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Test method to measure the efficiency of air filtration media against spherical nanomaterials —

Part 1: Size range from 20 nm to 500 nm

Méthode d'essai pour mesurer l'efficacité des médias de filtration d'air par rapport aux nanomatériaux sphériques —

Partie 1: Spectre granulométrique de 20 nm à 500 nm

Reference number
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Foreword

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This document was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 195, *Air filters for general cleaning*, in collaboration with ISO Technical Committee TC 142, *Cleaning equipment for air and other gases*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 21083 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Nano-objects are discrete piece of material with one, two or three external dimensions in the nanoscale (see ISO/TS 80004-2) and are building blocks of nanomaterials. Nanoparticles, referring to particles with at least one dimension below 100 nm, generally have a higher mobility than larger particles. Because of their higher mobility and larger specific surface area, available for surface chemical reactions, they can pose a more serious health risk than larger particles. Thus, particulate air pollution with large concentrations of nanoparticles can result in an increased adverse effect on human health and an increased mortality (see Reference [17]).

With the increased focus on nanomaterials and nanoparticles, the filtration of airborne nanoparticles is also subject to growing attention. Aerosol filtration can be used in diverse applications, such as air pollution control, emission reduction, respiratory protection for human and processing of hazardous materials. The filter efficiency can be determined by measuring the testing particle concentrations upstream and downstream of the filter. The particle concentration may be based on mass, surface area or number. Among these, the number concentration is the most sensitive parameter for nanoparticle measurement. State-of-the-art instruments enable accurate measurement of the particle number concentration in air and therefore precise fractional filtration efficiency. Understanding filtration efficiency for nanoparticles is crucial in schemes to remove nanoparticles, and thus, in a wider context, improve the general quality of the environment, including the working environment.

A large number of standards for testing air filters exist such as the ISO 29463 series and the ISO 16890 series. The test particle range in the ISO 29463 series is between 0,04 µm and 0,8 µm, and the focus is on measurement of the minimum efficiency at the most penetrating particle size (MPPS). The test particle range in the ISO 16890 series is between 0,3 µm and 10 µm. The ISO 21083 series aims to standardize the methods of determining the efficiencies of filter media, of all classes, used in most common air filtration products and it focuses on filtration efficiency of airborne nanoparticles, especially for particle size down to single-digit nanometres.

Test method to measure the efficiency of air filtration media against spherical nanomaterials —

Part 1: Size range from 20 nm to 500 nm

1 Scope

This document specifies the testing instruments and procedure for determining the fractional filtration efficiencies of flat sheet filter medium against airborne nanoparticles in the range of 20 nm to 500 nm. The testing methods in this document are limited to spherical or nearly-spherical particles to avoid uncertainties due to the particle shape.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 5167 (all parts), *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*

ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 15900, *Determination of particle size distribution — Differential electrical mobility analysis for aerosol particles*

ISO 27891, *Aerosol particle number concentration — Calibration of condensation particle counters*

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

ISO 29464, *Cleaning of air and other gases — Terminology*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5725-2, ISO 15900, ISO 27891 and ISO 29464 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.2 Symbols and abbreviated terms

3.2.1 Symbols

Symbol	Definition
A	Source strength of the radioactive source
A_0	Original source strength of the radioactive source
A_f	Effective filtration surface area
C_{up}	Particle concentration upstream of the filter medium
$C_{up,i}$	Concentration of particles with the i_{th} monodisperse size upstream of the filter medium
C_{down}	Particle concentration downstream of the filter medium
$C_{down,i}$	Concentration of particles with the i_{th} monodisperse size downstream of the filter medium
C_{ni}	Concentration of particles after the second DEMC for the particles with i charge(s)
d_d	Diameter of the initial droplet including the solvent
d_p	Diameter of the testing particle after complete evaporation of the solvent
E	Filtration efficiency of the test filter medium
E_i	Filtration efficiency of the test filter medium against the particles with the i_{th} monodisperse size
e	Charge of an electron
φ_v	Volume fraction of DEHS in the solution
$t_{0,5}$	Half-life of the radioactive source
N_{up}	Total count of particles upstream of the filter medium in a certain user-defined time interval
$N_{up,i}$	Counts of particles with the i_{th} monodisperse size upstream of the filter medium in a certain user-defined time interval
N_{down}	Total count of particles downstream of the filter medium in a certain user-defined time interval
$N_{down,i}$	Counts of particles with the i_{th} monodisperse size downstream of the filter medium in a certain used-defined time interval
N_{ni}	Total count of particles after the second DEMC for the particles with i charge(s)
n_p	Number of elementary charges
P	Fractional penetration of the test filter medium
P_i	Fractional penetration of particles with the i_{th} monodisperse size for the test filter medium
P_m	Penetration with the filter medium, before applying the correlation ratio
$P_{m,i}$	Measured penetration against particles with the i_{th} monodisperse size when the filter medium is installed in the filter medium holder, before applying the correlation ratio
q	Flow rate through the filter medium
q_e	Air flow rate through the electrometer
R	Correlation ratio
R_i	Correlation ratio for the i_{th} monodisperse particle size, obtained as the penetration without the filter media
R_{es}	Resistance of resistor
t	Time
v_f	Filter medium velocity
V	Voltage
x	Volume of the sampled air
α	Angle for the transition section in the filter medium holder
Δp	Pressure drop across the filter medium
E_0	Initial particulate efficiency of media sample
ΔE_c	Difference in particulate efficiency between E_0 and conditioned efficiency of the media sample
λ	Radioactive decay constant equal to $0{,}693/t_{0,5}$

3.2.2 Abbreviated terms

AC	Alternating current
CAS	Chemical abstracts service
CL	Concentration limit
CPC	Condensation particle counter
DEHS	Di(2-ethylhexyl) sebacate
DEMC	Differential electrical mobility classifier
DMAS	Differential mobility analysing system
HEPA	High efficiency particulate air
Kr	Krypton
IPA	Isopropyl alcohol
MPPS	Most penetrating particle size
Po	Polonium
PSL	Polystyrene latex
RH	Relative humidity
SRM	Standard reference material

4 Principle

The filtration efficiency of the filter medium is determined by measuring the particle number concentrations upstream and downstream of the filter medium. The fractional penetration, P, represents the fraction of aerosol particles which can go through the filter medium, defined as:

$$P = C_{down} / C_{up} \tag{1}$$

where C_{down} and C_{up} are the particle concentrations downstream and upstream of the filter medium, respectively. Another way is to measure the particle counts upstream and downstream of the filter medium for a certain same user-defined time interval and sampling volume rate. Then the penetration is the ratio between the downstream count N_{down} and upstream count N_{up}:

$$P = N_{down} / N_{up} \tag{2}$$

The filter medium efficiency, E, is the fraction of aerosol particles removed by the filter medium:

$$E = 1 - P \quad (3)$$

The filter medium efficiency is dependent on the challenge particle size. If the test is performed with a number of monodisperse particles with different sizes, the expression for the penetration of particles with the i_{th} monodisperse size P_i can be written as:

$$P_i = C_{\text{down},i} / C_{\text{up},i} \quad (4)$$

where $C_{\text{up},i}$ and $C_{\text{down},i}$ are the concentrations of particles with the i_{th} monodisperse size upstream and downstream of the filter medium, respectively. If the measurement is performed with the particle number count, P_i can be written as:

$$P_i = N_{\text{down},i} / N_{\text{up},i} \quad (5)$$

where $N_{\text{up},i}$ and $N_{\text{down},i}$ are the counts of particles with the i_{th} monodisperse size upstream and downstream of the filter medium in the same user-defined time interval and sampling volume rate, respectively. Correspondingly, the filtration efficiency E_i of the test filter medium against the particles with the i_{th} monodisperse size is:

$$E_i = 1 - P_i \quad (6)$$

The test aerosol from the aerosol generator is conditioned (e.g. evaporation of the solvent) and then neutralized. The particles are mixed homogeneously with filtered test air if necessary to achieve desired concentration and flow rate, before they are used to challenge the test filter medium.

A specimen of the sheet filter medium is fixed in a test filter assembly and subject to the test air flow corresponding to the prescribed filter medium velocity. Partial flow, which is the flow that the CPC operates with, of the test aerosol is sampled upstream and downstream of the filter medium, and the fractional penetration is determined from the upstream and downstream number concentrations or total numbers in user-defined time intervals. Furthermore, the measurement of the pressure drop across the filter medium is made at the prescribed filter medium velocity.

Additional equipment is required to measure the absolute pressure, temperature and RH of the test air. It is also needed to measure and control the air volume flow rate.

5 Test materials

5.1 General

Any aerosol used to test the filtration performance according to this test method shall only be introduced to the test section as long as needed to test the filtration performance properties of the test filter medium without changing the filtration performance properties of the subject filter medium due to loading, charge neutralization or other physical or chemical reaction.

5.2 Liquid phase aerosol

5.2.1 DEHS test aerosol

Test liquid aerosol of DEHS, as an example, is widely used in the testing of filters. DEHS aerosols are spherical in shape. Experiments conducted by comparing DEHS droplets and solid silver nanoparticles in the range of 20 nm to 30 nm demonstrated similar filtration efficiencies with the differences below 8 %[19].

DEHS/DES/DOS – formula:

$C_{26}H_{50}O_4$ or $CH_3(CH_2)_3CH(C_2H_5)CH_2OOC(CH_2)_8COOCH_2CH(C_2H_5)(CH_2)3CH_3$

DEHS properties:

Density	912 kg/m^3
Melting point	225 K
Boiling point	529 K
Flash point	>473 K
Vapour pressure	1,9 × 10^{-6} Pa at 273 K
Refractive index	1,450 at 600 · 10^{-9} m wavelength
Dynamic viscosity	0,022 Pa·s to 0,024 Pa·s
CAS number	122-62-3

5.2.2 Liquid phase aerosol generation

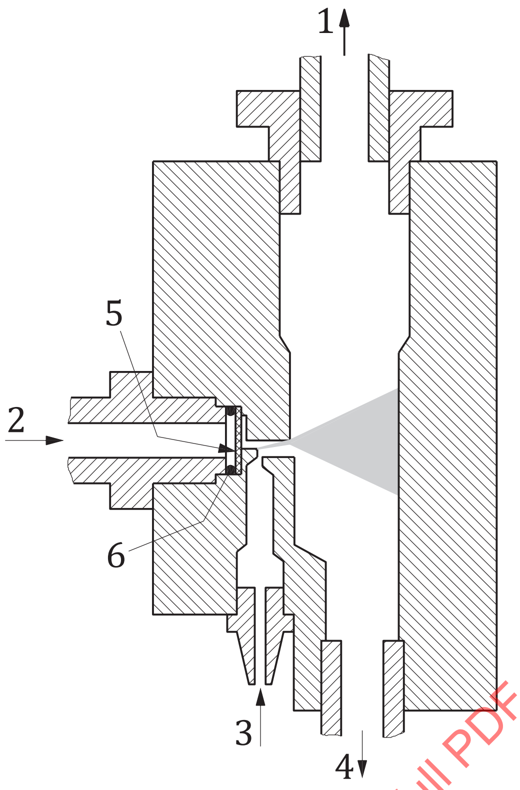
5.2.2.1 Principles and specifications

The test aerosol shall consist of pure DEHS in a suitable solvent (for example IPA), or other liquid phase test aerosols in accordance with the producer's specification.

Figure 1 gives an example of a system for generating the aerosol. Into more details, compressed air expands through an orifice to form a high-velocity jet. The liquid is drawn into the atomizing section through a vertical passage and is then atomized by the jet. Large droplets are removed by impaction on the wall opposite the jet and excess liquid is drained at the bottom of the atomizer assembly block. Fine spray leaves the atomizer through a fitting at the top.

Any other generator capable of producing droplets with a minimum concentration of about 1 000 particles per cubic centimetre in the particle size range of 20 nm to 500 nm can be used. The specifications of different atomizers, as examples, are presented in Annex A, Table A.1.

Before testing, regulation of the upstream concentration, to reach a steady state and to have a concentration in the range that the particle counter can measure, shall be carried out.



Key

1 aerosol out
2 compressed air in
3 liquid in
4 excess liquid to closed reservoir
5 hole
6 O-ring

Figure 1 — Schematic of the atomizer assembly block

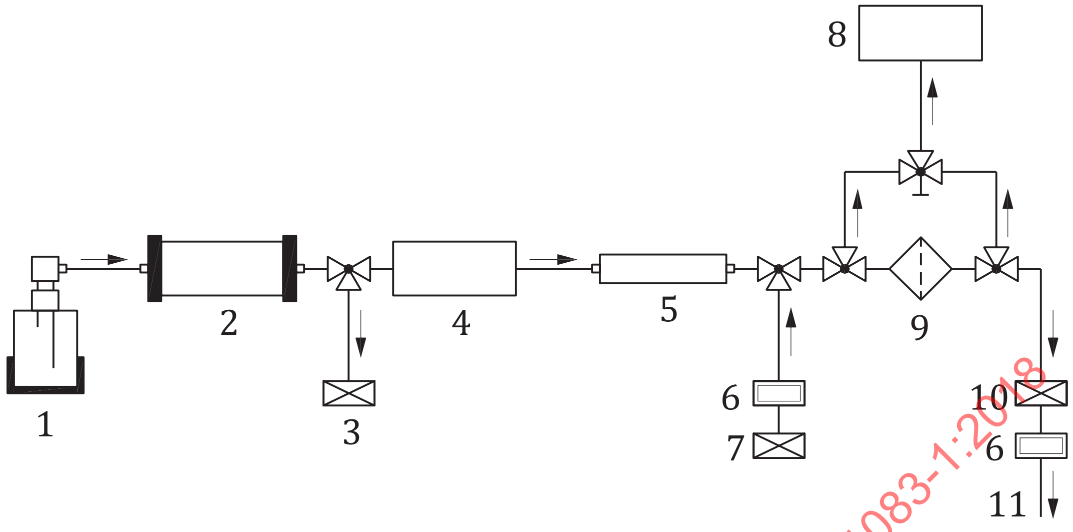
5.2.2.2 Atomizer maintenance

The atomizer shall be kept clean and free of rust. Even though most of the atomizer parts are made of stainless steel, solutes such as sodium chloride will eventually corrode them. In that case, it is recommended to clean and dry the atomizer assembly.

6 Test setup

6.1 General

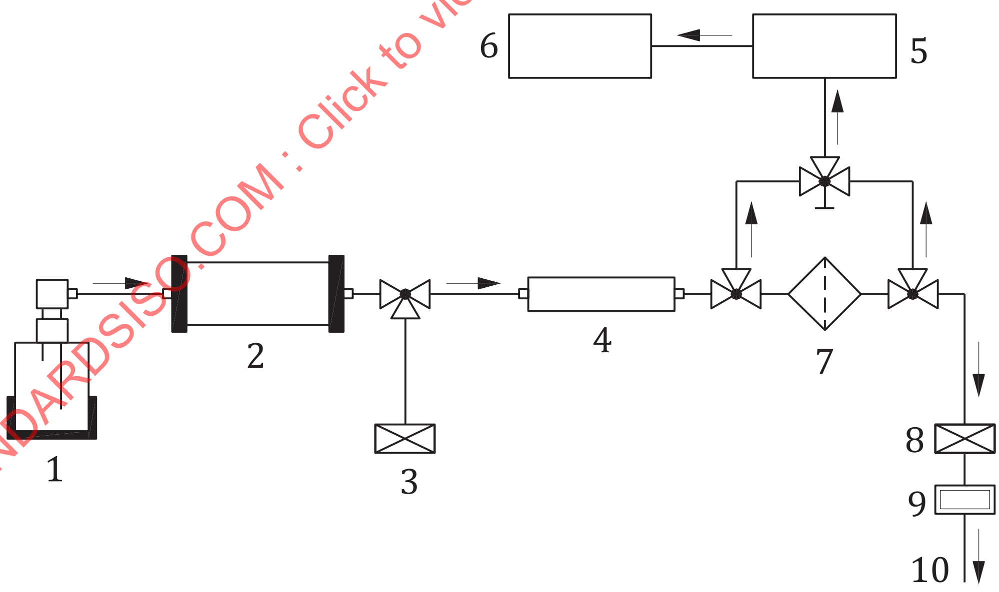
The test setup is shown in Figure 2 for monodisperse challenge particles and in Figure 3 for polydisperse challenge particles. When the challenge particles are monodisperse the setup consists of the three sections: the one that produces the aerosol particles (which contains the aerosol generator), the particle classification section (which contains the DEMC) and the particle measuring section (which contains the CPC). When the challenging particles are polydisperse, the particle classification shall be performed after sampling the aerosol from the upstream or downstream section.



Key

1 atomizer
2 diffusion dryer
3 excess flow with HEPA filter
4 DEMC
5 neutralizer
6 flow controller
7 make-up air with HEPA filter
8 CPC
9 filter medium holder
10 HEPA filter on the exhaust line
11 vacuum

Figure 2 — Test setup for monodisperse challenge particles



Key

1 atomizer
2 diffusion dryer
3 flow compensation through HEPA filter
4 neutralizer
5 DEMC
6 CPC
7 filter medium holder
8 HEPA filter on the exhaust line
9 flow controller
10 vacuum

Figure 3 — Test setup using polydisperse particles to obtain size resolved fractional filtration efficiency

6.2 Specification of setup

6.2.1 Aerosol generation system

The aerosol generation system is described in 5.2.2.

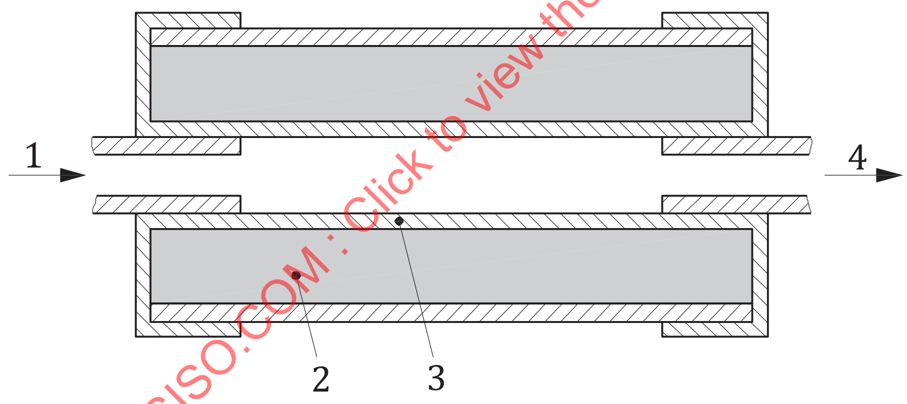
6.2.2 Tubing

Tubes shall be made of electrically conductive material (stainless steel, carbon embedded silicon tubing, etc.) in order to minimize particle losses due to electrostatic deposition. Furthermore, the tubing length shall be minimized so as to minimize particle losses due to diffusion. The upstream and downstream sample lines shall be nominally identical in geometry and material.

6.2.3 Dryer

6.2.3.1 Principles

In the case of generated aerosol from atomization, the particles coming out of the atomizer may have solvent attached and the solvent shall be evaporated. One approach is to pass the aerosol through a diffusion dryer. The dryer in this document refers to a device which can reduce the vapour pressure of the solvent in the test aerosol flow coming from the atomization process. The diffusion dryer consists of a porous tube for air flow passing through a bed of adsorptive materials, e.g. silica gel. The solvent vapour in the air has high diffusivity and can be adsorbed by the material in the diffusion dryer. For example, silica gel can adsorb IPA which may be used as the solvent for DEHS in the atomizer (see Reference [26]). A diffusion dryer is shown in Figure 4.



Key

1 aerosol in

2 annular space filled with an adsorptive material to reduce the vapour pressure of the solvent, for example silica gel

3 inner tube made of wire screen

4 aerosol flow with reduced amount of the solvent vapour

Figure 4 — Diffusion dryer

6.2.3.2 Maintenance

In order to ensure a partial pressure reduction for the solvent, the adsorptive material shall not be saturated. If silica gel is used, it shall be regenerated periodically until it loses its function after extensive use and regeneration cycles.

6.2.4 DEMC

6.2.4.1 Principles and specifications

The DMAS consists primarily of a bipolar charger to neutralize the charges on particles, a controller to control flows and high-voltage, a DEMC (see Figure 5) which separates particles based on their electrical mobilities, a particle detector, interconnecting plumbing, a computer and suitable software. The DEMC shall be able to classify particles in the size range of 20 nm to 500 nm and fulfil the qualification procedure described in 7.2. In case of the unipolar charger based instrument, the manufacturer shall be contacted for suitable size range, in order to avoid errors due to multiple charge effect. The losses of the smallest particles due to diffusion within the challenge range shall be considered as well.

NOTE For more information, see ISO 15900.

DEMC principles are as follows.

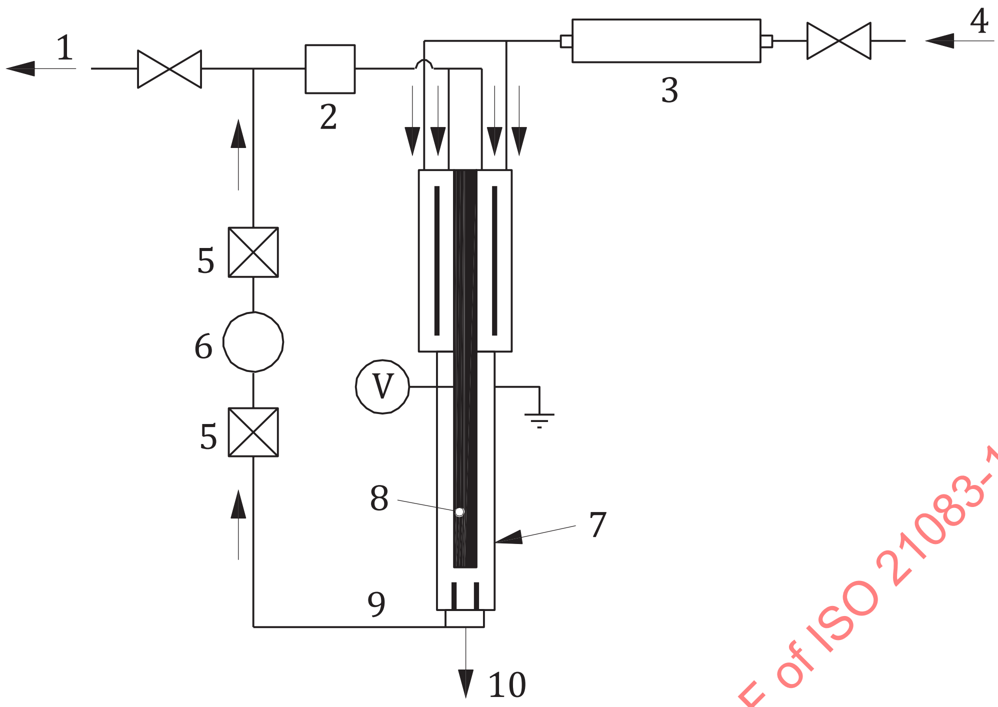
Particles are introduced at the circumference of a hollow tube. A radial electric field is maintained across the outer walls of this tube and a central electrode. As the charged particles flow through the tube, they are attracted towards the central electrode due to the electric field. These are removed through openings in the central electrode.

Small particles require weak electric fields to move them towards the central electrode. Larger particles require stronger fields. By adjusting the electric field, particles of a known size are attracted towards the opening in the central rod and are removed for measurements. Thus particles with a narrow range of sizes can be extracted for each voltage setting. The narrowness is mainly determined by the geometry and uniformity of air flow in the device. By stepping through a range of voltages, or electric field strength, the number of particles in different sizes in the sample can be measured and the particle size distribution of the sample determined.

Alternately, since the DEMC separates particles according to their electrical mobilities, if one knows the number of charges on a particle, it can be used to separate monodisperse particles from a polydisperse aerosol. In this measurement method test particles are first generated and then sent through a neutralizer. Afterwards, the test particles have the Boltzmann equilibrium charge distribution. In this case the singly charged particles represent the largest fraction of the charged particles (see the details in 7.3.2). In addition the size distribution can be controlled so that the target monodisperse particle size is on the right side of the mode of particle size distribution (see the details in 8.2.13). Under these carefully controlled conditions it is possible to use a DEMC to classify monodisperse particles in the range of 20 nm to 500 nm. (See ISO 15900 for more details.)

A DEMC suitable for the prescribed methods in this document shall be able to separate and provide monodisperse particles in the size range from 20 nm to 500 nm with a geometric standard deviation less than 1,10. In general, the ratio of the sheath flow rate to the aerosol flow rate into the DEMC determines the sizing resolution of the DEMC. A higher ratio provides more accurate sizing and avoids excessive diffusional broadening of the particle size distribution so that better monodispersity of the aerosol exiting the DEMC is achieved (see Reference [11]). In practice, a sheath flow to aerosol flow ratio of at least 5 is shown to give acceptable sizing resolution in the size range of interest for the filtration measurement purpose (see Reference [18]). Prescribing specifications for suitable devices are beyond the scope of this document.

NOTE For more information on DEMC principles see ISO 15900.



Key

1 sheath air
2 mass flow meter
3 neutralizer
4 polydisperse aerosol
5 HEPA filter
6 pump
7 outer cylinder
8 high voltage rod
9 excess flow
10 monodisperse flow
V high voltage power supply

Figure 5 — DEMC schematic diagram

6.2.4.2 Maintenance

The DEMC shall be cleaned periodically in order to ensure that it works within the manufacturer's specifications. If aerosol deposits accumulate in the electrodes or other components of the DEMC, they may cause an electrical breakdown of the high voltage or alter the performance of the unit. The maintenance interval shall be determined according to the manufacturer's recommendations for use of the device. When the instrument is used as an aerosol provision unit, the input aerosol concentration is usually high, thus, the DEMC requires more frequent cleaning. In the absence of the manufacturer's recommendations, the default maintenance interval is given in Table 1.

Table 1 — Maintenance task

	Operation time h
Clean the impactor	5 to 50
Clean the collector rod and outer tube of the DEMC	2 000
Clean the Dacron screen of the DEMC	2 000
Clean the bipolar charger	2 000
Replace the filter cartridges	2 000

6.2.5 Equilibrium charge distribution and neutralization of aerosol particles

In the atmosphere, particles of all sizes are present. From prolonged exposure to the naturally occurring bipolar ions, the charge on the population of these particles reaches a steady state or equilibrium. Collectively the particles are nearly neutral, i.e. there are nearly as many negatively charged particles as there are positive ones. In this steady state, the charge distributions for a few selected particle sizes are shown in Table 2. This steady state charge distribution is also known as Boltzmann charge distribution.

6.2.6 Neutralization of aerosol particles

The process of bringing an aerosol to the equilibrium charge distribution, or Boltzmann distribution, is also often referred to as neutralizing the aerosol. Thus, “neutralized” aerosol in the present document refers to particles with equilibrium charge distribution, and not completely uncharged particles. Individual particles may carry one or more charges, but the aerosol itself is neutral. Charge neutralization may be achieved by exposing the aerosol to high concentrations of bipolar charge ions for sufficient time until the aerosol reaches the equilibrium charge distribution. There are several bipolar ion sources including nuclear radioactive sources that produce α particles or β rays, corona discharge sources with AC voltage and X-rays, among others. Alternately, when ions of one polarity are used instead of bipolar ions, the process is unipolar charging. Unipolar charging is particularly useful for imparting a large number of charges of the desired polarity to particles.

The neutralization process in the bi-polar charger depends on the product of the ion concentration and the particle residence time. If the ion concentration is low (e.g. due to old radioactive source) or the residence time is short (e.g. due to high flow rate), the particles may not fully achieve the Boltzmann equilibrium charge distribution. Therefore, test of the neutralization efficiency is important.

Different particle generation methods produce different charge distributions. Without neutralization, the difference in charge distribution can impact the filtration test results. Therefore, a neutralizer shall be used for the challenging particles before entering the filter medium holder.

Table 2 — Equilibrium distribution (see Reference [22])

Particle diameter nm	Mobility (m^2/vs) x10^{-4}	Fraction of total particle concentration that carries this number (-6 to +6) of charges												
		−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6
2,21	4,22E-01	0	0	0	0	0	0,009 1	0,982 68	0,008 2	0	0	0	0	0
2,55	3,16E-01	0	0	0	0	0	0,010 5	0,980 07	0,009 4	0	0	0	0	0
2,94	2,38E-01	0	0	0	0	0	0,012 3	0,976 91	0,010 8	0	0	0	0	0
3,4	1,78E-01	0	0	0	0	0	0,014 4	0,973 1	0,012 5	0	0	0	0	0
3,92	1,34E-01	0	0	0	0	0	0,016 9	0,968 5	0,0146	0	0	0	0	0
4,53	1,01E-01	0	0	0	0	0	0,02	0,962 97	0,017	0	0	0	0	0
5,23	7,55E-02	0	0	0	0	0	0,023 7	0,956 34	0,019 9	0	0	0	0	0
6,04	5,68E-02	0	0	0	0	0	0,028 2	0,948 42	0,023 4	0	0	0	0	0
6,98	4,27E-02	0	0	0	0	0	0,033 5	0,939	0,027 5	0	0	0	0	0
8,06	3,21E-02	0	0	0	0	0	0,039 8	0,927 87	0,032 3	0	0	0	0	0
9,31	2,41E-02	0	0	0	0	0	0,047 2	0,914 8	0,038	0	0	0	0	0
10,75	1,82E-02	0	0	0	0	0	0,055 9	0,899 58	0,044 5	0	0	0	0	0
12,41	1,37E-02	0	0	0	0	0	0,065 9	0,882 02	0,052	0	0	0	0	0
14,33	1,03E-02	0	0	0	0	0	0,077 4	0,861 98	0,060 6	0	0	0	0	0

Table 2 *(continued)*

Particle diameter nm	Mobility (m^2/vs) x10^{-4}	Fraction of total particle concentration that carries this number (-6 to +6) of charges												
16,55	7,77E-03	0	0	0	0	0	0,090 3	0,839 38	0,070 3	0	0	0	0	0
19,11	5,86E-03	0	0	0	0	0	0,104 7	0,814 25	0,081	0	0	0	0	0
22,07	4,43E-03	0	0	0	0	0,000 4	0,120 5	0,786 18	0,092 8	0,000 2	0	0	0	0
25,48	3,35E-03	0	0	0	0	0,000 8	0,137 5	0,755 88	0,105 4	0,000 4	0	0	0	0
29,43	2,54E-03	0	0	0	0	0,001 5	0,155 4	0,723 34	0,118 8	0,000 9	0	0	0	0
33,98	1,93E-03	0	0	0	0	0,002 9	0,173 9	0,688 83	0,132 7	0,001 7	0	0	0	0
39,24	1,47E-03	0	0	0	0	0,005 1	0,192 6	0,652 72	0,146 7	0,002 9	0	0	0	0
45,32	1,12E-03	0	0	0	0	0,008 4	0,210 9	0,615 45	0,160 5	0,004 8	0	0	0	0
52,33	8,53E-04	0	0	0	0	0,013 1	0,228 2	0,577 55	0,173 7	0,007 5	0	0	0	0
60,43	6,54E-04	0	0	0	0	0,019 5	0,244	0,539 69	0,185 7	0,011 1	0	0	0	0
69,78	5,03E-04	0	0	0	0	0,027 8	0,257 6	0,502 6	0,196 3	0,015 7	0	0	0	0
80,58	3,89E-04	0	0	0	0,001 2	0,037 9	0,268 6	0,465 39	0,205	0,0213	0,000 5	0	0	0
93,06	3,01E-04	0	0	0	0,002 6	0,049 7	0,276 6	0,430 4	0,211 5	0,028	0,001 2	0	0	0
107,46	2,35E-04	0	0	0,000 1	0,005 1	0,062 8	0,281 2	0,397 28	0,215 5	0,035 6	0,002 3	0	0	0
124,09	1,84E-04	0	0	0,000 4	0,009 1	0,076 7	0,282 5	0,366 32	0,216 9	0,043 9	0,004 1	0,000 1	0	0
143,3	1,45E-04	0	0	0,001	0,014 6	0,090 9	0,280 4	0,337 74	0,215 8	0,052 5	0,006 6	0,000 4	0	0
165,48	1,15E-04	0	0,000 1	0,002 3	0,022	0,104 7	0,275 1	0,311 72	0,212 2	0,061 2	0,009 9	0,000 8	0	0
191,1	9,23E-05	0	0,000 3	0,004 4	0,030 9	0,117 4	0,267 1	0,288 41	0,206 5	0,069 4	0,013 9	0,001 5	0,000 1	0
220,67	7,43E-05	0,000 1	0,000 9	0,007 7	0,041 1	0,128 5	0,256 8	0,267 86	0,198 9	0,076 8	0,018 5	0,002 6	0,000 2	0
254,83	6,02E-05	0,000 2	0,001 9	0,012 5	0,052 2	0,137 6	0,244 8	0,250 06	0,189 8	0,082 9	0,023 4	0,004 3	0,000 5	0
294,27	4,91E-05	0,000 5	0,003 7	0,018 7	0,063 4	0,144 3	0,231 6	0,234 83	0,1797	0,087 3	0,028 4	0,006 4	0,001	0,000 1
339,82	4,04E-05	0,001 2	0,006 6	0,026 2	0,074 2	0,148 6	0,217 8	0,221 84	0,169	0,090 1	0,033 3	0,009	0,001 7	0,000 2
392,42	3,34E-05	0,002 5	0,010 8	0,034 8	0,084 2	0,150 5	0,203 9	0,210 58	0,158 1	0,091	0,037 8	0,012	0,002 8	0,000 5
453,16	2,77E-05	0,004 6	0,016 2	0,044	0,092 9	0,150 3	0,190 4	0,200 35	0,147 4	0,090 3	0,041 7	0,015 1	0,004 3	0,000 9
523,3	2,32E-05	0,007 9	0,022 9	0,053 4	0,100 1	0,148 1	0,177 7	0,190 35	0,137 2	0,088 3	0,044 9	0,018 3	0,006	0,001 6

6.2.7 Make-up air line

The make-up air-line shall be used in order to obtain the desired flow rate and to dilute the aerosol sample so that the aerosol concentration is within the limits of the particle counting system. HEPA filters shall be added in the make-up air-line to avoid foreign particles entering the system.

6.2.8 Test filter medium mounting assembly

The filter medium holder normally has a top part, a bottom part and a middle section where the flat sheet filter medium is located. The effective filtration surface area A_f (the surface area of the part of the filter medium directly exposed to the challenging aerosol flow) shall be large enough, so that the macroscopic non-uniformity of the filter medium can be compensated. The effective filtration surface area does not have a maximum limit. However, for large filter sizes, the challenging particle uniformity and minimum concentration can be difficult to achieve. The inlet of the holder connects to the transportation tubing and usually has a small diameter; whereas the middle section usually has a much larger diameter. The transition part from the inlet to the middle section shall gradually increase in diameter, to facilitate the smooth expansion of the air flow without undue turbulence and loss of aerosol uniformity. Aerosol uniformity shall be verified according to 7.5. The air flow ideally shall be distributed uniformly on the filter medium, and an air jet focusing on the centre part of the filter medium shall be avoided. The filter medium holder shall be closed by pneumatic chucks or by screws through the top and bottom parts. The filter medium holder shall be air tight during the test and a suitable gasket shall be used to achieve this.

Recommended values for the filter medium holder parameters are listed in Table 3. An example schematic of the side view of half the filter medium holder is shown in Figure 6. The other half shall be symmetric.

Table 3 — Suggested values for the filter medium holder parameters

Filter medium holder parameters	Value
Effective filtration surface area A_f	minimal 0,01 m^2 (0,113 m diameter)
Inlet diameter	>0,005 m
Angle for the transition section (angle α in Figure 6)	$0° < \alpha < 25°$

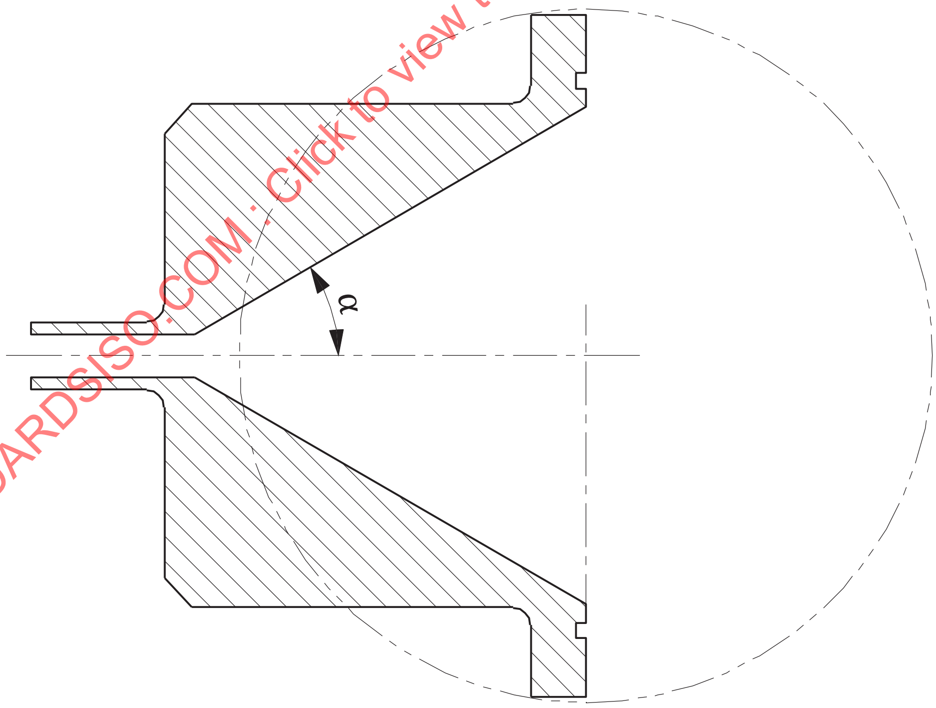


Figure 6 — An example schematic of the side view of the half filter medium holder

6.2.9 CPC

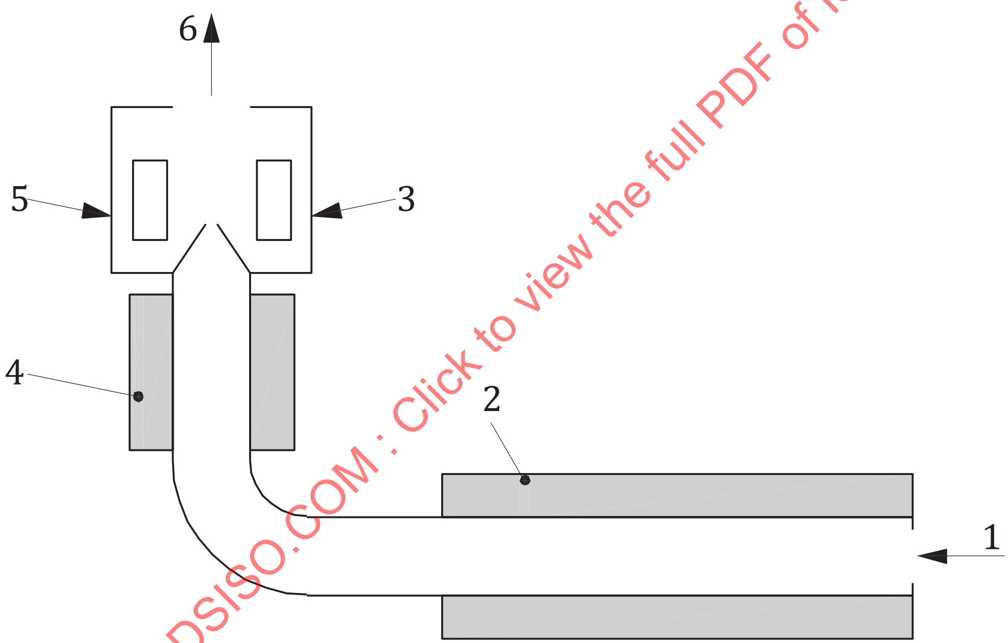
6.2.9.1 Principle and operation

In a CPC, particles that are too small for direct optical measurement are enlarged by condensation of a vapour of a fluid such as butanol, water or glycol before being subjected to light scattering or light extinction measurements. The test aerosols shall be compatible with the CPC working liquid in order to achieve the needed condensation growth for counting. The specification of the CPC shall be consulted for this purpose. The concentration of the resultant droplets is determined by counting or by photometry. However, using this method, the information about the original size of the particles is lost.

The super-saturation required for the vapour condensation can be produced for CPCs with continuous flow in basically two ways.

In the first case, the aerosol is first saturated with the vapour at a temperature above the ambient temperature and then cooled by contact with a cold pipe wall (external cooling).

Figure 7 shows the structure of such a device. The aerosol flows through a pipe in which it is saturated with butanol vapour, and then through a condensation pipe in which it is cooled from outside. The resultant drops are then detected by a scattered light sensor.

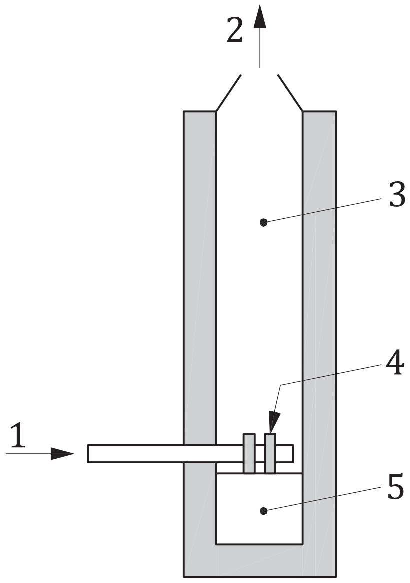


Key

1 aerosol inlet
2 saturator tube
3 laser
4 condenser tube
5 photodetector
6 to flowmeter and pump

Figure 7 — Structure of a CPC using the saturator and condensator

In the second case, the aerosol at ambient temperature is mixed with a warmer, particle-free, vapour saturated air flow. The mixing leads to super-saturation and condensation. This principle is shown in Figure 8.



Key

1 aerosol inlet
2 to laser and photodetector
3 condensation section
4 mixing nozzle
5 vapour inlet

Figure 8 — Structure of a CPC using the mixing principle

Here the aerosol is led directly to a mixing nozzle (see Reference [16]) by the shortest route. The drops of working fluid that form along the condensation section are again detected by a scattered light sensor.

6.2.9.2 Minimum specifications for CPC

The CPC shall be capable of measuring particles in the range of 20 nm to 500 nm. In the data analysis the exact particle detection efficiency of the CPC shall be taken into account.

6.2.9.3 Sources of error and limit errors

If a CPC is used in the single particle counting mode, then the determination of the particle concentration depends primarily on the accuracy of the sampling volume flow rate. Depending on the measuring or control method used, the sampling volume flow rate error shall be under 5 %.

In the photometric mode of operation, the relationship between the number concentration and the output signal also depends on the size of the droplets produced. Operation in the photometric mode shall be avoided because, in extreme cases, the measuring errors can be as large as 100 %.

6.2.9.4 Maintenance and inspection

The level of the vapour substance in the reservoir shall be checked at regular intervals. The vapour substance shall be exchanged at regular intervals, since water accumulates in it and changes its thermodynamic properties. Also for dry challenge aerosol, the working fluid can get contaminated.

The inspection of correct operation shall include a check of the flow, as well as a regular check of the zero count rate by inserting a suitable up-stream filter of class ISO 35 H or higher.

If several counters are available, a further operational check is possible by comparative measurements of a test aerosol.

The maintenance schedules recommended by the manufacturer shall be followed. The unit shall be calibrated at least annually.

6.2.9.5 Calibration

It is required to check the sampling volume flow after service and every six months.

The calibration of a CPC and the determination of its counting efficiency require the production of monodisperse aerosols of known concentration (using a DEMC and an aerosol electrometer). Details are provided in 7.1. Extensive information for CPC calibration is available in ISO 27891.

6.2.10 Final filter

The final filter (e.g. HEPA filter) is a high efficiency filter that removes most of the challenge particles that pass through the test device during the experiments. It is located before the pumping system due to safety reasons. When the HEPA filter is heavily clogged, it can affect the test flow rate. Therefore, monitoring the flow rate is a way to ensure the HEPA filter is not heavily clogged. If the test flow rate cannot be reached, the HEPA filter shall be changed.

Alternatively the loading level of HEPA filter can be determined by the increase of the pressure drop of the filter.

6.3 Detailed setup for test using DEHS particles

An example of the setup for the test using DEHS particles is shown in Figure 2. If test particles other than DEHS are used, the generation part in the test setup needs to be changed accordingly. The neutralization, classification and filtration testing parts described here are still applicable.

An atomizer is used to generate airborne droplets from a solution of DEHS with purity above 99,4 %. The solvent in the droplets evaporates and leaves airborne DEHS particles. A diffusion dryer is used to facilitate evaporation of the solvent. The particle size distribution can be adjusted by varying the DEHS concentration. Lower concentration gives rise to a smaller mean particle size.

The DEHS particles are given a Boltzmann equilibrium charge distribution by a neutralizer and classified by a DEMC. Since the test particles for this setup are expected to be in the range of 20 nm to 500 nm, a DEMC that can cover this range shall be used. In addition, the suitable DEMC shall be chosen to provide enough aerosol flow to satisfy the minimum downstream particle concentration or counts. Since the large particle size requires relatively low sheath flow rates, the sheath flow rate shall be limited so that the particle size can be classified by the DEMC. At the same time the sheath flow rate shall be high enough to keep a reasonable accuracy for the DEMC. A ratio of sheath flow to aerosol flow of at least 5 has been found to yield good results (see Reference [18]). The size of the monodisperse particles exiting the DEMC can be adjusted by changing the DEMC voltage. ISO 15900 provides extensive information on the good use of the DEMC.

The monodisperse particles exiting the DEMC have narrow size distributions and the majority of them carry one electrical charge and shall be neutralized again by a neutralizer before entering the filter medium holder. This approach reduces the electrostatic effect in filtration and the associated uncertainties. Before the filter medium, another flow path is provided for excess flow when the aerosol flow rate is higher than that needed through the filter medium holder or for make-up air when the aerosol flow rate is lower. The flow rate through the filter medium holder shall be calculated by the filtration surface area and the filter medium velocity. In the case when make-up air is needed, good mixture shall be obtained so that the particles are uniformly distributed in the air entering the filter medium holder. Aerosol uniformity shall be verified according to 7.5. This is usually readily achieved for particles below 500 nm due to their low inertia and high diffusivity. The specimen of the sheet filter medium is fixed in the test filter medium holder and exposed to the test air flow corresponding to the prescribed filter medium velocity.

Particles are counted upstream and downstream of the filter medium using either two CPCs in parallel or using only one such counter to measure the upstream and downstream concentrations alternately.

The two-CPC method avoids switching the sampling location and the associated disturbance of the flow. The measurement time can be significantly reduced when many particle sizes are to be tested. If two CPCs are used, the connection lines from the sampling points to the CPC inlets shall have the same tube diameter and length. If one CPC is used, the connection lines from the upstream sampling point and the downstream sampling point shall have the same tube diameter and length. The CPCs shall have a lower detection limit smaller than the test particle size. The sampling time shall be long enough so that the measured particle concentration is stable and reliable, e.g. variation of the upstream concentration within the estimated test duration shall be less than 5 %.

A pump positioned downstream draws the test aerosol through the test filter mounting assembly. The flow rate is controlled and measured to match the test volume flow rate.

Overpressure operation is allowed. One or more fans are positioned along the duct.

The transport tubing for aerosols shall consist of conductive materials, such as metal or carbon embedded silicon, to avoid electrostatic effect and excessive loss of test aerosols. Similarly, the valves and connectors on the aerosol transport path shall also consist of conductive materials. The length of the tubing shall be as short as possible, to avoid excessive loss due to diffusion.

6.4 Determination of the filter medium velocity

The filter medium velocity of the air flow, v_f, approaching the filter medium is directly related to the volume flow rate q. The volume flow rate shall be based on the ambient temperature and pressure of the experiment. The relationship is given by:

$$v_f = q / A_f \quad (7)$$

7 Qualification of the test rig and apparatus

7.1 CPC tests

7.1.1 CPC — Air flow rate stability test

7.1.1.1 General

Differences in sample air flow through the CPC(s) can significantly alter measurement capabilities during a test. This potential issue is enhanced as the resistance to air flow in the test rig is increased.

7.1.1.2 Air flow rate stability test protocol

Install a very high resistance to air flow filtration device or a perforated plate.

Measure the sampled air flow rate from the test rig at both the upstream and downstream sampling locations. The air flow rate through the CPC shall be within the specified range.

If the instruments have their own airflow check, the above mentioned check shall be substituted with those of the instruments.

7.1.1.3 Air flow rate stability test results

The air flow rates of the CPC using upstream and downstream sampling points shall be within 5 % of the instrument's specified air flow rate. The difference between the sample air flow rates into the CPC from the upstream and downstream sample lines shall not exceed 2 %.

7.1.2 CPC — Zero test

7.1.2.1 General

The ability of the CPC to zero count is a quick indication if maintenance is needed on the CPC.

7.1.2.2 Zero test protocol

For each CPC in the system, install a high efficiency filter (minimum at HEPA level) directly to the instrument's inlet and run a 1 min count.

7.1.2.3 Zero test results

The zero count of the CPC(s) shall be verified to be <2 total counts per minute.

To convert the aforementioned value to concentration, the following procedure shall be applied. If x cm^3 passes through the measuring point of the instrument, the concentration shall be $<2/x$ particles per cubic centimetre.

7.1.3 CPC — Overload test

7.1.3.1 General

CPC shall be used in the single particle counting mode. The concentration above which CPC does not operate in single particle counting mode is called the CL. CPCs may underestimate particle concentrations if their single particle CL is exceeded. Therefore, it is necessary to know the CL of the CPC being used. The maximum aerosol concentration used in the tests shall then be kept sufficiently lower than the CL so that the counting error resulting from coincidence is within the manufacturer's specifications.

7.1.3.2 Overload test protocol

A series of initial fractional efficiency tests shall be performed over a range of challenge aerosol concentration to determine a total concentration level for the fractional efficiency test that does not overload the CPC(s). The tests shall be performed following the procedures in Clause 8 on an air filter using a range of upstream aerosol concentration. The aerosol for these tests shall be generated using the same system and following the same procedures as specified in 5.2.2.

NOTE Concentration reduction can be achieved by increasing the air flow through the test device or by reducing the aerosol generator's output.

If the upstream concentration in the test rig cannot be reduced, e.g. for testing of high efficiency filter media, a dilution system shall be used for sampling to reduce the aerosol concentrations below the CPC´s CL. Upstream samples are then taken via the dilution system. The dilution factor needs to be taken into account to determine the upstream concentration.

7.1.3.3 Overload test results

The tests shall be performed over a sufficient range of total challenge concentrations to demonstrate that the CPC(s) is not overloaded at the intended test concentration. The measured filtration efficiencies shall be equal over the concentration range where overloading is not significant.

7.1.4 Counting accuracy calibration

Certain models of CPC have two modes for particle counting:

— concentration mode, where data are presented as particle concentration in p/cm^3, updated every second on the display (some models may have higher time resolution such as one-tenth of a second);

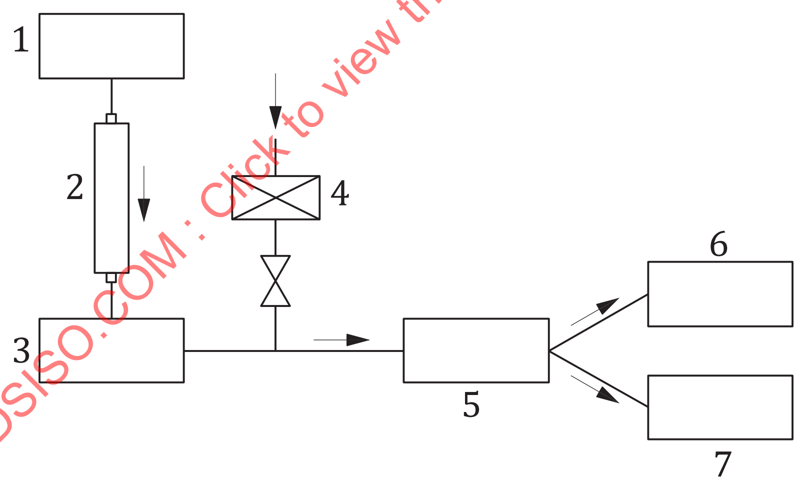
— totalizer mode, where total particle counts are accumulated and presented in a certain defined period of time.

Concentration mode is commonly used for most applications. Totalizer mode is used at very low particle concentrations. Particles can be accumulated until a desired statistical accuracy is achieved.

The CPC needs to be calibrated against a reference concentration (e.g. an aerosol electrometer or another certified CPC with a dilution bridge with a known dilution ratio) in order to provide accurate concentration measurements.

Into more details, the setup for the calibration of the CPC using an aerosol electrometer is presented in Figure 9. Particles are generated using a DEHS aerosol generator, in accordance with the procedure presented in Clause 5. They pass through a neutralizer to acquire Boltzmann equilibrium distribution charge and particles of a specific size are selected by the DEMC. Depending on the CPC model, 1 to 2 particle sizes below 20 nm (greater fraction of singly charged particles) are tested to evaluate the CPC measuring accuracy. The flow is diluted and equally distributed to the test CPC and the aerosol electrometer. The concentration measured by the CPC shall be compared to the one measured by the aerosol electrometer, and the difference shall be within the error range of the manufacturer's specification for the CPC. For testing the counting efficiency with particles below 20 nm, the manufacturer shall be contacted for a calibrated cut-off curve which shows the counting efficiency as a function of the particle size in the range near the lower detection limit. Extensive details for the calibration are presented in ISO 27891.

Equal tube lengths from flow splitter to the electrometer and CPC shall be provided so as to eliminate the difference of the diffusion loss. In addition, the CPC concentrations shall be kept below the concentration level at which the CPC can be operated with the single particle counting mode and corrected for coincidence.



Key

1	aerosol generator	5	flow splitter
2	neutralizer	6	aerosol electrometer/certified CPC
3	DEMC	7	test CPC
4	make-up air with HEPA filter		

Figure 9 — CPC calibration setup

An aerosol electrometer is shown in Figure 10. Its measurement principle is based on measuring the electric current induced by the charged particles trapped in the high efficient filter. The filter medium holder shall be made of highly conductive material. The concentration shall be calculated from Formula (8):

$$N = \frac{V}{e \cdot R_{es} \cdot n_p \cdot q_e} \quad (8)$$

where

N is the particle number concentration;

V is the electrometer voltage reading;

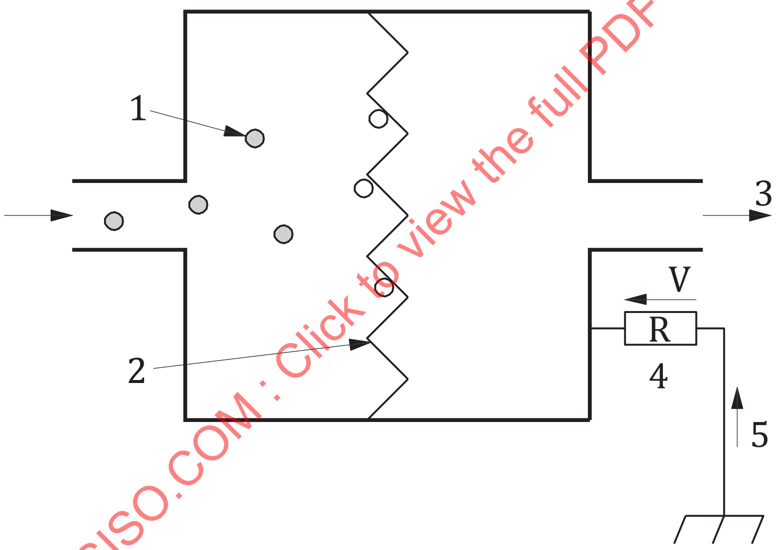
e is the unit charge;

R_{es} is the resistance of the resistor;

n_p is the number of charges per particle;

q_e is the air flow rate.

For most particles classified by the DEMC, $n_p = 1$ and the amount of multiply charged particles is small when the DEMC size is set to less than 20 nm.



Key

1 charged aerosol particles

2 particle filter

3 air flow

4 resistor

5 induced charge flow (current) in case of negatively charged aerosols

Figure 10 — Aerosol electrometer

The concentration measured by the test CPC is compared to the concentration computed from Formula (8) based on the electrometer measurement. The difference shall be within the error range of the manufacturer's specification for the CPC.

7.2 DEMC tests

DEMC can be calibrated using Standard Reference Materials such as SRM 1961 (269 nm), SRM 1963 (100 nm) or SRM 1964 (60 nm), issued by National Institute of Standards and Technology (see Reference [24]). Other certified reference materials can be used as well.

The SRM is aerosolized and passed through the DEMC. The DEMC and CPC can be operated in the scanning mode. After measuring the peak particle size, the measured particle size shall match the nominal SRM particle size within a tolerance of ±5 %. Detailed description is provided in ISO 15900.

7.3 Qualification of aerosol neutralization

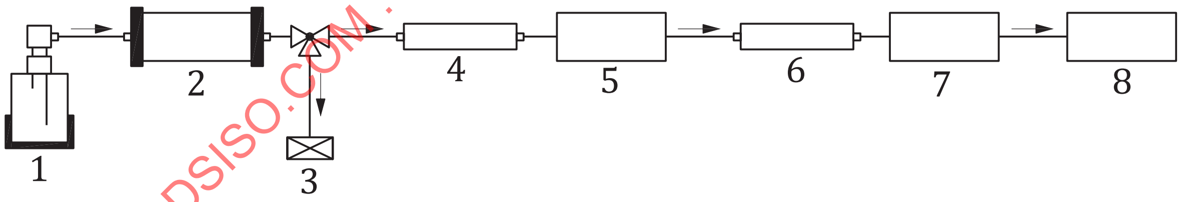
7.3.1 General

Neutralized aerosol is defined as aerosol whose charge level is reduced until it provides a Boltzmann equilibrium charge distribution. Different methods are described below and can be chosen based on available equipment.

7.3.2 Qualification of neutralization by checking the multiple charge fraction on the particles passing through the neutralizer

A neutralizer is used in order to achieve Boltzmann equilibrium charge distribution on the particles. The efficiency of the neutralizer is checked with the following experimental procedure:

The neutralization efficiency of the neutralizer (second neutralizer in the row) can be checked using PSL particles of known diameters. The test setup is presented in Figure 11. Two DEMCs shall be placed in a row. The first one is used to preselect the desired particle diameter and to remove the residual particles from the PSL suspension and the second one to select the particle diameter corresponding to singly, doubly, triply or even more highly charged particles. The concentration or counts is measured with the CPC. Upon data acquisition, the experimental ratios between the multiply charged particles and the singly charged particles are calculated (C_{ni}/C_{n1} or N_{ni}/N_{n1}) and shall be compared with the theoretical ones (e.g. calculated from Table 2.) The maximum deviation between the theoretical and experimental charge ratios shall be within 20 %.



Key

1 atomizer	5 1st DEMC
2 diffusion dryer	6 neutralizer being qualified
3 excess air through HEPA filter	7 2nd DEMC
4 neutralizer	8 CPC

Figure 11 — Test setup to evaluate the neutralization efficiency

7.3.3 Qualification of the aerosol neutralizer using corona discharge balanced output

The neutralizer output shall be checked for balance at a minimum of every two weeks. Remove the neutralizer from the test rig. Connect the aerosol neutralizer to a clean air flow supply. Hold the neutralizer 300 mm from any object which can interfere with any electromagnetic field. Hold the measuring plate of the static voltmeter 300 mm in front of the neutralizer perpendicular to the axis of the air stream exiting the neutralizer. Adjust the positive and negative output to obtain a reading as close as possible to zero (the static voltage level may bounce around: the average metre reading shall be zero).

7.3.4 Qualification of neutralization according to ISO/TS 19713-1

There are two methods to qualify the neutralization based on the effect of particle charge on the efficiency of the electret filter media. The electret filter media collect charged particles more efficiently than uncharged particles.

The first method (Method 1) involves reducing the concentration/flow rate to minimize electret efficiency. It is applicable to radioactive-type neutralizers and may also be used to check the concentration capabilities of electrostatic corona neutralizers. The second method (Method 2) involves adjusting the ion output to minimize electret efficiency. It is only applicable to electrostatic corona-type neutralizers.

Both test methods find the minimum electret efficiency that can be obtained with the neutralizing equipment being tested.

Detailed explanation for Method 1 and Method 2 is provided in ISO/TS 19713-1:2010, Annex G.

7.4 System leak checks

7.4.1 Air leakage tests

Purity of the test air and leakage of the system shall be tested by measuring the upstream particle concentration with the aerosol generator switched off. The setup is described in 6.3. The maximum allowed particles are 2 particles per minute.

7.4.2 Visual detection by cold smoke

Smoke aerosols will be generated and transported into the filter medium test system. Visual detection of smoke indicates leakage.

7.4.3 Pressurization of the test system

The filter medium test system is pressurized to 101 325 Pa + 3 times the filter medium pressure drop. The over-pressure variation shall be less than 5 % for at least 5 min if the system is leak free. The setup is described in 6.3.

7.4.4 Use of high efficiency filter media

High efficiency filter media, e.g. ISO 35H grade media per ISO 29463-1 shall be measured to ensure that the test rig does not have downstream leaks.

The stabilization time of aerosol generation shall be taken into account when determining the counting time.

The test shall be performed according to 8.2. Maximum 2 particles shall be counted downstream in 1 min.

7.5 Uniformity of the test aerosol concentration

The uniformity of the challenge aerosol in the medium test section shall be determined, for filter media sample larger than 100 cm^2, by measurement at the centre of the section and then at four points located in the centre of four equal areas in which the media test section is divided. The measurement can be done by using a single probe which can be repositioned. The velocity in the sampling probe is calculated from the cross sectional area and the sample flow rate which is depended on the measurement instrument. The measurement shall be repeated at 0,02 m/s, 0,05 m/s and 0,1 m/s filter medium velocities (the flow rate can be calculated according to 6.4). The sampling line shall be as short as possible to minimize sampling losses and shall also be of the same diameter as used in the efficiency test. The size of the probe inlet shall be minimized to reduce the interference with the airflow pattern, thus, a probe with a 3 mm opening shall be used.

The aerosol concentration shall be measured with a particle detection instrument meeting the specifications in this document. The measurement shall be carried out at each single location and air flow rate for at least 60 s. The measurements shall not deviate more than 15 % from the average value at each flow rate.

8 Test procedure

8.1 Determination of the correlation ratio/zero efficiency test

The particle concentrations can be measured either by one CPC or two CPCs in the tests with monodisperse particles, or by one or two sets of DMAS in the tests with polydisperse particles.

When one CPC is used, upstream and downstream, particle concentrations of the filter medium are taken sequentially. In this case, the line losses for the upstream and downstream sampling may be different. The difference can be significant when the particle size is very small and the diffusion loss is important. In addition, some particles may be deposited at the inlet, outlet or walls of the filter medium holder. Therefore it is important to establish correlation ratios by performing the measurement without any filter medium in the filter medium holder.

NOTE The method is similar to that used in ISO 16890-2.

The correlation ratio test shall be performed at the airflow rate of the test filter. The particle generator for the same challenge aerosol as for the test shall be turned on, but without a test filter medium in place. Upstream and downstream samples are measured for the same sampling time intervals. The general formula for the correlation ratio, R, as used in this document is:

$$R = N_{\text{down}} / N_{\text{up}} \text{ or } R = C_{\text{down}} / C_{\text{up}} \quad (9)$$

where

N_{up} is the particle counts measured at the upstream sampling location without a filter medium;

N_{down} is the particle counts measured at the downstream sampling location without a filter medium;

C_{up} is the particle concentration measured at the upstream sampling location without a filter medium;

C_{down} is the particle concentration measured at the downstream sampling location without a filter medium.

The zero efficiency, which is the filtration efficiency without the filter medium in place, can be calculated as:

$$E_0 = 1 - R \quad (10)$$

The correlation ratio is dependent on the particle size, and shall be obtained at the same particle sizes as those in the measurement for the test filter. The correlation ratio R_i, for the i_{th} monodisperse particle size can be written as:

$$R_i = N_{\text{down},i} / N_{\text{up},i} \text{ or } R_i = C_{\text{down},i} / C_{\text{up},i} \quad (11)$$

where

$N_{up,i}$ is the counts of particles with the i_{th} monodisperse size measured at the upstream sampling location without a filter medium;

$N_{down,i}$ is the counts of particles with the i_{th} monodisperse size measured at the downstream sampling location without a filter medium.

The zero efficiency $E_{0,i}$, for the i_{th} monodisperse particle size can be written as:

$$E_{0,i} = 1 - R_i \tag{12}$$

If the measured penetration when a filter medium is tested is P_m, the corrected penetration P takes the following form:

$$P = P_m / R \tag{13}$$

For the test performed with monodisperse particles, the penetration of particles with the i_{th} monodisperse size P_i can be written as:

$$P_i = P_{m,i} / R_i \tag{14}$$

where $P_{m,i}$ is the measured penetration against particles with the i_{th} monodisperse size when a filter medium is installed in the filter medium holder, and P_i is the corrected value with correlation ratio.

If two CPCs are used at the upstream and downstream, respectively, the correlation ratio is also needed because different CPC units usually give somewhat different readings when sampling the same aerosol, in addition, the line losses may be different. The correlation ratio R is obtained in the same way as described above, without the filter medium but using the readings of the two CPCs located upstream and downstream of the filter medium.

8.2 Protocol of filtration efficiency measurement

8.2.1 Preparatory checks

The accuracy of the DEMC, the CPC and the flow meters shall be within the specification of the manufacturers. The strength of the neutralizers shall be enough to achieve the Boltzmann equilibrium charge distribution for the required aerosol flow rate.

Overall, the instruments shall pass the qualification procedure.

8.2.2 Equipment preparation

All the equipment shall be turned on following the manufacturers' instructions. The status of the CPC and the DEMC shall be normal according to the instrument operation manual. The parameters such as the working liquid level, the temperature and the flow rate shall be in the normal operating range. The controllers for the sheath air and high voltage shall be checked.

8.2.3 Aerosol generator

8.2.3.1 Aerosol generator — Response time

The aerosol generator response time determines the amount of time delay needed to reach a steady state condition for testing.

8.2.3.2 Aerosol response test protocol

Measure the time interval for the aerosol concentration to go from background level to steady state test level.

The test shall be performed with the CPC sampling from the upstream probe. Similarly, measure the time interval for the aerosol to return to background level after turning off the generator.

NOTE This is to ensure that sufficient time is allowed for the aerosol concentration to stabilize prior to beginning the upstream/downstream sampling sequence during the filter testing.

Use the aerosol generator described in 5.2 and the CPC described in 6.2.9 to find the aerosol generator response time. The response time equals the time that the CPC needs to measure a stable aerosol concentration or particle counts. The concentration fluctuations shall be within 10 % of the average concentration. The stabilization time of aerosol generation shall be taken into account when determining the overall measuring time.

8.2.3.3 Aerosol response time results

These time intervals shall be used as the minimum waiting time between

a) activating the aerosol generator and beginning the CPC sampling sequence, and

b) deactivating the aerosol generator and beginning the CPC sampling sequence for determination of background aerosol concentrations.

8.2.4 Aerosol generator — Neutralizer

8.2.4.1 General

When testing electrostatically charged filter media any aerosol electric charge can affect the test results. Thus, neutralizing the challenge aerosol is a necessary procedure.

8.2.4.2 Aerosol neutralizer test protocol

Test the activity of the alpha or beta radiation source with an appropriate radiation detection device. If a corona discharge ionizer is used it shall have a minimum corona current of 3 µA and shall be balanced to provide equal amounts of positive and negative ions.

8.2.4.3 Aerosol neutralizer time results

The measurement shall be repeated annually and compared to prior measurements to determine if a substantial decrease in activity has occurred. Replace neutralizers showing a lack of activity in accordance with the manufacturer's recommendations.

8.2.4.4 Aerosol neutralizer – Radioactive service life verification

Verify that the source strength, A, is still above the minimum required value (185 MBq or 5 mCi) by checking the original source strength, the decay rate and the time passed from date of manufacture using Formula (15):

$$A = A_0 \cdot e^{-\lambda t} \qquad (15)$$

where

λ is the radioactive decay constant equal to $0{,}693/t_{0,5}$ where $t_{0,5}$ is the half-life of the radioactive source usually expressed in years;

T is the time in service of the radioactive source expressed in years;

A_0 is the original source strength which is the original radioactive source strength in MBq (mCi).

8.2.4.5 Radioactive aerosol neutralizer — Maintenance

Radioactive aerosol neutralizers shall be maintained according to the manufacturer's recommendations. Rinse with a solvent appropriate for the challenge aerosol used.

Alternatively, the neutralizer shall be cleaned by flowing clean air through it.

A safety protocol for handling radioactive device is provided in Annex D for information.

8.2.4.6 Aerosol neutralizer — Corona discharge current

8.2.4.6.1 General

The aerosol neutralizer current for corona discharge devices shall be measured as part of qualification and as part of each test. Measurement shall be performed with a Faraday cup electrometer. The minimum corona current shall be 3 µA.

8.2.4.6.2 Aerosol neutralizer based on corona discharge — Maintenance

The corona discharge points shall be inspected and cleaned according to the manufacturer's recommendations.

Disconnect ion source from power supply and refer to the manufacturers safety requirements prior to cleaning the corona neutralizer.

8.2.5 Filter medium neutralization

A preconditioning method which is able to eliminate all electrostatic effects in all filter media, while preserving media structure and leaving mechanical filtration and other media properties intact, shall be used. Some neutralization methods can be:

— discharge by particulate loading;

— discharge by liquid immersion;

— discharge by exposure to vapours;

— discharge with surfactants.

The selected method shall be verified not to impact the media structure leaving mechanical filtration and other media properties intact while at the same time removing completely the electrostatic charges.

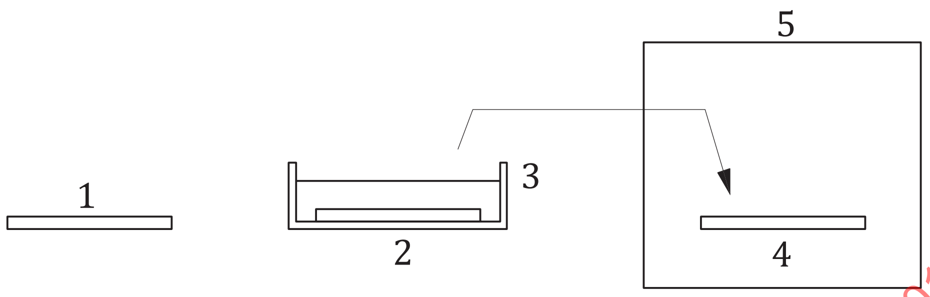
8.2.6 Filter medium neutralization according to ISO 29461-1

8.2.6.1 Equipment

The described procedure is based on a standardized treatment with IPA to evaluate electrostatic influence on filter medium particulate efficiency. IPA shall be handled with safety. More details regarding the safety handling of IPA are presented in Annex C.

The IPA test is made by first measuring the particulate efficiency of untreated medium samples. Next, the samples are treated with IPA vapour (>99,9 % technical grade). If IPA is reused the IPA purity shall remain above 99,9 %. After filter samples are exposed to the IPA vapour, they are placed on a flat, inert surface in a fume cupboard for drying. After the drying period of 15 min the particulate efficiency measurements are repeated. To verify that sample is free from residual IPA the sample is purged for 30 min with clean dry air and the particulate efficiency test is repeated. The efficiency measurement is performed according to the method described in this document, e.g. using the setup shown in Figure 2.

The IPA vapour treatment is made using the system shown in Figure 12. This system includes a vessel for the IPA. The system also includes flat perforated surfaces on which filter samples are placed for drying. The drying of the filter samples shall take place in a laboratory fume cupboard.



Key

1 filter medium sample
2 IPA treatment
3 IPA vessel
4 fume cupboard
5 drying

Figure 12 — Principle of the IPA test system

8.2.6.2 Preparation of test samples

A minimum of three media samples shall be tested. The total surface of the samples shall be ≥0,06 m^2. Samples shall be selected to represent the typical medium under consideration. Each effective medium sample area shall be ≥0,01 m^2.

8.2.6.3 Measurement of filter medium efficiency

The test is started by mounting the filter medium sample in the test equipment. The velocity through the medium sample is adjusted to be in the range of the velocity used in the normal applications of the medium. The filter medium sample pressure drop is measured. The particulate filtration efficiency of the sample is determined by measuring the particle concentrations from upstream and downstream of the filter medium sample. The criteria for test aerosol, size range and particulate efficiency measurement are according to the method described in this document.

8.2.6.4 IPA vapour treatment test

The IPA vapour exposure test is carried out as follows:

— initial particulate efficiency and pressure drop values of the filter medium samples are measured;

— filter medium samples are exposed to IPA vapour for 24 h;

— filter medium samples are placed on a flat inert surface for drying (this shall take place in a laboratory fume cupboard). To allow quick evaporation of the IPA the filter medium samples shall be placed on a perforated surface surrounded by air (see Figure 13);

— after a drying period of 15 min, the particulate efficiency and pressure drop measurements are repeated;

— after purging for 30 min with dry, clean air the particulate efficiency test is repeated for one of the samples. If efficiency has changed by more than ±3 percentage points or the pressure drop has changed by more than ±5 Pa, all samples are purged for 30 min with clean air and retested;

— if the required accuracy above cannot be met, there shall be a clear remark in the report that this requirement has not been met and the reason for this.

8.2.6.5 IPA vapour treatment method

— The allowed temperature range for the test container and the ambient air is +293 K to +303 K.

— The container with IPA shall not be in direct contact with sunlight or any other heat radiation that may alter the vapour characteristics significantly.

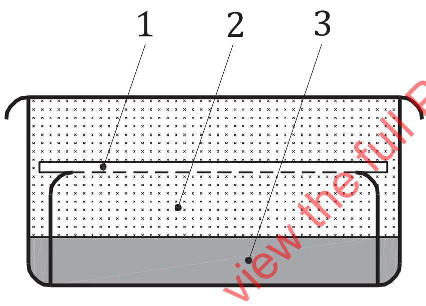
— The ambient humidity shall be within 40 % to 80 % RH.

— Add IPA into containers to about 10 mm in depth. Well above the liquid surface, place a screen to hold the sample media (see Figure 13).

— Place samples onto the screens and seal the containers.

— The mixture of ambient (room) air and IPA (and vapour) in the container shall not interact with the ambient air (proper seal).

— After a period of 24 h, open the containers and prepare the media for particulate efficiency test.



Key

1 filter medium sample

2 IPA vapour

3 liquid IPA

Figure 13 — Principle of the IPA container (vessel and lid)

The average efficiencies of the untreated and conditioned filter medium samples are calculated. The initial particulate efficiency of the untreated filter medium sample shall not differ by more than 5 percentage points of the average of all filter medium samples tested. If these two efficiencies differ by more than 5 percentage points, more filter media samples shall be tested and the results included in the calculation of the average initial particulate efficiency of the media samples until the two values differ by less than 5 percentage points. If this goal cannot be reached, a corresponding remark shall be made in the test report. The average efficiencies of the untreated and conditioned filter media samples are reported together with the aerosol and size range (DEHS 20 nm to 500 nm). The difference in particulate efficiency from the media tests (initial – conditioned) are calculated as the initial media particulate efficiency (E_0) minus the conditioned media efficiency [%]. This difference is then used to calculate the conditioned filter efficiency as $E_0 - \Delta E_C$.

8.2.7 Air flow measurement

Air flow measurement shall be made in accordance with the ISO 5167 series. Instrument error shall not exceed 5 % of the full scale.

8.2.8 Measurement of the pressure drop

The pressure drop Δp 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 controlled to give the desired flow velocity for the filter medium. The measurements shall be made when the system has reached a stable operating state and the pressure taps shall be located as close as possible upstream and downstream to the filter medium.

If the pressure drop of the filter medium sample increases during the test, it is an indication that the filter medium is getting clogged.

In this case a more sensitive downstream detector shall be used and the test shall be repeated at lower upstream aerosol particle concentration. If clogging still occurs under these conditions, it shall be reported in the test report.

8.2.9 Zero count test

Zero count shall be checked for the particle counter when it is measuring downstream particle concentration with the aerosol generator switched off and the filter medium sample in position.

8.2.10 Air leakage test

Purity of the test air and leakage of the system shall be tested by measuring the upstream particle concentration with aerosol generator switched off.

8.2.11 Loading effect test

The filtration efficiency shall be re-measured for particle sizes close to the MPPS after completing a measurement test, in order to see if the particle loading on the filter medium affects the filtration efficiency. If so, particle upstream concentration shall be decreased and the filtration test shall be re-conducted with a new piece of filter medium.

8.2.12 Reported values

The values of the absolute pressure and temperature of the test air on the downstream side of the filter medium shall be recorded.

The temperature measurement device shall be accurate to within ±1 K. The temperature measurement devices shall be calibrated yearly.

8.2.13 Measurement of filtration efficiency — DEHS particles

DEHS particles generated from an atomizer is an example of the test aerosols in the size range from 20 nm to 500 nm, because of its size distribution and the fact that the mode is often below 100 nm. Particles of other materials can be used as long as the qualification procedures including those listed in 7.1.3, 7.1.4, 8.2.3 are performed and the particle concentrations are high enough to achieve the minimum concentrations listed in Table 6.

In the range of 20 nm to 30 nm, two or three particle sizes are suggested. In the range above 30 nm to 500 nm, at least seven approximately logarithmically equidistant interpolated particle sizes shall be selected for the efficiency test. The suggested particles sizes are listed in Table 4.

Table 4 — Recommended testing particle sizes in the range from 20 nm to 500 nm

Total number of particle sizes	Particle sizes nm
9	20, 30, 45, 70, 100, 150, 220,335, 500
12	20, 25, 30, 40, 55, 80, 105, 145, 200, 270, 365, 500
14	20, 25, 30, 38, 50, 65, 83, 108, 140, 180, 232, 300, 387, 500
17	20, 25, 30, 36, 45, 55, 70, 82, 100, 125, 150, 180, 220, 270, 335, 410, 500

To achieve better monodispersity and reduce the amount of doubly charged particles, the DEMC shall select particle sizes which are larger than the mode size of a particle size distribution. For example, if a particle size distribution has a single mode at 100 nm, it is advisable to use DEMC to select particle sizes larger than 100 nm. Therefore one shall generate particles with small mode sizes for testing of small particle sizes. The particle size distribution can be adjusted by controlling the concentration of DEHS in the solvent. The size of the DEHS particle, d_p, after complete evaporation of the solvent, can be calculated from the initial droplet size d_d and the volume fraction of the DEHS φ_v:

$$d_p = d_d (\varphi_v)^{1/3} \tag{16}$$

Table 5 gives the calculated size of DEHS particles based on the initial droplet size and volume fraction. It is clear that the low concentration of DEHS shall be used when small particle sizes are tested, and the concentration increases with the needed particle size.

Table 5 — Calculated particle sizes after complete evaporation of solvent based on the initial droplet size and volume fraction of DEHS (adapted from Reference [23])

Volume fraction of DEHS	Particle size after complete evaporation of water (nm)			
	Droplet 300 nm	Droplet 500 nm	Droplet 1 000 nm	Droplet 3 000 nm
5 %	110,5	184,2	368,4	1 105,2
1 %	64,6	107,7	215,4	646,3
0,5 %	51,3	85,5	171,0	513,0
0,1 %	30,0	50,0	100,0	300,0
0,05 %	23,8	39,7	79,4	238,1
0,01 %	13,9	23,2	46,4	139,2

If the total particle counts upstream and downstream of the filter medium in a user-defined interval are measured to determine the filtration efficiency, reasonably large particle counts shall be obtained. For very small particle sizes, the filtration efficiency may be much higher than particle sizes in the rest of the size range. Thus the minimal downstream counts need to be set at a lower value for the very small particle sizes. The recommended minimal downstream counts are listed in Table 6.

Table 6 — Suggested value for the minimal downstream counts

Particle size range	Minimal downstream counts N_{down}
20 nm to 50 nm	10
50 nm to 500 nm	20

The overlapping range, between this document and ISO/TS 21083-2, from 20 nm to 30 nm can be used to check consistency of the two methods. Since diffusion is the dominant filtration mechanism for particles well below 100 nm, the particle material almost does not affect the efficiency in the 20 nm to 30 nm range (see References [19], [27], [28]).

For example, the difference in filtration efficiencies for silver and DEHS particles in the overlapping size range of 20 nm to 30 nm was below 8 % in the round robin test (see Reference [19]). In case the difference is higher, the qualification tests should be reapplied to define the error source.

8.3 Test evaluation

The procedures in 8.2.1, 8.2.2, 8.2.7, 8.2.8, 8.2.9 and 8.2.10 shall be carried out consecutively on a number of samples of the test filter medium to give statistically reliable evaluation. An initial test gives the first value of the filtration efficiency at the MPPS, i.e. the minimum efficiency. If the minimum efficiency is <85 %, 5 more samples shall be tested; if the minimum efficiency is ≥85 %, 2 more samples shall be tested. The minimum number of samples is listed in Table 7. The statistics of the results, including the average value and standard deviation of the filtration efficiency and pressure drop, shall be calculated. The detailed calculation method for the statistics can be found in Annex B.

Table 7 — Minimum number and effective surface area of testing samples

Filter type	Minimum number of total testing samples	Minimum total effective surface area of all testing samples
Minimum efficiency <85 %	6	0,06 m^2
Minimum efficiency ≥85 %	3	0,03 m^2

8.4 Measurement protocol for one sample — Summary

8.4.1 Using one CPC to measure the upstream and downstream particle concentrations

a) Start the air flow and let it stabilize.

b) Ensure that no particles enter the measuring instruments when the aerosol generator is off.

   1) Perform the air leakage test.

   2) Perform the zero count test.

c) Start the aerosol generator and let it stabilize.

d) Obtain the correlation ratio when there is no test filter medium in the holder.

   — Select the first particle size. Repeat the procedures d) 1) to d) 5) until at least 3 upstream and 3 downstream measurements have been obtained.

      1) Let the particle concentration stabilize (depending on concentration and particle size).

      2) Sample the upstream particles for at least 1 min and obtain the average concentration (C_{up}).

      3) Change to downstream measurement and let the particle concentration stabilize (depending on concentration and particle size).

      4) Sample the downstream particles for at least 1 min and obtain the average concentration (C_{down}).

      5) Calculate the correlation ratio as R = C_{down}/C_{up}.

      6) Calculate the average correlation ratio R using the 3 or more measurements stated above.

   — Select the second particle size. Repeat the procedures d) 1) to d) 5) until at least 3 upstream and 3 downstream measurements have been obtained, then calculate the average correlation ratio R.

   ...

   — Select the last particle size. Repeat the procedures d) 1) to d) 5) until at least 3 upstream and 3 downstream measurements have been obtained, calculate the average correlation ratio R.

e) Place the test filter medium in the holder. Measure filtration efficiencies for different particle sizes in the intended size range.

— Select the first particle size. Repeat the procedures e) 1) to e) 6) until at least 3 upstream and 3 downstream measurements have been obtained.

1) Let the particle concentration stabilize (depending on concentration and particle size).

2) Sample the upstream particles for at least 1 min and obtain the average concentration (C_{up}).

3) Change to downstream measurement and let the particle concentration stabilize (depends on concentration and particle size).

4) Sample the downstream particles for at least 1 min and obtain the average concentration (C_{down}).

5) Calculate the filtration efficiencies as $1 - C_{down}/C_{up}/R$ using the correlation ratio R corresponding to this particle size.

6) If the upstream concentration is low (lower than a few thousands of particles per cm^3) or the filter medium efficiency is expected to be very high (>98 %), switch to the totalizer mode (for the definition, see 7.1.4) of the CPC for the downstream measurement. Sample downstream for a time duration of t (s), so that the total measured particle count is above the minimum N_{down} (Table 6). Then calculate the downstream concentration C_{down} = the measured N_{down}/x (cm^{-3}), where x is the volume of air in cm^3 sampled by the CPC, equal to the CPC flow rate multiplying the time t.

Calculate the filtration efficiencies as $1 - C_{down}/C_{up}/R$ using the correlation ratio R corresponding to this particle size.

— Select the second particle size. Repeat the procedures e) 1) to e) 6) until at least 3 upstream and 3 downstream measurements have been obtained.

...

— Select the last particle size. Repeat the procedures e) 1) to e) 6) until at least 3 upstream and 3 downstream measurements have been obtained.

f) For each particle size, calculate the final filtration efficiency as an average of the 3 or more measured filtration efficiencies.

8.4.2 Using two CPCs to measure the upstream and downstream particle concentrations

a) Start the air flow and let it stabilize.

b) Ensure that no particles enter the measuring instruments when the aerosol generator is off.

1) Perform the air leakage test.

2) Perform the zero count test.

c) Start the aerosol generator and let it stabilize.

d) Obtain the correlation ratio when there is no test filter medium in the holder.

— Select the first particle size. Repeat the procedures d) 1) to d) 3) until at least 3 upstream and 3 downstream measurements have been obtained.

1) Let the particle concentration stabilize (depending on concentration and particle size).

2) Sample the upstream and downstream particles simultaneously for at least 1 min and obtain the average concentration (C_{up} and C_{down}).

3) Calculate the correlation ratio as R = C_{down}/C_{up}.

4) Calculate the average correlation ratio R using the 3 or more measurements stated above.

— Select the second particle size. Repeat the procedures d) 1) to d) 3) until at least 3 upstream and 3 downstream measurements have been obtained, then calculate the average correlation ratio R.

...

— Select the last particle size. Repeat the procedures d) 1) to d) 3) until at least 3 upstream and 3 downstream measurements have been obtained, calculate the average correlation ratio R.

e) Place the test filter medium in the holder. Measure filtration efficiencies for different particle sizes in the intended size range.

— Select the first particle size. Repeat the procedures e) 1) to e) 4) until at least 3 upstream and 3 downstream measurements have been obtained.

1) Let the particle concentration stabilize (depending on concentration and particle size).

2) Sample the upstream and downstream particles simultaneously for at least 1 min and obtain the average concentration (C_{up} and C_{down}).

3) Calculate the filtration efficiencies as 1 − C_{down}/C_{up}/R using the correlation ratio R corresponding to this particle size.

4) If the upstream concentration is low (lower than a few thousands of particles per cm^3) or the filter efficiency is expected to be very high (>98 %), switch to the totalizer mode (for the definition see 7.1.4) of the CPC for the downstream measurement. Sample downstream for a time duration of t (s), so that the total measured particle count is above the minimum N_{down} (Table 6). Then calculate the downstream concentration C_{down} = the measured N_{down} /x (cm^{-3}), where x is the volume of air in cm^3 sampled by the CPC, equal to the CPC flow rate multiplying the time t.

Calculate the filtration efficiencies as 1 − C_{down}/C_{up}/R.

— Select the second particle size. Repeat the procedures e) 1) to e) 4) until at least 3 upstream and 3 downstream measurements have been obtained.

...

— Select the last particle size. Repeat the procedures e) 1) to e) 4) until at least 3 upstream and 3 downstream measurements have been obtained.

f) For each particle size, calculate the final filtration efficiency as an average of the three or more measured filtration efficiencies.

9 Maintenance items

Apparatus maintenance ensures that the system is in good operating condition. Additional cleaning and maintenance operations subject to any normal laboratory operation will also be needed beyond what is listed here. The recommended maintenance schedule is shown in Table 8. If available, the manufacturer`s recommended maintenance guidelines shall be followed. Periodic items are shown with references to the appropriate clauses/subclauses. Several items listed here are also part of the qualification test requirements, but are listed here as they need to be performed and documented more often than the qualification requirement.

Table 8 — Maintenance schedule

Maintenance items[a]	Subclause	Each Test	2 Weeks	Monthly	6 Months	Yearly
Correlation ratio	8.1	X				
CPC	7.1					X
Pressure drop, temperature, RH measurement	8.2.8	X				
Temperature, RH – Calibration	8.2.12					X
Air flow measurement – Calibration	8.2.7					X
Zero count test	8.2.9	X				
Air leakage Test	8.2.10	X				
Aerosol generator – Response time	8.2.4.3				X	
Aerosol neutralizer – Radioactive service life	8.2.4.4					X
Aerosol neutralizer – Radioactive clean	8.2.4.5		X			
Aerosol neutralizer – Corona discharge current	8.2.4.6	X				
Aerosol neutralizer – Corona discharge clean source	8.2.4.6.2		X			

[a] Regular cleaning of all equipment shall be undertaken to maintain the performance of the setup.

10 Measurement uncertainties

The uncertainties of the measured values of the different variables during the experiments can affect the filtration efficiency measurement. Important uncertainty sources are the CPC particle measurement accuracy, the DEMC sizing accuracy and the flow rate deviation from the indicated value.

Table 9 presents the maximum allowed uncertainties during the measurements. Knowing the functional relationship involving the measured quantities listed in Table 9 and their uncertainties, the total effect of these uncertainties on the filtration efficiency can be estimated. (See Reference [25]).

Table 9 — Measurement uncertainties

Measurement		Maximum deviation (uncertainties) %
Particle generation (concentration)		10
Particle counting		10
Flow rate		5
DEMC sizing accuracy	20 nm	20
	40 nm	7
	60 nm	6
	100 nm	2
	193 nm	3

11 Reporting results

11.1 General

Test results shall be reported using the test report format shown in this document. Table 10 and Table 11 comprise the complete test report and are examples of acceptable forms. Use of this exact format is not required, but the report shall include all of the information shown in 11.2.

11.2 Required reporting elements

11.2.1 General

The following information is required in every test report. Any report not containing all required elements shall be considered invalid.

11.2.2 Report summary

The one page summary section of the test report (Table 10) shall include the following information.

a) Laboratory information:

   1) laboratory name;

   2) laboratory location and contact information;

   3) test operator's name(s);

   4) particle counting and sizing device(s) information:

      i) manufacturer's name;

      ii) model number;

      iii) CL;

   5) method of airflow measurement.

b) Test information:

   1) identification of this standard;

   2) unique test report identification;

   3) date of the test;

   4) how the sample was obtained.

c) Test medium information:

   1) manufacturer's name (or name of the marketing organization, if different from the manufacturer);

   2) filter medium reference;

   3) sample number;

   4) test medium condition (e.g. clean, discharged);

   5) dimensions;

6) physical description including:

   i) type of medium with description and identification code;

   ii) medium colour;

   iii) filter medium treatment/coating;

   iv) electrostatic charge, if known;

7) a photo of the actual test medium is highly recommended, but not required; any other pertinent descriptive attributes.

d) Test medium literature data or operating data as stated by the manufacturer:

   1) particle removal efficiency;

   2) any other literature data available or furnished operating data.

e) Test conditions:

   1) test airflow rate;

   2) test air temperature and RH;

   3) test aerosol used.

f) Test data:

   1) particle removal efficiency in each measured particle size range;

   2) total upstream concentration measured during testing (p/m^3) by size range;

   3) number of samples tested;

   4) standard deviation from the mean filtration efficiency.

11.2.3 Report Details

The report details (Table 11) shall include but are not limited to the following information:

a) pressure drop before and after the test;

b) measured results of the particle removal efficiency measurement, reported both in a table and graphical format;

c) measured pressure drop at each velocity, reported in a table and graphical format.;

d) concluding statement: The results of this test relate only to the test filter medium in the condition stated herein. The performance results cannot by themselves be quantitatively applied to predict the filtration performance in all "in-service" environments.

Table 10 — Test report summary page format

ISO 21083-1:20xx — TEST REPORT — SUMMARY	**Testing Organization**	
	Name:	
	Address:	
	Phone:	

GENERAL INFORMATION			
Filter medium reference:		Date of test:	
Test ID:		Operator:	
Sample number:		Sample dimensions (*Diameter x H*) (mm):	
Manufacturer:		Net effective filter medium area (m^2):	
Type of filter medium:		Filter medium treatment/ coating :	
Filter medium colour:		Filter medium electrostatic charge:	
Source of the filter medium sample:			
Sample condition: (*clean/initial, ...*)			
Other descriptive information:			

TEST DATA SUMMARY		
Particle Counter Information		
Manufacturer	Model	Concentration limit

Airflow measurement device:		Test air temperature (°C):	
		Test air relative humidity (%):	
Maximum concentration into the test duct (p/cm^3):		Test aerosol:	
Test air flow rate (cm^3/s):		Conditioning method:	

RESULTS					
Number of samples tested:		Particle Removal Efficiency (%)			
Test sample photo:					
		Particle diameter (nm)	Measured Efficiency	Standard deviation	Upstream Concentration (p/m^3)/ Counts (p)
		20			
		30			
		45			
		67			
		100			
		150			
		224			
		335			
		500			
Remarks:					

NOTE The results of this test relate only to the test filter medium in the condition stated herein. The performance results cannot by themselves be quantitatively applied to predict the filtration performance in all "in-service" environments.

Table 11 — Format of the details section of the test report

<table>
<tr><td colspan="3" rowspan="4">ISO 21083-1:20xx - DETAILED RESULTS</td><td colspan="3">Testing Organization</td></tr>
<tr><td>Name:</td><td colspan="2"></td></tr>
<tr><td>Address:</td><td colspan="2"></td></tr>
<tr><td>Phone:</td><td colspan="2"></td></tr>
<tr><td colspan="6">GENERAL INFORMATION</td></tr>
<tr><td>Filter medium reference:</td><td colspan="2"></td><td colspan="2">Date of test:</td><td></td></tr>
<tr><td>Test ID:</td><td colspan="2"></td><td colspan="2">Operator:</td><td></td></tr>
<tr><td colspan="6">TEST DATA</td></tr>
<tr><td colspan="3">Filter medium velocity (cm/s):</td><td colspan="3">Particle type:</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">Pressure drop at the beginning of the test (Pa):</td><td colspan="3">Pressure drop at the end of the test (Pa):</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="3">Total measuring time-upstream (s):</td><td colspan="3">Total measuring time-downstream (s)</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="6">TEST RESULTS</td></tr>
<tr><td>Particle diameter (nm)</td><td>Upstream concentration or count
(p/m^3)/ Counts (p)</td><td>Downstream concentration or count
(p/m^3)/ Counts (p)</td><td>Efficiency (%)</td><td>Average Efficiency (%)</td><td>Standard deviation</td></tr>
<tr><td>20 (test 1)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>20 (test 2)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>20 (test 3)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>...</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>30 (test 1)</td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>67</td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>100</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>150</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>224</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>335</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>500</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">NOTE The results of this test relate only to the test filter medium in the condition stated herein. The performance results cannot by themselves be quantitatively applied to predict the filtration performance in all "in-service" environments.</td></tr>
</table>

Table 11 *(continued)*

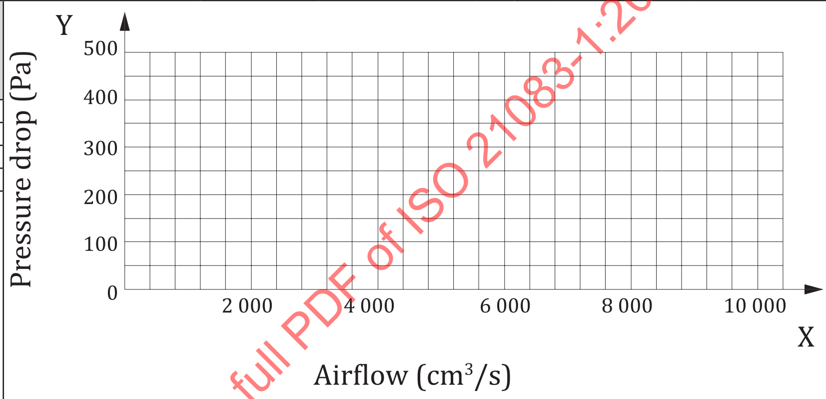
ISO 21083-1:20xx - DETAILED RESULTS	Testing Organization	
	Name:	
	Address:	
	Phone:	

GENERAL INFORMATION			
Filter medium reference:		Date of test:	
Test ID:		Operator:	

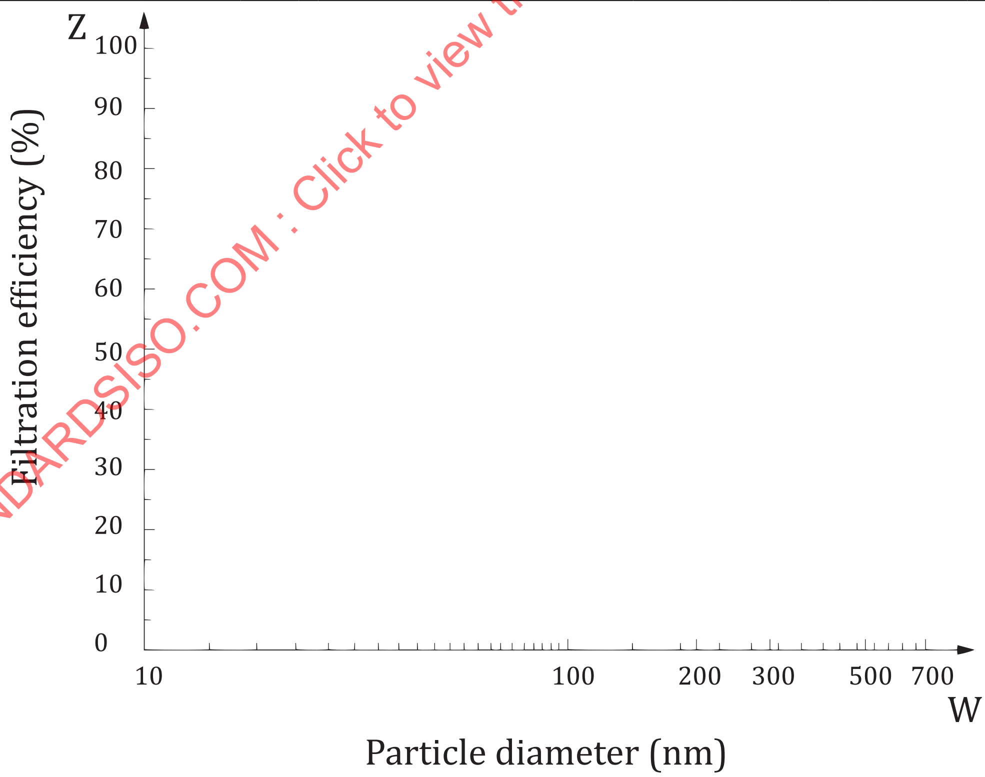
TEST DATA DETAILS

Pressure drop

Filter medium velocity (cm/s)	Airflow (cm^3/s)	Pressure drop (Pa)



Filtration Efficiency



NOTE The results of this test relate only to the test filter medium in the condition stated herein. The performance results cannot by themselves be quantitatively applied to predict the filtration performance in all "in-service" environments.

Annex A
(informative)

Instruments specifications

This annex includes the main characteristics of some of the instruments available on the market. The lists of instruments provided in Table A.1 and A.2 are not exhaustive and are provided to help the users of this document.

Table A.1 — Parameters of commercial aerosol generators

Atomizer	Operating pressure kPa	External compressed air	Air flow rate m^3/min (x0,001)	Output concentration	Droplet size distribution Mean diameter (µm)	GSD
Collison (BGI, USA)	100 140 170	Yes	2 12 2,7	8,8 (g/m^3) 7,7 (g/m^3)	MMD ≈2,5 to 3 MMD ≈2,1 to 3 MMD ≈1,9 to 2	2,7 to 3,4
Constant output atomizer 3076 (TSI, USA)	240	Yes	2,0 to 3,5	>10^7 #/cm^3	NMD ≈0,30 (DOP),0,35 (water)	1,6 to 2,0
Portable atomizer 3079 (TSI,USA)	Max 20	No	Max 5	>10^8 #/cm^3 (DOS)	Mode diameter ≈ 0,25 (DOS)	
Six-jet atomizer 9306 (TSI,USA)	34 to 380	Yes	2,4 per jet 12 per jet	>10^7 #/cm^3	NMD ≈0,30 (DOP),0,35 (water)	<2
Single-jet atomizer 9302 (TSI,USA)	34 to 380	Yes	2,4 to 12	>10^7 #/cm^3	NMD ≈0,30 (DOP),0,35 (water)	<2
Atomizer ATM 220 (Topas, DE)	Max 800	Yes	Max 4,2	>10^8 #/cm^3 (DOS)	Median diameter ≈ 0,1 to 0,5 (DOS)	
Atomizer ATM 226 (Topas, DE)	Max 20	No	Max 5	>10^8 #/cm^3 (DOS)	Median diameter ≈ 0,1 to 0,5 (DOS)	
Atomizer ATM 230 (Topas, DE)	Max 800	Yes	8,3 to 41,6	>10^8 #/cm^3 (DOS)	Median diameter ≈ 0,1 to 0,5 (DOS)	
Aerosol Generator AGF 2,0 (Palas, DE)		Yes	6 to 17	4 (g/h)	Mean diameter ≈ 0,25 (DOS)	
Aerosol Generator AGF 2,0 iP (Palas, DE)		No	16 to 18	2 (g/h)	Mean diameter ≈ 0,25 (DOS)	
Aerosol Generator AGF 10,0 (Palas, DE)		Yes	12 to 45	20 (g/h)	Mean diameter ≈ 0,5 (DOS)	

MMD: mass median diameter DOS: di(2-ethilhexyl) sebacate.

NMD: number median diameter DOP: di(2-ethilhexyl) phthalate.

GSD: geometric standard deviation.

Table A.2 — Information of a number of commercial CPC

Model	Min, detectable size (d_{50})	Max, detectable size	Single counting		Photometric		Sample flow rate (L/min)	Working liquid	DMAS compatible
			Concentration	Error	Concentration	Error			
A11 nCNC (Airmodus, FI)	1 nm	1 µm	<30 000 #/cm^3	<10 %	<100 000 #/cm^3	10 %	2,5	Diethylene Glycol (>99 %); n-Butanol (>99 %)	Yes
A20 CPC (Airmodus FI)	5 to 10 nm (on request)	2,5 µm	<30 000 #/cm^3	<10 %	100 000 #/cm^3	<10 %	1	Butanol	Yes
A23 CPC (Airmodus, FI)	23 nm	2,5 µm	<30 000 #/cm^3	<10 %	<100 000 #/cm^3	<10 %	1	n-Butanol (>99.5%)	Yes
Model 1720 Mixing CPC (Brechtel, USA)	7 nm	2 µm			100 000 #/cm^3	±8 %	0,36	n-Butanol	Yes
NPC 10 (PMS, USA)	10 nm	1 µm					2,83		
UF-CPC 50 (Palas, DE)	4 nm	10 µm	<2 000 #/cm^3	5 %	<10^7 #/cm^3	10 %	0,3 to 0,6	Butanol, IPA, water or other liquid	Yes
UF-CPC 100 (Palas, DE)			<5 × 10^4 #/cm^3						Yes
UF-CPC 200 (Palas, DE)			<10^6 #/cm^3						Yes

NOTE 1 The data for the Airmodus instruments are from the Airmodus website, https://airmodus.com/, retrieved on April 17, 2017.

NOTE 2 The data for the Brechtel instruments are from the Brechtel website, http://www.brechtel.com/, retrieved on April 17, 2017.

NOTE 3 The data for the PMS instruments are from the PMS website, http://www.pmeasuring.com/, retrieved on April 17, 2017.

NOTE 4 The data for the Palas instruments are from the Palas website http://www.palas.de/, retrieved on Aug 23, 2013.

NOTE 5 The data for the Grimm instruments are from the Grimm website http://www.grimm-aerosol.com/, retrieved on Aug 23, 2013.

NOTE 6 The data for the HCT instruments are from the website http://www.ioner.eu/, retrieved on Aug 23, 2013.

NOTE 7 The data for the TSI instruments are from the TSI website, www.tsi.com/, retrieved on May 9, 2018.

NOTE 8 The data for the MSP instruments are from the MSP website http://www.mspcorp.com/, retrieved on Aug 23, 2013.

NOTE 9 The data for the Kanomax instruments are from the Kanomax-USA website http://www.kanomax-usa.com/, retrieved on Aug 23, 2013.

Table A.2 *(continued)*

Model	Min, detectable size (d_{50})	Max, detectable size	Single counting		Photometric		Sample flow rate (L/min)	Working liquid	DMAS compatible
			Concentration	Error	Concentration	Error			
Mobile CPC 5,403 (Grimm, DE)	4,5 nm	>3 µm	0 to 14 000 #/cm^3	5 %	<10^7 #/cm^3	>10 %	0,3/1,5	1-Butanol	Yes
CPC 5,410 (Grimm, DE)	4 nm		<10^5 #/cm^3				0,6		No
CPC 5,414 (Grimm, DE)	4 nm		<1,5 × 10^5 #/cm^3				0,3/0,6		Yes
CPC 5,416 (Grimm, DE)	4 nm		<1,5 × 10^5 #/cm^3				0,3		Yes
CPC 0701 (HCT, KR)	7 nm		0 to 10^4 #/cm^3	±10 %	10^4 to 10^5 #/cm^3	±20 %	1	n-butyl alcohol	Yes
PCPC 2301 (HCT, KR)	23 nm		0 to 10^4 #/cm^3	±10 %			1	n-butyl alcohol	
CPC 3757-50 NanoEnhancer + CPC	1,1 nm		0 to 3 × 10^5 #/cm^3				2,5		Yes
CPC 3776 (TSI, USA)	2,5 nm	>3 µm	0 to 3 × 10^5 #/cm^3	±10 %			0,3/1,5	n-butyl alcohol	Yes
CPC 3788 (TSI, USA)	2,5 nm		0 to 4 × 10^5 #/cm^3	±10 %			0,6/1,5	water	Yes

NOTE 1 The data for the Airmodus instruments are from the Airmodus website, https://airmodus.com/, retrieved on April 17, 2017.

NOTE 2 The data for the Brechtel instruments are from the Brechtel website, http://www.brechtel.com/, retrieved on April 17, 2017.

NOTE 3 The data for the PMS instruments are from the PMS website, http://www.pmeasuring.com/, retrieved on April 17, 2017.

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NOTE 7 The data for the TSI instruments are from the TSI website, www.tsi.com/, retrieved on May 9, 2018.

NOTE 8 The data for the MSP instruments are from the MSP website http://www.mspcorp.com/, retrieved on Aug 23, 2013.

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