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

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

IMPORTANT — Please use this updated version dated 2021-10-05, and discard any previous version of this FDIS.

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Foreword

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

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

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

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

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

This document was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control*.

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

The main changes compared to the previous edition are as follows:

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

— harmonization of conductivity levels with ISO 23369.

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

Introduction

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

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

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

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

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

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

It is also necessary that the test provide an acceptable level of repeatability and reproducibility, and 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 under development to evaluate performance with cyclic flow, high viscosity, flow fatigue, etc.

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

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

1 Scope

This document describes the following:

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

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

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 reservoir gravimetric level of less than 200 mg/L;

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

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

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

This document applies to three test conditions:

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

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

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

2 Normative references

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

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

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

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

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

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

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

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

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

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

ISO 12103-1:2016, *Road vehicles — Test contaminants for filter evaluation — Part 1: Arizona test dust*

3 Terms and definitions

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

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

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

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

3.1 General terms

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

3.1.2
rest conductivity
electrical conductivity at the initial instant of current measurement after a d.c. voltage is impressed between electrodes

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

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

3.2 Terms related to differential pressure

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

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

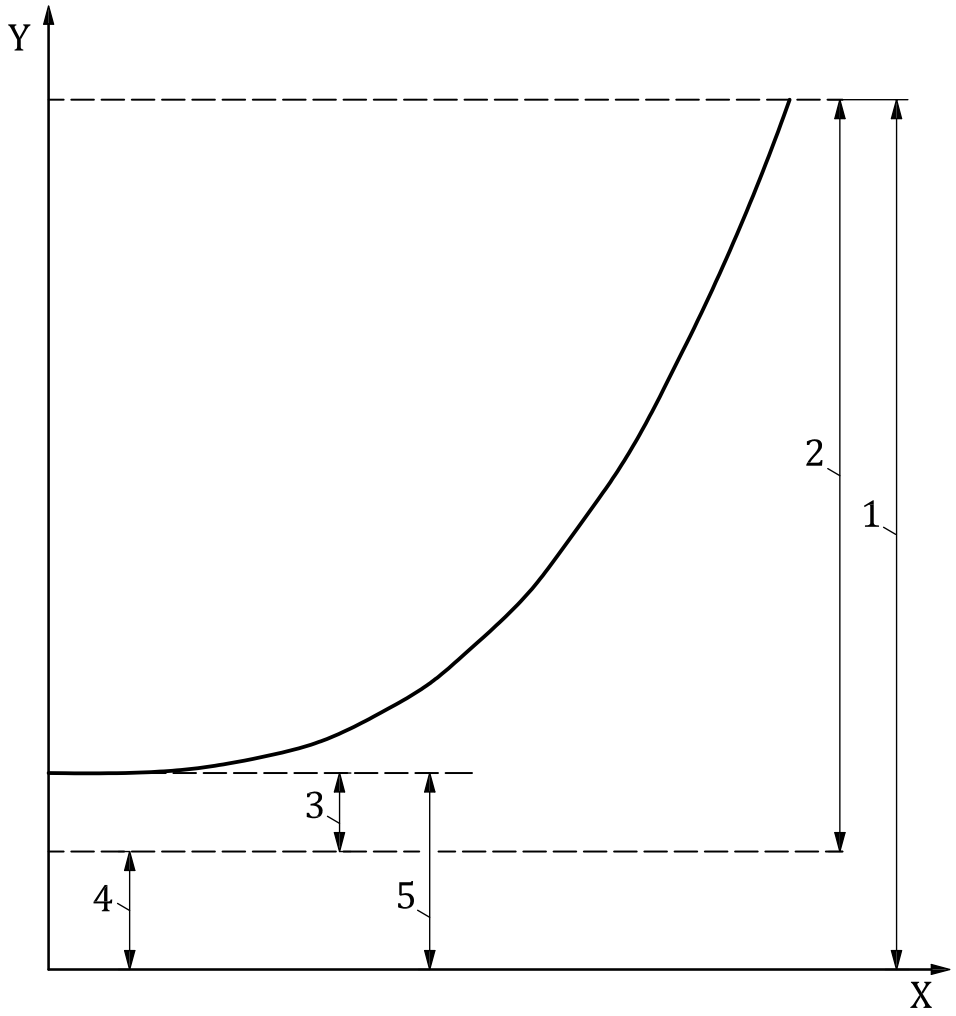
3.2.2
clean assembly differential pressure
difference between the tested component inlet and outlet pressures as measured with a clean filter housing containing a clean filter element

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

3.2.4
final assembly differential pressure
assembly differential pressure at the end of a test, equal to the sum of the housing plus the terminal element differential pressures

3.2.5
housing differential pressure
differential pressure of the filter housing without an element

3.2.6
terminal element differential pressure
maximum differential pressure across the filter element as designated by the manufacturer to limit useful performance



Key

X	test time or mass injected	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 graphical symbols used in this document are in accordance with ISO 1219-1.

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

Table 1 — Letter symbols

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

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

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

Table 1 *(continued)*

Symbol	Unit	Description or explanation
V_{min}	litres	minimum required operating injection system volume
V_{tf}	litres	final measured filter test system volume
V_v	litres	minimum validated injection system volume
x_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 document using automatic particle counters calibrated in accordance with ISO 11171.

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

5 General procedures

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

5.2 Validate equipment in accordance with Clause 8.

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

5.4 Analyse test data in accordance with Clause 12.

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

6 Test equipment

6.1 Suitable timer.

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

6.3 ISO medium test dust (ISO MTD, ISO 12103-1 — A3), in accordance with ISO 12103-1, dried at 110 °C to 150 °C for not less than 1 h for quantities less than 200 g.

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

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

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

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

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

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

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

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

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

6.7.1 Filter test system, consisting of the following:

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

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

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

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

e) pressure taps in accordance with ISO 3968;

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

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

6.7.2 Contaminant injection system, consisting of the following:

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

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

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

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

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

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

7 Measuring instrument accuracy and test condition variations

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

Table 2 — Measuring instrument accuracy and test condition variation

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

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

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

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

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

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

Table 3 — Test condition values

Parameter	Condition 1	Condition 2	Condition 3
Initial contamination level for filter test system	Less than 1 % of the minimum level specified in ISO 11943:2021, Table C.2, measured at the smallest particle size being counted.		
Initial contamination level for injection system	Less than 1 % of the injection gravimetric level.		
Base upstream gravimetric level, mg/L [a]	3 ± 0,3	10 ± 1,0	15 ± 1,5
Recommended particle sizes for counting [b]	Minimum of five sizes, including 30 µm(c), selected to cover the presumed filter performance range from 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 are expected to be the same.

[b] When a fine filter element is being tested, it might not be possible to count those particle sizes for which filtration ratios are low (for example, 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 document.

8 Filter performance test circuit validation procedures

8.1 Filter test system validation

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

8.1.2 Adjust the total fluid volume of the filter test system (exclusive of the clean-up filter circuit), such that it is numerically within the range of 25 % to 50 % of the minimum volume flow rate, expressed in litres per minute, with a minimum of 5 L.

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

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

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

8.1.4 Verify that the flow rate through each particle-counting sensor is equal to the value used for the particle-counter calibration within the limits of Table 2.

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

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

8.1.7 Accept the validation test only if:

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

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

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

8.2 Validation of contaminant injection system

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

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

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

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

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

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

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

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

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

8.2.9 Accept the validation only if:

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

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

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

9 Summary of information required prior to testing

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

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

b) filter element test flow rate,

c) terminal element differential pressure,

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

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

10 Preliminary preparation

10.1 Test filter assembly

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

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

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

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

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

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

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 Formula (1), is preferably in the range of 1 h to 3 h:

$$t_{pr} = \frac{1\,000 \times m_e}{c_b' \times q} \tag{1}$$

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 Formula (2):

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

The volume calculated in Formula (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 Formula (3):

$$c_i' = \frac{c_b' \times q}{q_i'} \tag{3}$$

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 Formula (4):

$$m = \frac{c_i' \times V_{ii}}{1\,000} \tag{4}$$

10.2.6 Prior to adding the ISO 12103-1 — 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 12103-1 —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 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

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 mm^2/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 mm^2/s ± 1,0 mm^2/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 ±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_{tf}.

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 Formulae (5) and (6) and the specific instructions in a) to d):

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

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

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

a) Delete the first three 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 (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 2 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 Formula (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.

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

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 Formulae (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.

$$\bar{A}_{\mathrm{u},x} = \sum_{k=1}^{10} \bar{N}_{\mathrm{u},x,t} \tag{8}$$

$$\bar{A}_{\mathrm{d},x} = \sum_{k=1}^{10} \bar{N}_{\mathrm{d},x,t} \tag{9}$$

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

$$\beta_{x(c)} = \frac{\overline{A}_{u,x}}{\overline{A}_{d,x}} \tag{10}$$

NOTE The (c) in the subscript signifies that the filtration ratio $\overline{\beta}_{x(c)}$ is determined in accordance with this document, 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, $\overline{c}_i$, of the gravimetric levels of the two injection system samples and accept the test only if the gravimetric level of each injection system sample is within ±5 % of $\overline{c}_i$.

If $\overline{c}_i$ differs from the selected value c_i' (from 10.2.3) 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 Formula (11), calculate and record on the report sheet given in Figure 2 the average injection flow rate, $\overline{q}_i$, by subtracting the final injection system volume from the initial injection system volume and dividing the result by the final test time:

$$\overline{q}_i = \frac{V_{ii} - V_{if}}{t_f} \tag{11}$$

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

12.12 Using Formula (12), calculate and record on the report sheet given in Figure 2 the average base upstream gravimetric level, c_b:

$$\overline{c}_b = \frac{\overline{c}_i \times \overline{q}_i}{q} \tag{12}$$

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 document. 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 12103-1 — 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 Formula (13):

$$m_i = \frac{\bar{c}_i \times \bar{q}_i \times t_f}{1\,000} \tag{13}$$

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

$$m_R = m_i - \frac{c_{80} \times V_{tf}}{1\,000} - \frac{q_d \times t_f \times (c_{80} - \bar{c}_b)}{1\,000} - \frac{q_u \times t_f \times [(c_{80} + \bar{c}_b)/2]}{1\,000} \tag{14}$$

NOTE In Formula (14), the following are subtracted from the mass of ISO 12103-1 — A3 test dust injected:

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

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

c) an estimate of the amount of contaminant extracted from the upstream sample flow, q_u, that is permanently discarded from the test system; the term $[(c_{80} + \bar{c}_b)/2]$ is an estimate of the average upstream gravimetric contamination level. If the upstream sample flow is recycled and not discarded, Formula (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 Formula (15):

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

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 β = 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 Formula (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:

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

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 µm(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 Formula (16).

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

NOTE 3 For an example of the calculations in this text please refer to Annex C.

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

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

“Method for determining filtration performance data in accordance with ISO 16889:2021, 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 12103-1 - 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 $\overline{q}_i$ (L/min)	
Gravimetric level (mg/L)			Gravimetric level $\overline{c}_i$ (mg/L)	

Counting system

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

Counter calibration: Method: _____ Date: _____

Test results

Element integrity

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

Differential pressure

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

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

Differential pressure versus contaminant added

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

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, µm(c)						

Test results (*continued*)

Particle counts per millilitre and filtration ratio												
Time interval	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β
Initial up												
10 % Up												
Down												
20 % Up												
Down												
30 % Up												
Down												
40 % Up												
Down												
50 % Up												
Down												
60 % Up												
Down												
70 % Up												
Down												
80 % Up												
Down												
90 % Up												
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 °C

b) flash point with closed cup (min.): 82 °C

c) acid or base number (max.): 0,10 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 °C (min.): 13,2 mm^2/s

   2) at 100 °C (min.): 4,9 mm^2/s

   3) at −50 °C (max.): 2 500 mm^2/s

   4) at −40 °C (max.): 600 mm^2/s

b) pour point (max.): −60 °C

c) flash point with closed cup (min.): 82 °C

d) acid number (max.): 0,20 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 µg/g

i) steel-on-steel wear (average wear scar, max. diameter): 1 mm

j) chlorine (max.): 50 µg/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

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 D-4308 or ISO equivalent). This can be accomplished by the addition of an anti-static agent.

The use of an anti-static agent that has a date code older than 18 months is not recommended

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 document.

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

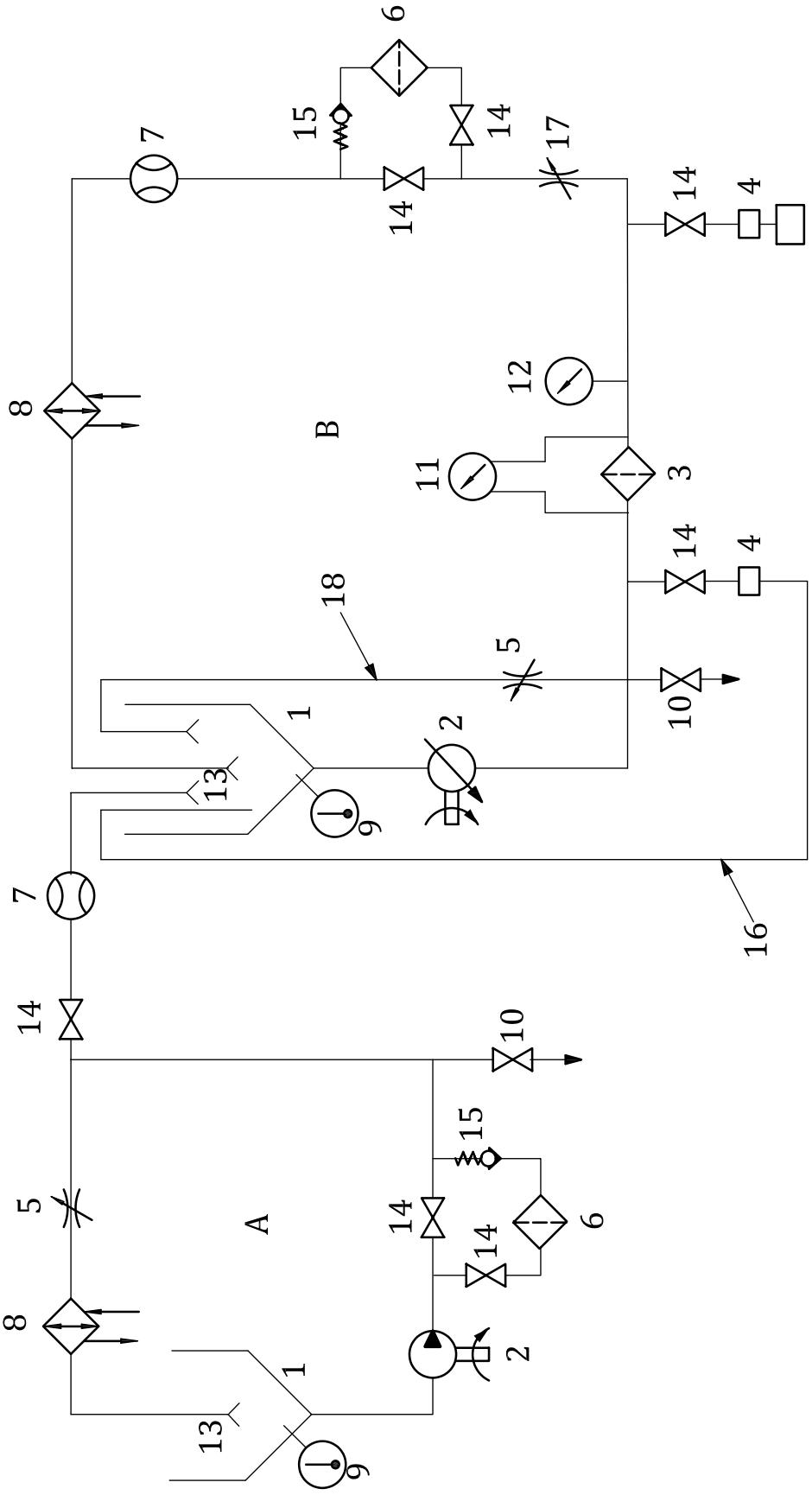
B.2.1.1 The circuit diagram of the basic equipment is shown in Figure B.1. It consists of two systems: the filter test system and the contaminant injection system.

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.



Key

A	contaminant injection system	6	clean-up filter	13	diffuser
B	filter test system	7	flow meter	14	shut-off valve

1	reservoir	8	temperature controller	15	non-return (check) valve
2	pump	9	temperature sensor	16	optional return to reservoir
3	test filter	10	sampling valve	17	back pressure valve
4	particle counting system (APC)	11	differential pressure indicator	18	optional bypass section
5	flow control valve	12	pressure gauge		

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.

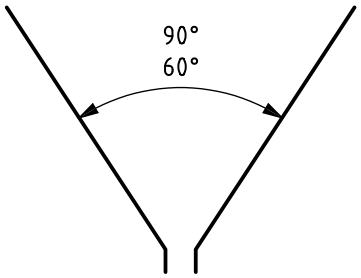


Figure B.2 — Full cone

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.

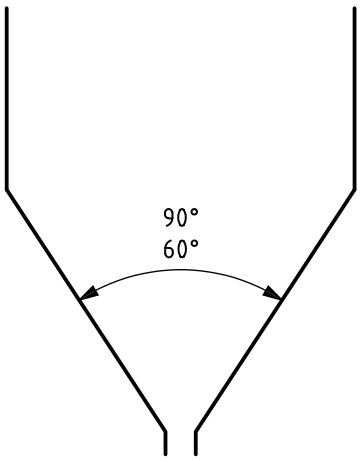


Figure B.3 — Cone and cylinder

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 conforming 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 Due to 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

C.1 Introduction

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

C.2 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 µm(c).

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

$$t_{pr} = \frac{1\,000 \times 40\,\text{g}}{10\,\frac{\text{mg}}{\text{L}} \times 100\,\text{L/min}} = 40\,\text{min}$$

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

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

Calculate c_i' using Formula (3) (see 10.2.3):

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

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

$$m = \frac{4\,000\,\frac{\text{mg}}{\text{L}} \times 20\,\text{L}}{1\,000} = 80\,\text{g}$$

C.3 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 Formula (11) (see 12.11) and $\bar{c}_b$ using Formula (12) (see 12.12):

$$\bar{q}_i = \frac{20\,L - 11{,}4\,\mathrm{L}}{34{,}2\,\mathrm{min}} = 0{,}252\,\mathrm{L/min}$$

$$\bar{c}_b = \frac{3\,980\,\frac{\mathrm{mg}}{\mathrm{L}} \times 0{,}252\,\frac{\mathrm{mg}}{\mathrm{L}}}{100\,\mathrm{L/min}} = 10\,\mathrm{mg/L}$$

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

$$m_i = \frac{3\,980\,\frac{\mathrm{mg}}{\mathrm{L}} \times 0{,}252\,\frac{\mathrm{L}}{\mathrm{min}} \times 34{,}2\,\mathrm{min}}{1\,000} = 34{,}3\,\mathrm{g\,(rounded\,to\,34\,g)}$$

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 Formula (14) (see 13.2):

$$m_R = 34{,}3\,\mathrm{g} - \frac{22{,}3\,\frac{\mathrm{mg}}{\mathrm{L}} \times 24{,}5\,\mathrm{L}}{1\,000} - \frac{0{,}2\,\frac{\mathrm{L}}{\mathrm{min}} \times 34{,}2\,\mathrm{min} \times \left(22{,}3\,\frac{\mathrm{mg}}{\mathrm{L}} - 10\,\frac{\mathrm{mg}}{\mathrm{L}}\right)}{1\,000}$$

$$- \frac{0{,}05\,\frac{\mathrm{L}}{\mathrm{min}} \times 34{,}2\,\mathrm{min} \times \left[\left(22{,}3\,\frac{\mathrm{mg}}{\mathrm{L}} + 10\,\frac{\mathrm{mg}}{\mathrm{L}}\right)/2\right]}{1\,000}$$

$$= 34{,}3 - 0{,}55 - 0{,}08 - 0{,}03$$

$$= 33{,}6\,\mathrm{g\,(rounded\,to\,34\,g)}$$

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

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.

Formula (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 Formula (16) to calculate the particle size, x, where $\beta_{x(c)}$ = 75, an interpolation is made between 10 µm(c) and 15 µm(c).

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

The particle size for $\beta_{x(c)}$ = 2 cannot be calculated because it occurs below the smallest particle size counted, that is, 5 µm(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-PRF-5606 Batch No.: 1234

Viscosity at the test temperature (mm^2/s): 14,9 Temperature (°C): 37,2

Anti-static: Yes X No ____ Type: Stadis 450 Conductivity (pS/m): 1 250

Test contaminant

Type: ISO 12103-1 - 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 $\overline{q}_i$ (L/min)	0,252
Gravimetric level (mg/L)	3 979,7	3 981,1	Gravimetric level $\overline{c}_i$ (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-PRF-5606

Differential pressure

Filter housing (kPa): 31,0 Clean assembly (kPa): 39,4

Clean element (kPa): 8,4 Final element (kPa): 400

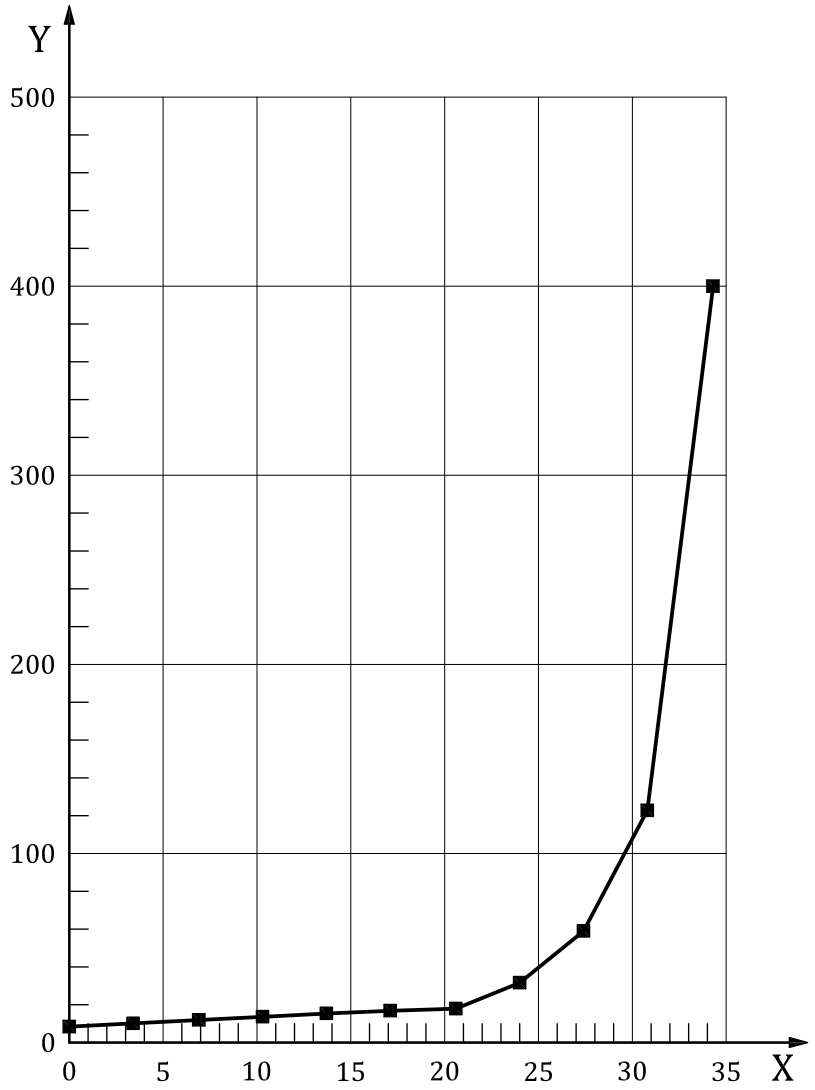
Differential pressure versus contaminant added

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, µm(c)		< 5	7,80	13,7	14,6	15,9	18,7

Particle counts per millilitre and filtration ratio													
Time interval		d > 5 µm(c)	β	d > 10 µm(c)	β	d > 15 µm(c)	β	d > 20 µm(c)	β	d > 30 µm(c)	β	d > µm(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



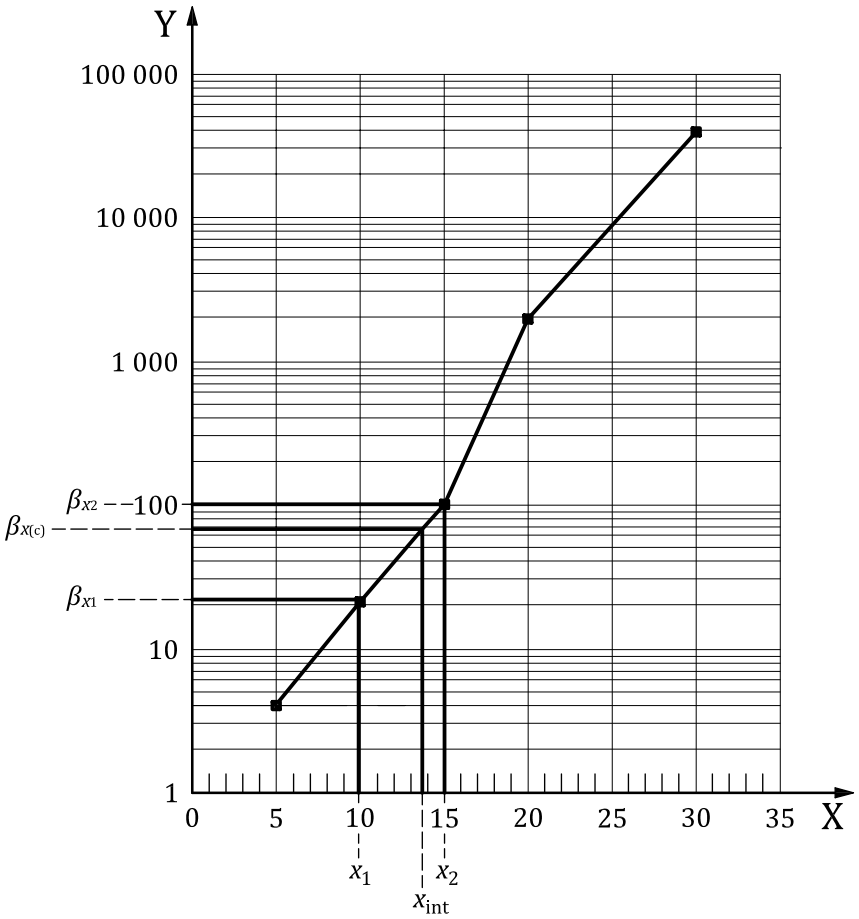
Key

X mass of ISO 12103-1 — A3 test dust injected, expressed in g

Y element differential pressure, expressed in kPa

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

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 µm(c) and x_2 = 15 µm(c) corresponding to β_{x1} = 21,1 and β_{x1} = 116, respectively. The interpolated value for $\beta_{x(c)}$ = 75 occurs at a particle size of x_{int} = 13,7 µm(c), that is $\beta_{13,7(c)}$ = 75.

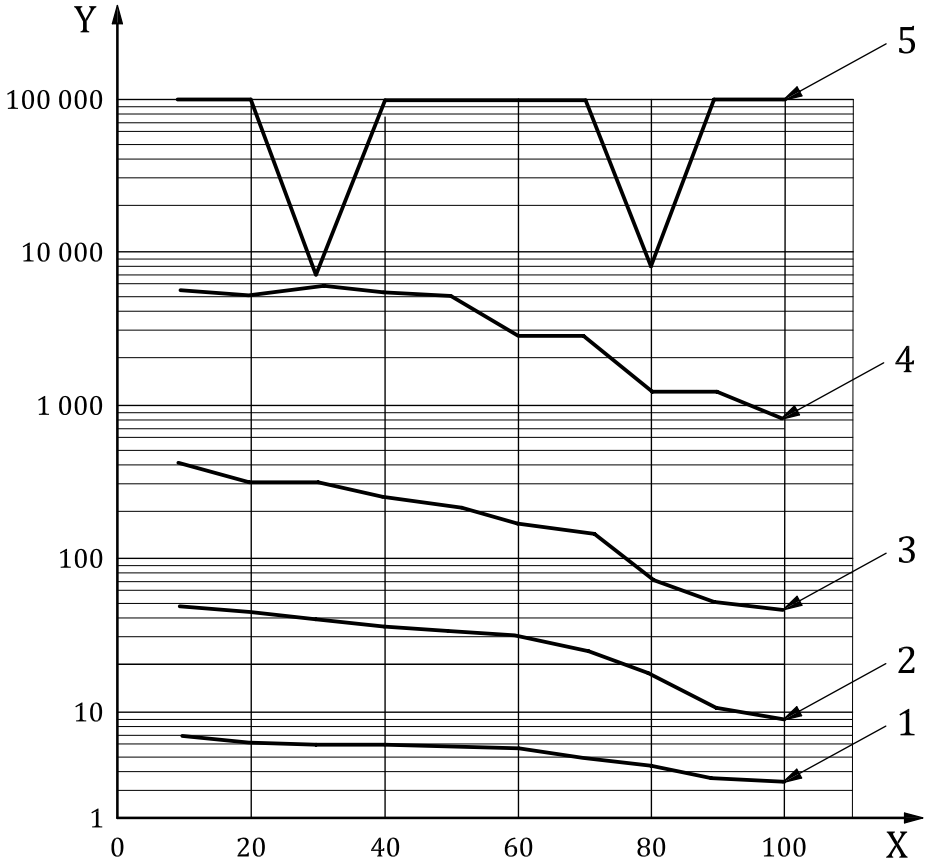


Key

X	particle size, x, expressed in µm(c)	
Y	filtration ratio, $\beta_{x(c)}$	
NOTE	x_1 = 10 µm(c)	β_{x1} = 21,1
	x_2 = 15 µm(c)	β_{x2} = 116
	x_{int} = 13,7 µm(c)	$\beta_{x(c)} = \beta_{13,7(c)}$ = 75

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

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 µm(c) were infinity; however, the points are plotted at $\beta_{x(c)}$ = 100 000.

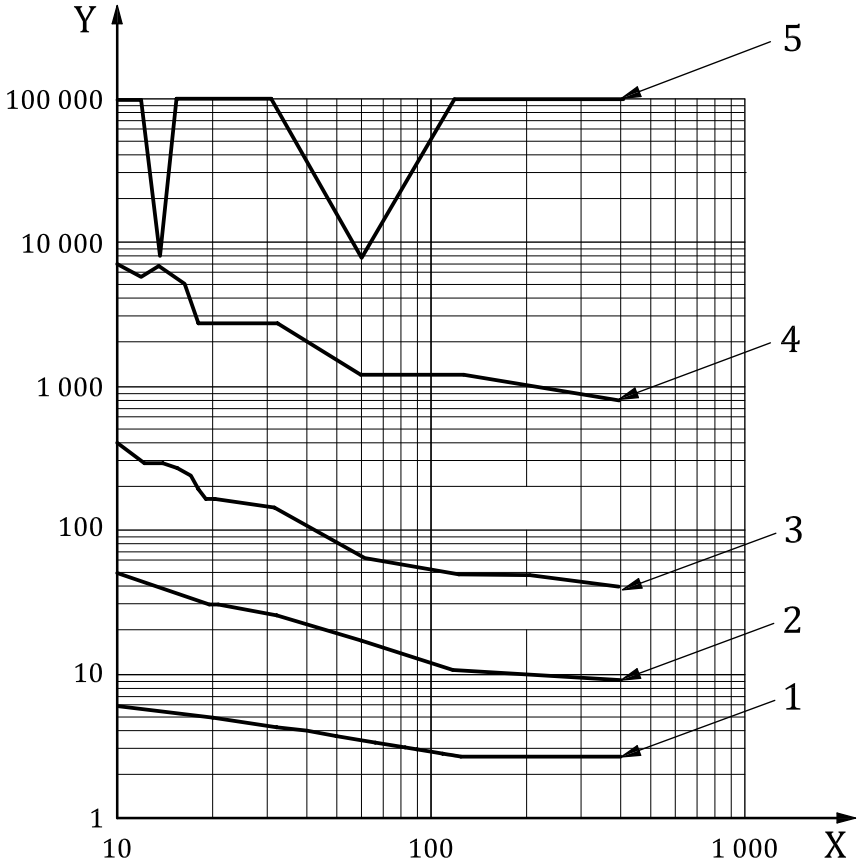


Key

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

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

Figure C.5 is a plot of average filtration ratio, $\beta_{x(c)}$, at each of the particle sizes versus element differential pressure. These values are also shown in Figure C.1. Again, note that values for $\beta_{x(c)} = \infty$ are plotted at $\beta_{x(c)} = 100\,000$.



Key

X	element differential pressure, expressed in kPa	3	curve for x = 15 µm(c)
Y	filtration ratio, $\beta_{x(c)}$	4	curve for x = 20 µm(c)
1	curve for x = 5 µm(c)	5	curve for x = 30 µm(c)
2	curve for x = 10 µm(c)		

Figure C.5 — Example of a filtration ratio versus element differential pressure plot

Annex D
(informative)

Summary of data from the interlaboratory test programme conducted to verify the procedure in this document

D.1 Preliminary note

This annex is based on ISO 16889:1999, Annex D[1)]. It has been simplified in view of keeping only information useful to those laboratories accredited to ISO/IEC 17025 that need to regularly compare their test or validation results to those of other laboratories or of interlaboratory trials.

Information relative to the scope of the interlaboratory trial and to test conditions has been duplicated.

As the particle counter calibration protocol presented in ISO 16889:2008 is not the most recent (that is, as presented in ISO 11171) and the test contaminant was a specific batch of the ISO 12103–1 — A3 dust currently in use, the absolute particle counts are deleted and only statistical values are reported. Furthermore, because filtration ratios in this edition, i.e. ISO 16889:2021, are calculated from time-based, instantaneous, on-line particle counts, the comparison with previous time-weighted average filtration ratios has been deleted.

D.2 Introduction

This first edition of this document was developed to replace ISO 4572:1981[2)]. The revision incorporated new requirements for both the quality of the instruments and the equipment used, which is proven by their calibration and validation, and the test conditions, which are more precisely specified.

As soon as the revision reached the necessary degree of development, an international interlaboratory trial was organized with two goals:

a) to quantify the overall variations of test results both within and between laboratories, including the effects of variations in the calibration of automatic particle counters (APC) and other measuring instruments, in test equipment validation and in operating conditions; the values obtained are necessary to those filter test laboratories conforming with ISO/IEC 17025 or wishing to compare their results to those of other laboratories;

b) to validate some technical choices made by the ISO working group by checking their impact (or absence of impact) on the results.

At the time of the test (summer 1994), the APC calibration procedures ISO 11171 and ISO 11943 referenced in the draft of ISO 16889:1999 were not yet published. Therefore, the APCs were calibrated in accordance with ISO 11171's predecessor, ISO 4402:1991[3)], using AC fine test dust. As a consequence, the actual sizes of the test contaminant particles might have been different from those reported, and the particle sizes reported in this annex should be adjusted according to ISO/TR 16386:1999[4)], Table 1, if compared to results obtained by the method of this document.

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1) Withdrawn and replaced by this document.

2) Withdrawn and replaced by this document.

3) Withdrawn and replaced by ISO 11171.

4) Withdrawn and replaced by ISO/TR 16386:2014.

D.3 Interlaboratory trial protocol

D.3.1 General

27 laboratories from eight countries were involved in the trial, which was coordinated by the National Fluid Power Association (USA). Each laboratory was required to:

a) calibrate APCs and validate on-line particle counting systems,

b) validate the test system, including the filter test loop itself and the contaminant injection system, and

c) test filters of several types under the different conditions specified in ISO 16889:1999, along with some additional conditions.

All test data, coded so as not to reveal the source laboratory, were sent to the inter-laboratory trial coordinator for a statistical analysis performed in accordance with ISO 5725 (all parts).

The results obtained by 21 laboratories from eight countries (six sets of results were declared outliers and not included in the statistical analysis) are summarized in D.3.2, D.4 and D.5, and the conclusions drawn from these results are summarized in D.7.

D.3.2 Test filters and conditions

Three types of filters were tested according to the protocol in various conditions as summarized in Table D.1.

Common conditions were a fluid viscosity of 15 mm^2/s and a filter final differential pressure (Δp_f) of 100 kPa. Another variable was the relationship of the total volume of fluid to the test volume flow rate (see 10.3.4); half of the labs used a total fluid volume, expressed in litres, that was numerically 25 % of the test volume flow rate, expressed in litres per minute, and the other half used a total fluid volume, expressed in litres, that was numerically 50 % of the test volume flow rate, expressed in litres per minute.

Table D.1 — Summary of test conditions

Filter type	Number of filters tested	Fluid	Gravimetric level of test contaminant (ISO MTD) mg/L	Anti-static additive	Conductivity pS/m	Flow rate L/min
1	28	MIL-H-5606	3	N	< 1 000	100
	14			Y	> 1 000	
	2	MIL-L-23699		N	—	
2	29	MIL-H-5606	10	N	< 1 000	100
	18			Y	> 1 000	
	2	MIL-L-23699		N	—	
3	4	MIL-H-5606	15	Y	> 1 000	95

D.4 Results of preliminary calibration and validation tests

D.4.1 Calibration of automatic particle counters and validation of on-line counting system

APCs were calibrated by each laboratory according to ISO 4402 using a calibration suspension prepared according to ISO 4402 and supplied by the coordinator. On-line counting systems were

validated according to ISO 11943 using one batch of ISO 12103-1 — A3 test contaminant supplied by the coordinator. The results obtained are available in ISO 11943:1999, Annex C.

D.4.2 Validation of multi-pass filter test system

Each laboratory was required to perform the filter test system validation specified in Clause 8 of this document. None of the labs used the 15 mg/L gravimetric level. The fluid counting volume varied from laboratory to laboratory; values of 1 mL, 10 mL, 20 mL, 25 mL, 30 mL and 50 mL were used. Statistical data, excluding outliers, are reported in Table D.2.

Table D.2 — Average counts of particles larger than selected sizes per millilitre at a gravimetric level of 1 mg/L and their related standard deviations and coefficients of variation

Statistical parameter	Values for particle sizes										
	1 µm	2 µm	3 µm	5 µm	7 µm	10 µm	12 µm	15 µm	20 µm	30 µm	40 µm
Mean	2 030,1	1 644,6	1 274,2	740,8	454,1	212,1	128,8	66,9	28,5	7,7	2,5
Standard deviation	6,1	72,4	48,2	25,8	22,9	11,1	7,7	4,7	2,2	1,3	0,5
Coefficient of variation	0,003	0,044	0,038	0,035	0,050	0,052	0,060	0,070	0,078	0,169	0,184

D.4.3 Validation of contaminant injection system

Each laboratory chose a desired gravimetric level to be achieved in the contaminant injection reservoir and made a few measurements to check it. The results are reported in Table D.3.

Table D.3 — Gravimetric levels measured in contaminant injection reservoir

Lab. number	Selected gravimetric level	Measured gravimetric level mg/L				Average measured gravimetric level	Percentage variation between samples[a]	Percentage difference between average measured gravimetric level and selected gravimetric level[b]
	mg/L	1	2	3	4	mg/L	%	%
1	1 890	1 857	1 881	1 879	1 853	1 867	0,8	1,2
2	14 710	14 900	14 794	14 582	14 573	14 712	1,3	0,0
3	—	537	560	512	523	533	5,1[c]	—
4	1 000	1 005	1 017	1 004	1 000	1 007	1,0	0,7
5	3 409	3,33	3,25	3,25	3,22	3,26	2,1	—
6	1 000	993	1 003	1 003	1 003	1 000	0,7	0,0
8	3 400	3 407	3 404	3 391	3 395	3 399	0,2	0,0
9	1 500	1 417	1 423	1 461	1 408	1 427	2,4	4,9
10	2 200	2 219	2 212	2 272	2 208	2 228	2,0	1,3
11	—	1 774	1 729	1 750	1 737	1 748	1,5	—
12	3 000	3 119	2 995	3 071	3 095	3 070	2,4	2,3

[a] Maximum percentage variation between samples is 5 %.

[b] Maximum percentage difference between average measured gravimetric level and selected gravimetric level is 10 %.

[c] Exceeded maximum percentage variation requirement by 0,1 %.

[d] Exceeded maximum percentage difference requirement by 1,5 %.

Table D.3 *(continued)*

Lab. number	Selected gravimetric level	Measured gravimetric level mg/L				Average measured gravimetric level	Percentage variation between samples[a]	Percentage difference between average measured gravimetric level and selected gravimetric level[b]
	mg/L	1	2	3	4	mg/L	%	%
13	1 600	1 652	1 690	1 606	1 680	1 657	3,1	3,6
14	2 000	1 873	1 881	1 792	1 825	1 843	2,8	7,9
15	1 110	1 076	1 081	1 039	1 031	1 057	2,5	4,8
16	9 463	9 610	9 998	9 846	10 019	9 868	2,6	4,3
19	8 516	8 489	8 485	8 444	8 459	8 469	0,3	0,6
19	5 678	5 657	5 653	5 664	5 653	5 657	0,1	0,4
22	8 485	8 693	8 529	8 564	8 698	8 621	1,1	1,6
24	1 100	1 015	1 030	1 055	1 098	1 050	4,6	4,6
26	5 000	5 048	5 030	5 136	5 076	5 073	1,3	1,5
27	4 000	4 053	3 996	4 021	4 022	4 023	0,7	0,6
28	1 500	1 289	1 263	1 384	1 377	1 328	4,9	11,5[d]
Averages							2,2	3,5

[a] Maximum percentage variation between samples is 5 %.

[b] Maximum percentage difference between average measured gravimetric level and selected gravimetric level is 10 %.

[c] Exceeded maximum percentage variation requirement by 0,1 %.

[d] Exceeded maximum percentage difference requirement by 1,5 %.

D.5 Results of multi-pass tests on types 1, 2 and 3 filters and test conditions

Table D.4 summarizes the number of each type of filter that was tested and the number of laboratories that tested each type of filter.

Table D.4 — Summary of types of filters tested, number of each type tested and number of laboratories that tested each type

Filter type	Number of each filter type tested	Number of laboratories that tested each filter type
1	44	20
2	47	21
3	4	2

Table D.5 summarizes the number of filters tested at each combination of test conditions.

Table D.5 — Summary of number of filters tested at each combination of test conditions

Filter type	Flow rate	Final differential pressure	Basic upstream gravimetric level	Number of filters tested with			
				Fluid type		Fluid conductivity	
	L/min	kPa	mg/L	MIL-H-5606	MIL-L-23699	< 1 000 pS/m	> 1 000 pS/m
1	100	400	3	42	2	28	14
2	100	400	10	47	2	29	18
3	95	400	15	4	0	4	0
NOTE Two types of fluid were used: the standard MIL-H-5606 with or without anti-static additive (which can explain fluid conductivity levels lower or higher than 1 000 pS/m) and the alternate fluid MIL-L-23699, which is a polyolester-based turbine lubrication oil with a naturally high conductivity.							

D.5.3 All the results for retained capacities and filtration efficiencies are given in Tables D.6 through D.10.

Table D.6 — Clean element differential pressure data

Type of test	Type 1 filters and test condition				Type 2 filters and test condition			
	Δp kPa	COV %	r %	R %	Δp kPa	COV %	r %	R %
All tests	19	18	29	51	9,0	30	19	87
Tests run at fluid conductivity > 1 000 pS/m	19	25	35	55	8,2	37	12	109
Tests run at fluid conductivity < 1 000 pS/m	19	11	36	31	9,9	31	11	89

Table D.7 — Contaminant mass injected data

Type of test	Type 1 filters and test condition				Type 2 filters and test condition			
	m g	COV %	r %	R %	m g	COV %	r %	R %
All tests	36,5	17	18	47	40,6	10	16	29
Tests run at fluid conductivity > 1 000 pS/m	32,9	10	9	23	40,1	9	8	25
Tests run at fluid conductivity < 1 000 pS/m	37,6	16	22	36	40,2	10	7	28

Table D.8 — Data related to average particle size for Type 1 filters and test conditions for a filtration ratio of 1 000

Filtration ratio β	All tests				Tests run at fluid conductivity > 1 000 pS/m				Tests run at fluid conductivity < 1 000 pS/m			
	Average particle size µm	COV %	r %	R %	Average particle size µm	COV %	r %	R %	Average particle size µm	COV %	r %	R %
1 000	3,3	28	23	80	3,6	21	22	59	3,3	32	26	108

Table D.9 — Data related to average particle size for Type 2 filters and test conditions for filtration ratios of 10, 75, 100, 200 and 1 000

Filtration ratio β	All tests				Tests run at fluid conductivity > 1 000 pS/m				Tests run at fluid conductivity < 1 000 pS/m			
	Average particle size µm	COV %	r %	R %	Average particle size µm	COV %	r %	R %	Average particle size µm	COV %	r %	R %
10	7,6	15	11	42	7,9	9	7	26	7,5	18	8	53
75	12,6	16	8	45	12,7	11	3	33	12,1	16	6	47
100	13,2	17	9	47	13,2	11	3	31	13,2	20	10	56
200	14,1	12	6	34	14,4	10	3	29	13,8	13	5	38
1000	16,7	10	6	30	15,9	4	5	32	17,0	12	5	34

Table D.10 — Data related to average particle size and filtration ratios for Type 3 filters and test conditions

Parameter	Clean element differential pressure	Capacities		Filtration ratio for particle sizes					Particle size at filtration ratios µm					
		Injected mass	Retained mass	10 µm	20 µm	25 µm	30 µm	40 µm	β = 2	β = 10	β = 75	β = 100	β = 200	β = 1 000
Mean	4,5 kPa	39,3 g	36,2 g	1,22	1,98	2,88	4,85	21,1	19,7	34,8	31,1	31,3	31,6	32,4
COV	38 %	8 %	10 %	—	—	7 %	18 %	18 %	—	—	—	—	—	—

D.6 Discussion of multi-pass test results

The variation of mean test results between laboratories using an anti-static agent (conductivity at or above 1 000 pS/m) and those who did not (or conductivity below 1 000 pS/m) was very small, whatever the parameter (initial differential pressure, contaminant mass injected, calculated particle size ratings). The data are inadequate to calculate statistical summaries for the Type 3 filters and test conditions.

The variation of the particle size ratings for the various filtration ratio values, β, is somewhat higher for the Type 1 filters than for the Type 2 filters. This is believed to be due in part to the reduced base upstream gravimetric level of 3 mg/L for the Type 1 condition versus 10 mg/L for the Type 2 condition. This, combined with the higher efficiencies of Type 1 filters, results in a smaller downstream particle count and more scatter in the data. To improve the results, it is recommended that the Type 2 or 3 test conditions with a base upstream level of 10 mg/L or 15 mg/L be used where possible, and a larger volume of fluid be counted at each interval.

D.7 Conclusion

Based upon the successful completion of each phase of the inter-laboratory trial and the repeatability and reproducibility demonstrated by the results, it is concluded that the procedures contained in this document are valid.

Bibliography

[1] ISO 5725 (all parts), *Accuracy (trueness and precision) of measurement methods and results*

[2] ISO/TR 16144:2002[5)], *Hydraulic fluid power — Calibration of liquid automatic particle counters — Procedures used to certify the standard reference material SRM 2806*

[3] ISO/TR 16386:1999[6)], *Impact of changes in ISO fluid power particle counting — Contamination control and filter test standards*

[4] ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

[5] ASTM D-4308-95, *Standard Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter*

5) Withdrawn.

6) Withdrawn and replaced by ISO/TR 16386:2014.

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