INTERNATIONAL STANDARD

ISO 16889

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

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

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 16889 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 6, *Contamination control and hydraulic fluids*.

This first edition cancels and replaces ISO 4572:1981, of which it constitutes a technical revision.

Annex A forms a normative part of this International Standard. Annexes B to D are for information only.

Introduction

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

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

To enable the relative performance of filters to be compared so that the most appropriate filter can be selected, test procedures should 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, a realistic laboratory test that establishes the relative performance of a filter should provide the test filter with a continuous supply of ingressed contaminant and allow the periodic monitoring of the filtration performance characteristics of the filter.

The test should also provide an acceptable level of repeatability and reproducibility and a standard test contaminant [ISO medium test dust (ISO 12103-A3) in accordance with ISO 12103-1] is featured. This has been shown to have a consistent particle size distribution and is available worldwide. The filtration performance of the filter is determined by measurement of the upstream and downstream particle size distributions using automatic particle counters validated according to ISO standards.

Since it is difficult to specify, achieve and verify a cyclic flow requirement that is both realistic and consistent with the flow variations occurring in actual systems, the compromise of steady-state condition has been used for this test to enhance the repeatability and reproducibility of results.

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

1 Scope

1.1 This International Standard specifies:

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

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

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

NOTE The range of flows and the lower particle size limit that can be used in test facilities will be determined by validation.

— a test using ISO medium test dust contaminant and a test fluid according to annex A.

1.2 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.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 1219-1:1991, *Fluid power systems and components — Graphic symbols and circuit diagrams — Part 1: Graphic symbols*.

ISO 2942:1994, *Hydraulic fluid power — Filter elements — Verification of fabrication integrity and determination of the first bubble point*.

ISO 3722:1976, *Hydraulic fluid power — Fluid sample containers — Qualifying and controlling cleaning methods*.

ISO 3968:1981, *Hydraulic fluid power — Filters — Evaluation of pressure drop versus flow characteristics*.

ISO 4021:1992, *Hydraulic fluid power — Particulate contamination analysis — Extraction of fluid samples from lines of an operating system*.

ISO 4405:1991, *Hydraulic fluid power —- Fluid contamination — Determination of particulate contamination by the gravimetric method*.

ISO 5598:1985, *Fluid power systems and components — Vocabulary*.

ISO 11171:1999, *Hydraulic fluid power — Calibration of liquid automatic particle counters*.

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*.

ASTM D 4308-95, *Standard test method for electrical conductivity of liquid hydrocarbons by precision meter*.

3 Terms and definitions

For the purposes of this International Standard, 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 Δp

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

See Figure 1.

3.2.1
clean assembly differential pressure
difference between the tested component inlet and outlet pressure as measured with a clean filter body containing a clean filter element

See Figure 1.

3.2.2
clean element differential pressure
differential pressure of the clean element calculated as the difference between the clean assembly Δp and the housing

See Figure 1.

3.2.3
final assembly differential pressure
assembly differential pressure at end of test equal to sum of housing plus terminal element differential pressures

See Figure 1.

3.2.4
housing differential pressure
differential pressure of the filter body without an element

See Figure 1.

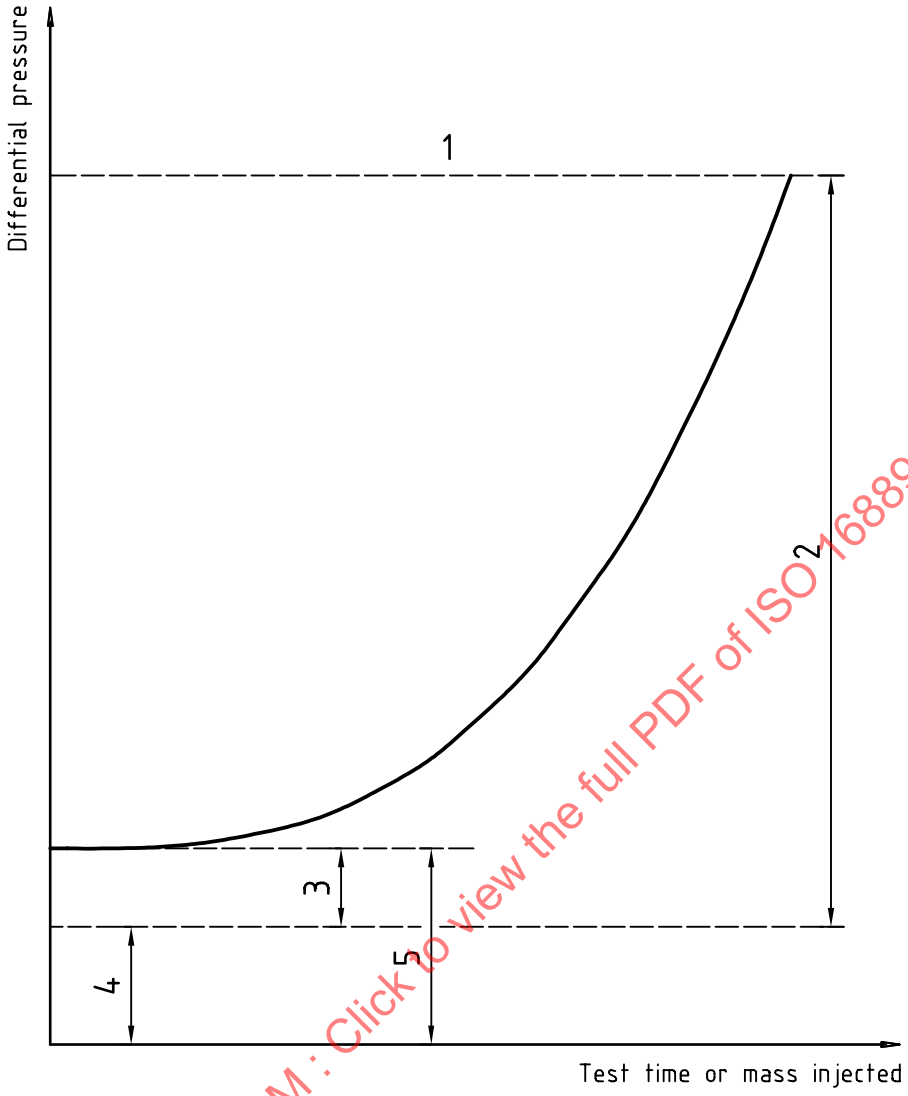
3.2.5
terminal element differential pressure
maximum differential pressure across the filter element as designated by the manufacturer to limit useful performance

See Figure 1.

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 equal to the reciprocal of the resistance of uncharged fluid in the absence of ionic depletion or polarization.

3.4
retained capacity
mass of specific particulate contaminant effectively retained by the filter element when terminal element Δp is reached



Key

1 Final assembly (end of test) differential pressure
2 Terminal element differential pressure
3 Clean element differential pressure
4 Housing differential pressure
5 Clean assembly differential pressure

Figure 1 — Differential pressure conventions for multi-pass test

4 Symbols

4.1 Graphic symbols

Graphic symbols used are in accordance with ISO 1219-1.

4.2 Quantity symbols

Reference	Symbol	Units	Description or explanation
4.2.1	$\overline{A}_{u,x}$	part/ml	Overall average upstream count > size x
4.2.2	$\overline{A}_{d,x}$	part/ml	Overall average downstream count > size x
4.2.3 [a]	$\beta_{x(c)}$	None	Filtration ratio at particle size x (ISO 11171 calibration)
4.2.4	$\beta_{x,t}$	None	Filtration ratio at particle size x and time interval t
4.2.5 [a]	$\overline{\beta}_{x(c)}$	None	Average filtration ratio at particle size x (ISO 11171 calibration)
4.2.6	C_R	g	Retained capacity
4.2.7	G_b	mg/l	Average base upstream gravimetric level
4.2.8	G_b'	mg/l	Desired base upstream gravimetric level
4.2.9	G_i	mg/l	Average injection gravimetric level
4.2.10	G_i'	mg/l	Desired injection gravimetric level
4.2.11	G_{80}	mg/l	Test reservoir gravimetric level at 80 % assembly Δp
4.2.12	M	g	Mass of contaminant needed for injection
4.2.13	M_e	g	Estimated filter element capacity (mass injected)
4.2.14	M_I	g	Contaminant mass injected
4.2.15	M_p	g	Contaminant mass injected at element differential pressure Δp
4.2.16	n	none	Number of counts in specific time period
4.2.17	$N_{u,x,i}$	part/ml	Number of upstream particles > size x at count i
4.2.18	$N_{d,x,i}$	part/ml	Number of downstream particles > size x at count i
4.2.19	$\overline{N}_{u,x,t}$	part/ml	Average upstream count > size x at time interval t
4.2.20	$\overline{N}_{d,x,t}$	part/ml	Average downstream count > size x at time interval t
4.2.21	p	Pa, kPa or bar	Pressure
4.2.22	Δp	Pa, kPa or bar	Differential pressure
4.2.23	q	l/min	Test flow rate
4.2.24	q_d	l/min	Discarded downstream sample flow rate
4.2.25	q_i	l/min	Average injection flow rate
4.2.26	q_i'	l/min	Desired injection flow rate
4.2.27	q_u	l/min	Discarded upstream sample flow rate
4.2.28	t	min	Test time
4.2.29	t'	min	Predicted test time
4.2.30	t_f	min	Final test time
4.2.31	t_p	min	Test time at element differential pressure Δp
4.2.32	V_{if}	l	Final measured injection system volume
4.2.33	V_{ii}	l	Initial measured injection system volume
4.2.34	V_{min}	l	Minimum required operating injection system volume
4.2.35	V_{tf}	l	Final measured filter test system volume
4.2.36	V_v	l	Minimum validated 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 based on this standard test method (ISO 16889) using particle counters calibrated in accordance with ISO 11171.

5 General procedure

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

5.2 Validate equipment in accordance with clause 8.

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

5.4 Analyse test data in accordance with clause 12.

5.5 Present data from clauses 10, 11 and 12 in accordance with clause 13.

6 Test equipment

6.1 Suitable timer.

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

6.3 ISO medium test dust (ISO 12103-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 and for use in the test system, mix in the test fluid, mechanically agitate, then disperse ultrasonically with a power density of 3 000 W/m^2 to 10 000 W/m^2.

NOTE This dust is commercially available. For availability of ISO 12103-A3 test dust, contact the ISO secretariat service or national members of ISO.

6.4 Online counting system, and **dilution system** if necessary, that has been validated in accordance with ISO 11943.

6.5 Sample bottles containing less than 20 particles per millilitre of bottle volume greater than 6 µm(c), as 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 If an anti-static agent is added to this test fluid it may affect the test results.

6.7 Filter performance test circuit comprised of a "filter test system" and a "contaminant injection system".

6.7.1 Filter test system consisting of:

a) a reservoir, pump, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures and volumes required by the procedure and is 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 2;

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

d) a configuration that will 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 to be satisfactory refer to annex B.

6.7.2 Contaminant injection system consisting of:

a) a reservoir, pump, fluid conditioning apparatus and instrumentation that are capable of accommodating the range of flows, pressures and volumes required by the procedure and is capable of meeting the validation requirements of clause 8;

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

c) a configuration that will 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 proven to be satisfactory, refer to annex B.

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

7 Accuracy of measurements and test conditions

7.1 Utilize and maintain instrument accuracy and test conditions within the limits given in Table 1.

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

Table 1 — Instrument accuracy and test condition variation

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

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

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

c Or as required to guarantee the viscosity tolerance.

Table 2 — Test condition values

Filter test condition	Condition 1	Condition 2	Condition 3
Initial contamination level for filter test systems:	Less than 1 % of the minimum level specified in Table 3 measured at the minimum particle size to be counted.		
Initial contamination level for injection system:	Less than 1 % of injection gravimetric level.		
Base upstream gravimetric level, mg/l [a]	3 ± 0,3	10 ± 1,0	15 ± 1,5
Recommended particle counting sizes [b]	Minimum of five sizes selected to cover the presumed filter performance range from β = 2 to β = 1 000. Typical sizes are: (4, 5, 6, 7, 8, 10, 12, 14, 20, 25, 30) µm(c).		
Sampling and counting method	Online automatic particle counting		

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

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

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 Validation of filter test system

8.1.1 Validate at the minimum flow at which the filter test system will be 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 one-fourth (25 %) to one-half (50 %) of the minimum volume flow per minute value, with a minimum of 5 l.

NOTE 1 It is recommended that the system be validated with a fluid volume numerically equal to one-half (50 %) of the minimum test volume flow per minute value for flow rates less than or equal to 60 l/min, or one-fourth (25 %) of the minimum test volume flow per value for flow rates greater than 60 l/min.

NOTE 2 This is the volume to flow ratio required by the filter test procedure (see 10.3.4).

8.1.3 Contaminate the system fluid for each test condition (1, 2, or 3) to be used to the base upstream gravimetric level as shown in Table 2 using 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 1.

8.1.5 Circulate the fluid in the test system for 1 h, conducting continuous online automatic particle counts from the upstream sampling section for a period of 60 min.

Sample flow from this section shall not be interrupted for the duration of the validation.

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

8.1.7 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;

b) the average of all cumulative particle counts per millilitre are within the range of acceptable counts shown in Table 3.

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

Table 3 — Acceptable cumulative particle count per millilitre

Particle size	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

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 a 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 utilized in preparation of the contaminant injection system become part of the validation procedure. Alteration of these procedures will require revalidation of the system.

8.2.3 Add dust and circulate for a minimum of 15 min.

8.2.4 Initiate injection flow from the contaminant injection system, collecting this flow externally from the system. Obtain 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, 60, 90 and 120) min or at least four equal intervals depending upon the depletion rate of the system.

8.2.7 Analyse each sample from 8.2.6 gravimetrically in accordance with ISO 4405.

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

8.2.9 Accept the validation only if the gravimetric level of each sample is within ± 10 % of the gravimetric level determined in 8.2.1 and the variation between samples does not exceed ± 5 % of the mean.

8.2.10 Accept the validation only if the injection flow rate at each sample point is within ± 5 % of the selected validation flow rate (8.2.1) and the variation between sample flow rates does not exceed ± 5 % of the average.

8.2.11 Accept the validation only if the volume remaining in the injection system (8.2.8) plus the quantity [average injection flow rate (8.2.10) times total injection time (8.2.6)] is equal within ± 10 % to the initial volume (8.2.2).

9 Summary of information required prior to testing

The following information is needed prior to applying this International Standard to a particular filter element:

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

b) filter element test flow;

c) terminal element differential pressure;

d) the presumed micrometre values for specific filtration ratios;

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

10 Preliminary preparation

10.1 Test filter assembly

10.1.1 Insure that test fluid cannot bypass the filter element to be evaluated.

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

NOTE 1 The test fluid used in 6.6 can be used for fabrication integrity testing.

NOTE 2 If the element is not readily accessible as in the case of a spin-on configuration, the fabrication integrity test can be conducted following the multi-pass test with the element removed. However, it should be appreciated that a low and perhaps unacceptable 1st bubble point value does not necessarily mean such a value at the start of the test.

NOTE 3 Disqualify the element from further testing if it fails to exhibit at least the designated test pressure.

NOTE 4 Allow the fluid to evaporate from the test filter element before installing in the test filter housing, where applicable.

10.2 Contaminant injection system

10.2.1 Select a desired base upstream gravimetric level (G_b') from Table 2 such that the predicted test time (t′) calculated by the following equation is preferably in the range of 1 h to 3 h:

$$t' = \frac{1\,000 \times M_e}{G_b' \times q} \qquad (1)$$

NOTE 1 A second 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 2 Predicted test times of less than 1 h or longer than 3 h are acceptable as long as test conditions 1, 2, or 3 are maintained.

10.2.2 Calculate the minimum required operating injection system volume that is compatible with the predicted test time, t′, and a desired value for the injection flow using the following equation:

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

NOTE 1 The volume calculated above will assure a sufficient quantity of contaminated fluid to load the test element plus 20 % for adequate circulation throughout the test. Larger injection system volumes may be used.

NOTE 2 A value for the injection flow of 0,25 l/min is commonly used and ensures that the downstream sample flow expelled from the filter test system will 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 (G_i') of the injection system fluid using the following equation:

$$G_i' = \frac{G_b' \times q}{q_i'} \quad (3)$$

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

10.2.5 Calculate the quantity of contaminant (M) needed for the contaminant injection system by the following equation:

$$M = \frac{G_i' \times V_{ii}}{1\,000} \quad (4)$$

10.2.6 Prior to the addition of ISO 12103-A3 test dust to the contaminant injection system, verify that the background fluid contamination level is less than shown in Table 2.

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

10.2.8 Adjust the injection flow rate at stabilized temperature to within ± 5 % of the value selected in 10.2.2 and maintain throughout the test. Record on the report sheet given in Figure 2.

10.2.8.1 Return the injection system sampling flow directly to the injection reservoir during setup.

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 test fluid rest conductivity should be checked and maintained in the range of 1 000 pS/m to 10 000 pS/m (see ASTM D-4308-95). This can be accomplished by the addition of an anti-static additive.

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

10.3.3 Circulate the fluid in the filter test system at rated flow and at a test temperature such that the fluid viscosity is maintained at 15 mm^2/s ± 1,0 mm^2/s, record the temperature and differential pressure of the empty filter housing per ISO 3968.

10.3.4 Adjust the total fluid volume of the filter test system (exclusive of the clean-up filter circuit) such that it is numerically within the range of one-fourth (25 %) to one-half (50 %) of the designated test volume flow per minute through the filter, with a minimum of 5 l.

NOTE 1 It is recommended that the filter test system fluid volume be numerically equal to one-half (50 %) of the test volume flow per minute value for flow rates less than or equal to 60 l/min, or one-fourth (25 %) of the test volume flow per minute value for flow rates greater than 60 l/min.

NOTE 2 Repeatable results require that the system volume be maintained constant. The specified range of 1:4 to 1:2 volume to flow ratio 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 of less than that specified in Table 2.

10.3.6 Effectuate online automatic particle counting

10.3.6.1 Adjust the upstream and downstream sampling flows to an initial upstream value compatible with the sampling procedure utilized and adjust the downstream flow to within ± 5 % of the injection flow. Maintain uninterrupted flow from both sampling points during the entire test.

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

NOTE 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 1.

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

NOTE 1 If the upstream sample is diluted or filtered for online automatic particle counting, the diluted or filtered fluid should be collected outside of the filter test system.

NOTE 2 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 to the values selected (Table 2).

11 Filter performance test

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

11.2 Measure and record the clean assembly differential pressure. Calculate and record the clean element differential pressure using the clean assembly minus the housing differential pressure measured in 10.3.3.

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

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

11.5 Bypass the system clean-up filter if the upstream contamination level is less than specified in Table 2.

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.

NOTE Continuous measurement of the injection flow rate is required throughout the test to ensure the flow is maintained within the specified tolerances.

11.8 Initiate the filter test as follows:

11.8.1 Allow the injection flow to enter the filter test system reservoir.

11.8.2 Start the timer.

11.8.3 Divert the downstream sample flow from the test system to maintain a constant system volume (± 5 %). See 10.3.6.1.

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

NOTE 1 The upstream and downstream sensor flow rates should be equal to the values chosen in 10.3.6.2 within the limits of Table 1.

NOTE 2 Flow rates through sensors should be monitored and recorded throughout the test and maintained within the limits of Table 1.

NOTE 3 Care should be taken to use online dilution as required to avoid exceeding the coincidence limit of the automatic particle counter as determined according to ISO 11171.

NOTE 4 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.

NOTE 5 It is recommended that a minimum counting volume of 10 ml be used to obtain statistically significant numbers.

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

NOTE 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 as follows.

11.12.1 Record the final test time.

11.12.2 Divert the injection flow from the filter test system.

11.12.3 Stop the flow to the test filter.

11.13 Measure and record the final volume, V_{tf} , in the filter test system.

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

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

11.16 Check that no visual evidence of 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 equal to (10, 20, 30 ... 100) % of the final test time (11.12.1) and record these times on the report sheet given 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 (11.9) calculate the cumulative particle count per millilitre at each size by dividing the raw counts obtained by the counted volume and adjusting for any dilution if used.

12.5 Calculate average upstream and downstream particle counts at each particle size, x, for each of the 10 reporting times, t, using the following equations and specific instructions:

$$\overline{N}_{\mathrm{u},x,t} = \frac{\sum_{i=1}^{n} N_{\mathrm{u},x,i}}{n} \tag{5}$$

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

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

12.5.1 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.

12.5.2 For the first reporting time (10 %), using the above equations, average the upstream and downstream counts obtained in clause 12.4 for all the particle counts that were started before the first reporting time (with the exception of the first three which were deleted above). Record these average counts on the report sheet given in Figure 2.

NOTE For a total test time less than 30 min, there may be no data for the 10 % reporting time so leave the entries blank.

12.5.3 For the second reporting time (20 %), average the upstream and downstream counts obtained in clause 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.

12.5.4 For the third through tenth reporting times (30 % to 100 %), repeat 12.5.3 in a similar manner using only the counts that were started in each reporting interval. Record these average counts on the report sheet given in Figure 2.

12.6 Calculate the filtration ratios ($\beta_{x,t}$) corresponding to each of the 10 reporting times by dividing the average upstream by the average downstream particle count at each size, x, corresponding to that respective reporting time (see equation below). Record on the report sheet given in Figure 2 to three significant digits (i.e. 1,75; 20,1; 300).

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

Particle counts shall be averaged and average filtration ratios (β values) shall be calculated from these average counts. Under no circumstances shall β values be averaged.

12.7 Calculate the overall test average upstream and downstream particle counts by numerically averaging the 10 average counts from 12.6 corresponding to each of the 10 reporting times (see equations below). Record on the report sheet given in Figure 2.

$$\overline{A}_{u,x} = \sum_{t=10}^{100} \overline{N}_{u,x,t} \quad (8)$$

$$\overline{A}_{d,x} = \sum_{t=10}^{100} \overline{N}_{d,x,t} \quad (9)$$

where t is the ten reporting time intervals from 10 to 100.

12.8 Calculate the overall average filtration ratios, $\overline{\beta}_{x(c)}$, using the following equation by dividing the overall test average upstream by the downstream cumulative particle counts at each size, x µm(c). Record on the report sheet given in Figure 2 to three significant digits.

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

NOTE The subscript (c) signifies that the filtration ratio, $\beta_{x(c)}$, is based on this standard test method, ISO 16889, using particle counters calibrated in accordance with ISO 11171.

Particle counts shall be averaged then average filtration ratios (β values) shall be calculated from these average counts. Under no circumstances shall β values be averaged.

12.9 Conduct a gravimetric analysis on the two samples extracted from the contaminant injection system (from 11.6 and 11.15). Report values to nearest 0,1 mg/l. (See ISO 4405)

12.9.1 Calculate the average (G_i) of these two gravimetric levels from the injection system.

12.9.2 Accept the test only if the gravimetic level of each injection system sample is within ± 5 % of this average.

NOTE If the average injection gravimetric value, G_i , differs from the selected value, G_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 be repeated (8.2).

12.10 Conduct three gravimetric analyses on the 80 % upstream sample (from 11.11) and record the average of these analyses as the final system gravimetric level. Report values to nearest 0,1 mg/l.

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

12.11 Calculate and record the average injection flow rate (q_i) by subtracting the final from the initial injection system volume and dividing by the final test time as shown in the following equation:

$$q_i = \frac{V_{ii} - V_{if}}{t_f} \quad (11)$$

Accept the test only if this value is equal to the selected value (10.2.2) ± 5 %.

12.12 Calculate and record the average base upstream gravimetric level (G_b) as shown in the following formula:

$$G_b = \frac{G_i \times q_i}{q} \quad (12)$$

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

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 sheets be adopted as shown.

13.2 Using the actual test time (t_f) to reach the terminal element differential pressure, the average gravimetric level (G_i) of the injection stream, and the average injection flow rate, q_i, calculate the filter element ISO 12103-A3 test dust mass injected (M_I) using the following equation:

$$M_I = \frac{G_i \times q_i \times t_f}{1000} \tag{13}$$

Calculate and report the ISO 12103-A3 test dust retained capacity, rounded to the nearest two significant figures, using the following formula:

$$C_R = M_I - \frac{G_{80} \times V_f}{1000} - \frac{q_d \times t_f \times (G_{80} - G_b)}{1000} - \frac{q_u \times t_f \times (G_{80} + G_b)/2}{1000} \tag{14}$$

NOTE 1 The above formula subtracts from the ISO 12103-A3 test dust mass injected:

NOTE 2 The three terms subtracted from the mass injected represent (1) the weight of contaminant remaining in the test system at the end of the test; (2) an estimate of the amount of contaminant permanently extracted from the system through the filter downstream sampling tap [the term ($G_{80} - G_b$) is a conservative estimate of the gravimetric level downstream of the test filter]; and (3) an estimate of the amount of contaminant extracted from the upstream sample flow (q_u) that is permanently discarded from the test system [the term ($G_{80} + G_b$)/2 is an estimate of the average upstream gravimetric level]. If the upstream sample flow is recycled and not discarded, the equation is applied without the final term.

13.3 Report the values of the gravimetric levels obtained in 12.9 and 12.10.

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

$$M_p = \frac{G_i \times q_i \times t_p}{1000} \tag{15}$$

where M_p is 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, β values being on the log scale with β = 100 000 as the highest values plotted. See the example in Figure C.3.

NOTE When $\beta_{x(c)}$ equal infinity values (zero downstream particle count) are recorded, they should be plotted as $\beta_{x(c)}$ = 100 000.

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

NOTE 1 For many filters, micrometre values for each of the above β ratios cannot be obtained by interpolation. In these cases, the values unobtainable should be noted as either less than the minimum size counted or greater than the maximum size counted whichever is appropriate. Values should be reported for at least two or more consecutive filtration ratios from the above values.

NOTE 2 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 and particle sizes β_{x1}, β_{x2} and x_1, x_2 respectively), use the following equation:

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

NOTE 3 For β values greater than 100 000, use the value of 100 000 in the above equation.

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)

Use the following statement in test reports, catalogues and sales literature when electing to comply with this International Standard:

"Method for determining filtration performance data in accordance with ISO 16889:1999, *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): _____

Antistatic: 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 concentration G_b (mg/l) _____ Final volume (l): _____

Injection system

Injection parameters	Initial	Final	Average injection parameters	
System volume (l)			Injection flow q_i (l/min)	
Concentration (mg/l)			Concentration G_i (mg/l)	

Counting system	Counter and sensor ref.	Flowrate (ml/min)	Dilution ratio
Upstream			
Downstream			

Counter calibration: Method: _____ Date: _____

TEST RESULTS

Element integrity

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

Differential pressure

Filter housing (kPa): _____ Clean ass'y (kPa): _____

Clean element (kPa): _____ Final Δp 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 12103-A3 test dust mass injected M_i (g): _____ ISO 12103-A3 test dust retained capacity C_R (g): _____

80 % upstream concentration G_{80} (mg/l): _____

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

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

Figure 2 — Filter element multi-pass report sheet

TEST RESULTS (*continued*)

Particle counts (per ml) and filtration ratio

Time interval		$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β	$d >$ µm(c)	β
Initial up													
10 %	Up												
	Down												
20 %	Up												
	Down												
30 %	Up												
	Down												
40 %	Up												
	Down												
50 %	Up												
	Down												
60 %	Up												
	Down												
70 %	Up												
	Down												
80 %	Up												
	Down												
90 %	Up												
	Down												
100 %	Up												
	Down												
Avg.	Up												
Avg.	Down												

Figure 2 *(continued)*

Annex A
(normative)

Properties of base test fluid

A.1 Properties of mineral oil stock

— pour point (max.) – 60 °C;

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

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

A.2 Additive materials

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

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

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

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

A.3 Properties of finished oil

— viscosity: at 40 °C (min.) 13,2 mm^2/s;

at 100 °C (min.) 4,9 mm^2/s;

at –50 °C (max.) 2 500 mm^2/s;

at –40 °C (max.) 600 mm^2/s;

— pour point (max.) –60 °C;

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

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

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

— evaporation loss (max.) 20 %;

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

— water content (max., µg/g) 100;

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

— chlorine (max., µg/g) 50.

A.4 Colour of finished oil

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

A.5 Qualified fluids

During the preparation of this International Standard, the following fluids were found to fulfil the above requirements:

— Mil-H-5606;

— AIR 3520;

— Nato Code H-515/520;

— 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 1 000 pS/m to 10 000 pS/m (see ASTM D-4308-95). This can be accomplished by the addition of an anti-static additive.

CAUTION — Use of additive having a date code of 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 will meet 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 the equipment.

B.2 Basic test system

B.2.1 General guidelines

B.2.1.1 The schematic 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 Lines

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

B.2.1.3 Fittings

Fittings should not have internally exposed threads or lips that may be contaminant traps.

B.2.1.4 Lines and fittings

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

B.2.1.5 Valves

Ball valves are preferable to other types of valves as they are not contaminant traps and have a self-cleaning action.

B.2.2 Filter test system

The filter test system consists of the following elements.

B.2.2.1 Reservoir

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

NOTE This construction technique eliminates horizontal surfaces that may promote contaminant settling.

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

B.2.2.1.3 The reservoir design pictured in Figure B.3 is a cylinder with a conical bottom and is useful in containing a desired fluid volume in a system where reservoir diameter is critical.

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

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 operative 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. Centrifugal and progressive cavity pumps have 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 desirable 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 2 of the test method.

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

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

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

B.2.2.4 Heat exchanger/heater

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

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

— Either side or multi-pass heat exchangers have been successfully utilized as described above.

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

— Other cooling methods such as coils wrapped on the external surface of reservoirs and pipes have also proved satisfactory as have double wall conduits.

— Fluid heating: fluid heating, if required, may be accomplished by the use of heating tapes on external surfaces or by using a second heat exchanger with a high temperature fluid on the shell side.

B.2.2.5 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 returning directly to the reservoir. This section allows the system pump to be operated at a higher speed for low flow tests eliminating high flow ripples and drive over heating. Diaphragm, weir or pinch valves have proved suitable for bypassing the filter.

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

B.2.2.5.2 Counter pressure regulation valve

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

B.2.2.6 Flow meter

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

B.2.3 Contaminant injection system

The contaminant injection system consists of the following elements.

B.2.3.1 Reservoir

Construction and design precautions are the same as for the test system reservoir.

NOTE Owing to the large volume and high contaminant concentrations encountered, some auxiliary agitation system for the contaminant injection reservoir is desirable. These may 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 this circuit makes the choice of the pump limited to those with a complete insensitivity to abrasive slurries. Centrifugal and progressive cavity pumps have been shown to be acceptable.

B.2.3.2.2 When using centrifugal pumps, vertical mounting with the inlet down or horizontal mounting with the discharge at the bottom have proven successful.

B.2.3.3 Clean-up filter

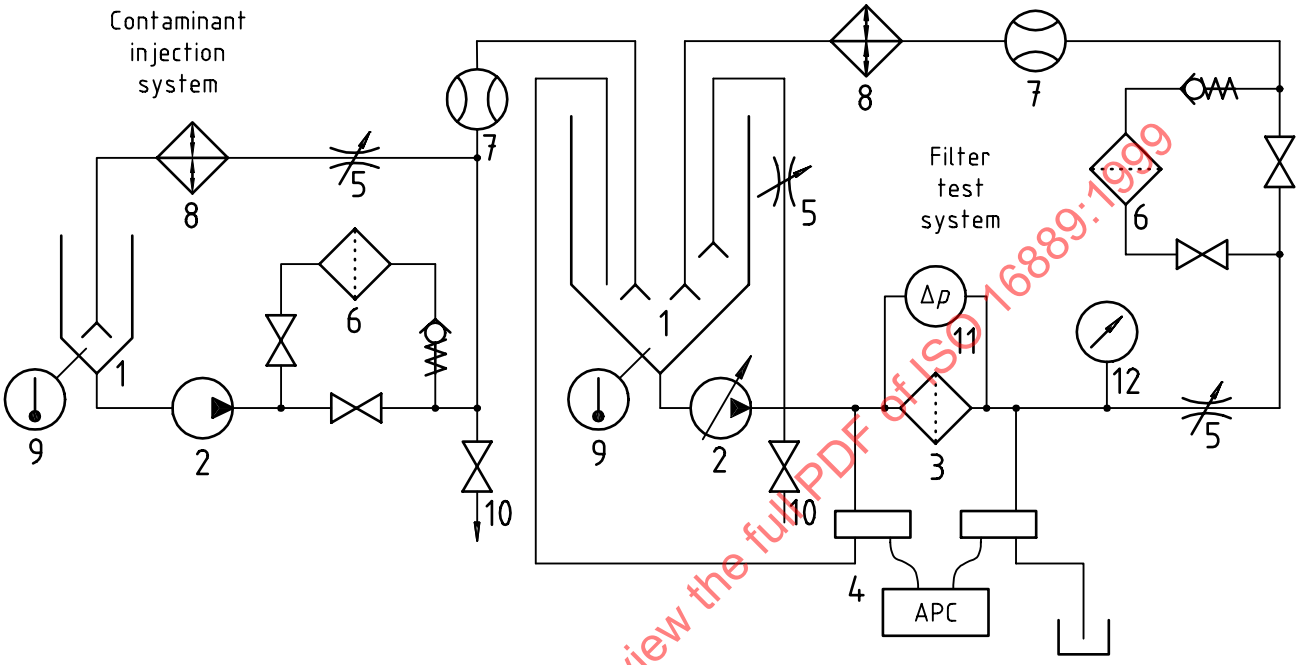
The same considerations as for the filter test system apply except that contaminant holding capacity is of prime importance.

B.2.3.4 Heat exchangers

See the previous recommendations for filter test system in B.2.2.4.

B.2.3.5 Flowmeter

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



Key

1	Reservoir	7	Flow meter
2	Pump	8	Heat exchanger
3	Test filter	9	Temperature sensor
4	Particle counting system	10	Sampling valve
5	Regulating valve	11	Differential pressure indicator
6	Cleanup filters	12	Pressure gauge

Figure B.1 — System schematic

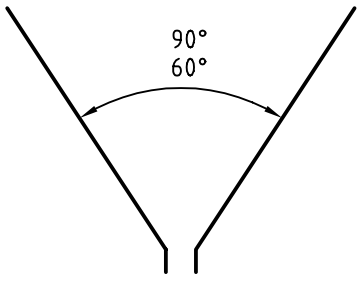


Figure B.2 — Full cone

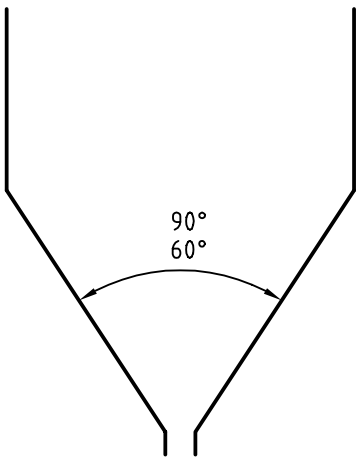


Figure B.3 — Cone and cylinder

Annex C
(informative)

Example report calculations and graphs

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

C.1 Preliminary information

The information required prior to conducting the test according to clause 9 were as follows:

Fabrication integrity pressure:	1 500 Pa;
Test flow, q_i :	100 l/min;
Terminal element Δp:	400 kPa;
Presumed filtration ratios:	$\beta_{5(c)} = 4$, $\beta_{15(c)} = 75$;
Estimated capacity, M_e:	40 g.

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

Desired base upstream gravimetric level, G_b':	10 mg/l;
Desired injection flow, q_i':	0,25 l/min;
Particle count sizes:	(5, 10, 15, 20, 30) µm(c)

From 10.2.1, formula (1): $$t' = \frac{1000 \times 40\ \text{g}}{10\ \text{mg/l} \times 100\ \text{l/min}} = 40\ \text{min}$$

From 10.2.2, formula (2): $$V_{min} = (1{,}2 \times 40\ \text{min} \times 0{,}25\ \text{l/min}) + 8\ \text{l} = 20\ \text{l}$$

From 10.2.3, formula (3): $$G_i' = \frac{10\ \text{mg/l} \times 100\ \text{l/min}}{0{,}25\ \text{l/min}} = 4\,000\ \text{mg/l}$$

From 10.2.5, formula (4): $$M = \frac{4\,000\ \text{mg/l} \times 20\ \text{l}}{1000} = 80\ \text{g}$$

C.2 Multi-pass test results

The multi-pass test was conducted with the above parameters and the remaining test conditions and test results are shown in Figure C.1. The calculated test results reported in Figure C.1 were determined as follows:

From 12.11, formula (11): $$q_i = \frac{20\ \text{l} - 11{,}4\ \text{l}}{34{,}2\ \text{min}} = 0{,}252\ \text{l/min}$$

From 12.12, formula (12): $$G_b = \frac{3\,980\ \text{mg/l} \times 0{,}252\ \text{l/min}}{100\ \text{l/min}} = 10\ \text{mg/l}$$

Test laboratory: Example Test Lab Test date: 4 December 1999 Operator: ABC

FILTER AND ELEMENT IDENTIFICATION

Element ID: Example test filter Housing ID: Test Housing

Spin on: YES / (NO) Minimum element bubble point (Pa); 1500

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 (°C): 37,2

Antistatic: (YES) / NO Type: Stadis 450 Conductivity (pS/m): 1250

Test contaminant

Type ISO 12103-A3 test dust Batch no.: 4390 C

Test system

Flowrate q (l/min): 100 Initial volume (l): 25,0

Base upstream concentration G_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 q_i (l/min)	0,252
Concentration (mg/l)	3 979,7	3 981,1	Concentration G_i (mg/l)	3 980

Counting system	Counter and sensor ref	Flowrate (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 11171:1999 Date: 4 December 1999

TEST RESULTS

Element integrity

Bubble point to ISO 2942 (Pa): 2 190 Wetting fluid: Mil-H-5606

Differential pressure

Filter housing (kPa): 31,0 Clean ass'y (kPa): 39,4

Clean element (kPa): 8,4 Final Δp 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	123,0	30,8
50 %	17,1	16,8	17,1	100 %	34,2	400,0	34,3

Retention capacity

ISO 12103-A3 test dust mass injected M_i (g): 34 ISO 12103-A3 test dust retained capacity C_R (g): 34

80 % upstream concentration G_{80} (mg/l): 22,3

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

Average filtration ratio	2	10	75	100	200	1 000
Particle size, µm(c)	—	7,80	13,7	14,6	15,9	18,7

Figure C.1 — Filter element multi-pass report sheet

TEST RESULTS (*continued*)

Particle counts (per ml) 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	0,0	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	0,0	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	0,0	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	0,0	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	0,0	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	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	0,1	2 590	0,0	∞		
80 %	Up	16 800		1 910		508		187		32			
	Down	5 050	3,3	117,0	16,3	6,3	80,9	0,1	1 260	0,0	7 680		
90 %	Up	19 400		2 030		527		190		32,4			
	Down	7 520	2,6	186,0	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	224,0	9,3	12,3	43,3	0,3	753,0	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	0,1	2 130	0,0	37 900		

Figure C.1 (*continued*)

From 13.2, formula (13): $M_l = \frac{3\,980\ \text{mg/l} \times 0{,}252\ \text{l/min} \times 34{,}2\ \text{min}}{1000} = 34{,}3\ \text{g}$, rounded to 34 g.

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

Discarded downstream sample flow rate, q_d: 0,20 l/min;

Discarded upstream sample flow rate, q_u: 0,05 l/min;

From 13.2.1, formula (14):

$$C_R = 34{,}3\ \text{g} - \frac{22{,}3\ \text{mg/l} \times 24{,}5\ \text{l}}{1000} - \frac{0{,}2\ \text{l/min} \times 34{,}2\ \text{min} \times (22{,}3\ \text{mg/l} - 10\ \text{mg/l})}{1000} -$$

$$\frac{0{,}5\ \text{l/min} \times 34{,}2\ \text{min} \times (22{,}3\ \text{mg/l} + 10\ \text{mg/l})/2}{1000} = 34{,}3 - 0{,}55 - 0{,}08 - 0{,}03 = 33{,}6\ \text{g (round to 34 g).}$$

Each of the dust injected values reported in Figure C.1 were calculated using formula (15) in 13.4. The average particle counts and filtration ratios were calculated using formulas (5), (6), (7), (8), (9) and (10).

Figure C.2 is a graph of element differential pressure versus dust 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) was used to calculate the interpolated particle sizes for the specific filtration ratios reported at the bottom of Figure C.1. As an example, to calculate the particle size, x, where $\beta_{x(c)} = 75$, an interpolation is made between 10 µm(c) and 15 µm(c) as follows:

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

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

Figure C.3 is a plot of β versus particle with straight line segments connecting the data points at the various particle sizes. The linear interpolation calculated above is illustrated between particle sizes for 10 µm(c) and 15 µm(c) corresponding to β values of 21,1 and 116 respectively. The interpolated value for $\beta = 75$ occurs at a particle size of 13,7 µm(c) or $\beta_{13{,}7(c)} = 75$.

Figure C.4 is a plot of average filtration ratio at each of the particle sizes versus per cent test time. These values are also shown in Figure C.1. Note that several of the measured values for β at 30 µm(c) were infinity; however, the points are plotted at $\beta = 100\ 000$.

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

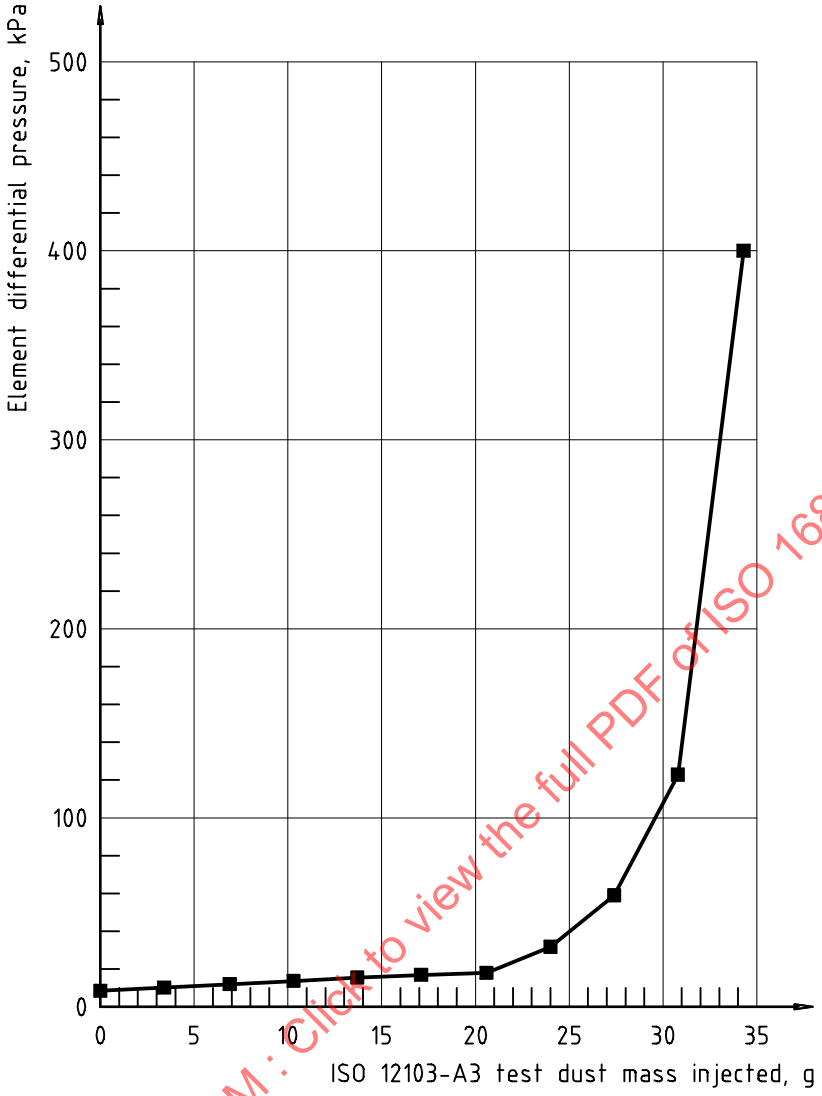


Figure C.2 — Example differential pressure versus contaminant added curve

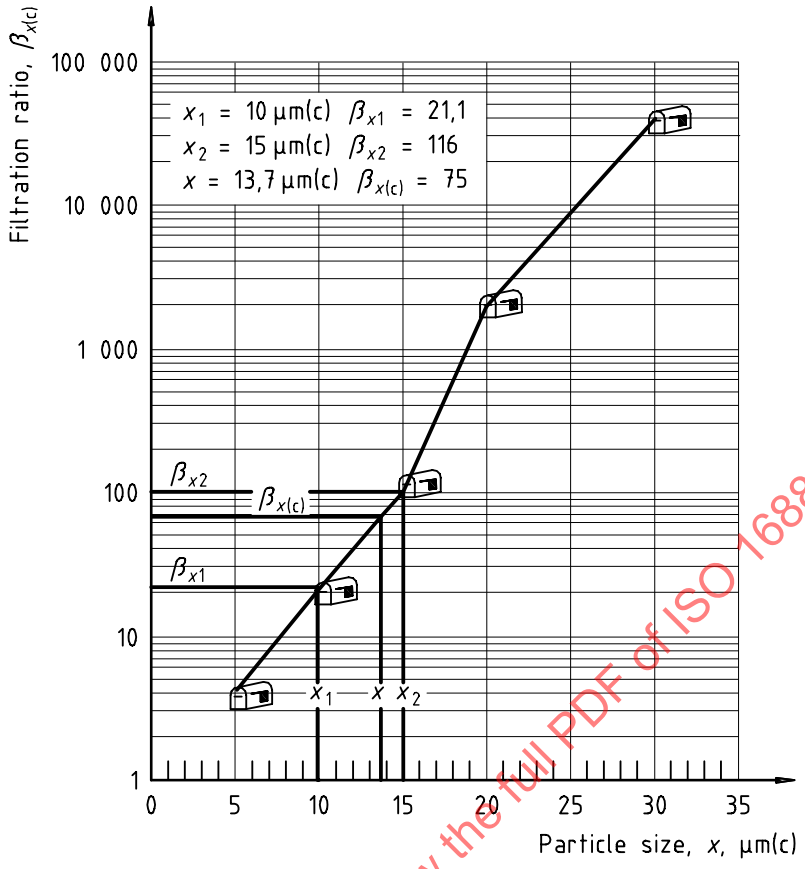


Figure C.3 — Example filtration ratio versus particle size curve

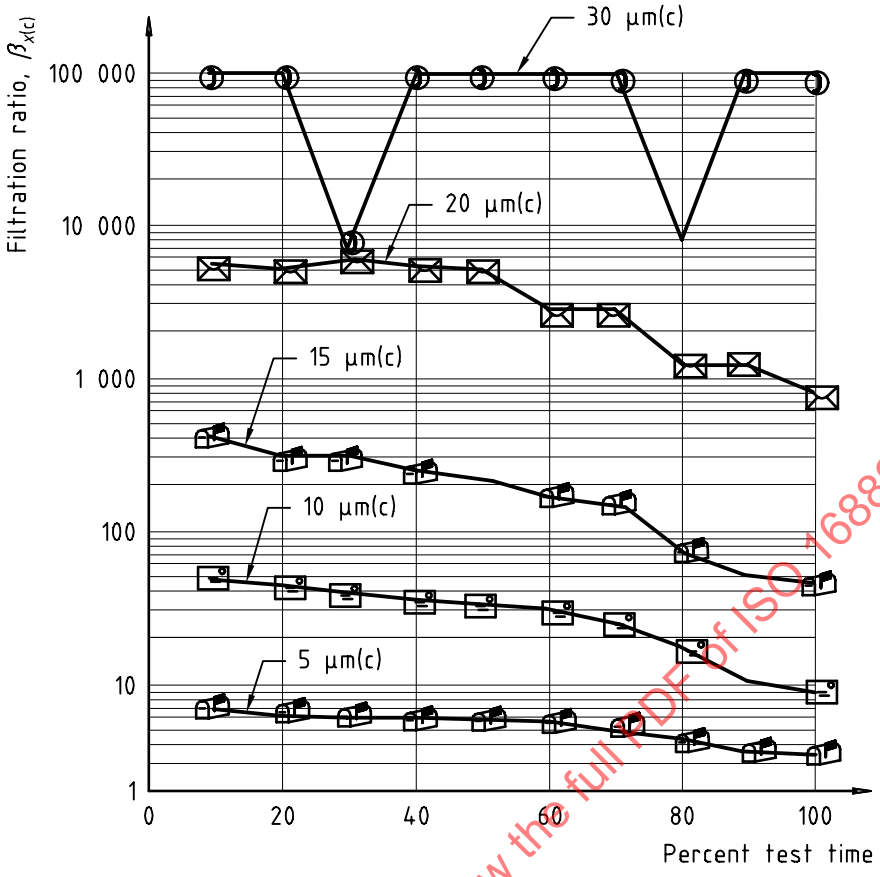


Figure C.4 — Example plot of filtration ratio versus percent test time

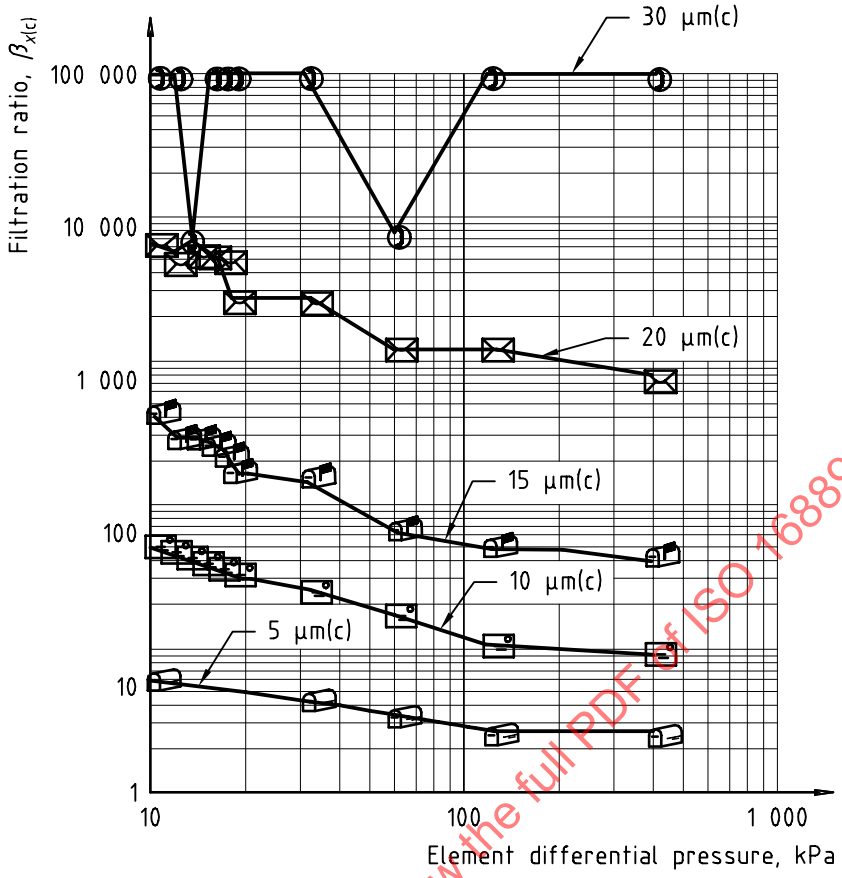


Figure C.5 — Example plot of filtration ratio versus element differential pressure

Annex D
(informative)

Summary of ISO round robin for the multi-pass test (ISO/CD 4572)

D.1 Background

NOTE The round robin reported in this annex was conducted using automatic particle counter calibration in accordance with ISO 4402-1991 and ISO/WD 11943 using AC Fine Test Dust. The calibration procedure called out in this international standard uses ISO 12103-A3 test dust in accordance with ISO 11171 and ISO 11943. Therefore, the particle sizes reported in this annex should be adjusted accordingly if compared to results that use this standard. Also the procedure was renumbered from the original ISO 4572 to 16889 during the development of this revision.

In the summer of 1994, an international round robin was conducted with 27 laboratories initially participating from eight countries. Automatic particle counter calibration samples prepared in accordance with ISO 4402 were supplied to each participant. Using these samples and a supplied batch of ISO 12103-A3 test dust, each laboratory was asked to conduct an on-line automatic particle counter calibration and validation in accordance with ISO/WD 11943. Three sets of filter elements were also supplied to be tested under conditions 1, 2, and 3 in accordance with Table 2 of this International Standard. Initially there were only two types of elements for conditions 1 and 2 respectively, but the program was extended to a few laboratories to include a third type of element and test condition. Three elements for each condition were supplied with all elements of each type from the same manufacturing lot. Each participating laboratory was asked to test two elements of each type according to the procedures of ISO/CD 4572. The results, coded so as not to reveal the laboratory, were all sent to the National Fluid Power Association for analysis.

There were a total of 21 laboratories submitting data from the round robin representing eight countries. The following are summary and conclusions drawn from the multi-pass round robin conducted for ISO/TC 131/SC 8/WG 9. Comments are given on each major step and the complete data and summaries are included in the tables. Outliers have been excluded from the statistical results presented.

D.2 Multi-pass filter test system validation

The results of the filter test system validation are included in Tables D.1 and D.2. Table D.2 shows the laboratories that successfully passed and those that did not. The outliers eliminated from the final analysis either were outliers on the calibration according to ISO/WD 11943 or did not validate their on-line system prior to conducting this test.

Most of the laboratories who did not successfully pass the on-line particle counter calibration and validation also did not generally pass the filter test system validation. Most laboratories who did pass ISO 11943 were also able to successfully validate their filter test stands at all particle sizes per the ISO/CD 4572 procedures with 93 % of the validations passing the requirements of subclause 8.1.

D.3 Contaminant injection system validation

As shown in Table D.3, nearly all laboratories passed the injection system validation. Only two laboratories failed and by a very small amount.

Table D.1 — Filter test system validation: particle counts average particles/µg > size (µm)

Lab no.	Count. vol. ml	Conc. mg/l	Average particles/µg > size, µm											Average particle counts/ml per 1 mg/l greater than size, µm										
			Average particle counts greater than size, µm																					
			1	2	3	5	7	10	12	15	20	30	40	1	2	3	5	7	10	12	15	20	30	40
												REF Count >		2000	1660	1300	757	450	215	126	70	29	7,3	2,3
1	25	10			12781	7114	4091	2076	1278	680	287	67				1278	711	409	208	128	68	29	6,7	
2	9,9	3		3891	2939	1700	990	434		136	60	16	5		1297	980	567	330	145		45	20	5,4	1,7
2	9,9	10		13154	9979	5686	3332	1204	875	466	208	55	16		1315	998	569	333	120	88	47	21	5,5	1,6
2	9,9	15		19095	14606	8497	4923	2168	1313	708	317	82	25		1273	974	566	328	145	88	47	21	5,5	1,6
3	50	3		5106	3950	2529	1434	654	404	193	93	22			1702	1317	843	478	218	135	64	31	7,4	
4	20	3			3933	2243	1411	661	416							1311	748	470	220	139					
4	20	5				3819		1017		331	141	35					764		203		66	28	7,0	
5	25	3		5257	3982	2327	1310	566	362	188	75	18	5		1752	1327	776	437	189	121	63	25	6,0	1,7
5	25	3		5203	3965	2311	1301	565	356	188	78	19	5		1734	1322	770	434	188	119	63	26	6,3	1,7
6	30	3,1		4775	3460	2133	1386	731	486	286					1530	1109	684	444	234	156	92			
6	30	9,5				6066		2258		828	320	80	30				639		238		87	34	8,4	3,2
8	25	3		5199	3951	2291	1386	685	383	203	90	24			1733	1317	764	462	228	128	68	30	7,8	
8	25	10		15320	11812	7257	4595	2138	1307	682	290	75			1532	1181	726	460	214	131	68	29	7,5	
9	25	3		123505	96584	60339	35105	16279	10379	5641	2496	646	193		1647	1288	805	468	217	138	75	33	8,6	2,6
10	25	3				2145		607		183	80	21	8				715		202		61	27	7,1	2,6
11	50	3		4660	3734	2269	1415	674	406						1553	1245	756	472	225	135				
11	50	3		5004	3817	2266	1401	681	431						1668	1272	755	467	227	144				
12	1	3			3711	2200	1178	626	375	190	81	23	5			1237	733	393	209	125	63	27	7,8	1,8
13	25	2,5	5086		3387		1169		291		63	13		2034		1355		468		117		25	5,3	
13	25	2,5	5065		3338		1172		294		61	13		2026		1335		469		117		24	5,2	
14	10	3			3821	2277	1343	625	371	212						1274	759	448	208	124	71			
15	25	3		95408	75356	44282	28100	12008	7992	4813	2170	713	329		1272	1005	590	375	160	107	64	29	9,5	4,4
16	10	10		14049	11178	8000		2429		813	363	85	22		1405	1118	800		243		81	36	8,5	2,2
16	10	10		14871	11793	8393		2559		846	370	87	24		1487	1179	839		256		85	37	8,7	2,4
19	50	1		1648	1314	765	470	218	128	70	28	8	3		1648	1314	765	470	218	128	70	28	8,0	2,6
19	50	1		1647	1249	741	475	202	131	73	28	7	2		1647	1249	741	475	202	131	73	28	7,2	2,1
22	20	10		15723	11776	6990		1936		691	301	80	29		1572	1178	699		194		69	30	8,0	2,9
24	25	2,9			87179	50853	31342	14695				622				1224	714	440	206				8,7	
24	25	2,9			87521	52496	31517	15248				653				1228	737	442	214				9,2	
26	10	3			3827	2309		604		183	85		5			1276	770		201		61	28		1,8
26	10	10			13123	7425		2143		697	285		24			1342	742		214		70	28		2,4
27	50	3		5200	3936	2185	1342	699	377						1733	1312	728	447	233	126				
27	50	3		5139	3897	2229	1381	675	369						1713	1299	743	460	225	123				
27	50	10				7268		1996		615	287	97	30				727		200		62	29	9,7	3,0
27	50	10				6960		1971		599	317	93	29				696		197		60	32	9,3	2,9
28	25	5		6717	4747	2646	1298	816	480	242	107	35	7		1343	949	529	260	163	96	48	21	7,0	1,3
								mean						2030	1550	1218	720	428	205	123	66	28	7,4	2,3
								st.dev.						6,1	169,7	121,9	77,1	57,5	29,4	16,6	11,6	4,3	1,4	0,7
								cov.						0,3%	11%	10%	11%	13%	14%	13%	17%	15%	19%	32%
								mean without 2,3,6,15,16,28						2030	1645	1274	741	454	212	129	67	28	7,7	2,5
								st.dev.						6,1	72,4	48,2	25,8	22,9	11,1	7,7	4,7	2,2	1,3	0,5
								cov.						0,3%	4%	4%	3%	5%	5%	6%	7%	8%	17%	18%

Table D.2 — Filter test system validation check

Lab. no.	Validation – Each count within ? ? % of average												Validate – Each count within required range? Yes (1) No (0)												Remarks
	1	2	3	5	7	10	12	15	20	30	40		1	2	3	5	7	10	12	15	20	30	40		
1			1%	1%	1%	1%	1%	1%	1%	2%					1	1	1	1	1	1	1	1	1		
2		2%	1%	1%	2%	2%		3%	5%	8%	20%				0	0	0	0		0	0	0	1	Outlier, ISO 12103-A3 counts
2		1%	2%	7%	4%	63%	5%	5%	8%	10%	18%				0	0	0	0	0	0	0	0	1	Outlier, ISO 12103-A3 counts
2		1%	1%	1%	1%	3%	4%	5%	6%	4%	11%				0	0	0	0	0	0	0	0	1	Outlier, ISO 12103-A3 counts
3		2%	2%	16%	4%	5%	6%	7%	6%	12%				1	1	0	1	1	1	1	1	1	0	Outlier, ISO 12103-A3 counts
4			5%	2%	3%	2%	1%								1	1	1	1	1					
4				1%		1%		6%	3%	8%						1		1		1	1	1		
5		1%	1%	1%	2%	3%	4%	6%	6%	14%	16%			1	1	1	1	0	1	1	1	1	1	
5		1%	1%	0%	1%	2%	3%	5%	8%	13%	16%			1	1	1	1	1	0	1	1	1	1	
6		2%	1%	2%	3%	7%	12%	21%						1	0									Did not validate
6				2%		2%		4%	5%	12%	38%					0			0	0	0	1	0	Did not validate
8		1%	1%	1%	1%	20%	3%	4%	10%	15%				1	1	1	1	1	1	1	1	1		
8		2%	1%	0%	5%	5%	5%	7%	12%	15%				1	1	1	1	1	1	1	1	1		
9		3%	3%	2%	3%	2%	6%	3%	4%	1%	2%				1	1	1	1	1	1	0	1	1	
10				1%		2%		3%	5%	6%	16%					1			1		0	1	1	
11		11%	2%	2%	2%	3%	4%							1	1	1	1	1	1					
11		2%	1%	1%	1%	1%	9%							1	1	1	1	1	0					
12			1%	1%	1%	0%	1%	1%	2%	5%	12%				1	0	1	1	1	1	1	1	1	
13	2%		1%		2%		3%		11%	19%			1			1			1		1	0		
13	1%		1%		2%		6%		12%	21%			1		1		1		1		0	0		
14			1%	2%	5%	6%	6%	8%							1	1	1	1	1	1				
15		2%	1%	1%	1%	2%	3%	3%	4%	4%	7%			0	0	0	0	0	0	1	1	0	0	Outlier, ISO 12103-A3 counts
16		2%	2%	1%		3%		3%	3%	1%	6%			0	0	1			0		0	1	1	No on-line validation
16		2%	2%	2%		1%		1%	1%	5%	5%			0	1	0			0	0	0	1	1	No on-line validation
19		0%	0%	1%	3%	4%	1%	2%	3%	3%	7%			1	1	1	1	1	1	1	1	1	1	
19		1%	1%	2%	6%	1%	2%	4%	6%	12%	11%			1	1	1	1	1	1	1	1	1	1	
22		1%	1%	0%		1%		1%	2%	3%	3%			1	1	1			1	1	1	1	1	
24			1%	1%	1%	2%				15%					1	1	1	1	1			1		
24			2%	0%	1%	2%				14%					1	1	1	1	1			0		
26			2%	4%		2%		2%	4%		11%				1	1			1	1	1		1	
26			1%	2%		2%		3%	5%		20%				1	1			1	1	1		1	
27		0%	0%	3%	4%	1%	1%							1	1	1	1	1	1					
27		1%	0%	1%	1%	1%	2%							1	1	1	1	1	1					
27			0%		1%		1%	1%	0%	1%	3%					1			1	1	1	0	1	
27			1%		1%		1%	1%	25%	1%	2%					1			1	0	1	0		
28		2%	3%	7%	10%	12%	14%	17%	23%	35%	54%			0	0	0	0	0	1	0	0	1	0	No on-line validation
	Number of labs passing >												2	13	24	26	20	24	17	17	18	18	17	
	Total number of labs >												2	17	31	34	26	34	23	27	27	27	21	
	% of labs passing >												100%	76%	71%	76%	77%	71%	74%	63%	67%	67%	81%	73 % pass
	Number of labs passing without 2,3,6,15,16, 28 >												2	11	22	24	18	22	16	15	16	13	12	
	Number of labs without 2,3,6,15,16,28 >												2	11	22	24	19	24	17	17	18	18	12	
	% of labs passing without 2,3,6,15,16,28 >												100%	100%	100%	100%	95%	92%	94%	88%	89%	72%	100%	93 % pass

Table D.3 — Validation of contaminant injection system

Lab. no.	Selected	Measured gravimetric levels, mg/l				Average grav. level	Maximum difference %	Diff. from desired %
		Grav. 1	Grav. 2	Grav. 3	Grav. 4			
	mg/l					mg/l	5 % max.	10 % max.
1	1890	1857	1881	1879	1853	1867	0,8	1,2
2	14710	14900	14794	14582	14573	14712	1,3	0,0
3	?	537	560	512	523	533	5,1	n/a [a]
4	1000	1005	1017	1004	1000	1007	1,0	0,7
5	3409	3,33	3,25	3,25	3,22	3,26	2,1	
6	1000	993	1003	1003	1003	1000	0,7	0,0
8	3400	3407	3404	3391	3395	3399	0,2	0,0
9	1500	1417	1423	1461	1408	1427	2,4	4,9
10	2200	2219	2212	2272	2208	2228	2,0	1,3
11	?	1774	1729	1750	1737	1748	1,5	n/a
12	3000	3119	2995	3071	3095	3070	2,4	2,3
13	1600	1652	1690	1606	1680	1657	3,1	3,6
14	2000	1873	1881	1792	1825	1843	2,8	7,9
15	1110	1076	1081	1039	1031	1057	2,5	4,8
16	9463	9610	9998	9846	10019	9868	2,6	4,3
19	8516	8489	8485	8444	8459	8469	0,3	0,6
19	5678	5657	5653	5664	5653	5657	0,1	0,4
22	8485	8693	8529	8564	8698	8621	1,1	1,6
24	1100	1015	1030	1055	1098	1050	4,6	4,6
26	5000	5048	5030	5136	5076	5073	1,3	1,5
27	4000	4053	3996	4021	4022	4023	0,7	0,6
28	1500	1289	1263	1384	1377	1328	4,9	11,5 [b]
						Average	2,2	3,5

[a] 5,1 % failed maximum % difference requirement by 0,1 %

[b] 11,5 % failed maximum variation from desired requirement by 1,5 %

D.4 Multi-pass results, types 1, 2, and 3 filters and test conditions

A total of 44 type 1 filters were tested in 20 laboratories using Mil-H-5606 hydraulic fluid. A total of 47 type 2 filters were tested in 21 laboratories using Mil-H-5606 hydraulic fluid. A total of four type 3 filters were tested in two laboratories using Mil-H-5606 hydraulic fluid.

For type 1 and 2 filters, the flow rate was 100 l/min and for type 3 the flow was 95 l/min. The test viscosity was 15 mm^2/s and the terminal Δp was 400 kPa differential for all tests.