TECHNICAL SPECIFICATION

ISO/TS 21083-2

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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

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 [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
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
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):

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

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}, as shown in Formula (2):

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

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

$$E = 1 - P \tag{3}$$

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 shown in Formula (4):

$$P_i = C_{\text{down},i} / C_{\text{up},i} \tag{4}$$

where $C_{\text{up},i}$ and $C_{\text{down},i}$ are the concentration of particles with the i_{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	$10{,}49 \cdot 10^3$ 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^3/s to $50 \cdot 10^{-6}$ m^3/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^3 under any of the test mode, such as monodisperse or polydisperse test described in Clause 6, can be used.

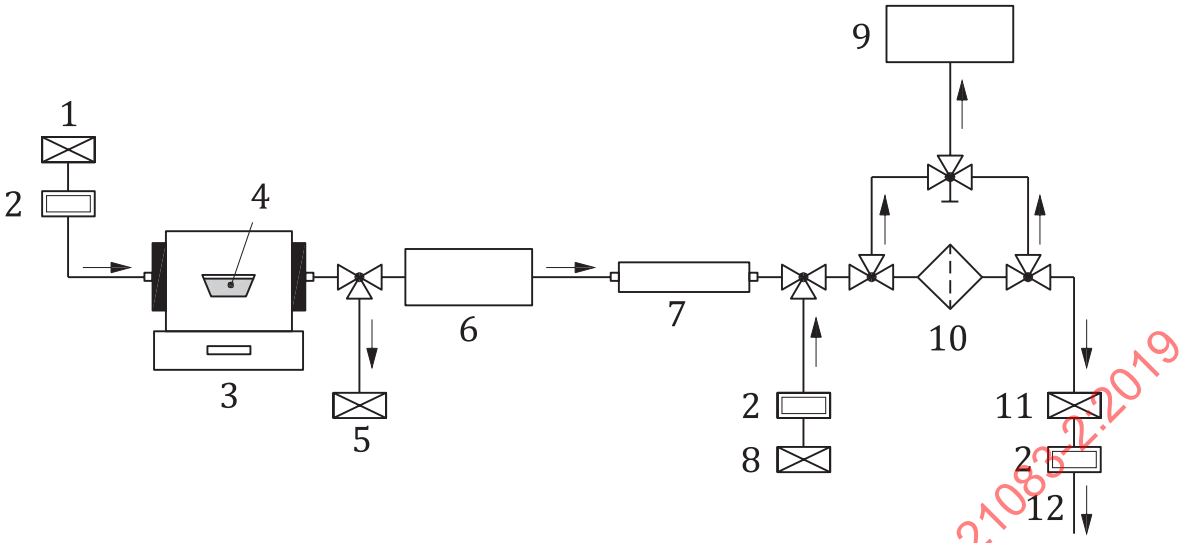
6 Test setup

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.

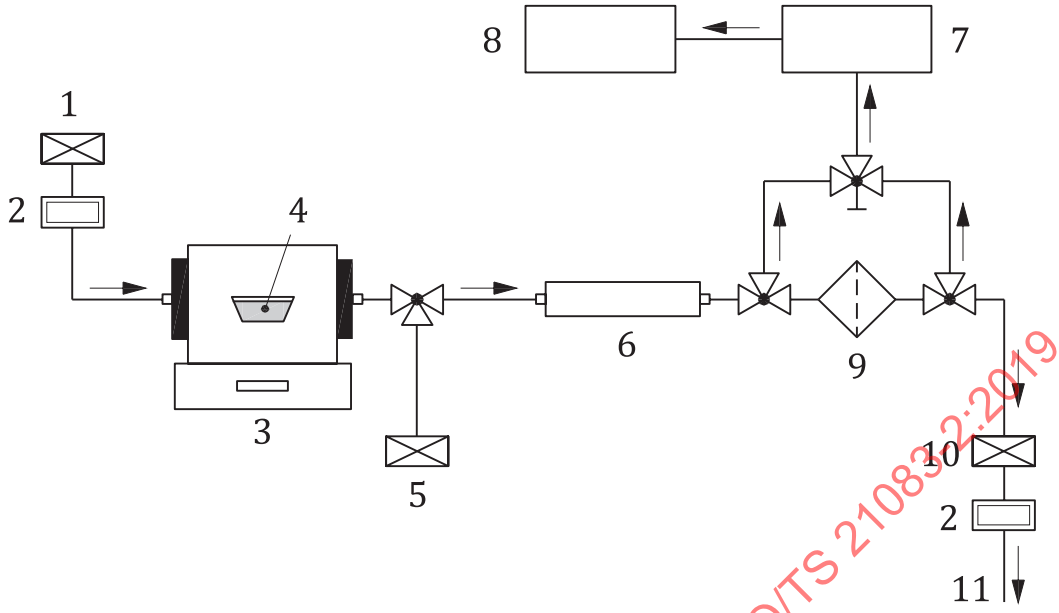
Tests using monodisperse and polydisperse aerosols should yield equivalent results if they are carried out correctly. Japuntich et al.[9] performed both polydisperse and monodisperse measurements down to 20 nm to 30 nm range and showed reasonable agreement. Buha et al.[20] compared polydisperse test 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_2	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.

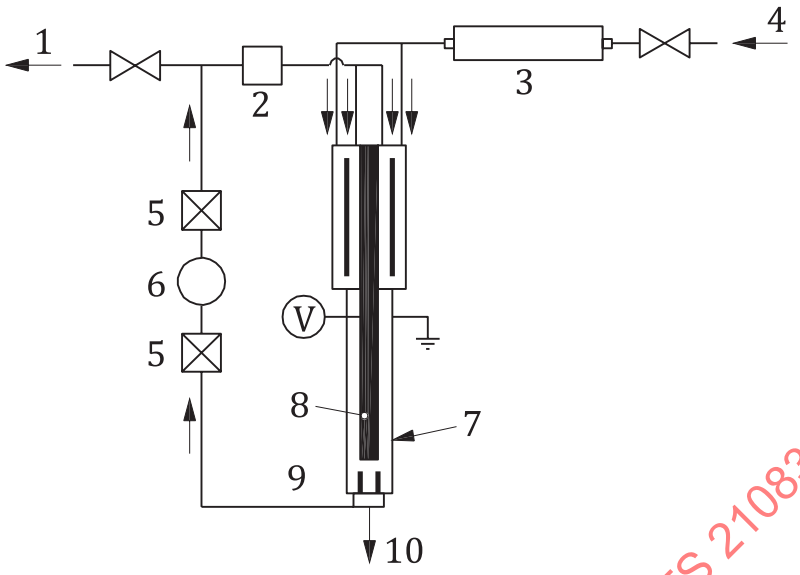
Small particles require weak electric fields to move them towards the central electrode. Larger particles require stronger fields. By adjusting the electric field, particles of a known size are attracted towards the opening in the central rod and are removed for measurements. Thus, particles with a narrow 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 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 α particles or β 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 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	0,0091	0,98268	0,0082	0	0	0	0	0
2,55	3,16E-01	0	0	0	0	0	0,0105	0,98007	0,0094	0	0	0	0	0
2,94	2,38E-01	0	0	0	0	0	0,0123	0,97691	0,0108	0	0	0	0	0
3,4	1,78E-01	0	0	0	0	0	0,0144	0,9731	0,0125	0	0	0	0	0
3,92	1,34E-01	0	0	0	0	0	0,0169	0,9685	0,0146	0	0	0	0	0
4,53	1,01E-01	0	0	0	0	0	0,02	0,96297	0,017	0	0	0	0	0
5,23	7,55E-02	0	0	0	0	0	0,0237	0,95634	0,0199	0	0	0	0	0
6,04	5,68E-02	0	0	0	0	0	0,0282	0,94842	0,0234	0	0	0	0	0
6,98	4,27E-02	0	0	0	0	0	0,0335	0,939	0,0275	0	0	0	0	0
8,06	3,21E-02	0	0	0	0	0	0,0398	0,92787	0,0323	0	0	0	0	0
9,31	2,41E-02	0	0	0	0	0	0,0472	0,9148	0,038	0	0	0	0	0
10,75	1,82E-02	0	0	0	0	0	0,0559	0,89958	0,0445	0	0	0	0	0
12,41	1,37E-02	0	0	0	0	0	0,0659	0,88202	0,052	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												
		−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6
14,33	1,03E-02	0	0	0	0	0	0,0774	0,86198	0,0606	0	0	0	0	0
16,55	7,77E-03	0	0	0	0	0	0,0903	0,83938	0,0703	0	0	0	0	0
19,11	5,86E-03	0	0	0	0	0	0,1047	0,81425	0,081	0	0	0	0	0
22,07	4,43E-03	0	0	0	0	0,0004	0,1205	0,78618	0,0928	0,0002	0	0	0	0
25,48	3,35E-03	0	0	0	0	0,0008	0,1375	0,75588	0,1054	0,0004	0	0	0	0
29,43	2,54E-03	0	0	0	0	0,0015	0,1554	0,72334	0,1188	0,0009	0	0	0	0
33,98	1,93E-03	0	0	0	0	0,0029	0,1739	0,68883	0,1327	0,0017	0	0	0	0
39,24	1,47E-03	0	0	0	0	0,0051	0,1926	0,65272	0,1467	0,0029	0	0	0	0
45,32	1,12E-03	0	0	0	0	0,0084	0,2109	0,61545	0,1605	0,0048	0	0	0	0
52,33	8,53E-04	0	0	0	0	0,0131	0,2282	0,57755	0,1737	0,0075	0	0	0	0
60,43	6,54E-04	0	0	0	0	0,0195	0,244	0,53969	0,1857	0,0111	0	0	0	0
69,78	5,03E-04	0	0	0	0	0,0278	0,2576	0,5026	0,1963	0,0157	0	0	0	0
80,58	3,89E-04	0	0	0	0,0012	0,0379	0,2686	0,46539	0,205	0,0213	0,0005	0	0	0
93,06	3,01E-04	0	0	0	0,0026	0,0497	0,2766	0,4304	0,2115	0,028	0,0012	0	0	0
107,46	2,35E-04	0	0	0,0001	0,0051	0,0628	0,2812	0,39728	0,2155	0,0356	0,0023	0	0	0
124,09	1,84E-04	0	0	0,0004	0,0091	0,0767	0,2825	0,36632	0,2169	0,0439	0,0041	0,0001	0	0
143,3	1,45E-04	0	0	0,001	0,0146	0,0909	0,2804	0,33774	0,2158	0,0525	0,0066	0,0004	0	0
165,48	1,15E-04	0	0,0001	0,0023	0,022	0,1047	0,2751	0,31172	0,2122	0,0612	0,0099	0,0008	0	0
191,1	9,23E-05	0	0,0003	0,0044	0,0309	0,1174	0,2671	0,28841	0,2065	0,0694	0,0139	0,0015	0,0001	0
220,67	7,43E-05	0,0001	0,0009	0,0077	0,0411	0,1285	0,2568	0,26786	0,1989	0,0768	0,0185	0,0026	0,0002	0
254,83	6,02E-05	0,0002	0,0019	0,0125	0,0522	0,1376	0,2448	0,25006	0,1898	0,0829	0,0234	0,0043	0,0005	0
294,27	4,91E-05	0,0005	0,0037	0,0187	0,0634	0,1443	0,2316	0,23483	0,1797	0,0873	0,0284	0,0064	0,001	0,0001
339,82	4,04E-05	0,0012	0,0066	0,0262	0,0742	0,1486	0,2178	0,22184	0,169	0,0901	0,0333	0,009	0,0017	0,0002
392,42	3,34E-05	0,0025	0,0108	0,0348	0,0842	0,1505	0,2039	0,21058	0,1581	0,091	0,0378	0,012	0,0028	0,0005
453,16	2,77E-05	0,0046	0,0162	0,044	0,0929	0,1503	0,1904	0,20035	0,1474	0,0903	0,0417	0,0151	0,0043	0,0009
523,3	2,32E-05	0,0079	0,0229	0,0534	0,1001	0,1481	0,1777	0,19035	0,1372	0,0883	0,0449	0,0183	0,006	0,0016

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^2 (0,113 m diameter)
Inlet diameter	>0,005 m
Angle for the transition section (angle α in Figure 4)	0° < α < 25°

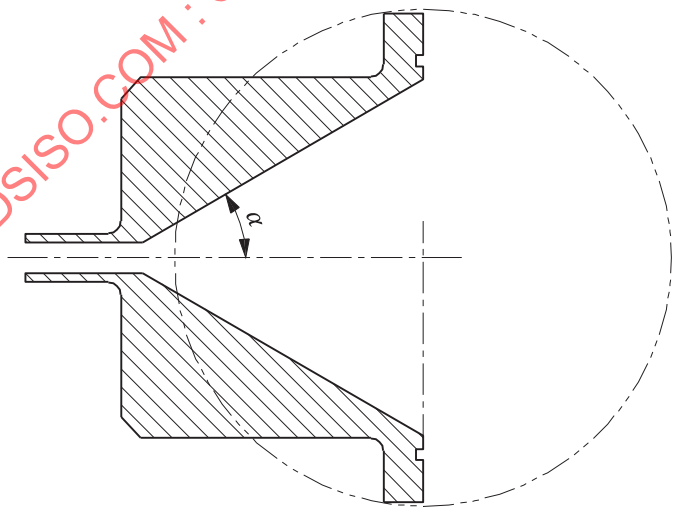


Figure 4 — An example schematic of the side view of the half filter medium holder

6.2.8 CPC

6.2.8.1 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.

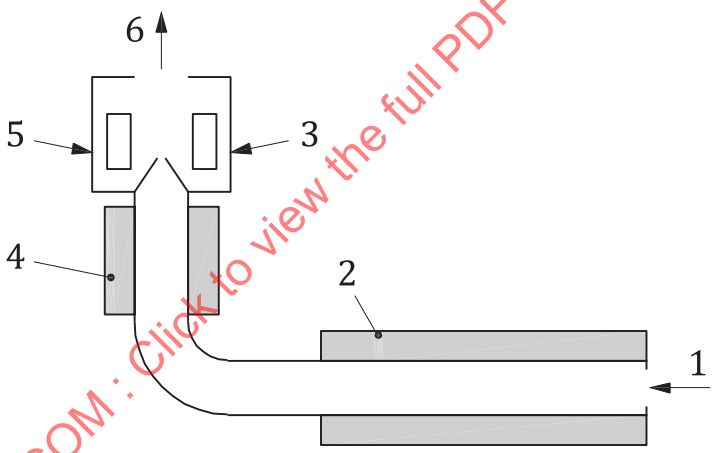
The test aerosols shall be compatible with the CPC working liquid in order to achieve the needed condensation growth for counting. The specification of the CPC shall be consulted for this purpose.

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 5 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.

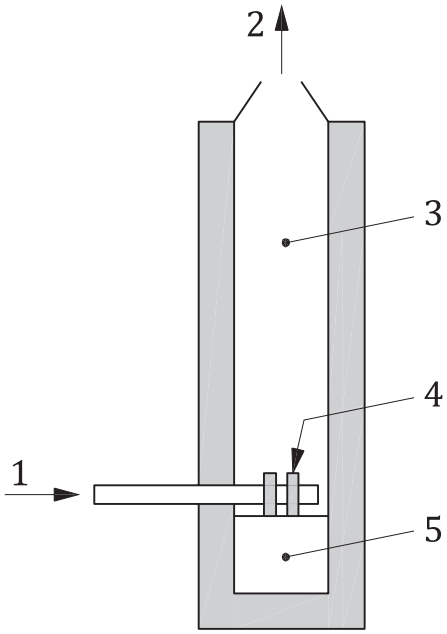


Key

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

Figure 5 — 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 6.



Key

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

Figure 6 — Structure of a CPC using the mixing principle.

Here, the aerosol is led directly to a mixing nozzle (see Reference [10]) by the shortest route. The drops of working fluid that form along the condensation section are again detected by a scattered light sensor.

6.2.8.2 Minimum specification for CPC

The CPC shall be capable of measuring particles in the range of 3 nm to 30 nm. In the data analysis the exact particle detection efficiency of the CPC shall be taken into account.

6.2.8.3 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 %.

6.2.8.4 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 upstream 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.

6.2.8.5 Calibration

It is required to check the CPC 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.

6.2.9 Final filter

The final filter (e.g. HEPA filter) is a high efficiency filter that will remove 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 silver nanoparticles

An example of the setup for the test using silver nanoparticles is shown in Figure 1. The particle size distribution can be adjusted by changing the furnace temperature. The average size and the particle number concentration of silver nanoparticles generated by the furnace increase with the furnace temperature, because at a higher temperature, the evaporation rate increases, giving rise to a larger amount of condensable vapour which allows the particles to grow to larger sizes by agglomeration and condensation. The furnace temperature range is about 1 123 K to 1 373 K. The CMD of the particle size distribution shall not be larger than 30 nm. Diffusional losses for 3 nm particles are remarkable and should be considered. Table 4 summarizes the suggested operation parameters for the furnace and the CMD of the generated particle size distribution.

Table 4 — Suggested operation parameters for the furnace and the CMD of the generated particle size distribution

Carrier gas flow rate	1 l/min to 3 l/min (16,7 m^3/s to $50 \cdot 10^{-6}$ m^3/s)
Furnace temperature range	1 123 K to 1 373 K
CMD of generated particle size distribution	<30 nm

The silver nanoparticles are neutralized to reach Boltzmann equilibrium charge distribution by a neutralizer (e.g. Po-210, Kr-85, Am-241 or soft X-ray) and classified by a DEMC. Since the test particles for this setup are expected to be in the range of 3 nm to 30 nm, a DEMC designed for very small nanometre particles is preferred. In addition, the suitable DEMC should be chosen to provide enough aerosol flow to satisfy the minimum downstream particle concentration or counts. The size of the monodisperse particles exiting the DEMC can be adjusted by changing the DEMC voltage. The flow rate of the aerosol entering the DEMC can be adjusted by using the valve on the excess flow route and is measured by a laminar flow meter. The laminar flow meter measures the flow rate by the pressure drop caused by the flow through a tube with known length and diameter. The test aerosol is then classified by the DEMC with a certain sheath flow rate.

The test aerosol shall be neutralized again by a neutralizer. This approach is to reduce the effect of particle charges on the filter medium and thus reduce uncertainties in the results. Before the filter medium, another flow path is provided for bypass 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 30 nm due to their low inertia and high diffusivity. Specimens of the sheet filter medium are 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 shown in Formula (7):

$$v_f = q/A_f \tag{7}$$

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 abovementioned check shall be substituted with those of the instruments.

7.1.1.3 Air flow rate stability test results

The air flow rate 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 rate 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, then 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 below 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 concentrations 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 concentrations. The aerosol for these tests shall be generated using the same system and following the same procedures as specified in 5.3.

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);

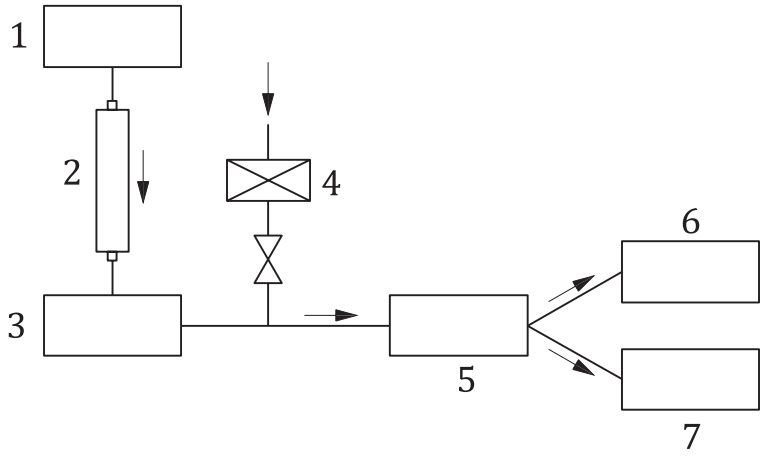
— totalizer mode: where total particle counts are accumulated and presented in certain defined period of time.

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 7. Particles are generated using a silver aerosol generator, in accordance with the procedure presented in Clause 4. They pass through a neutralizer to acquire Boltzmann equilibrium distribution charge and particles of a specific size are selected by the nano 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. 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
2 neutralizer
3 DEMC
4 make up air with HEPA filter
5 flow splitter
6 aerosol electrometer/certified CPC
7 test CPC

Figure 7 — CPC calibration setup.

An aerosol electrometer is shown in Figure 8. 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 as shown in Formula (8):

$$N = \frac{V}{e \cdot R_{es} \cdot n_p \cdot q_e} \tag{8}$$

where

N is the particle number concentration;

V is the electrometer voltage reading;

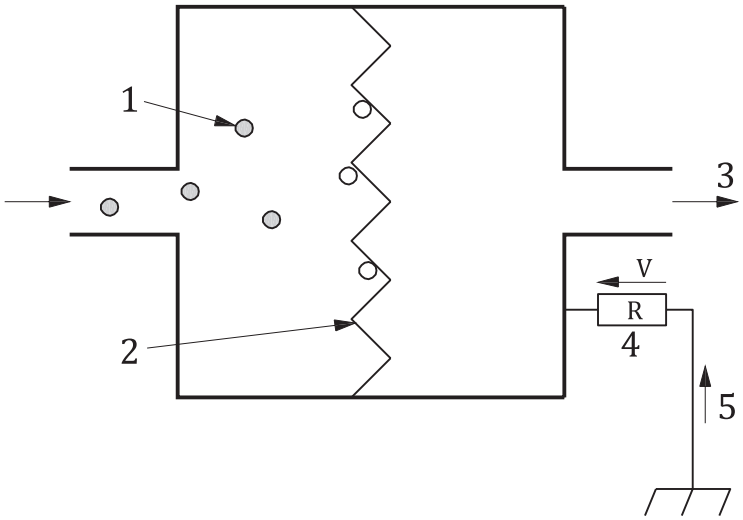
e is the unit charge;

R_{es} is the resistance of 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 8 — 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 [14]). 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

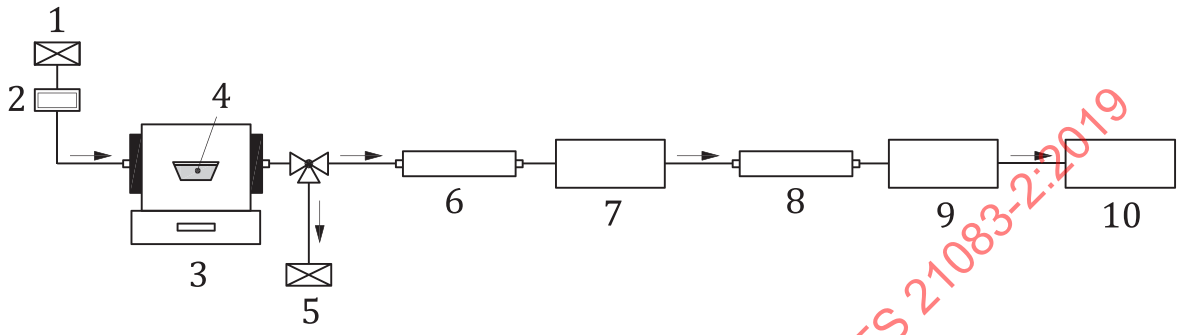
Neutralized aerosol is defined as an aerosol whose charge level is reduced until it provides a Boltzmann equilibrium charge distribution. Different methods are described below and can be chosen based on available equipment.

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 9. 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	air or N_2 through HEPA filter	6	neutralizer
2	flow controller	7	1st DEMC
3	furnace	8	neutralizer being qualified
4	silver	9	2nd DEMC
5	excess air through HEPA filter	10	CPC

Figure 9 — 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 35 H 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 medium 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 dependent 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

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 shown in Formulae (9) and (10):

$$R = N_{\text{down}} / N_{\text{up}} \tag{9}$$

or

$$R = C_{\text{down}}/C_{\text{up}} \tag{10}$$

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 shown in Formula (11):

$$E_0 = 1 - R \tag{11}$$

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 shown in Formulae (12) and (13):

$$R_i = N_{\text{down},i} / N_{\text{up},i} \tag{12}$$

or

$$R_i = C_{\text{down},i} / C_{\text{up},i} \tag{13}$$

where

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

$N_{\text{down,i}}$ is the particle counts 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 shown in Formula (14):

$$E_{0,i} = 1 - R_i \tag{14}$$

If the measured penetration when a filter medium is tested is P_m, the corrected penetration, P, takes the form shown in Formula (15):

$$P = P_m / R \tag{15}$$

For the test performed with monodisperse particles, the penetration of particles with the i_{th} monodisperse size, P_i, can be written as shown in Formula (16):

$$P_i = P_{m,i} / R_i \tag{16}$$

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 tube furnace shall be turned on and enough time shall be provided for the particle production to stabilize. If the furnace temperature needs to be changed to achieve a different particle size distribution, enough time shall be given for the temperature to become steady and for the new particle size distribution to stabilize. 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 5.3 and the CPC described in 6.2.8 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, as shown in Formula (17):

$$A = A_0 \cdot e^{-\lambda t} \tag{17}$$

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_o 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, or

— 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.

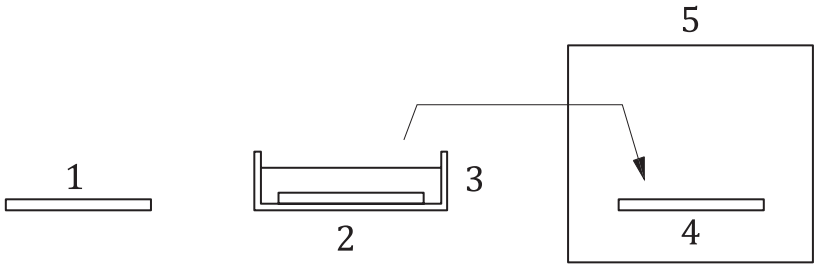
8.2.6 Filter medium neutralization according to ISO 29461-1

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. Isopropyl alcohol shall be handled with safety. More details regarding the safety handling of isopropyl alcohol 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 the 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 9.

The IPA vapour treatment is made using the system shown in Figure 10. This system includes a vessel for 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 10 — 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 the quick evaporation of the IPA, the filter medium samples shall be placed on a perforated surface surrounded by air;

— 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.

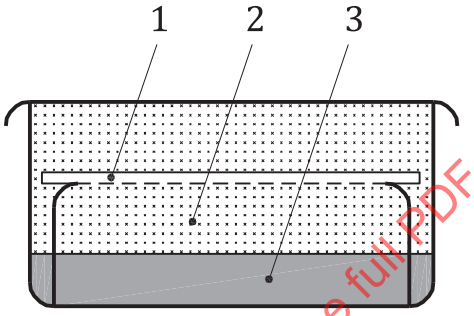
— The ambient humidity shall be within 40 % to 80 % RH.

— Add IPA into containers to about 10 mm in depth. Well above the liquid surface, place a screen to hold the sample media (Figure 11).

— 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 11 — 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 more than 5 percentage points of the average of all filter medium samples tested.. If these two efficiencies differ 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 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 (Silver 3 nm to 30 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 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 — Silver nanoparticles

A piece of new filter medium shall be used for the efficiency test and it shall be placed in the test filter mounting assembly with proper sealing. For the range of 3 nm to 30 nm, five or eight approximately equidistant interpolated particle sizes shall be selected for the efficiency test. The suggested particles sizes are listed in Table 5.

Table 5 — Recommended testing particle sizes in the range from 3 nm to 30 nm

Total number of particle sizes	Particle sizes nm
5	3, 10, 15, 25, 30
8	3, 5, 8, 10, 15, 20, 25, 30

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 DEMC voltage is varied to classify particles with different diameters in succession. The particle number concentrations upstream and downstream of the filter medium are measured, either

simultaneously, using two particle counters working in parallel, or successively using one particle counter first on the upstream and then on the downstream side. In the second case, a flush out period for the CPC shall be included because the aerosol sample needs some time to travel through the tubing and reach the CPC (see Reference [8]). When the CPC sampling is switched from upstream to downstream, enough time interval shall be allowed to ensure that the CPC is counting the intended sample. Usually, the CPC reading changes dramatically when the sampling position is changed Stabilization of the CPC reading at a new value is an indication that the CPC is ready to record the new concentration. When switching from one test particle size to another, a long enough waiting period shall be observed before starting the CPC measurement to ensure that the particles of the previous size are flushed out of the system.

The CPCs shall be operated within the particle concentration range specified by the manufacturers. If the level of the upstream number concentration exceeds the measuring range of the counter, then a dilution system shall be included between the sampling point and the counter. The testing particle size shall be between the minimum and maximum detectable sizes. The information of a number of commercial CPCs on the particles concentration range, detectable sizes, sample flow rate, working liquid and compatibility with DEMC is shown in Annex A, Table A.5.

Some CPC models have different measuring ranges corresponding to the measurement mode, i.e. single-particle counting mode and photometric mode (see Table A.5). The single-particle counting mode features lower concentration range and smaller counting error compared to the photometric model. Therefore, to obtain the most accurate results, the particle concentrations both upstream and downstream of the filter shall be in the range of the single-particle counting mode. The upstream and downstream concentrations may be different by more than five or six decades when high-efficiency filters are tested. Therefore, it is possible that the upstream concentration exceeds the range for the single-particle counting mode. A dilution system between the upstream sampling point and the CPC can be employed to bring the particle concentration to suitable range. For such a dilution system, the makeup air flow rate shall be accurately controlled and measured; together with the CPC inlet flow rate, the dilution ratio can be determined. The flow from the upstream sampling point to the CPC cannot be restricted by a valve or similar devices because that would lead to particle loss.

The CPC reading for particle concentration is based on the total particle counts over regular pre-set time intervals and the flow rate. When the particle concentration is low, the CPC reading oscillates with time due to its statistical nature even with a stable aerosol sample. Using a long sampling time and taking the average value improve the accuracy of the measurement. For testing of high-efficiency filters, the downstream concentration can be very low and the CPC concentration reading fluctuates close to zero. In this case, it is beneficial to operate the CPC in the mode counting the total particles for a user defined time interval. The particle count upstream of the filter in the same time interval can be obtained. Then the penetration is obtained as in Formulae (2) and (5) using the upstream and downstream particle number counts.

To obtain statistically reliable results, reasonably large particle counts shall be obtained. When the filter efficiency is high and the particle size is very small, the amount of particles which can penetrate through the filter is very low, thus a long sampling time may be needed. 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}
3 nm to 30 nm	10

The overlapping range, between this document and ISO 21083-1, 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 (see References [11], [18], [19]), the particle material almost does not affect the efficiency in the 20 nm to 30 nm range.

For example, the difference in filtration efficiencies for silver and di(2-ethylhexyl) sebacate particles in the overlapping size range of 20 nm to 30 nm was below 8 % in the round robin test (see Reference [12]). In case the difference is higher, the qualification tests should be reapplied to define the error source.

8.3 Test evaluation

The procedures described 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 minimal efficiency in the range of 3 nm to 30 nm. If the minimum efficiency is <95 %, five more samples shall be tested; if the minimum efficiency is ≥95 %, then two 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 < 95 %	6	0,06 m^2
Minimum efficiency ≥ 95 %	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 and then measure filtration efficiencies for different particle sizes in the intended size range.

— Select the first particle size. Repeat the procedures e) 1) to e) 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 minute 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 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 7). 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) 5) until at least 3 upstream and 3 downstream measurements have been obtained.

.....

— Select the last particle size. Repeat the procedures e) 1) to e) 5) 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.

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, then 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 7). 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	8.2.6.5	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	0	—	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 is 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 [16]).

Table 9 — Measurement uncertainties

Measurement		Maximum deviation (uncertainties) %
Particle generation (concentration)		10
Particle counting		10
Flow rate		5
DEMC sizing accuracy	20 nm	20

11 Reporting results

11.1 General

Test results shall be reported using the test report format shown in this document. Tables 10 and 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 items 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) sample number;
   3) filter medium reference;
   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 TS 21083-2:20xx - 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):	
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 10 *(continued)*

ISO TS 21083-2:20xx - TEST REPORT - SUMMARY				**Testing Organization**	
				Name	
				Address	
				Phone	
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 per cm^3)			Test aerosol:		
Test air flow rate (cm^3/s):			Conditioning method:		
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 10 *(continued)*

ISO TS 21083-2:20xx - TEST REPORT - SUMMARY	**Testing Organization**	
	Name	
	Address	
	Phone	

RESULTS				
Number of samples tested		Particle Removal Efficiency (%)		
Test sample photo		Particle diameter (nm)	Measured Efficiency	Standard deviation	Upstream Concentration (p/m³)/ Counts (p)
		3			
		5			
		8			
		10			
		15			
		20			
		25			
		30			
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

ISO TS 21083-2:20xx - DETAILED RESULTS	**Testing Organization**	
	Name	
	Address	
	Phone	

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

TEST DATA	
Filter medium velocity (cm/s)	Particle type
Pressure drop at the beginning of the test (Pa):	Pressure drop at the end of the test (Pa):
Total measuring time-upstream (s)	Total measuring time-downstream (s)

Key

X: Airflow (cm³/s)

Y: Pressure drop (Pa)

Z: Filtration efficiency (%)

W: Particle diameter (nm)

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 *(continued)*

ISO TS 21083-2:20xx - DETAILED RESULTS						**Testing Organization**	
						Name	
						Address	
						Phone	
GENERAL INFORMATION							
Filter medium reference:				Date of test:			
Test ID:				Operator:			
TEST RESULTS							
Particle diameter (nm)	Upstream concentration or count (p/m³)/ Counts (p)	Downstream concentration or count (p/m³)/ Counts (p)	Efficiency (%)	Average Efficiency (%)	Standard deviation		
3 (test 1)							
3 (test 2)							
3 (test 3)							
…							
5 (test 1)							
…							
8							
…							
10							
…							
15							
20							
25							
30							
TEST DATA DETAILS							
Pressure drop							
Key *X*: Airflow (cm³/s) *Y*: Pressure drop (Pa) *Z*: Filtration efficiency (%) *W*: Particle diameter (nm) 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.							

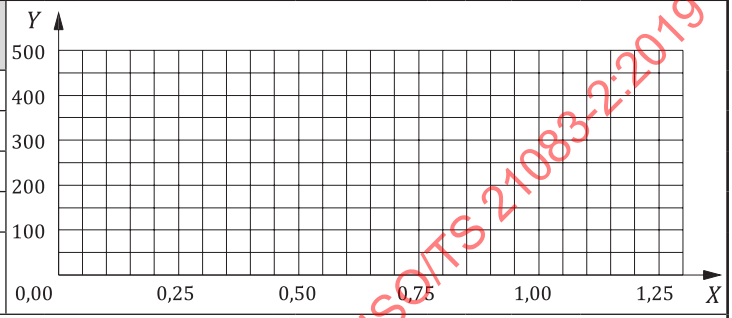
Table 11 *(continued)*

ISO TS 21083-2:20xx - DETAILED RESULTS	Testing Organization	
	Name	
	Address	
	Phone	

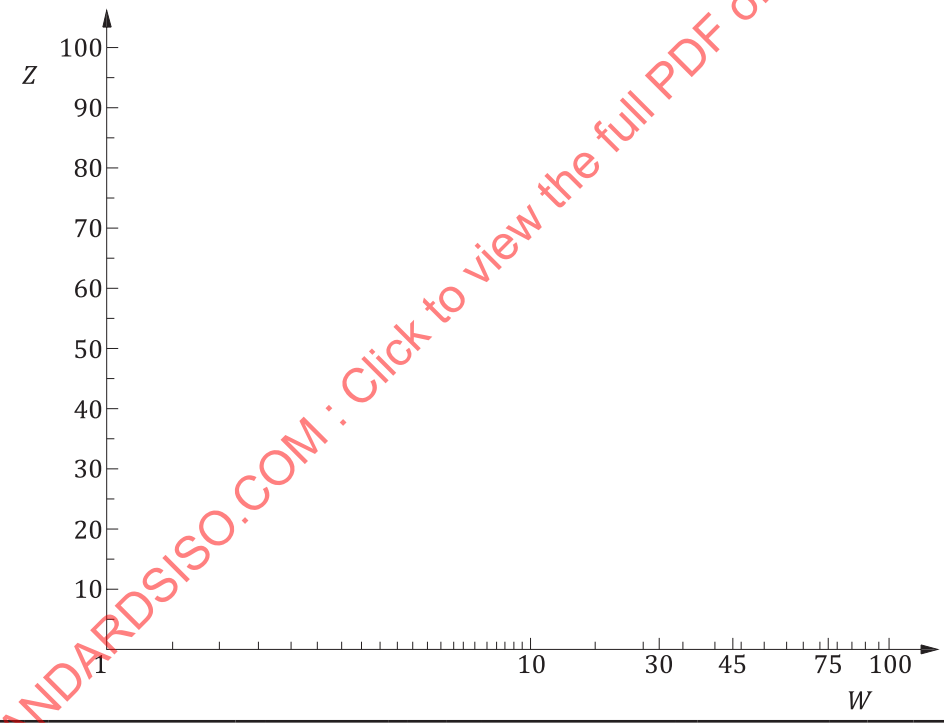
GENERAL INFORMATION

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

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



Filtration Efficiency



Key

X: Airflow (cm^3/s)

Y: Pressure drop (Pa)

Z: Filtration efficiency (%)

W: Particle diameter (nm)

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 the following tables are not exhaustive and are provided to help the users of this document.

Table A.1 — Technical specification of Carbolite tube furnaces

Model	Maximum temperature (°C)	Maximum power (kW)	Work tube bore (mm)	Work tube length (mm)	Heated length (mm)	Net weight[a] (kg)
Tube furnaces with a ceramic work tube wound with resistance wire						
STF 15/–/450	1 500 °C	5	25 to 75	900 to 1 200	450	35
STF 15/–/610	1 500 °C	6	25 to 75	1 200 to 1 500	610	40
STF 16/–/450	1 600 °C	6	25 to 75	900 to 1 200	450	35
STF 16/-/610	1 600 °C	7	25 to 75	1 200 to 1 500	610	40
[a] Weights are approximate for horizontal models and do not include fittings or vertical stands.						

Table A.2 — Technical specification of Horiba tube furnaces

Model	Maximum temperature (°C)	Tube length (mm)	Heated length (mm)	Tube inside diameter (mm)	Power rating (kW)	Outer measurements excluding tube (mm)	Heat up time (min)	Weight (kg)
MTF 10/15/130	1 000	150	130	15	0,4	265/150/175	5	5
MTF 10/25/130	1 000	150	130	25	0,4	265/150/175	10	6
MTF 12/25/250	1 200	300	250	25	0,7	375/370/375	15	10
MTF 12/25/400	1 200	450	400	25	1	375/450/375	25	15
MTF 12/25/250	1 200	300	250	25	0,7	375/370/375	15	10
MTF 12/25/400	1 200	450	400	25	1	375/450/375	25	15
MTF 12/38/850	1 200	900	850	38	2,6	430/900/375	—	—

Table A.3 — Technical specification of Lindberg/Blue M tube furnaces

Model	Temperature range (°C)	Diameter Process tube (cm)	Heated zone (cm)
STF55433C-1	500 to 1 500	2,54 to 7,62	30,5
STF55433PC-1	500 to 1 500	2,54 to 7,63	30,5
STF55433PBC	500 to 1 500	2,54 to 7,64	30,5

Table A.4 — Technical specification of Borel tube furnaces

Model	Maximum temperature (°C)	Heated length (mm)	Tube dimension (ø× length) (mm)	(W×H×D) (mm)	Power rating (kW)	Weight (kg)
TU 1 400–20–180	1 400	180	20 × 800	630 × 510 × 380	3,5	35
TU 1 400–38–180	1 400	180	38 × 800	630 × 510 × 380	3,5	37
TU 1 400–50–180	1 400	180	50 × 800	630 × 510 × 380	3,5	40
TU 1 400–20–250	1 400	250	20 × 900	630 × 510 × 380	3	35
TU 1 400–38–250	1 400	250	38 × 900	630 × 510 × 380	3,6	39
TU 1 400–50–250	1400	250	50 × 900	630 × 510 × 380	4	42
TU 1 400–75–450	1 400	450	50 × 1 000	720 × 710 × 430	4	51
TU 1 400–105–450	1 400	450	75 × 1 000	720 × 710 × 430	4,5	58
TU 1 400–105–451	1 400	450	105 × 1 000	720 × 710 × 430	5,5	64
TU 1 400–50–610	1 400	610	105 × 1 300	920 × 710 × 430	6,2	68
TU 1 400–75–610	1 400	610	50 × 1 300	920 × 710 × 430	5,2	51
TU 1 400–75–611	1 400	610	75 × 1 300	921 × 710 × 430	5,5	63
TU 1 500–38–180	1 500	180	38 × 800	720 × 710 × 430	3,6	48
TU 1 500–50–180	1 500	180	50 × 800	720 × 710 × 430	3,9	51
TU 1 500–50–250	1 500	250	50 × 900	720 × 710 × 430	3,1	51
TU 1 500–50–450	1 500	450	50 × 1 000	720 × 710 × 430	4,5	53
TU 1 500–75–450	1 500	450	75 × 1 000	720 × 710 × 430	6	63
TU 1 500–50–610	1 500	610	50 × 1 300	920 × 710 × 430	6	56
TU 1 500–75–610	1 500	610	75 × 1 300	920 × 710 × 430	6,2	68
TU 1 600–38–250	1 600	250	38 × 900	720 × 710 × 430	4,5	48
TU 1 600–50–250	1 600	250	50 × 900	720 × 710 × 430	4,5	48
TU 1 600–50–450	1 600	450	50 × 1 000	720 × 710 × 430	5	55
TU 1 600–75–450	1 600	450	75 × 1 000	720 × 710 × 430	6	63
TU 1 600–50–610	1 600	610	50 × 1 300	920 × 710 × 430	7	58