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Diesel fuel and petrol filters for internal combustion engines — Filtration efficiency using particle counting and contaminant retention capacity

Filtres à carburant, essence ou diesel, pour moteurs à combustion interne — Efficacité de filtration par comptage des particules et capacité de rétention

Reference number
ISO 19438:2003(E)

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Foreword

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

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 19438 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 7, *Injection equipment and filters for use on road vehicles*.

It is intended that ISO 19438 replace ISO/TS 13353:2002 when that document is reviewed after three years.

This corrected version of ISO 19438:2003 incorporates the following corrections:

— in the test report in Annex B, under the headings “Presentation of test results… Initial filtration efficiency — Elapsed time: 6,00 min…” and “… Initial filtration efficiency — Elapsed time: 15,00 min…”, the particle size “⩾ 3 µm(c)” has been corrected to "⩾ 13 µm(c)”;

— in Figure D.4, the curve labelled at left of the legend as “LATOUR T2” has been corrected to read “LATOUR T1”;

— an explanation that the barred values in the table are discarded outliers has been inserted in the title of Table D.2;

— ISO/TS 13353 has been added to the bibliography;

— typographical errors have been corrected.

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Introduction

An interlaboratory trial was conducted using ISO 19438 by six laboratories in 2002. Typical filters were evaluated and results for filtration efficiencies and retention capacities analysed to deduce repeatability, reproducibility and coefficient of variation of the method. Initial filtration efficiency results were found to closely correlate to those obtained through the method specified in ISO/TS 13353, thus making the method given in that Technical Specification redundant.

A summary of the results is given in Annex D.

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Diesel fuel and petrol filters for internal combustion engines — Filtration efficiency using particle counting and contaminant retention capacity

1 Scope

This International Standard specifies a multi-pass filtration test, with continuous contaminant injection and using the on-line particle counting method, for evaluating the performance of diesel fuel and petrol filters for internal combustion engines submitted to a constant flow rate of test liquid. The test procedure determines the contaminant capacity of a filter, its particulate removal characteristics and differential pressure. This International Standard is applicable to filter elements having a rated flow of between 50 l/h and 800 l/h; however, by agreement between filter manufacturer and customer, and with some modification, the procedure is permitted for application to fuel filters with higher flow rates.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1219-1:1991, *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 3968:2001, *Hydraulic fluid power — Filters — Evaluation of differential pressure versus flow characteristics*

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

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

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

ISO 11841-1, *Road vehicles and internal combustion engines — Filter vocabulary — Part 1: Definitions of filters and filter components*

ISO 11841-2, *Road vehicles and internal combustion engines — Filter vocabulary — Part 2: Definitions of characteristics of filters and their components*

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

ISO 12103-1:1997, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11841-1 and ISO 11841-2 and the following apply.

3.1
multipass test
test which requires the recirculation of filtered fluid through the filter element

3.2
base upstream gravimetric level
upstream contaminant concentration if no contaminant is recirculated

3.3
filtration efficiency
ability of the filter to retain particles expressed as the percentage of particles of a given size retained by the filter under test

3.4
overall efficiency
efficiency calculated from the average upstream and downstream particle counts obtained during the entire test

3.5
filter rating
particle size corresponding to an initial efficiency or cumulative overall efficiency of a given percentage

NOTE It is expressed in micrometres(c) [µm(c)], which signifies throughout this International Standard that a particle size measurement is carried out using an automatic particle counter calibrated in accordance with ISO 11171.

3.6
filter reference rating
filter rating at 99 % efficiency

NOTE It is expressed in micrometres(c) [µm(c)], which signifies throughout this International Standard that a particle size measurement is carried out using an automatic particle counter calibrated in accordance with ISO 11171.

3.7
initial efficiency
efficiency at first data points calculated from 4 min, 5 min and 6 min particle counts

4 Symbols

Graphical symbols used in this International Standard for fluid power system components are in accordance with ISO 1219-1.

5 Test equipment and materials

5.1 Test equipment

5.1.1 Test rig

The test rig, shown diagrammatically in Figure 1 (to which the numbers in parentheses throughout this International Standard refer), shall comprise the following.

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5.1.1.1 **Filter test circuit**, including the components specified in 5.1.1.1.1 to 5.1.1.1.7.

5.1.1.1.1 **Reservoir** (1), constructed with a conical bottom having an included angle of not more than 90° and where the oil entering is diffused below the fluid surface.

5.1.1.1.2 **Oil pump** (2), which does not alter the contaminant particle size distribution and does not exhibit pressure pulsation with an amplitude greater than 10 % of the average pressure at the filter inlet.

5.1.1.1.3 **Device**, such as a filter head to accommodate spin-on filters, which connects the test filter (6) and which can be by-passed or replaced by a straight section of pipe.

5.1.1.1.4 **System clean-up filter** (9), capable of providing an initial system contamination level of less than 15 particles/ml having a size greater than 10 µm(c).

5.1.1.1.5 **Sampling valves**, in accordance with ISO 4021, for turbulent sampling upstream and downstream of the test filter, for on-line particle counting (18) and for gravimetric analysis (11).

5.1.1.1.6 **Pressure tappings**, in accordance with ISO 3968.

5.1.1.1.7 **Piping**, sized to ensure that turbulent mixing conditions exist throughout the filter test circuit.

5.1.1.2 **Contaminant injection circuit**, including the components specified in 5.1.1.2.1 to 5.1.1.2.3.

5.1.1.2.1 **Reservoir** (12), constructed with a conical bottom having an included angle of not more than 90° and where the oil entering is diffused below the fluid surface.

5.1.1.2.2 **Oil pump** (13), of centrifugal or other type, which does not alter the contaminant particle size distribution.

5.1.1.2.3 **System clean-up filter** (14), capable of providing either of the following conditions:

a) an initial system contamination level of less than 1 000 particles/ml having a size greater than 10 µm(c);

b) a gravimetric level less than 2 % of the calculated level at which the test is being conducted, measured using the double membrane gravimetric method in accordance with ISO 4405.

5.1.1.2.4 **Piping**, sized to ensure that turbulent mixing conditions exist throughout the contaminant injection circuit.

While injection flows lower than 0,25 l/min may be used if validated, an injection flow of 0,25 l/min is recommended.

Injection flows higher than 0,25 l/min shall not be used to minimize the effect of fluid extraction on filter capacity.

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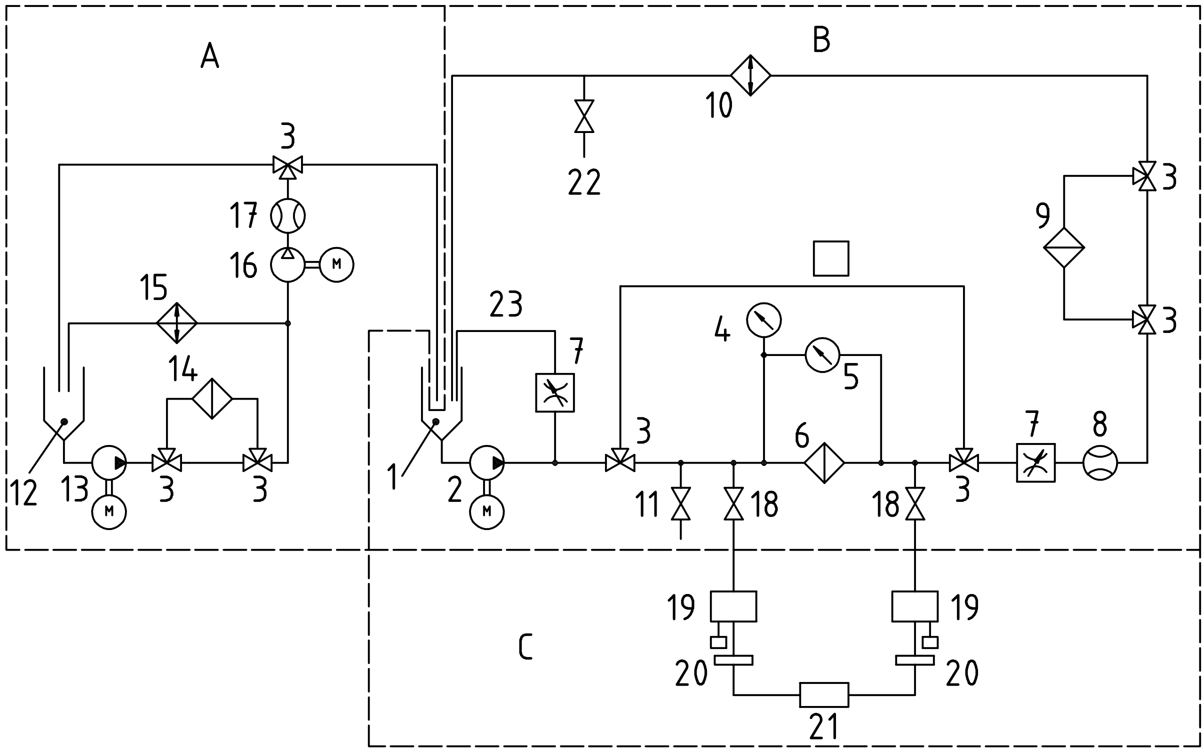

Key

1 reservoir incorporating thermostatically controlled heater
2 test pump
3 three-way ball valve
4 pressure gauge
5 differential pressure gauge
6 test filter
7 throttle valve (for flow regulation)
8 flow meter
9 clean-up filter
10 heat exchanger
11 sampling valve
12 reservoir incorporating thermostatically controlled heater
13 circulation pump
14 clean-up filter
15 heat exchanger
16 injection pump
17 flow meter
18 sampling valve
19 dilution system
20 particle counter sensor
21 particle counter
22 sampling valve
23 by-pass flow circuit

A contaminant injection circuit
B filter test circuit
C dilution and counting system

Figure 1 — Diagrammatic arrangement of test rig

5.1.2 On-line dilution and particle counting system

The on-line dilution and particle counting system shall be in accordance with ISO 11943 and include the components specified in 5.1.2.1 to 5.1.2.4.

5.1.2.1 On-line sample delivery pipework, sized to maintain a fluid velocity that prevents silting at a flow rate of 0,125 l/min. For tests with sampling flows > 10 % of the total filter flow rate, the amount of dust discarded in the sampling flow will be significant. This amount shall be evaluated and deducted from the retained capacity. Lower flow rates may be used provided they are validated.

5.1.2.2 Dilution system (19), comprising appropriate reservoir, pump, clean-up filters, flow meters and flow regulation valves.

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5.1.2.3 Two optical particle sensors (20), connected to a particle counter (21) having a minimum of five channels.

5.1.2.4 Timer, capable of measuring minutes and seconds.

5.2 Test materials

5.2.1 Test contaminant

5.2.1.1 Contaminant grade

The contaminant shall be in accordance with the specification of ISO 12103-A3 medium grade test dust.

5.2.1.2 Contaminant preparation

The test dust shall be pre-dried in quantities no larger than 200 g for at least 1 h at (105 ± 5) °C and cooled to room temperature. Maintain in a desiccator until required for use.

5.2.2 Test fluid

The test fluid shall have a petroleum base and conform to the specifications given in Annex A.

6 Accuracy of measuring instruments and test conditions

The measuring instruments shall be capable of measuring to the levels of accuracy given in Table 1. The last column in the table gives the limits within which the test conditions shall be maintained.

Table 1 — Instrument accuracy and test condition variation

Test condition	Unit	Measurement accuracy	Allowed test condition variation
Flow			
Filter Test Flow	l/min	± 2 %	± 5 %
Sampling Flow	ml/min	± 1,5 %	± 3 %
Injection Flow	ml/min	± 2 %	± 5 %
Pressure	Pa	± 5 %	—
Temperature	°C	± 1 °C	2 °C
Volume	l	± 5 %	± 10 %
Base upstream gravimetric level	mg/l	—	± 10 %
Conductivity	pS/m	± 10 %	See 8.3.4
Viscosity [a]	mm^2/s	± 5 %	—

[a] The viscosity of the test liquid should be checked at regular intervals to ensure that the test is conducted at a liquid temperature which corresponds to a viscosity of 15 ± 1 mm^2/s.

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7 Test rig validation

7.1 General

These validation procedures reveal the effectiveness of the test rig in maintaining contaminant entrainment or preventing contaminant size modification or both.

7.2 Validation of the on-line dilution and particle counting system

Proceed in accordance with ISO 11943 to validate the on-line dilution system and in accordance with ISO 11171 to validate the particle counter.

7.3 Validation of filter test circuit

7.3.1 Validate the filter test circuit at the minimum flow rate at which the circuit will be operated.

7.3.2 Install a straight section of pipe in place of a test filter during the validation procedure.

7.3.3 Adjust the total circuit volume so that it is numerically equal to half the value of the minimum flow volume per minute through the filter, with a minimum of 6 l. The total circuit volume should include sump, piping and filter. A by-pass flow loop should be utilized for low flow test conditions.

7.3.4 Contaminate the fluid to the calculated gravimetric level of 5 mg/l using ISO 12103-A3 test dust.

NOTE This contamination level is below the coincidence limit of automatic particle counters.

7.3.5 Circulate the fluid in the test system for 1 h while obtaining downstream cumulative counts at 5 µm(c), 10 µm(c) and 20 µm(c), without on-line dilution, at 10 min sample intervals.

7.3.6 Calculate and record the on-line count (C_o) in particles per millilitre, using the equation:

$$C_o = \frac{N_c}{V}$$

where

N_c is the cumulative count for the selected sample period, in number of particles;

V is the volume of fluid, in millilitres, passed through the particle counter sensor during the sample period.

7.3.7 The validation shall be accepted only if

a) each particle count obtained at 5 µm(c), 10 µm(c) and 20 µm(c) does not deviate by more than 10 % from the average particle count for these sizes,

b) the average for all particles per millilitre at channels $\geqslant$ 5 µm(c) is not less than 6 000 and not greater than 7 300,

c) the average for all particles per millilitre at channels $\geqslant$ 10 µm(c) is not less than 815 and not greater than 1 015, and

d) the average for all particles per millilitre at channel $\geqslant$ 20 µm(c) is not less than 77 and not greater than 106.

7.3.8 Contaminate the fluid to the maximum gravimetric level to be tested using ISO 12103-A3 test dust.

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7.3.9 Circulate the fluid in the test system for 1 h while obtaining downstream cumulative counts at 5 µm(c), 10 µm(c) and 20 µm(c), with on-line dilution, at 10 min sample intervals.

7.3.10 The validation test shall be accepted only if each particle count obtained at 5 µm(c), 10 µm(c) and 20 µm(c) does not deviate by more than 10 % from the average particle count for these sizes.

7.4 Validation of contaminant injection circuit

7.4.1 Validate the contaminant injection circuit at the maximum volume and the maximum gravimetric level to be used.

7.4.2 Add the required quantity of contaminant in slurry form to the injection circuit fluid and circulate for a time sufficient to completely disperse the contaminant.

NOTE All systems might not disperse contaminant at the same rate. A period of 10 min to 20 min could be necessary for complete dispersion.

7.4.3 Extract fluid samples at the point where the injection fluid is discharged into the filter test circuit reservoir at 30 min intervals over 2 h and analyse each sample gravimetrically. These samples should be taken at the intended test injection flow rate.

7.4.4 The validation test shall be accepted only if the gravimetric level of each sample is within ± 5 % of the average of the four samples and if this average is within ± 5 % of the gravimetric value selected in 7.3.1.

8 Preliminary preparation

8.1 Test filter assembly

8.1.1 Ensure that the test fluid cannot by pass the filter element to be evaluated.

8.1.2 Subject the test filter element to a fabrication integrity test in accordance with ISO 2942:1994 using MIL-H-5606 fluid prior to the multi-pass test or following it, if the element is not readily accessible as in the spin-on configuration.

8.1.3 If the integrity test has been made prior to the multi-pass test and if the test filter element fails to meet the test pressure agreed between the purchaser and the manufacturer, the element shall be disqualified from further testing. If the integrity test has been made after the multi-pass test and if the element fails, the test result shall be disqualified.

8.2 Contaminant injection circuit

8.2.1 Using 50 mg/l as the base upstream gravimetric level, calculate the predicted test time, T_e, in minutes, from the equation:

$$T_e = \frac{F_c}{G \times Q} = \frac{F_c}{50 \times Q}$$

where

F_c is the estimated capacity of the filter element, in milligrams;

G is the base upstream gravimetric level, in milligrams per litre;

Q is the test flow rate, in litres per minute.

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The test duration should be > 30 min. The base upstream gravimetric level of 50 mg/l should be adhered to unless otherwise agreed upon by purchaser and manufacturer. Base upstream gravimetric levels up to 100 mg/l may be used to shorten test times, while base upstream gravimetric levels down to 25 mg/l may be used to lengthen test times, but only the results of filter tests using the same base upstream gravimetric level may be compared.

NOTE If the estimated capacity of the filter element (F_c) is not supplied by the manufacturer, it might be necessary to determine the capacity by testing an element.

8.2.2 Calculate the minimum volume of fluid, V_m, in litres, required for the operation of the injection circuit, compatible with the predicted test time and an injection flow rate of 0,25 l/min, using the equation:

$$V_m = 1{,}2T_e \times Q_i + V_o$$

where

T_e is the predicted test time, in minutes, in accordance with 8.2.1;

Q_i is the injection flow rate, in litres per minute;

V_o is the minimum volume of fluid in the injection circuit necessary to avoid air entrainment.

The calculated minimum volume should ensure a quantity of contaminant fluid sufficient to load the element, plus 20 % for adequate circulation throughout the test and to avoid entrainment. Larger injection volumes may be used.

8.2.3 Calculate the gravimetric level, G_i, in milligrams per litre of the injection fluid, from the equation:

$$G_i = \frac{\rho \times Q}{Q_i} = \frac{50Q}{Q_i}$$

where

G is the base upstream gravimetric level, in milligrams per litre, in accordance with 8.2.1;

Q is the test flow rate, in litres per minute;

Q_i is the injection flow rate, in litres per minute.

8.2.4 Calculate the quantity of contaminant, W, in grams, needed for the contaminant injection circuit, using the equation:

$$W = \frac{G_i \times V_i}{1\,000}$$

where

G_i is the gravimetric level, in milligrams per litre, in accordance with 8.2.3;

V_i is the volume of fluid contained in the injection circuit, in litres.

8.2.5 Adjust the injection flow rate at stabilized temperature to within ± 5 % of the value selected in 8.2.2 and maintain throughout the test.

8.2.6 Circulate the fluid in the contaminant injection circuit through the clean-up filter (14) until either of the following conditions are attained:

a) a contamination level of less than 1 000 particles per millilitre having a size greater than 10 µm(c);

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b) a gravimetric level of less than 2 % of the value calculated in accordance with 8.2.3.

8.2.7 By pass the system clean-up filter (14) after the required initial contamination has been achieved.

8.2.8 Adjust the total volume of the contaminant injection system to the value determined in 8.2.2.

8.2.9 Ensure that the conductivity of the test fluid and the injection fluid is at least 1 000 pS/m by measuring fluid conductivity prior to each test. A level of 1 500 pS/m ± 500 pS/m should be used. An initial level of 100 ppm of an antistatic agent has been shown to produce conductivity within this range.

8.2.10 Add in slurry form to the contaminant injection circuit reservoir (12) the quantity of contaminant (W) determined in 8.2.4, and circulate until the contaminant is completely dispersed.

NOTE Complete dispersal of the contaminant can take between 10 min and 20 min.

8.3 Filter test circuit

8.3.1 Install a straight section of pipe in place of the test filter.

8.3.2 Circulate the fluid in the filter test circuit through the clean-up filter (9) until a contamination level of less than 15 particles per millilitre having a size greater than 10 µm(c) is attained. Record this value as the initial cleanliness level of the system.

The contamination level should be checked with the on-line particle counting system, which will at the same time clean the sampling lines.

8.3.3 Adjust the fluid volume of the filter test circuit to the value determined in 7.2.3 and record this value.

8.3.4 Ensure that the conductivity of the test fluid is at least 1 000 pS/m by measuring fluid conductivity prior to each test. A level of 1 500 pS/m ± 500 pS/m should be used. An initial level of 100 ppm of an antistatic agent has been shown to produce conductivity within this range.

8.3.5 Install the filter housing, without the test element, in the filter test circuit. For a spin-on type filter, install this spin-on filter body without an element inside.

8.3.6 Circulate the fluid in the filter test circuit at the rated flow and at the stabilized test temperature specified in 9.1.1 ± 2 °C. Measure and record the differential pressure, Δp_3, of the empty filter housing.

8.3.7 Adjust the channels on the particle counter to read the following particle sizes, in micrometres(c).

— 5 [6] channel counter: [4], 5, 10, 15, 20, 30.

— 16 channel counter: 4, 5, 6, 7, 8, 9, 10, 11, 13, 15, 17, 20, 25, 30, 40, 50.

9 Test procedure

9.1 Initial procedure

9.1.1 Install the test filter element (6) in its housing and subject the assembly to the flow rate required by the purchaser and to the temperature required to maintain an oil viscosity of 15 mm²/s ± 1 mm²/s. Recheck the fluid level.

9.1.2 Measure and record the clean assembly differential pressure, Δp_1.

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9.1.3 Calculate and record the clean element differential pressure, Δp_2, from the equation:

$$\Delta p_2 = \Delta p_1 - \Delta p_3$$

where

Δp_1 is the clean assembly differential pressure measured at 9.1.2;

Δp_3 is the empty filter housing differential pressure measured at 8.3.6.

9.1.4 Calculate the differential pressure, Δp_5, corresponding to increases of 80 % and 100 % of the net differential pressure, using the equation:

$$\Delta p_5 = \Delta p_4 - \Delta p_2$$

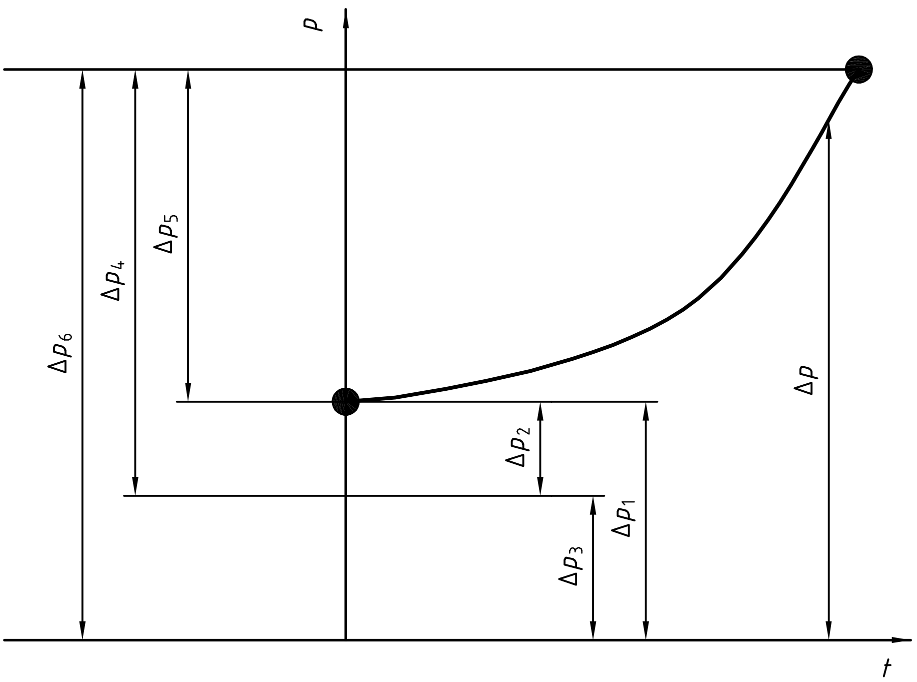
where

Δp_4 is the element final differential pressure;

Δp_2 is the clean element differential pressure obtained from 9.1.3.

For clarity, Δp_1 to Δp_6 are shown in Figure 2.

In the absence of manufacturer specification, use 30 kPa as the final differential pressure of the element.



Δp_1 clean assembly differential pressure

Δp_2 clean element differential pressure

Δp_3 housing differential pressure

Δp_4 element final differential pressure

Δp_5 net differential pressure

Δp_6 final differential pressure across filter assembly = differential pressure at end of test

Δp measured differential pressure

Figure 2 — Diagrammatic representation of filter differential pressures

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9.1.5 Obtain a fluid sample from the contaminant injection circuit, at the point where the fluid return pipe discharges into the reservoir (12).

9.1.6 Measure and record the injection flow rate.

9.1.7 Adjust the dilution at the start of the test to the anticipated maximum dilution required during the test to avoid particle counter saturation.

9.2 Filter test

9.2.1 By-pass the clean-up filter (9).

9.2.2 Allow the injection flow to enter the filter test circuit reservoir.

9.2.3 Start the timer.

9.2.4 Start the upstream and downstream sample flows.

9.2.5 Record the differential pressure, and count particles upstream and downstream during 50 s every minute at the specified flow within the sensor.

9.2.6 Calculate and record the on-line count (C_o) (number of particles per millilitre) using the equation:

$$C_\mathrm{o} = \frac{N_\mathrm{c} \times D}{V}$$

where

N_c is the cumulative count for the sample interval, in number of particles;

D is the dilution factor;

V is the volume of fluid passed through the particle counter sensor during the sample interval, in millilitres.

9.2.7 Record the test time, in minutes, required for the differential pressure across the filter assembly to increase the net differential pressure by 80 % and 100 %.

9.2.8 Take an upstream sample at valve (11) for gravimetric analysis when the differential pressure across the filter assembly has increased by 80 % of the net differential pressure.

NOTE The sample is taken at the 80 % point because it often overlaps the 100 % point.

9.2.9 Stop the flow to the test filter and measure and record the exact final volume of test fluid, V_f.

If 100 % net differential pressure is reached during sampling, complete sampling before stopping the flow to the test filter.

9.2.10 The test shall be accepted if V_f is within ± 10 % of the initial volume.

9.2.11 Obtain a final fluid sample from the contaminant injection circuit at the point where the injection fluid is discharged into the filter test circuit.

9.2.12 Measure and record the final injection flow rate.

9.2.13 Remove the element and check that there is no visual evidence of filter damage as a result of performing this test.

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10 Calculation and reporting of test results

10.1 Test report

See Annex B for a typical test report sheet. The test report shall include a graph of overall efficiency with respect to particle size, as illustrated in Figure B.1, and a graph of differential pressure with respect to time and to mass of contaminant added, as shown in Figure B.2. If required by the purchaser, the manufacturer shall also include a graph of overall efficiency with respect to particle size, as shown in Figure B.3.

10.2 Calculation

10.2.1 General

Carry out the following calculations and record the results in the test report.

10.2.2 Gravimetric levels

10.2.2.1 Conduct a gravimetric analysis according to ISO 4405 on the two samples extracted from the contaminant injection circuit (see 9.1.5 and 9.2.11) and on the upstream sample extracted from the filter test circuit at the 80 % sample point (see 9.2.8)

10.2.2.2 Record the non-retained contaminant concentration, in milligrams per litre, at the 80 % sampling point as the final system gravimetric level, G_f.

10.2.2.3 Calculate and record the average of the gravimetric levels, G_{ia}, for the two samples taken from the contaminant injection circuit in 9.1.5 and 9.2.11.

10.2.2.4 The test shall be accepted only if the gravimetric level of each sample is within ± 10 % of the average G_{ia} calculated in 10.2.2.3.

10.2.2.5 Calculate and record the injection flow rate, Q_{ia}, by averaging the measurements taken at 9.1.6 and 9.2.12.

10.2.2.6 The test shall be accepted only if the value of Q_{ia} is equal to the selected value ± 5 % (see 8.2.2).

10.2.2.7 Calculate and record the actual base upstream gravimetric level, G_a, in milligrams per litre, using the equation:

$$G_a = \frac{G_{ia} \times Q_{ia}}{Q}$$

where

G_{ia} is the average injection gravimetric level, in milligrams per litre, obtained at 10.2.2.3;

Q_{ia} is the average injection flow rate, in litres per minute, obtained at 10.2.2.5;

Q is the test flow rate, in litres per minute.

10.2.2.8 The test shall be accepted only if G_a is equal to 50 mg/l or to some other acceptable value in accordance with 8.2.1 within the variation given in Table 1.

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10.2.3 Filtration efficiencies

10.2.3.1 Initial efficiency

From the upstream and downstream particle counts recorded from each channel of the counter at 8.3.7, calculate the initial efficiency at each particle size, in accordance with Annex C (see C.1 and C.2).

Record the initial efficiency for each particle size in the *filtration efficiencies* section of the test report (see Annex B).

10.2.3.2 Average intermediate efficiencies

From the upstream and downstream particle counts, calculate the average intermediate efficiencies at each particle size, in accordance with Annex C (see C.1 and C.3).

Identify the minimum calculated intermediate efficiency for each particle size and record it in the *filtration efficiencies* section of the test report.

10.2.3.3 Overall efficiencies

Calculate the overall efficiency, at each particle size, in accordance with Annex C (see C.4).

Record the calculated overall efficiency at each particle size in the *filtration efficiencies* section of the test report.

Prepare a graph of overall efficiency versus particle size as shown in Figure B.1 and, if required by the purchaser, also provide a graph as shown in Figure B.3.

10.2.4 Filter ratings

A graph of initial or overall efficiency versus particle size can highlight those particle sizes which correspond to efficiencies of 50 %, 90 %, 95 %, and 99 %, as shown in the example of Figure B.2. These particle sizes shall be recorded in the test report sheet.

The particle sizes which correspond to overall efficiencies of 95 % and 99 % cannot be determined graphically with acceptable accuracy. These values should therefore be calculated by linear Interpolation.

10.2.5 Injected mass of contaminant

Calculate the mass of contaminant injected into the filter element, m_i, in grams, using the equation:

$$m_\text{i} = \frac{Q_\text{ia} \times G_\text{ia} \times T}{1\,000}$$

where

Q_ia is the average injection flow rate, in litres per minute, obtained at 10.2.2.5;

G_ia is the average gravimetric level of the injection fluid, in milligrams per litre, obtained at 10.2.2.3;

T is the time required to reach the terminal differential pressure, in minutes (see 9.2.7).

Record the calculated value of m_i in the test report.

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10.2.6 Non-retained mass of contaminant

Calculate the non-retained mass of contaminant, m_{nr}, in grams, using the equation:

$$m_{nr} = \frac{\left[V_f G_f + Q_d T (G_f - G_a) + Q_u T \frac{(G_f + G_a)}{2} \right]}{1\,000}$$

where

V_f is the final volume of test fluid, in litres, obtained at 9.2.9;

G_f is the final system gravimetric level, in milligrams per litre, obtained at 10.2.2.2;

Q_d is the average flow rate through the downstream sampling system, in litres per minute;

Q_u is the average flow rate through the upstream sampling system, in litres per minute.

Record the calculated value of m_{nr} in the test report.

NOTE The three terms in the above equation represent

a) the weight 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 downstream sampling system [the term ($G_f - G_a$) is a conservative estimate of the gravimetric level downstream of the filter], and

c) an estimate of the amount of contaminant permanently extracted from the system through the upstream sampling system [the term ($G_f - G_a$)/2 is an estimate of the gravimetric level upstream of the filter].

10.2.7 Retained filter capacity

Calculate the retained filter capacity (C_r), in grams, using the equation:

$$C_r = m_i - m_{nr}$$

where

m_i is the mass of contaminant injected into the filter element, in grams, obtained at 10.2.5;

m_{nr} is the non-retained mass of contaminant, in grams, obtained in 10.2.6.

Record the calculated value of C_r in the test report.

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Annex A
(normative)

Specification of test fluid for filter test

NOTE Suitable test fluids are aircraft hydraulic oils MIL-H-5606 and AIR 3520.

A.1 Petroleum base stock

The petroleum base stock shall have the following properties.

- Pour point: – 59,4 °C (min.)
- Flash point: 93,3 °C (min.)
- Acid or base number: 0,10 (max.)
- Precipitation number: 0

A.2 Additives

The test fluid shall contain the following additive materials.

- Viscosity-temperature coefficient improver: 10 % (max.)
- Oxidation inhibitors: 2 % (max.)
- Tricresyl phosphate anti-wear agent: 0,5 % ± 0,1 %

The free phenol content of the tricresyl phosphate anti-wear agent should not exceed 0,05 %.

A.3 Properties

The test fluid shall have the following properties.

- Viscosity[1)]: 13,2 mm^2/s at 40 °C min.
- Viscosity: 500 mm^2/s at – 40 °C min.
- Pour point: – 59,4 °C min.
- Flash point: 93,3 °C min.
- Precipitation number: 0
- Acid or base number: 0,2 mg KOH/g max.

1) 1 mm^2/s = 1 cSt.

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A.4 Colour

The test fluid shall be clear and transparent. For identification purposes, it shall contain a red dye in a proportion not greater than one part of dye per 10 000 parts of oil.

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Annex B
(informative)

Typical filter test report, presentation of test results

Test report: ISO 19438		
Test date:	Test location:	Test ID:
Test time:	Operator:	Project:

Filter identification		
Filter ID:		Fab. integrity: hPa
Housing type:		Date const:

Operating conditions		
Test fluid	Type:	Viscosity: mm^2/s
	Conductivity: pS/m	Temperature: °C
Test dust	Type:	Batch no.
Injection system	Dust added, W: g	Injection grav. initial: mg/l
	Volume, V_i: l	Injection grav. final: mg/l
	Injection flow rate, Q_{ia}: ml/min	Injection grav. Average, G_{ia}: mg/l
Test system :	Flow rate, Q: l/min	Initial cleanliness: no. > 10 µm(c)/ml
	Volume: l	Base gravimetric level, G_a: mg/l
	Final volume, V_f: l	Final gravimetric level, G_f: mg/l
Dilution system	Sensor type:	Sample time: s
	Flow rate: ml/min	Hold time: s
	Counting method:	Sampling time: min
	Upstream dilution ratio:	No records to average:
	Downstream dilution ratio:	Total record read:

Test results		
Δp	Clean assembly Δp_1: kPa	Clean element Δp_2: kPa
	Housing Δp_3: kPa	Final net Δp_5: kPa

% net Δp	5	10	15	20	40	80	100
Assembly Δp: kPa							
Test time, min							

Filtration efficiencies

Particle size	$\geqslant$ 4 µm(c)	$\geqslant$ 5 µm(c)	$\geqslant$ 6 µm(c)	$\geqslant$ 7 µm(c)	$\geqslant$ 8 µm(c)	$\geqslant$ 9 µm(c)	$\geqslant$ 10 µm(c)	$\geqslant$ 11 µm(c)
Initial Eff. (%)								
Min. Eff. (%)								
Overall Eff. (%)								

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Particle size	⩾ 13µm(c)	⩾ 15 µm(c)	⩾ 17 µm(c)	⩾ 20 µm(c)	⩾ 25 µm(c)	⩾ 30 µm(c)	⩾ 40 µm(c)	⩾ 50 µm(c)
Initial Eff. (%)								
Min. Eff. (%)								
Overall Eff. (%)								

Injected mass, m_i:	g	Efficiency (%)	50	90	95	99 [a]
Non-retained mass, m_{nr}:	g	Initial filter rating [µm(c)]				
Retained capacity, C_r:	g	Overall filter rating [µm(c)]				

[a] Filter reference rating.

Presentation of test results

Test date:	Test location:	Test ID:
Test time:	Operator:	Project:

Initial filtration efficiency — Elapsed time: 6,00 min — Diff. pressure: 63,88 kPa

Particle size	⩾ 4 µm(c)	⩾ 5 µm(c)	⩾ 6 µm(c)	⩾ 7 µm(c)	⩾ 8 µm(c)	⩾ 9 µm(c)	⩾ 10 µm(c)	⩾ 11 µm(c)
Upstream (cnts/ml)	25 530,67	18 282,82	13 346,41	9 839,04	7 295,43	5 463,28	3 040,80	1 810,17
Downstream (cnts/ml)	8 819,81	5 101,95	2 986,96	1 799,02	1 051,93	637,18	215,72	77,71
Efficiency (%)	65,45	72,09	77,62	81,72	85,58	88,34	92,91	95,71
Particle size	⩾ 13 µm(c)	⩾ 15 µm(c)	⩾ 17 µm(c)	⩾ 20 µm(c)	⩾ 25 µm(c)	⩾ 30 µm(c)	⩾ 40 µm(c)	⩾ 50 µm(c)
Upstream (cnts/ml)	1 108,04	723,27	492,52	233,32	113,00	67,59	36,62	14,02
Downstream (cnts/ml)	28,62	9,17	3,76	0,56	0,18	0,18	0	0
Efficiency (%)	97,42	98,71	99,24	99,76	99,84	99,73	99,99	99,99

Filtration efficiency — Elapsed time: 10,00 min — Diff. pressure: 64,56 kPa

Particle size	⩾ 4 µm(c)	⩾ 5 µm(c)	⩾ 6 µm(c)	⩾ 7 µm(c)	⩾ 8 µm(c)	⩾ 9 µm(c)	⩾ 10 µm(c)	⩾ 11 µm(c)
Upstream (cnts/ml)	27 855,07	19 682,25	14 264,96	10 376,26	7 617,47	5 685,05	3 132,44	1 836,56
Downstream (cnts/ml)	11 712,46	6 886,89	4 160,77	2 534,51	1 512,46	937,77	354,48	136,28
Efficiency (%)	57,95	65,01	70,83	75,57	80,14	83,50	88,68	92,58
Particle size	⩾ 13 µm(c)	⩾ 15 µm(c)	⩾ 17 µm(c)	⩾ 20 µm(c)	⩾ 25 µm(c)	⩾ 30 µm(c)	⩾ 40 µm(c)	⩾ 50 µm(c)
Upstream (cnts/ml)	1 126,19	726,39	490,31	226,00	112,28	65,36	38,61	15,24
Downstream (cnts/ml)	56,9	22,32	9,37	0,60	0	0	0	0
Efficiency (%)	94,99	96,93	98,09	99,74	99,99	99,99	99,99	99,99

Filtration efficiency — Elapsed time: 15,00 min — Diff. pressure: 60,25 kPa

Particle size	⩾ 4 µm(c)	⩾ 5 µm(c)	⩾ 6 µm(c)	⩾ 7 µm(c)	⩾ 8 µm(c)	⩾ 9 µm(c)	⩾ 10 µm(c)	⩾ 11 µm(c)
Upstream (cnts/ml)	31 072,96	21 814,17	15 695,25	11 403,34	8 394,78	6 210,63	3 394,82	1 983,12
Downstream (cnts/ml)	13 826,42	8 245,83	5 023,72	3 123,81	1 850,97	1 152,67	420,57	156,80
Efficiency (%)	55,50	62,20	67,99	72,61	77,95	81,44	87,61	92,09

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Particle size	⩾ 13 µm(c)	⩾ 15 µm(c)	⩾ 17 µm(c)	⩾ 20 µm(c)	⩾ 25 µm(c)	⩾ 30 µm(c)	⩾ 40 µm(c)	⩾ 50 µm(c)
Upstream (cnts/ml)	1 224,52	781,08	529,93	237,74	118,22	66,43	39,48	14,18
Downstream (cnts/ml)	60,09	25,70	10,77	0,97	0,20	0	0	0
Efficiency (%)	95,09	96,71	97,97	99,59	99,83	99,99	99,99	99,99
Filtration efficiency — Elapsed time: 20,00 min — Diff. pressure: 61,51 kPa								
Particle size	⩾ 4 µm(c)	⩾ 5 µm(c)	⩾ 6 µm(c)	⩾ 7 µm(c)	⩾ 8 µm(c)	⩾ 9 µm(c)	⩾ 10 µm(c)	⩾ 11 µm(c)
Upstream (cnts/ml)	32 759,21	22 855,29	16 421,83	11 831,78	8 654,75	6 347,78	3 479,81	2 036,89
Downstream (cnts/ml)	15 691,99	9 290,40	5 698,19	3 506,52	2 106,79	1 310,74	479,40	183,56
Efficiency (%)	52,10	59,35	65,30	70,36	75,66	79,35	86,22	90,99
Particle size	⩾ 13 µm(c)	⩾ 15 µm(c)	⩾ 17 µm(c)	⩾ 20 µm(c)	⩾ 25 µm(c)	⩾ 30 µm(c)	⩾ 40 µm(c)	⩾ 50 µm(c)
Upstream (cnts/ml)	1 249,57	793,43	531,29	233,19	118,66	66,30	30,66	11,75
Downstream (cnts/ml)	67,25	23,28	8,28	1,36	0,20	0	0	0
Efficiency (%)	94,62	97,07	98,44	99,42	99,83	99,99	99,99	99,99

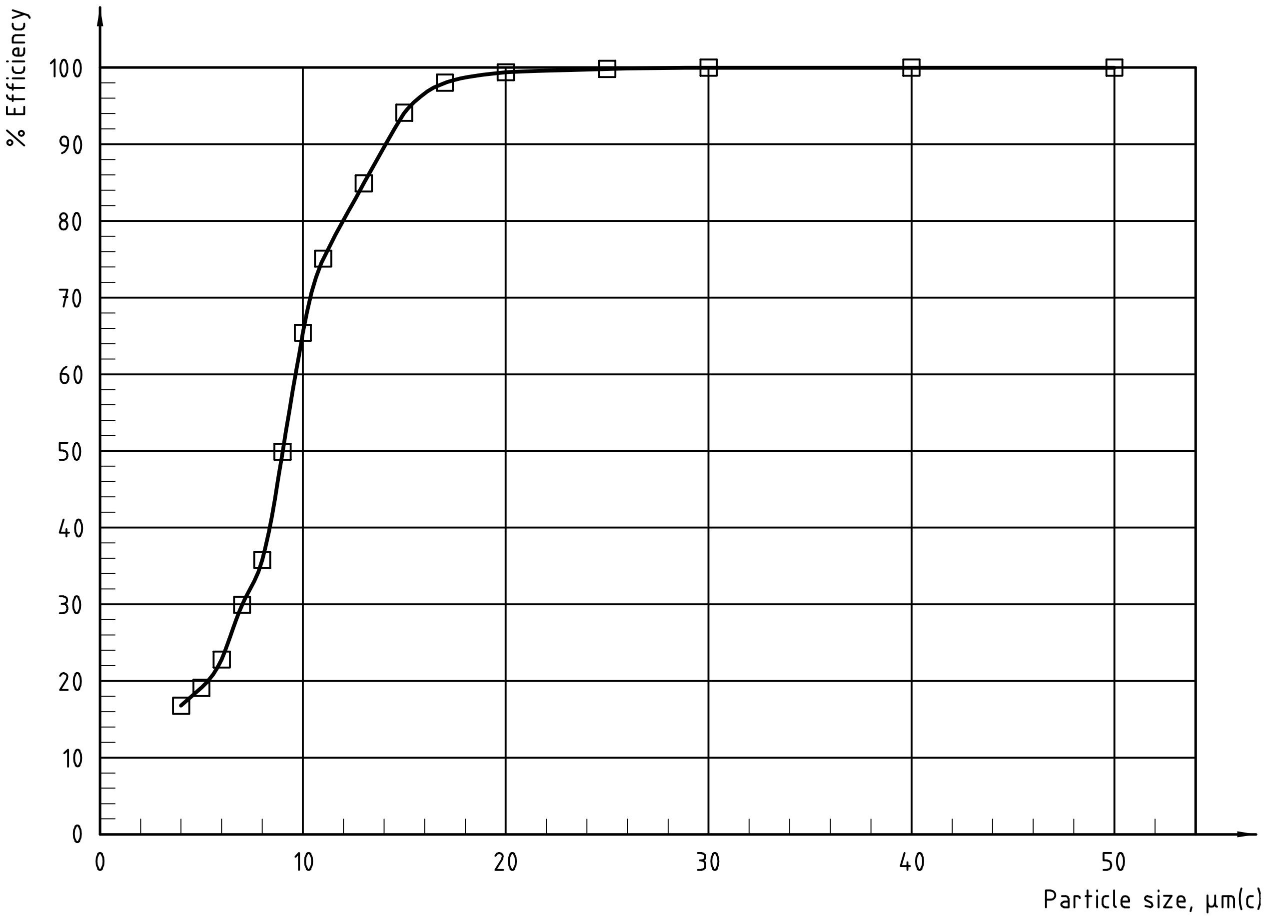

Figure B.1 — Overall efficiency vs. particle size (linear presentation) graph — Example

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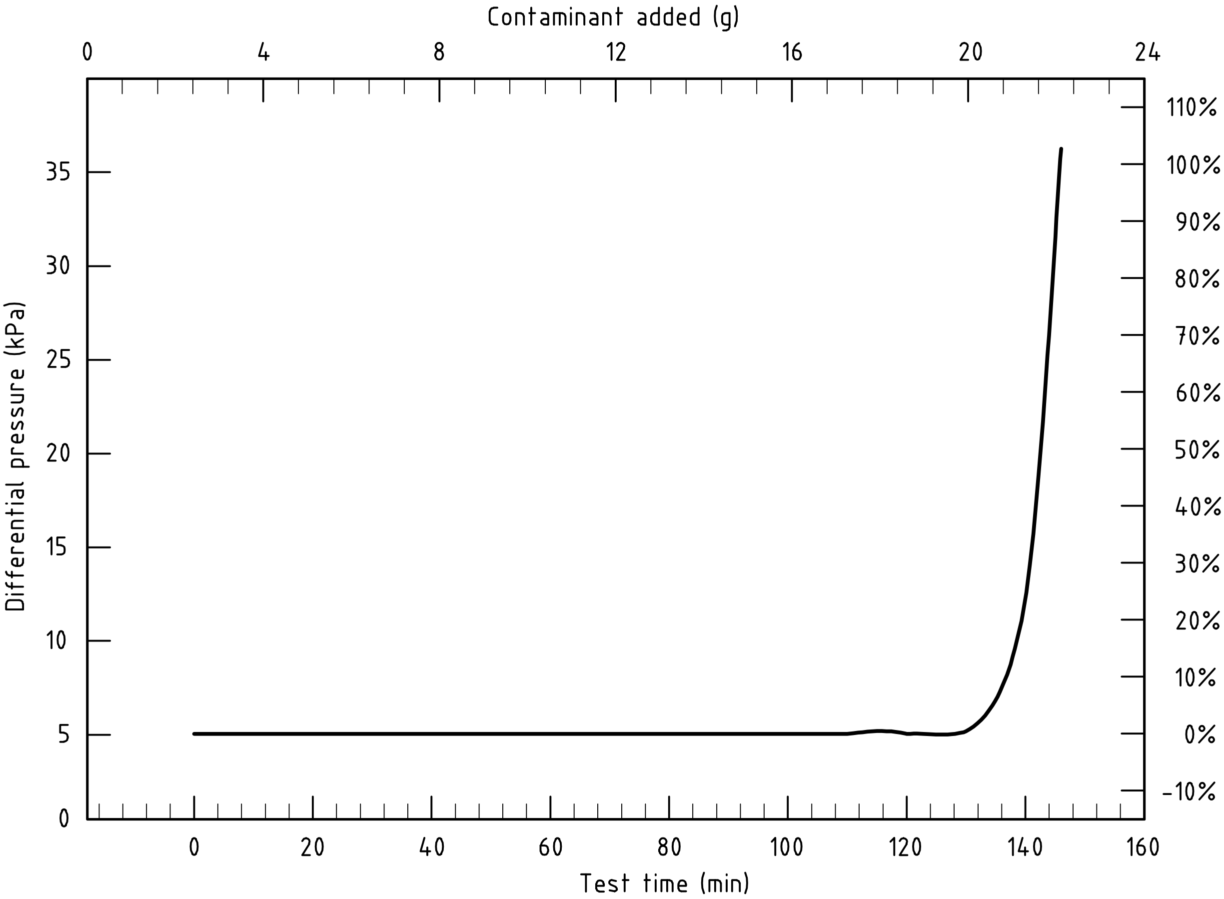

Figure B.2 — Differential pressure vs. test time graph — Example

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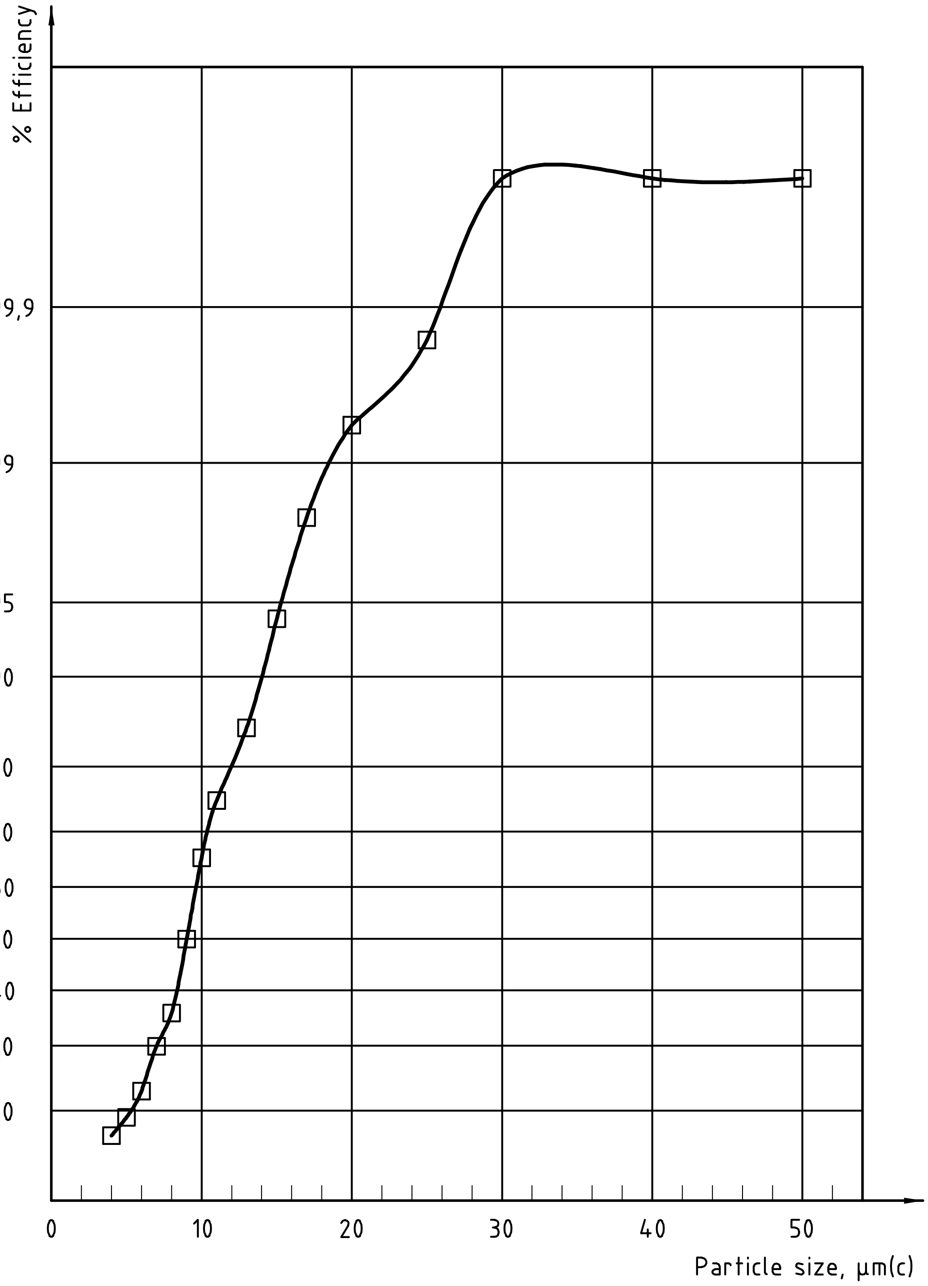

Figure B.3 — Overall efficiency vs. particle size (probabilistic presentation) graph — Example

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Annex C
(informative)

Example filter efficiency calculations

C.1 General conditions

For the purpose of these example calculations, it is assumed that particles were counted at one minute intervals, upstream and downstream, in 16 channels, for a test duration of 86 min. The calculations relate to one channel in which the particle size was > 20 µm(c) and the readings taken at one minute intervals were as shown in Table C.1.

Table C.1 — Particle counter readings in one channel

Time interval	Particle count		Time interval	Particle count	
min	upstream	downstream	min	upstream	downstream
1	14,4	1,0	16	209,6	77,0
2	171,4	35,3	17	217,8	73,1
3	191,7	53,8	18	193,3	68,9
4	163,7	47,3	19	204,2	84,3
5	190,9	51,5	20	224,4	85,5
6	182,8	54,9	—	—	—
7	165,2	41,8	—	—	—
8	191,5	66,7	—	—	—
9	186,4	57,5	80	382,6	207,8
10	218,4	49,4	81	350,9	198,2
11	190,7	54,9	82	347,7	208,3
12	174,8	59,1	83	308,3	165,2
13	210,6	55,0	84	309,0	157,7
14	242,3	66,9	85	297,5	162,0
15	188,0	82,8	86	295,7	147,4

NOTE The readings taken at time intervals 21 min to 79 min have been omitted from the table since they are not relevant to the example calculations.

C.2 Calculation of filter initial efficiency

The filter initial efficiency, E_6, is calculated from the average particle counts, upstream and downstream, at the 6 min interval, using the equation:

$$E_6 = \frac{C_{u6} - C_{d6}}{C_{u6}} \times 100$$

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where

C_{u6} is the average of the upstream counts taken at the 4 min, 5 min and 6 min intervals, i.e.

$$\frac{163{,}7 + 190{,}9 + 182{,}8}{3} = 179{,}13$$

C_{d6} is the average of the downstream counts taken at the 4 min, 5 min and 6 min intervals, i.e.

$$\frac{47{,}3 + 51{,}5 + 54{,}9}{3} = 51{,}23$$

therefore,

$$E_6 = \frac{179{,}13 - 51{,}23}{179{,}13} \times 100 = 71{,}40$$

in percent.

C.3 Calculation of filter intermediate efficiencies

C.3.1 General

Intermediate efficiencies are calculated from the average particle counts, upstream and downstream, at either of the following time intervals.

a) 5 min: if the duration of the test did not exceed one hour.

b) 10 min: if the duration of the test exceeded one hour.

In the present example, the duration of the test was 86 min. Therefore, the intermediate efficiencies are calculated for each 10 min interval.

C.3.2 First 10 min interval

In order to eliminate potentially erroneous particle counts obtained prior to stabilization of the system, the first 3 min of the test are disregarded.

The intermediate efficiency of the filter at the 10 min interval, E_{10}, is calculated using the equation:

$$E_{10} = \frac{C_{u10} - C_{d10}}{C_{u10}} \times 100$$

where

C_{u10} is the average of the upstream counts taken at the 4 min to 10 min intervals, i.e.

$$\frac{163{,}7 + 190{,}9 + ... + 218{,}4}{7} = 185{,}56$$

C_{d10} is the average of the downstream counts taken at the 4 min to 10 min intervals, i.e.

$$\frac{47{,}3 + 51{,}5 + ... + 49{,}4}{7} = 52{,}73$$

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therefore,

$$E_{10} = \frac{185{,}56 - 52{,}73}{185{,}56} \times 100 = 71{,}58$$

in percent.

C.3.1 Subsequent 10 min intervals

The intermediate efficiency is calculated for each of the subsequent 10 min intervals in accordance with the following example, E_{20}, which corresponds to the 20 min interval.

$$E_{20} = \frac{C_{u20} - C_{d20}}{C_{u20}} \times 100$$

where

C_{u20} is the average of the upstream counts taken at the 11 min to 20 min intervals, i.e.

$$\frac{190{,}7 + 174{,}8 + ... + 224{,}4}{10} = 205{,}57$$

C_{d20} is the average of the downstream counts taken at the 11 min to 20 min intervals, i.e.

$$\frac{54{,}9 + 59{,}1 + ... + 85{,}5}{10} = 70{,}75$$

therefore,

$$E_{20} = \frac{205{,}57 - 70{,}75}{205{,}57} \times 100 = 65{,}58$$

in percent.

C.3.2 Final interval

The intermediate efficiency for the final interval of 6 min (i.e. the period from 81 min to 86 min) is calculated using the equation:

$$E_{86} = \frac{C_{u86} - C_{d86}}{C_{u86}} \times 100$$

where

C_{u86} is the average of the upstream counts taken at the 81 min to 86 min intervals, i.e.

$$\frac{350{,}9 + 347{,}7 + ... + 295{,}7}{6} = 318{,}18$$

C_{d86} is the average of the downstream counts taken at the 81 min to 86 min intervals, i.e.

$$\frac{198{,}2 + 208{,}3 + ... + 147{,}4}{6} = 173{,}13$$

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therefore,

$$E_{86} = \frac{318,18 - 173,13}{318,18} \times 100 = 45,59$$

in percent.

C.4 Calculation of filter overall efficiencies

The overall efficiency of the filter at the > 20 µm(c) particle size, selected for this example, is calculated using the equation:

$$E_{020} = \frac{C_{u020} - C_{d020}}{C_{u020}} \times 100$$

where

C_{u020} is the average of the upstream counts taken at 1 min intervals from 4 min to 86 min, i.e.,

$$\frac{163,7 + 190,9 + ... + 295,7}{83} = 287,35$$

C_{d020} is the average of the downstream counts taken at 1 min intervals from 4 min to 86 min, i.e.,

$$\frac{47,3 + 51,5 + ... + 147,4}{83} = 142,5$$

therefore,

$$E_{020} = \frac{287,35 - 142,5}{287,35} \times 100 = 50,41$$

in percent.

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Annex D
(informative)

Summary of international interlaboratory trial ("round robin") to validate ISO 19438 protocol

D.1 Historical

ISO 19438 has been developed to measure the variations of the filtration efficiency of fuel filters when they are clogged by a mineral standard particulate contaminant, up to a given differential pressure, and to calculate the retention capacity of the filter.

The efficiency is determined by comparing particle counts measured at various sizes upstream and downstream of the filter, counting being by optical automatic particle counters (APCs) using the light extraction principle.

The international "round robin" organized by ISO TC22/SC7 had two goals:

a) quantify the overall variations of results both within and between laboratories, including the effects of APCs calibration, test stand validation and operating conditions variations;

b) compare the initial filtration efficiency measured during the first 6 min of the test with those measured using the ISO/TS 13353 method during 60 min.

The six laboratories involved were asked to proceed according to a detailed protocol including four steps:

a) calibration of particle counters per ISO 11171;

b) validation of on-line counting and dilution system per ISO 11943;

c) validation of the test stand according to ISO 19438 and, when agreed, ISO/TS 13353;

d) fuel filter tests according to ISO 19438 and ISO/TS 13353.

A step could be passed only if the previous one had been fully validated.

Test results were processed according to ISO 5725-2 and ISO 5725-6 to calculate statistical parameters. Each participant tested two fuel filters of two grades with close mean pore sizes.

D.2 Preliminary calibration/validation tests

D.2.1 Particle counting system calibration

Each lab calibrated one particle counter with its sensor according to either ISO 11171:1999, Clause 6, using NIST SRM 2806 (primary calibration) or ISO 11943:1999, Clause 9, using an ISO MTD suspension certified with a primary APC and circulating in a validated loop (secondary calibration). The second APC was matched to the first according to Clause 10 of this International Standard.

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D.2.2 On-line counting and dilution system validation

The contaminant concentration specified for the test (50 mg/l) was higher than the saturation concentration of the APC sensors. For that reason, the test fluid had to be continuously diluted before being counted. The dilution system of each participant was validated according to Clause 11.

D.2.3 Test stand validation

Each test stand, including filter test circuit and contaminant injection system, was validated according to Clause 7 of this International Standard and ISO/TS 13353:2002, Clause 6.

Validation criteria are summarized in Table D.1, which was completed in by each participant.

Table D.1 — Validation data sheet

VALIDATION SHEET / ISO 19438			
Name :			
Delivery date :			
	Parameters to be respected	YES	Comments
Table 1 (Particle counter sizing calibration - ISO 11171, Clause 6)			
1	First threshold setting > 1.5 x Noise level		
2	First count > 10 000		
3	All counts > 100		
4	Counting volume > 10 ml		
5	Calibration date < 6 months		
6	DQ calculated < Dq max		
Table 2 (On-line particle counter calibration - ISO 11943, Clause 9 up to 9.11)			
1	Counting volume ~ 25 ml (option)		
2	STDEV < Acceptable		
Table 3 (On-line particle counting system validation - ISO 11943, 9.12 up to 9.17)			
1	Column 3 = Column 2 +/- 1.3* Column 4		
Table 4 (On line particle counting system validation - ISO 11943, Clause 10)			
1	Upstream average/µg = Column 3 +/- Column 4 (Table 3)		
2	Downstream average/µg = Column 3 +/- Column 4 (Table 3)		
3	Upstream -Downstream counts < Column 5		
Tables 5a and 5b (On-line dilution system validation - ISO 11943, Clause 11)			
1	3 counts, 1 min each		
2	Upstream average/µg = Column 3 +/- Column 4 (Table 3)		
3	Downstream average/µg = Column 3 +/- Column 4 (Table 3)		
4	Upstream -Downstream counts < Column 5		
Table 6 (Test stand validation - Filter test circuit ISO/DIS 19438, 7.1)			
1	C = 5 mg/l		
2	Batch 4961 F		
3	Each count = +/- 10 % average		
4	Average count > 10 µm(c) = 750-1000		
5	Average count > 20 µm(c) = 70-120		
Table 7 (Test stand validation - Injection circuit ISO/DIS 19438, 7.2)			
1	Each measurement = +/- 5% average		
2	Average = +/- 5 % Presumed value		
CONCLUSION			

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D.3 Test conditions

D.3.1 Test filters

Two samples of two grades of fuel filters were tested:

— 2 filters “A”, MFP[2] = 5 µm, C_R ≈ 10 to 12 g;

— 2 filters “B”, MFP = 15 µm, C_R ≈ 10 to 15 g

D.3.2 Test parameters

D.3.2.1 Filtration efficiency and retention capacity per ISO 19438

Fluid: type MIL H 5606 (AIR 3520) — Viscosity: 15 mm^2/s

Volume: 6 l — Conductivity: 1500 ± 500 pS/m

Test flowrate: Filter A: 180 l/h; Filter B: 50 l/h

Contaminant: ISO 12103-A3, batch No. 4961F

Concentration: 50 mg/l

Final differential pressure: $\Delta P_F = \Delta P_o$ + 30 kPa

D.3.2.2 Initial filtration efficiency per ISO/TS 13353

Same operating conditions as above but for

Test concentration: 5 mg/l

Test time: 60 min

D.4 Interlaboratory trial test results

D.4.1 Differential pressure, concentration, capacities

Table D.2 presents results obtained on Filters A and B tested twice and the corresponding average, coefficient of variation, repeatability (r) and reproducibility (R).

2) MFP = mean flow pore size.

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Table D.2 — Differential pressures, contaminant concentrations and filter capacities measured by five laboratories on two grades of fuel filters (barred values represent discarded outliers)

Lab No.	Name	Differential pressure (kPa)		Gravimetric level (mg/l)		Capacities (g)	
		Assy (ΔP1)	Final net ΔP5	Base up.	80 % up.	Injected	Retained
Filter A							
1	CISSAC - T1	13	30	51,2	59,6	12,4	11,1
	CISSAC - T2	13	30	52,3	52,3	13,5	12,3
2	LATOUR - T1	14	30	50,9	34,6	14,7	14,5
	LATOUR - T2	13	30	49,0	42,6	15,6	15,4
3	MARGAUX - T1	~~47,5~~	30,1	50	/	7,7	/
	MARGAUX - T2	~~50,4~~	31,5	50	/	7,7	/
7	LAFITE - T1	~~40~~	~~70~~	50	50,4	10,5	10,2
11	PETRUS - T1	16,8	30	49,6	55,8	17,3	17
	PETRUS - T2	16,8	30	50,2	41,01	16,5	16,2
	Mean	**14,4**	**30,2**	**50,4**	**48,0**	**12,9**	**13,8**
	COV	**13%**	**2%**	**2%**	**19%**	**28%**	**19%**
	***r* (%)**	**8%**	**5%**	**4%**	**32%**	**12%**	**15%**
	***R* (%)**	**29%**	**4%**	**4%**	**38%**	**60%**	**47%**
Filter B							
1	CISSAC - T1	5	30	51,3	72,7	6,4	3,9
	CISSAC - T2	5	30	51,6	82,4	6,8	3,8
3	MARGAUX - T1	5,8	30,4	50	/	3,7	/
	MARGAUX - T2	5,8	36,1	50	/	3,6	/
7	LAFITE - T1	~~85~~	~~115~~	50	51,7	3,8	3,5
	Mean	**5,4**	**31,6**	**50,6**	**68,9**	**4,9**	**3,8**
	COV	**9%**	**9%**	**2%**	**23%**	**33%**	**6%**
	***r* (%)**	**0%**	**25%**	**1%**	**25%**	**11%**	**6%**
	***R* (%)**	**21%**	**23%**	**4%**	**69%**	**76%**	**18%**

D.4.2 Average filtration efficiencies

D.4.2.1 ISO 19438

Filtration efficiency of the test filter is calculated every minute from online upstream and downstream particle counts.

The overall efficiencies measured twice on Filter A and Filter B by each lab are reported on Figures D.1 and D.2.

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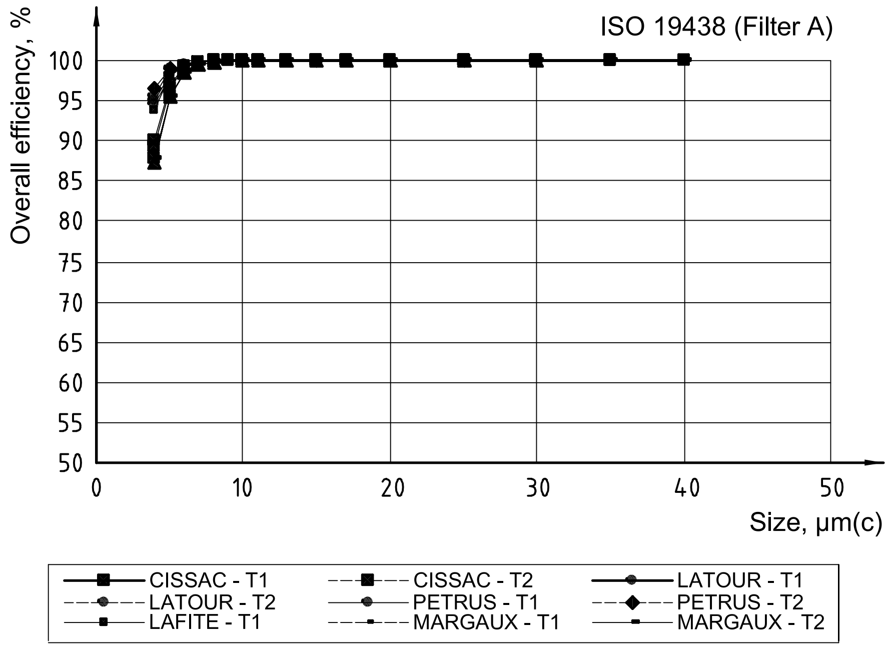

Figure D.1 — Plot of average filtration efficiency curves measured by 5 laboratories on Filter A

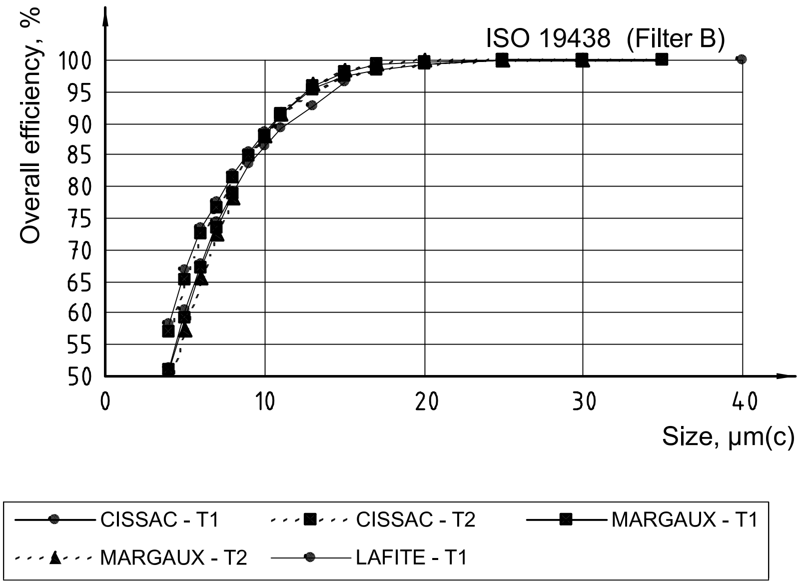

Figure D.2 — Plot of average filtration efficiency curves measured by 5 laboratories on Filter B

The overall, initial and minimum filtration efficiencies as well as the corresponding average, coefficient of variation, repeatability and reproducibility are reported in Table D, for Filter A and Filter B.

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Table D.3 — Overall, initial and minimum efficiency vs. particle size for Filter A and Filter B — Average, COV, repeatability and reproducibility

		Efficiency (%)															
		Size [µm(c)]															
		4	5	6	7	8	9	10	11	13	15	17	20	25	30	35	40
Filter A																	
Overall	**Mean based on all data**	**92,2**	**97,4**	**99,1**	**99,7**	**99,9**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	COV based on all data	3,85%	1,41%	0,42%	0,13%	0,04%	0,02%	0,01%	0,01%	0,01%	0,02%	0,02%	0,00%	0,01%	0,01%	0,01%	0,00%
	Repeatability (*r*)	1,44%	0,33%	0,18%	0,09%	0,03%	0,01%	0,01%	0,01%	0,01%	0,01%	0,00%	0,00%	0,01%	0,03%	0,00%	0,00%
	Reproducibility (*R*)	8,21%	3,04%	0,95%	0,29%	0,08%	0,04%	0,02%	0,03%	0,03%	0,03%	0,03%	0,01%	0,02%	0,03%	0,01%	0,00%
Min.	**Mean based on all data**	**79,7**	**92,3**	**97,2**	**99,1**	**99,7**	**99,9**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**99,9**	**100**	**100**
	COV based on all data	8,96%	3,23%	0,58%	0,23%	0,10%	0,02%	0,02%	0,02%	0,03%	0,03%	0,03%	0,02%	0,04%	0,08%	0,01%	0%
	Repeatability (*r*)	5,76%	2,47%	0,93%	0,47%	0,25%	0,06%	0,05%	0,02%	0,02%	0,04%	0,02%	0,03%	0,12%	0,26%	0,01%	0%
	Reproducibility (*R*)	18,3%	7,01%	1,83%	0,66%	0,23%	0,02%	0,06%	0,05%	0,05%	0,07%	0,08%	0,04%	0,09%	0,20%	0,38%	0%
Initial	**Mean based on all data**	**80,4**	**92,7**	**97,8**	**99,3**	**99,8**	**99,9**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	COV based on all data	10,3%	3,66%	0,87%	0,29%	0,07%	0,04%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,00%
	Repeatability (*r*)	5,21%	2,30%	0,57%	0,21%	0,23%	0,06%	0,05%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Reproducibility (*R*)	21,0%	7,76%	1,80%	0,58%	0,17%	0,06%	0,03%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,00%
Filter B																	
Overall	**Mean based on all data**	**53,7**	**62,2**	**69,6**	**75,0**	**80,1**	**85,0**	**88,1**	**91,4**	**95,7**	**97,8**	**98,8**	**99,6**	**100,0**	**100,0**	**100,0**	**—**
	COV based on all data	8,64%	7,33%	5,61%	3,26%	2,37%	0,58%	0,34%	0,25%	0,37%	0,46%	0,52%	0,25%	0,01%	0,01%	0,00%	—
	Repeatability (*r*)	7,24%	5,29%	3,53%	2,54%	1,83%	1,63%	0,74%	0,61%	0,33%	0,27%	0,15%	0,13%	0,04%	0,01%	0,00%	—
	Reproducibility (*R*)	17,8%	14,6%	11,4%	6,40%	4,82%	10,5%	2,64%	3,24%	4,15%	1,82%	1,25%	0,67%	0,06%	0,01%	0,00%	—
Min.	**Mean based on all data**	**28,3**	**39,3**	**50,2**	**58,6**	**67,1**	**70,8**	**80,2**	**85,5**	**92,8**	**96,3**	**97,9**	**99,2**	**99,9**	**100,0**	**100,0**	**—**
	COV based on all data	18,1%	11,2%	7,09%	7,35%	5,12%	0,69%	4,04%	3,37%	2,01%	1,35%	1,16%	0,57%	0,06%	0,04%	0,00%	—
	Repeatability (*r*)	20,4%	12,4%	8,48%	5,97%	2,83%	1,93%	0,76%	0,80%	0,68%	0,19%	0,19%	0,13%	0,10%	0,13%	0,00%	—
	Reproducibility (*R*)	35,1%	22,4%	14,2%	15,4%	10,3%	11,1%	7,90%	7,39%	6,95%	3,56%	2,81%	1,86%	0,91%	0,50%	0,00%	—
Initial	**Mean based on all data**	**24,2**	**35,7**	**47,4**	**55,0**	**64,2**	**71,0**	**77,7**	**83,3**	**91,2**	**95,2**	**96,9**	**98,9**	**100,0**	**100,0**	**100,0**	**—**
	COV based on all data	12,5%	7,12%	4,80%	3,30%	1,67%	1,02%	0,47%	0,27%	0,44%	0,57%	0,39%	0,19%	0,00%	0,00%	0,00%	—
	Repeatability (*r*)	35,1%	19,9%	13,4%	9,25%	4,69%	2,84%	1,33%	0,76%	1,24%	1,60%	1,10%	0,54%	0,00%	0,00%	0,00%	—
	Reproducibility (*R*)	50,1%	35,3%	21,9%	24,7%	15,5%	12,8%	6,54%	3,58%	3,42%	0,91%	4,40%	1,74%	0,02%	0,02%	0,00%	—

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From the average, minimum and maximum filtration efficiencies given in Table D.3, Figure D.3 illustrates the difference between Filters A and B and thus the sensitivity of the method.

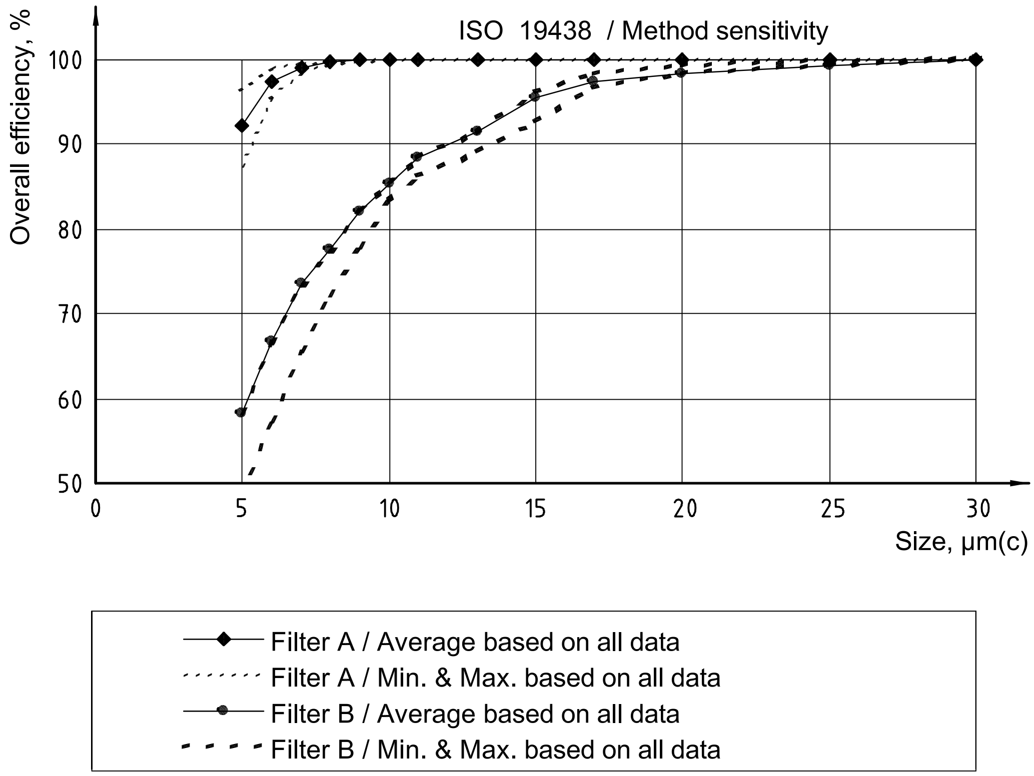

Figure D.3 — Plot of average, minimal and maximal data for overall filtration efficiency vs. particle size — Method sensitivity

D.4.2.2 ISO/TS 13353

Initial filtration efficiency is calculated from counts measured upstream and downstream the test filter every minute.

According to ISO/TS 13353, efficiency results have to be expressed versus differential counts.

In order to compare ISO/TS 13353 and ISO 19438 results, they are also given versus cumulative counts.

The initial efficiencies determined twice on Filter A and Filter B by each lab are gathered in Figures D.4 to D.7, both in term of “differential” and “cumulative” average initial efficiency.

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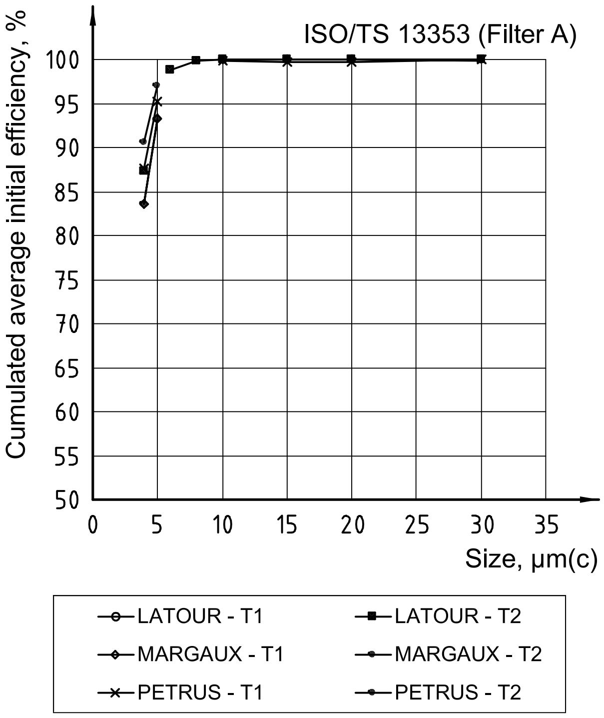

Figure D.4 — Plot of *cumulative* average initial efficiency curves measured by 3 laboratories on Filter A

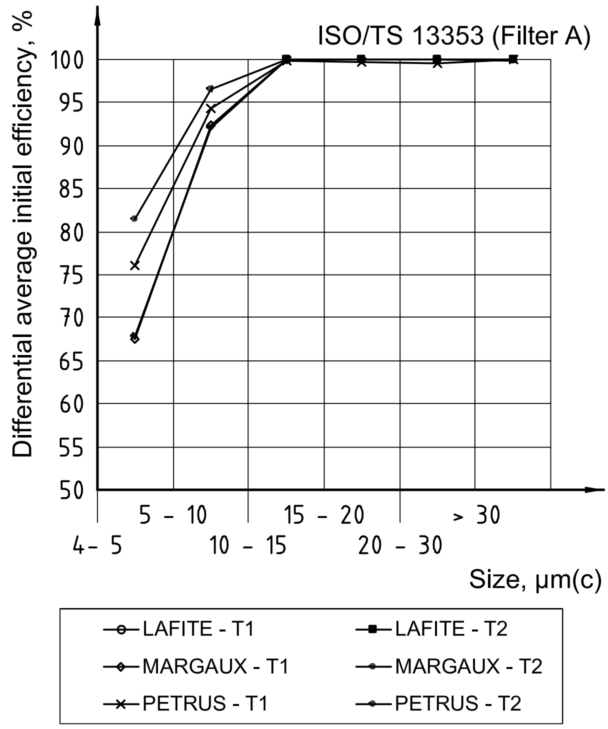

Figure D.5 — Plot of *differential* average initial efficiency curves measured by 3 laboratories on Filter A

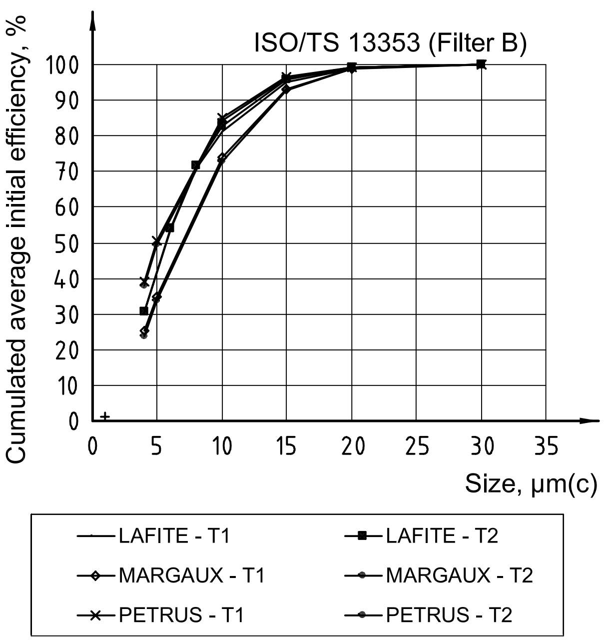

Figure D.6 — Plot of *cumulative* average initial efficiency curves measured by 3 laboratories on Filter B

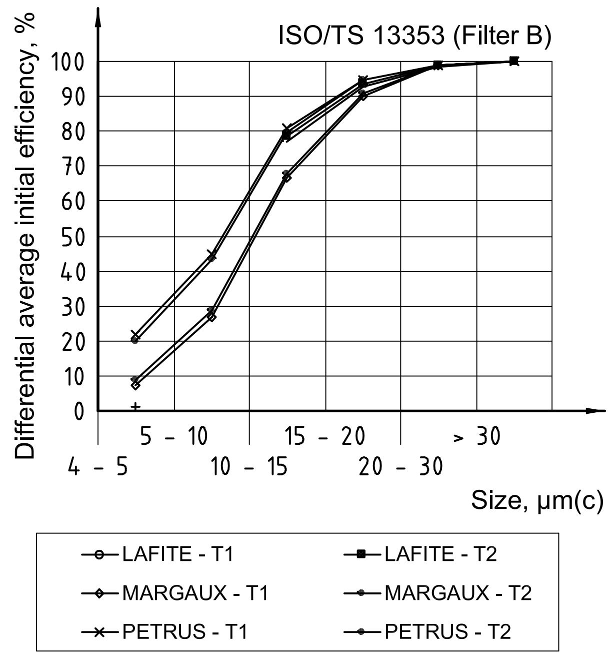

Figure D.7 — Plot of *differential* average initial efficiency curves measured by 3 laboratories on Filter B

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The average, minimum and maximum efficiency values of all the data obtained from all the labs are reported for both Filters A and B in Figures D.8 and D.9.

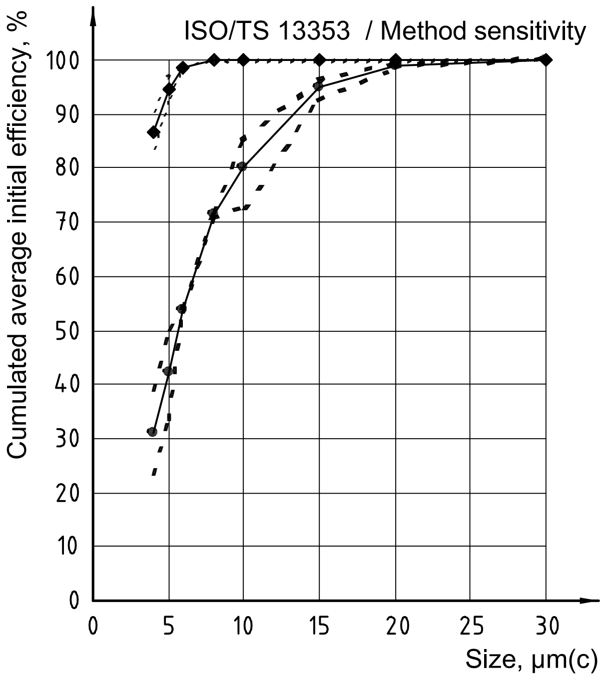

Figure D.8 — Plot of *cumulative* average initial efficiency for Filter A and Filter B (Average/Minimum/Maximum based on all data)

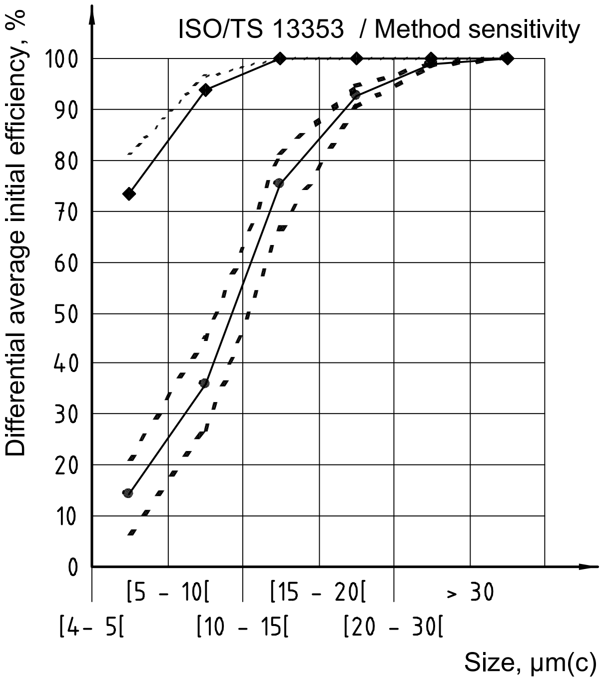

Figure D.9 — Plot of *differential* average initial efficiency for Filter A and Filter B (Average/Minimum/Maximum based on all data)

These plots exhibit no overlap between the Filter A and Filter B characteristics measured with ISO/TS 13353 method in all labs, showing the sensitivity of this method.

D.4.2.3 Comparison of initial filtration efficiencies upon ISO 19438 and ISO/TS 13353

To illustrate a difference, if any, between filter ratings as determined by initial single pass efficiency test according to ISO/TS 13353 and by multipass test according to ISO 19438, one reports the efficiencies

— measured during the first 6 min of the ISO 19438 test (50 mg/l), and

— measured during the first 60 min of the ISO/TS 13353 test (5 mg/l).

Table D.4 below shows mean results obtained on Filter B tested twice by all the participating labs.

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Table D.4 — Initial average efficiencies of Filter B measured in accordance with ISO 19438 and ISO/TS 13353

	Initial average efficiency (%)															
	Size [µm(c)]															
	4	5	6	7	8	9	10	11	13	15	17	20	25	30	35	40
ISO/TS 13353																
Mean based on all data	31,2	42,2	53,9	—	71,3	—	80,0	—	—	94,9	—	99,0	—	100	—	—
COV based on all data	20%	22%	1,0%	—	1,0%	—	7,0%	—	—	2,0%	—	0,20%	—	0,05%	—	—
Min.	23,6	33,6	53,6	—	70,9	—	72,9	—	—	92,6	—	98,7	—	99,9	—	—
Max.	39,1	50,7	54,1	—	71,8	—	85,1	—	—	96,5	—	99,2	—	100,0	—	—
Repeatability (*r*)	7,0%	6,0%	2,0%	—	2,7%	—	2,9%	—	—	1,3%	—	0,49%	—	0,04%	—	—
Reproducibility (*R*)	45%	53%	—	—	—	—	15%	—	—	3,9%	—	0,48%	—	0,11%	—	—
ISO 19438																
Mean based on all data	26,6	38,1	49,3	57,6	66,1	72,7	78,6	83,8	90,6	95,1	97,7	99,2	100	100	100	100
COV based on all data	17%	12%	7,4%	8%	5,0%	4%	2,1%	1%	1%	0,4%	1%	0,57%	0,01%	0,01%	0,00%	—
Min.	22,1	33,9	45,8	53,7	63,5	70,5	77,4	83,1	89,5	94,8	96,7	98,7	100	100	100	100
Max.	31,2	42,9	53,1	62,8	69,8	69,8	80,5	84,9	91,5	95,6	99,3	100	100	100	100	100
Repeatability (*r*)	35,1%	19,9%	13,4%	9%	4,7%	3%	1,3%	1%	1%	1,6%	1%	0,54%	0%	0,00%	0,0%	0,0%
Reproducibility (*R*)	50%	35%	22%	25%	15%	13%	7%	4%	3%	0,9%	4%	1,74%	0%	0,02%	0,0%	0,0%

Results are illustrated for both Filter A and Filter B in Figures D.10 and D.11, which show the similarity between the results obtained by either ISO/TS 13353 or ISO 19438.

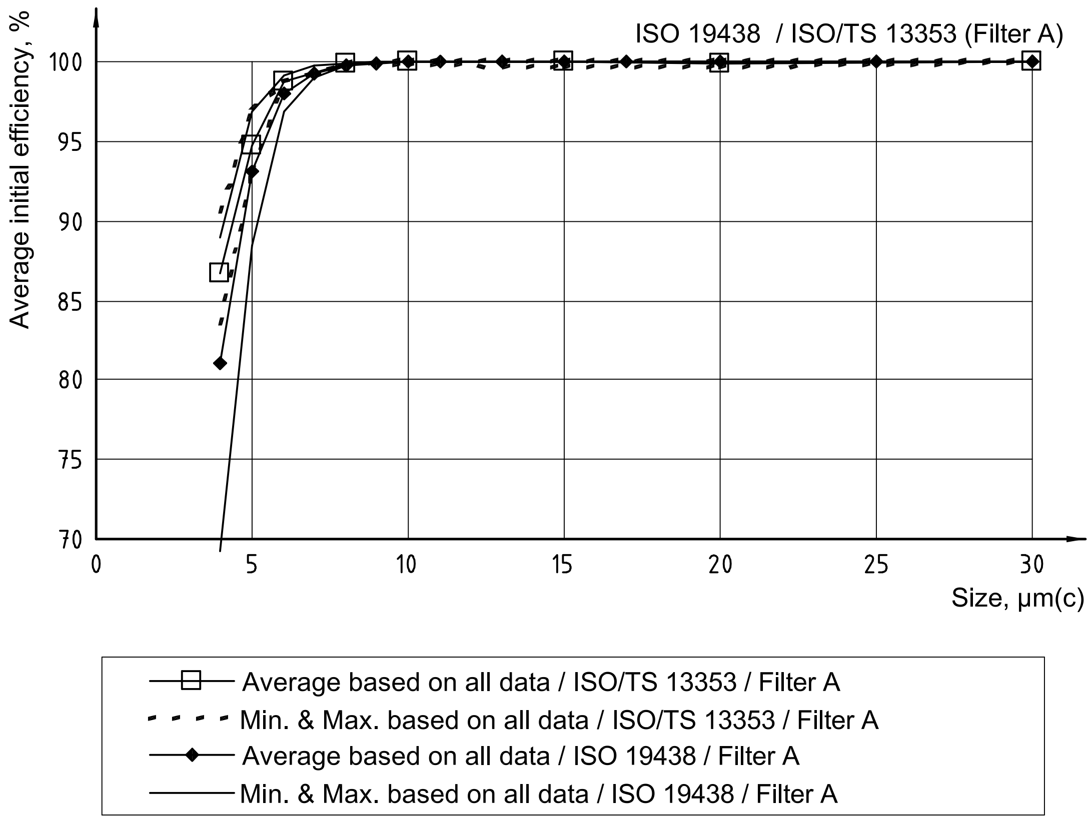

Figure D.10 — Comparison of average initial efficiency measured on Filter A with the two methods

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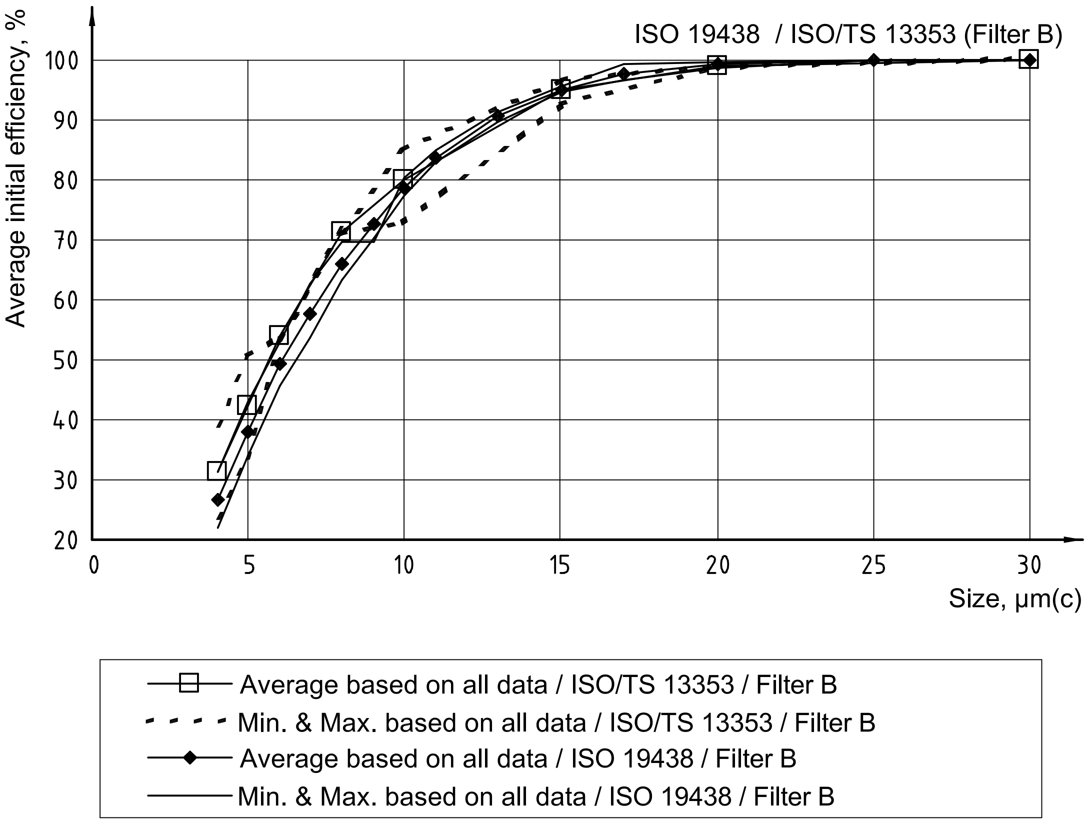

Figure D.11 — Comparison of average initial efficiency measured on Filter B with the two methods

D.4.3 Filter rating

From Table D.4, it is possible to determine for each filter the particle size corresponding to various preset efficiencies from which the filter rating is defined. These values are reported in Table D.5.

Table D.5 — Filter ratings at various efficiencies for Filter A and Filter B

ISO 19438	Size [µm(c)]				
	Overall efficiency (%)				
	50	75	90	95	99
Filter A					
Mean based on all data	2,1	3,2	4,1	4,6	5,9
COV based on all data	1,0%	1,2%	6,8%	6,1%	6,2%
Repeatability (*r*)	2,9%	3,5%	3,5%	4,2%	2,5%
Reproducibility (*R*)	—	—	19%	19%	14%
Filter B					
Mean based on all data	4,0	6,8	10,8	—	16,5
COV based on all data	—	4,4%	2,4%	—	4,3%
Repeatability (*r*)	0,0%	4,1%	1,3%	—	12,0%
Reproducibility (*R*)	8%	15%	11%	—	32%

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D.5 Conclusion

The limited number of participants reduces the significance of the “round robin” test. However, some conclusions have been able to be drawn by the ISO TC22/SC7 expert group.

a) ISO 19438 provides industry with a good test method with high repeatability, which makes it a very precise tool to follow-up a manufacturing process. It allows a precise determination of the test filter rating and retention capacity.

b) ISO 19438 has good reproducibility (variation between labs) on fine filters and a lower one on coarse filters.

c) ISO 19438 leads to similar initial filtration efficiencies measured during the first 6 min of test as the one obtained during 60 min using ISO/TS 13353.

Thus, initial filter ratings measured using ISO/TS 13353 and ISO 19438 are the same.

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[2] ISO/TS 13353:2002, *Diesel fuel and petrol filters for internal combustion engines — Initial efficiency by particule counting*

3) American Society for Testing and Materials.

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