INTERNATIONAL STANDARD

ISO 29463-3

First edition
2011-10-15

High-efficiency filters and filter media for removing particles in air —

Part 3:
Testing flat sheet filter media

Filtres à haut rendement et filtres pour l'élimination des particules dans l'air —

Partie 3: Méthode d'essai des filtres à feuille plate

Reference number
ISO 29463-3:2011(E)

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

Published in Switzerland

Contents

Page

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 29463-3 was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases*.

ISO 29463 consists of the following parts, under the general title *High-efficiency filters and filter media for removing particles in air*:

— *Part 1: Classification, performance, testing and marking*

— *Part 2: Aerosol production, measuring equipment, particle-counting statistics*

— *Part 3: Testing flat sheet filter media*

— *Part 4: Test method for determining leakage of filter element — Scan method*

— *Part 5: Test method for filter elements*

Introduction

ISO 29463 (all parts) is derived from EN 1822 (all parts) with extensive changes to meet the requests from non-EU p-members. It contains requirements, fundamental principles of testing and the marking for high-efficiency particulate air filters with efficiencies from 95 % to 99,999 995 % that can be used for classifying filters in general or for specific use by agreement between users and suppliers.

ISO 29463 (all parts) establishes a procedure for the determination of the efficiency of all filters on the basis of a particle counting method using a liquid (or alternatively a solid) test aerosol, and allows a standardized classification of these filters in terms of their efficiency, both local and overall efficiency, which actually covers most requirements of different applications. The difference between ISO 29463 (all parts) and other national standards lies in the technique used for the determination of the overall efficiency. Instead of mass relationships or total concentrations, this technique is based on particle counting at the most penetrating particle size (MPPS), which, for micro-glass filter mediums, is usually in the range of 0,12 µm to 0,25 µm. This method also allows testing ultra-low penetration air filters, which was not possible with the previous test methods because of their inadequate sensitivity. For membrane filter media, separate rules apply, and they are described in ISO 29463-5:2011, Annex B. Although no equivalent test procedures for testing filters with charged media is prescribed, a method for dealing with these types of filters is described in ISO 29463-5:2011, Annex C. Specific requirements for test method, frequency, and reporting requirements can be modified by agreement between supplier and customer. For lower efficiency filters (group H, as described below), alternate leak test methods described in ISO 29463-4:2011, Annex A can be used by specific agreement between users and suppliers, but only if the use of these other methods is clearly designated in the filter markings as described in ISO 29463-4:2011, Annex A.

There are differences between ISO 29463 (all parts) and other normative practices common in several countries. For example, many of these rely on total aerosol concentrations rather than individual particles. For information, a brief summary of these methods and their reference standards are provided in ISO 29463-5:2011, Annex A.

High-efficiency filters and filter media for removing particles in air —

Part 3:
Testing flat sheet filter media

1 Scope

This part of ISO 29463 specifies the test procedure for testing the efficiency of flat sheet filter media. It is intended for use in conjunction with ISO 29463-1, ISO 29463-2, ISO 29463-4 and ISO 29463-5.

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 29463-1:2011, *High-efficiency filters and filter media for removing particles in air — Part 1: Classification, performance, testing and marking*

ISO 29463-2:2011, *High-efficiency filters and filter media for removing particles in air — Part 2: Aerosol production, measuring equipment, particle-counting statistics*

ISO 29463-4:2011, *High-efficiency filters and filter media for removing particles in air — Part 4: Test method for determining leakage of filter element — Scan method*

ISO 29463-5:2011, *High-efficiency filters and filter media for removing particles in air — Part 5: Test method for filter elements*

ISO 29464[1)], *Cleaning equipment for air and other gases — Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29463-1, ISO 29463-2 and ISO 29464 apply.

4 Symbols and abbreviations

Table 1 presents the quantities (terms and symbols) used in this part of ISO 29463 to represent measurement variables and calculated values. The values should be inserted in the equation given for these calculations in the units specified.

1) To be published.

Table 1 — Quantities, symbols and units

Term	Symbol	Unit	Equation for the calculation
Measured variables			
Exposed area	A	cm^2	
Test volume flow rate	$\dot{V}$	cm^3/s	
Pressure drop	Δp	Pa	
Mean particle diameter	$\bar{d}_p$	µm	
Particle number	N	—	
Sampling volume flow rate	$\dot{V}_s$	cm^3/s	
Sampling duration	t	s	
Calculated quantities			
Filter medium face velocity	u	cm/s	$u = \frac{V}{A}$
Mean differential pressure	$\Delta\bar{p}$	Pa	$\Delta\bar{p} = \frac{1}{n}\sum_{i=1}^{n}\Delta\bar{p}_i$
Particle number concentration	c_N	cm^{-3}	$c_N = \frac{N}{\dot{V}_s \cdot t}$
Penetration for particles in size range i	P_i	a	$P_i = \frac{c_{N,d,i}}{c_{N,u,i}}$ b
Mean penetration	$\bar{P}$	a	$\bar{P} = \frac{1}{n}\sum_{i=1}^{n}P_i$
Mean efficiency	$\bar{E}$	a	$\bar{E} = 1 - \bar{P}$
Number of particles for the upper or lower limit of the 95 % level of confidence	$N_{95\,\%}$	—	ISO 29463-2:2011, Clause 7
Penetration as upper limit value for the 95 % level of confidence	$P_{95\,\%,i}$	a	$P_{95\,\%,i} = \frac{c_{N,d,95\,\%,i}}{c_{N,u,95\,\%,i}}$ b
Mean penetration as upper limit value for the 95 % level of confidence	$\bar{P}_{95\,\%}$	a	$\bar{P}_{95\,\%} = \frac{1}{n}\sum_{i=1}^{n}P_{95\,\%,i}$
Mean efficiency as lower limit value for the 95 % level of confidence	$\bar{E}_{95\,\%}$	a	$\bar{E}_{95\,\%} = 1 - \bar{P}_{95\,\%}$

a These quantities are usually given as a percentage.

b The index, u, refers to upstream particle counts, and the index, d, refers to downstream particle counts.

5 Principle

When testing the sheet filter medium, the particle size efficiency is determined using a particle counting method. The testing may use a mono-disperse or a poly-disperse test aerosol. The methods differ in terms of both the production of the aerosol and the particle counter used. Furthermore, the measurement of the pressure drop is made at the prescribed filter medium velocity.

Specimens of the sheet filter medium are fixed in a test filter assembly and subjected to the test air flow corresponding to the prescribed filter medium velocity. The test aerosol from the aerosol generator is conditioned (e.g. vaporization of a solvent), then neutralized, mixed homogeneously with filtered test air and directed to the test filter assembly.

In order to determine the efficiency, partial flows of the test aerosol are sampled upstream and downstream of the filter medium. Using a particle counting instrument, the number concentration of the particles contained is determined for various particle sizes. The results of these measurements are used to draw a graph of efficiency against particle size for the filter medium, and to determine the particle size for which the efficiency is a minimum. This particle size is known as the most penetrating particle size (MPPS).

When measuring the particles on the upstream side of the filter medium, it can be necessary to use a dilution system in order to reduce the concentration of particles down to the measuring range of the particle counter used.

Additional equipment is required to measure the absolute pressure, temperature and relative humidity of the test aerosol and to measure and control the test volume flow rate.

6 Sampling of sheet filter media

The testing of the sheet filter medium shall be carried out on at least five samples.

The samples shall be handled with care; the area being tested shall be free from all folds, kinks, holes or other irregularities.

All samples shall be clearly and permanently marked with the following details:

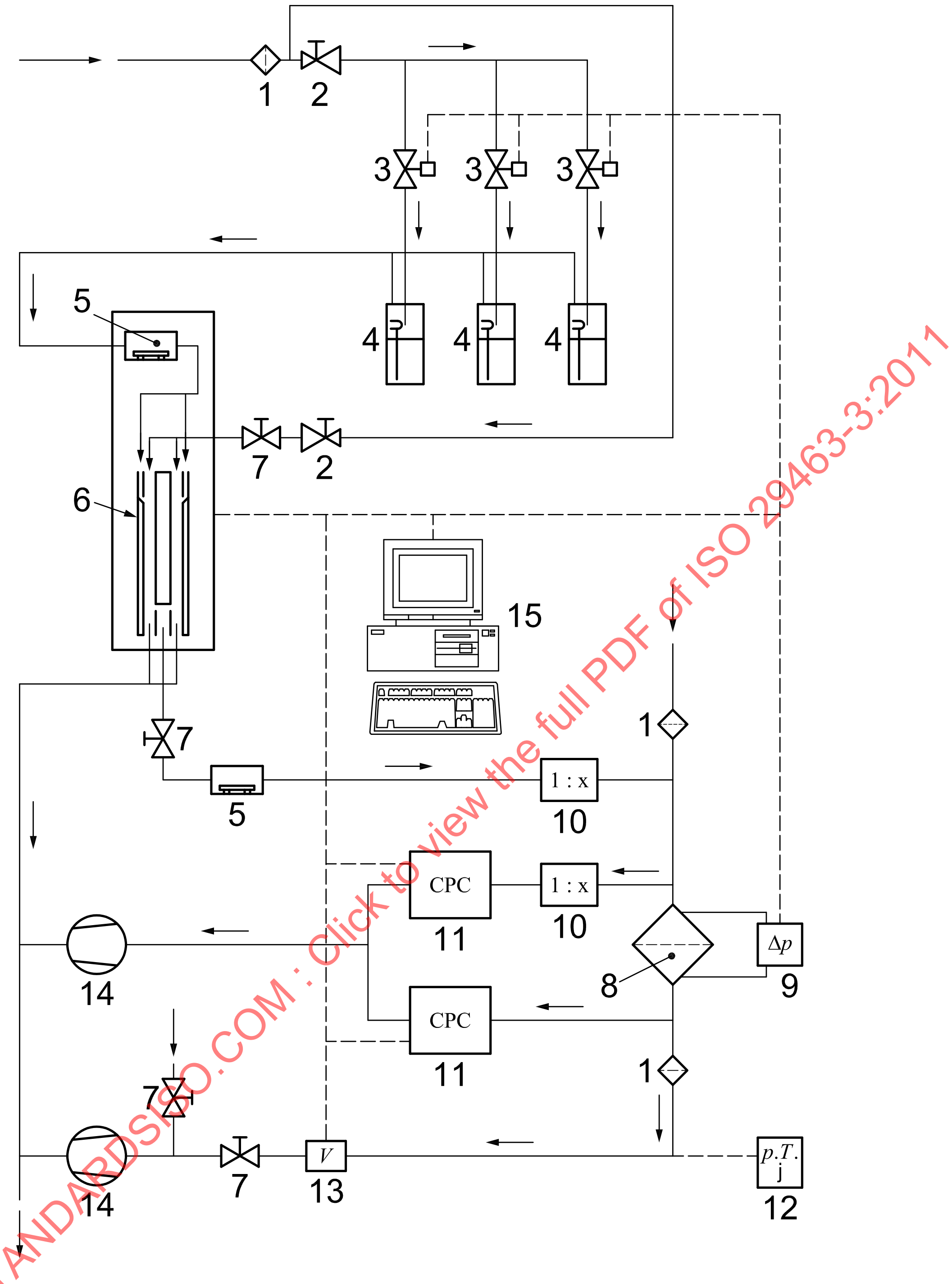
a) designation of the filter medium;

b) upstream side of the filter medium.

7 Test apparatus

The test apparatus being used and the arrangement of the components and measuring equipment are shown in Figure 1.

The basic details for the aerosol generation and the aerosol neutralization, together with the details of suitable types of apparatus, are given in ISO 29463-2.



Key

1 filter
2 pressure valve
3 solenoid valve
4 jet nebulizer
5 neutralizer
6 differential mobility analyser
7 needle valve
8 test filter mounting assembly
9 differential pressure gauge
10 dilution system
11 condensation particle counter
12 measuring equipment for absolute pressure, temperature and relative humidity
13 volume flow rate meter
14 vacuum pump
15 computer for control and data storage

Figure 1 — Set-up for testing with mono-disperse test aerosols

7.1 Test arrangements for testing with mono-disperse test aerosol

When testing sheet filter media with a mono-disperse test aerosol, the particle number concentration is determined using a total count method with a condensation particle counter. The arrangement of the test apparatus is shown in Figure 1.

The mono-disperse test aerosol is created in a number of steps. Firstly, a poly-disperse primary aerosol is produced using a jet nebulizer with, for example, a DEHS- or DOP-iso-propanol solution. The particles are reduced to a convenient size for the following process by evaporation of the solvent. The aerosol is then neutralized and passed to a differential mobility analyser. The quasi-mono-disperse test aerosol available at the output of the differential mobility analyser is once again neutralized, and then mixed homogeneously with filtered test air in order to achieve at the test volume flow rate required for the filter medium velocity.

The mean particle diameter of the number distribution is varied by adjusting the voltage between the electrodes of the differential mobility analyser[2)].

In order to achieve a sufficiently high particle number concentration over the entire test range from 0,04 µm to 0,8 µm, it can prove necessary to use several jet nebulizers with differing concentrations of the aerosol substances in the solvent. Numerical concentrations that are too high can be adjusted by diluting the test aerosol before the test filter mounting assembly. The number concentration in the test aerosol shall be selected so that no dilution is necessary for the measurements made downstream from the filter.

A pump positioned downstream draws the test aerosol through the test filter mounting assembly. This ensures that the differential mobility analyser can always operate under nearly the same conditions, independent of the pressure drop across the tested filter medium. In contrast, the testing system operates with an overpressure, which ensures that leaks in the system do not falsify the test measurements.

Particles are counted upstream and downstream from the filter using either two condensation particle counters in parallel, or using only one such counter to measure the upstream and downstream concentrations alternately. If the level of the upstream number concentration exceeds the measuring range of the counter, then a dilution system shall be included between the sampling point and the counter.

7.2 Test arrangements for testing with a poly-disperse test aerosol

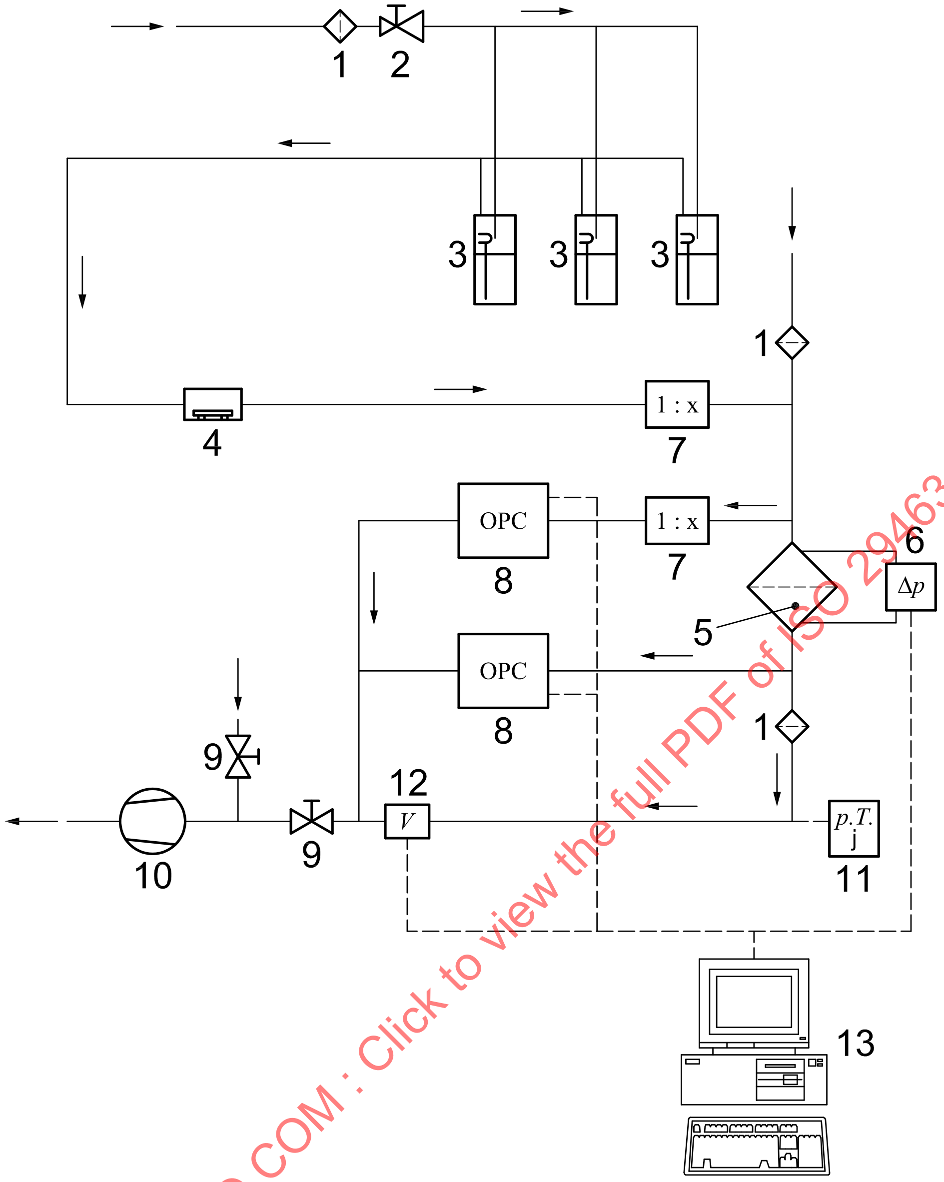
When testing sheet filter media with a poly-disperse test aerosol, optical particle counters that determine the number distribution and the number concentration of the test aerosol are used.

The tests can be carried out directly with the poly-disperse, neutralized primary aerosol. In order to cover the test range, it can be necessary to use several jet nebulizers with different concentrations of the aerosol substance in the solvent. The mean particle diameter of the number distribution shall not lie outside the test range of the particle counter used.

The arrangement of the test apparatus is shown in Figure 2. Instead of the single or two parallel condensation particle counters (CPC), optical particle counters are used to determine the number distribution and the number concentration of the poly-disperse test aerosol on the upstream and downstream sides of the filter medium.

When testing with a poly-disperse test aerosol and particle counting and sizing equipment, it is also necessary to ensure that the number concentration of the test aerosol is adjusted to suit the measuring range of the particle counter, if necessary by the inclusion of a dilution system.

2) The adjustment gives the mode of number distribution. This can be taken as equal to the median value with sufficient accuracy.



Key

1 filter
2 pressure reduction valve
3 jet nebulizer
4 neutralizer
5 test filter mounting assembly
6 differential pressure gauge
7 dilution system
8 optical particle counter
9 needle valve
10 vacuum pump
11 measuring equipment for absolute pressure, temperature and relative humidity
12 volume flow rate meter
13 computer for control and data storage

Figure 2 — Set-up for testing with poly-disperse test aerosols

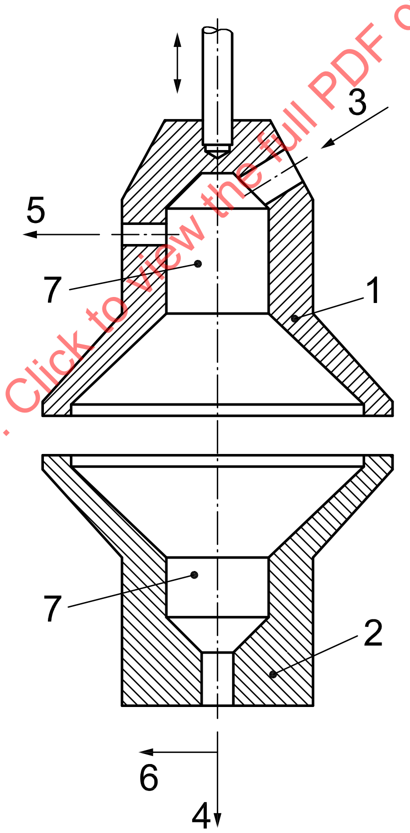
7.3 Test filter mounting assembly

The test filter mounting assembly consists of a moveable upper section and a fixed lower section (an example is shown in Figure 3). The sheet filter medium shall have a circular exposed area of 100 cm^2. The filter medium shall be mounted in such a way that the measurements obtained are not influenced by by-pass leaks. Where seals are used for this purpose, they shall not change the exposed area.

The test aerosol is introduced through the inlet opening in the upper section of the test filter mounting assembly. It shall be ensured that the test aerosol to which the filter medium is exposed possesses a homogeneous local concentration over the entire passage area (standard deviation $\sigma < 10$ %). An outlet for the test aerosol is provided in the base section of the test filter mounting assembly.

Further connections are provided for sampling of partial flows of the test aerosol on the upstream side and downstream side to measure the particles, as well as for the measurement of the pressure drop.

All the materials of the test filter mounting assembly with which the test aerosol comes into contact shall be kept clean, and shall be easy to keep clean, shall be resistant to corrosion, shall conduct electricity and shall be earthed (electrically grounded). Stainless steel and anodized aluminium shall preferably be used. The test filter mounting assembly may have any appropriate constructional form, but shall meet all the test requirements specified in this part of ISO 29463.



Key

1 upper section (moveable)

2 lower section (fixed)

3 inlet for the test aerosol

4 outlet for the test aerosol

5 upstream sampling part

6 downstream sampling part

7 measurement points for differential pressure

Figure 3 — Test filter mounting assembly — Example

7.3.1 Measurement of differential pressure

The differential pressure across the sheet filter medium is measured using differential pressure measuring equipment (see ISO 29463-2) which is attached to the upstream and downstream differential pressure measuring points of the test filter mounting assembly. At the measuring points the static pressure shall be measured.

The measuring points shall be arranged at right angles to the inner surface of the test filter mounting assembly so that as far as possible the measurements are not influenced by the flow rate. The inner edges of the drill holes must be sharp-edged and free of burrs. The connections from the measurement points to the pressure gauge shall be leakproof and clean.

7.3.2 Sampling

For the sampling of the test aerosol on the upstream and downstream sides, it shall be ensured that the partial flows contain representative number particle concentrations. Given the small particle sizes being measured in the testing, isokinetic sampling is not absolutely necessary at this point.

The connections from the sampling point to the measuring apparatus shall be kept clean, shall be easy to keep clean, shall be resistant to corrosion, shall conduct electricity and shall be earthed. In order to avoid the loss of particles, it is important that the connections be short. The inclusion of disturbances in the line, such as valves, constrictions, etc., shall be avoided.

7.4 Determination of the filter medium face velocity

The filter medium velocity is not measured directly, but is determined by dividing the test volume flow rate by the exposed area in the test filter mounting assembly. For this, it is necessary to know the exposed filter medium area with an accuracy of ±2 %.

Depending on the positioning of the extraction point on the downstream side relative to the measurement point for the test volume flow rate, it can be necessary to include the partial flow extracted for the particle counter in the calculation of the test volume flow rate.

The volume flow rate can be measured using a floatmeter, a thermal mass flow meter, or other measuring equipment that can be calibrated. The minimum performance data are the following:

— measuring range: up to 800 cm^3/s;

— accuracy: <5 % of measured value;

— reproducibility: <1 % of measured value.

8 Requirements for the test air

Before mixing with the test aerosol, the test air shall be so prepared that its temperature, relative humidity and purity shall be in accordance with ISO 29463-1:2011, 7.2.

The test air shall be cleaned of solid or liquid components using a high-efficiency filter (for example, a commercially available cartridge filter), the size of which shall be determined depending on the maximum test volume flow rate.

9 Testing procedure

9.1 Preparatory checks

9.1.1 After switching on the test apparatus prior to testing the sheet filter medium, the following parameters shall be checked or registered.

— Readiness for use of the measuring equipment:

Start-up procedures specified by the manufacturers of the measuring equipment shall be followed, for example, the condensation nucleus counters shall be filled with operating fluid, the volume flow rates through the measuring equipment shall be correct, etc.

Any other routine inspections recommended by the equipment manufacturers shall also be carried out before the measurements.

— Zero count rate of the particle counter:

The zero count rate shall be checked by measuring the downstream particle number concentration with the aerosol generator switched off and the filter medium in position.

— Purity of the test air:

The purity of the test air shall be checked by measuring the upstream particle number concentration with the aerosol generator switched off.

— Absolute pressure, temperature and relative humidity of the test air:

The values of these parameters shall be registered in the test volume flow on the downstream side of the test filter mounting assembly.

When any of these parameters lie outside the ranges specified in ISO 29463-1 and ISO 29463-2, appropriate corrective measures shall be undertaken.

9.1.2 For reference filter medium measurement, it is useful to establish reference filter media samples of different filter classes for differential pressure and for efficiency measurements. Immediately after the checks listed in 9.1.1, the measurement of a reference filter medium of the same class as the medium being tested shall be performed. Trends established by such repeated tests provide information about the overall repeatability of the test system (test system drift/damages and faults in the test system).

9.2 Procedure

Following the preparatory steps specified in 9.1, the test specimen shall be placed in the test filter mounting assembly. It shall be established that the measuring range of the instrumentation employed comfortably includes the minimum of the efficiency particle size curve and, thus, the position of the most penetrating particle size (MPPS).

9.2.1 Measurement of the pressure drop

The pressure drop across the filter medium shall be measured with pure test air before the filter is loaded with aerosol. The test volume flow rate shall be set up with such accuracy that the flow rate values for the individual samples of the filter medium do not vary by more than ±2 % from the required value. The measurements shall be made when the system has reached a stable operating state.

9.2.2 Testing with a mono-disperse test aerosol

The test aerosol shall be mixed homogeneously with the test air (see 7.3). To determine the particle size efficiency, at least six approximately logarithmically equidistant interpolation points in the range of the particle sizes being tested shall be determined. Using the differential mobility analyser, six (quasi-) mono-disperse test aerosols shall be generated in succession with the appropriate mean particle diameters, and their number concentrations shall be measured on the upstream and downstream sides of the filter medium, either simultaneously using two condensation nucleus counters working in parallel, or successively using one condensation nucleus counter, first on the upstream and then on the downstream side. In the second case, a flush-out period for the CPC shall be included so that, before beginning the measurement on the downstream side, the particle number concentration at the condensation nucleus counter will have fallen to a level such that the particles on the downstream side of the filter medium can be registered reliably.

9.2.3 Testing with a poly-disperse test aerosol

As an alternative to testing with a mono-disperse test aerosol, it is also possible to measure the number concentration and the number distribution of a poly-disperse test aerosol at at least six approximately logarithmically equidistant interpolation points in the range of the particle size being tested. Optical particle counters shall be used to count the particles. Care shall be taken to ensure that, in particular when measuring the number concentration and number distribution on the upstream side, tolerable coincidence errors are not exceeded. Furthermore, the resolution of the optical particle counter shall be sufficient to meet the measuring requirements.

9.3 Reference test method

Reference test method is the test procedure according to 9.2.2 (see also ISO 29463-1:2011, 7.4.4).

10 Evaluation

The test described in Clause 9 shall be carried out consecutively on the five samples of the filter medium.

For the differential pressure, the arithmetic mean of the results of the individual measurements shall be calculated.

The evaluation of the particle counts shall take into account the particle counting statistics as specified in ISO 29463-2. The calculation of the particle size penetration and efficiency shall make use of the less favourable of the limit values of the confidence interval.

For each of the six or more interpolation points of the efficiency curve, the following arithmetic means shall be calculated from the individual measurements:

— mean efficiency for the particles counted;

— mean efficiency as lower limit for the 95 % confidence interval.

The values of these efficiencies shall be presented as lines on a graph. Either using a suitable mathematical fitting method or a graphical method, the particle size shall be determined at the minimum of the curve for the mean efficiency as lower limit for the 95 % confidence interval. In this way, allowance is made for both the quality of the measurements and also statistical uncertainties involved with the procedures for measuring with low numbers of particles.

The particle size at which the efficiency is at a minimum is known as the MPPS, and shall be recorded together with the appropriate value of the efficiency at that particle size.

For information, an example application with evaluation is provided in Annex A.

11 Test report

The test report for the testing of the flat sheet filter medium shall contain at least the following information:

a) test object:

1) type designation of the filter medium tested,

2) number of samples;

b) test parameters:

1) filter medium face velocity,

2) type designation of the particle measuring equipment used,

3) characterization the test aerosol used;

c) test results:

1) mean differential pressure across the filter medium at the start of testing,

2) MPPS,

3) efficiency at MPPS,

4) calculated mean efficiency, $\overline{E}_{95\,\%}$, as lower limit value for the 95 % confidence interval (see A.2.3 and Table A.3),

5) diagram showing mean efficiency, $\overline{E}$, and the lower limit values of the mean efficiencies, $\overline{E}_{95\,\%}$, as a function of the particle size (see Figure A.1 for an example).

12 Maintenance and inspection of the test apparatus

The work on the components and measuring equipment of the test apparatus listed in Table 2 shall be carried out at least at the following specified intervals (or more frequently). The successful carrying through of the annually instrument calibration shall be documented with individual calibration protocols.

Table 2 — Nature and frequency of the maintenance and inspection

Components	Nature and frequency of the maintenance and inspection
Operating materials	Daily checks Exchange after depletion
Aerosol generators	Monthly cleaning
Volume flow rate meter	Annual testing and zero point control, or after each change
Aerosol lines	Annual cleaning
Filters for test air	Exchanged annually
Waste air filter	Exchanged annually
Parts of the test apparatus at under-pressure	Testing for leaks required if the zero count rate of the particle counter is unsatisfactory
Switching valve between the test points (when installed)	Annual testing for leaks

Otherwise, all components and measuring equipment of the test apparatus shall be maintained and checked at the intervals specified in ISO 29463-2:2011, Table 2. The successful carrying through of the specified instrument calibration shall be documented with individual calibration protocols.

13 Production test for media

13.1 Measurement of differential pressure

Use the test procedure as given in 9.2.1.

13.2 HEPA filter media penetration test

Penetration of group H (HEPA) filter media can be determined with the use of various test instrumentations; however, due to the requirement for near real-time penetration data, photometric methods are preferred. These methods are valid for group H filter media between classes ISO 15 E and ISO 45 H. For ratings above class ISO 45 H, particle count methods should be used. Detailed information about test methods suitable for the filter media penetration test can be found in Annex B.

To ensure comparable data presentation, it is recommended that both the penetration test data and the test technique be stated. Suitable test equipment includes those compliant with 42CFR part 84, or BS 3928.

14 Physical property test of filter media

Filter manufacturers and filter customers are also interested in the physical properties of filter media, such as thickness, tensile, elongation, stiffness, loss on ignition and water repellency. For information, a brief summary about the corresponding test methods and other reference standards is provided in Annex C.

Annex A
(informative)

Example of an application with evaluation

A.1 Testing the sheet filter medium

After completing the adjustments and checks on the parameters as specified in 9.1, the pressure drop is measured for each of the specimens of the filter medium and the particle counts determined at the given filter medium face velocity.

The following example of measurements shows the results of a test with a mono-disperse test aerosol using the total counting procedure for a sample of the filter medium.

A.1.1 Measurement of the differential pressure

The pressure drop across the filter medium shall be measured in accordance with 9.2.1 and the following:

- test conditions: exposed area, $A = 100\ \text{cm}^2$;
- test air volume flow rate: $\bar{V} = 175\ \text{cm}^3/\text{s}$;
- filter medium face velocity: $u = 1{,}75$ cm/s;
- test result: differential pressure, $\Delta p_1 = 109$ Pa.

A.1.2 Particle counting

When testing with a mono-disperse test aerosol, the particle counting shall be in accordance with 9.2.2. For each mean particle diameter, $\bar{d}_\text{p}$, of the six or more interpolation points used for the efficiency curve, the upstream and downstream number particle concentrations, $c_{N,\text{u}}$ and $c_{N,\text{d}}$, respectively, shall be measured. The number concentrations are normally available as direct measurements from the particle counters and can be used for the further evaluation without change. The determination of the penetration is done using the equations for calculation in accordance with Clause 4.

In order to take into account the particle counting statistics as specified in ISO 29463-2:2011, Clause 7, it is necessary to determine the downstream particle numbers, N_d, for the evaluation considering the following:

- test conditions: filter medium face velocity, $u = 1{,}75$ cm/s;
- particle measuring device: condensation nucleus counter;
- test aerosol: DEHS, mono-disperse;
- test result: measurement results and the values calculated for the particle size penetration P_1, as given in Table A.1.

Table A.1 — Measurement results and calculated values of the particle counting

$\bar{d}_p$, µm	0,080	0,100	0,125	0,160	0,200	0,250
$c_{N,u,1}$[a]	2,21 × 10^6 cm^{-3}	1,46 × 10^6 cm^{-3}	8,72 × 10^5 cm^{-3}	4,96 × 10^5 cm^{-3}	3,21 × 10^5 cm^{-3}	2,02 × 10^5 cm^{-3}
$c_{N,d,1}$[b]	3,74 × 10^1 cm^{-3}	2,80 × 10^1 cm^{-3}	2,06 × 10^1 cm^{-3}	1,17 × 10^1 cm^{-3}	7,12 × 10^0 cm^{-3}	3,52 × 10^0 cm^{-3}
$N_{d,1}$[b]	3 000	2 228	1 653	951	568	264
P_1, %	0,001 69	0,001 92	0,002 36	0,002 37	0,002 22	0,001 74

[a] Index u refers to samples from the upstream side.

[b] Index d refers to samples from the downstream side.

A.2 Calculation of the arithmetic means

At least five samples of the sheet filter medium are tested. From the results of the individual measurements (see A.1 as an example for one sample), arithmetic means are then calculated. The following evaluation can be carried out for both particle counting methods in the same manner.

A.2.1 Mean differential pressure

Test results for the measurement of the differential pressure are measured across the five samples of the filter medium at the given filter medium velocity u = 1,75 cm/s and the following:

— differential pressure, Δp_i = 109,1 Pa; 110,1 Pa; 109,4 Pa; 109,8 Pa; 109,6 Pa;

— mean differential pressure, $\Delta\bar{p}$ = 109,6 Pa.

A.2.2 Mean efficiency

For the calculation of the mean efficiency, $\bar{E}$, for each interpolation point of the efficiency curve, the mean penetration, $\bar{P}$, is first determined from the individual penetrations, $\bar{P}_i$, for the five samples of the filter medium.

The calculations and results are shown in Table A.2.

Table A.2 — Calculated values for the determination of the mean efficiency

$\bar{d}_p$, µm	0,080	0,100	0,125	0,160	0,200	0,250
P_1, %	0,001 69	0,001 92	0,002 36	0,002 37	0,002 22	0,001 74
P_2, %	0,001 97	0,002 09	0,002 33	0,002 31	0,002 11	0,001 86
P_3, %	0,001 99	0,002 16	0,002 33	0,002 50	0,002 55	0,002 07
P_4, %	0,001 84	0,002 17	0,002 29	0,002 27	0,002 08	0,001 78
P_5, %	0,001 79	0,002 16	0,002 35	0,002 39	0,002 21	0,001 51
$\bar{P}$, %	0,001 86	0,002 10	0,002 33	0,002 37	0,002 23	0,001 79
$\bar{E}$, %	99,998 14	99,997 90	99,997 67	99,997 63	99,997 77	99,998 21

A.2.3 Mean efficiencies as lower limit values for the 95 % confidence interval

The calculation of the mean efficiency, $\bar{E}_{95\,\%}$, as lower limit value for the 95 % confidence interval takes into account the specifications for the particle counting statistics contained in ISO 29463-2:2011, Clause 7, in accordance with which the least favourable limit value of the confidence interval is determined in each case, and this value is used for the calculations. In the example shown, the measurements of the particle number and number concentration on the upstream side are not corrected statistically. The large numbers of particles means that the influence of statistical uncertainty can be neglected, i.e. for this example, $c_{N,\mathrm{u},95\%,i} = c_{N,\mathrm{u},i}$.

The penetration, $P_{95\%,i}$, is calculated taking into account the corresponding calculated value for the downstream number concentration, $c_{N,\mathrm{d},95\%,i}$, with the less favourable of the values of the particle number for the 95 % confidence interval, $N_{\mathrm{d},95\%,i}$. From the measurements on the five samples of the filter medium, the mean penetration, $\bar{P}_{95\,\%}$, is first calculated as the upper limit value for the 95 % confidence interval. From this the mean efficiency, $\bar{E}_{95\,\%}$, is calculated as the lower limit value for the 95 % confidence interval for each interpolation point of the efficiency versus particle size curve.

The calculated values and the results are shown in Table A.3.

Table A.3 — Calculated values for the determination of the mean efficiency as the lower limit value for the 95 % confidence interval

$\bar{d}_\mathrm{p}$, µm	0,080	0,100	0,125	0,160	0,200	0,250
$N_{\mathrm{d},1}$	3 000	2 228	1 653	951	568	264
$N_{\mathrm{d},95\,\%,1}$	3 107	2 321	1 733	1 011	615	296
$P_{95\,\%,1}$, %	0,001 75	0,002 00	0,002 47	0,002 52	0,002 40	0,001 95
$N_{\mathrm{d},2}$	3 036	2 283	1 665	953	546	302
$N_{\mathrm{d},95\,\%,2}$	3 144	2 377	1 745	1 014	592	336
$P_{95\,\%,2}$, %	0,002 04	0,002 18	0,002 44	0,002 46	0,002 29	0,002 07
$N_{\mathrm{d},3}$	3 194	2 346	1 603	948	673	379
$N_{\mathrm{d},95\,\%,3}$	3 305	2 441	1 681	1 008	724	417
$P_{95\,\%,3}$, %	0,00 06	0,002 25	0,002 44	0,002 66	0,002 74	0,002 28
$N_{\mathrm{d},4}$	3 090	2 429	1 638	958	581	320
$N_{\mathrm{d},95\,\%,4}$	3 199	2 526	1 717	1 019	628	355
$P_{95\,\%,4}$, %	0,001 90	0,002 26	0,002 40	0,002 41	0,002 25	0,001 98
$N_{\mathrm{d},5}$	2 938	2 383	1 678	1 004	609	271
$N_{\mathrm{d},95\,\%,5}$	3 044	2 479	1 758	1 066	657	303
$P_{95\,\%,5}$, %	0,001 85	0,002 25	0,002 46	0,002 54	0,002 39	0,001 69
$\bar{P}_{95\,\%}$, %	0,001 92	0,002 19	0,002 44	0,002 52	0,002 41	0,001 99
$\bar{E}_{95\,\%}$, %	99,998 08	99,997 81	99,997 56	99,997 48	99,997 59	99,998 01

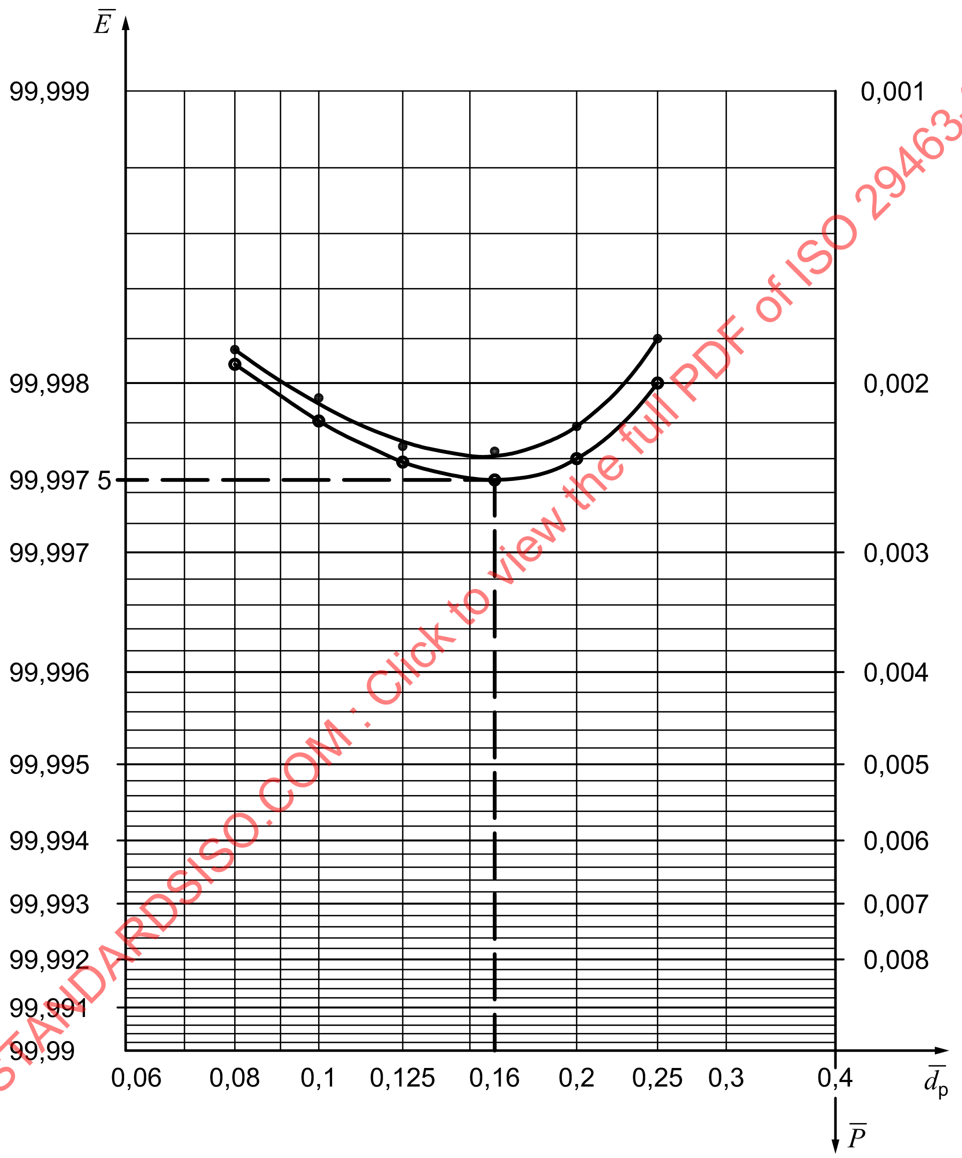
A.3 Representation of the efficiency curve

For each interpolation point with the mean particle diameter, $\bar{d}_p$, the values of the mean efficiency, $\bar{E}$, and the values of the mean efficiencies, $\bar{E}_{95\,\%}$, are presented in a diagram as curves of efficiency vs particle size.

For the example shown, the following values for the minimum of the curve can be determined (see Figure A.1):

— MPPS: 0,16 µm;

— efficiency for this particle size: 99,997 5 %.



Key

$\bar{d}_p$ average particle diameter

$\bar{P}$ average penetration

___ mean efficiency, $\bar{E}$

- - - $\bar{E}_{95\,\%}$

Figure A.1 — Mean efficiency as a function of the particle diameter