BRITISH STANDARD

BS EN 1822-3:2009

High efficiency air filters (EPA, HEPA and ULPA)

Part 3: Testing flat sheet filter media

ICS 13.040.40; 23.120

British Standards

National foreword

This British Standard is the UK implementation of EN 1822-3:2009. It supersedes BS EN 1822-3:1998 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/21/3, Air filters other than for air supply for I.C. engines and compressors.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 December 2009

ISBN 978 0 580 61792 8

Amendments/corrigenda issued since publication

Date	Comments

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1822-3

November 2009

ICS 13.040.40

Supersedes EN 1822-3:1998

English Version

High efficiency air filters (EPA, HEPA and ULPA) - Part 3: Testing flat sheet filter media

Filtres à air à haute efficacité (EPA, HEPA et ULPA) - Partie 3: Essais de medias filtrants plans

Schwebstofffilter (EPA, HEPA und ULPA) - Teil 3: Prüfung des planen Filtermediums

This European Standard was approved by CEN on 17 October 2009.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 1822-3:2009: E

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Foreword

This document (EN 1822-3:2009) has been prepared by Technical Committee CEN/TC 195 "Air filters for general air cleaning", the secretariat of which is held by UNI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2010, and conflicting national standards shall be withdrawn at the latest by May 2010.

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

This document supersedes EN 1822-3:1998.

It is dealing with the performance testing of efficient particulate air filters (EPA), high efficiency particulate air filters (HEPA) and ultra low penetration air filters (ULPA).

The series of standards EN 1822, *High efficiency air filters (EPA, HEPA and ULPA)* consists of the following parts:

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

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

— *Part 3: Testing flat sheet filter media*

— *Part 4: Determining leakage of filter elements (scan method)*

— *Part 5: Determining the efficiency of filter elements*

As decided by CEN/TC 195, this European Standard is based on particle counting methods which actually cover most needs of different applications. The difference between this European Standard and previous national standards lies in the technique used for the determination of the integral efficiency. Instead of mass relationships, this new technique is based on particle counting at the most penetrating particle size (MPPS; range: 0,12 µm to 0,25 µm). It also allows ultra low penetration air filters to be tested, which is not possible with the previous test methods because of their inadequate sensitivity.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

As decided by CEN/TC 195, this European Standard is based on particle counting methods which actually cover most needs of different applications. The difference between this European Standard and previous national standards lies in the technique used for the determination of the integral efficiency. Instead of mass relationships, this technique is based on particle counting at the most penetrating particle size (MPPS), which is for micro-glass filter mediums usually in the range of 0,12 µm to 0,25 µm.

For Membrane filter media, separate rules apply, see Annex A of EN 1822-5:2009. This method also allows to test ultra low penetration air filters, which was not possible with the previous test methods because of their inadequate sensitivity.

1 Scope

This European Standard applies to high efficiency particulate air filters and ultra low penetration air filters (EPA, HEPA and ULPA) used in the field of ventilation and air conditioning and for technical processes, e.g. for applications in clean room technology or pharmaceutical industry.

It establishes a procedure for the determination of the efficiency on the basis of a particle counting method using a liquid test aerosol, and allows a standardized classification of these filters in terms of their efficiency.

This European Standard applies to testing sheet filter media used in high efficiency air filters. The procedure includes methods, test assemblies and conditions for carrying out the test, and the basis for calculating results.

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.

EN 1822-1:2009, *High efficiency air filters (EPA, HEPA and ULPA) — Part 1: Classification, performance testing, marking*

EN 1822-2:2009, *High efficiency air filters (EPA, HEPA and ULPA) — Part 2: Aerosol production, measuring equipment, particle counting statistics*

EN 14799:2007, *Air filters for general air cleaning — Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 14799:2007 apply.

4 Symbols and abbreviations

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

Table 1 — Quantities

Term	Symbol	Unit	Equation for the calculation
Measured variables			
Exposed area	A	cm²	
Test volume flow rate	$\dot{V}$	cm³/s	
Pressure drop	Δp	Pa	
Mean particle diameter	$\tilde{d}_\mathrm{p}$	µm	
Particle number	N	-	
Sampling volume flow rate	$\dot{V}_\mathrm{S}$	cm³/s	
Sampling duration	t	s	
Calculated quantities			
Filter medium face velocity	u	cm/s	$u = \dfrac{\dot{V}}{A}$
Mean differential pressure	$\Delta\overline{p}$	Pa	$\Delta\overline{p} = \dfrac{1}{\mathrm{n}} \sum_{i=1}^{n} \Delta p_i$
Particle number concentration	c_N	cm⁻³	$c_N = \dfrac{N}{\dot{V}_\mathrm{S} \cdot t}$
Penetration for particles in size range i	P_i	[a]	$P_i = \dfrac{c_{N,d,i}}{c_{N,u,i}}$ [b]
Mean penetration	$\overline{P}$	[a]	$\overline{P} = \dfrac{1}{n}\sum_{i=1}^{n} P_i$
Mean efficiency	$\overline{E}$	[a]	$\overline{E} = 1 - \overline{P}$
Number of particles for the upper or lower limit of the 95 % level of confidence	$N_{95\%}$	-	See Clause 7 of EN 1822-2:2009
Penetration as upper limit value for the 95 % level of confidence	$P_{95\%,\,\mathrm{i}}$	[a]	$P_{95\%,i} = \dfrac{c_{N,d,95\%,i}}{c_{N,u,95\%,i}}$ [b]
Mean penetration as upper limit value for the 95 % level of confidence	$\overline{P}_{95\%}$	[a]	$\overline{P}_{95\%} = \dfrac{1}{n}\sum_{i=1}^{n} P_{95\%,i}$
Mean efficiency as lower limit value for the 95 % level of confidence	$\overline{E}_{95\%}$	[a]	$\overline{E}_{95\%} = 1 - \overline{P}_{95\%}$

[a] These quantities are usually given as a percentage.

[b] The index "u" refers to up-stream particle counts, and the index "d" refers to down-stream particle counts.

5 Description of the test method

When testing the sheet filter medium the fractional efficiency is determined using a particle counting method. The testing can use a monodisperse or a polydisperse 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 shall be conditioned (e.g. vaporisation of a solvent) then neutralised, mixed homogeneously with filtered test air and led 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 may 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 to be 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) The designation of the filter medium;

b) The upstream side of the filter medium.

7 Test apparatus

7.1 General

The test apparatus to be used and the arrangement of the components and measuring equipment are shown in Figure 1 of EN 1822-1:2009.

The basic details for the aerosol generation and the aerosol neutralisation, together with the details of suitable types of apparatus are contained in EN 1822-2.

7.2 Test arrangements for testing with monodisperse test aerosol

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

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

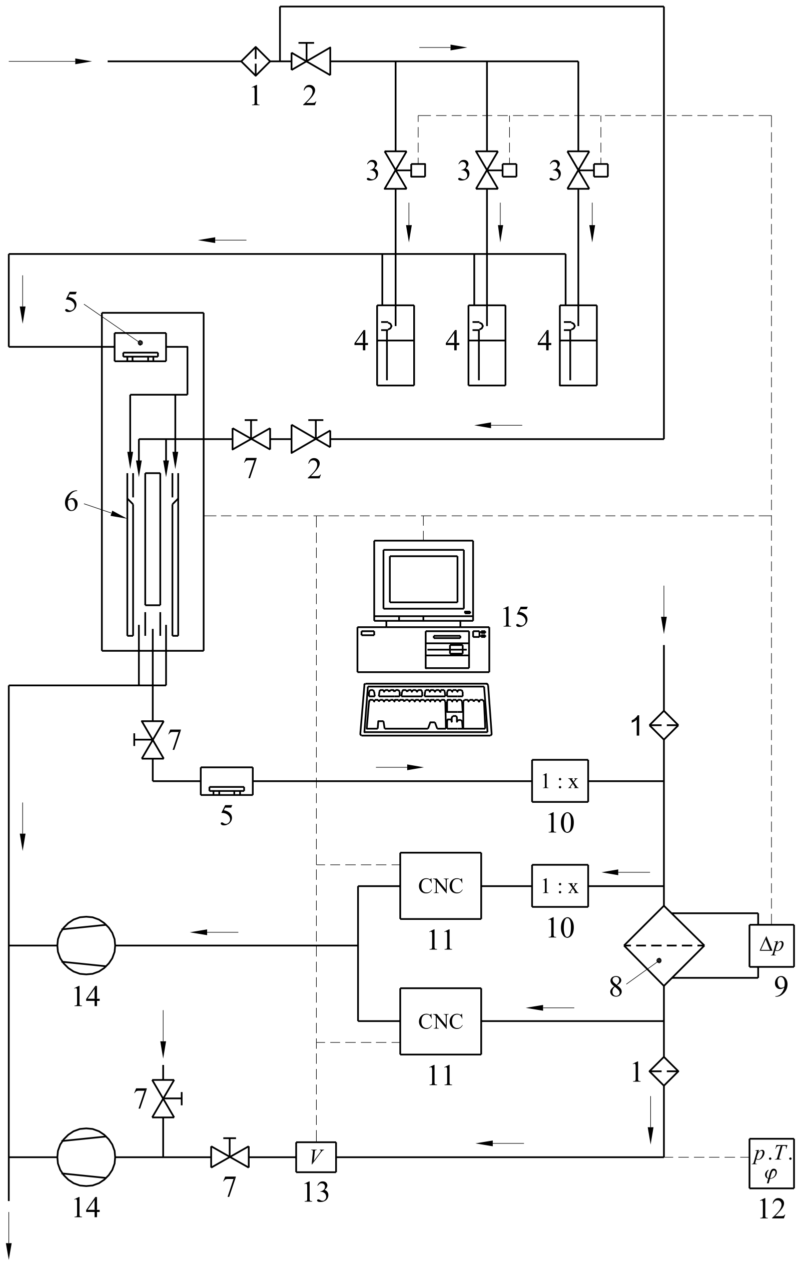
The mean particle diameter of the number distribution is varied by adjusting the voltage between the electrodes of the differential mobility analyzer[1)]

In order to achieve a sufficiently high particle number concentration over the entire test range from 0,04 µm to 0,8 µm it may prove necessary to use several jet nebulizers with differing concentrations of the aerosol substances in the solvent. Numerical concentrations which 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, where the testing system operates with an overpressure this 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 nucleus 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.

1) Actually, 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 valve
3 Solenoid valve
4 Jet nebuliser
5 Neutraliser
6 Differential mobility analyser
7 Needle valve
8 Test filter mounting assembly
9 Differential pressure gauge
10 Dilution system
11 Condensation nucleus 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 — Setup for testing with monodisperse test aerosols

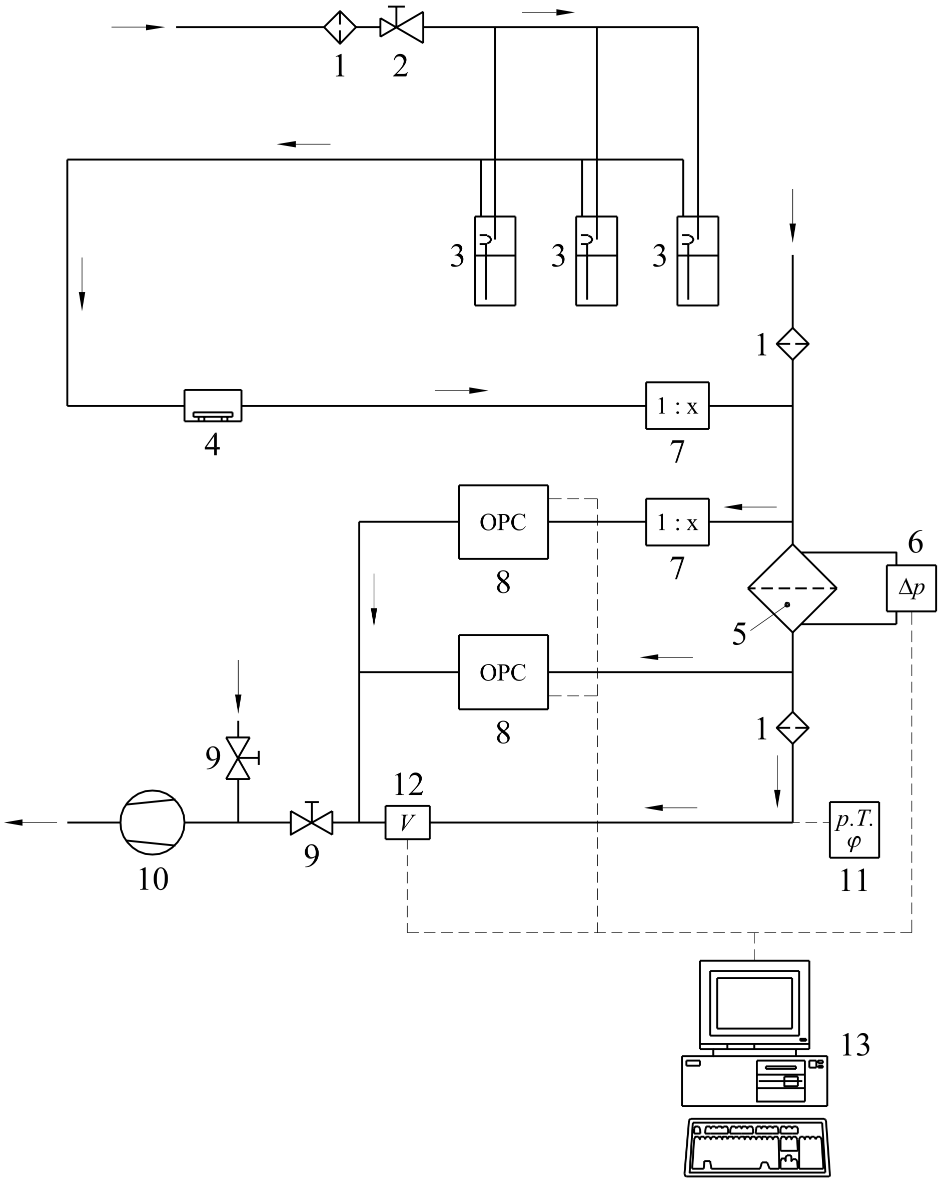
7.3 Test arrangements for testing with a polydisperse test aerosol

When testing sheet filter media with a polydisperse test aerosol optical particle counters are used, which determine the number distribution and the number concentration of the test aerosol.

The tests can be carried out directly with the polydisperse, neutralised primary aerosol. In order to cover the test range it may be necessary to use several jet nebulisers 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 0,04 µm to 0,8 µm.

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

When testing with a polydisperse 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.



Key

1 Filter
2 Pressure reduction valve
3 Jet nebuliser
4 Neutraliser
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 — Setup for testing with polydisperse test aerosols

7.4 Test filter mounting assembly

7.4.1 General

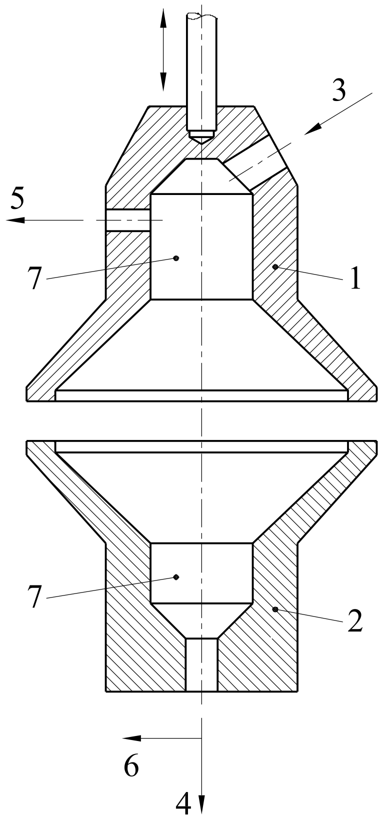
The test filter mounting assembly consists of a moveable upper section and a fixed lower section (an example is shown in Figure 3). The sheet filter medium shall have a circular exposed area of 100 cm^2. The filter medium shall be mounted in such a way that the measurements obtained are not influenced 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 an homogeneous local concentration over the entire passage area (standard deviation σ < 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, resistant to corrosion, shall conduct electricity and shall be earthed. Stainless steel and anodized aluminium shall be used preferably.

The test filter mounting assembly may have any appropriate constructional form, but shall meet all the test requirements specified in this standard.



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 — Example of a test filter mounting assembly

7.4.2 Measurement of differential pressure

The differential pressure across the sheet filter medium is measured using differential pressure measuring equipment (see 5.6 of EN 1822-2:2009) 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 leak proof and clean.

7.4.3 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 to be measured in the testing, isokinetic sampling is not absolutely necessary at this point.

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

7.5 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 the exposed filter medium area must be known 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 may 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 which can be calibrated. The minimum performance data are:

— 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 the requirements specified in 7.2 of EN 1822-1:2009.

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

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 must be followed; such as the condensation nucleus counters must be filled with operating fluid; the volume flow rates through the measuring equipment must be correct; etc.

Any other routine inspections recommend 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 down-stream 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 up-stream 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 down-stream side of the test filter mounting assembly.

When any of these parameters lies outside the ranges specified in EN 1822-1 and EN 1822-2, appropriate corrective measures shall be undertaken.

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 mentioned above, the measurement of a reference filter medium of the same class as the medium to be tested shall be performed. Trends established by such repeated tests will provide information about the overall repeatability of the test system (test system drift/damages and faults in the test system).

9.2 Procedure

9.2.1 General

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 fractional efficiency curve and thus the position of the most penetrating particle size (MPPS).

9.2.2 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.

9.2.3 Testing with a monodisperse test aerosol

The test aerosol shall be mixed homogeneously with the test air (see 7.4). To determine the fractional efficiency at least six approximately logarithmically equidistant interpolation points in the range of the particle sizes to be tested shall be determined. Using the differential mobility analyser six (quasi-)monodisperse 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 CNC shall be included so that before beginning the measurement on the downstream side the particle number concentration at the condensation nucleus counter has fallen to a level such that the particles on the downstream side of the filter medium can be registered reliably.

9.2.4 Testing with a polydisperse test aerosol

As an alternative to testing with a monodisperse test aerosol it is also possible to measure the number concentration and the number distribution of a polydisperse test aerosol at at least six approximately logarithmically equidistant interpolation points in the range of the particle size to be 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 up-stream 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 9.2.3 (see also 7.4.5 of EN 1822-1:2009).

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 Clause 7 of EN 1822-2:2009. There the calculation of the fractional 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 both the quality of the measurements and also statistical uncertainties involved with the procedures for measuring with low numbers of particles are allowed for.

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

An example of 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) Characterisation the test aerosol used;

c) Test results:

   1) Mean differential pressure across the filter medium at start of testing;

   2) Most Penetrating Particle Size (MPPS);

   3) Efficiency at MPPS;

   4) Calculated mean efficiency $\overline{E}_{95\%}$ as lower limit value for the 95 % confidence interval (see A.2.4 and Table A.3 of this standard);

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

12 Maintenance and inspection of the test apparatus

The following work on the components and measuring equipment of the test apparatus 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.

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 Table 2 of EN 1822-2:2009. The successful carrying-through of the specified instrument calibration shall be documented with individual calibration protocols.

Annex A
(informative)

Example of an application with evaluation

A.1 Testing the sheet filter medium

A.1.1 General

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 particles counts determined at the given filter medium face velocity.

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

A.1.2 Measurement of the differential pressure

The pressure drop across the filter medium is measured in accordance with 9.2.2:

— Test conditions: Exposed area A = 100 cm²

— Test air volume flow rate: $\dot{V}$ = 175 cm³/s

— Filter medium face velocity: u = 1,75 cm/s

— Test result: Differential pressure Δp_1 = 109 Pa

A.1.3 Particle counting

When testing with a monodisperse test aerosol the particle counting has to be in accordance with 9.2.3. For each mean particle diameter $\tilde{d}_p$ of the six or more interpolation points used for the efficiency curve the upstream and downstream number particle concentrations ($c_{N,u}$; $c_{N,d}$) has to 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 according to Clause 4.

In order to take into account the particle counting statistics as specified in Clause 7 of EN 1822-2:2009, the downstream particle numbers N_d has also to be determined for the evaluation.

— Test conditions: Filter medium face velocity u = 1,75 cm/s

— Particle measuring device: Condensation nucleus counter

— Test aerosol: DEHS, monodisperse

— Test result: The measurement results and the values calculated for the fractional penetration P_1 are contained in Table A.1.

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

$\tilde{d}_p$	0,080 µm	0,100 µm	0,125 µm	0,160 µm	0,200 µm	0,250 µm
$c_{N,u,1}$	2,21 x 10^6 cm^{-3}	1,46 x 10^6 cm^{-3}	8,72 x 10^5 cm^{-3}	4,96 x 10^5 cm^{-3}	3,21 x 10^5 cm^{-3}	2,02 x 10^5 cm^{-3}
$c_{N,d,1}$	3,74 x 10^1 cm^{-3}	2,80 x 10^1 cm^{-3}	2,06 x 10^1 cm^{-3}	1,17 x 10^1 cm^{-3}	7,12 x 10^0 cm^{-3}	3,52 x 10^0 cm^{-3}
$N_{d,1}$	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 %
Index "u" refers to samples from the upstream side. Index "d" refers to samples from the downstream side.						

A.2 Calculation of the arithmetic means

A.2.1 General

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.2.2 Mean differential pressure

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

Differential pressure:

Δp_i = 109,1 Pa; 110,1 Pa; 109,4 Pa; 109,8 Pa; 109,6 Pa

Mean differential pressure:

$\Delta \overline{p}$ = 109,6 Pa

A.2.3 Mean efficiency $\overline{E}$

For the calculation of the mean efficiency $\overline{E}$ for each interpolation point of the efficiency curve, the mean penetration $\overline{P}$ is first determined from the individual penetrations $\overline{P}_i$ 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

$\widetilde{d}_p$	0,080 µm	0,100 µm	0,125 µm	0,160 µm	0,200 µm	0,250 µm
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 %
$\overline{P}$	0,001 86 %	0,002 10 %	0,002 33 %	0,002 37 %	0,002 23 %	0,001 79 %
$\overline{E}$	99,998 14 %	99,997 90 %	99,997 67 %	99,997 63 %	99,997 77 %	99,998 21 %

A.2.4 Mean efficiencies $\overline{E}_{95\%}$ as lower limit values for the 95 % confidence interval

The calculation of the mean efficiency $\overline{E}_{95\%}$ as lower limit value for the 95 % confidence interval takes into account the specifications for the particle counting statistics contained in Clause 7 of EN 1822-2:2009, in accordance with which the least favourable limit value of the confidence interval is determined in each case and this value used for the calculations. In the example shown the measurements of the particle number and number concentration on the upstream side were not corrected statistically. The large numbers of particles mean that the influence of statistical uncertainty can be neglected, i.e. for this example $c_{N,u,95\%,i} = c_{N,u,i}$.

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

$\tilde{d}_p$	0,080 µm	0,100 µm	0,125 µm	0,160 µm	0,200 µm	0,250 µm
$N_{d,1}$	3 000	2 228	1 653	951	568	264
$N_{d,95\%,1}$	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 %
$N_{d,2}$	3 036	2 283	1 665	953	546	302
$N_{d,95\%,2}$	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 %
$N_{d,3}$	3 194	2 346	1 603	948	673	379
$N_{d,95\%,3}$	3 305	2 441	1 681	1 008	724	417
$P_{95\%,3}$	0,002 06 %	0,002 25 %	0,002 44 %	0,002 66 %	0,002 74 %	0,002 28 %
$N_{d,4}$	3 090	2 429	1 638	958	581	320
$N_{d,95\%,4}$	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 %
$N_{d,5}$	2 938	2 383	1 678	1 004	609	271
$N_{d,95\%,5}$	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 %
$\overline{P}_{95\%}$	0,001 92 %	0,002 19 %	0,002 44 %	0,002 52 %	0,002 41 %	0,001 99 %
$\overline{E}_{95\%}$	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 $\tilde{d}_p$ the values of the mean efficiency $\overline{E}$ and the values of the mean efficiencies $\overline{E}_{95\%}$ are presented in a diagram as curves of efficiency against particle size.

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

— Most penetrating particle size (MPPS): 0,16 µm;

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

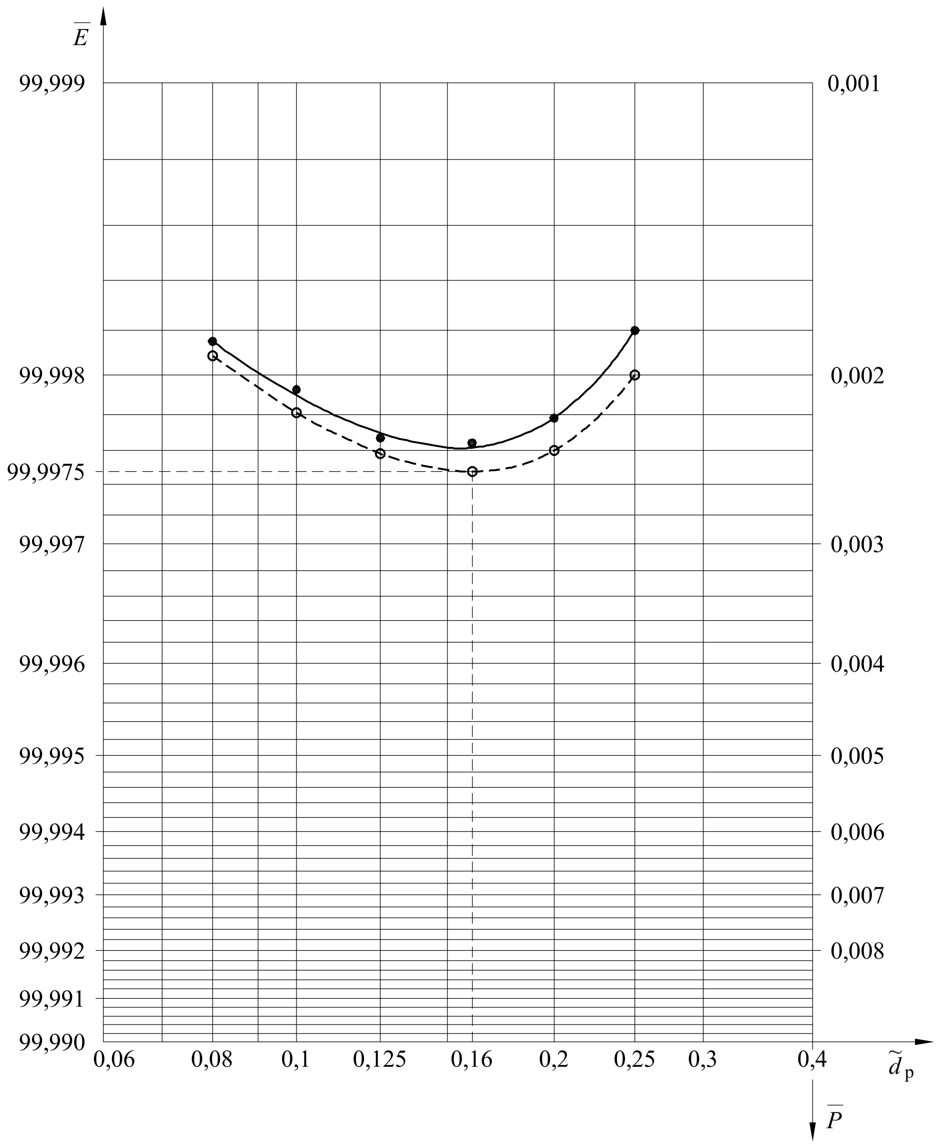


Figure A.1 — Mean efficiency $\overline{E}$ (—) and $\overline{E}_{95\%}$ (- - -) as a function of the particle diameter $\tilde{d}_p$

Bibliography

[1] EN 1822-5:2009, *High efficiency air filters (EPA, HEPA and ULPA) — Part 5: Determining the efficiency of filter elements*

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