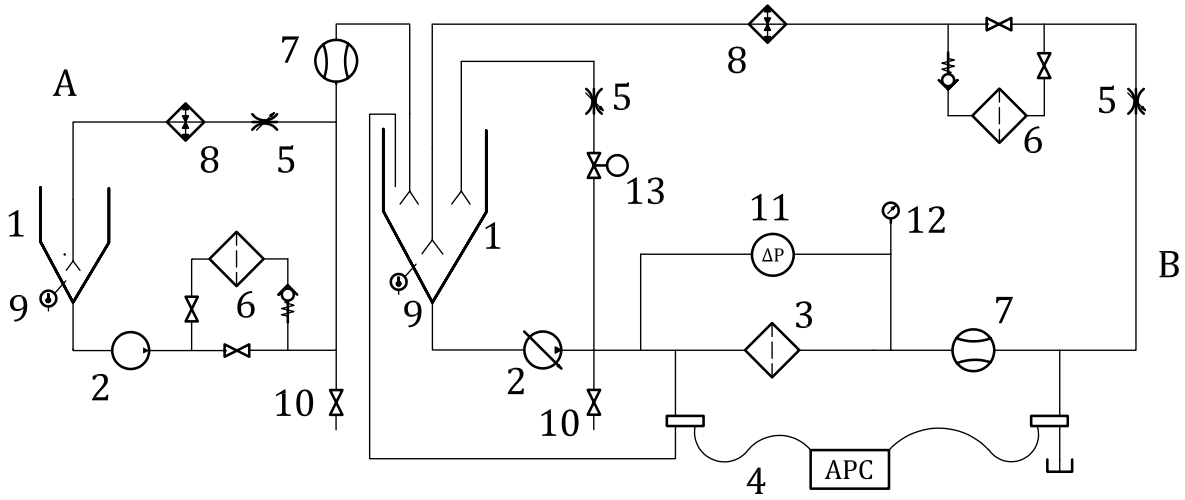
The same considerations as for the filter test system (see B.2.2.4) apply except that contaminant holding capacity is of prime importance.

B.2.3.5 Heat exchangers

See B.2.2.5.

B.2.3.6 Flowmeter

Any flowmeter used in the contaminant injection system should be compatible with the high concentration of abrasive particles.



Key

1	reservoir	8	heat exchanger
2	pump	9	temperature sensor
3	test filter	10	sampling valve
4	particle counting system	11	differential pressure indicator
5	regulating valve	12	pressure gauge
6	clean-up filter	13	cyclic flow bypass valve
7	flowmeter	A	contaminant injection system
		B	filter test system

Figure B.1 — Circuit diagram of the basic test system

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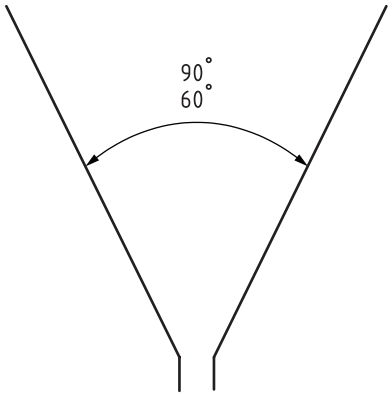

Figure B.2 — Full cone reservoir

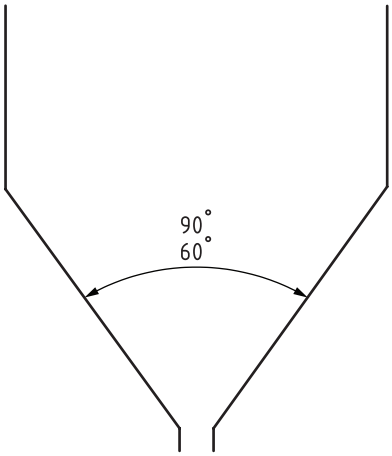

Figure B.3 — Cylindrical reservoir with a conical bottom

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Annex C
(informative)

Example report, calculations and graphs

C.1 General

Annex C contains examples of test data, calculations and graphs resulting from a typical multi-pass test under cyclic flow conditions.

C.2 Preliminary information

The information required prior to conducting the test (see Clause 9) is as shown in Table C.1.

Table C.1 — Information required prior to conducting multi-pass test under cyclic flow conditions

Parameter	Value
Fabrication integrity pressure	1 500 Pa
Maximum test flow rate (q_{max})	100 L/min
Terminal element differential pressure	400 kPa
Presumed filtration ratios	$\alpha_{5(c)}$ = 4 and $\alpha_{15(c)}$ = 75
Estimated filter element capacity (m_e)	40 g

The test laboratory selected the test conditions shown in Table C.2.

Table C.2 — Selected test conditions for multi-pass test under cyclic flow conditions

Parameter	Value
Desired base upstream gravimetric level, c_b'	10 mg/l
Desired injection flow, q_i'	0,25 L/min
Particle count sizes	5, 10, 15, 20 and 30 µm(c)

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Using Formula (1) gives:

$$\overline{q} = \left(\frac{q_{\max} + q_{\min}}{2} \right) = \overline{q} = \left(\frac{100 + 25}{2} \right) = 62{,}5\,\mathrm{L/min}$$

Using Formula (2) gives:

$$t' = \frac{1\,000 \times m_e}{c_b' \times \overline{q}} = \frac{1\,000 \times 40}{10 \times 62{,}5} = 64\,\mathrm{min}$$

Using Formula (3) gives:

$$V_{\min} = (1{,}2 \times t' \times q_i') + V_v = (1{,}2 \times 64 \times 0{,}25) + 8 = 27{,}2\,\mathrm{L}$$

Using Formula (4) gives:

$$c_i' = \frac{c_b' \times \overline{q}}{q_i'} = \frac{10 \times 62{,}5}{0{,}25} = 2\,500\,\mathrm{mg/L}$$

Using Formula (5) gives:

$$m = \frac{c_i' \times V_{ii}}{1\,000} = \frac{2\,500 \times 20}{1\,000} = 50\,\mathrm{g}$$

C.3 Results of multi-pass test under cyclic flow conditions

The multi-pass test under cyclic flow conditions was conducted with the above parameters. The calculated test results were determined as follows:

Using Formula (13) gives:

$$\overline{q}_i = \frac{V_{ii} - V_{if}}{t_f} = \frac{19{,}2 - 11{,}4}{34{,}2} = 0{,}228\,L/\mathrm{min}$$

Using Formula (14) gives:

For this example, $\overline{c_i} = c_i'$

$$\overline{c_b} = \frac{\overline{c_i} \times \overline{q_i}}{\overline{q}} = \frac{2\,500 \times 0{,}228}{62{,}5} = 9\,\mathrm{mg}/L$$

Using Formula (15) gives:

$$m_i = \frac{\overline{c_i} \times \overline{q_i} \times t_f}{1\,000} = \frac{2\,500 \times 0{,}252 \times 34{,}2}{1\,000} = 21{,}5\,\mathrm{g}$$

In order to calculate the retained capacity, the following parameters not reported on the report sheet are required:

Discarded downstream sample flow rate, $q_{d:}$ 0,20 L/min;

Discarded upstream sample flow rate, $q_{u:}$ 0,05 L/min;

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Using Formula (16) gives:

$$m_R = m_i - \frac{c_{80} \times V_{if}}{1\,000} - \frac{q_d \times t_f \times (c_{80} - \bar{c}_b)}{1\,000} - \frac{q_u \times t_f \times \left(\frac{c_{80} + \bar{c}_b}{2}\right)}{1\,000}$$

$$m_R = 21{,}5 - \frac{22{,}3 \times 11{,}4}{1\,000} - \frac{0{,}2 \times 34{,}2 \times (22{,}3 - 9)}{1\,000} - \frac{0{,}05 \times 34{,}2 \times \left(\frac{22{,}3 + 9}{2}\right)}{1\,000}$$

$$m_R = 21{,}5 - 0{,}25 - 0{,}09 - 0{,}027 = 21{,}0 \text{ g}$$

Each of the contaminant-injected values reported in Table C.3 were calculated using Formula (17). The average particle counts and filtration ratios reported in Table C.3 were calculated using Formulae (5), (7), (8), (9), (10) and (11).

Figure C.1 is a graph of element differential pressure versus contaminant added. The first data point represents the clean element differential pressure at the beginning of the test, and each of the remaining data points (10 minimum) represents one of the reporting times from 10 % to 100 % of final test time. These values are also shown in Table C.3.

Formula (18) was used to calculate the interpolated particle sizes for the specific filtration ratios reported at the bottom of Table C.3. As an example, to calculate the particle size (x) where $\alpha_{x(c)} = 75$, an interpolation is made between 10 µm(c) and 15 µm(c) as follows:

$$x = \frac{(x1 - x2) \times log(\alpha_{x(c)} / \alpha_{x_1})}{log(\alpha_{x_1} / \alpha_{x_2})} + x1$$

$$x = \frac{(10 - 15) \times log\left(\frac{75}{21{,}1}\right)}{log(21{,}1 / 116)} + 10 = 13{,}7\,\mu m(c)$$

The particle size for $\alpha = 2$ could not be calculated because it occurs below the lowest particle size counted, that is, 5 µm(c), and extrapolation is not allowed

Table C.3 — Report sheet for filter element multi-pass test under cyclic flow conditions

Test laboratory:	Test date:	Operator:
Filter and element identification		
Element identification:	Housing identification:	
Spin-on: Yes No	Element first bubble point:	Pa
Operating conditions		
Test fluid		
Type:	Reference:	Batch no.:
Viscosity at the test temperature (mm^2/s):		Temperature (°C):
Antistatic: Yes No	Type:	Conductivity (pS/m):
Test contaminant		
Type: ISO MTD	Batch no.:	
Test system		
Flow rate, $\bar{q}$ (L/min):		Initial volume (L):
q_{min} (L/min):		
q_{max} (L/min):		

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Table C.3 *(continued)*

Ramp Time, $t_{R,F}$ (sec):					Final volume (L):		
Base upstream concentration, $\bar{c}_b$ (mg/L):							
Injection system							
Injection parameters	**Initial**	**Final**	**Average injection parameters**				
System volume	L	L	Injection flow $\bar{q}_i$ (L/min):				
Concentration	mg/L	mg/L	Concentration $\bar{c}_i$ (mg/L):				
Counting system							
Location	**Counter and sensor ref.**	**Flow rate**	**Dilution ratio**				
Upstream		mL/min					
Downstream		mL/min					
Counter calibration:	Method:		Date:				
Element integrity			Wetting fluid:				
Bubble point to ISO 2942(Pa):			Clean assembly ΔP (kPa):				
Differential pressure (ΔP)			Final ΔP of element(kPa):				
Filter housing ΔP (kPa):							
Clean element ΔP (kPa):							
Differential pressure versus contaminant added							
Time interval	Test time	Element ΔP	Injected mass	Time interval	Test time	Element ΔP	Injected mass
10 %	min	kPa	g	60 %	min	kPa	g
20 %	min	kPa	g	70 %	min	kPa	g
30 %	min	kPa	g	80 %	min	kPa	g
40 %	min	kPa	g	90 %	min	kPa	g
50 %	min	kPa	g	100 %	min	kPa	g
Retention capacity							
ISO MTD mass injected m_i(g): ISO MTD retained capacity m_R(g):							
80 % upstream concentration m_{80}(mg/L):							
Filtration ratio $\alpha_{x(c)}$							
Average filtration ratio	2	10	75	100	200	1 000	
Particle size	µm(c)	µm(c)	µm(c)	µm(c)	µm(c)	µm(c)	

Particle counts per millilitre and filtration ratio α												
Time interval	d > µm(c)	α	d > µm(c)	α	d > µm(c)	α	d > µm(c)	α	d > µm(c)	α	d > µm(c)	α
Initial up												
10 % Up												
10 % Down												
20 % Up												
20 % Down												
30 % Up												
30 % Down												
40 % Up												
40 % Down												

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Table C.3 *(continued)*

50 %	Up												
	Down												
60 %	Up												
	Down												
70 %	Up												
	Down												
80 %	Up												
	Down												
90 %	Up												
	Down												
100 %	Up												
	Down												
Avg. Up													
Avg. Down													

Figure C.2 is a plot of α versus particle size with straight-line segments connecting the data points at the various particle sizes. The linear interpolation calculated above is illustrated between particle sizes for 10 µm(c) and 15 µm(c) corresponding to α values of 21,1 and 116, respectively. The interpolated value for $\alpha = 75$ occurs at a particle size of 13,7 µm(c) or $\alpha_{13,7(c)} = 75$.

Figure C.3 is a plot of average filtration ratio at each of the particle sizes versus percent test time. These values are also shown in Table C.3. Note that several of the measured values for α at 30 µm(c) were infinity; however, the points are plotted at $\alpha = 100\,000$.

Figure C.4 is a plot of average filtration ratio at each of the particle sizes versus element differential pressure. These values are also shown in Table C.3. Again, note that values for $\alpha = \infty$ are plotted at $\alpha = 100\,000$.

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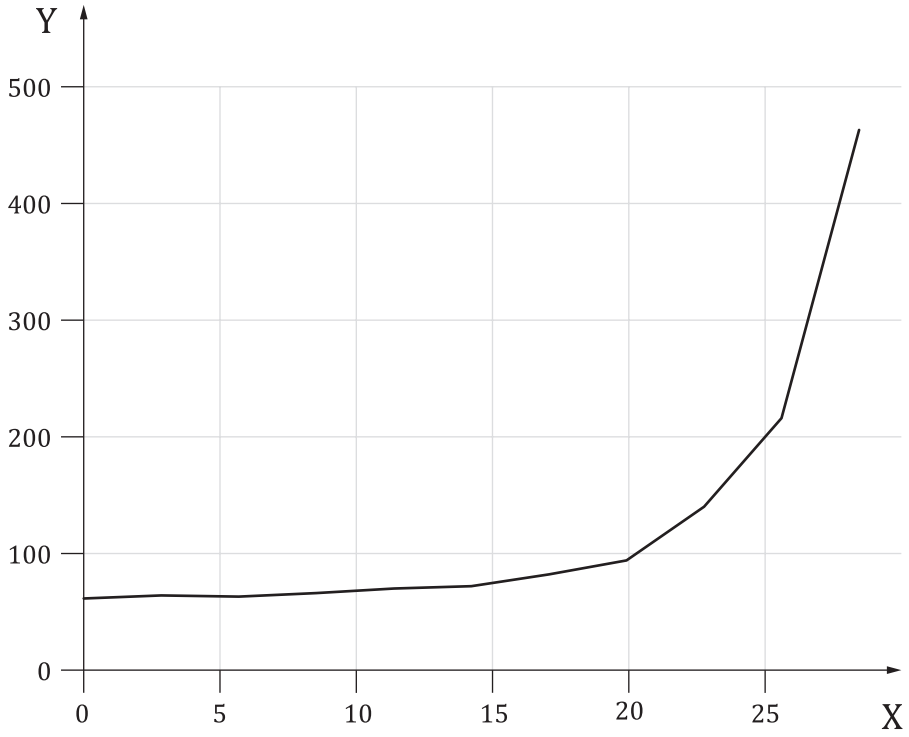

Key

X ISO 12103, A3 test dust mass injected (g)

Y element differential pressure (kPa)

Figure C.1 — Example of element differential pressure versus contaminant added curve

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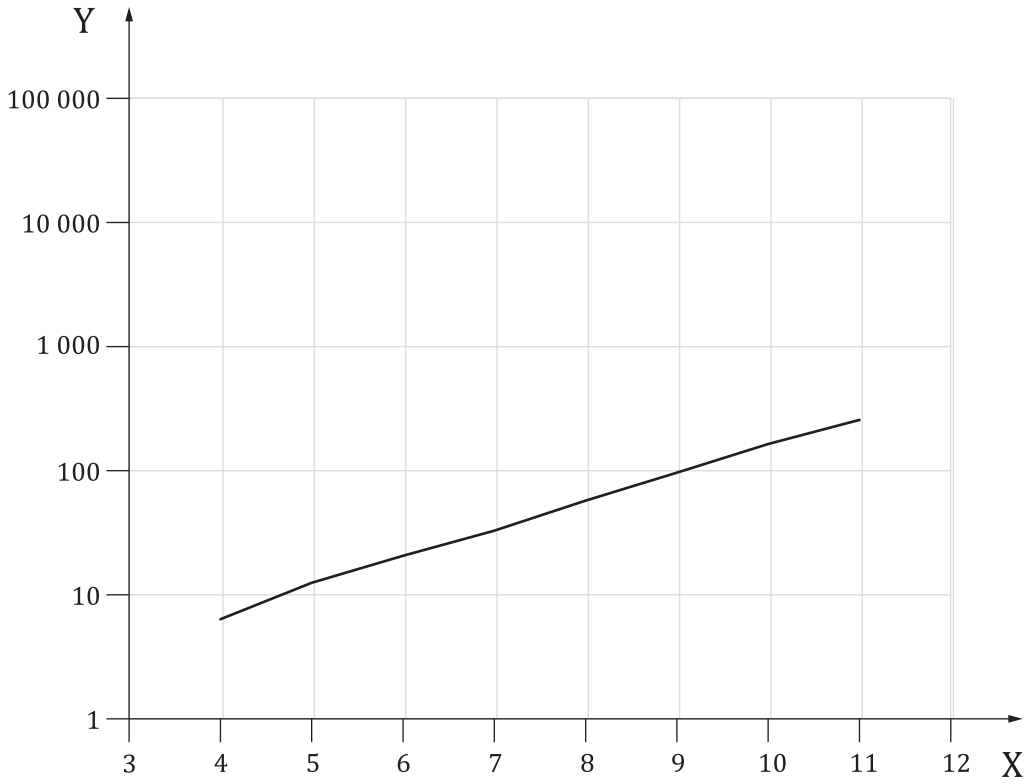

Key

X particle size (µm)

Y filtration ratio $\alpha_{x(c)}$

Figure C.2 — Example of filtration ratio versus particle size curve

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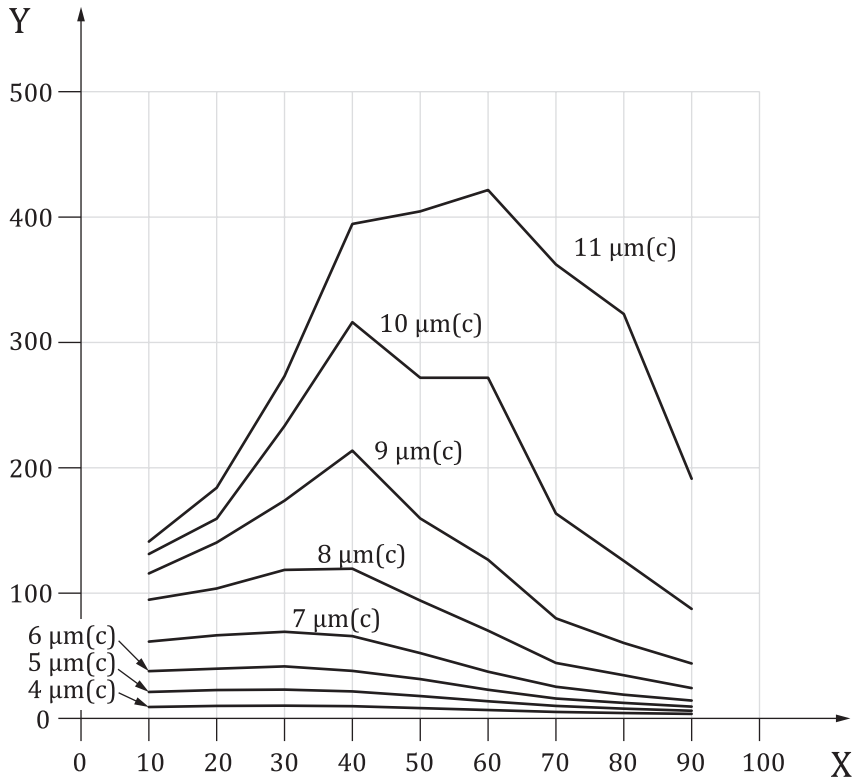

Key

X test time (%)

Y filtration ratio $\alpha_{x(c)}$

Figure C.3 — Example plot of filtration ratio versus percent test time

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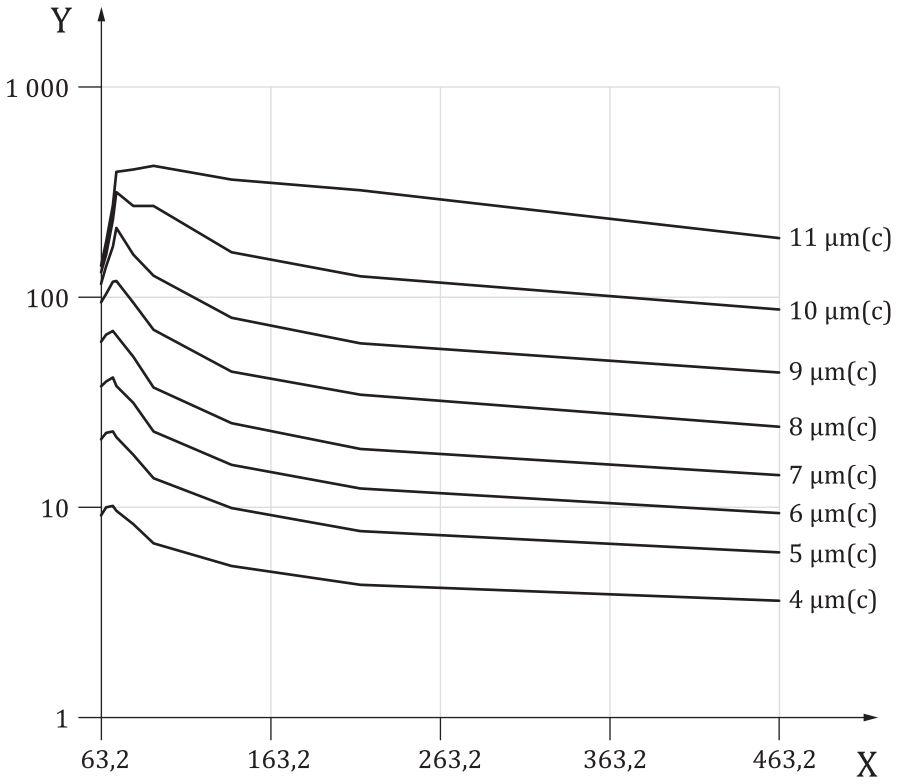

Key

X element differential pressure (kPa)

Y filtration ratio $\alpha_{x(c)}$

Figure C.4 — Example plot of filtration ratio versus element differential pressure

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