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

**Part 2:  
Size range from 3 nm to 30 nm**

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

*Partie 2: Spectre granulométrique de 3 nm à 30 nm*





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## Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

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](http://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 [15]).

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 nanoparticles 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.

Filtration testing for nanoparticles, especially those down to single-digit nanometres, is a challenging task which necessitates generation of a large amount of extremely small particles, and accurate sizing and quantification of such particles. The thermal rebound remains a question for particles down to 1 nm to 2 nm (see Reference [11]). The accuracy of particle size classification is complicated by very strong diffusion of particles below 10 nm (see References [7] and [8]). The state-of-the-art commercial condensation particle counters for general purposes can detect particles down to 1 nm to 2 nm.

A large number of standards for testing air filters exist such as the ISO 29463 and 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.

Advances in aerosol instruments and studies on nanoparticle filtration in the recent years provide a solid base for development of a test method to determine effectiveness of filtration media against airborne nanoparticles down to 3 nm range.

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

## Part 2: Size range from 3 nm to 30 nm

### 1 Scope

This document specifies the testing instruments and procedure for determining the filtration efficiencies of flat sheet filter media against airborne nanoparticles in the range of 3 nm to 30 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 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

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 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 5167-1, ISO 5725-1, 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 <https://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                                                                                                                                                             |
| $\phi_v$     | 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 user-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                                                                                                                                                         |
| $\alpha$     | Angle for the transition section in the filter medium holder                                                                                                                      |
| $\Delta p$   | Pressure drop across the filter medium                                                                                                                                            |
| $E_0$        | Initial particulate efficiency of media sample                                                                                                                                    |
| $\Delta E_c$ | Difference in particulate efficiency between $E_0$ and conditioned efficiency of the media sample                                                                                 |
| $\lambda$    | 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                         |
| CMD  | Count median diameter                       |
| 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, as shown in [Formula \(1\)](#):

$$P = C_{\text{down}} / C_{\text{up}} \quad (1)$$

where  $C_{\text{down}}$  and  $C_{\text{up}}$  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,  $N_{\text{down}}$ , and upstream count,  $N_{\text{up}}$ , as shown in [Formula \(2\)](#):

$$P = N_{\text{down}} / N_{\text{up}} \quad (2)$$

The filter medium efficiency,  $E$ , is the fraction of aerosols particles removed by the filter medium, as shown in [Formula \(3\)](#):

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

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  $i_{\text{th}}$  monodisperse size,  $P_i$ , can be written as shown in [Formula \(4\)](#):

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

where  $C_{\text{up},i}$  and  $C_{\text{down},i}$  are the concentration of particles with the  $i_{\text{th}}$  monodisperse size upstream and downstream of the filter medium, respectively. 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 shown in [Formula \(5\)](#):

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

where  $N_{up,i}$  and  $N_{down,i}$  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 as shown in [Formula \(6\)](#):

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

The test particles in the range from 3 nm to 30 nm are generated by an evaporation-condensation method. One realization of this method is the generation of silver (Ag) particles from an electrical tube furnace.

The test particle from the generator is 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 is 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 test filter medium due to loading, charge neutralization or other physical or chemical reaction.

### 5.2 Solid phase aerosol — Silver test aerosol as an example

Pure silver powder source – Ag (99,999 %)

#### Pure silver powder properties:

Density  $10,49 \cdot 10^3 \text{ kg/m}^3$

Melting point 1 234 K

Boiling point 2 434 K

Solubility insoluble in water

### 5.3 Solid phase aerosol generation method

Silver nanoparticles or nanoparticles of other materials can be used as long as the qualification procedure is performed and the requirements are fulfilled.

Silver nanoparticles can be generated by the evaporation-condensation method (see Reference [17]). An electric furnace is used to generate silver nanoparticles from a pure silver powder source (99,999 %), and clean compressed air or other gases, such as nitrogen, is used as a carrier gas with flow rate of 16,7 m<sup>3</sup>/s to 50·10<sup>-6</sup> m<sup>3</sup>/s (1 l/min to 3,0 l/min). The silver powder source located in the centre of a heating tube is vaporized and condensed into silver nanoparticles with a relatively wide size distribution when the air flow exits the tube furnace. For very small particles a rapid temperature decrease may be applied at the exit of the tube furnace so as to produce particles in the desired size range. As an example, some technical specifications regarding tube furnaces are presented in [Annex A, Tables A.1 to A.4](#).

Any other generator capable of producing particles in sufficient concentrations in the particle size range of 3 nm to 30 nm so that the particle concentration upstream of the test filter medium is at least 1 000 per cm<sup>3</sup> under any of the test mode, such as monodisperse or polydisperse test described in [Clause 6](#), can be used.

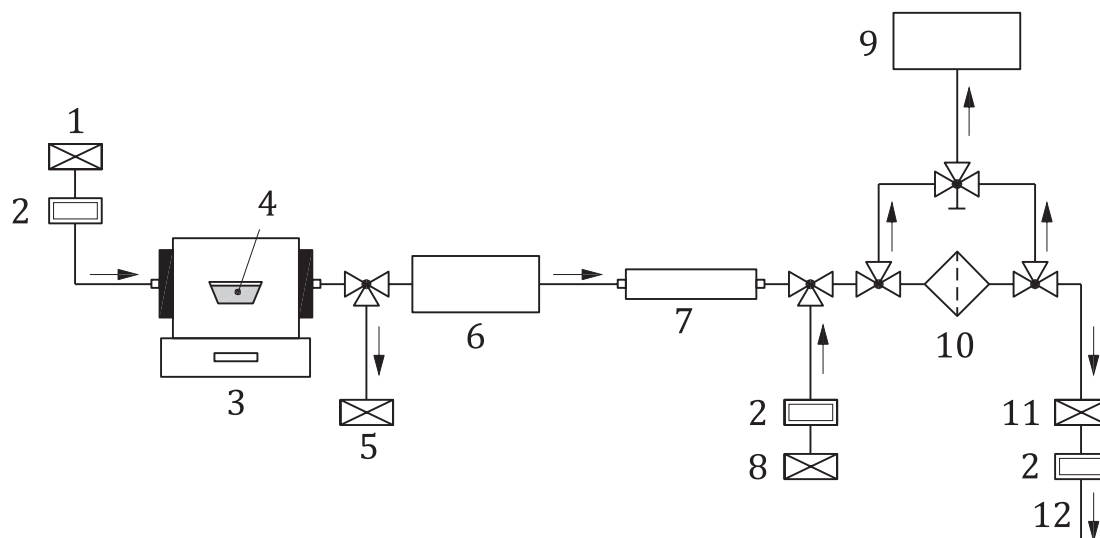
## 6 Test setup

### 6.1 General

The test setup is shown in [Figure 1](#) for monodisperse challenge particles and in [Figure 2](#) for polydisperse challenge particles. When the challenge particles are monodisperse, the setup consists of 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 challenge particles are polydisperse, the particle classification shall be performed after sampling the aerosol from the upstream or downstream section.

The measurement with monodisperse particles is the reference test while the measurement with polydisperse particles shall be qualified carefully and verified by comparison with monodisperse test for validating the measurement procedure.

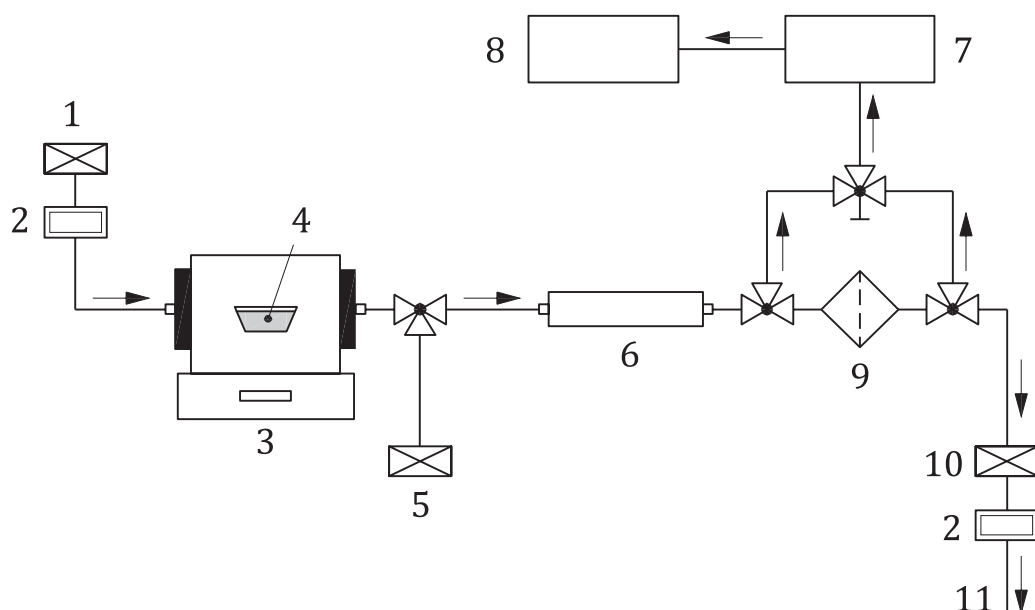
Tests using monodisperse and polydisperse aerosols should yield equivalent results if they are carried out correctly. Japuntich et al.[9] performed both polydisperse and monodisperse measurements down to 20 nm to 30 nm range and showed reasonable agreement. Buha et al.[20] compared polydisperse test results with models down to similar size range and showed good agreement. With the particles in even smaller size range, the size distribution measurement downstream of the filter is increasingly difficult.



# Key

- |   |                               |    |                                 |
|---|-------------------------------|----|---------------------------------|
| 1 | air or N2 through HEPA filter | 7  | neutralizer                     |
| 2 | flow controller               | 8  | make up air with HEPA filter    |
| 3 | furnace                       | 9  | CPC                             |
| 4 | silver                        | 10 | filter medium holder            |
| 5 | excess flow with HEPA filter  | 11 | HEPA filter on the exhaust line |
| 6 | DEMC                          | 12 | vacuum                          |

**Figure 1 — Test setup for monodisperse challenge particles**



### Key

|   |                                       |    |                                 |
|---|---------------------------------------|----|---------------------------------|
| 1 | air or N <sub>2</sub>                 | 7  | DEMC                            |
| 2 | flow controller                       | 8  | CPC                             |
| 3 | furnace                               | 9  | filter medium holder            |
| 4 | silver                                | 10 | HEPA filter on the exhaust line |
| 5 | flow compensation through HEPA filter | 11 | vacuum                          |
| 6 | neutralizer                           |    |                                 |

**Figure 2 — Test setup for polydisperse challenge particles**

## 6.2 Specifications of setup

### 6.2.1 Aerosol generation system

The aerosol generation system is described in [5.3](#).

### 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 DEMC

#### 6.2.3.1 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 3](#)) 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 3 nm to 30 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.

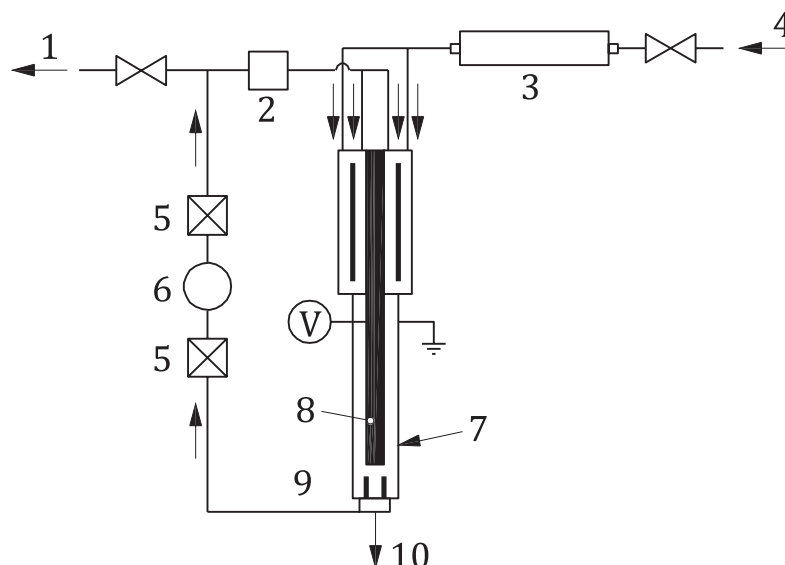
Small particles require weak electric fields to move them towards the central electrode. Larger particles require stronger fields. By adjusting the electric field, particles of a known size are attracted towards the opening in the central rod and are removed for measurements. Thus, particles with a narrow 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 strengths, the number of particles in different sizes in the sample can be measured and the particle size distribution of the sample determined.

Alternatively, 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 3 nm to 30 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 3 nm to 30 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 [\[7\]](#)). 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           | 7 outer cylinder            |
| 2 mass flow meter      | 8 high voltage rod          |
| 3 neutralizer          | 9 excess flow               |
| 4 polydisperse aerosol | 10 monodisperse flow        |
| 5 HEPA filter          | V high voltage power supply |
| 6 pump                 |                             |

**Figure 3 — DEMC schematic diagram**

#### 6.2.3.2 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<br>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               |

#### 6.2.4 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 charges on the population of these particles reach 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.

### 6.2.5 Neutralization of aerosol particles

Depending on the particle generation method, the charges on the generated particles vary. 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 this 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  $\alpha$  particles or  $\beta$  rays, corona discharge sources with AC voltage, and X-rays, among others. Alternatively, 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 bipolar 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 [13])**

| Particle diameter<br>nm | Mobility<br>(m <sup>2</sup> /Vs)<br>x10 <sup>-4</sup> | 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<br>1 | 0,982<br>68 | 0,008<br>2 | 0 | 0 | 0 | 0 | 0 |
| 2,55                    | 3,16E-01                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,010<br>5 | 0,980<br>07 | 0,009<br>4 | 0 | 0 | 0 | 0 | 0 |
| 2,94                    | 2,38E-01                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,012<br>3 | 0,976<br>91 | 0,010<br>8 | 0 | 0 | 0 | 0 | 0 |
| 3,4                     | 1,78E-01                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,014<br>4 | 0,973<br>1  | 0,012<br>5 | 0 | 0 | 0 | 0 | 0 |
| 3,92                    | 1,34E-01                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,016<br>9 | 0,968<br>5  | 0,014<br>6 | 0 | 0 | 0 | 0 | 0 |
| 4,53                    | 1,01E-01                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,02       | 0,962<br>97 | 0,017      | 0 | 0 | 0 | 0 | 0 |
| 5,23                    | 7,55E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,023<br>7 | 0,956<br>34 | 0,019<br>9 | 0 | 0 | 0 | 0 | 0 |
| 6,04                    | 5,68E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,028<br>2 | 0,948<br>42 | 0,023<br>4 | 0 | 0 | 0 | 0 | 0 |
| 6,98                    | 4,27E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,033<br>5 | 0,939       | 0,027<br>5 | 0 | 0 | 0 | 0 | 0 |
| 8,06                    | 3,21E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,039<br>8 | 0,927<br>87 | 0,032<br>3 | 0 | 0 | 0 | 0 | 0 |
| 9,31                    | 2,41E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,047<br>2 | 0,914<br>8  | 0,038      | 0 | 0 | 0 | 0 | 0 |
| 10,75                   | 1,82E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,055<br>9 | 0,899<br>58 | 0,044<br>5 | 0 | 0 | 0 | 0 | 0 |
| 12,41                   | 1,37E-02                                              | 0                                                                                       | 0  | 0  | 0  | 0  | 0,065<br>9 | 0,882<br>02 | 0,052      | 0 | 0 | 0 | 0 | 0 |

Table 2 (continued)

| Particle diameter<br>nm | Mobility<br>(m <sup>2</sup> /vs)<br>x10 <sup>-4</sup> | 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          |
| 14,33                   | 1,03E-02                                              | 0                                                                                       | 0          | 0          | 0          | 0          | 0,077<br>4 | 0,861<br>98 | 0,060<br>6 | 0          | 0          | 0          | 0          | 0          |
| 16,55                   | 7,77E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0          | 0,090<br>3 | 0,839<br>38 | 0,070<br>3 | 0          | 0          | 0          | 0          | 0          |
| 19,11                   | 5,86E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0          | 0,104<br>7 | 0,814<br>25 | 0,081      | 0          | 0          | 0          | 0          | 0          |
| 22,07                   | 4,43E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0,000<br>4 | 0,120<br>5 | 0,786<br>18 | 0,092<br>8 | 0,000<br>2 | 0          | 0          | 0          | 0          |
| 25,48                   | 3,35E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0,000<br>8 | 0,137<br>5 | 0,755<br>88 | 0,105<br>4 | 0,000<br>4 | 0          | 0          | 0          | 0          |
| 29,43                   | 2,54E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0,001<br>5 | 0,155<br>4 | 0,723<br>34 | 0,118<br>8 | 0,000<br>9 | 0          | 0          | 0          | 0          |
| 33,98                   | 1,93E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0,002<br>9 | 0,173<br>9 | 0,688<br>83 | 0,132<br>7 | 0,001<br>7 | 0          | 0          | 0          | 0          |
| 39,24                   | 1,47E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0,005<br>1 | 0,192<br>6 | 0,652<br>72 | 0,146<br>7 | 0,002<br>9 | 0          | 0          | 0          | 0          |
| 45,32                   | 1,12E-03                                              | 0                                                                                       | 0          | 0          | 0          | 0,008<br>4 | 0,210<br>9 | 0,615<br>45 | 0,160<br>5 | 0,004<br>8 | 0          | 0          | 0          | 0          |
| 52,33                   | 8,53E-04                                              | 0                                                                                       | 0          | 0          | 0          | 0,013<br>1 | 0,228<br>2 | 0,577<br>55 | 0,1737     | 0,007<br>5 | 0          | 0          | 0          | 0          |
| 60,43                   | 6,54E-04                                              | 0                                                                                       | 0          | 0          | 0          | 0,019<br>5 | 0,244      | 0,539<br>69 | 0,185<br>7 | 0,011<br>1 | 0          | 0          | 0          | 0          |
| 69,78                   | 5,03E-04                                              | 0                                                                                       | 0          | 0          | 0          | 0,027<br>8 | 0,257<br>6 | 0,502<br>6  | 0,196<br>3 | 0,015<br>7 | 0          | 0          | 0          | 0          |
| 80,58                   | 3,89E-04                                              | 0                                                                                       | 0          | 0          | 0,001<br>2 | 0,037<br>9 | 0,268<br>6 | 0,465<br>39 | 0,205      | 0,021<br>3 | 0,000<br>5 | 0          | 0          | 0          |
| 93,06                   | 3,01E-04                                              | 0                                                                                       | 0          | 0          | 0,002<br>6 | 0,049<br>7 | 0,276<br>6 | 0,4304      | 0,211<br>5 | 0,028      | 0,001<br>2 | 0          | 0          | 0          |
| 107,46                  | 2,35E-04                                              | 0                                                                                       | 0          | 0,000<br>1 | 0,005<br>1 | 0,062<br>8 | 0,281<br>2 | 0,397<br>28 | 0,215<br>5 | 0,035<br>6 | 0,002<br>3 | 0          | 0          | 0          |
| 124,09                  | 1,84E-04                                              | 0                                                                                       | 0          | 0,000<br>4 | 0,009<br>1 | 0,076<br>7 | 0,282<br>5 | 0,366<br>32 | 0,216<br>9 | 0,043<br>9 | 0,004<br>1 | 0,000<br>1 | 0          | 0          |
| 143,3                   | 1,45E-04                                              | 0                                                                                       | 0          | 0,001      | 0,014<br>6 | 0,090<br>9 | 0,280<br>4 | 0,337<br>74 | 0,215<br>8 | 0,052<br>5 | 0,006<br>6 | 0,000<br>4 | 0          | 0          |
| 165,48                  | 1,15E-04                                              | 0                                                                                       | 0,000<br>1 | 0,002<br>3 | 0,022      | 0,104<br>7 | 0,275<br>1 | 0,311<br>72 | 0,212<br>2 | 0,061<br>2 | 0,009<br>9 | 0,000<br>8 | 0          | 0          |
| 191,1                   | 9,23E-05                                              | 0                                                                                       | 0,000<br>3 | 0,004<br>4 | 0,030<br>9 | 0,117<br>4 | 0,267<br>1 | 0,288<br>41 | 0,206<br>5 | 0,069<br>4 | 0,013<br>9 | 0,001<br>5 | 0,000<br>1 | 0          |
| 220,67                  | 7,43E-05                                              | 0,000<br>1                                                                              | 0,000<br>9 | 0,007<br>7 | 0,041<br>1 | 0,128<br>5 | 0,256<br>8 | 0,267<br>86 | 0,198<br>9 | 0,076<br>8 | 0,018<br>5 | 0,002<br>6 | 0,000<br>2 | 0          |
| 254,83                  | 6,02E-05                                              | 0,000<br>2                                                                              | 0,001<br>9 | 0,012<br>5 | 0,052<br>2 | 0,137<br>6 | 0,244<br>8 | 0,250<br>06 | 0,189<br>8 | 0,082<br>9 | 0,023<br>4 | 0,004<br>3 | 0,000<br>5 | 0          |
| 294,27                  | 4,91E-05                                              | 0,000<br>5                                                                              | 0,003<br>7 | 0,018<br>7 | 0,063<br>4 | 0,144<br>3 | 0,231<br>6 | 0,234<br>83 | 0,179<br>7 | 0,087<br>3 | 0,028<br>4 | 0,006<br>4 | 0,001      | 0,000<br>1 |
| 339,82                  | 4,04E-05                                              | 0,001<br>2                                                                              | 0,006<br>6 | 0,026<br>2 | 0,074<br>2 | 0,148<br>6 | 0,217<br>8 | 0,221<br>84 | 0,169      | 0,090<br>1 | 0,033<br>3 | 0,009      | 0,001<br>7 | 0,000<br>2 |
| 392,42                  | 3,34E-05                                              | 0,002<br>5                                                                              | 0,010<br>8 | 0,034<br>8 | 0,084<br>2 | 0,150<br>5 | 0,203<br>9 | 0,210<br>58 | 0,158<br>1 | 0,091      | 0,037<br>8 | 0,012      | 0,002<br>8 | 0,000<br>5 |
| 453,16                  | 2,77E-05                                              | 0,004<br>6                                                                              | 0,016<br>2 | 0,044      | 0,092<br>9 | 0,150<br>3 | 0,190<br>4 | 0,200<br>35 | 0,147<br>4 | 0,090<br>3 | 0,041<br>7 | 0,015<br>1 | 0,004<br>3 | 0,000<br>9 |
| 523,3                   | 2,32E-05                                              | 0,007<br>9                                                                              | 0,022<br>9 | 0,053<br>4 | 0,100<br>1 | 0,148<br>1 | 0,177<br>7 | 0,190<br>35 | 0,137<br>2 | 0,088<br>3 | 0,044<br>9 | 0,018<br>3 | 0,006      | 0,001<br>6 |

### 6.2.6 Make-up air line

The make-up air-line shall be used in order to obtain the desired flow rate and to dilute the 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.

### 6.2.7 Test filter 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 4. 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 <sup>2</sup> (0,113 m diameter) |
| Inlet diameter                                                | >0,005 m                                       |
| Angle for the transition section (angle $\alpha$ in Figure 4) | $0^\circ < \alpha < 25^\circ$                  |

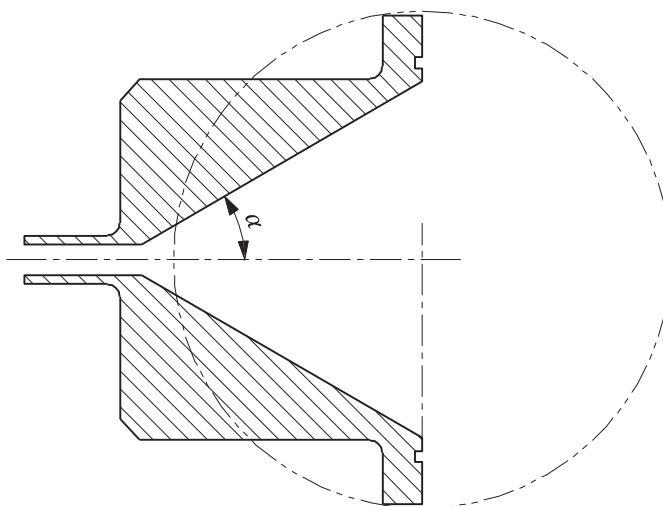


**Figure 4 — An example schematic of the side view of the half filter medium holder**