
**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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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 16889 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 16889:1999), 6.3 and Annex A of which have been technically revised, Annex A by the deletion of detailed round-robin data.

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 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 to ISO 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 in development to evaluate performance with cyclic flow, high viscosity, flow fatigue, etc.

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

1 Scope

This International Standard describes the following:

- a) a multi-pass filtration performance test 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 $\leq 25 \mu\text{m(c)}$, and a final reservoir gravimetric level of less than 200 mg/L;

NOTE 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 medium test dust contaminant and a test fluid in accordance with Annex A.

This International Standard 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 International Standard 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 referenced documents are indispensable for the application 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 — Graphic symbols and circuit diagrams — Part 1: Graphic 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 characteristics*

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 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

ISO 11171:1999, *Hydraulic fluid power — Calibration of automatic particle counters for liquids*

ISO 11943:1999, *Hydraulic fluid power — On-line automatic particle-counting systems for liquids — Methods of calibration and validation*

ISO 12103-1:1997, *Road vehicles — Test dust 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.

3.1

contaminant mass injected

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

3.2

differential pressure

Δp

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

NOTE See Figure 1 for a graphical depiction of differential pressure terms.

3.2.1

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

3.2.2

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

3.2.3

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

3.2.4

housing differential pressure

differential pressure of the filter housing without an element

3.2.5

terminal element differential pressure

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

3.3

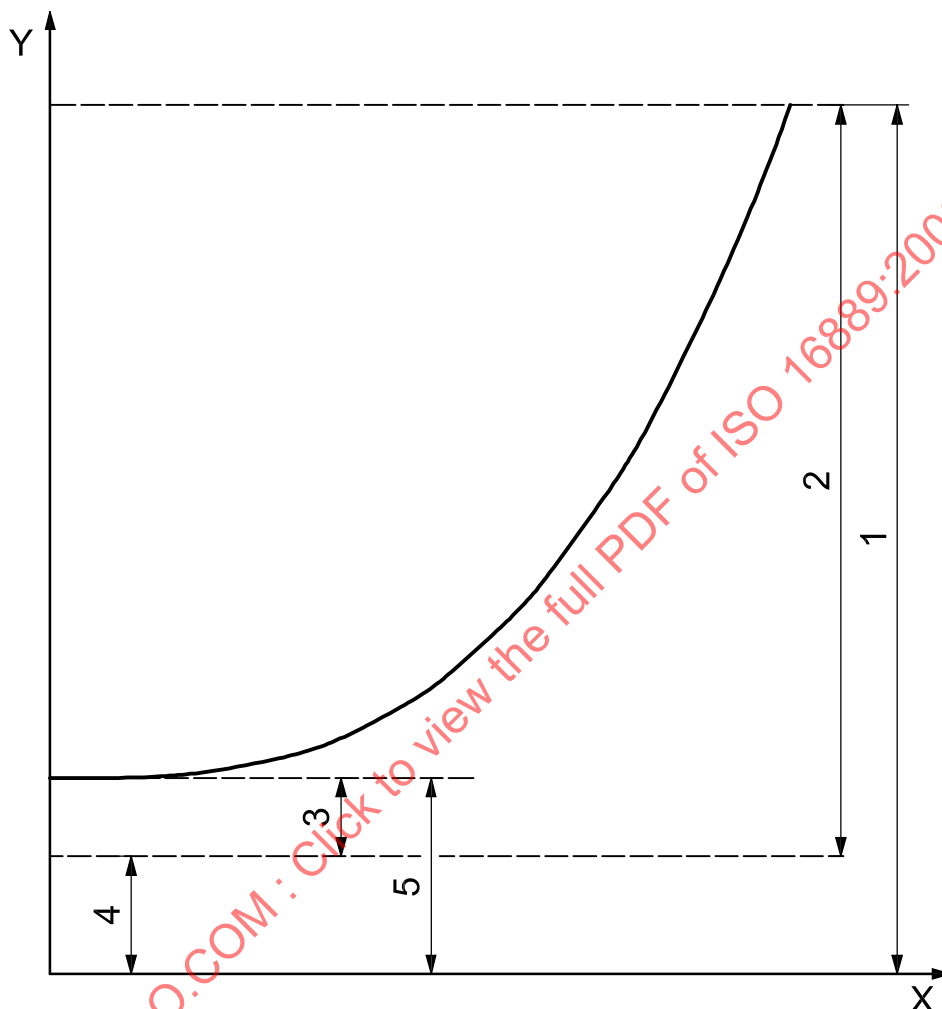
rest conductivity

electrical conductivity at the initial instant of current measurement after a d.c. voltage is impressed between electrodes

NOTE It is the reciprocal of the resistance of uncharged fluid in the absence of ionic depletion or polarization.

3.4**retained capacity**

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

**Key**

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

Figure 1 — Differential pressure conventions for multi-pass test

4 Symbols

4.1 The graphic symbols used are in accordance with ISO 1219-1.

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

Table 1 — Letter symbols

Symbol	Unit	Description or explanation
$\bar{A}_{u,x}$	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
$\bar{c}_b$	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
$N_{u,x,j}$	particles per millilitre	Number of upstream particles larger than size x at count j
$N_{d,x,j}$	particles per millilitre	Number of downstream 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
$\bar{N}_{d,x,t}$	particles per millilitre	Average downstream count of particles larger than size x at time interval t
p	pascals or kilopascals (bar)	Pressure
Δp	pascals or kilopascals (bar)	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_{pr}	minute	Predicted test time
t_f	minute	Final 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
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
$\beta_{x(c)}^a$	—	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 International Standard using automatic particle counters calibrated in accordance with ISO 11171.

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) (APC), 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/m² to 10 000 W/m².

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 12103-1:1997, 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-base 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 world-wide 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 %	1 000 to 10 000
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 %
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 mm²/s = 1 cSt (centistoke).

^c Or as required to guarantee the viscosity tolerance.

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 Table 4, 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 β = 2 to β = 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 should 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, β = 2 or β = 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, β = 200 or β = 1 000), because this can require measurements that are beyond the limits of the APC or the test conditions specified in this International Standard.			

8 Filter performance test circuit validation procedures

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

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-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

- 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
- the average of all cumulative particle counts per millilitre is within the range of acceptable counts shown in Table 4.

Table 4 — Particle size versus acceptable cumulative particle counts per millilitre

Particle size	Acceptable cumulative particle counts per millilitre ^a					
	Test condition 1 (3 mg/L)		Test condition 2 (10 mg/L)		Test condition 3 (15 mg/L)	
µm(c)	min.	max.	min.	max.	min.	max.
1	104 000	128 000	348 000	426 000	522 000	639 000
2	26 100	31 900	86 900	106 000	130 000	159 000
3	10 800	13 200	36 000	44 000	54 000	66 000
4	5 870	7 190	19 600	24 000	29 400	35 900
5	3 590	4 390	12 000	14 600	17 900	22 000
6	2 300	2 830	7 690	9 420	11 500	14 100
7	1 510	1 860	5 050	6 190	7 570	9 290
8	1 010	1 250	3 380	4 160	5 080	6 230
10	489	609	1 630	2 030	2 460	3 030
12	265	335	888	1 110	1 340	1 660
14	160	205	536	681	810	1 020
20	46	64	155	211	237	312
25	16	27	56	86	87	126
30	6	12	21	40	34	58
40	1,1	4,5	4,4	14,2	7,9	20
50	0,15	2,4	1,0	7,6	2,4	11

^a The minimum and maximum values are based on particle counts determined by the National Institute for Standards and Technology (United States) for SRM 2806 (see ISO/TR 16144) with a calculated variation based on the Poisson distribution.

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 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 external 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 $\pm 5\%$ 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
- the gravimetric level of each sample obtained in 8.2.6 is within $\pm 10\%$ of the gravimetric level determined in 8.2.1 and the variation between the samples does not exceed $\pm 5\%$ of the mean,
 - the injection flow rate at each sample point is within $\pm 5\%$ of the selected validation flow rate (see 8.2.1) and the variation between sample flow rates does not exceed $\pm 5\%$ of the average, and
 - 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 $\pm 10\%$ of the initial volume (see 8.2.2).

9 Summary of information required prior to testing

Prior to applying the requirements of this International Standard to a particular hydraulic filter element, establish the

- fabrication integrity test pressure (see ISO 2942),
- filter element test flow rate,
- terminal element differential pressure,
- presumed particle size values for specific filtration ratios, and
- 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.

10.2 Contaminant injection system

10.2.1 Select a desired base upstream gravimetric level, c_b' , from Table 3 such that the predicted test time, t_{pr} , calculated in accordance with Equation (1), is preferably in the range of 1 h to 3 h:

$$t_{pr} = \frac{1000 \times m_e}{c_b' \times q} \quad (1)$$

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

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

10.2.2 Calculate the minimum required operating injection system volume, V_{min} , that is compatible with the predicted test time, t_{pr} , and a desired value for the injection flow rate, using Equation (2):

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

The volume calculated in Equation (2) assures 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_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. The injection flow rate should equal or exceed the value used in 8.2.5.

10.2.3 Calculate the desired gravimetric level, c_i' , of the injection system using Equation (3):

$$c_i' = \frac{c_b' \times q}{q_i'} \quad (3)$$

10.2.4 Adjust the total initial volume, V_{ii} , of the contaminant injection system (measured at the test temperature) to the value calculated in 10.2.2, and record this value on the report sheet given in Figure 2.

10.2.5 Calculate the quantity of contaminant, m , needed for the contaminant injection system using Equation (4):

$$m = \frac{c_i' \times V_{ii}}{1000} \quad (4)$$

10.2.6 Prior to adding the ISO 12103-A3 test dust to the contaminant injection system, verify that the background fluid contamination is less than that specified in Table 3.

10.2.7 Prepare the contaminant injection system to contain the quantity of fluid, V_{ii} , and ISO 12103-A3 test dust, m (see 10.2.5), using the same procedure that is used for the contamination injection system validation (see 8.2).

10.2.8 Adjust the injection flow rate at stabilized test temperature to within ± 5 % of the value calculated in 10.2.2 and maintain throughout the test. Record this value on the report sheet given in Figure 2. Return the injection system sampling flow directly to the injection reservoir during set-up.

10.3 Filter test system

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

10.3.2 Verify that the rest conductivity of the test fluid is maintained in the range of 1 000 pS/m to 10 000 pS/m (see ASTM D4308-95). If it is outside this range, either add anti-static agent to increase the conductivity or more new fluid to reduce it.

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

10.3.3 Circulate the fluid in the filter test system at the rated flow and at a test temperature such that the fluid viscosity is maintained at 15 mm²/s; record the temperature and determine the 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 of 25 % to 50 % of the designated test volume flow rate through the filter, expressed in litres per minute, with a minimum value of 5 L.

If the designated 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 test volume flow rate. If the designated 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 test volume flow rate.

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

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

10.3.6 Effectuate on-line automatic particle counting in accordance with the following procedure.

- a) Adjust the upstream and downstream sampling flow rates to an initial upstream value compatible with the sampling procedure used and adjust the downstream flow rate to within ± 5 % of the injection flow rate, maintaining uninterrupted flow from both sampling points during the entire test.
- b) Adjust the upstream and downstream dilution flow rates, if required for automatic particle counting, so that at the end of testing, the flow rates and concentrations at the particle counters are compatible with the instrument requirements.

The upstream and downstream sensor flow rates should be set and maintained at the values and within the limits specified in 8.1.4 and Table 2.

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

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

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

10.3.7 Adjust the particle counter thresholds corresponding to the particle sizes selected from Table 3.

11 Filter performance test

11.1 Install the test filter element into its housing and subject the assembly to the specified test conditions (test flow rate and test temperature established in 10.3.3 to maintain viscosity at $15 \text{ mm}^2/\text{s} \pm 1,0 \text{ mm}^2/\text{s}$) and reaffirm the fluid level.

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 by adding the terminal element differential pressure to the housing differential pressure.

11.4 Measure and record the initial system contamination level using on-line particle counting 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.

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

11.8 Initiate the filter test by

- a) allowing the injection flow to enter the filter test system reservoir,
- b) starting the timer, and
- c) diverting the downstream sample flow from the test system to maintain a constant system volume within a tolerance of $\pm 5 \%$ [see 10.3.6 a)].

11.9 Conduct and record the on-line particle counts on the upstream and downstream fluid at equal time intervals not exceeding 1 min until the differential pressure across the filter assembly has increased to the terminal value calculated in 11.3.

The upstream and downstream sensor flow rates should be equal to the values chosen in 10.3.6 b), within the limits specified in Table 2.

Flow rates through sensors should be monitored and recorded throughout the test and maintained within the limits specified in Table 2.

Care should be taken to use on-line dilution as required to avoid exceeding the coincidence limit of the automatic particle counter, as determined in accordance with ISO 11171.

It is recommended that the flow rate and dilution ratio be controlled and recorded to calculate the exact amount of test fluid that is passed through the sensor for each count.

It is recommended that a minimum counting volume of 10 mL be used to obtain statistically significant particle counts.

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

Continuous differential pressure measurements using a differential pressure transducer are recommended for this purpose.

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

11.12 Conclude the test at the final assembly differential pressure by

- a) recording the final test time,
- b) diverting the injection flow from the filter test system, and
- c) stopping the flow to the test filter.

11.13 Measure and record the final volume in the filter test system as V_{ff} .

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

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

11.16 Check that there is no visual evidence that filter element damage has occurred as a result of performing this test.

NOTE 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, t , equal to 10 %, 20 %, 30 % ... 100 % of the final test time [see 11.12 a)] and record these times on the report sheet shown in Figure 2.

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 given in Figure 2 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 (see 11.9), calculate the cumulative particle count per millilitre at each particle size by dividing the raw counts obtained in the counted volume and adjusting for any dilution, if used.

12.5 Calculate the average upstream and downstream particle counts at each particle size, x , for each of the 10 reporting times, t , by using Equations (5) and (6) and the specific instructions in a) to d):

$$\bar{N}_{u,x,t} = \frac{\sum_{j=1}^n N_{u,x,j}}{n} \quad (5)$$

$$\bar{N}_{d,x,t} = \frac{\sum_{j=1}^n N_{d,x,j}}{n} \quad (6)$$

where n is the number of particle counts started in the specific reporting time period, determined as follows.

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

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

- b) For the first reporting time (10 %), using Equations (5) and (6), average the upstream and downstream counts calculated 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 a) above]. Record these average counts on the report sheet given in Figure 2.

NOTE For a total test time less than 30 min, there might not be any data for the 10 % reporting; in this case, the entries are left blank.

- c) For the second reporting time (20 %), average the upstream and downstream counts calculated 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 counts on the report sheet given in Figure 2.
- d) For the third through tenth reporting times (30 % to 100 %), repeat c) in a similar manner using only the counts that were started in each reporting interval. Round the results to three digits of precision (e.g. 1,75; 20,1; 400), and record on the report sheet given in Figure 2.

12.6 Using Equation (7), calculate the filtration ratios, $\beta_{x,t}$, corresponding to each of the 10 reporting times by dividing the average upstream particle count by the average downstream particle count at each size, x , corresponding to that respective reporting time. Round the results to three digits of precision (e.g. 1,75; 20,1; 400), and record on the report sheet given in Figure 2.

$$\beta_{x,t} = \frac{\bar{N}_{u,x,t}}{\bar{N}_{d,x,t}} \quad (7)$$

The particle counts shall be averaged and average filtration ratios, the β values, shall be calculated from these average counts. Under no circumstances shall the β values be averaged.

12.7 Using Equations (8) and (9), calculate the overall test average upstream and downstream particle counts by numerically averaging the 10 average counts from 12.5 corresponding to each of the 10 reporting times. Record the results on the report sheet given in Figure 2.

$$\bar{A}_{u,x} = \sum_{k=1}^{10} \bar{N}_{u,x,t} \quad (8)$$

$$\bar{A}_{d,x} = \sum_{k=1}^{10} \bar{N}_{d,x,t} \quad (9)$$

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

12.8 Using Equation (10), calculate the overall average filtration ratios, $\bar{\beta}_{x(c)}$, by dividing the overall test average upstream by the downstream cumulative particle counts at each size, x $\mu\text{m}(c)$. Record the results, to three significant figures, on the report sheet given in Figure 2:

$$\bar{\beta}_{x(c)} = \frac{\bar{A}_{u,x}}{\bar{A}_{d,x}} \quad (10)$$

NOTE The (c) in the subscript signifies that the filtration ratio $\bar{\beta}_{x(c)}$ is determined in accordance with this International Standard, using automatic particle counters calibrated in accordance with ISO 11171.

The particle counts shall be averaged and the average filtration ratios, the β values, shall be calculated from these average counts. Under no circumstances shall the β values be averaged.

12.9 Conduct a gravimetric analysis in accordance with ISO 4405 on the two samples extracted from the contaminant injections system (see 11.6 and 11.15). Report the gravimetric contamination results to the nearest 0,1 mg/L on the report sheet given in Figure 2. 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_i' (from 10.2.3) 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 8.2 be repeated.

12.10 Conduct a gravimetric analysis in accordance with ISO 4405 on the 80 % upstream sample (from 11.11) and record the result of this analysis as the final system gravimetric level. Report the gravimetric contamination results to the nearest 0,1 mg/L on the report sheet given in Figure 2.

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

12.11 Using Equation (11), calculate and record on the report sheet given in Figure 2 the average injection flow rate, $\bar{q}_i$, by subtracting the final injection system volume from the initial injection system volume and dividing the result by the final test time:

$$\bar{q}_i = \frac{V_{ii} - V_{if}}{t_f} \quad (11)$$

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

12.12 Using Equation (12), calculate and record on the report sheet given in Figure 2 the average base upstream gravimetric level, $\bar{c}_b$:

$$\bar{c}_b = \frac{\bar{c}_i \times q_i}{q} \quad (12)$$

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 following minimum information for filter elements evaluated in accordance with this International Standard. Present all test and calculation results as included in the report sheet given in Figure 2. It is recommended that the layout of the report sheet be used as shown.

13.2 Calculate the mass of ISO 12103-A3 test dust injected, m_i , using the actual test time, t_f , to reach the terminal element differential pressure, the average gravimetric level of the injection system, $\bar{c}_i$, and the average injection flow rate, $\bar{q}_i$, as given in Equation (13):

$$m_i = \frac{\bar{c}_i \times \bar{q}_i \times t_f}{1000} \quad (13)$$

Calculate and report on the test sheet given in Figure 2 the ISO 12103-A3 test dust retained capacity, m_R , using Equation (14) and round the result to the nearest two significant figures:

$$m_R = m_i - \frac{c_{80} \times V_f}{1000} - \frac{q_d \times t_f \times (c_{80} - \bar{c}_b)}{1000} - \frac{q_u \times t_f \times [(c_{80} - \bar{c}_b)/2]}{1000} \quad (14)$$

NOTE In Equation (14), the following are subtracted from the mass of ISO 12103-A3 test dust injected:

- mass of contaminant remaining in the test system at the end of the test;
- an estimate of the amount of contaminant permanently extracted from the system through the filter downstream sampling point; the term $(c_{80} - \bar{c}_b)$ is a conservative estimate of the gravimetric contamination level downstream of the test filter;
- an estimate of the amount of contaminant extracted from the upstream sample flow, q_u , that is permanently discarded from the test system; the term $(c_{80} - \bar{c}_b)/2$ is an estimate of the average upstream gravimetric contamination level. If the upstream sample flow is recycled and not discarded, Equation (14) is applied without the final term.

13.3 Record the values of the gravimetric levels obtained in 12.9 and 12.10 on the report sheet given in Figure 2.

13.4 Calculate, record on the report sheet given in Figure 2, and plot on linear coordinates (see Figure C.2) element differential pressure versus the ISO 12103-A3 test dust contaminant added by using Equation (15):

$$m_p = \frac{\bar{c}_i \times \bar{q}_i \times t_p}{1000} \quad (15)$$

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

13.5 Plot on semi-log (log linear) coordinates average β versus particle size, x , with the β values on the log scale and $\beta = 100\,000$ as the highest value plotted (see the example in Figure C.3).

When a value of $\beta_{x(c)}$ equal to infinity is recorded (i.e. for zero downstream particle count), the value should be plotted as $\beta_{x(c)} = 100\,000$.

13.6 Using Equation (16), calculate, and record on the report sheet given in Figure 2, the particle size values corresponding to average filtration ratios of 2, 10, 75, 100, 200 and 1 000, using an interpolation of straight-line segments connecting points on the semi-log β versus particle size, x , plot. Do not extrapolate:

$$x = \frac{(x_1 - x_2) \times \log \left[\frac{\beta_{x(c)}}{\beta_{x1}} \right]}{\log \left(\frac{\beta_{x1}}{\beta_{x2}} \right)} + x_1 \quad (16)$$

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

NOTE 1 For calculation of the interpolated particle size, $x_{\mu m(c)}$, for a specified filtration ratio, $\beta_{x(c)}$, where the value falls between two of the points from the plot in 13.5 (corresponding to filtration ratios β_{x1} , β_{x2} , and particle sizes x_1 , x_2 , respectively), use Equation (16).

NOTE 2 For β values greater than 100 000, use the value of 100 000 in Equation (16).

13.7 Plot on semi-log (log linear) coordinates average β values for each particle size versus percent test time, with the β values on the log scale (see the example in Figure C.4).

13.8 Plot on log-log coordinates average β values for each particle size versus element differential pressure, with the β values on the ordinate (see the example in Figure C.5).

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

14 Identification statement (reference to this International Standard)

It is strongly recommended to manufacturers who have chosen to conform to this International Standard that the following statement be used in test reports, catalogues and sales literature:

“Method for determining filtration performance data in accordance with ISO 16889:2008, *Hydraulic fluid power — Filters — Multi-pass method for evaluating filtration performance of a filter element.*”

Test laboratory: _____		Test date: _____		Operator: _____			
Filter and element identification							
Element ID: _____		Housing ID: _____					
Spin-on: YES / NO		Minimum element bubble point (Pa): _____					
Operating conditions							
Test fluid							
Type: _____		Ref.: _____		Batch No.: _____			
Viscosity at the test temperature (mm ² /s): _____		Temperature (°C): _____					
Anti-static: Yes _____ No _____		Type: _____		Conductivity (pS/m): _____			
Test contaminant							
Type: ISO 12103-A3 test dust		Batch No.: _____					
Test system							
Flow rate, q (L/min): _____		Initial volume (L): _____					
Base upstream gravimetric level, c_b (mg/L): _____		Final volume (L): _____					
Injection system							
Injection parameters		Initial	Final	Average injection parameters			
System volume (L)				Injection flow $\bar{q}_i$ (L/min)			
Gravimetric level (mg/L)				Gravimetric level $\bar{c}_i$ (mg/L)			
Counting system							
Location		Counter and sensor ref.		Flow rate (mL/min)			
Upstream							
Downstream							
Counter calibration:		Method: _____		Date: _____			
Test results							
Element integrity							
Bubble point to ISO 2942 (Pa): _____		Test fluid: _____					
Differential pressure							
Filter housing (kPa): _____		Clean assembly (kPa): _____					
Clean element (kPa): _____		Final element (kPa): _____					
Differential pressure versus contaminant added							
Time interval %	Test time min	Element Δp kPa	Injected mass g	Time interval %	Test time min	Element Δp kPa	Injected mass g
10				60			
20				70			
30				80			
40				90			
50				100			
Retention capacity							
ISO MTD mass injected, m_i (g): _____		ISO MTD retained capacity, m_R (g): _____					
80% upstream gravimetric level, c_{80} (mg/L): _____							
Filtration ratio $\beta_{x(c)}$							
Average filtration ratio	2	10	75	100	200	1 000	
Particle size, $\mu\text{m}(c)$							

Figure 2 (continued)

Test results (continued)

Particle counts per millilitre and filtration ratio												
Time interval	$d >$ $\mu\text{m(c)}$	β	$d >$ $\mu\text{m(c)}$	β	$d >$ $\mu\text{m(c)}$	β	$d >$ $\mu\text{m(c)}$	β	$d >$ $\mu\text{m(c)}$	β	$d >$ $\mu\text{m(c)}$	β
Initial up												
10 % Up												
Down												
20 % Up												
Down												
30 % Up												
Down												
40 % Up												
Down												
50 % Up												
Down												
60 % Up												
Down												
70 % Up												
Down												
80 % Up												
Down												
90 % Up												
Down												
100 % Up												
Down												
Avg. Up												
Avg. Down												

Figure 2 — Filter element multi-pass report sheet

Annex A (normative)

Base test-fluid properties

A.1 Properties of mineral oil stock

- a) pour point (max.): $-60\text{ }^{\circ}\text{C}$
- b) flash point with closed cup (min.): $82\text{ }^{\circ}\text{C}$
- c) acid or base number, (max.): $0,10\text{ mg KOH/g}$

A.2 Additive materials

- a) viscosity/temperature coefficient improvers: not to exceed 20 % (by mass)
- b) oxidation inhibitors: not to exceed 2 % (by mass)
- c) anti-wear agent, such as tricresyl phosphate (TCP): $< 3\%$ by mass

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

A.3 Properties of finished oil

- a) viscosity:
 - 1) at $40\text{ }^{\circ}\text{C}$ (min.): $13,2\text{ mm}^2/\text{s}$
 - 2) at $100\text{ }^{\circ}\text{C}$ (min.): $4,9\text{ mm}^2/\text{s}$
 - 3) at $-50\text{ }^{\circ}\text{C}$ (max.): $2\,500\text{ mm}^2/\text{s}$
 - 4) at $-40\text{ }^{\circ}\text{C}$ (max.): $600\text{ mm}^2/\text{s}$
- b) pour point (max.): $-60\text{ }^{\circ}\text{C}$
- c) flash point with closed cup (min.): $82\text{ }^{\circ}\text{C}$
- d) acid number (max.): $0,20\text{ mg KOH/g}$
- e) rubber swell, standard synthetic rubber: 19 % to 30 %
- f) evaporation loss (max.): 20 %
- g) copper strip corrosion (ASTM standard, max.): No. 2^e
- h) water content (max.): $100\text{ }\mu\text{g/g}$
- i) steel-on-steel wear (average wear scar, max. diameter): 1 mm
- j) chlorine (max.): $50\text{ }\mu\text{g/g}$

A.4 Colour of finished oil

Use oil that is clear and transparent and that contains red dye (used for identification only) in a proportion not greater than one part of dye per 10 000 parts of oil (by mass).

A.5 Qualified fluids

Fluids found to fulfil the requirements of A.1 through A.4 are:

- a) MIL-PRF-5606;
- b) DCSEA 415;
- c) NATO Codes H-515 and H-520;
- d) UK DEF STAN 91-48.

A.6 Rest conductivity

Verify that the rest conductivity of the test fluid is maintained within the range of 1 000 pS/m to 10 000 pS/m (see ASTM D4308-95). If it is outside this range, either add anti-static agent to increase the conductivity or more new fluid to reduce it.

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Annex B (informative)

Test system design guide

B.1 Introduction

B.1.1 The multi-pass test procedure requires a pre-test validation procedure to determine the acceptability of the equipment to perform the desired test.

B.1.2 This annex is intended to provide basic guidance in constructing equipment that meets the validation requirements of this International Standard.

B.1.3 The reader is cautioned that this annex provides only guidelines for construction and in no way guarantees successful validation of equipment.

B.2 Basic test system

B.2.1 General guidelines

B.2.1.1 The circuit diagram of the basic equipment is shown in Figure B.1. It consists of two systems: the filter test system and the contaminant injection system.

B.2.1.2 All lines should be sized for turbulent mixing flow and long, straight runs should be avoided.

B.2.1.3 Connectors (fittings) should not have internally exposed threads or lips that can trap contaminants.

B.2.1.4 The use of ball valves is preferred, as they do not trap contaminants and have a self-cleaning action.

B.2.1.5 Lines and connectors should be arranged to eliminate dead flow zones and, where possible, vertical runs are preferable to horizontal runs.

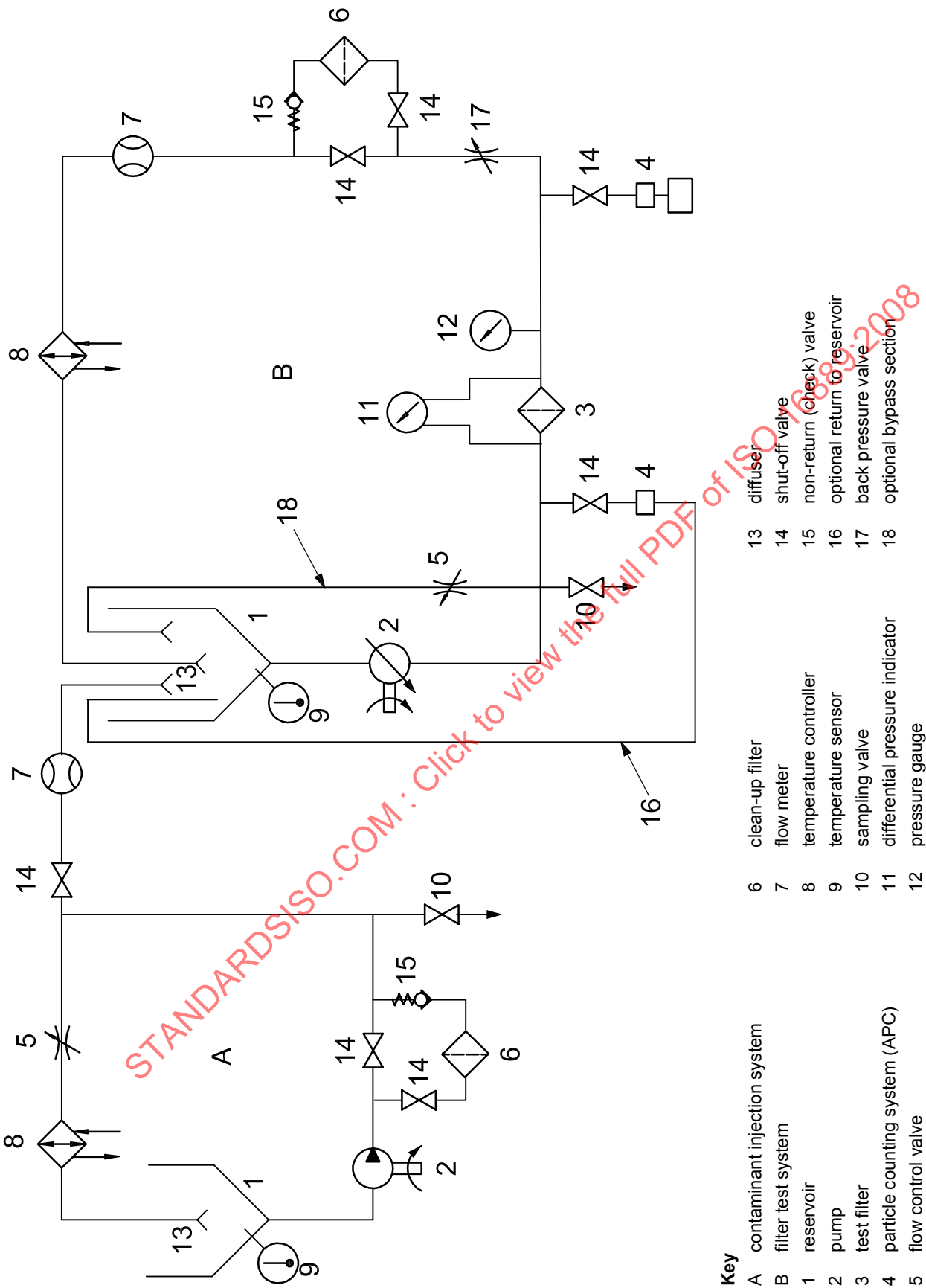


Figure B.1 — System circuit diagram

B.2.2 Filter test system

B.2.2.1 Reservoir

B.2.2.1.1 A reservoir, constructed with a conical bottom with an included angle of not more than 90° and with the entering oil diffused below the fluid surface, should be used.

NOTE This construction eliminates horizontal surfaces that can promote contaminant settling.

B.2.2.1.2 The reservoir design shown in Figure B.2 is a full cone and is useful for containing a desired fluid volume in a system where reservoir height is critical.

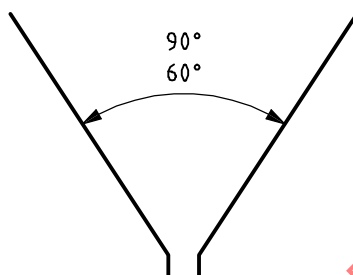


Figure B.2 — Full cone

B.2.2.1.3 The reservoir design shown 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.

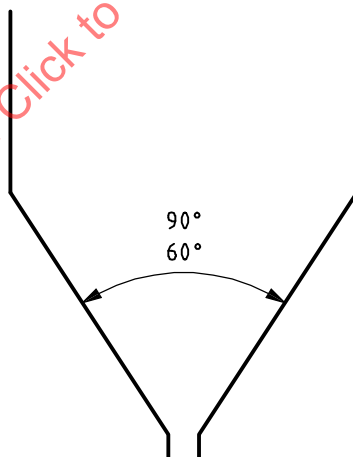


Figure B.3 — Cone and cylinder

B.2.2.1.4 Reservoirs with included angles between 60° and 90° offer the best balance of ease of construction and the ability to discriminate between the various fluid levels.

B.2.2.1.5 A device for monitoring the level of clean fluid in the test reservoir is used to check that the level remains constant.

B.2.2.2 System pump and drive

B.2.2.2.1 The system pump should be selected from a pump family that is relatively insensitive to contaminant at the desired operating pressures.

B.2.2.2.2 The system pump should exhibit a relatively low flow pulsation characteristic (less than 10 %), so as not to cause erroneous test results.

B.2.2.2.3 The system pump should not cause alteration of the test contaminant distribution as a result of its pumping mechanism.

NOTE Gear pumps and some types of piston pumps have demonstrated capability in these respects. The use of centrifugal and progressive cavity pumps has resulted in difficulties in complying with validation.

B.2.2.2.4 The pump drive should be of the variable speed type to provide the capability of adjusting the test flow rate.

B.2.2.2.5 The pump drive should be relatively insensitive to changes in load, so as to maintain a constant speed.

NOTE Variable-frequency a.c. drives and d.c. drives exhibit these desired characteristics.

B.2.2.3 Clean-up filter

B.2.2.3.1 The system clean-up filter should be capable of providing an initial system contamination level as shown in Table 3.

B.2.2.3.2 To promote rapid clean-up, the filter should typically be finer than the filter being tested and should be sized to accommodate at least the maximum system flow rate.

B.2.2.3.3 To promote economy, the filter should also possess a high contaminant-retaining capacity.

B.2.2.3.4 The use of multiple or large filters to achieve a low flow rate per unit area of filter media is desirable.

B.2.2.4 Temperature controller

Depending upon system power capabilities, cooling or heating of the system fluid can be required.

If cooling of the system fluid is necessary, a conventional shell-and-tube heat exchanger may be used. It is recommended that the heat exchanger be mounted vertically, with the oil being cooled entering the tube side from the bottom. This reduces the possibility of particles settling or being captured in the heat exchanger. Both side- and multi-pass heat exchangers have been successfully used. Some data indicate that up to a 65 % loss in thermal transfer can occur when operating a heat exchanger with the oil on the tube side; therefore, care should be taken to size the heat exchanger accordingly. Other cooling methods, such as coils wrapped around the external surface of reservoirs and tubes or double-wall conduits, have also proved satisfactory.

If heating of the system fluid is necessary, it may be accomplished by the use of heating tapes on external surfaces or by using a second heat exchanger with the high-temperature fluid on the shell side.

B.2.2.5 Regulation valves

B.2.2.5.1 Bypass valve

It is often convenient to incorporate a test-filter bypass section, including a bypass valve, upstream of the filter to return fluid directly to the reservoir. This section allows the system pump to be operated at a higher speed for tests run at low flow rates, eliminating high-flow ripples and overheating of the pump drive. Diaphragm, weir or pinch valves have proven suitable for use in this application.

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

B.2.2.5.2 Back pressure valve

This optional valve, located downstream from the test filter, allows testing of the filter under the pressure that is generally required for on-line, automatic particle counting. Ball, diaphragm, weir or pinch valves are suitable for use in this application.

B.2.2.6 Flow meter

The flow meter should be located downstream of the test filter and the downstream sampling port, in order to eliminate the possibility of influencing the downstream particle count. Therefore, the flow rate measured is actually slightly lower than the test-filter flow rate. An adjustment should be made in the flow to account for this variation, so the true flow rate reported is the sum of the measured flow rate and the downstream sample flow rate. Locating the flow meter downstream of the test filter provides the maximum protection for the flow meter from an abrasive contaminant. Turbine flow meters using sealed bearings have proven suitable for use in this application.

B.2.3 Contaminant injection system

B.2.3.1 Reservoir

The construction and design recommendations and precautions given in B.2.2.1 for the reservoir in the filter-test system apply.

NOTE Because of the large volume and high contaminant concentrations encountered, some auxiliary agitation system for the contamination injection reservoir is desirable. These can be stirrers, auxiliary circulation loops or similar high-energy input devices.

B.2.3.2 Pump

B.2.3.2.1 The high contaminant concentration in the contaminant injection system 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 for use in this application.

B.2.3.2.2 If a centrifugal pump is used, mounting the pump vertically with the inlet down or mounting the pump horizontally with the discharge at the bottom have proved successful.

B.2.3.3 Clean-up filter

The recommendations given in B.2.2.3 for the clean-up filter in the filter test system apply, except that the contaminant retention capacity is of prime importance.

B.2.3.4 Temperature controller

The recommendations given in B.2.2.4 for heat exchangers and/or heaters in the filter test system apply.

B.2.3.5 Flow meter

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

Annex C (informative)

Examples of report calculations and graphs

NOTE This annex contains examples of test data, calculations and graphs resulting from a typical multi-pass test.

C.1 Preliminary information

The information required prior to conducting the test is, in accordance with Clause 9, as follows:

- a) fabrication integrity pressure: 1 500 Pa;
- b) test flow rate, q : 100 L/min;
- c) terminal element differential pressure: 400 kPa;
- d) presumed filtration ratios: $\beta_{5(c)} = 4$, $\beta_{15(c)} = 75$;
- e) estimated capacity, m_e : 40 g.

For test purposes, the laboratory selected the following test conditions:

- desired base upstream gravimetric level, c'_b : 10 mg/L;
- desired injection flow rate, q'_i : 0,25 L/min;
- particle sizes to be counted: 5, 10, 15, 20 and 30 $\mu\text{m(c)}$.

Calculate t_{pr} using Equation (1) (see 10.2.1):

$$\begin{aligned} t_{pr} &= \frac{1000 \times 40 \text{ g}}{10 \text{ mg/L} \times 100 \text{ L/min}} \\ &= 40 \text{ min} \end{aligned}$$

Calculate V_{min} using Equation (2) (see 10.2.2):

$$\begin{aligned} V_{min} &= (1,2 \times 40 \text{ min} \times 0,25 \text{ L/min}) + 8 \text{ L} \\ &= 20 \text{ L} \end{aligned}$$

Calculate c'_i using Equation (3) (see 10.2.3):

$$\begin{aligned} c'_i &= \frac{10 \text{ mg/L} \times 100 \text{ L/min}}{0,25 \text{ L/min}} \\ &= 4\,000 \text{ mg/L} \end{aligned}$$

Calculate m using Equation (4) (see 10.2.5):

$$\begin{aligned} m &= \frac{4\,000 \text{ mg/L} \times 20 \text{ L}}{1\,000} \\ &= 80 \text{ g} \end{aligned}$$

C.2 Multi-pass test results

C.2.1 The multi-pass test was conducted with the parameters mentioned in Clause C.1; the remaining test conditions and test results are shown in Figure C.1. The calculated test results reported in Figure C.1 are determined by calculating $\bar{q}_i$ using Equation (11) (see 12.11) and $\bar{c}_b$ using Equation (12) (see 12.12):

$$\begin{aligned}\bar{q}_i &= \frac{20 \text{ L} - 11,4 \text{ L}}{34,2 \text{ min}} \\ &= 0,252 \text{ L/min}\end{aligned}$$

$$\begin{aligned}\bar{c}_b &= \frac{3980 \text{ mg/L} \times 0,252 \text{ mg/L}}{100 \text{ L/min}} \\ &= 10 \text{ mg/L}\end{aligned}$$

Calculate m_i using Equation (13) (see 13.2):

$$\begin{aligned}m_i &= \frac{3980 \text{ mg/L} \times 0,252 \text{ L/min} \times 34,2 \text{ min}}{1000} \\ &= 34,3 \text{ g (rounded to 34 g)}\end{aligned}$$

C.2.2 In order to calculate the retained capacity, m_R , and in addition to the parameters reported on the report sheet, the discarded downstream sample flow rate, q_d (in this example, 0,20 L/min), and the discarded upstream sample flow rate, q_u (in this example, 0,05 L/min), are required.

C.2.3 Calculate m_R using Equation (14) (see 13.2):

$$\begin{aligned}m_R &= 34,3 \text{ g} - \frac{22,3 \text{ mg/L} \times 24,5 \text{ L}}{1000} - \frac{0,2 \text{ L/min} \times 34,2 \text{ min} \times (22,3 \text{ mg/L} - 10 \text{ mg/L})}{1000} - \dots \\ &\quad \dots - \frac{0,05 \text{ L/min} \times 34,2 \text{ min} \times (22,3 \text{ mg/L} + 10 \text{ mg/L})}{1000} \\ &= 34,3 - 0,55 - 0,08 - 0,03 \\ &= 33,6 \text{ g (rounded to 34 g)}\end{aligned}$$

C.2.4 Each of the contaminant injected values reported in Figure C.1 was calculated using Equation (15) (see 13.4). The average particle counts and filtration ratios are calculated using Equations (5), (6), (7), (8), (9) and (10).

C.2.5 Figure C.2 is a graph of element differential pressure versus contaminant injected. 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 Figure C.1.

C.2.6 Equation (16) is used to calculate the interpolated particle sizes for the specific filtration ratios reported at the bottom of the first page of the report sheet shown in Figure C.1. As an example, and using Equation (16) to calculate the particle size, x , where $\beta_{x(c)} = 75$, an interpolation is made between 10 $\mu\text{m}(c)$ and 15 $\mu\text{m}(c)$.

$$\begin{aligned}x &= \frac{[10 \mu\text{m}(c) - 15 \mu\text{m}(c)] \times \log\left(\frac{75}{21,1}\right)}{\log\left(\frac{21,1}{116}\right)} + 10 \mu\text{m}(c) \\ &= 13,7 \mu\text{m}(c)\end{aligned}$$

The particle size for $\beta_{x(c)} = 2$ cannot be calculated because it occurs below the smallest particle size counted, that is, 5 $\mu\text{m}(c)$, and extrapolation is not allowed.

Test laboratory: Example Test Laboratory Test date: 4 Dec 1999 Operator: ABC

Filter and element identification

Element ID: Example Test Filter

Housing ID: Example Test Housing

Spin-on: YES / NO

Minimum element bubble point (Pa): 1 500

Operating conditions

Test fluid

Type: Fluid Manufacturer XYZ

Ref.: Mil-H-5606

Batch No.: 1234

Viscosity at the test temperature (mm^2/s): 14,9

Temperature ($^{\circ}\text{C}$): 37,2

Anti-static: Yes X No

Type: Stadis 450

Conductivity (pS/m): 1 250

Test contaminant

Type: ISO 12103-A3 test dust

Batch No.: 4390C

Test system

Flow rate, q (L/min): 100

Initial volume (L): 25,0

Base upstream gravimetric level, c_b (mg/L): 10,0

Final volume (L): 24,5

Injection system

Injection parameters	Initial	Final	Average injection parameters	
System volume (L)	20,0	11,4	Injection flow $\bar{q}_i$ (L/min)	0,252
Gravimetric level (mg/L)	3 979,7	3 981,1	Gravimetric level $\bar{c}_i$ (mg/L)	3 980

Counting system

Location	Counter and sensor ref.	Flow rate (ml/min)	Dilution ratio
Upstream	ABC model 123, s/n 21	100	1:1
Downstream	ABC model 123, s/n 22	100	None

Counter calibration: Method: ISO 11171 Date: 4 December 1999

Test results

Element integrity

Bubble point to ISO 2942 (Pa): 2 190

Test fluid: Mil-H-5606

Differential pressure

Filter housing (kPa): 31,0

Clean assembly (kPa): 39,4

Clean element (kPa): 8,4

Final element (kPa): 400

Differential pressure versus contaminant added

Time interval %	Test time min.	Element Δp kPa	Injected mass g	Time interval %	Test time min.	Element Δp kPa	Injected mass g
10	3,4	10,1	3,4	60	20,5	17,9	20,6
20	6,8	11,9	6,9	70	24,0	31,7	24,0
30	10,3	13,7	10,3	80	27,4	59,0	27,4
40	13,7	15,4	13,7	90	30,8	123	30,8
50	17,1	16,8	17,1	100	34,2	400	34,3

Retention capacity

ISO MTD mass injected, m_i (g): 34

ISO MTD retained capacity, m_R (g): 34

80 % upstream gravimetric level, c_{80} (mg/L): 22,3

Filtration ratio $\beta_{x(c)}$

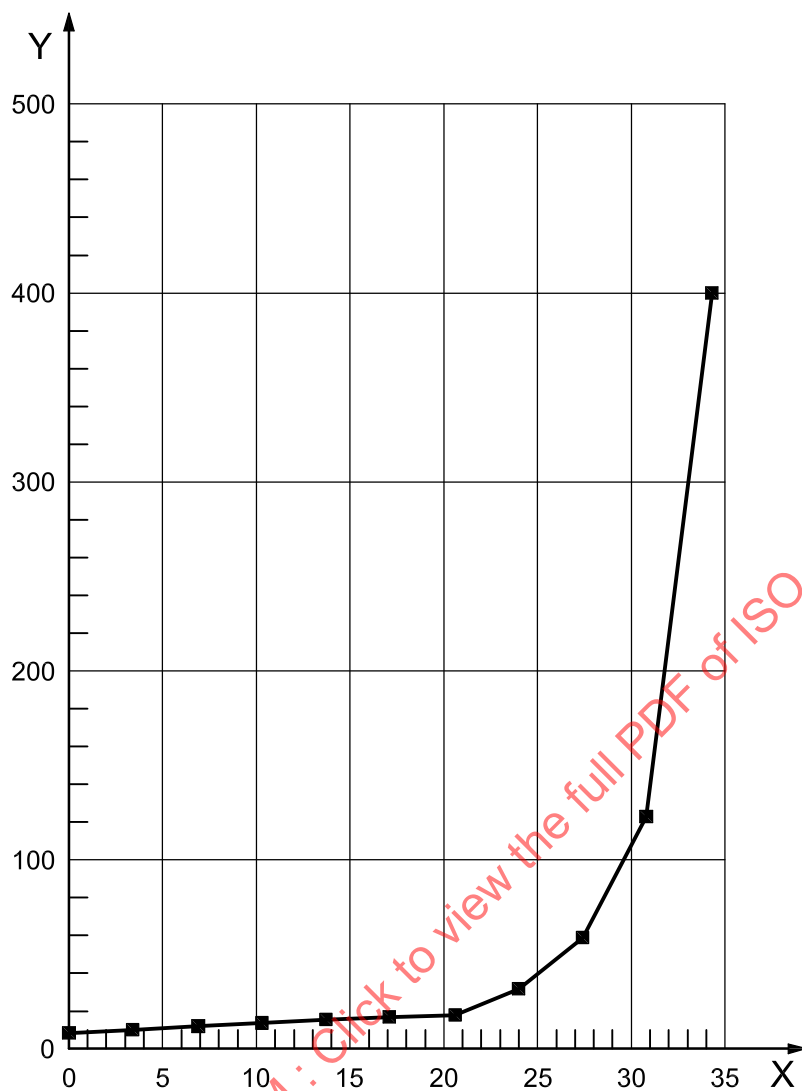
Average filtration ratio	2	10	75	100	200	1 000
Particle size, $\mu\text{m}(c)$	< 5	7,80	13,7	14,6	15,9	18,7

Figure C.1 (continued)

Test results (continued)

Particle counts per millilitre and filtration ratio												
Time interval	$d > 5$ $\mu\text{m(c)}$	β	$d > 10$ $\mu\text{m(c)}$	β	$d > 15$ $\mu\text{m(c)}$	β	$d > 20$ $\mu\text{m(c)}$	β	$d > 30$ $\mu\text{m(c)}$	β	$d >$ $\mu\text{m(c)}$	β
Initial up	0,50		0,20		0,10		0,00		0,00			
10 % Up	13 900		1 750		480		174		29			
Down	2 240	6,2	33,7	51,9	1,1	432	0,0	5 490	0,0	∞		
20 % Up	14 200		1 760		481		179		31			
Down	2 490	5,7	39,1	45,0	1,7	285	0,0	4 710	0,0	∞		
30 % Up	14 400		1 770		482		176		30			
Down	2 800	5,1	45,4	39,0	1,7	289	0,0	5 770	0,0	7 210		
40 % Up	15 600		1 890		520		192		34			
Down	3 100	5,0	53,5	35,3	2,1	252	0,0	5 320	0,0	∞		
50 % Up	15 500		1 870		504		184		31			
Down	3 230	4,8	56,3	33,2	2,2	225	0,0	5 010	0,0	∞		
60 % Up	15 600		1 860		504		186		33			
Down	3 350	4,7	60,9	30,5	2,9	177	0,1	2 690	0,0	∞		
70 % Up	16 000		1 890		518		190		33			
Down	3 750	4,3	74,7	25,3	3,3	158	0,1	2 590	0,0	7 680		
80 % Up	16 800		1 910		508		187		32			
Down	5 050	3,3	117	16,3	6,3	80,9	0,1	1 260	0,0	∞		
90 % Up	19 400		2 030		527		190		32			
Down	7 520	2,6	186	10,9	10,0	52,9	0,1	1 280	0,0	∞		
100 % Up	21 200		2 090		532		192		33			
Down	8 760	2,4	224	9,3	12,3	43,3	0,3	753	0,0	∞		
Avg. Up	16 300		1 880		506		185		32			
Avg. Down	4 230	3,9	89,0	21,1	4,4	116	0,1	2 130	0,0	37 900		

Figure C.1 — Example of a completed filter element multi-pass report sheet



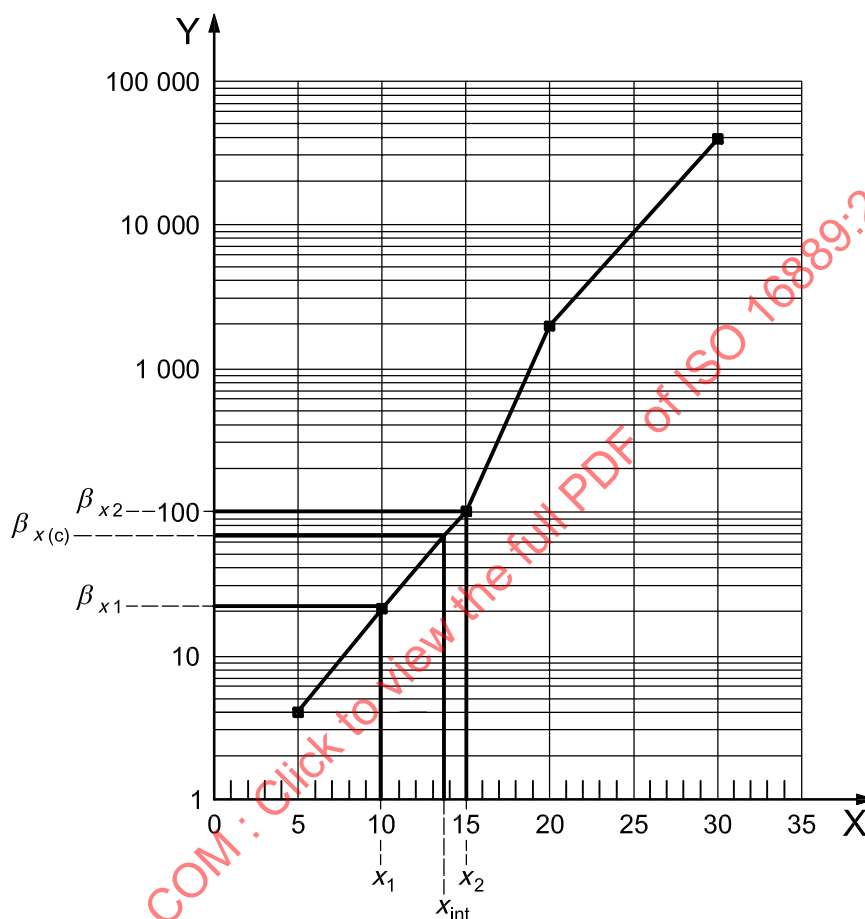
Key

X mass of ISO 12103-A3 test dust injected, expressed in grams

Y element differential pressure, expressed in kilopascals

Figure C.2 — Example of a differential pressure versus contaminant injected curve

C.2.7 Figure C.3 is a plot of $\beta_{x(c)}$ versus particle size, x , with straight-line segments connecting the data points at the various particle sizes. The linear interpolation calculated in C.2.6 is illustrated between particle sizes $x_1 = 10 \mu\text{m}(c)$ and $x_2 = 15 \mu\text{m}(c)$ corresponding to $\beta_{x1} = 21,1$ and $\beta_{x2} = 116$, respectively. The interpolated value for $\beta_{x(c)} = 75$ occurs at a particle size of $x_{\text{int}} = 13,7 \mu\text{m}(c)$, that is $\beta_{13,7(c)} = 75$.



Key

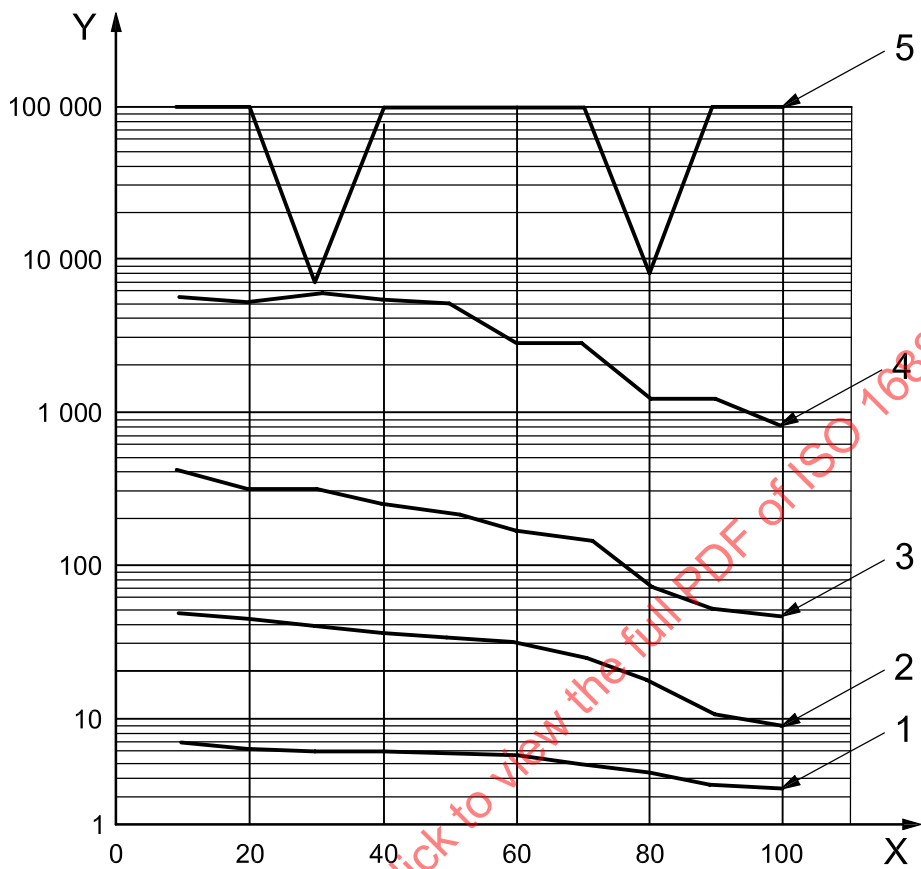
X particle size, x , expressed in $\mu\text{m}(c)$

Y filtration ratio, $\beta_{x(c)}$

NOTE $x_1 = 10 \mu\text{m}(c)$ $\beta_{x1} = 21,1$
 $x_2 = 15 \mu\text{m}(c)$ $\beta_{x2} = 116$
 $x_{\text{int}} = 13,7 \mu\text{m}(c)$ $\beta_{x(c)} = \beta_{13,7(c)} = 75$

Figure C.3 — Example of a filtration ratio versus particle size curve

C.2.8 Figure C.4 is a plot of the average filtration ratio, $\beta_{x(c)}$, at each of the particle sizes versus test time as a percentage of t_f . These values are also shown in Figure C.1. Note that several of the measured values for x at 30 $\mu\text{m}(c)$ were infinity; however, the points are plotted at $\beta_{x(c)} = 100\,000$.



- Key**
- | | | | |
|---|---|---|------------------------------------|
| X | test time, expressed as a percentage of t_f | 3 | curve for $x = 15\ \mu\text{m}(c)$ |
| Y | filtration ratio, $\beta_{x(c)}$ | 4 | curve for $x = 20\ \mu\text{m}(c)$ |
| 1 | curve for $x = 5\ \mu\text{m}(c)$ | 5 | curve for $x = 30\ \mu\text{m}(c)$ |
| 2 | curve for $x = 10\ \mu\text{m}(c)$ | | |

Figure C.4 — Example of a filtration ratio versus percent test time plot