TECHNICAL SPECIFICATION

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Road vehicles — Inlet air cleaning equipment for internal combustion engines and compressors —

Part 2: Fractional efficiency testing with coarse particles (5 µm to 40 µm optical diameter)

Véhicules routiers — Équipement d'épuration d'air d'entrée pour moteurs à combustion interne et compresseurs —

Partie 2: Contrôle d'efficacité fractionnelle avec grosses particules (diamètre optique de 5 µm à 40 µm)

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Foreword

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In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

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ISO/TS 19713-2 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 7, *Injection equipment and filters for use on road vehicles*.

ISO/TS 19713 consists of the following parts, under the general title *Road vehicles — Inlet air cleaning equipment for internal combustion engines and compressors*:

— *Part 1: Fractional efficiency testing with fine particles (0,3 µm to 5 µm optical diameter)*

— *Part 2: Fractional efficiency testing with coarse particles (5 µm to 40 µm optical diameter)*

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Introduction

The engine air cleaner/filter fractional efficiency test methods described in this part of ISO/TS 19713 have been developed to cover traditional and new particulate air filters in order to remove airborne contaminants specifically to protect the engine.

Air cleaner fractional efficiency is one of the main air cleaner performance characteristics. This part of ISO/TS 19713 has been established to address the measurement of this parameter. The objective of the procedure is to maintain a uniform test method for evaluating fractional efficiency of air cleaners and air filters on specified laboratory test stands.

The data collected in accordance with this part of ISO/TS 19713 can be used to establish fractional efficiency characteristics for air cleaners and filters tested in this manner. The actual field operating conditions (including contaminants, humidity, temperature, mechanical vibration, flow pulsation, etc.) are difficult to duplicate. However, with the procedure and equipment set forth, comparison of air filter fractional efficiency can be made with a high degree of confidence.

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Road vehicles — Inlet air cleaning equipment for internal combustion engines and compressors —

Part 2: Fractional efficiency testing with coarse particles (5 µm to 40 µm optical diameter)

1 Scope

This part of ISO/TS 19713 describes laboratory test methods to measure engine air cleaner and filter performance by fractional efficiency tests for particles from 5 µm to 40 µm, using ISO 12103-1 test dusts.

Performance includes, but is not limited to, airflow restriction or pressure loss, initial and incremental fractional efficiencies during dust loading.

ISO/TS 19713-1 describes fractional efficiency tests for particles from 0,3 µm to 5 µm optical diameter.

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 5011:2000, *Inlet air cleaning equipment for internal combustion engines and compressors — Performance testing*

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
air cleaner assembly
assembly which includes the air cleaner housing and the air filter element

3.1.1
single-stage air cleaner
air cleaner which does not incorporate a separate pre-cleaner

3.1.2
multistage air cleaner
air cleaner consisting of two or more stages, the first usually being a pre-cleaner, followed by one or more filter elements

NOTE If two elements are used, the first is called the primary element and the second is called the secondary element.

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3.1.3
pre-cleaner
device usually using inertial or centrifugal means to remove a portion of the test dust before reaching the filter element

3.2
air filter element
actual filter supported and sealed within the air cleaner assembly

3.3
test airflow rate
measure of the volume of air passing through the test duct per unit time

NOTE The test airflow rate is expressed in cubic metres per second.

3.4
pressure loss
permanent pressure reduction due to a decrease in the flow energy (velocity head) caused by the filter (Pa at standard conditions of 20 °C and 101,3 kPa)

3.5
fractional efficiency
$E_{\mathrm{f},i}$
ability of the air filter to remove particles of a specified size expressed as a percentage for particle size i

$$E_{\mathrm{f},i} = \frac{C_{1,i} - C_{2,i}}{C_{1,i}} \times 100 \quad (1)$$

where

$C_{1,i}$ is the number of particles per unit volume of specified size, i, upstream;

$C_{2,i}$ is the number of particles per unit volume of specified size, i, downstream

NOTE Fractional efficiency is expressed in percent.

3.6
fractional efficiency before dust loading
efficiency before the collected particles have any measurable effect on the efficiency of the filter under test

NOTE The collected particles can affect the measured filter efficiency before enough aerosol is collected to have any measurable effect on the filter pressure loss.

3.7
incremental fractional efficiency
efficiency, determined at the specified flow rate as a function of particle size at 10 %, 25 %, 50 % and 100 % of filter life, which is determined by pressure loss across the filter as the filter is loaded with ISO 12103-1 test dust

NOTE 1 The values of filter pressure loss, ΔP_i, at which the incremental fractional efficiencies are measured can be calculated from

$$\Delta P_i = \Delta P_\mathrm{o} + \Delta L_i(\Delta P_\mathrm{d} - \Delta P_\mathrm{o}) \quad (2)$$

where

ΔP_o is the initial pressure loss;

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ΔL_i is the fraction of filter life;

ΔP_d is the specified terminal pressure loss.

NOTE 2 If necessary, the requester and the tester can agree upon different criteria for incremental fractional efficiency.

3.8
fractional penetration
$P_{f,i}$
ratio of the concentration of particles of specified size exiting the filter to the concentration of particles of specified size entering the filter expressed in a percentage for particle size i

$$P_{f,i} = 100 - E_{f,i} \quad (3)$$

NOTE Fractional penetration is expressed in percent.

3.9
test dust loading
mass of test dust collected by the air cleaner assembly or air filter element at a specified flow rate expressed in grams

3.10
particle measurement device
aerosol spectrometer
instrument for sizing, or counting, or sizing and counting, aerosol particles

NOTE Recommended particle counters are optical particle counters (OPC) or other counters demonstrating good correlation in measuring particle sizes, e.g. aerodynamic particle counters (APC).

3.11
test aerosol
particles suspended in air, used for filter efficiency evaluation or dust loading

3.11.1
fractional efficiency test aerosol
aerosol used to measure the efficiency of the test filter, the concentration of which is low enough to prevent coincidence-related errors in the particle counters, and does not change the filter efficiency due to loading

NOTE The aerosol charge is reduced so that it approximates a Boltzman equilibrium charge distribution. The requirements for the efficiency challenge aerosol are given in 4.2.10 and 4.2.11.

3.11.2
loading test aerosol
aerosol used to load the filter, the concentration of which is high enough to allow loading of the filter in a reasonable amount of time

NOTE The requirements for the loading test aerosol are given in 4.2.13.2.

3.12
correlation ratio
R
ratio of the number of particles observed at the downstream sampling location to the number of particles at the upstream sampling location when no filter is installed in the test system

NOTE 1 This number can be greater or less than 1.

NOTE 2 The method of calculating the correlation ratio is given in Annex B.

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3.13
log mean diameter
$D_{l,i}$
weighted mean diameter calculated by

$$D_{l,i} = \left(D_i \times D_{i+1}\right)^{1/2} \quad (4)$$

where

D_i is the lower threshold of particle size range;

D_{i+1} is the upper threshold of particle size range

3.14
geometric (volume equivalent) diameter
$D_{g,i}$
diameter of a sphere with the same volume as the particle being measured

NOTE For a spherical particle, it is the diameter of the sphere.

3.15
optical (equivalent) diameter
$D_{o,i}$
diameter of a particle of the type used to calibrate an optical sizing instrument that scatters the same amount of light as the particle being measured

NOTE Optical diameter depends on the instrument, the type of particle used to calibrate the instrument (usually polystyrene latex spheres), the optical properties of the particle being measured, and the size of the particle.

3.16
aerodynamic (equivalent) diameter
D_{ae}
diameter of a sphere of density 1 g/cm^3 with the same terminal velocity as the particle being measured, due to gravitational force in calm air

NOTE 1 The aerodynamic diameter will be used to report results to avoid different diameter measures due to different sizing and counting techniques.

NOTE 2 Annex F provides additional information about aerodynamic diameter.

3.17
high efficiency particulate air
HEPA
filter having 99,95 % efficiency at most penetrating particle size (class H13 in accordance with EN 1822), or 99,97 % (or higher) fractional efficiency at 0,3 µm using DOP aerosol as defined by IEST RP-CC001 recommended practice

3.18
neutralization
aerosol whose charge distribution is reduced until it provides a Boltzman equilibrium charge distribution

4 Test equipment, accuracy and validation

4.1 Measurement accuracy

Accuracy requirements are given in Table E.1.

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4.2 Test stand configuration

4.2.1 General

Complete vehicle manufacturer air cleaner assemblies or individual air filter elements may be tested. The test stand shall consist of the following major components and shall be arranged as shown in Figure 2.

NOTE 1 Results can vary depending on configuration.

NOTE 2 Air cleaner assembly orientation will affect performance. It is advisable that air cleaner assemblies be oriented and tested as installed in the vehicle.

Figure 2 shows a set-up to measure the performance of an air cleaner assembly.

Figure 3 shows a recommended air cleaner housing to measure the performance of a panel-type air filter element.

Figure 4 shows a recommended air cleaner housing to measure the performance of a cylindrical-type air filter element.

4.2.2 Unit under test

4.2.2.1 General

The unit under test may be an air cleaner housing with filter element or elements or it may be a housing designed to hold a filter element with appropriate inlet and outlets. The unit under test may be or may include a pre-cleaner. The scope of this test procedure does not include the testing of air cleaner systems without tubular inlet and outlet connections. However, designs such as perforated or louvered inlet systems could be tested with the unit under test inside a plenum that would include a tubular inlet. Non-tubular air cleaner systems outside the scope of this test procedure may still be evaluated as agreed upon between the tester and customer.

4.2.2.2 Air cleaner assembly

Air cleaner assemblies shall be evaluated using the set-up shown in Figure 2.

4.2.2.3 Evaluating panel air filter elements

In general, panel-type air filter elements may be tested using the recommended housing shown in Figure 3.

4.2.2.4 Evaluating cylindrical/round air filter elements

Figure 4 shows a recommended housing to test cylindrical-type air filter elements. This housing design is similar to the one recommended in ISO 5011.

4.2.3 Ducting

Upstream and downstream cylindrical ducting shall be made of conductive material and all components shall be commonly grounded from the aerosol inlet section to the downstream sampling section.

4.2.4 Airflow conditioning

Inlet air shall be conditioned in accordance with the requirements of ISO 5011, i.e. (23 ± 5) °C and (55 ± 15) % relative humidity (RH). The inlet air shall be filtered with a HEPA filter if the background particle concentration exceeds that defined in Annex E.

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4.2.5 Test configurations

The upstream and downstream ducting can be constructed vertically (recommended), horizontally, or a combination based on space constraints. The example in this procedure shows a vertical configuration to test both air cleaners and panel-type air filters. Preferably, the particle samplers should be located vertically in each test section, which reduces the probability of particle loss and enables sampling of large particle sizes of interest. The underlying test system design will reduce particle losses and meet the requirements of Tables E.1 and E.2.

4.2.6 Airflow ducting

The test system should be capable of handling user-specified flow rates. Further, the test system will maintain the required flow rates with air cleaner assembly pressure loss up to 10 kPa. Primary duct sizing shall conform to the “nominal” duct diameter and Reynolds numbers in Table 1. Higher and lower flow rates may use duct sizes scaled appropriately.

Table 1 — Duct diameter versus flow range

Nominal duct diameter	Area	Velocity	Flow range low	Flow range high	Reynolds number	
mm	m^2	m/s	m^3/h	m^3/h	at low flow	at high flow
50	0,002 02	11,6	85	425	40 407	202 034
100	0,008 10	5,8	170	850	40 407	202 034
150	0,018 20	5,2	340	1 700	53 876	269 378
200	0,032 40	5,8	680	3 400	80 813	404 067

NOTE A 10 µm particle with a specific gravity of 2 settles at about 6×10^{-3} m/s in still air. At the minimum velocity of approximately 5,1 m/s, this would result in a 10 mm drop in that 10 µm particle over a 3 m run.

4.2.7 Inlet filtration

Test inlet airflow shall be filtered with a HEPA filter to remove the majority of ambient aerosol, if required, in accordance with Annex E.

4.2.8 Flow uniformity

The test system shall be designed to provide uniform and steady airflow to the air cleaner assembly or to the air filter element under test, as stated in the test set-up.

NOTE Uniform airflow is required in sections where isokinetic samplers are located when evaluating air cleaner assemblies. Proper flow distribution will facilitate a representative aerosol sample being drawn by the isokinetic samplers. See 4.2.10.4 for flow uniformity measurements.

4.2.9 Leakage

It is important to minimize leakage into the test system to obtain valid data. Depending on where the leakage occurs, it can cause major errors in particle counting.

As a minimum, all connections and joints should be checked for visual leakage using soap bubbles. Any known soap solution can be used for the test. Preferably, the soap solution (foam) will be applied using a brush at all connections and joints. Leaks are especially important on the clean side of the air cleaner.

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4.2.10 Fractional efficiency test aerosol generator

4.2.10.1 General

The aerosol generator for fractional efficiency tests shall provide a stable and homogenous aerosol concentration and size distribution. The size distribution of the aerosol shall have sufficient particles for statistical evaluation in each size class, as explained in B.6. If high-resolution particle spectrometers are used, size classes may be combined to achieve the required counts. The total concentration of the aerosol in the test duct shall not exceed the limit of the particle counter discussed in 4.2.14.3. The efficiency test aerosol concentration shall be low enough so there is no change in efficiency during the test as described in Clause 5 (i.e. no loading effects).

4.2.10.2 Aerosol generation

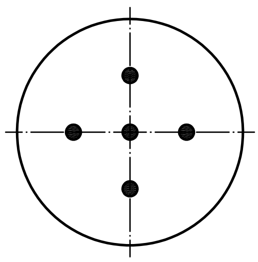
Test dust and aerosol generation shall be in accordance with ISO 5011:2000, 6.2.1 to 6.2.5.

4.2.10.3 Aerosol dispersion

The efficiency test aerosol should be injected with the airflow in accordance with Figure 2 (see ISO 5011:2000, 6.2.1 to 6.2.5).

4.2.10.4 Aerosol uniformity

During validation of uniformity and concentration of the efficiency test aerosol, no air cleaner shall be installed in the location of the test filter (see Figure 2). Instead, a smooth, straight pipe or an elbow may be used. The uniformity of the particle size distribution and the concentration of the test aerosol used for fractional efficiency tests may be verified by use of a particle-sizing instrument that will also be used in the test system. This particle-sizing instrument shall draw samples upstream and downstream of the air cleaner mounting position using the isokinetic samplers. For each test duct the minimum and maximum flow rate will be used for this evaluation (see Table 1). Samples shall be drawn by the isokinetic samplers along a diameter at three locations. Locations will be 0,15 D, 0,5 D and 0,85 D (see Figure 1). The measurements will be performed in a plane along two perpendicular diameters. A minimum of three samples shall be drawn at each sampling location, and the resulting number distribution shall be averaged. As far as possible, the samples will be taken at random. The average values for each reported particle-size range shall not vary by more than ±10 % for channels less than 15 µm particles and ±20 % for channels greater than 15 µm particles among the five locations. This indicates that the efficiency test aerosol is uniformly distributed across the test duct, and that the centreline sample is representative of the overall challenge.



NOTE For tube diameter D, the sampling positions are the following:

— horizontal: 0,15D; 0,5D; 0,85D;

— vertical: 0,15D; 0,85D.

Figure 1 — Location of isokinetic sampling points for validation

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4.2.11 Aerosol neutralizer for coarse test dust

Neutralization is not used in this part of ISO/TS 19713.

4.2.12 Upstream and downstream sample probes

Sampling probes shall be isokinetic (local velocity of duct and probe to be equal) to within ±20 %. The same probe design should be used upstream and downstream of the filter. Sampling probes shall be located on the centreline of the test duct. Sample probes shall be located at least seven diameters downstream of any bends, reducers, expanders, etc. The sampling probe shall be at least four diameters upstream of any bends, reducers, expanders, etc. The samplers will also be located in the centre of the duct. The probes shall be made of electrically conductive metallic tubing with a smooth inside surface. The design of the probes and sampling lines will reduce particle losses. The inlet of the sampling probes shall be sharp edged and shall be located near the centre of the duct. Both the upstream/downstream sampling lines should be identical, straight (or no more than one bend) and as short as possible. See Annex G for details on isokinetic sampling. A short ($\leqslant$ 50 mm) flexible connection to the particle counter may be used to allow some flexibility and reduce stress on the counter inlet. PTFE may not be used as flexible tubing. Use conductive tubing (e.g. plasticized PVC) instead. For more information on tubing, see the Bibliography.

Sampling probe ducting to the particle counter must be set up in a way that no sedimentation of large particles takes place, i.e.

- vertical orientation of the tubing;
- sufficient flow velocity;
- short connection length between n particle counter and sampling;
- avoidance of bends in the tubing;
- no sharp angles if bends are necessary.

4.2.13 Loading test aerosol generator (see ISO 5011)

4.2.13.1 General

Aerosol generation shall be in accordance with ISO 5011:2000, 6.2.1 to 6.2.5. (See also 4.2.10.)

4.2.13.2 Loading test aerosol (air cleaner assembly only)

A dust injector (see ISO 5011:2000, Figure B.2 or B.3) shall be used to disperse the loading test aerosol (ISO 12103-1 test dust). The dust feeder location is shown in Figure 2.

4.2.13.3 Loading test aerosol dust feeder

A dust feeder capable of feeding a stable (within ±5 %) concentration of 1 g/m^3 of air at the test flow rate shall be used. Reference the dust feeder specifications and validation procedure in ISO 5011.

4.2.14 Upstream and downstream particle counter

4.2.14.1 General

Upstream and downstream particle counter shall be of the same model and shall be matched as closely as possible. A single particle counter can also be used for efficiency measurements using sequential measurements. The airborne particle counter shall be capable of recording particles in the 5 µm to 40 µm geometric equivalent size range. The particle counter shall be able, at a minimum, to discriminate eight logarithmically spaced particle size classes.

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4.2.14.2 Particle counter calibration

The particle counter shall be calibrated with polystyrene latex particles of appropriate size or other suitable particle standards prior to system start-up and a minimum of once a year to verify that the size calibration has not changed. It is recommended that the particle counter calibration be verified periodically during the year between calibrations.

4.2.14.3 Maximum particle concentration

The maximum total particle concentration shall be established to prevent coincidence counting (i.e. counting more than one particle at a time). A recommended method for establishing this limit is to conduct filter efficiency tests at a series of different concentrations and compare the results. The maximum concentration is determined at the point where increasing the concentration by a factor of two causes the fractional efficiency in the smallest size range at the higher concentration to be more than 5 % less than the fractional efficiency at the lower concentration. Another method is to increase the concentration in steps (e.g. by using a diluted and an undiluted aerosol) and determine the concentration where the particle measurement device starts showing significant deviation from the expected concentration in the smallest size range. An example is given in Annex D.

4.2.14.4 Particle counter flow

The particle measurement device flow rate shall remain constant within ±5 % for the duration of a test including the correlation done before the test.

4.2.14.5 Upstream/downstream particle counter correlation ratios

Correlation shall be performed using an elbow, or a tube, or an elbow and tube, the same size as the test ducting in place of the air cleaner assembly and in the same orientation as the air cleaner assembly inlet/outlet tubes under test. See Annex B to calculate correlation ratios.

4.2.15 Inlet and outlet piezometer tubes

Inlet and outlet piezometer tubes shall be installed upstream and downstream of the air cleaner unit under test. Inlet and outlet transition tubes shall adapt the unit under test to the piezometers if they are a different size from the piezometer. The inlet and outlet piezometer tubes shall be designed as specified in ISO 5011.

4.2.16 Airflow measurement

Measure airflow with an accuracy in accordance with Annex E. Convert all volume flow rates to actual conditions (ambient pressure and temperature).

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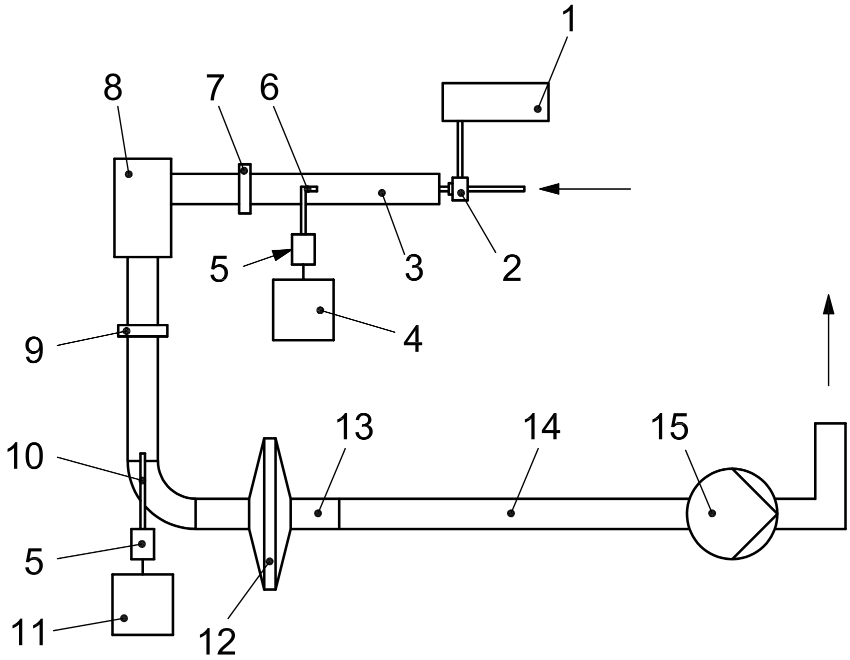

Key

1 dust feeder
2 dust injector
3 static mixer
4 upstream particle counter
5 dilution (if required)
6 upstream isokinetic sample probe
7 inlet piezometer tube
8 unit under test
9 downstream piezometer tube
10 downstream isokinetic sample probe
11 downstream particle counter
12 absolute filter
13 airflow straightener
14 airflow meter
15 airflow pump

Figure 2 — Test set-up to evaluate air cleaner assembly

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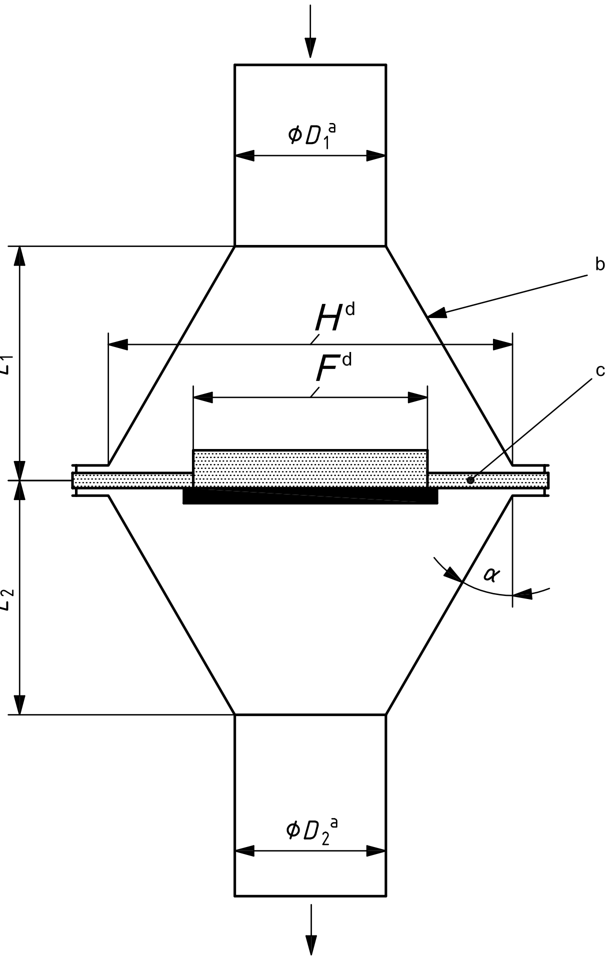

Key

D_1, D_2 tube diameters

F cross-sectional area of the panel filter element paper pack

H cross-sectional area of the housing

L_1, L_2 length of air cleaner housing

α angle $\leqslant$ 30° around the perimeter of the diffuser

[a] $D_1 = D_2$ and depends on the test flow rate (see Table 1).

[b] Smooth transition from a round duct to a rectangular cross-section.

[c] Filter should be sealed to the plate, for example see ISO 5011.

[d] Ratio of H to F shall not be less than 0,5.

[e] $L_1 = L_2$ and depends on area H and included angle α.

Figure 3 — Test set-up for panel-type and axial flow cylindrical-type air filter elements

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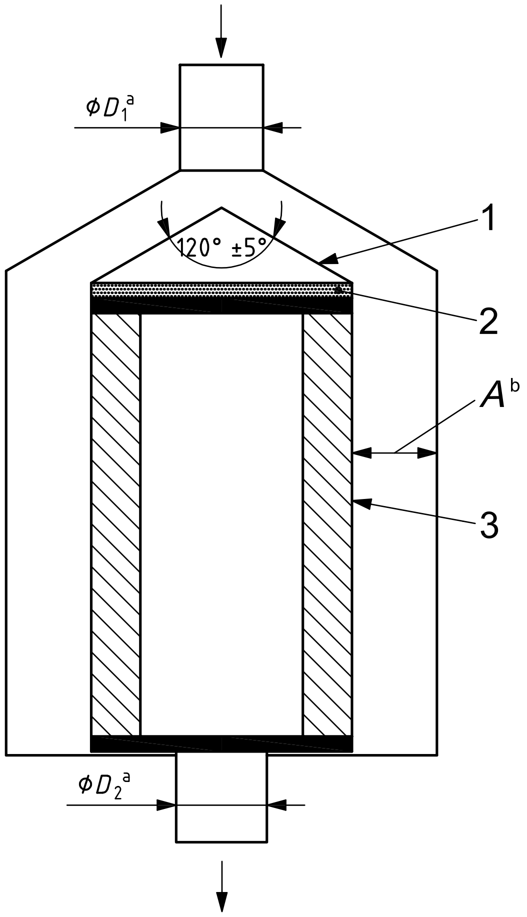

Key

D_1, D_2 tube diameters

A area

1 diffuser plate/cone

2 sealing plate

3 cylindrical round conical tapered air filter

[a] $D_1 = D_2$ and depends on the test flow rate (see Table 1).

[b] Area A is adjusted so that the annular face velocity of entry is in the range of (900 ± 50) m/min.

Figure 4 — Test set-up for cylindrical radial flow-type air filter elements

4.3 Test conditions

4.3.1 General

All tests shall be conducted with air entering the air cleaner assembly or air filter element in accordance with 4.2.4, with the permissible humidity variation throughout one single test being ±2 %.

4.3.2 Test aerosol

4.3.2.1 Fractional test aerosol

For this part of ISO/TS 19713, the KCl (potassium chloride) test aerosol shall be used.

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4.3.2.2 Loading test aerosol

For this part of ISO/TS 19713, the following test dust shall be used:

— for single-stage air cleaner assemblies and air filter elements: ISO 12103-1 A2 test dust;

— for pre-cleaners and multistage air cleaner assemblies: ISO 12103-1 A4 test dust.

Before a test, condition the dust in accordance with ISO 5011.

4.3.3 HEPA filter

A HEPA filter is used to provide clean air to the test stand if required. A high efficiency filter may be used downstream to protect the flow meter and air moving devices.

4.4 Validation

Prior to initial use, the test stand shall be validated in accordance with Table E.2.

IMPORTANT — If the test set-up undergoes any hardware/component changes, it needs to be re-verified and re-evaluated for that portion of the test stand and for those changes.

The validation certifying the performance of a system in accordance with this part of ISO/TS 19713 shall be documented, including the following:

a) system diagram and detailed description:

  — particle materials used in the tests including traceability;

  — manufacturer and model of the particle measurement device;

  — calibration data for the particle counter(s);

  — calibration data for flow measuring device;

b) calibration data for pressure transducers;

c) system performance on flow uniformity;

d) system performance on particle concentration uniformity;

e) data demonstrating that the coincidence counting error meets the criteria of Table E.2;

f) data showing the agreement between upstream and downstream particle counters for a single or dual-counter system;

g) data showing that the efficiency test aerosol concentration is low enough to avoid loading effects during the efficiency test for an unloaded filter element;

h) sample test data;

i) sample test data showing the repeatability of test results;

j) data demonstrating the amount of particle loss for large particles in the sampling system.

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4.5 Reference air cleaner assemblies/air filter elements

4.5.1 General

Upon initial calibration and validation of the system, the efficiency of an unloaded reference air cleaner assembly should be measured. This air cleaner assembly is taken as the reference that will be used to monitor changes in the test system and will be taken for periodic checks of the system performance.

4.5.2 Sampling lines

All sampling lines shall be flushed (cleaned) with clean filtered compressed air to remove any residual aerosols from the previous tests. A HEPA filter cartridge may be used as an end cleanup filter for cleaning the compressed air.

4.5.3 Particle counter

The particle counter shall be checked periodically for zero count.

4.6 Routine operating procedure

4.6.1 General

See Table E.3.

4.6.2 Periodical start-up procedure

Periodically, as required to maintain accuracy in accordance with Annex E, certain start-up procedures shall be performed to verify the continued proper operation of the test system. Such procedures include but are not limited to:

— verification of particle counter operation such as flow rate and zero count (Table E.3);

— measurement of background particle count in the test duct with no test filter and no test aerosol;

— correlation of upstream and downstream particle sampling and measuring systems;

— check zero on pressure measurement devices.

See, for example, Table E.3. The reference air cleaner assemblies or air filters will be used for daily checks of system performance.

4.6.3 Other periodic procedures

See Table E.3.

5 Fractional efficiency test

5.1 General

The purpose of this test is to determine the particle collection capabilities of the filter. This test is conducted with constant airflow rate using the aerosol described in 4.2.10.

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5.2 Test procedure

a) Monitor temperature and relative humidity continuously.

b) Set the specified volume flow rate and measure the tare pressure loss with no air cleaner or filter in the test stand.

c) Perform all necessary calibration after every change in test set-up as described in Annex E.

d) Mount the air cleaner assembly or air filter element in their respective test housing in accordance with Figure 2, 3 or 4. Test the air cleaner assembly as installed in the vehicle.

e) Set the specified volume airflow rate.

f) Condition the air cleaner assembly or the air filter element by stabilizing to temperature and humidity test conditions in accordance with 4.3 at rated flow for at least 15 min.

g) Measure pressure loss (ΔP_i) of new filter.

h) Start feeding the efficiency test aerosol (as specified in 4.2.10) and wait for the upstream aerosol to become stable.

i) Stabilize dust feeder to the required dust mass flow and keep these settings.

NOTE The particle counts upstream should be within ±5 % of the average of three measurements.

j) Determine the fractional efficiencies by particle counting as follows:

- For sequential counting systems, start with the counter connected to the upstream sample probe; wait for the sampling system to equilibrate; then the upstream particles should be counted. Switch to the downstream sample probe; wait for the sampling system to equilibrate; then the downstream sample should be counted. The upstream-downstream cycle should be repeated two more times for a total of three upstream and three downstream samples. Calculate the filter efficiency for each of the three samples.

- For simultaneous counting systems, the particles for both the upstream and downstream should be counted and recorded. Repeat two more times for a total of three upstream and three downstream samples. Calculate the filter efficiency for each of the three samples.

- Follow the procedure for efficiency data reduction in Annex B.

k) Examine the three filter efficiency measurements for trends. Filter efficiency may decrease or increase as a filter is loaded. If the efficiency aerosol concentration is too high, then it might load the filter enough to alter the measured efficiency. In that case, the measured efficiency will not represent the fractional efficiency before dust loading. The three efficiency measurements might vary within ±5 % in the 5 µm particle size class. If efficiency measurements are > ±5 % apart, then the current test is invalid and the efficiency aerosol concentration should be reduced prior to any additional tests. After reducing the concentration of the test aerosol, start a new test with a new filter in the air cleaner assembly.

l) If there is no significant trend in the filter efficiency from the beginning to the end of these tests, then calculate the efficiency of the unloaded filter element by calculating the average values of the three measurements.

m) If these efficiency tests with the unloaded filter element will be followed by an additional loading and/or incremental fractional efficiency tests, then continue that test immediately upon completion of the efficiency test. If only the fractional efficiency before dust loading test is required, then calculate the results.

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n) Start or resume feeding the loading dust until the pressure loss across the filter has reached the second incremental pressure loss.

o) Measure the incremental fractional efficiency with the particle counters as described above.

p) Repeat the cycle of measuring fractional efficiency and loading until the final pressure loss has been reached and the final fractional efficiency has been measured.

q) Calculate the efficiency and confidence limits for each particle size range and each loading increment using the methods in Annex B. For calculations where the smallest number count exceeds 500, the efficiency may be calculated without using the upper and lower confidence limits.

r) The minimum information to be included in the report is shown in Annex A. As a proposal, use the form in Annex A to report results.

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Annex A
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Test report

Engine air cleaners for light, medium and heavy duty vehicles **Fractional efficiency test report**		
1 Test unit		
Manufacturer: .... Type of filter media: .... Air cleaner description and orientation: .... Air filter description and orientation: .... Pre-cleaner/pre-separators:		
2 Test equipment		
Test duct set-up and orientation		
Dust feeder:	Contaminant for efficiency measurements (ISO 12103-1 A2/A4 test dust) Equipment: .... Settings/feed rate:	
	Contaminant for loading (ISO 12103-1 A2 test dust) Equipment: .... Settings/feed rate:	
Particle counter:	Type: .... Sample flow:	
3 Test conditions		
Test flow rate (m^3/h): .... Test termination criteria:		
Temperature (°C):	Before test: .... After test:	
Barometric pressure (kPa):	Before test: .... After test:	
Relative humidity (%):	Before test: .... After test:	
Total cumulative counts (counts/cm^3): .... Test termination (kPa): .... Fractional efficiency intervals: .... Initial restriction (kPa):		
4 General comments		
Date:	Test conducted by:	

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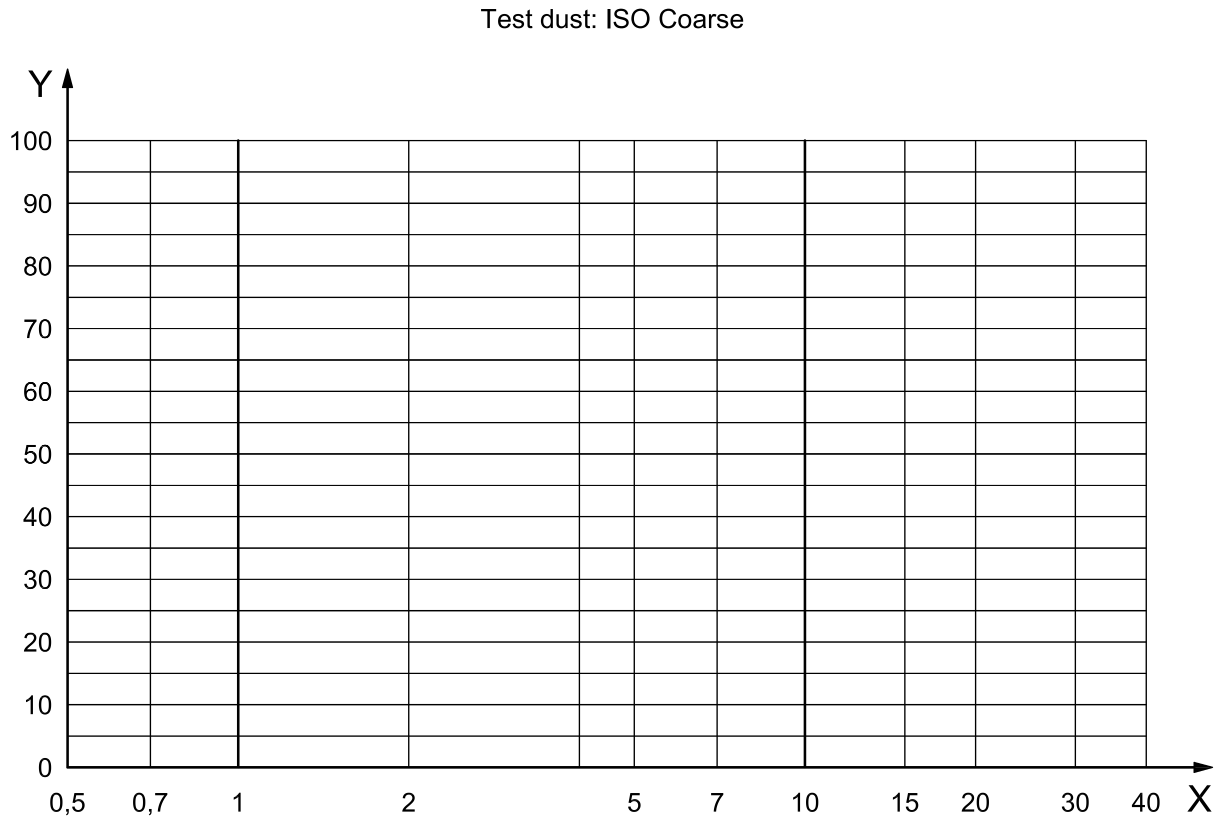
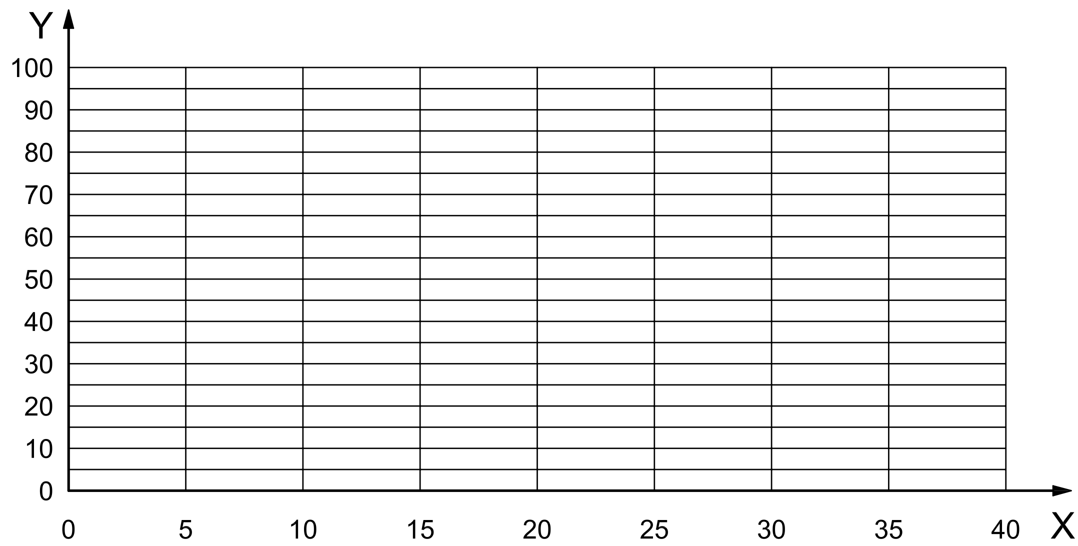


Key

X optical particle diameter, in µm

Y fractional filtration efficiency, in percentage

Figure A.1 — Fractional efficiency as a function of particle size and dust capacity at test flow rate



Key

X dust loading, in g

Y pressure difference, in Pa

Figure A.2 — Pressure loss versus aerosol loading

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Annex B
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Efficiency data reduction

B.1 Overview

B.1.1 General

When using particle counters to evaluate fractional size filtration efficiency, it is necessary to consider limitations imposed by this method. The efficiency is determined by comparing the particles detected and counted upstream of the air cleaner or air filter to the particles detected and counted downstream of the air cleaner or air filter. Inevitably, there are differences between the upstream and downstream sampling and detection equipment. This annex presents a method to calculate correlation ratios to minimize the errors due to the difference between the upstream and downstream equipment. In addition to correcting for small variations between upstream and downstream equipment, the correlation ratio may be used to correct for unequal upstream and downstream sample times.

When the number of particles counted in any size class is low, potential errors may occur as a result of counting a few randomly occurring events. The method to quantify the size of the potential error from counting a few particles is presented. Because the error due to counting random events is a function of the total number of particles counted, it is important to work with the actual counts, not concentrations or averages. In the efficiency tests described in this test code, three upstream and three downstream samples are counted. The counts from those three samples shall be added together to obtain total upstream and total downstream counts in each size class. The totals are used for the calculations described in this annex. Using average counts will cause the calculated confidence limits to be worse than they should be.

These data reduction techniques only address the correlation of upstream and downstream sampling and counting, and the statistics of counting a small number of particles. The confidence intervals calculated with the methods in this annex do not necessarily reflect the overall test accuracy or precision. The test accuracy and precision can not be any better than the confidence interval calculated from the counting statistics but it may be worse because these data reduction techniques do not address any other sources of error. To minimize the other sources of errors, it is important that the test system be qualified and calibrated as described in Clauses 4 and 5.

Clauses B.2 to B.5 present “cook book” calculations. Clause B.6 presents more detail, including a sample calculation. The calculations are carried out in terms of penetration, the ratio of the concentration of particles downstream of the filter to the concentration upstream. The penetrations can be converted to efficiencies after the calculations are completed. The calculations are carried out for each particle size class of interest.

The symbols and subscripts in B.1.2.1 and B.1.2.2 are used in equations in this annex.

B.1.2 Symbols and subscripts

B.1.2.1 Symbols

N particle counts

R correlation ratio

P penetration

T sampling time

E efficiency

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B.1.2.2 Subscripts

o	observed
ucl	upper confidence limit
lcl	lower confidence limit
spec	specified performance
c	correlation (i.e. no filter installed)
t	testing a filter
uc	upstream during correlation
dc	downstream during correlation
ut	upstream during test
dt	downstream during test

B.2 Correlation ratio

B.2.1 Observed value — Correlation ratio

Using counts obtained with test filter replaced by a straight vertical tube, the observed correlation ratio should be calculated for each size class as shown in Equation (B.1):

$$R_{\text{o,c}} = \frac{N_{\text{o,dc}}}{N_{\text{o,uc}}} \quad \text{(B.1)}$$

NOTE Any dilution system to be used for the measurement also needs to be present for the correlation ratio measurement.

B.2.2 Upper confidence limit and lower confidence limit values — Correlation ratio

B.2.2.1 For numbers $N \leqslant 50$, Table B.4 should be used to determine the 95 % upper and lower confidence limits for each size class for the upstream and downstream counts with no filter installed.

B.2.2.2 For numbers $N > 50$, use Equation (B.2) to determine the upper and lower confidence limits for each size class:

$$N \pm \left(2 \times \sqrt{N}\right) \quad \text{(B.2)}$$

EXAMPLE $N_{\text{ucl,dc}} = N_{\text{o,dc}} + \left(2 \times \sqrt{N_{\text{o,dc}}}\right)$

Equations (B.3) and (B.4) calculate confidence limits on the correlation ratio:

$$R_{\text{ucl,c}} = \frac{N_{\text{ucl,dc}}}{N_{\text{lcl,uc}}} \quad \text{(B.3)}$$

$$R_{\text{lcl,c}} = \frac{N_{\text{lcl,dc}}}{N_{\text{ucl,uc}}} \quad \text{(B.4)}$$

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B.3 Penetration

B.3.1 Observed penetration

With the test filter installed, upstream and downstream counts should be obtained to calculate the observed penetration for each size class, as shown in Equation (B.5):

$$P_{\text{o}} = \frac{N_{\text{o,dt}}}{N_{\text{o,ut}} \times R_{\text{o,c}}} \quad \text{(B.5)}$$

B.3.2 Upper confidence limit and lower confidence limit values — Penetration

The upper confidence limit and lower confidence limit values should be calculated for the upstream and downstream counts for each size class, using Table B.4 for numbers $N \leqslant 50$ and by means of Equation (B.2) for numbers $N > 50$. The upper confidence limit and lower confidence limit of the penetration should be calculated for each size class as shown in Equations (B.6) and (B.7):

$$P_{\text{ucl}} = \frac{N_{\text{ucl,dt}}}{N_{\text{lcl,ut}} \times R_{\text{lcl,c}}} \quad \text{(B.6)}$$

$$P_{\text{lcl}} = \frac{N_{\text{lcl,dt}}}{N_{\text{ucl,ut}} \times R_{\text{ucl,c}}} \quad \text{(B.7)}$$

B.4 Calculations for unequal sample times

If Equation (B.8) is true, then no adjustments for sampling time needs to be made:

$$\frac{T_{\text{uc}}}{T_{\text{dc}}} = \frac{T_{\text{ut}}}{T_{\text{dt}}} \quad \text{(B.8)}$$

If the condition in Equation (B.8) is not met, then the calculation for the observed penetration is as shown in Equation (B.9):

$$P_{\text{o}} = \frac{T_{\text{ut}}}{T_{\text{dt}}} \times \frac{N_{\text{o,dt}}}{N_{\text{o,ut}} \times \left(\frac{N_{\text{o,dc}}}{N_{\text{o,uc}}} \right) \times \left(\frac{T_{\text{uc}}}{T_{\text{dc}}} \right)} \quad \text{(B.9)}$$

The calculation for the upper confidence limit and lower confidence limit values of the penetration are as shown in Equations (B.10) and (B.11):

$$P_{\text{ucl}} = \frac{T_{\text{ut}}}{T_{\text{dt}}} \times \frac{N_{\text{ucl,dt}}}{N_{\text{lcl,ut}} \times \left(\frac{N_{\text{lcl,dc}}}{N_{\text{ucl,uc}}} \right) \times \left(\frac{T_{\text{uc}}}{T_{\text{dc}}} \right)} \quad \text{(B.10)}$$

$$P_{\text{lcl}} = \frac{T_{\text{ut}}}{T_{\text{dt}}} \times \frac{N_{\text{lcl,dt}}}{N_{\text{ucl,ut}} \times \left(\frac{N_{\text{ucl,dc}}}{N_{\text{lcl,uc}}} \right) \times \left(\frac{T_{\text{uc}}}{T_{\text{dc}}} \right)} \quad \text{(B.11)}$$

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B.5 Efficiency

The efficiency for each size class is calculated from the penetration, as shown in Equations (B.12) to (B.14):

$$E_{o} = 1 - P_{o} \quad \text{(B.12)}$$

$$E_{lcl} = 1 - P_{ucl} \quad \text{(B.13)}$$

$$E_{ucl} = 1 - P_{lcl} \quad \text{(B.14)}$$

B.6 Poisson statistics and counting

B.6.1 Theory

When a well-mixed, stable aerosol penetrates a filter, penetrating particles will appear downstream of the filter (or in a small downstream air sample) randomly, but at some average population density. A particle measurement device will detect these randomly in time, but at an average rate. For the purpose of calculating penetration, the average rate (particles per unit time or per unit volume) is obtained from the cumulative counts measured over the time period of the test or over the volume sampled.

The statistics of particle counting become increasingly important as the filter penetration, and hence downstream counts, decrease. These variations are described by Poisson statistics. Of primary importance to this type of testing is the relationship between the results of a single test and the results that would be obtained from a test of infinite duration — the true mean result. This relationship between an observed result and the implied confidence limits on the true mean result is described very well in the literature (see the Bibliography).

B.6.2 Practice

When top performance, noise-free particle counters are used in a good duct in accordance with this part of ISO/TS 19713, count statistics may become the largest error on highly efficient filter tests. When testing highly efficient filters in accordance with this part of ISO/TS 19713, low downstream particle counts are the largest source of uncertainty.

B.6.3 Recommendation

B.6.3.1 Determination of confidence limits on a count

This procedure uses particle count data to establish the confidence limits on penetration. Equation (B.2) gives the 95 % confidence limits on a single observed particle count N when $N > 50$. For a single observed particle count N, there is a 95 % confidence that the true mean count is between the upper and lower limits given by the equation. The true mean count is the average count that would be obtained if the tests were repeated indefinitely (see Reference [16]).

Table B.1 — Example of confidence limits

Observed count	95 % confidence limits	
N	lower	upper
100	80	120
10 000	9 800	10 200

Once the confidence limits on a particle count are established, it is necessary to establish the confidence limits on the correlation ratio and penetration.

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B.6.3.2 Determination of confidence limits on correlation ratio

Statistical uncertainty exists in the ratio of downstream to upstream counts, with no filter in the system. This uncertainty should be established before the penetration is calculated. For example, consider a correlation where the observed counts are 10 000 upstream and 12 000 downstream, as shown in Table B.2.

Table B.2 — Example of correlation ratios

Observed value	95 % confidence limits on correlation ratio	
	lower	upper
10 000 counts upstream	9 800	10 200
12 000 counts downstream	11 781	12 219
NOTE In this example, there are fewer upstream counts than downstream counts due to slight differences in the sampling systems and counters.		

The confidence limits on the correlation ratio are as follows:

— observed: $R_{o,c} = \frac{12\,000}{10\,000} = 1{,}20$;

— lower: $R_{lcl} = \frac{11781}{10\,200} = 1{,}15$;

— upper: $R_{ucl} = \frac{12\,219}{9\,800} = 1{,}25$.

If the uncertainty in the correlation ratio is significantly less than the uncertainty in the penetration of the filter under test, it is reasonable to use the observed value of the correlation ratio. Otherwise, the 95 % confidence limits of the correlation ratio should be used.

B.6.3.3 Determination of confidence limits on filter penetration

The correlation example in B.6.3.2 is used to calculate the penetration of a filter test as shown in Table B.3.

Table B.3 — Example of filter penetration

Observed value	95 % confidence limits on filter penetration	
	lower	upper
1 000 counts upstream	937	1 063
100 counts downstream	80	120

Using the 95 % confidence limits on the correlation ratio:

a) the confidence limits on filter penetration are as follows:

— observed: $P_o = \frac{100}{1\,000 \times 1{,}2} = 0{,}083 = 8{,}3\,\%$;

— lower: $P_{lcl} = \frac{80}{1\,063 \times 1{,}25} = 0{,}060 = 6{,}0\,\%$;

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— upper: $P_{\text{ucl}} = \dfrac{120}{937 \times 1{,}15} = 0{,}111 = 11{,}1\,\%$;

b) the efficiency is as follows:

— observed: $E_{\text{o}} = 1 - 0{,}083 = 0{,}917 = 91{,}7\,\%$;

— lower: $E_{\text{lcl}} = 1 - 0{,}111 = 0{,}889 = 88{,}9\,\%$;

— upper: $E_{\text{o}} = 1 - 0{,}060 = 0{,}940 = 94{,}0\,\%$.

In the above example, it can be stated with 95 % confidence that the filter penetration is between 6,0 % and 11,1 %, or that the efficiency is between 88,9 % and 94,0 %.

The following points should be noted:

— the particle size range in which the counts were obtained should also be given;

— this confidence level is based on counting statistics only;

— other error sources may contribute to the uncertainty of the penetration and efficiency measurements;

— for very low penetration filters, the errors due to the counting statistics may be a major factor in determining the overall test precision; for higher penetration filters, when it is possible to obtain higher number counts, this error source becomes less important as compared to the other error sources;

— the statistical procedures described here apply only to raw count data: it is improper to apply these methods to data that have been scaled, averaged, multiplied by correlation ratios, converted to rates or concentrations, etc., because this would yield erroneous results.

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Table B.4 — 95 % confidence limits for the mean value of a Poisson variable

Observed count N	Lower limit	Upper limit
0	0,0	3,7
1	0,1	5,6
2	0,2	7,2
3	0,6	8,8
4	1,1	10,2
5	1,6	11,7
6	2,2	13,1
7	2,8	14,4
8	3,5	15,8
9	4,1	17,1
10	4,8	18,4
11	5,5	19,7
12	6,2	21,0
13	6,9	22,3
14	7,7	23,5
15	8,4	24,8
16	9,2	26,0
17	9,9	27,2
18	10,7	28,4
19	11,4	29,6
20	12,2	30,8
21	13,0	32,0
22	13,8	33,2
23	14,6	34,4
24	15,4	35,6
25	16,2	36,8
26	17,0	38,0
27	17,8	39,2
28	18,6	40,4
29	19,4	41,6
30	20,2	42,8
31	21,1	44,0
32	21,9	45,1
33	22,7	46,3
34	23,5	47,5
35	24,4	48,7
36	25,2	49,8
37	26,1	51,0
38	26,9	52,2
39	27,7	53,3
40	28,6	54,5
41	29,4	55,6
42	30,3	56,8
43	31,1	57,9
44	32,0	59,0
45	32,8	60,2
46	33,7	61,3
47	34,5	62,5
48	35,4	63,6
49	36,3	64,8
50	37,1	65,9
NOTE See Reference [17].		

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Annex C
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Pressure loss data reduction

If the temperature and pressure at the filter under test are different from the standard conditions of 20 ± 5 °C and 101,3 kPa, then the measured pressure loss shall be corrected to indicate the pressure loss that would be measured if the conditions were standard.

The correction required for the pressure loss measurement depends on the test conditions and on the type of air cleaner or air filter being tested. For tests in accordance with this part of ISO/TS 19713, the temperature shall be controlled to the standard temperature so the primary variable is the absolute pressure at the unit under test. This part of ISO/TS 19713 requires that the test be conducted at specified actual volume flow rates in order to minimize changes in the efficiency measurement due to different velocities. Therefore, if the absolute pressure at the filter under test is not standard pressure, then the measured filter pressure loss is corrected as follows.

NOTE 1 This is independent of the corrections required for the flow rate measurement device that are required to establish the correct actual volume flow rate at the filter under test.

Measure the unit pressure loss, ΔP, as a function of volume flow rate, Q, or at a set flow rate, Q. Plot the measured pressure loss, ΔP_m, as a function of the measured flow rate, Q_m. Note that in this test method, Q_m is the actual volume flow rate at the filter at the test conditions. Find K_1 and K_2 by doing a least squares curve fit of Equation (C.1) to the data:

$$\Delta P_m = (K_1 \times \eta_m \times Q_m) + \left(K_2 \times \rho_m \times Q_m{}^2\right) \tag{C.1}$$

where

η_m is the dynamic viscosity of air in the unit at the test conditions;

ρ_m is the mass density of air in the unit at the test conditions.

Use Equation (C.2) to calculate the standard filter pressure loss, ΔP_s, at the specified flow rate in the range of flow rates measured. Extrapolation to flow rates outside the measured range is not recommended.

$$\Delta P_s = (K_1 \times \eta_s \times Q_s) + \left(K_2 \times \rho_s \times Q_s{}^2\right) \tag{C.2}$$

where

η_s is the dynamic viscosity of air at standard conditions;

ρ_s is the mass density of air at standard conditions;

Q_s is the flow at standard conditions.

NOTE 2 Since the temperatures are controlled to standard conditions, the correction due to the $(K_1 \times \eta_s \times Q)$ term will be negligible.

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Annex D
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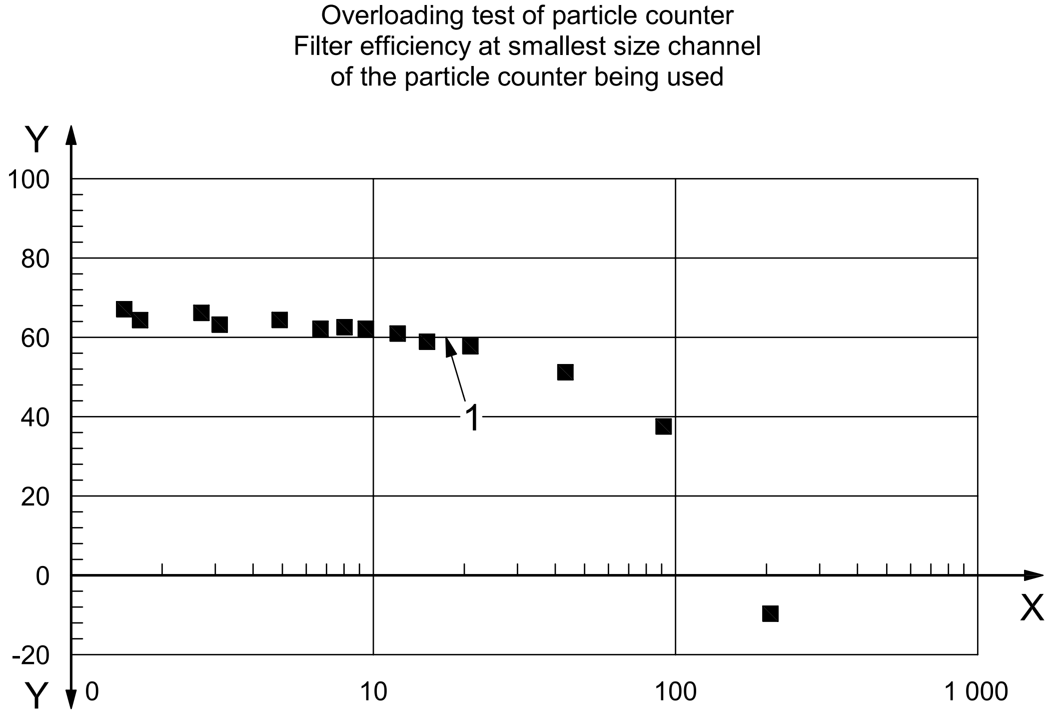
Determination of maximum efficiency aerosol concentration

In 4.2.14, it is recommended to perform fractional efficiency tests versus particle concentration for particle size ranges using particle counters. An example is illustrated in Figure D.1. When the concentration is low, the fractional efficiencies are not stable due to lack of enough counts as seen on the left-hand side of the curves. The fractional efficiencies will then be stable over a range of particle concentrations. As the particle concentration is further increased, the efficiency of the lowest channel will start to drop due to coincidence problem. The appropriate particle concentration range should be the range in which the fractional efficiencies are stable. It should be noted that the appropriate particle concentration range for different particle counters may be different. The tests described here should be performed when different counters are used.



Key

X total concentration

Y filtration efficiency, in percentage

1 upper limit for testing

Figure D.1 — Example for efficiency at various sizes versus particle counts

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Annex E
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Accuracy requirements, validation and routine operation

Tables E.1 to E.3 provide lists of the items that need to be designed, verified, measured, calibrated or certified to ensure that a test system meets the requirements of this part of ISO/TS 19713. This part of ISO/TS 19713 describes the required performance of the test system, rather than requiring specific hardware and specific procedures. Hence, it is up to the builder and user of the test system to verify that the required performance is in fact achieved.

Table E.1 contains instrumentation accuracy and other requirements that are generally established by the instrumentation used in the test system. The criteria for most items in Table E.1 are met with traceable calibration.

Table E.2 contains system characteristics that are established by system design. These characteristics need to be measured once to verify the system design and to verify the initial performance of the test system. The criteria for most items in Table E.2 are verified by measurement of the characteristic of the test system.

NOTE Requirements for documenting the test system validation are given in 4.4.

Table E.3 contains calibrations, measurements and activities that need to be repeated on a scheduled basis to ensure the continued repeatability and reproducibility of the test system.

Clause numbers in Tables E.1 to E.3 refer to the clauses of this part of ISO/TS 19713 in which the information may be found.

Table E.1 — Instrument accuracy requirements

Clause	Description	Criteria	Comments
ISO 5011:2000, Clause 4	Airflow rate measurement accuracy	±2 % of reading	±2 % repeatability
—	Air velocity measurement accuracy	±3 % of reading	—
—	Pressure loss measurement accuracy	±1 % of reading	—
4.3	Temperature measurement accuracy	±0,5 ºC	—
4.3	Relative humidity measurement accuracy	±2 % RH	—
—	Barometric pressure measurement accuracy	±300 Pa	—
4.2.13	Particle measurement device size range	5 µm to 40 µm	Geometric equivalent diameter

Table E.2 — Validation (measurement devices and procedures)

Clause	Description	Criteria	Comments
	Test system, conductive and grounded	—	Verify with continuity tester
Annex B	Test system, minimize particle loss	—	Verify by correlation measurement
4.2.5	Temperature control	(23 ± 5) °C	In accordance with ISO 5011
4.2.5	Relative humidity control	(55 ± 15) %	In accordance with ISO 5011
4.2.9	Test duct air leakage	—	Verify by inspection
4.2.7	Air cleanliness, background particle counter	< 2 % of efficiency challenge	In accordance with size channel

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Table E.2 (*continued*)

Clause	Description	Criteria	Comments
Table E.1	Flow rate control accuracy, shall be accurate as mounted in system	±5 % accuracy	±2 % repeatability
4.2.8	Airflow uniformity	±10 %	—
Annex E	Pressure loss measurement accuracy	±2 %	—
4.2.12	Sample probe isokinetic	0 % to ±20 %	By calculation from flow rates and diameters
4.2.12	Sample probe location in accordance with Figure 3, upstream, centred, close to filter, centred at least $6 \times D$ downstream of any bends and obstructions	100 mm	Approximate distance, allows for different filter thickness
4.2.12	Sample probe location in accordance with Figure 3, downstream, centred, at least $6 \times D$ downstream of any bends and obstructions	—	—
4.2.12	Sample line design and conductivity	—	Inspection and electrical continuity to ground
4.2.10	Aerosol generator, fraction efficiency, stable size distribution (within each size channel)	ISO 12103-1/ ISO 5011	—
5.2	Minimum number of particle counts upstream in each size range	500	Typical minimum
5.2	Fractional efficiency aerosol, concentration low enough so there is no change in efficiency during test (i.e. no loading effects)	This is established on a clean filter	No significant trend compared to the test system repeatability as measured in 5.1.3.3
4.2.13	Dust feeder for loading aerosol, stable concentration	±5 %	—
4.2.13	Dust feeder for loading aerosol and efficiency measurement, concentration	1 g/m^3	Same as ISO 5011
4.2.12	Dust feeder for loading aerosol and efficiency measurement, size distribution in test duct	—	Use ISO 5011 dust injector or demonstrated equivalent
4.2.13	Particle counters, primary size calibration	—	In accordance with manufacturer specification
4.2.14.3	Aerosol, fractional efficiency, concentration below particle measurement device limit to prevent coincidence	Maximum of 5 % decrease	Procedure in Annex D
Annex B	Correlation of sampling systems and counters (zero efficiency filter)	Stable within 5 % for three measurements	—
5.2	Repeatability of pressure loss and efficiency	±5 %	To be done at installation and repeated minimum annually
4.4	Reference filter test	Set baseline	Use to monitor changes in test system performance
4.4	Performance certification documentation	Not applicable	For the test system validation to be complete it shall be documented
NOTE The order in which the validation tests are done is important. The order given in this table can be used as a guide. See also Table E.3.			

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Table E.3 — Routine operation

Clause	Description	Criteria	Frequency[a]	Comments
5.2	Pressure loss across empty test section (tare pressure loss)	—	As required to maintain accuracy	—
4.6.2	Particle measurement device zero check	—	Weekly	Maximum 10 counts per minute per channel
4.6.2	Air cleanliness, background particle count	< 2 % of efficiency challenge	As required to maintain accuracy	In accordance with size channel
4.2.14	Particle measurement device calibration	—	Annually	In accordance with manufacturer specification
4.2.13	Dust feeder for loading aerosol, stable concentration	±5 %	New design or test flow rate	—
4.2.13	Loading test aerosol concentration	1 g/m^3	As required to maintain accuracy	See ISO 5011
Annex D	Coincidence error	—	Change	—
4.2.7	Leak test	—	After every test	Visual inspection
Annex E	Calibration of airflow measurement	±2 %	Annually	—
Annex E	Calibration of pressure loss measurement	±1 %	Annually	—
Annex E	Calibration of other instrumentation (temperature, relative humidity, etc.)	See Table E.1	Annually	In accordance with instrument manufacturer's recommendations or annually
—	Cleaning of test duct and components	—	After every test	As needed

[a] Change refers to any change in the test system that might affect the performance.

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Annex F
(informative)

Particle diameters

F.1 General

As the challenge aerosol particles are non-spherical particles, the definition of equivalent diameters is necessary. Depending on the physical measurement principle, or the investigated particle characteristic, it is possible to measure on one particle different equivalent diameters. Hence, the equivalent diameter does not describe the real size of an irregular shaped particle.

F.2 Equivalent diameter

An equivalent diameter is the diameter of a sphere, which results at the measurement of a particle characteristic in the same diameter as the irregular shaped particle.

For example, the deposition of airborne particles in a filter, transportation losses in ducts and the behaviour of particles in the human respiratory tract are based on the particle's aerodynamic properties. Therefore, the Stokes diameter is used to characterize particles in these cases. Optical particle counters measure the scattering light equivalent diameter of the particle which, besides the orientation of the particle, also depends on the optical properties of the particle's material.

The Stokes diameter is the diameter of a sphere with the same terminal settling velocity as the particle, due to gravitational force in calm air, under the prevailing conditions of temperature, pressure and relative humidity.

The Stokes diameter D_{W} is defined as shown in Equation (F.1):

$$D_{\mathrm{W}} = \sqrt{\frac{18\,\eta_{\mathrm{fl}}\,w_g}{\left(\rho_{\mathrm{s}} - \rho_{\mathrm{fl}}\right) g}} \quad \text{(F.1)}$$

where

ρ_{s} is the density of the test dust particle, in kg/m^3;

ρ_{fl} is the density of the fluid, in kg/m^3;

g is the gravitational constant, 9,81 m/s^2;

η_{fl} is the dynamic viscosity of the fluid, in Pa;

w_g is the terminal settling velocity of the investigated particle, in m/s.

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F.3 Shape factors

As every different physical measurement principle measures different particle characteristics, the particle size measured at the same particles can be different. To have comparable results, a shape factor is necessary to convert an equivalent diameter into another. The shape factors are proportions of different equivalent diameters D_A and D_B:

$$\Psi_{A,B} = \frac{D_A}{D_B} \tag{F.2}$$

where $0 < \Psi_{A,B} \leqslant 1$.

Consequently, the measured particle size distributions need to be corrected, if necessary, for each size class with different shape factors. The shape factor can be calculated by a comparison of the defined particle size distribution of the used standard test dust in accordance with ISO 12103-1 A2 test dust to the measured size distribution.

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Annex G
(normative)

Aerosol isokinetic sampling

Fractional efficiency defines the ability of an air filter to remove particles of given sizes, and is measured by comparing upstream and downstream particle concentrations during laboratory testing. A major factor in making this measurement is the ability to collect representative samples for analysis. Isokinetic sampling, including proper probe alignment, provides a method for obtaining representative samples at the inlets of upstream and downstream sampling probes. Isokinetic sampling, using thin-walled, sharp-edged tubes or nozzles, ensures that there is no distortion of the streamlines at the nozzle inlet and, therefore, no loss or gain of particles regardless of their size or inertia. Sampling is considered isokinetic when the probe is aligned parallel to the air streamlines and the air velocity entering the probe is the same as the free stream velocity approaching the inlet, as shown in Figure G.1 a), with $V_{\mathrm{S}} = V_{\infty}$.

In most cases, for circular ducts, the probe inlet is located along the duct centreline, parallel to the flow, facing upstream, at least four to six diameters from bends or obstructions. Cases requiring probe locations of less than four to six diameters downstream from bends or obstructions, or when sampling in non-circular ducts, are likely to require samples from multiple cross-sectional regions, greatly complicating the sampling task. Local velocities can be measured across the duct to establish the velocity profile in support of isokinetic sampling. It is important to recognize that the particle size distribution of the upstream particles can be skewed from the velocity profile, depending on duct geometry and upstream and downstream obstructions. In addition, isokinetic sampling does not guarantee that there are no particle losses between the nozzle entrance and the particle counter.

Failure to sample isokinetically, termed anisokinetic sampling, is likely to cause distortions in both particle size distribution and particle concentration. This is caused by particle inertia along the curved streamlines, as the flow converges or diverges at the nozzle inlet, as illustrated in Figures G.1 b) and G.1 c) for super- and sub-isokinetic sampling, respectively. The extent of the errors in concentration for given particle sizes depends on the square root of the Stokes number, which is directly proportional to particle size and depends on the actual sampling conditions.

As shown in Figure G.1 b), the suction area in the case of super-isokinetic sampling (when the velocity entering the probe exceeds the stream velocity) is greater than for isokinetic sampling. In this case, larger particles with high inertia from this area cannot follow the converging streamlines and will be lost from the sample, while an excessive number of finer particles will follow the streamlines and enter the nozzle. This will lead to an overrepresentation of fine particles in the aerosol sample.

For sub-isokinetic sampling [Figure G.1 c),with probe velocity less than stream velocity], the suction area is smaller than for isokinetic sampling. In this case, larger particles from outside of the original sampling area will enter the nozzle, while some of the finer particles originally in the sampling area will follow the streamlines and diverge past the nozzle. This will lead to an overrepresentation of larger particles in the aerosol sample.

Isoaxial and isokinetic sampling is the ideal sampling configuration and will aspirate all representative particle sizes with nearly 100 % efficiency, especially for particles in the submicron to 10 µm range. A departure from this ideal configuration into regions of anisokinetic and anisoaxial sampling results in non-representative sampling. This should be avoided when making fractional efficiency measurements.

Because particle counters have fixed flow rates, isokinetic sampling is achieved by changing the size of the sampling probe inlet to provide velocity matching. This is accomplished using Equation (G.1), assuming the probe inlet and approach velocities are equal and that probe and duct airflow rates are known. For this case, the probe inside diameter, d, would normally be equal to the main duct diameter, D, multiplied by the square root of the ratio of the sampler flow rate, q, to the main duct flow rate, Q, as shown in Equation (G.1):

$$d = D\sqrt{\left(\frac{q}{Q}\right)} \quad \text{(G.1)}$$

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It has been shown, however, that more accurate results are obtained when using Equation (G.2) to determine inside probe diameter:

$$d = \sqrt{\frac{Q\left(D^2 - d_\text{o}^{\;2}\right)}{q}} \tag{G.2}$$

where

Q is the flow rate in test duct;

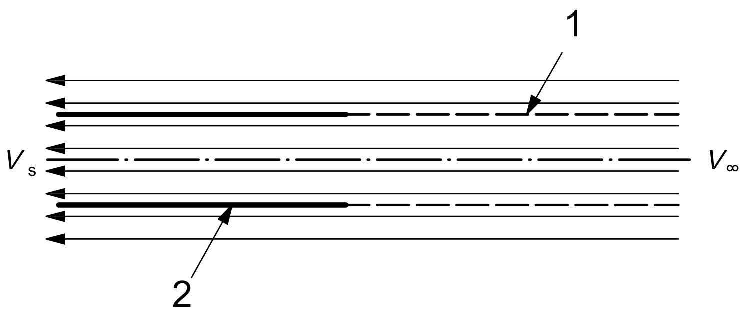
D is the diameter of test duct;

d_o is the outside diameter of sampling probe;

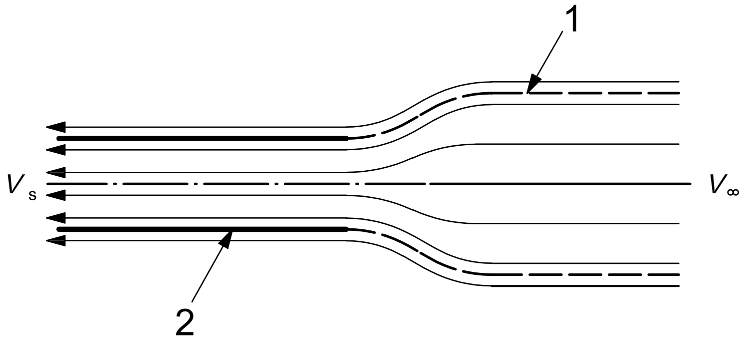
q is the flow rate in sample line.

Acceptable sampling nozzle designs are shown in Figure G.2.

As noted, anisoaxial sampling causes particles with sufficient inertia to diverge from the aerosol streamlines, resulting in lower sampling efficiencies that can significantly deviate from 100 %. Thus, anisoaxial sampling will almost always underestimate particle concentration. However, for misalignments up to 15°, the error in concentration is small for all particle sizes. Because misalignment is visually obvious, eye positioning of the sample probe is adequate when the direction of the streamlines is well known.



a) Isokinetic sampling, $V_\text{s} = V_\infty$



b) Isokinetic sampling, $V_\text{s} > V_\infty$

Figure G.1 — Types of aerosol isokinetic sampling (*continued*)

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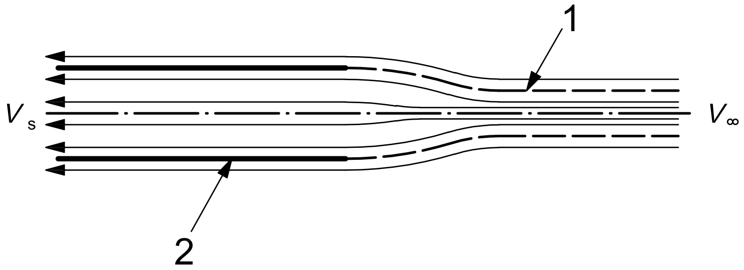

c) Isokinetic sampling, $V_s < V_\infty$

Key

1 limiting streamline

2 sampling nozzle

V_∞ air velocity entering the probe

V_s freestream velocity approaching the inlet

Figure G.1 — Types of aerosol isokinetic sampling

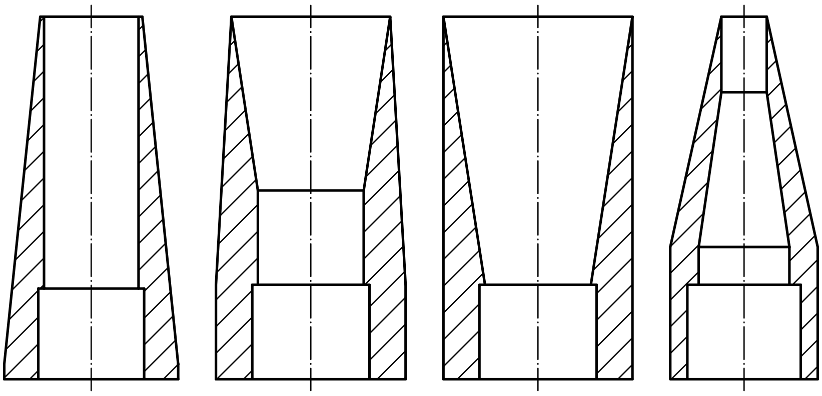

Figure G.2 — Types of sampling nozzles

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Annex H
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Fractional efficiency

As defined in 3.5, the fractional efficiency, $E_{f,i}$, expressed as a percentage, is calculated as follows:

$$E_{f,i} = \frac{C_{1,i} - C_{2,i}}{C_{1,i}} \times 100 \qquad \text{(H.1)}$$

where

$C_{1,i}$ is the number of particles per unit volume of specified size, i, upstream;

$C_{2,i}$ is the number of particles per unit volume of specified size, i, downstream.

If only one particle counter is used downstream of the filter element, the fractional separation efficiency can also be calculated from the particle size distribution of the test dust, $Q_{3,A}(x)$, the actual dust mass flow, $\dot{m}_A(t)$, measured by an online balance, the actual particle concentration, $c_F(t,\Delta x)$ in each size class, Δx, measured downstream of the filter system and the volume flow rate, $\dot{V}$, as shown in Equation (H.2):

$$\eta(x) = \frac{\frac{\dot{m}_A(t)}{\dot{V}} \times \Delta Q_{3,A}(\Delta x)}{c_F(t,\Delta x)} \qquad \text{(H.2)}$$

Alternatively, the calculation of the fractional separation efficiency is possible with the volume distribution, $q_{3,A}(x)$, the current gravimetric separation efficiency of the filter system, $g(t)$, and the volume distribution measured downstream of the filter system, $q_{3,F}(x,t)$, with the particle counter, as shown in Equation (H.3):

$$\eta(x,t) = g(t) \times \frac{q_{3,F}(x)}{q_{3,A}(x)} \qquad \text{(H.3)}$$

where $q_{3,A}(x,t)$ may be considered constant, i.e. $q_{3,A}(x,t) = q_{3,A}(x)$, and $g(t)$ is defined as shown in Equation (H.4):

$$g(t) = 1 - \frac{\dot{m}_F(t)}{\dot{m}_A(t)} \qquad \text{(H.4)}$$

where

$\dot{m}_A(t)$ is the particle mass flow measured by the online balance;

$\dot{m}_F(t)$ is the particle mass flow downstream the filter system.

The particle size distribution, $Q_{3,A}(x)$, and the volume distribution, $q_{3,A}(x)$, of the challenge test dust is done with the downstream particle counter at a particle concentration suitable for the particle counter used.

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