BRITISH STANDARD

High efficiency air filters (EPA, HEPA and ULPA)

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

ICS 13.040.40; 23.120

BSi

British Standards

National foreword

This British Standard is the UK implementation of EN 1822-2:2009. It supersedes BS EN 1822-2:1998 which is withdrawn.

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

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

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

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

Amendments/corrigenda issued since publication

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Schwebstofffilter (EPA, HEPA und ULPA) - Teil 2: Aerosolerzeugung, Meßgeräte, Partikelzählstatistik

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

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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Contents

Foreword

This document (EN 1822-2:2009) has been prepared by Technical Committee CEN/TC 195 "Air filters for general air cleaning", the secretariat of which is held by UNI.

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of an identical text or by endorsement, at the latest by May 2010, and conflicting national standards shall be withdrawn at the latest by May 2010.

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

This document supersedes EN 1822-2:1998.

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

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

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

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

— *Part 3: Testing flat sheet filter media*

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

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

This European Standard is based on particle counting methods which actually cover most needs of different applications. The difference between this European Standard and its previous edition lies in the addition of:

— an alternative test method for using a solid, instead of a liquid, test aerosol;

— a method for testing and classification of filters made out of membrane type filter media;

— a method for testing and classification filters made out of synthetic fibre media; and

— an alternative method for leak testing of group H filters with other than panel shape.

Beside that, various editorial corrections have been implemented.

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

Introduction

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

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

1   Scope

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

It establishes a procedure for the determination of the efficiency on the basis of a particle counting method using a liquid (or alternatively a solid) test aerosol, and allows a standardized classification of these filters in terms of their efficiency, both local and integral efficiency.

This European Standard describes the measuring instruments and aerosol generators used in the course of this testing. With regard to particle counting it specifies the statistical basis for the evaluation of counts with only small numbers of counted events.

2   Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

EN 1822-3, *High efficiency air filters (EPA, HEPA and ULPA) — Part 3: Testing flat sheet filter media*

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

3   Terms and definitions

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

4   Aerosol production

4.1 General

When testing a filter a test aerosol with liquid particles shall be used as reference test method and as defined in EN 1822-1. Alternatively, a solid PSL aerosol can be used for local efficiency (leak) testing (see EN 1822-4:2009, Annex D).

The testing of high-performance filters (U16 and U17) requires methods of aerosol production with high production rates (10^{10} s^{-1} to 10^{11} s^{-1}), in order to provide statistically significant measurements downstream of the filter.

By adjusting the operating parameters of the aerosol generator it shall be possible to adjust the mean particle diameter of the aerosol so that it is equal to the MPPS. The concentration and the size distribution of the aerosol produced shall remain constant throughout the test.

4.2 Aerosol substances

A suitable aerosol substance for the reference test method is a liquid with a vapour pressure which is so low at the ambient temperature that the size of the droplets produced does not change significantly due to evaporation over the time scale relevant for the test procedure (typically max. 5 s).

Possible substances include but are not limited to:

— DEHS;

— PAO;

— Paraffin oil (low viscosity).

The most critical properties of a possible aerosol substance are:

— Index of refraction;

— Vapour pressure;

— Density;

which should not differ too much from the values given for the three substances suggested in Table 1.

NOTE   Standard laboratory safety regulations should be observed when handling these substances. It should be ensured by means of suitable exhaust systems and air-tight aerosol ducting systems that the test aerosols are not inhaled. In case of doubt the safety data sheets for the appropriate substances should be consulted.

Table 1 — Important data for aerosol substances at 20 °C

	DEHS	**PAO** [a]	**Paraffin oil (low visc.)**
Chemical designation	Sebacic acid-bis(2-ethylhexyl) ester	Poly-Alpha-Olephin (e.g. CAS [b] No. 68649-12-7)	Mixture (e.g. CAS # 64742-46-7)
Trivial name	Diethylhexylsebacyte	Polyalphaolefin	Paraffinoil
Density (kg/m^3)	912	800 – 820 (820 [c])	843
Melting point (K)	225	~ 280	259
Boiling point (K)	529	650 – 780 (674 [c])	
Flash point (K)	> 473	445 – 500	453
Vapour pressure at 293 K (µPa)	1,9	100 – 130	
Dynamic viscosity (kg/m s)	0,022 to 0,024	0,003 1 – 0,004 at 373 K (0,013 at 313 K [c]) (Kinematic viscosity at 373 K: 3,8 – 4,1 mm^2/s)	0,026
Index of refraction/ wavelength (nm)	1,450/650 1,452/600 1,453 5/550 1,454 5/500 1,458 5/450 1,475/400	(1,455 6 [c])	

[a]   US Patents 5,059,349 [3] and 5,059,352 [4] describe and restrict the use of PAO for filter testing. Material properties of PAO as per Japan JACA Standard No. 37-2001: "The guideline of substitute materials to DOP" [5], Japan JISZ Standard No. 8901-206 [6] and ISO Standard No. 14644-3 [7].

[b]   CAS #, Chemical Abstracts Service Registry Number, substances have been registered in Chemical Abstracts, issued by American Chemical Society [8].

[c]   Data for "Emery 3004" as a specific example of a PAO.

Source: Crosby, David W., Concentration produced by a Laskin nozzle generator, a comparison of substitute materials and DOP, 21st DOE/NRC Nuclear Air Cleaning Conference [9].

4.3 Producing monodisperse aerosols

4.3.1   Condensation methods

4.3.1.1   General

Condensation methods are preferred for the creation of monodisperse aerosols, i.e. the particles are formed by condensation from the vapour phase. It is necessary to distinguish between heterogeneous and homogeneous condensation.

4.3.1.2   Heterogeneous condensation

4.3.1.2.1   General

In the case of heterogeneous condensation the vapour condenses at a relatively low level of supersaturation onto very small particles which are already present, the so-called condensation nuclei. The size distribution of the resultant aerosol has a geometrical standard deviation between $\sigma_g = 1,05$ and $\sigma_g = 1,15$.

Aerosol generators which operate using the principle of heterogeneous condensation are the Sinclair-LaMer generators (Figure 1) and the Rapaport-Weinstock generator (Figure 2).

4.3.1.2.2   Sinclair-LaMer aerosol generator (Figure 1)

A simple nebuliser operated with nitrogen nebulises a weak aqueous solution of sodium chloride. After large water drops have been excluded in a drop eliminator, the smaller droplets are passed into a diffusion drier where they vaporise. The resultant sodium chloride aerosol is then passed into a vessel containing the actual aerosol substance, where it becomes saturated with the vapour of this substance. The aerosol vapour mixture is then passed through a re-heater, and then on through a condensation chimney, where the vapour condenses on the salt particles, forming a homogeneous droplet aerosol (see also [10]).
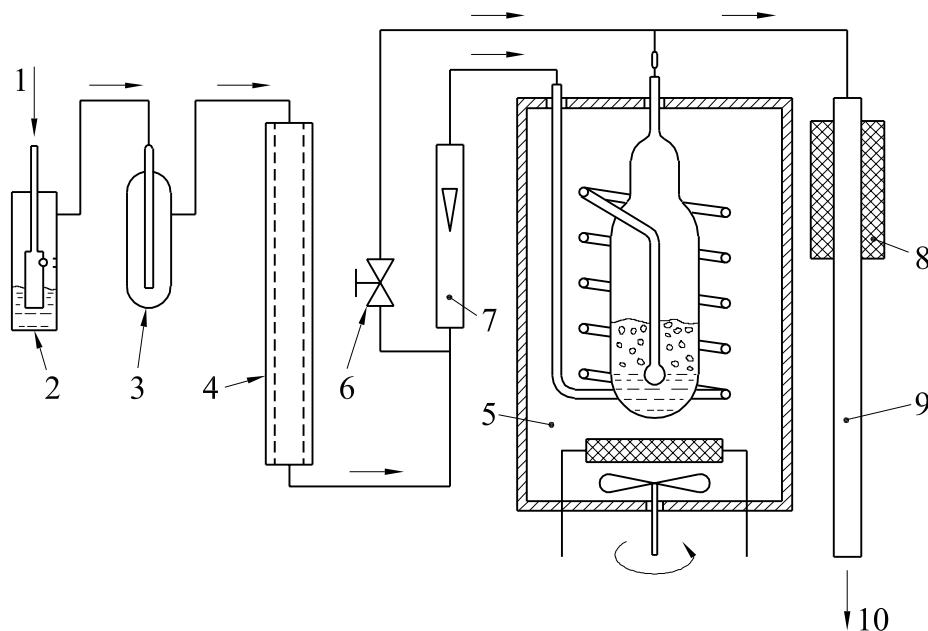
Key

1   Nitrogen supply
2   Nebuliser
3   Drop eliminator
4   Diffusion drier
5   Thermostatic oven
6   By-pass valve
7   Flow meter
8   Re-heater
9   Condensation chimney
10   Aerosol

**Figure 1 — Structure of the Sinclair-LaMer aerosol generator**

The vessel containing the aerosol substance is contained in a thermostatic oven, whose temperature can be adjusted so as to regulate the amount of vapour and the diameter of the particles. A part of the sodium

chloride aerosol can also be diverted past the oven using the by-pass valve, and added to the flow again before the re-heater. This makes it possible to achieve a relatively rapid drop in the vapour concentration in the re-heater, and thus a reduction in the particle diameter.

The rates of particle production which can be achieved by means of this type of generator are in the order of $10^8 s^{-1}$; the particle diameter can be adjusted between approximately 0,1 µm and 4 µm.

4.3.1.2.3 Rapaport-Weinstock generator (Figure 2)

An aerosol substance is nebulised through a nozzle, either as a pure substance or in solution, and the resultant polydisperse aerosol is then vaporised along the heated section of a glass tube. Residual nuclei of the impurities in the material remain.
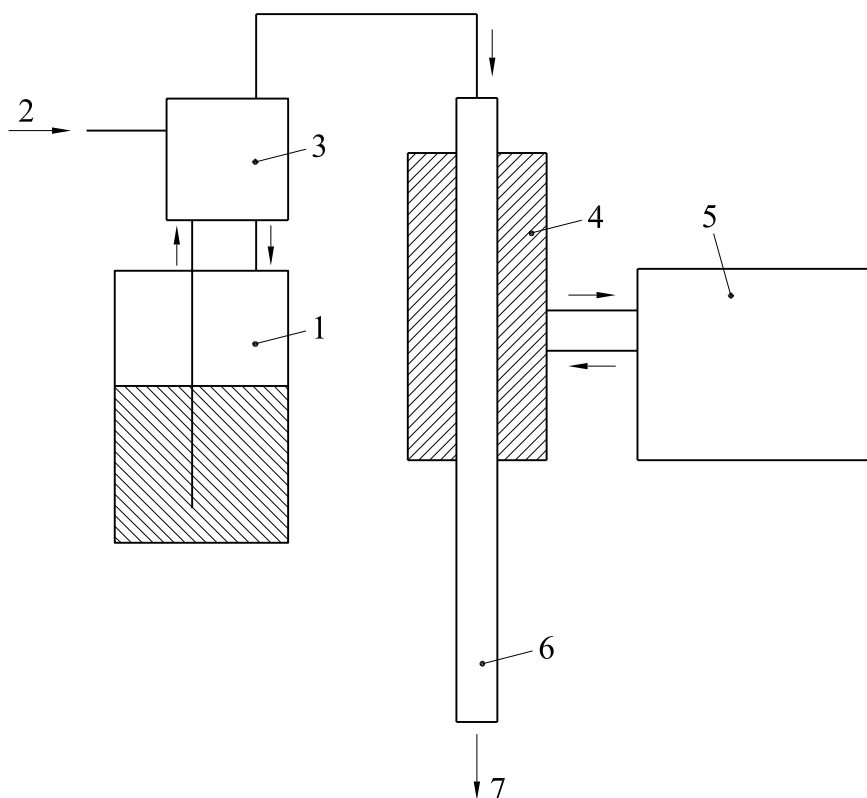
Key

1 Liquid reservoir
2 Compressed air
3 Nebuliser
4 Vaporisation section
5 Thermostat
6 Condensation section
7 Aerosol

Figure 2 — Structure of the Rapaport and Weinstock aerosol generator

In the subsequent condensation section the aerosol substance then condenses on these nuclei to form a mondisperse aerosol (see also [11]).

The particle diameter of this aerosol is determined by the mixing ratio of aerosol substance and solvent. The final aerosol contains the solvent used (e.g. Propanol) as a vapour.

Generators of this type achieve particle production rates of 10^9 s^{-1}; the particle diameter can be adjusted between approximately 0,1 µm and 1,5 µm.

4.3.1.3 Homogeneous condensation

At higher levels of super-saturation, clusters of vapour molecules form spontaneously without the presence of condensation nuclei, and these then grow to particles which are some nanometres in diameter (homogeneous condensation). Larger particles then form as a result of coagulation of these particles with one another. The resultant size distribution has a standard deviation of $\sigma_g \sim 15$ independent of the median particle size, and can thus only be referred to as quasi-monodisperse. On the other hand, rates of production of particles achieved can be as much as two orders of magnitude larger than those possible using heterogeneous condensation (more than 10^{11} s^{-1}).

Figure 3 shows the structure of a free-jet condensation aerosol generator which makes use of this principle.
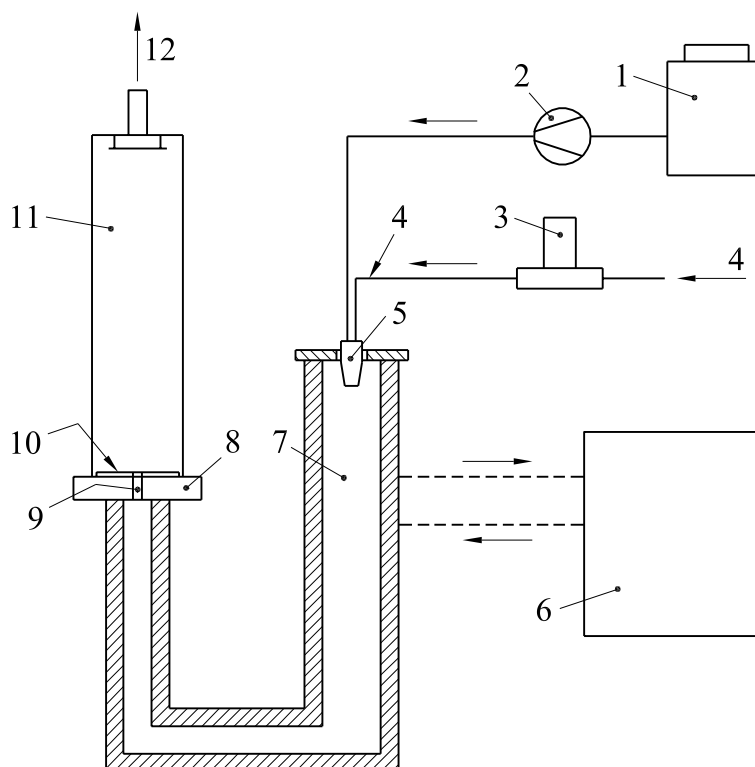
Key

1 DEHS tank
2 Pump
3 Flow controller
4 Nitrogen
5 Ultra-sonic nebuliser
6 Thermostat
7 Vaporisation pipe with heater and insulation
8 Sheath air
9 Nozzle
10 Sintered metal plate
11 Coagulation section
12 Aerosol

Figure 3 — Set-up of a free-jet condensation aerosol generator

An aerosol substance is delivered by a pump at a defined flow rate to an ultrasonic nebuliser. The relatively large droplets which are produced (> 20 µm) are then vaporised in a heated pipe. The concentration of residual nuclei is so low that they do not influence the subsequent homogeneous condensation process. The hot stream of nitrogen carrying the vapour then passes through a nozzle into a cold, laminar flow of sheath air. The turbulent mixing of the free jet with the cold air produces the super-saturation necessary for the homogeneous condensation.

The particle size and particle concentration can be adjusted by varying the volume flow rates of the aerosol substance (DEHS), nitrogen and envelope air.

4.3.2   Particle size classification

Using a differential mobility analyser as described in 5.3 it is possible to separate a fraction with almost the same electrical mobility from a polydisperse aerosol (see also [12]). Provided all these particle carry only a single electrical charge, then this mono-mobile fraction is also monodisperse. If necessary, larger particles which carry a multiple charge, and which thus have the same electrical mobility as the single-charged particles, must be removed from the polydisperse input aerosol by suitable means.

Since the proportion of singly-charged particles in the relevant size-range is less than 10 %, from which only a narrow size-band is selected, then the number concentration of the monodisperse output aerosol is lower than the input concentration by a factor of at least 100. In consequence this method of producing monodisperse aerosols is only suitable for the measurement of the fractional efficiency of the filter medium (see EN 1822-3).

The degree of monodispersity achieved by this method can be described by a geometrical standard deviation of $\sigma_g < 1,1$. In practise, however, the operating parameters are often amended to increase the particle concentration, at the expense of a greater standard deviation.

4.4 Generating polydisperse aerosols

Polydisperse liquid aerosols are usually produced by nebulising the aerosol substance through a binary nozzle using compressed air.

A subsequent inertial separator, in the form of baffle plates or a cyclone separator serves to precipitate larger particles and to reduce the range of the size distribution. The geometrical standard deviation of the distribution generated lies between 1,6 and 2,5. The particle diameter can be influenced to a small degree by changing the operating pressure of the nozzle. Greater influence on the particle size is usually achieved by dissolving the aerosol in a volatile solvent (e.g. Propanol) before nebulisation. When the solvent evaporates it leaves behind particles whose size is governed by the ratio of aerosol substance to solvent which is used.

It is comparatively simple to increase the particle production rate by using a number of jets in parallel.

The maximum rate of particle production which can be achieved using one nozzle is 5×10^{10} s^{-1}.

NOTE   A typical jet nebuliser is described for example in [13].

4.5 Neutralisation of aerosols

Since electrically charged particles are removed more effectively by filters than are uncharged particles, electrically neutral particles should be used for testing filters. A neutral state of charge is generally understood to be the stationary equilibrium achieved when charged aerosol particles are brought together with a sufficient number of positive and negative gas ions. This is usually carried out by ionising the carrier gas of the aerosol using a radioactive source or by corona discharge. The low level of residual charge in the aerosol after this neutralisation can be neglected for the filtration process.

Aerosol particles become electrically charged when there is a division of charges in the course of production (e.g. nebulisation). This is above all the case when polar liquids such as water (or, to a lesser extent Propanol) are nebulised. In the case of pure DEHS or DOP relatively few charges occur. Condensation processes without prior nebulisation generate virtually charge-free aerosols, which do not have to be neutralised.

In order to ensure neutralisation of the highly-concentrated aerosols needed for testing filters, it is necessary for the neutralisers to have a sufficiently high concentration of ions. The aerosol shall also be kept in the ionising atmosphere for a sufficiently long period (see also [14]).

4.6 Minimum performance parameters for aerosol generators

a)   Generators for testing media:

Particle production rate: 10^6 s^{-1} to 10^8 s^{-1}

Particle diameter adjustable over the range: 0,04 μm to 1,0 μm

b)   Generators for testing filter elements:

Particle production rate: 10^8 s^{-1} to 10^{11} s^{-1}

Particle diameter adjustable over the range: 0,08 μm to 1,0 μm

4.7 Sources of error

Care shall be taken that the pressure of the gas supply for the aerosol generators (compressed air, Nitrogen) remains constant. The supplied gas shall be free of particles and of a sufficiently low humidity.

Nebuliser nozzles may gradually become blocked, leading to unnoticed changes in the nebulisation characteristics.

Condensation generators are sensitive to variations in temperature along the condensation path, arising for example due to draughts.

NOTE   Aerosol substances which are subjected to higher temperatures for longer periods will undergo changes and should be exchanged at regular intervals.

4.8 Maintenance and inspection

Aerosol generators shall be maintained regularly in accordance with the manufacturer's instructions.

Suitable measuring systems in accordance with Clause 5 shall be used to check the size distribution and the constancy of the production rate at the intervals specified in Clause 6.

5   Measuring devices

5.1 Optical particle counters

5.1.1   Operation

In an optical particle counter the particles are led individually through an intensively illuminated measuring volume. When passing through the measuring volume, the particle scatters light, which is detected at a defined spatial angle by a photo detector and transformed into an electrical pulse. The level of this pulse allows corresponds with the size of the particle, and the number of pulses per unit time with the particle concentration in the air volume analyzed.

Figure 4 shows the general structure of an optical particle counter with a laser light source as an example.

5.1.2 Minimum performance parameters

Measuring range for the particle size:

0,1 μm to 2,0 μm (for 100 % counting efficiency)

Minimum number of particle size classes between 0,1 μm and 0,5 μm:

— for testing the filter medium five size classes;

— for testing the filter element two size classes.

Zero count rate < 1 min^{-1}.
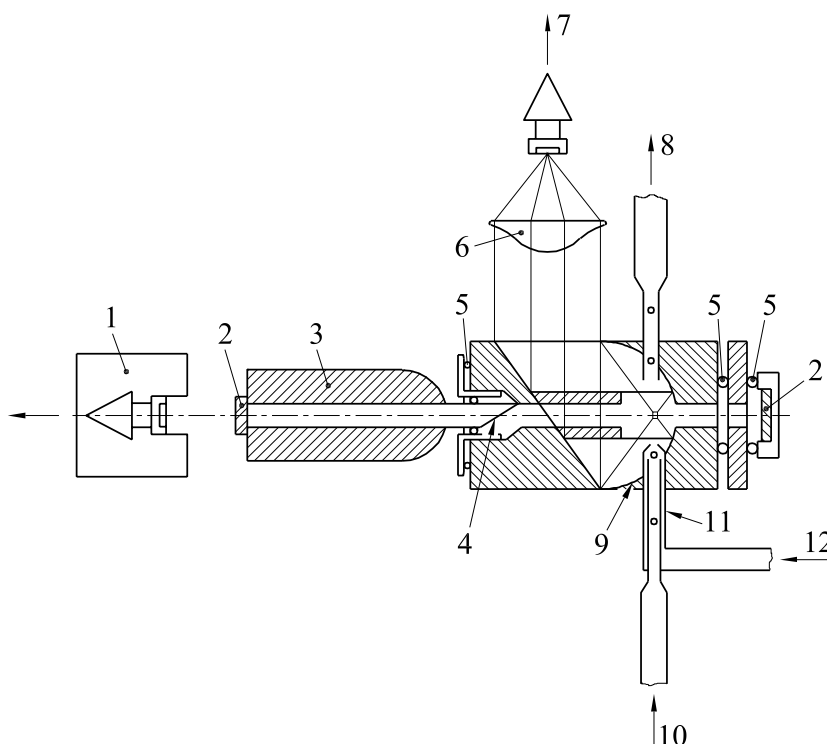
Key

1   Reference detector
2   Laser mirror
3   He-Ne-laser
4   Brewster-window
5   Gasket ring
6   Aspherical lens
7   Photo detector
8   Aerosol outlet
9   Parabolic mirror
10 Aerosol inlet
11 Aerosol nozzle
12 Sheath air

Figure 4 — Structure of an optical particle counter (example)[1)]

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1) Taken from [15], reprinted with the permission of Verein Deutscher Ingenieure.

5.1.3 Sources of error and limit errors

The particle size determined by an optical particle counter is a scattered-light equivalent diameter (see also [16]) which is dependent not only on the geometrical particle size but also on the shape of the particle and the optical properties of the particle material. The nature of this dependency varies according to the constructional type of the particle counter. Measurement results can only be compared between two different particle counters if these have been calibrated for the particle material in question.

If the particle concentration is too high so-called coincidence errors occur. This means that several particles enter the measuring volume at the same time, and are interpreted as one larger particle. Suitable dilution measures shall be adopted (see 5.5) to ensure that the maximum concentration specified by the manufacturer is not exceeded.

Most counters only have a relatively inaccurate flow meter to display the volume flow rate which is analysed. A more suitable meter shall be used to determine the exact particle concentration.

5.1.4 Maintenance and inspection

Optical particle counters shall be regularly maintained and inspected by qualified personnel. This also includes a calibration using latex aerosols.

The inspection of correct operation by the user shall include a check of the flow rate, as well as a regular check of the zero count rate by inserting a suitable up-stream filter of class H13 or higher.

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

5.1.5 Calibration

Optical particle counters are normally calibrated using latex particles (see also [17] and [18]). A calibration with other, usually liquid aerosol materials (e.g. DEHS) is possible using a vibrating orifice aerosol generator (see also [19]) or independent aerosol sizing equipment.

The determination of the counting efficiency requires the production of mono-disperse aerosols of known concentration (e.g. with the aid of a differential mobility analyser and an aerosol electrometer or condensation nucleus counter). This is usually only possible in well-equipped aerosol laboratories (see also [12]).

As an alternative, the counting efficiency can also be tested using latex aerosols by means of comparative measurements with another optical particle counter. Since the counting efficiency depends on the particle size, and decreases progressively in the proximity of the lower detection limit of the particle counter the lower measuring limit of the comparison counter shall be clearly lower than that of the counter to be calibrated.

5.2 Condensation nucleus counter

5.2.1 Operation

In a condensation nucleus counter (CNC) particles which are too small for direct optical measurement are enlarged by condensation of a vapour before being subjected to light scattering or light extinction measurements. 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 CNC's with continuous flow in basically two ways. One way is that 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) (see also [20]).

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 registered by a scattered light sensor.
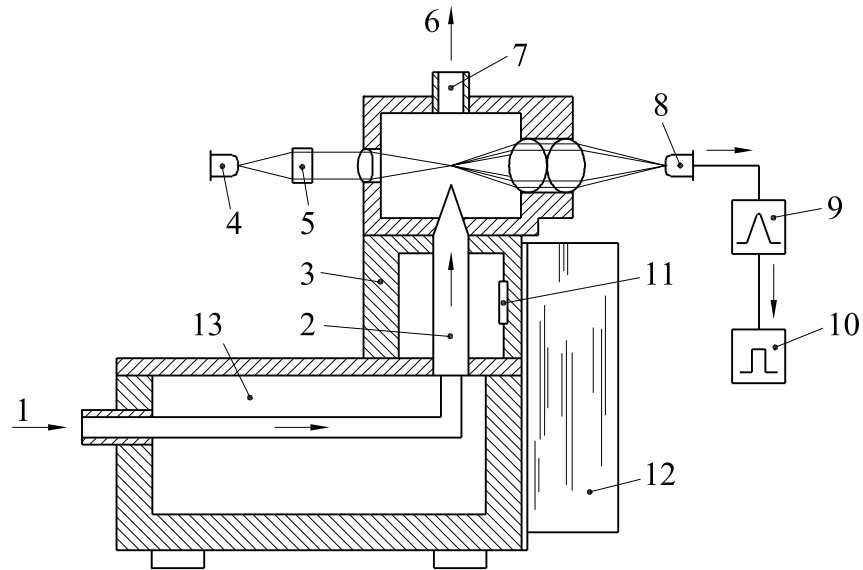
Key

1 Aerosol inlet
2 Condensation pipe
3 Thermal insulation
4 Laser diode
5 Lens system
6 Aerosol outlet
7 Nozzle
8 Photo detector
9 Analogue signal
10 Digital signal
11 Peltier element
12 Heat sink (free convection)
13 Saturation tube and alcohol reservoir

Figure 5 — Structure of a condensation nucleus counter using the principle of external cooling

In the other 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 (see also [21]). This principle is shown in Figure 6.
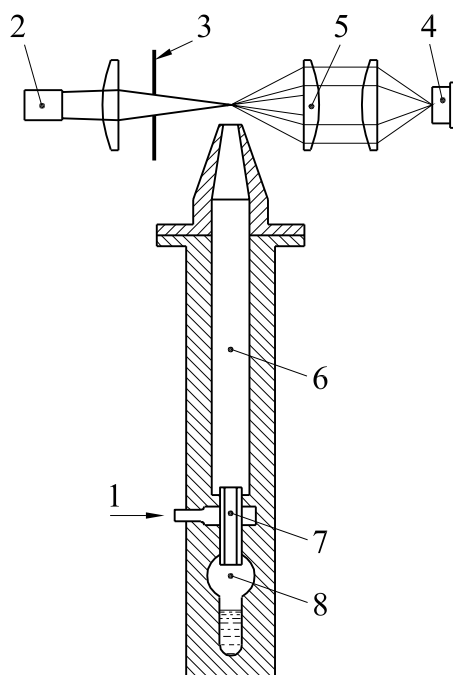
Key

1   Aerosol inlet
2   Laser diode
3   Aperture
4   Photo detector
5   Light trap
6   Condensation section
7   Mixing nozzle
8   Vapour inlet

Figure 6 — Structure of a condensation nucleus counter using the mixing principle

Here the aerosol is led directly to a mixing nozzle by the shortest route. The drops of propylene glycol which form along the condensation section are again registered by a scattered light sensor.

5.2.2   Minimum performance parameters

Measuring range for the particle size:

50 nm to 0,8 µm (for 100 % counting efficiency)

Zero count rate < 1 min^{-1}

5.2.3   Sources of error and limit errors

If a CNC is used in the 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 this lies between 2 % and 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 should be avoided because in extreme cases the measuring inaccuracies can be as large as 100 % (see also [22] and [23]).

5.2.4 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 intervals, since water accumulates in it and changes its thermodynamic properties.

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 filter up-stream filter of class H13 or higher.

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

5.2.5 Calibration

A condensation nucleus counter operating in the counting mode can be regarded as an independent measuring method which requires nearly no calibration. It is only necessary to check the sampling volume flow from time to time by comparison, for example, with a floating element flowmeter.

The calibration of a CNC in its photometric mode and the determination of its counting efficiency require the production of monodisperse aerosols of known concentration (using a differential mobility analyser and an aerosol electrometer, see also [12]) and is usually only possible in well-equipped aerosol laboratories.

5.3 Differential mobility analyser

5.3.1 Operation

In a differential mobility analyser (DMA) particles can be classified according to their electrical mobility. The electrical mobility of a particle is a function of the particle size and the number of electrical charges on the particle. Figure 7 shows the structure of a DMA.

The mobility analyser itself consists of two concentric cylindrical electrodes. The polydisperse aerosol to be classified is first brought to a defined state of electrical charge by the attachment of gas ions, and finally introduced through a narrow circular gap along the outer electrode into the DMA. Iso-kinetic, particle-free air is introduced along the inner electrode. Under the influence of an electric field between the electrodes, particles with a charge of one polarity move at right angles to the flow direction towards the central electrode, whereas the particles with the opposite charge polarity are attracted to the outer electrode. At the lower end of the inner electrodes is a narrow slit through which a partial flow with particles of a defined electrical mobility is extracted.

An appropriate choice of size distribution of the polydisperse primary aerosol ensures that these particles will all have only a single electrical charge and are thus of the same size.
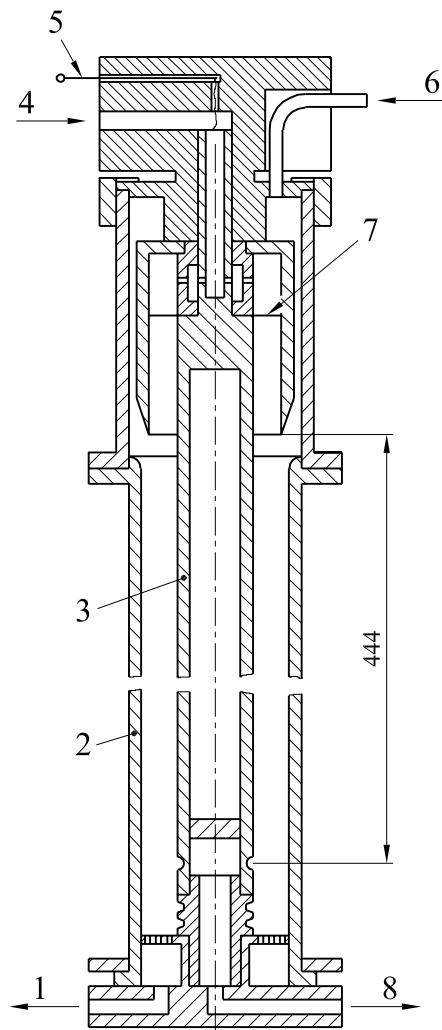
Key

1 Excess air
2 Outer electrode
3 Central electrode
4 Sheath air
5 High voltage
6 Polydisperse aerosol
7 Flow laminator
8 Monodisperse aerosol

Figure 7 — Structure of a differential mobility analyser (DMA)

5.3.2 Minimum performance parameters

Operational particle size range 10 nm to 0,8 µm.

Geometrical standard deviation of the (quasi) monodisperse aerosol < 1,3.

5.3.3 Sources of error and limit errors

If the size distribution of the primary aerosol is not precisely adapted to the size of the monodisperse output aerosol, then in the particle size range above 0,1 µm there can be a considerable proportion of larger particles with multiple charges in the output aerosol.

Leaks and maladjusted volume flow rates can lead to a drift from the selected particle size and inadequate monodispersity.

5.3.4 Maintenance and inspection

Since particles are deposited on the electrodes in the course of operation these shall be cleaned at regular intervals.

After every cleaning the apparatus shall be tested for leaks in accordance with the manufacturer's instructions. From time to time the calibration of the internal mass flowmeters shall be checked. The correct adjustment of volume flow rates in the apparatus is of the greatest importance for its proper operation. If particles are observed at the outlet of the apparatus when there is no potential difference between the electrodes, then it is necessary to check the volume flow rates.

5.3.5 Calibration

It is possible to calculate the diameter of the monodisperse output aerosol from the known geometry of the apparatus, the volume flow rate and the applied potential difference. For this reason the apparatus is often used as a calibration standard. The proper function of the apparatus should be checked in regular time intervals by using reference filters with known efficiency at specific particle sizes. If it is felt that the apparatus is not working properly, a comparison with another device of the same type, or the use of latex aerosols (see also [17] and [24]) may be necessary to calibrate the apparatus.

5.4 Particle size analysis system on the basis of differential mobility analysis

5.4.1 Operation

The differential mobility particle sizer (DMPS) described here involves a combination of a DMA and a CNC. If the number concentration of the monodisperse aerosol is measured at the output of the DMA with a number of suitable central electrode voltages, then the size distribution of the initial polydisperse aerosol can be calculated if the distribution of the electrical charges on the aerosol particles is known. The measurement process of the DMPS is controlled by the same computer which evaluates the measurement data.

5.4.2 Minimum performance parameters

Sampling volume flow rate > 0,3 l/min

Measuring range for the

— Particle size 10 nm to 0,8 µm

— Particle concentration 10^3 cm^{-3} to 10^6 cm^{-3}

5.4.3 Sources of errors and error limits

In order to use this measuring method it is necessary to know the charge distribution for the aerosol. The charging mechanism of the particles can be disturbed by the composition of the carrier gas (e.g. alcohol molecules), but also by concentrations of particles which are too high.

5.4.4 Maintenance and inspection

See CNC (5.2.4) and DMA (5.3.4).

5.4.5 Calibration

See CNC (5.2.5) and DMA (5.3.5).

5.5 Dilution systems

5.5.1   Operation

Dilution systems reduce the concentration of an aerosol to a defined extent by the addition of a particle-free gas (usually air). The dilution behaviour for the relevant particle size range shall be independent of the particle size and shall be constant over time.

The clean air can be obtained by filtering a partial flow of the aerosol. The unfiltered part is usually fed along a capillary and the drop of pressure over this capillary is used to check the volume flow rate (see also [25]).

Another possibility is the introduction of external particle-free air (for example, from a compressed air line).

Here some systems operate on the ejector principle. The pure air flow creates a pressure drop at a constriction, which draws in the aerosol to be diluted (see also [26]). The dilution ratio of these systems is defined solely by the geometry of the set-up and as a rule cannot be altered by the operator.

A further option is the controlled mixing of an aerosol flow with a pure-air flow without using the ejector effect. The volume flow of the aerosol in this case shall be determined by taking a balance of the other volume flows. The dilution ratio can be freely adjusted within certain limits.

By means of a cascade system using several dilution systems high dilution factors (up to 10 000) can be achieved with a high level of accuracy (see also [25] and [27]).

5.5.2   Minimum performance parameters

Volume flow adjustable to the relevant measuring device

Dilution ratio between 10 and 10 000 depending on the initial gas concentration and the measuring device used

Accuracy 5 % (of the dilution ratio).

Zero count rate < 10 min^{-1} (measured with an "absolute filter" at the intake of the dilution system).

5.5.3   Sources of error and limit errors

Clogging of the capillaries and the nozzles can alter the dilution ratio.

5.5.4   Maintenance and inspection

Installed filters shall be replaced at the intervals specified by the manufacturers. If on testing the system with particle-free air it is found to "produce" particles, then the dilution system shall be cleaned. The dilution ratio shall be checked from time to time, for example by measuring the particle concentration at the intake and the outlet of a dilution stage.

5.6 Differential pressure measuring equipment

In order to determine the pressure drop across a filter a pressure measuring device can be used which either measures this directly (such as a liquid manometer or a membrane manometer) or measures it indirectly (such as an electrical or pneumatic measuring transducer). Electrical transducers need regular calibration.

Minimum performance parameters:

Accuracy < 3 % of the measured value

5.7 Absolute pressure measuring equipment

The absolute pressure at the intake of the restrictor may be measured using a mercury barometer, aneroid barometer, or a barometer with electrical sensor/ transducer.

Minimum performance parameters:

Measuring range 90 kPa to 120 kPa

Accuracy $\pm$ 0,6 kPa

5.8 Thermometers

The temperature may be determined using either a liquid thermometer or a thermometer with electrical sensor/transducer (see also [28]).

Minimum performance parameters:

Measuring range 273 K to 313 K

Accuracy 2 K

5.9 Hygrometer

The relative humidity shall be determined using a sitable type of hygrometer, e.g. electrolysis, LiCl, dew-point, dew-point mirror hygrometer, psychrometer, etc.; see also [28].

Minimum performance parameters:

Measuring range 25 % to 95 % relative humidity

Accuracy 5 % relative humidity

6   Maintenance and inspection intervals

For the individual devices the maintenance and inspection procedures specified in Table 2 shall be carried out at least once within the given time periods. The successful carrying-through of the annually instrument calibration shall be documented with individual calibration protocols.

Table 2 — Summary of the maintenance and inspection intervals

Item	per filter	daily	weekly	monthly	annually	after changes [a]
Pressure difference						
Zero adjustment						x
Absolute pressure					x	x
Temperature					x	x
Relative humidity					x	x
Laser particle counter						
Zero count rate	x					x
Size determination					x	x
Counting efficiency					x	x
Coincidence error					x	x
Volume flow rate					x	x
DMA						
Zero voltage check		X				x
Volume flow rates					x	x
Cleaning				x		x
CNC						
Zero count rate	x					x
Counting efficiency					x	x
Coincidence error					x	x
Volume flow rate					x	x
Filling level		x				x
Aerosol generator						
Size distribution						x
Stability					x	x
Neutrality					x	x
Dilution system						
Zero count rate		x				x
Dilution factor					x	x

[a] Alteration to the test set-up or the relevant device.

7   Particle counting statistics

Counting particles is subject to statistical variation. The smaller the number of events which are counted, then the lower is the level of confidence. The level of confidence can be estimated by the use of the Poisson distribution.

The following table gives limits for the 95 % two-sided confidence interval for a given number of events using the Poisson distribution.

Table 3 — Upper and lower limit of the 95 % confidence interval of a Poisson distribution for particle numbers

No. of particles	Lower limit	Upper limit	No. of particles	Lower limit	Upper limit
0	0,0	3,7	35	24,4	48,7
1	0,1	5,6	40	28,6	54,5
2	0,2	7,2	45	32,8	60,2
3	0,6	8,8	50	37,1	65,9
4	1,0	10,2	55	41,4	71,6
5	1,6	11,7	60	45,8	77,2
6	2,2	13,1	65	50,2	82,9
8	3,4	15,8	70	54,6	88,4
10	4,7	18,4	75	59,0	94,0
12	6,2	21,0	80	63,4	99,6
14	7,7	23,5	85	67,9	105,1
16	9,4	26,0	90	72,4	110,6
18	10,7	28,4	95	76,9	116,1
20	12,2	30,8	100	81,4	121,6
25	16,2	36,8			
30	20,2	42,8			

For example, if five particles are being counted, then Table 3 shows that 95 % of repeated measurements of the same object would produce measuring rates between 1,6 and 11,7.

For small counts the limit values of the confidence interval are very unsymmetrical distributed in terms of the number counted. For larger numbers the Poisson distribution transforms into a symmetrical normal distribution. In these cases the 95 % confidence range may be calculated from the equation

$$N_{95\%} = N \pm 1,96 \times N^{1/2}$$

When calculating the filter efficiency and the penetration on the basis of the numbers of particles counted, then the least favourable limit value of the confidence interval shall be determined and used as a basis for the calculation. This normally means that instead of the measured value, the lower limit value shall be used for the upstream measurement, and the upper limit value for the downstream measurement.

Care shall be taken that the limit value is determined on the basis of the primary counts, rather than derived quantities (such as particle concentrations or numbers in which dilution factors have already been included).

The Poisson statistics can only be used to account for errors arising from small numbers of counted particles. Where they can be determined, other random and systematic errors must be reduced by additional corrections.

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