BS EN ISO 29461-1:2013

BSI Standards Publication

Air intake filter systems for rotary machinery — Test methods

Part 1: Static filter elements (ISO 29461-1:2013)

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National foreword

This British Standard is the UK implementation of EN ISO 29461-1:2013.

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.

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Luftfiltereinlasssysteme von Rotationsmaschinen - Prüfverfahren - Teil 1: Statische Filterelemente (ISO 29461-1:2013)

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Foreword

This document (EN ISO 29461-1:2012) has been prepared by Technical Committee ISO/TC 142 "Cleaning equipment for air and other gases" in collaboration with 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of an identical text or by endorsement, at the latest by October 2013, and conflicting national standards shall be withdrawn at the latest by October 2013.

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.

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Endorsement notice

The text of ISO 29461-1:2013 has been approved by CEN as EN ISO 29461-1:2013 without any modification.

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 29461-1 was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases*.

ISO 29461 consists of the following parts, under the general title *Air intake filter systems for rotary machinery — Test methods*:

— *Part 1: Static filter elements*

Cleanable (pulse jet) and surface loading filters, mechanical integrity of filter elements, *in situ* testing, marine and offshore environment filter systems, and cleanable (pulse Jet) filter elements will form the subjects of future parts.

0 Introduction

0.1 Filters in power generating/compressor applications

In rotating machinery applications, the filtering system, typically a set of filter elements arranged in a suitable manner, are an important part of the whole turbine/compressor system. The development of turbine machinery used for energy production or others has led to more sophisticated equipment and therefore the importance of good protection of these systems has become more important in the recent years. It is known that particulate contamination can deteriorate a turbine power system quite substantially if not taken care of.

This event is often described as “erosion”, “fouling” and “hot corrosion” where salt and other corrosive particles are known as potential problems. Other particulate matters may also cause significant reduction of efficiency of the systems. It is important to understand that air filter devices in such systems are located in various environmental conditions. The range of climate and particulate contamination is very wide, ranging from deserts to humid rain forests to arctic environments. The requirements on these filter systems are obviously different depending on where they will be operating.

ISO 29461 has based the performance of the air intake filter systems not only upon heavy dust collection but also particulate efficiency in a size range that is considered to be the problematic area for these applications. Both ultra-fine and fine particles, as well as larger particles, should be considered when evaluating turbine fouling. In typical outdoor air, ultra-fine and fine particles in the size range from 0,01 µm to 1 µm contribute to >99 % of the number concentration and to >90 % of the surface contamination. The majority of the mass normally comes from larger particles (>1,0 µm).

Turbo-machinery filters comprise a wide range of products from filters for very coarse particles to filters for very fine, sub-micron particles. The range of products varies from self-cleaning to depth and surface loading systems. The filters and the systems have to withstand a wide temperature and humidity range, very low to very high dust concentration and mechanical stress. The shape of products existing today can be of many different types and have different functions such as droplet separators, coalescing products, filter pads, metal filters, inertial filters, filter cells, bag filters, panel-type, self-cleanable and depth loading filter cartridges and pleated media surface filter elements.

ISO 29461 will provide a way to compare these products in a similar way and define what criteria are important for air filter intake systems for rotary machinery performance protection. The performance of products in this broad range must be compared in a good manner. Comparing different filters and filter types must be done with respect to the operating conditions they finally will be used in.

For instance, if a filter or a filter system is meant to operate in an extreme, very dusty environment, the real particulate efficiency of such a filter cannot be predicted because the dust loading of the filter plays an important role. ISO 29461-2 will address the performance of cleanable and surface loading filters.

0.2 Filtration characteristics

Initiatives to address the potential problems of particle re-entrainment, shedding and the in-service charge neutralization characteristics of certain types of media have been included in Annexes A and B.

Certain types of filter media rely on electrostatic effects to achieve high efficiencies at low resistance to airflow. Exposure to some types of challenge, such as combustion particles or other fine particles, may inhibit such charges with the result that filter performance suffers. The normative test procedure, described in Annex A, provides techniques for identifying this type of behaviour. This procedure is used to determine whether the filter particulate efficiency is dependent on the electrostatic removal mechanism and to provide quantitative information about the importance of the electrostatic removal. The procedure was selected because it is well established, reproducible, relatively fast and easy to perform.

In an ideal filtration process, each particle would be permanently arrested at the first contact with a filter fibre, but incoming particles may impact on a captured particle and dislodge it into the air stream. Fibres or particles from the filter itself could also be released, due to mechanical forces. From the user’s point of view it might be important to know this, see Annex B.

Filters with a low initial or conditioned particulate efficiency (<35 %) for sub-micron particles (0,4 µm) that do not increase their efficiency during the operation will typically not provide any major protection for the operating machinery when challenged with typical atmospheric aerosols where the majority of particles are smaller than 1,0 µm. However, in some cases with aerosols having a dominant fraction of coarse particles, filters with low efficiencies at sub-micron particles can serve as a protection for later filter stages and can also have a higher average particulate efficiency (e.g. surface loading filters) at 0,4 µm due to the dust loading. Therefore a gravimetric test can provide some information about capacity and gravimetric efficiency for those aerosols. In general, a lower total filtration level than 35 % at 0,4 µm should not be recommended for an air intake filter system for rotary machinery when the aerosol loading of the filters are not contributing to a significant increase of the efficiency during the operation.

0.3 Organization of ISO 29461

The methods and procedures for determining particulate efficiency, pressure drop and the corresponding reporting formats are the same for all types of static filter element.

The test methods concerning particulate efficiency, pressure drop and reported values are the same for all filters, except for loading characteristics and cleaning procedure, which are different for cleanable surface loading filters. These filters incorporate cleaning procedures and have different loading characteristics; therefore, they require appropriately modified test methods, which will be defined in Part 2.

Part 3 will provide methods for determining the mechanical integrity of filters under conditions that may be encountered in abnormal operating environments.

Part 4 will describe methods of testing installed filters under in-service operating conditions (*in situ* testing).

Part 5 will cover test methods for the specific requirement of offshore and marine application, and specify methods for determining the sea salt removal efficiency of individual filters and/or complete filter systems.

Part 6 will cover test methods for cleanable filter elements, and will not cover the system testing (e.g. cleaning device) as in Part 2.

This part of ISO 29461 describes the test methods for static filter units, typically of the depth loading type (see definitions 3.43 and 3.44). All filters can be tested in the same manner, thus obtaining comparable results. However, for surface loading filters, reverse pulse filters, marine and offshore filter systems, as well as other filter systems that are not regarded as static filter units, the appropriate part shall be used.

For multi-stage systems that use a number of components (e.g. equipment for cleaning, filters), this part of ISO 29461 may be used as long as the qualification requirements of the test rig can be fulfilled. In cases where this is not possible, Part 4 (*in situ* testing) procedures may be applied.

Air intake filter systems for rotary machinery — Test methods —

Part 1:
Static filter elements

1 Scope

ISO 29461 specifies methods and procedures for determining the performance of particulate air filters used in air intake filter systems for rotary machinery such as stationary gas turbines, compressors and other stationary internal combustion engines. It applies to air filters having an initial particle efficiency up to 99,9 % with respect to 0,4 µm particles. Filters with higher initial particle efficiencies are tested and classified according to other standards (e.g. EN 1822). These procedures are intended for filters which operating at flow rates within the range 0,25 m^3/s (900 m^3/h) up to 1,67 m^3/s (6000 m^3/h).

This part of ISO 29461 refers to static (barrier) filter systems but can be applied to other filter types and systems in appropriate circumstances.

Two methods of determining the efficiency are used in this part of ISO 29461:

— particulate efficiency (measured with respect to particle number and size);

— gravimetric efficiency (percentage weighted mass removal of loading dust).

Also a flat sheet media sample or media pack sample from an identical filter is conditioned (discharged) to provide information about the intensity of the electrostatic removal mechanism.

After determination of its initial particle efficiency, the untreated filter is loaded with dust in steps until its final test pressure drop is reached. Information on the loaded performance of the filter is then obtained.

The performance results obtained in accordance with this part of ISO 29461 cannot be quantitatively applied (by themselves) to predict performance in service with regard to efficiency and lifetime. Other factors influencing performance to be taken into account are described in the annexes.

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.

ISO 2854, *Statistical interpretation of data — Techniques of estimation and tests relating to means and variances*

ISO 5167 (all parts), *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*

ISO 12103-1, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*

ISO 14644-3:2005, *Cleanrooms and associated controlled environments — Part 3: Test methods*

ISO 21501-1, *Determination of particle size distribution — Single particle light interaction methods — Part 1: Light scattering aerosol spectrometer*

ISO 21501-4, *Determination of particle size distribution — Single particle light interaction methods — Part 4: Light scattering airborne particle counter for clean spaces*

ASHRAE 52.2:1999, *Method of testing general ventilation air-cleaning devices for removal efficiency by particle size*

IEST-RP-CC014, *Calibration and Characterization of Optical Airborne Particle Counters*

JIS Z 8901:2006, *Test powders and test particles*

JACA No.37:2001, *Guideline of Substitute Materials for DOP*

3 Terms and definitions

3.1
test airflow rate
volumetric airflow rate used for testing

[Source: ISO 29464:2011; 3.1.106]

3.2 Velocity

3.2.1
filter face velocity
airflow rate divided by the filter face area

[Source: ISO 29464:2011, 3.1.84]

3.2.2
media velocity
airflow rate divided by the effective filtering area

Note 1 to entry: Expressed at an accuracy of three significant figures.

3.3 Efficiency

3.3.1
particulate efficiency
percentage particulate removal efficiency of the filter at specified particle sizes measured with a particle counter in the range of 0,3 µm to 3,0 µm

3.3.2
initial efficiency
particulate efficiency of the clean filter operating at the test airflow rate

Note 1 to entry: A clean filter is a filter not exposed to any test aerosol or substance prior to the efficiency test.

3.3.3
minimum efficiency
lowest particulate efficiency of initial, conditioned or dust loaded efficiencies

3.3.4
conditioned efficiency
efficiency of the conditioned filter media (per Annex A) operating at an average media velocity corresponding to the test airflow rate in the filter

3.3.5
gravimetric efficiency
A_{50}
weighted (mass) removal of loading dust after 50 g of dust load

3.3.6
average gravimetric efficiency
A_{avg}
ratio of the total amount of loading dust retained by the filter to the total amount of dust fed up to final test pressure drop

3.3.7
dust loaded efficiency
efficiency of the filter operating at test flow rate and after dust loadings up to final test pressure differential

3.4
penetration
ratio of the particle concentration detected downstream versus the concentration upstream of the filter

3.5 Pressure drop (differential pressure)

3.5.1
initial pressure drop
pressure drop of the clean filter operating at the test airflow rate

3.5.2
final test pressure drop
maximum pressure drop of the filter up to which the filtration performance is measured

3.5.3
final test pressure drop – recommended
maximum operating pressure drop of the filter as recommended by the manufacturer at rated airflow

3.6 Filter area

3.6.1
filter face area
frontal face area of the filter including the header frame

[Source: ISO 29464:2011, 3.1.83]

Note 1 to entry: Typical nominal values: 0,610 m × 0,610 m (24 in × 24 in).

3.6.2
effective filtering area
area of filter medium in the filter which collects dust

[Source: ISO 29464:2011; 3.1.79]

3.7 Filters

3.7.1
static filter
air filter that will be removed (exchanged) after it has reached its final test pressure drop and that is not cleaned with jet pulses or other means in order to fully, or partially, retrieve its initial performance (pressure drop and efficiency)

3.7.2
pulse jet filter
cleanable air filter, that typically is cleaned with air jet pulses to provide a longer service life

3.7.3
surface loading filter
filter in which the dust is collected on the surface of the filter medium

3.7.4
depth loading filter
filter in which particles penetrate into the filter medium and are collected on the fibres in the depth of the filter medium

3.7.5
low efficiency filter
air filter with an initial particulate efficiency at 0,4 µm particles in the range $E < 35$ %

3.7.6
medium efficiency filter
air filter with an initial particulate efficiency at 0,4 µm particles in the range 35 % $\leq E \leq$ 85 %

3.7.7
high efficiency filter
air filter with an initial particulate efficiency at 0,4 µm particles in the range $E \geq 85$ %

3.7.8
EPA filter
air filter with a particulate efficiency at most penetrating particle size (MPPS) in the range 85 % $\leq E \leq$ 99,95 % (typically 0,05 µm to 0,3 µm size range)

3.7.9
final filter
air filter used to collect the loading dust passing through or shedding from the filter under test

[Source: ISO 29464:2011; 3.1.86]

3.7.10
charged filter
filter in which the medium is electrostatically charged or polarized

[Source: ISO 29464:2011; 3.1.75]

3.7.11
untreated filter
air filter not submitted to conditioning per Annex A

3.8 Test aerosol

3.8.1
test aerosol
aerosol used for determining the particulate efficiency of the filter

3.8.2
particle size
geometric diameter (equivalent spherical, optical or aerodynamic, depending on the context) of the particles of an aerosol

[Source: ISO 29464:2011; 3.1.126]

3.8.3
mean diameter
geometric mean value of the upper and lower border diameters in a size range

3.8.4
particle number concentration
number of particles per unit volume of air

3.8.5
neutralization
action of bringing the aerosol to a Boltzmann charge equilibrium distribution with bipolar ions

3.9 Test dust

3.9.1
loading dust
synthetic test dust
synthetic dust formulated specifically for determination of the test dust capacity and arrestance of air filters

3.9.2
test dust capacity
dust loading capacity
TDC
amount of loading dust held by the filter at final test pressure drop

3.10 Particle sampling

3.10.1
isokinetic sampling
technique for air sampling such that the probe inlet air velocity is the same as the velocity of the air surrounding the sampling point

[Source: ISO 29464:2011; 3.1.144]

3.10.2
counting rate
number of counting events per unit time

[Source: ISO 29464:2011; 3.1.41]

3.10.3
correlation ratio
downstream particle concentration divided by the upstream particle concentration (measured without filter)

[Source: ISO 29464:2011; 3.1.26]

3.11 Particle shedding

3.11.1
shedding
release to the airflow of particles due to particle bounce and re-entrainment effects and to the release of fibres or particulate matter from the filter or filtering material

[Source: ISO 29464:2011; 3.1.150]

3.11.2
particle bounce
behaviour of particles that impinge on the filter without being retained

[Source: ISO 29464:2011; 3.1.121]

3.11.3
re-entrainment
release to the airflow of particles previously collected on the filter

[Source: ISO 29464:2011; 3.1.142]

4 Symbols and abbreviated terms

A_{50}	gravimetric efficiency after 50 g dust load, %
A_{avg}	average gravimetric efficiency %
CL	concentration limits of particulate counter
C_{V}	coefficient of variation
$C_{\mathrm{V,i}}$	coefficient of variation in size range “i”
$C_{\mathrm{mean,i}}$	mean of measuring points value for size range “i”
CL_{E}	lower confidence limit of particulate efficiency (95 % confidence level)
$\overline{CL_{\mathrm{E}}}$	average lower confidence limit of particulate efficiency (95 % confidence level). Average value from repeated measurement cycles for one efficiency calculation
CL_{Nd}	upper confidence limit (95 %) of number of particles downstream of the filter
CL_{Nu}	lower confidence limit (95 %) of number of particles upstream of the filter
d_{i}	geometric mean of a size range, µm
d_{l}	lower border diameter in a size range, µm
d_{u}	upper border diameter in a size range, µm
DR	dilution ratio, when diluter is used
$\overline{E}_{\mathrm{i}}$	average particulate efficiency in a size range “i”
m	mass passing the filter, g
m_{d}	mass of dust downstream of the test filter, g
m_{50}	mass of dust fed to filter in order to test gravimetric efficiency (50 g), g
m_{p50}	mass of dust that has passed the filter (the mass gain of final filter and the dust in the duct between the filter and the final filter) after 50 g of dust loading
m_{tot}	cumulative mass of dust fed to filter, g
m_1	mass of final filter before dust increment, g
m_2	mass of final filter after dust increment, g
N	number of points
N_{d}	number of particles downstream of the filter
$N_{\mathrm{d,i}}$	number of particles in size range “i” downstream of the filter
$\overline{N}_{\mathrm{d}}$	average number of particles downstream of the filter
N_{u}	number of particles upstream of the filter
$N_{\mathrm{u,i}}$	number of particles in size range “i” upstream of the filter

$\overline{N}_\mathrm{u}$	average number of particles upstream of the filter
n	exponent
p	pressure, Pa
p_a	absolute air pressure upstream of filter, kPa
p_sf	airflow meter static pressure, kPa
q_m	mass flow rate, kg/s
q_V	airflow rate at filter, $\mathrm{m^3/s}$
q_Vf	airflow rate at airflow meter, $\mathrm{m^3/s}$
R	correlation ratio
R_i	correlation ratio for size range “i”
T	temperature upstream of filter, °C (°F)
T_f	temperature at airflow meter, °C (°F)
$t_{(1-\alpha/2)}$	distribution variable
U	uncertainty, % units
v_mean	mean value of velocity
δ	standard deviation
ν	number of degrees of freedom
ρ	air density, $\mathrm{kg/m^3}$
φ	relative humidity upstream of filter, %
Δm	dust increment, g
Δm_ff	mass gain of final filter, g
Δp	filter pressure drop, Pa
Δp_f	Differential pressure, Pa
$\Delta p_{1,20}$	filter pressure drop at air density 1,20 $\mathrm{kg/m^3}$, Pa
ΔE_C	difference in particulate efficiency between initial particulate efficiency (E_0) of media sample and conditioned efficiency (media samples) per Annex A
OPC	optical particle counter
DEHS	liquid (DiEthylHexylSebacate) used for generating the DEHS test aerosol
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASTM	American Society for Testing and Materials

CAS	Chemical Abstracts
CEN	European Committee for Standardization
EN	European Standard
EUROVENT	European Committee of Air Handling and Refrigeration Equipment Manufacturers
ISO	International Organization for Standardization

5 General requirements

Static filter systems normally use multiple stages of coarse and fine filter elements to protect the machinery. The scope of this part of ISO 29461 includes methods for performance testing of individual filter elements. It does not include methods for the direct measurement of the performance of entire systems as installed in service except in cases where they can meet the qualification criteria for the test assembly.

6 Test rig and equipment

6.1 Test condition

Room air or outdoor air may be used as the test air source. Relative humidity shall be in the range of 30 % to 70 % in the tests. The air temperature shall be in the range of 10 °C to 38 °C. The exhaust flow may be discharged outdoors, indoors or re-circulated. Requirements of certain measuring equipment may impose limits on the temperature of the test air.

Filtration of the exhaust flow is recommended when test aerosol, loading dust or smell from filter may be present.

6.2 Test rig

The test rig (see Figure 1) consists of several square duct sections with typical 610 mm × 610 mm (24 in × 24 in) nominal inner dimensions except for the section where the filter is installed. This section has nominal inner dimensions between 616 mm (24,25 in) and 622 mm (24,50 in). The length of this duct section shall be at least 1,1 times the length of the filter, with a minimum length of 1 m, Figures 3 and 4. The filter must be within the section and must not protrude out of this section, either upstream or downstream. The test duct may need to have larger dimensions in cases when very large filters or integrated filter-system-element are to be tested. In those cases other dimensions are allowed as long as the qualification procedures described in Clause 7 are fulfilled. An example of a special (large) filter transition can be seen in Figure 5.

In case of circular cartridges, the test setup (mounting of the filters in the test duct) shall be as close to the real application as possible. In cases of large cylinders, a mounting plate with an additional hole for the air inlet/outlet can be sufficient. In terms of much smaller cylinders an additional transition could be inserted in the duct, Figure 6. This must however be analysed specifically for each construction, taking into consideration possible jetting effect that can affect the velocity and aerosol concentration in the test duct cross section.

The duct material shall be electrically conductive and electrically grounded, and shall have a smooth interior finish and be sufficiently rigid to maintain its shape at the operating pressure. Smaller parts of the test duct could be made in glass or similar material to see the filter and equipment. Provision of windows to allow monitoring of test progress is desirable.

High efficiency filters shall be placed upstream of section 1 - in which the aerosol for efficiency testing is dispersed and mixed to create a uniform concentration upstream of the filter.

Final filter for gravimetric efficiency measurement shall be placed after the test filter upstream of the measurement orifice.

Section 2 includes in the upstream section the mixing orifice (10), in the centre of which the dust feeder discharge nozzle is located. Downstream of the dust feeder is a perforated plate (11) intended to achieve a uniform dust distribution. In the last third of this duct section is the upstream aerosol sample head. For dust loading tests, this sampling head shall be blanked off or removed.

To avoid turbulence, the mixing orifice and the perforated plate should be removed during the readings of pressure drop (initial and final) and test of particulate efficiency. To avoid systematic error, removal of these items during pressure drop measurements is recommended. The uniformity of air velocity and aerosol in the measurement cross section shall be ensured according to 7.2 and 7.3.

Section 5 may be used for both efficiency and dust loading measurements and is fitted with a final filter for the loading test and with the downstream sampling head for the particulate efficiency test. Section 5 could also be duplicated, allowing one part to be used for loading test and the other for the particulate efficiency test.

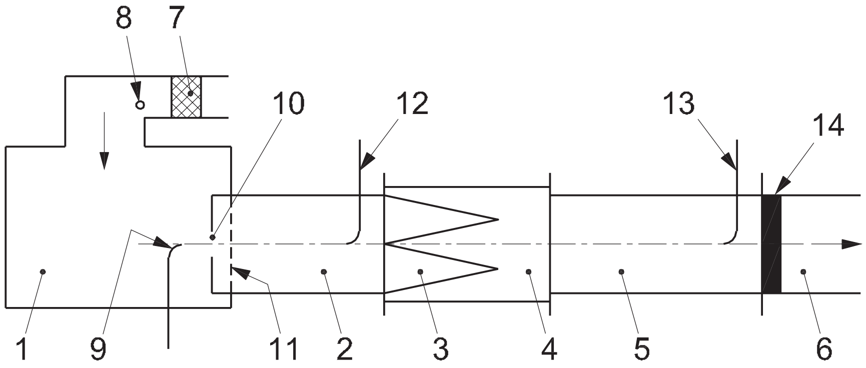
The test rig can be operated either in a negative or positive pressure airflow arrangement. In the case of positive pressure operation (i.e. the fan upstream of the test rig), the test aerosol and loading dust could leak into the laboratory, while at negative pressure particles could leak into the test system and affect the number of measured particles. These possible air leaks shall be located and sealed prior to filter tests.

The dimensions of the test rig and the position of the pressure taps are shown in Figure 3. Figure 2 shows the pressure taps for the test object (the filter).

The pressure drop of the tested filter shall be measured using static pressure taps located as shown in Figure 2. Pressure taps shall be provided at four points over the periphery of the duct and connected together by a ring line.

The entry plenum and the relative location of high efficiency filters and aerosol injections are discretionary and a bend in the downstream part of duct is optional, thereby allowing both a straight duct and a U-shaped duct configuration. Except for the bend itself, all dimensions and components are the same for the straight and U-shaped configurations. A downstream mixing baffle shall be included in the duct after the bend.

NOTE The purpose of the mixing baffle is to straighten out the flow and mix any aerosol that is downstream of the bend.



Key

1 duct section of the test rig (entry plenum)
2 duct section of the test rig
3 filter to be tested
4 duct section including the filter to be tested
5 duct section of the test rig
6 duct section of the test rig
7 high efficiency filter (at least 99.97 % on 0,3 µm particles)
8 inlet point for DEHS particles
9 dust injection nozzle
10 mixing orifice
11 perforated plate
12 upstream sampling head
13 downstream sampling head
14 final filter, gravimetric efficiency

Figure 1 — Schematic diagram of the test rig

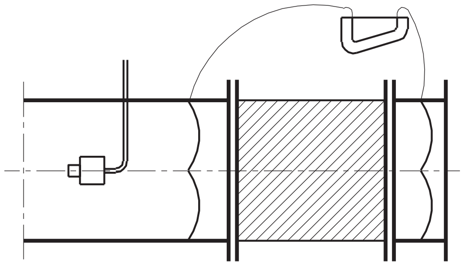


Figure 2 — Duct section including the filter to be tested (4). Pressure taps, filter

Dimensions in millimetres

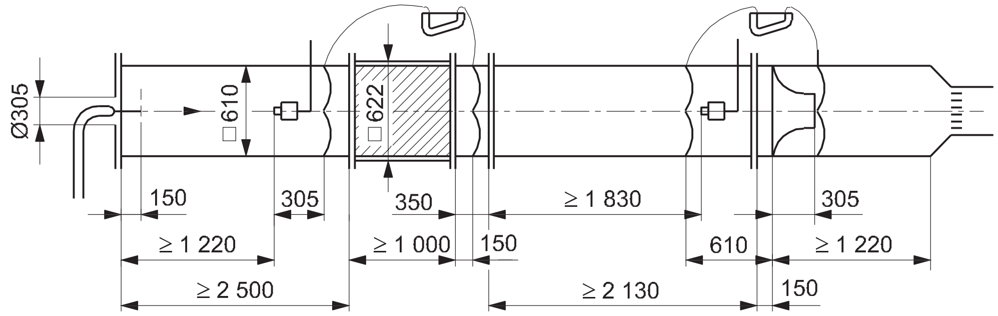
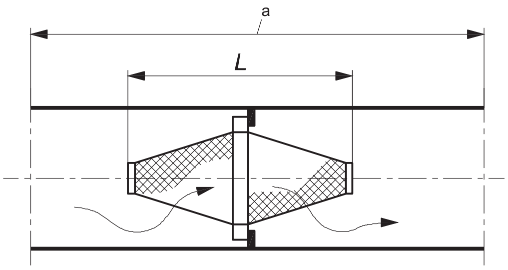
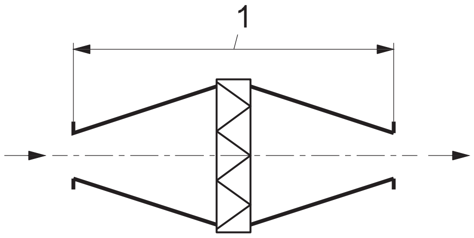


Figure 3 — Dimensions of the test rig



[a] >1 000 mm and/or 1,1 × *L*

Figure 4 — Duct section including the filter to be tested (4) and filter length (*L*)



Key

1 filter section

Figure 5 — Example of filter section with transition for special filter construction

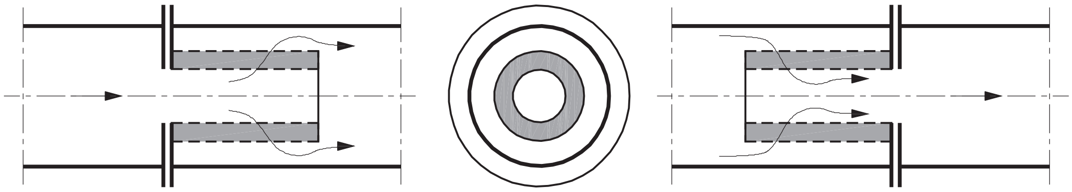
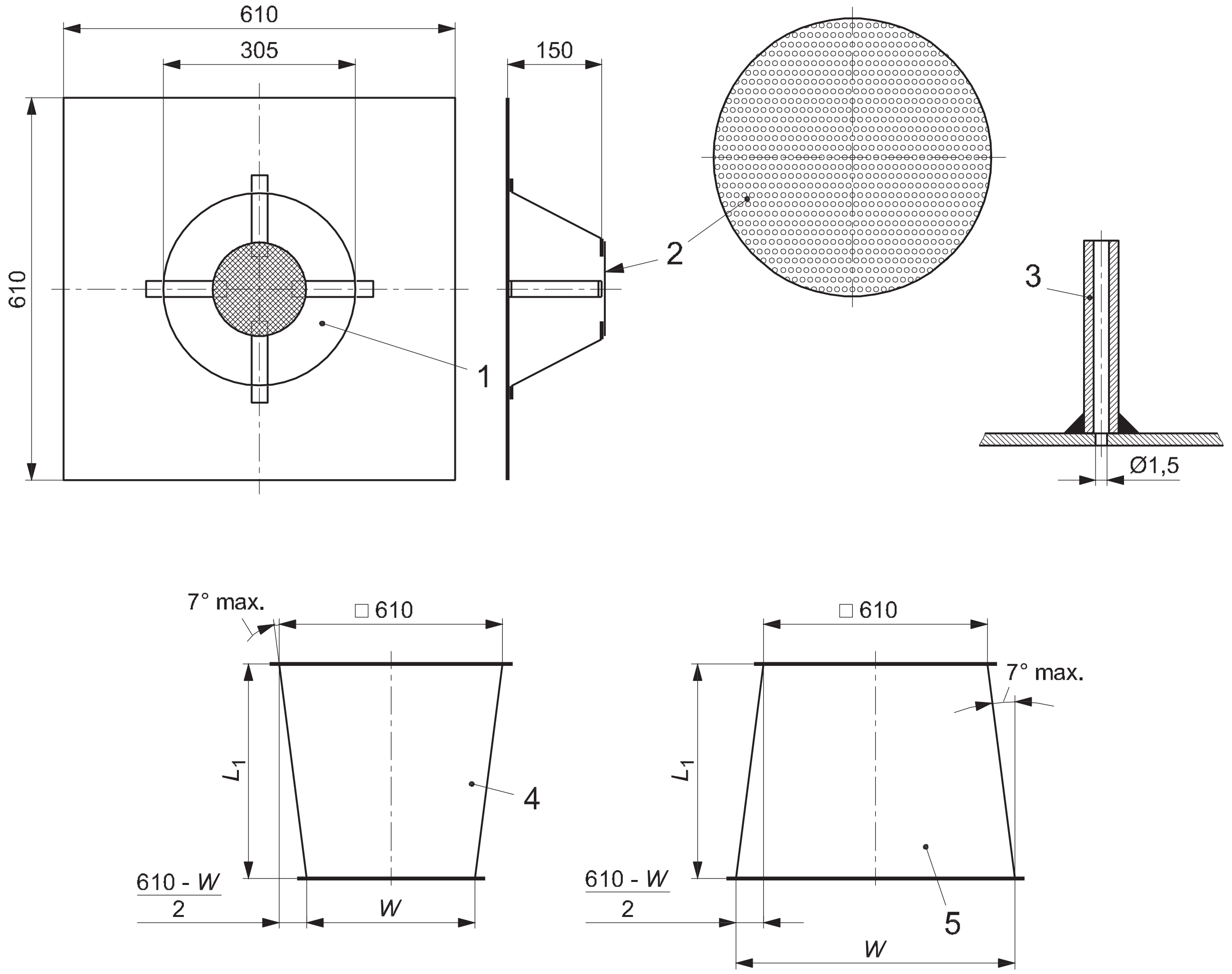


Figure 6 — Examples of mounting of circular cartridge in test duct

Dimensions in millimetres



Key

1 mixing orifice

2 perforated plate with diameter 152 mm ± 2 mm and 40 % open area

3 pressure tap

4 transition duct - test filter smaller than duct

5 transition duct - test filter larger than duct

Figure 7 — Details of test duct components

6.3 DEHS test aerosol generation

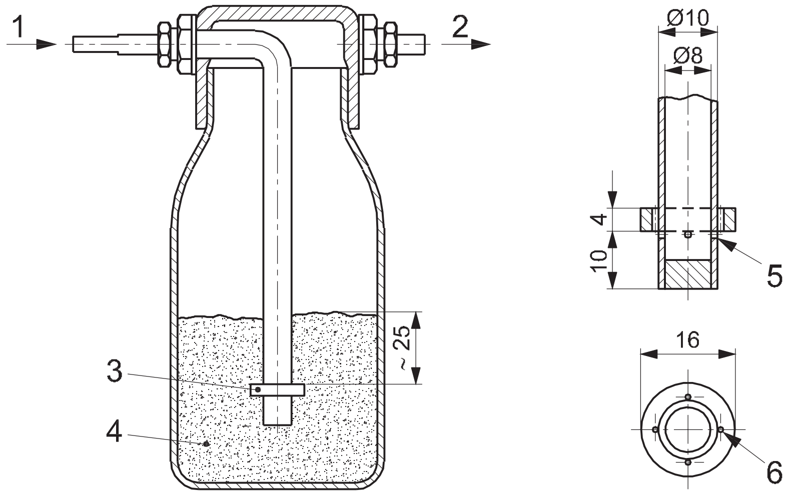
The test aerosol shall consist of undiluted DEHS, or other aerosols in accordance with 8.2. Test aerosol of DEHS (DiEthylHexylSebacate) produced by a Laskin nozzle aerosol generator is widely used in performance testing of high efficiency filters. The aerosol shall be virtually un-charged, which means that no additional treatment of the aerosol (such as neutralization with radioactive sources, electrostatic charge generators, etc.) is allowed.

Figure 8 gives an example of a system for generating the aerosol. It consists of a small container with DEHS liquid and a Laskin nozzle. The aerosol is generated by feeding compressed particle-free air through the Laskin nozzle. The atomized droplets are then directly introduced into the test rig. The pressure and airflow to the nozzle are varied according to the test flow and the required aerosol concentration. For a test flow of 0,944 m^3/s the pressure is about 17 kPa, corresponding to an airflow of about 0,39 dm^3/s (1,4 m^3/h) through the nozzle.

Any other generator capable of producing droplets in sufficient concentrations in the size range of 0,3 µm to 3,0 µm can be used.

Before testing, regulate the upstream concentration to reach steady-state and to have a concentration below the level of the particle counter.

Dimensions in millimetres



Key

1 particle-free air (pressure about 17 kPa)

2 aerosol to test rig

3 Laskin nozzle

4 test aerosol (for instance DEHS)

5 four 1,0 mm diameter holes 90° apart top edge of holes and just touching the bottom of the collar

6 four 2,0 mm diameter holes next to tube in line with radial holes

Figure 8 — DEHS particle generation system

6.4 Aerosol sampling system

Figure 9 gives an example of an aerosol sampling system. Two sample lines of equal length and equivalent geometry (bends and straight lengths) shall connect the upstream and downstream sampling heads to the particle counter. The sample tubes shall be electrically conducting or have a high dielectric constant. The tubing shall have a smooth inside surface (steel, Tygon[1], etc.).

The sampling probes shall have a sharp edge tapered to the outside diameter. The probes are placed in the centre of the upstream and downstream measuring sections. The sampling heads shall be centrally located with the inlet tip facing the inlet of the rig parallel to the airflow. The sampling probes shall be designed so they maintain an isokinetic sampling within 10 % at a test flow rate of 0,944 m^3/s. The probes can be used for all test airflows (from 0,25 m^3/s up to 1,67 m^3/s).

Three one-way valves make it possible to sample the aerosol upstream or downstream of the filter under test, or to have a "blank" suction through a high efficiency filter. These valves shall be of a straight-through design. Due to possible particle losses from the sampling system, the first measurement after a valve is switched should be ignored.

The flow rate can be maintained by the pump in the counter in the case of a particle counter with a high flow rate (e.g. $0,47 \times 10^{-3}$ m^3/s) or by an auxiliary pump in the case of a counter with smaller sample

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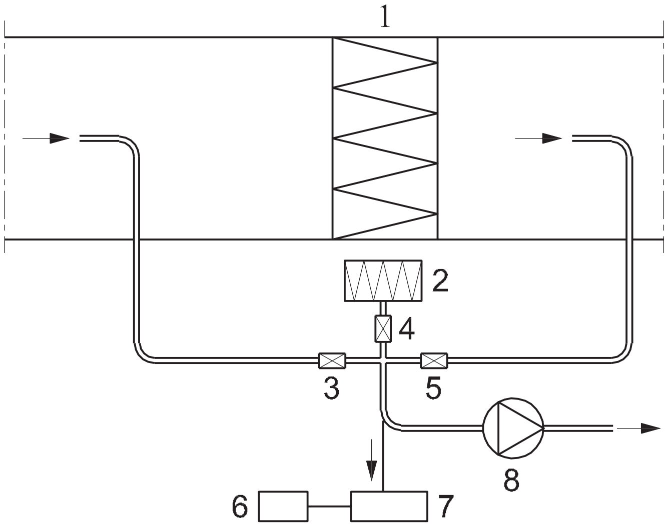
[1] Tygon is an example of a family of suitable products available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of these products.

flow rates. The line from the valves (to the pump) shall then be fitted with an isokinetic sampling nozzle directly connected to the particle counter to achieve isokinetic conditions within a tolerance of ±10 %.

Particle losses will occur in the test duct, aerosol transport lines and particle counter. Minimization of particle losses is desirable because a smaller number of counted particles will mean larger statistical errors and thus less accurate results. The influence of particle losses on the result is minimized if the upstream and downstream sampling losses are made as near equal as possible.



Key

1 filter
2 high efficiency filter (clean air)
3 valve, upstream
4 valve, clean air
5 valve, downstream
6 computer
7 particle counter
8 pump

Figure 9 — Schematic diagram of the aerosol sampling system

6.5 Flow measurement

Flow measurement shall be made by Standardized or calibrated flow measuring devices in accordance with ISO 5167. Examples are orifice plates, nozzles, Venturi tubes, etc.

The uncertainty of measurement shall not exceed 5 % of the measured value at 95 % confidence level.

6.6 Particle counter

NOTE See ISO 21501-4, as reference to this subclause.

This method requires the use of an optical particle counter (OPC) having a particle size range of at least 0,3 µm to 3 µm. The counting efficiency shall be 50 % ± 20 % for calibration particles with a size close to the minimum detectable size, and it shall be 100 % ± 10 % for calibration particles that are 1,5 to 2 times larger than the minimum detectable particle size. The size range shall be divided into at least five size classes, the boundaries of which should be approximately equidistant on a logarithmic scale.

The number of particle size measurements will enable the user to generate a curve of efficiency vs. particle size data covering at least the 0,3 µm to 3 µm particle size range. The efficiency can then be calculated (by interpolation on a log-lin graph) for any given geometric particle size, for example, 0,4 µm, 0,6 µm, 0,8 µm, 1,2 µm, 1,8 µm and 2,6 µm.

The particulate efficiency measurements may be made with one particle counter sampling sequentially upstream and downstream or may be performed with two particle counters sampling simultaneously. Clause 7 contains further information and details about the calibration and operation of OPCs used for this test.

An example of how a single or dual particle counter system might be configured is shown below.

Single Counter Example		
Complete range	**Channel boundaries** (µm)	**Geometric mean diameter of range** (µm)
Class 1	0,30 – 0,54	0,40
Class 2	0,54 - 0,66	0,60
Class 3	0,66 – 1,00	0,81
Class 4	1,00 – 1,45	1,20
Class 5	1,45 - 2,23	1,80
Class 6	2,23 – 3,00	2,59

6.7 Differential pressure measuring equipment

Measurements of pressure drop shall be taken between measuring points located in the duct wall as shown in Figure 2. Each measuring point shall comprise four interconnected static taps equally distributed around the periphery of the duct cross section.

The pressure measuring equipment used shall be capable of measuring pressure differences with an accuracy of ±2 Pa in the range of 0 Pa to 70 Pa. Above 70, the accuracy shall be ±3 % of the measured value.

6.8 Dust feeder

The purpose of the dust feeder is to supply the loading dust to the filter under test at a constant rate and over the test period. The general design of the dust feeder and its critical dimensions are given in Figure 10 and Figure 11. Any dust feeder can be chosen as long as it gives the same test result as the described dust feeder. The angle between the dust pickup tube and dust feed trough is 90° in the figure but could be less in real application. A certain mass of dust previously weighed is loaded into the mobile dust feeder tray. The tray moves at a uniform speed and the dust is taken up by a paddle wheel and carried to the slot of the dust pickup tube of the ejector.

The ejector disperses the dust with compressed air and directs it into the test rig through the dust feed tube. The dust injection nozzle shall be positioned at the entrance of duct section 2 and be collinear with the duct centre line.

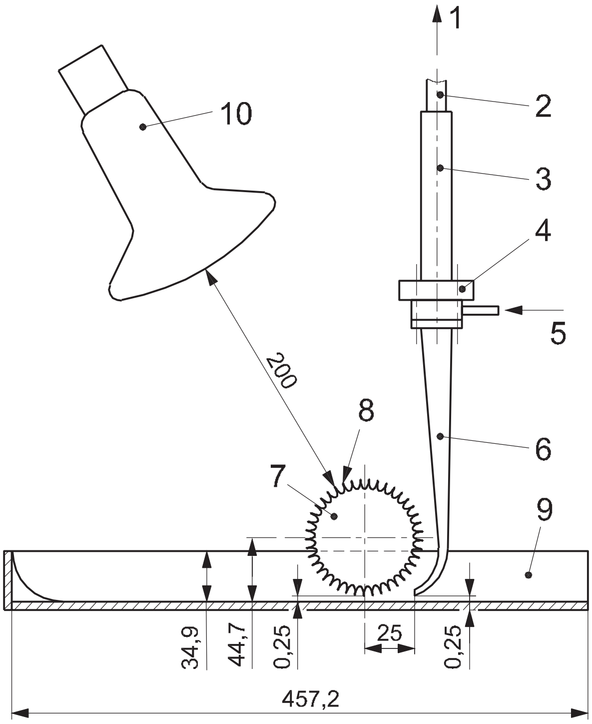
Backflow of air through the pickup tube from the positive duct pressure shall be prevented when the feeder is not in use.

All tubing, nozzles, etc. that are in direct contact with the dust during the operation must be electrically conductive and grounded. This is needed in order to minimize the errors in measurements due to electrostatic charging of dust during the operation of the dust feeder.

The degree of dust dispersion by the feeder is dependent on the characteristics of the compressed air, the geometry of the aspirator assembly and the rate of airflow through the aspirator. The aspirator Venturi is subject to wear from the aspirated dust and will become enlarged with use. Its dimension shall be monitored periodically to ensure that the tolerances shown in Figure 11 are met. The dust should preferably be homogenized in a shaker, maintained at a given temperature and in a controlled relative humidity.

The gauge pressure on the air line to the Venturi corresponding to an airflow of the dust-feeder pipe of $6{,}8 \times 10^{-3}\ \mathrm{m}^3/\mathrm{s} \pm 0{,}24 \times 10^{-3}\ \mathrm{m}^3/\mathrm{s}$ shall be measured periodically for different static pressure in the duct. See 7.13 for qualification requirements of the dust feeder.

Dimensions in millimetres

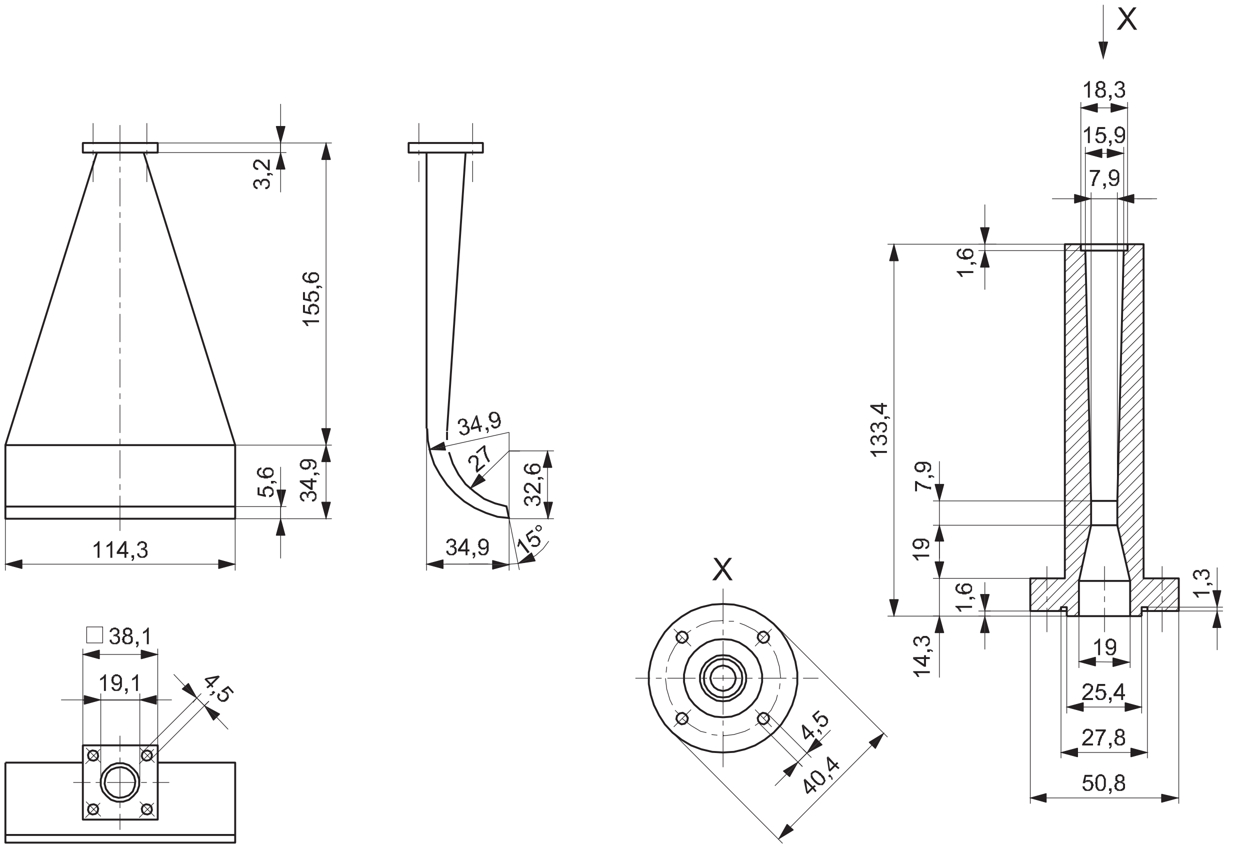


Key

1 dust feed tube (to inlet of test duct)
2 thin-wall galvanized conduit
3 Venturi ejector
4 ejector
5 dry compressed air feed
6 dust pickup tube (0,25 mm from dust feed tray)
7 dust paddle wheel. diameter 88,9 mm (outer dimension), 114,3 mm long with 60 teeth 5 mm deep
8 teeth in paddle wheel (60 teeth)
9 dust feed tray
10 150 W infrared-reflector lamp

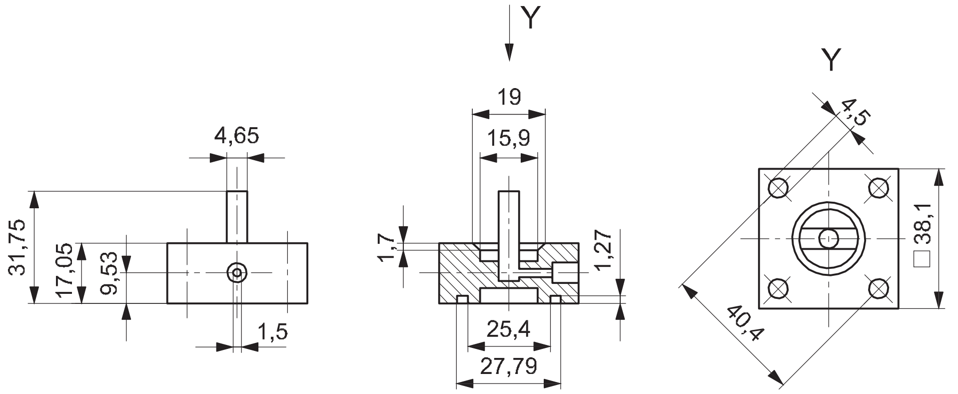
Figure 10 — Critical dimensions of dust feeder assembly

Dimensions in millimetres



a) Dust pickup tube

b) Ejector



c) Venturi ejector

Tolerances:
for integers: ±0,8 mm
for decimals: ±0,03 mm

Figure 11 — Ejector, Venturi ejector and pickup details for the dust feeder

6.9 Diluter equipment

In order to be able to test high efficiency filters (>85 % at 0,4 µm) a dilution system may be needed to avoid coincidence errors at the upstream aerosol measurement. The dilution ratio required is determined by the particle counter performance and the upstream concentration needed.

6.9.1 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 particle size and shall be consistent over time.

The clean air can be obtained by filtering a partial flow of the aerosol. The unfiltered part can be fed along a capillary and the drop of pressure over this capillary is used to check the volume flow rate.

Another possibility is the introduction of an external particle-free air (for example, from a compressed air line). Some systems are operating by the ejector principle. The pure airflow creates a pressure drop at a constriction, which draws in the aerosol to be diluted. 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.

By means of a cascade system using several dilution systems high dilution factors (>1000) can be achieved with a high level of accuracy.

6.9.2 Minimum performance parameters

Volume flow:	Adjustable to the relevant measuring device
Dilution ratio:	Between 10 and 10 000 depending on the initial particle concentration and the measuring device used
Accuracy:	5 % of the dilution ratio
Zero count rate:	< 10 particles/min

NOTE The zero count rate is measured with an H13 filter at the intake of the dilution system.

6.9.3 Sources of error and limit errors

Clogging of capillaries and nozzles can alter the dilution ratio.

6.9.4 Maintenance and inspection

Any installed filters in dilution equipment shall be replaced at the intervals specified by the manufacturers. If the dilution system is found to generate particles when checking it with particle-free air (zero-count check), 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.

7 Qualification of test rig and apparatus

7.1 General

The summary of the qualification requirements and frequency of maintenance are specified in 7.15 and 7.16.

7.2 Air velocity uniformity in the test duct

The uniformity of the air velocity in the test duct shall be determined by measuring the velocity at nine points located as in Figure 12, immediately upstream of the test filter section without the test filter and the mixing device. Measurements shall be made with an instrument having an accuracy of ±10 % with a resolution of minimum 0,05 m/s.

Measurements shall be conducted at 0,25 m^3/s, 0,944 m^3/s and 1,5 m^3/s. It is important that no significant disturbance of the airflow occurs (from instrument, operator, etc.) when measuring the velocities.

For each measurement, a sample time of at least 15 s shall be used. The average of three measurements shall be calculated for each of the nine points and the mean and the standard deviation shall be calculated from these nine values.

The coefficient of variation C_V shall be calculated as follows:

$$C_V = \delta / v_{mean} \tag{1}$$

where

δ	is the standard deviation of the nine measuring points;
v_{mean}	is the velocity mean value of the nine measuring points.

The C_V shall be less than 10 % at each airflow setting.

7.3 Aerosol uniformity in the test duct

The uniformity of the challenge aerosol (DEHS) in the test duct shall be determined by measurements at nine points immediately upstream of the filter (see Figure 12). The mixing device should be removed during qualification tests. By using a single probe that can be repositioned, the measurements can be done. The probe shall be of the same shape as the probe used in the particulate efficiency test and have an appropriate entrance diameter to obtain isokinetic sampling within 10 % at 0,944 m^3/s. The same probe and sample flow shall be used at test duct flows 0,25 m^3/s, 0,944 m^3/s and 1,5 m^3/s. 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 particulate efficiency test.

The aerosol concentration shall be measured with a particle counter meeting the specification in this standard. The number of particles counted in all specified size ranges in a single measurement should be >500 in order to reduce the statistical error.

Dimensions in millimetres

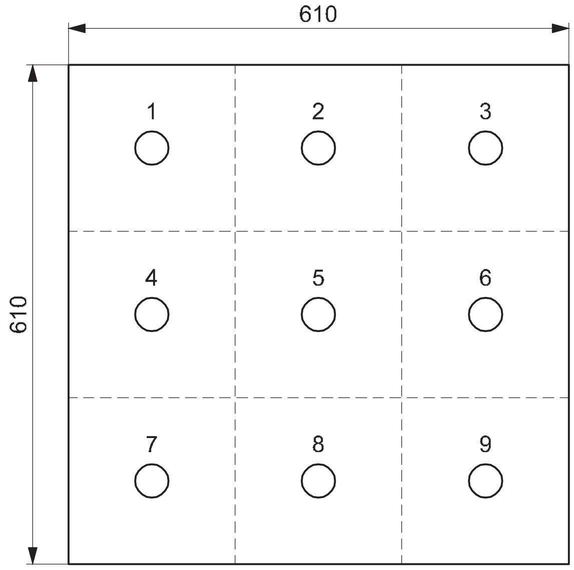


Figure 12 — Air velocity and aerosol uniformity: sampling points for measuring uniformity of air velocity and aerosol dispersion

A sample is taken successively at each measuring point. This procedure shall be repeated until five samples from each measuring point are obtained. The five values for each point shall be averaged for all size ranges of the particle counter and the coefficient of variation $C_{\mathrm{V,i}}$ shall be calculated for each for size range “i” as follows:

$$C_{\mathrm{V,i}} = \delta_{\mathrm{i}}/C_{\mathrm{mean,i}} \tag{2}$$

where

δ_{i} is the standard deviation (of the nine measuring points) for size range “i”;

$C_{\mathrm{mean,i}}$ is the mean value of the nine measuring points for size range “i”.

The $C_{\mathrm{V,i}}$ shall be less than 15 % for 0,25 m^3/s, 0,944 m^3/s and 1,5 m^3/s.

7.4 Particle counter sizing accuracy

Optical particle counters (OPCs) measure the particle concentration and the equivalent optical particle size. The indicated particle size is strongly dependent on the calibration of the OPC.

To avoid effects caused by different aerodynamic, optical and electronic systems of various types of OPCs, measurements both upstream and downstream of the filter shall be made by one or two identical instruments.

The OPC shall be calibrated prior to initial system start-up and thereafter in regular intervals of no longer than one year and shall have a valid calibration certificate. The calibration of the OPC shall be done by the OPC manufacturer or any similarly qualified organization according to established standardized procedures (e.g. IEST-RP-CC014; ASTM-F328; ASTM-F649; ISO 21501-4, ISO 21501-1) with polystyrene micro spheres (PSL) in single dispersion, having a refractive index of 1,59. The calibration has to be performed for at least 3 channels of the OPC in the measuring range 0,3 µm to 3 µm.

It is a good practice to check the sizing accuracy of the particle counter on a regular basis, such as at the start of every day. This quick calibration check will help the operator discover potential measurement problems prior to running the filter test. By generating an aerosol of a known size of polystyrene micro spheres and verifying these particles appear in the corresponding size class(es) of the OPC(s), the user can quickly verify the accuracy of the sizing capabilities of the equipment. Checks with polystyrene micro spheres at the low and high ends of the particle size range(s) are especially meaningful.

The sampling airflow of the OPC shall be calibrated to be within ±5 % of the OPC’s rated airflow, in compliance with one established standardized procedure (e.g. IEST-RP-CC014).

7.5 Particle counter zero test

The particle counter count rate shall be verified to have less than 10 total counts per minute in the 0,3 µm to 3 µm size range when operating with a high efficiency filter (>99,95 % of 0,3 µm particles) directly attached to the sampling nozzle inlet. This also includes the sampling system.

7.6 Particle counter overload test

OPCs may underestimate particle concentrations if their concentration limit is exceeded. Therefore it is necessary to know the concentration limit of the OPC being used. The maximum aerosol concentration used in the tests should then be kept sufficiently below this limit, so that the counting error resulting from coincidence does not exceed 5 % error in particle counts. Operating OPCs above their concentration limit will cause particulate efficiency results to be lower than they really are.

If the upstream concentration in the test duct cannot be reduced, a dilution system may be used to reduce the aerosol concentrations below the OPC´s concentration limit. It is then necessary to take upstream and downstream samples via the dilution system in order to eliminate errors arising from uncertainty in the dilution factor’s value.

Either one of the two following procedures may be used to determine whether the data values are influenced by coincidence errors. Procedure 2 is the more reliable of the two options and is therefore the recommended procedure:

- Procedure 1: The particulate efficiency of a reference filter shall be measured at different concentrations. At a concentration above the OPC´s CL, efficiency starts to decrease; typically for smaller particles (<1,0 microns).
- Procedure 2: An upstream particle concentration distribution shall be measured. Afterward, the concentration shall be uniformly reduced or diluted (this can be done by a known or an unknown factor) and the measurement of the particle concentration distribution repeated. If the shape of the latter particle size distribution curve shifts towards smaller particles, this is a clear sign that the former concentration was higher than the OPC´s CL. If the factor for concentration reduction or dilution is known, this factor should be found in each size class of the OPC, between the two concentration measurements.

Concentration reduction may be achieved by reducing the aerosol generator's output. Concentration dilution may be achieved by a dilution system in the sampling line of the OPC.

7.7 100 % efficiency test

The purpose of this test is to ensure that the test duct and sampling system are capable of providing a 100 % particulate efficiency measurement. The test shall be made using a high efficiency filter of minimum H13 class. The normal test procedure for determination of particulate efficiency is used. The test shall be performed at the test airflow of 0,944 m^3/s. The efficiency shall be greater than 99,95 % for all particle sizes.

7.8 Zero % efficiency test

The zero % particulate efficiency test is a test of the accuracy of the overall duct, sampling system, measurement and aerosol generation systems. The test shall be performed as a normal particulate efficiency test but with no test filter installed. The test airflow shall be 0,944 m^3/s. Two tests shall be done according to standard test procedure and the calculated zero efficiency shall meet the following criteria:

- 0 % ± 3 % for particle sizes equal to or less than 1,0 µm;
- 0 % ± 7 % for particle sizes larger than 1,0 µm.

The total number of counted particles for each size shall be >500 in order to limit the statistical error.

7.9 Aerosol generator response time

The time interval for the aerosol concentration to go from background level to steady-state test level shall be measured. This is to ensure that sufficient time is allowed for the concentration to stabilize before performing any tests.

Start the aerosol generator and record the time interval for the concentration to stabilize to a steady-state condition. The time interval shall be used as a minimum delay time before starting a test sequence according to this standard.

7.10 Dilution ratio

The dilution ratio, DR_i, is calculated by the following:

$$DR_\mathrm{i} = \frac{N_\text{Diluter Upstream,i}}{N_\text{Diluter Downstream,i}} \tag{3}$$

where

$N_\text{Diluter Upstream,i}$ is the number of particles in the size range “i” upstream of the dilution system;

$N_\text{Diluter Downstream,i}$ is the number of particles in the size range “i” downstream of the dilution system.

In order to check the dilution ratio a zero check of the system shall be done by using a filter of minimum H13 filter (99,95 % at MPPS). Any installed filters shall be replaced at the intervals specified by the manufacturers. If the system when tested with particle-free air (zero-check) is found to generate particles, the dilution system shall be cleaned. The dilution ratio (DR) shall be checked from time to time, for example by measuring the particle concentration at the intake and the outlet of a dilution stage. This can be done at lower concentrations with the same particle counters used in the test system or preferably with another particle counter with the capability to measure higher aerosol concentrations with no significant coincidence errors in the adequate size range.

7.11 Correlation ratio

The correlation ratio, R, shall be used to correct for any bias between the upstream and downstream sampling systems. If the zero % efficiency test fails but the correlation ratio limits are within requirements in 7.15, the correlation ratio correction shall be used to continue the test. If particulate efficiency is outside the limits, the test shall not be allowed.

The correlation ratio shall be established from the ratio of downstream to upstream particle counts without the test device installed in the test duct and before testing an air cleaner. The test shall be performed at the airflow rate of the test filter. The general equation for the correlation ratio, R, as used in this standard is

$$R = N_\mathrm{d}/N_\mathrm{u} \tag{4}$$

where

N_d is the number of particles downstream of the filter;

N_u is the number of particles upstream of the filter.

The particle generator shall be on, but without a test device in place. Upstream and downstream sampling times shall be the same during this test. The aerosol used shall be the same as the aerosol to be used to test the filters (DEHS). The data from the zero % efficiency test can be used for this calculation.

The average upstream count $\overline{N}_\mathrm{u}$ and average downstream count $\overline{N}_\mathrm{d}$ shall be calculated for each particle size channel “i”.

$$\overline{N}_\mathrm{u} = \frac{\sum\limits_{\mathrm{i}=1 \to n} N_\mathrm{u,i}}{N} \tag{5}$$

$$\overline{N}_{\mathrm{d}} = \frac{\sum\limits_{i=1 \to n} N_{\mathrm{d,i}}}{N} \tag{6}$$

where

N is the number of points.

The correlation ratio shall be calculated for each particle size channel “i”.

$$R_{\mathrm{i}} = \frac{\overline{N}_{\mathrm{d}}}{\overline{N}_{\mathrm{u}}} \tag{7}$$

7.12 Pressure drop checking

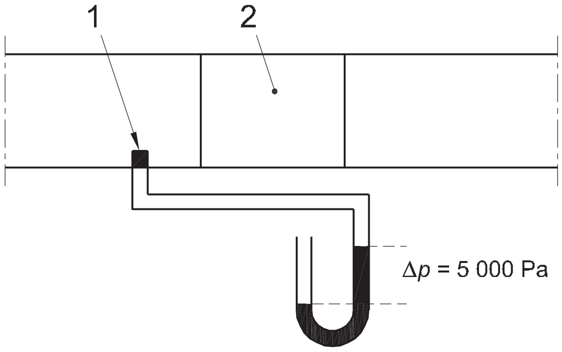
All equipment for pressure drop readings shall meet the requirements in 7.15.

This test is to verify that leaks in the equipment for pressure drop readings, instrument lines, etc. do not significantly affect the accuracy of the measurements of airflow or pressure drop. The test may be made by calibrated devices or by the system described below.

Seal the pressure sample points in the test duct carefully. Disconnect the pressure drop meter. Pressurize the tubes with a constant negative pressure of 5 000 Pa. Check all sampling lines in this manner (see Figure 13). No changes in pressure are allowed.

Pressurize the pressure drop measuring equipment at the maximum permitted pressure according to the instrument specification. The procedure shall be carried out sequentially on both positive and negative pressure lines. No changes in pressure are permitted on either inlet.

As an addition, a perforated plate (or other reference) having known pressure drops at 0,5 m³/s, 0,75 m³/s, 0,944 m³/s and 1,5 m³/s may be used for periodic checks on the pressure drop measurement system.



Key

1 sealed pressure inlet

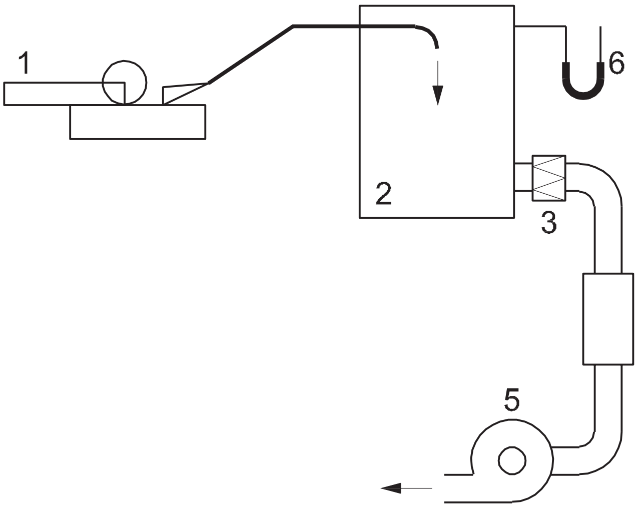
2 test device section

Figure 13 — Pressure line test

7.13 Dust feeder airflow rate

The purpose of this test is to verify that the airflow rate for the dust feeder is correct.

The aspirator Venturi is subject to wear from the dust and compressed air and will thereby become enlarged. It is therefore important periodically to monitor the airflow rate from the dust feeder. The flow shall be $6{,}8 \times 10^{-3}$ m³/s ± $0{,}24 \times 10^{-3}$ m³/s. This airflow is determined as in Figure 14.



Key

1 dust feeder

2 plenum with minimum volume of 0,25 m^3

3 high efficiency filter (minimum H13 class)

4 flow metering device

5 fan

6 pressure drop measurement device (the differential pressure should be zero)

Figure 14 — Dust feeder airflow rate

7.14 Reference filter check

For each test duct a minimum of three identical reference filters shall be maintained by the testing facility solely for initial particulate efficiency testing on a bi-weekly basis and these filters shall not be exposed to dust loading. The three filters shall be labelled as “primary”, “secondary” and “reserve”. The “primary” filter shall be checked every two weeks. The filters should be pleated, compact-style filters utilizing glass filter media. This type of filter elements has shown very little deviation in particulate efficiency and pressure drop when used as reference filters in laboratories.

If the filtration particulate efficiency values shift by >2 percentage points for any of the particle sizing channels, the “secondary” filter shall be tested. If both “primary” and “secondary” filters shows shifts >2 percentage points for any of the particle sizing channels, the particle counter shall be recalibrated or other system maintenance performed as needed (e.g. clean sample lines) to restore the reference filter particulate efficiency test to <2 percentage point shift. The reserve filter shall be used if either the primary or secondary filters become unusable (e.g. damaged).

The measured pressure drop across the reference filter shall be within 5 % or 5 Pa, whichever is the highest value, of the reference value. If the pressure drop deviates by more than 5 %, system maintenance shall be performed to restore the pressure drop to be within 5 % of the reference value. The pressure drop can also be checked versus a perforated plate with reasonable pressure drop instead of a filter.

The reference filter tests shall be performed at 0,944 m^3/s and particulate efficiency of the reference filter shall have about 50 % and 90 % particulate efficiency for 0,4 µm, and 1 µm particles respectively.

Immediately after calibration of the particle counter, retest each of the reference filters (or a new set of filters) to establish new filtration efficiency and pressure drop reference values.

When either the primary or secondary filtration particulate efficiency values shift by >2 percentage points for any of the particle sizing channels and either the secondary or the reserve filter does not, the primary or secondary filter shall be replaced with an identical filter or filters; if available, a new set of identical filters shall be obtained.

7.15 Summary of qualification requirements

Table 1 — Summary of qualification requirements

Parameter	Subclause	Requirement
Air velocity uniformity	7.2	C_V (coefficient of variation) < 10 %
Aerosol uniformity	7.3	C_V (coefficient of variation) < 15 %
Particle counter sizing accuracy	7.4	According to manufacturer valid calibration certificate
Particle counter – overload test	7.6	No overloading
Particle counter zero	7.5	< 10 counts per minute in size range 0,3 µm to 3,0 µm
100 % efficiency test	7.7	> 99,95 %
0 % efficiency test	7.8	Sizes ≤.1,0 µm: ±3 % Sizes > 1,0 µm: ±7 %
Correlation ratio	7.11	Sizes > 0,3 µm to 1 µm: ±10 % Sizes > 1,0 µm to 3,0 µm: ±20 %
Aerosol generator response time	7.9	As measured
Dilution system	6.9, 7.10	5 % accuracy in sizes < 1,0 µm
Manometer calibration	7.12	Size range: (0 Pa to 70 Pa) ± 2 Pa > 70 Pa ± 3 % of the measured value
Pressure drop test	7.12	No detectable leaks
Dust feeder airflow rate	7.13	$6{,}8 \times 10^{-3}$ m^3/s ± $0{,}24 \times 10^{-3}$ m^3/s
Reference filter check	7.14	≤ 2 % particulate efficiency measurement (absolute value) shift in each size channel

7.16 Apparatus maintenance

Table 2 — Frequency of maintenance

Maintenance item	Subclause	Daily	Monthly	Bi-annually	Annually	After any change that might alter performance
TEST DUCT						
Air velocity uniformity	7.2					X
Aerosol uniformity	7.3					X
100 % efficiency test	7.7		X			X
0 % efficiency test	7.8	X				X
Pressure drop test	7.12			X		X
INSTRUMENT						
Dilution system	6.9, 7.10			X		X
Aerosol generator response time	7.9			X		X
Manometer calibration	7.12				X	X
Particle counter - sizing accuracy	7.4	X[a]			X	X

Table 2 *(continued)*

Maintenance item	Subclause	Daily	Monthly	Bi-annually	Annually	After any change that might alter performance
Particle counter - overload test	7.6					X
Particle counter - zero test	7.5	X				X
Dust feeder airflow rate	7.13			X		X
Reference filter check	7.14		Every 2nd week			X

NOTE Regular cleaning of all equipment should be undertaken so that the performance of the test system is maintained.

[a] It is a good practice to check the sizing accuracy of the particle counter on a regular basis, such as at the start of every day or a new test. This quick calibration check will help the operator discover potential measurement problems prior to running the filter test. By generating an aerosol of a known size of polystyrene micro spheres and verifying these particles appear in the corresponding size class(es) of the OPC(s), the user can quickly verify the accuracy of the sizing capabilities of the equipment. Checks with polystyrene micro spheres at the low and high ends of the particle size range(s) are especially meaningful.

8 Test materials

8.1 Test air

Room air or outdoor air is used as the test air source. In the efficiency tests the air is filtered with high efficiency filters to obtain a test air free of background particles. The test conditions shall be in accordance with 6.1. The exhaust flow may be discharged outdoors, indoors or re-circulated. Filtration of the exhaust flow is recommended when test aerosol and loading dust may be present.

The compressed air for the dust feeder shall be dry, clean and free from oil.

8.2 Test aerosol

All filters will be tested for particulate efficiency against DEHS particles from 0,3 µm to 3,0 µm and for gravimetric efficiency against ISO fine test dust.

8.2.1 DEHS test aerosol

Test liquid aerosol of DEHS (DiEthylHexylSebacate) produced by a Laskin nozzle arrangement is widely used in the testing of high efficiency filters. DEHS is the same as DES Di(2-ethylhexyl) Sebacate or Bis (2-ethylhexyl) Sebacate.

The DEHS aerosol shall be used undiluted and uncharged (no added charge or neutralization) and introduced directly into the test rig. The aerodynamic, geometric and light scattering sizes are close to each other when measured with optical particle counters.

DEHS/DES/DOS – formula:

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

DEHS properties:

Density:	912 kg/m^3 (57 lb/ft^3)
Melting point:	225 K

Boiling point:	529 K
Flash point:	> 473 K
Vapour pressure:	1,9 µPa (1,9 × 10^{-6} Pa) at 273 K
Refractive index:	1,450 at 600 nm wavelength
Dynamic viscosity:	0,022 Pa·s to 0,024 Pa·s, CAS number 122-62-3

8.2.2 PAO test aerosol

Test aerosol of PAO (Polyalphaolefins, CAS number 68649-12-7) produced by a Laskin nozzle arrangement is also used for testing of high efficiency filters and can be used as an alternative to DEHS (ISO 14644-3, JIS Z 8901:2006, JACA No.37-2001).

8.3 Loading dust

ISO fine test dust is used for the loading of filters according to the test method in 9.5.

8.3.1 ISO fine loading dust (ISO 12103-A2)

The loading test dust “fine” is defined in ISO 12103-1, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*, and consists mainly of silica particles.

8.4 Final filter

The final filter captures any loading dust that passes through the tested filter during the dust loading procedure. The final filter shall have a minimum particulate efficiency of >85 % with respect to 0,4 µm DEHS particles and not gain or lose more than one gram, e.g. as a result of humidity variations met during one test cycle.

9 Test procedure

The test method uses two aerosols to measure two different efficiency values (particle and gravimetric efficiency). The “particulate efficiency” method uses DEHS or PAO as test aerosol and gives the particulate efficiency in the range of 0,3 µm to 3,0 µm. The “gravimetric efficiency” uses the loading dust as the test aerosol and the difference in mass of the final filter after 50 g of dust fed is used to calculate the gravimetric efficiency. All filters shall be tested the same way; however, if a certain filter is determined to be of low efficiency type (filters with initial particulate efficiency <35 % at 0,4 µm) it can be tested up to 375 Pa (1,5 inch WG) instead of 625 Pa (2,5 inch WG) final test pressure drop.

Table 3 — Overview of test procedure

Test method	**Size range**	**Test aerosol**	**Conditioning**	**Loading dust in two steps (first step 50 g)**	**Final test pressure drop** Pa (in WG)
Particulate efficiency	0,3 µm – 3,0 µm	DEHS	Yes	ISO fine (140 mg/m^3) (4,0 g/1000 ft^3) [two steps]	625 (2,5)
Gravimetric efficiency	ISO 12103-A2	ISO 12103-A2	Yes	ISO fine (140 mg/m^3) (4,0 g/1000 ft^3) [two steps]	375 (1,5)

This section describes the sampling sequence and data analysis procedures for sequential upstream-downstream sampling with one particle counter. For dual particle counter systems with simultaneous upstream-downstream sampling, the same procedures apply. The data quality requirements for single and dual particle counter systems are identical.

9.1 Preparation of filter to be tested

The filter shall be mounted in accordance with the manufacturer's recommendations and after equilibration with the test air weighted to the nearest gram. Devices requiring external accessories shall be operated during the test with accessories having characteristics equivalent to those used in actual practice. The filter, including any normal mounting frame, shall be sealed into the duct in a manner that prevents leakages.

NOTE This test method does not test the filter sealing mechanism.

The tightness shall be checked by visual inspection and no visible leaks are acceptable. If for any reason, dimensions do not allow testing of a filter under standard test conditions, assembly of two or more filters of the same type or model is permitted, provided no leaks occur in the resulting filter. The operating conditions of such accessory equipment shall be recorded.

9.2 Initial pressure drop

The value of the initial pressure drop shall be recorded at 50 %, 75 %, 100 % and 125 % of the rated airflow to establish a curve of pressure drop as a function of the airflow rate. The airflow is reported as measured at the local conditions. If the air density is not between 1,16 kg/m^3 and 1,24 kg/m^3 then the pressure drop readings shall be corrected to an air density of 1,20 kg/m^3 (see Annex D), which corresponds to standard air conditions: temperature 20 °C (68 °F), barometric pressure 101,3 kPa and relative humidity 50 %.

9.3 Initial particulate efficiency measurement

The initial particulate efficiency of a new "untreated" filter shall be tested at rated airflow. The efficiency is measured according to 9.3.1.

All filters tested shall also be tested according to 9.4.

9.3.1 Particulate efficiency test for filters of low and medium efficiency (≤85 % at at 0,4 µm)

The zero % efficiency test according to 7.8 shall be performed daily or before starting testing.

If the zero % efficiency test fails and the limits are within requirements in 7.15, the correlation ratio correction shall be used to continue the test. If particulate efficiency is outside the limits, the test shall not be allowed.

The particulate efficiency E_i for a given particle size range (between two particle diameters) shall be calculated as follows:

$$E_i = 1 - \frac{N_{d,i}}{N_{u,i} R_i} \tag{8}$$

where

R_i is the correlation ratio according to 7.11;

$N_{d,i}$ is the number of particles in the size range "i" downstream of filter;

$N_{u,i}$ is the number of particles in the size range "i" upstream of filter.

The initial particulate efficiency (E_0) data versus the size range diameters shall be presented in a table. A graph may also be added. Such a graph must cover x-axis in logarithmic scale and a y-axis covering the

0–100 % range. The size range diameter or the mean diameter d_i is the geometric average of the lower and upper border diameters in the size range “i”:

$$d_i = \sqrt{d_l \times d_u} \tag{9}$$

where

d_l is the lower border diameter in the size range;

d_u is the upper border diameter in the size range.

The aerosol generator output is adjusted to generate a stable concentration of aerosol within the OPC coincidence level requirements and such that the downstream count rate is sufficient for a statistically valid result within an acceptable time scale.

The particulate efficiency measurement is done by a series of at least 13 counts of a minimum 20 s conducted successively upstream and downstream of the filter under test and with a purge before each count, or with one intervening sample upstream or downstream without counting, in order to stabilize the concentration of particles in the transfer lines.

The counting cycle for size range ”i” will then be as in Table 4.

Table 4 — Counting cycle for a size range “i”

Count no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Upstream	$N_{u,1,i}$		$N_{u,2,i}$		$N_{u,3,i}$		$N_{u,4,i}$		$N_{u,5,i}$		$N_{u,6,i}$		$N_{u,7,i}$
Downstream		$N_{d,1,i}$		$N_{d,2,i}$		$N_{d,3,i}$		$N_{d,4,i}$		$N_{d,5,i}$		$N_{d,6,i}$	

The first single particulate efficiency $E_{1,i}$ for size range ”i” shall be calculated as follows:

$$E_{1,i} = 1 - \frac{N_{d,1,i}}{\frac{(N_{u,1,i} + N_{u,2,i})R_i}{2}} \tag{10}$$

where

R_i is the correlation ratio for size range “i” according to 7.11

The 13 measurements give six single efficiency ($E_{1,i}$, ..., $E_{6,i}$) results. The average efficiency $\bar{E}_i$ shall be calculated for the size range ”i” as follows:

$$\bar{E}_i = \frac{E_{1,i} + \ldots + E_{6,i}}{6} \tag{11}$$

Dual particle counter systems with simultaneous upstream and downstream sampling are also allowed.

In that case there will be an equal number of upstream and downstream counts. Formula (8) shall be used instead of Formula (11). Here measurement no. 13, is not required ($N_{u,7,i}$), see Table 4, since the measurements upstream and downstream are measured at the same time.

$$E_{1,i} = 1 - \frac{N_{d,1,i}}{(N_{u,1,i})R_i} \tag{12}$$

9.3.2 Particulate efficiency test for filters of high efficiency (>85 % at 0,4 µm)

When testing filters with high initial efficiencies (above 85 % at 0,4 µm) the procedure will be similar to 9.3.1 but with another approach for counting statistics, and with the addition of the use of dilution equipment. In order to avoid coincidence errors in the particle counter and to get statistical good accuracy of the measurement, a high number concentration of aerosol is needed. In comparison with a standard filter with lower efficiencies a concentration of about 10 to 1 000 times higher (depending on the particle counter performance) aerosol concentration will be needed.

For particulate efficiency measurement and calculation using dilution equipment with the dilution ratio *DR*, the following procedure should be used:

The zero % efficiency test according to 7.8 shall be performed daily or before starting testing.

The method is the same for filters tested against DEHS particles in size range 0,3 µm to 3,0 µm. If the zero % efficiency test fails and the limits are within requirements in 7.15, the correlation ratio correction shall be used to continue the test. If efficiency is outside the limits, the test shall not be allowed.

The particulate efficiency *E* for a given particle size range (between two particle diameters) shall be calculated as follows:

$$E = 1 - \frac{N_\text{d}}{DR \times N_\text{u}} \tag{13}$$

where

N_d is the number of particles in the size range “i” downstream of filter;

N_u is the number of particles in the size range “i” upstream of filter;

DR is the dilution ratio.

$$DR = \frac{N_\text{real}}{N_\text{counted}} \tag{14}$$

The initial particulate efficiency data versus the particle size shall be presented in a table. A graph may be also added if required. Such graph must have x-axis in logarithmic scale while y-axis must cover the 0 %–100 % range. The size range diameter or the mean diameter d_i is the geometric average of the lower and upper border diameters in the size range “i”:

$$d_\text{i} = \sqrt{d_\text{l} \times d_\text{u}} \tag{15}$$

where

d_l is the lower border diameter in the size range;

d_u is the upper border diameter in the size range.

The aerosol generator output is adjusted to generate a stable concentration of aerosol within the OPC coincidence level requirements and such that the downstream count rate is sufficient for a statistically valid result within an acceptable time scale. The upstream concentration should be diluted to an acceptable degree so coincidence error on the upstream measurement will be within the requirements of the OPC. The downstream particle concentration accuracy should be evaluated with applicable counting statistics; see Clause 10 for counting statistics.

The particulate efficiency measurement is done by a series of at least 13 counts of a minimum 20 s conducted successively upstream and downstream of the filter under test and with a purge before each count, or with one intervening sample upstream or downstream without counting, in order to stabilize the concentration of particles in the transfer lines.

The counting cycle for size range “i” will then be as in Table 5.

Table 5 — Counting cycle for a size range “i”

Count no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Upstream	$N_{u,1,i}$		$N_{u,2,i}$		$N_{u,3,i}$		$N_{u,4,i}$		$N_{u,5,i}$		$N_{u,6,i}$		$N_{u,7,i}$
Downstream		$N_{d,1,i}$		$N_{d,2,i}$		$N_{d,3,i}$		$N_{d,4,i}$		$N_{d,5,i}$		$N_{d,6,i}$	

The first single particulate efficiency $E_{1,i}$ for size range ”i” shall be calculated as follows:

$$E_{1,i} = 1 - \frac{N_{d,1,i}}{\frac{DR \times (N_{u,1,i} + N_{u,2,i})}{2}} \tag{16}$$

The 95 % confidence level for the first single particulate efficiency $E_{1,i}$ for size range ”i” (accuracy 95 %) shall be calculated as follows:

$$CL_{E1,i} = 1 - \frac{CL_{N\,d,1,i}}{DR \times \frac{(CL_{N\,u,1,i} + CL_{N\,u,2,i})}{2}} \tag{17}$$

where

CL_{Nd} is the number of particles in upper confidence limit of the size range “i” downstream of filter;

CL_{Nu} is the number of particles in the lower confidence limit of the size range “i” upstream of filter.

$CL_{El,i}$ is the minimum average particulate efficiency (95 % confidence level)

The 13 measurements give six single efficiency ($E_{1,i}$, ..., $E_{6,i}$) and ($CL_{E1,i}$, ..., $CL_{E6,i}$) results for the mean as well as for the upper confidence level. The average particulate efficiency $\bar{E}_i$ shall be calculated for the size range ”i” as follows:

$$\bar{E}_i = \frac{\left(E_{1,i} + \ldots + E_{6,i}\right)}{6} \tag{18}$$

and the minimum average particulate efficiency (with 95 % confidence level), see 10.2.

$$\overline{CL_{E\,i}} = \frac{\left(CL_{E1,i} + \ldots + CL_{E6,i}\right)}{6} \tag{19}$$

Dual particle counter systems with simultaneous upstream and downstream sampling are also allowed.

In that case there will be an equal number of upstream and downstream counts. Formula (20) shall be used instead of Formula (16). Here measurement no. 13 is not required ($N_{u,7,i}$), see Table 5, since the measurements upstream and downstream are measured at the same time.

Equation for efficiency (dual particle counters):

$$E_{1,i} = 1 - \frac{N_{d,1,i}}{(N_{u,1,i}) \times DR} \tag{20}$$

For the 95 % confidence level calculation Formula (21) replaces Formula (17):

$$CL_{E1,i} = 1 - \frac{CL_{N\,d,1,i}}{DR \times (CL_{N\,u,1,i})} \tag{21}$$

9.4 Conditioning test

Separate media (samples) of the same identity as the media in the filter used for the main test shall be tested according to Annex A. Filters shall be tested against DEHS in size range 0,3 µm to 3,0 µm.

9.5 Dust loading

9.5.1 Method for medium and high efficiency filters (initial particulate efficiency ≥35 % at 0,4 µm)

Filters with medium or high particulate efficiency (higher performance class) shall be tested according to the following:

- measurement of initial DEHS efficiencies from 0,3 µm to 3,0 µm for the filter (9.3.1);
- measurement of conditioned efficiency (Annex A) with DEHS aerosol in range 0,3 µm to 3,0 µm for media;
- two-step loading with ISO 12103-A2 dust (140 mg/m^3) up to 625 Pa (2,5 inch WG) final test pressure drop according to the loading procedure in 9.5.3 for filter;
- test of DEHS particulate efficiency after each dust loading-step according to 9.5.4 for the filter;
- determination of gravimetric efficiency according to the loading procedure in 9.5.3.

9.5.2 Method for low efficiency filters (initial particulate efficiency <35 % at 0,4 µm)

Filters with low initial particulate efficiency (<35 % at 0,4 µm) shall be tested according to 9.5.1 with the following change: After loading up to 375 Pa (1,5 in WG) final test pressure drop, the filters may be tested up to 625 Pa (2,5 inch WG) final test pressure drop for comparison purposes.

9.5.3 Loading procedure

The test rig shall have a final filter installed that is weighed prior to starting the test installed. The test filter is progressively loaded with the standardized test dust (ISO dust). Dust increments are weighed to ±0,1 g and placed in the dust tray. The ISO fine dust shall be fed at a concentration of 140 mg/m^3 (4,0 g/1 000 ft^3) until final test pressure drop is attained. Once dust loading is started, interruptions in the airflow may change the filter characteristics such as pressure drop. Once dust loading is started, the airflow through the filter shall not be interrupted until the loading procedure is completed except as required in this procedure (for example: for the efficiency measurement at 50 grams).

The dust shall be loaded in two phases, starting with a 50 g dust load increment in order to allow for one measurement of efficiency in between initial state and the fully loaded filter. The second efficiency should be measured after one dust-loading step of 50 g of ISO fine dust. At this point the measurement of the gravimetric efficiency (A_{50}) is done. For the medium and high efficiency filters the pressure drop shall be recorded at 375 Pa (1,5 in WG) for comparison purposes.

Before stopping dust feeding, brush whatever dust remains in the feeder tray to the dust pickup tube so that it is entrained in the duct airflow. Vibrate or rap the dust feeder tube for 30 s. The dust fed to the filter could also be estimated by weighing the remaining dust in the feeder. With the test airflow on, re-entrain any synthetic dust in the duct upstream of the filter by the use of a compressed air jet directed obliquely away from the tested filter. After reaching the final test pressure drop, stop the test and reweigh the final filter (to at least 0,5 g accuracy) to determine the amount of synthetic dust collected. Any dust deposited in the duct between the filter and the final filter should be collected with a fine brush and included in the final filter mass.

The mass increase of the final filter indicates the mass of dust that has passed the test filter. The gravimetric efficiency A during the dust loading shall be calculated as follows:

$$A_{50} = \left(1 - m_{\mathrm{p50}} / m_{50}\right) \times 100 \ \ [\%] \tag{22}$$

where

m_{p50} is the mass of dust that has passed the filter (the mass gain of final filter and the dust in the duct between the filter and the final filter) after 50 g of dust loading;

m_{50} is the mass of dust fed during the first dust loading (50 g).

The test dust capacity (TDC) for final test pressure drop is the difference between m_{tot} and m:

$$\mathrm{TDC} = m_{\mathrm{tot}} - m \tag{23}$$

where

m_{tot} is the total mass of dust fed up to the final test pressure drop;

m is the total mass of dust that has passed the filter through the full test (final test pressure drop).

9.5.4 Efficiency of dust loaded filter

The loaded efficiency shall be determined as follows.

a) Particulate efficiency values shall be recorded after 50 g of ISO dust and after dust loading the test filter to the final test pressure drop.

b) Gravimetric efficiency values shall be recorded after dust loading the test filter to 50 g.

Especially after dust loadings, there may be a release of particles (shedding of particles) downstream of the filter, which will influence particulate efficiency. To adjust for that dust migration the airflow shall be maintained through the device for 20 min before testing particulate efficiency. A period of less than 20 min is allowable if a re-entrainment of no more than 5 % is obtained in each of the particle size ranges.

At a re-entrainment more than 5 %, the particle measurement can be done after adjusting the upstream concentration to a higher value in order to reduce the influence of particles from shedding. In that case the report shall include a remark that the upstream concentration has been adjusted for release of particles. (High concentrations upstream will reduce this problem.)

The particulate efficiency measurement is done in the same way as for initial particulate efficiency (9.3.1) by a series of at least 13 counts of a minimum of 20 s conducted successively upstream and downstream of the filter under test.

10 Uncertainty calculation of the test results

10.1 Particulate efficiency for medium efficiency filters (initial particulate efficiency: 35 ≤ E ≤ 85 % at 0,4 µm)

The uncertainty on the average particulate efficiency as defined corresponds to a two-sided confidence interval of the average value based on a 95 % confidence level. An upstream sample of no less than 500 particles shall be counted in evaluated size ranges up to 5 µm, in accordance with ISO 2854:

$$\overline{E}_{\mathrm{i}} = U \le \overline{E}_{\mathrm{i}} \le \overline{E}_{\mathrm{i}} + U \tag{24}$$

$$\bar{E}_{\mathrm{i}} = \frac{1}{N} \sum E \tag{25}$$

$$U = t_{(1-\alpha/2)} \times \frac{\delta}{\sqrt{N}} \tag{26}$$

$$\nu = N - 1 \tag{27}$$

$$\delta = \sqrt{\frac{\sum (E \cdot \bar{E}_{\mathrm{i}})^2}{N-1}} \tag{28}$$

where

$\bar{E}_{\mathrm{i}}$	is the average particulate efficiency in size range “i”;
U	is the uncertainty;
E	is the calculated single value of the particulate efficiency in size range “i” (E_1, E_2, ... see 9.3.1);
ν	is the number of degrees of freedom;
$t_{(1-\alpha/2)}$	is the student’s distribution, depending on the number of degrees of freedom ν (see Table 6);
N	is the number of calculated single particulate efficiency values E_{i} ;
δ	is the standard deviation.

The uncertainty is calculated for each size range “i”.

Table 6 — Student’s distribution according to ISO 2854

Samples N	**Number of degrees of freedom** $\nu = N - 1$	**Uncertainty** $t_{(1-\alpha/2)} \times \frac{1}{\sqrt{N}}$
4	3	1,591
5	4	1,242
6	5	1,049
7	6	0,925
8	7	0,836
NOTE 95 % confidence level (α = 0,05).		

10.2 Particulate efficiency for high efficiency filters (initial particulate efficiency >85 % at 0,4 µm)

The particle counting is subject to statistical variation. The smaller the number of events that are counted, the lower the level of confidence. The level of confidence can be estimated by the use of Poisson distribution. Table 7 gives limits for the two-sided 95 % confidence interval for a given number of events using the Poisson distribution. Thus, if 5 particles are counted the table 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 in terms of the number counted. For larger numbers the Poisson distribution turns into symmetrical normal distribution. In these cases the 95 % interval can be calculated by:

$$N_{95\%} = N \pm 1{,}96 N^{1/2} \tag{29}$$

Where N is the number of particles counted.

Table 7 — Upper and lower limit of the 95 % confidence interval of a Poisson distribution for particle numbers

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

The 95 % confidence level for the first single particulate efficiency $E_{1,\mathrm{i}}$ for size range “i” (accuracy 95 %) shall be calculated as follows:

$$CL_{\mathrm{E}1,\mathrm{i}} = 1 - \frac{CL_{\mathrm{N\,d},1,\mathrm{i}}}{DR \times \frac{(CL_{\mathrm{N\,u},1,\mathrm{i}} - CL_{\mathrm{N\,u},2,\mathrm{i}})}{2}} \qquad (30)$$

where

CL_{Nd}	is the number of particles in **upper confidence limit** of the size range “i” downstream of filter;
CL_{Nu}	is the number of particles in the **lower confidence limit** of the size range “i” upstream of filter;
$CL_{\mathrm{El},\mathrm{i}}$	is the minimum average particulate efficiency (95 % confidence level).

The 13 measurements give six single particulate efficiency ($E_{1,\mathrm{i}}$, ..., $E_{6,\mathrm{i}}$) and ($CL_{\mathrm{E}1,\mathrm{i}}$, ..., $CL_{\mathrm{E}6,\mathrm{i}}$) results for the lower 95 % confidence level. The minimum average efficiency (with 95 % confidence level) is calculated in analogy with 9.3.2.

$$\overline{CL}_{\mathrm{E}1,\mathrm{i}} = \frac{\left(CL_{\mathrm{E}1,\mathrm{i}} + \ldots + CL_{\mathrm{E}6,\mathrm{i}}\right)}{6} \qquad (31)$$

In the case of dual particle counters:

For the 95 % confidence level calculation, Formula (32) replaces Formula (30):

$$CL_{\mathrm{E}1,\mathrm{i}} = 1 - \frac{CL_{\mathrm{N\,d},1,\mathrm{i}}}{DR \times CL_{\mathrm{N\,u},1,\mathrm{i}}} \qquad (32)$$

10.3 Gravimetric efficiency

The gravimetric efficiency is a value obtained from the measurement of the mass of dust that has passed the test filter. The maximum gravimetric efficiency that can be stated is 99 %. Higher values shall be reported as >99 %.

11 Reporting

11.1 General

The test report shall include an explanation of the test results and a description of the test method and any deviations from it. The type and identification number of the particle counter used should be reported, as well as the method of airflow rate measurement. The report shall include the following:

- the interpretation of test reports, as detailed in 11.2;
- summary of the results;
- measured efficiencies and their uncertainties;
- data and results of airflow rate and test pressure drop measurements.

Test results shall be reported using the test report format presented in this standard. Figures 15 and 16 and Tables 9 to 13 comprise the complete test report and are examples of acceptable forms. Exact formats are not requested, but the report shall include all items shown. The legend of each table and graph should preferably include the following:

- type of filter;
- the number of this standard;
- test number;
- test aerosol and loading dust;
- test airflow rate.

11.2 Interpretation of test reports

This brief digest shall be included in the test reports and summary reports. This shall be included after the issued report and shall be a one-page addition with the text sized to fill the page.

The interpretation of test reports

This brief review of the test procedures, including those for addressing the testing of electrostatically charged filters, is provided for those unfamiliar with this ISO procedure. It is intended to assist in understanding and interpreting the results in the test report/summary.

Many types of air filter rely on the effects of passive electrostatic charge on the fibres to achieve high efficiencies, particularly in the initial stages of their working life. Environmental factors encountered in service may affect the action of these electrostatic charges so that the initial particulate efficiency may drop substantially after an initial period of service. In many cases this is offset or countered by an increase in efficiency ("mechanical efficiency") as dust deposits build up to form a dust cake. In the later stages of operating life the efficiency may increase to equal or exceed the initial efficiency. The reported, untreated and conditioned (discharged) efficiency shows the extent of the electrostatically charge effect on initial performance and indicates the level of efficiency reachable when the charge effect is completely removed and there is not a compensating increase of the mechanical efficiency.

The reported untreated and conditioned (discharged) efficiencies show the extent of the electrostatically charge effect on initial performance. It should not be assumed that the measured conditioned (discharged) particulate efficiency represents real life behaviour. It merely indicates the level of efficiency obtainable with the charge effect completely removed and with no compensating increase in mechanical efficiency.

For reasons of consistency filter efficiencies are measured using artificially generated dust clouds of synthetic dusts with closely controlled particle size. The test dust selected for testing a given filter depends on its initial filtration particulate efficiency with respect to 0,4 µm liquid droplets

The particulate efficiency measurements are repeated after the filter has been loaded with ISO fine loading dust until the resistance has risen to a value of 375 Pa in the case of test of low efficiency filters, and up to a value of 625 Pa for the medium and high efficiency filters.

Test dust capacities measured in this way should not be assumed to simulate real life operating conditions as the properties of dusts encountered in service conditions vary very widely. Comparative performances and rankings may be established, but it should always be borne in mind it's the actual conditions on site that will determine the in-service filter performance.

11.3 Summary

When applicable the one page summary section of the performance report (Figure 15) shall include the following information:

- **General:**
  1) Testing organization;
  2) Date of test;
  3) Name of test operator;
  4) Report number;
  5) Test requested by;
  6) Name of supplier of device;
  7) Date of receiving the device.
- **Manufacturer's data of the tested device:**
  8) Description of the device;
  9) Type, identification and marking;
  10) Manufacturer of device;

11) Physical description of construction (e.g. pocket filter, number of pockets);

12) Dimensions (actual width, height and depth. In case of cylindrical cartridges the inner and outer diameter of the cartridge);

13) Type of media, if possible or available the following shall be described:

    - Identification code (e.g. glass fibre type ABC123, inorganic fibre type 123ABC);
    - Effective filtering area in device;
    - Type and amount of dust adhesive on filter media if feasible.

14) Photographs of the air entering and air leaving sides of the as received device;

15) Additional information as needed for proper filter identification.

— **Test data:**

16) Test airflow rate;

17) Test air temperature, relative humidity and barometric pressure;

18) Type of loading dust and test aerosol;

19) Initial pressure drop and final test pressure drop;

20) Pressure drop curve versus airflow rate for clean filter;

21) Table of initial particulate efficiency, conditioned efficiency and dust loaded particulate efficiency versus particle size. For all filters the particulate efficiency measurement shall use the 0,4 µm, 0,6 µm, 0,8 µm and 1,2 µm sizes. The conditioned filter efficiency is calculated from the initial filter particulate efficiency and the difference in efficiency (ΔE_C) of the media samples from the conditioning procedure. See Table 8.

Table 8 — Particulate efficiency versus DEHS-particles, example values

	Optical particle size			
Particulate efficiency	**0,4 µm**	**0,6 µm**	**0,8 µm**	**1,2 µm**
Filter				
Initial (E_0)	50 ± 2	60 ± 2	70 ± 2	80 ± 2
Conditioned ($E_0 - \Delta E_C$)	26	50	60	79
Dust loaded (50 g)	60 ± 2	75 ± 2	85 ± 2	90 ± 2
Media				
Initial	54 ± 2	63 ± 2	72 ± 2	81 ± 2
Conditioned	30 ± 2	53 ± 2	62 ± 2	80 ± 2
ΔE_C (Initial-Conditioned)	24	10	10	1

22) Gravimetric efficiency

— **Statement:**

23) The results relate only to the tested item;

24) The performance results cannot by themselves be quantitatively applied to predict filter performance in service.

In the summary report, the results shall be rounded to the nearest integer except for filters with efficiencies >95 %. The efficiency result shall be reported with a two-digit accuracy of the penetration value.

11.4 Efficiency

In addition to the summary report, when applicable, results of the efficiency measurements shall be reported both in tables and as graphs.

- **Tables:**
  1) Particulate efficiency and uncertainty at each particle size after dust loading to final test pressure drop (Table 9);
  2) Pressure drop versus airflow for clean filter (Table 10);
  3) Pressure drop and gravimetric efficiency (Table 11);
  4) Particulate efficiency and pressure drop in the conditioning test (Annex A) (Table 12 and Table 13).
- **Graphs:**
  1) Initial and dust loaded particulate efficiency (final test pressure drop) versus particle size (Figure 16).

11.5 Pressure drop and airflow rate

When applicable all required data and results of the airflow rate and pressure drop measurements throughout the complete test shall be reported in table format. The pressure drop curve for the clean filter is reported in the summary section.

The airflow shall be reported as measured while the pressure drops shall be corrected to an air density of 1,20 kg/m^3 if required in accordance with 10.2. The corrections can be made as described in Annex D.

11.6 Marking

The filter shall be marked with a type identifying marking. The following details shall be provided:

- Name, trade mark or other means of identification of the manufacturer;
- Type and reference number of the filter;
- Number of this standard;
- Flow rate at which the filter has been tested.

If the correct mounting cannot be deduced, marking is necessary for correct fitting in the test duct (e.g. ”top”, ”direction of flow”).

The marking shall be as clearly visible and as durable as possible.

ISO 29461-1		
Testing organization:		**Report #:**
GENERAL		
Test no.:	Date of test: yyyy-mm-dd	Supervisor:
Test requested by:		Device receiving date: yyyy-mm-dd
Device supplied by:		
DEVICE TESTED		
Model:	Manufacturer:	Construction:
Type of media:	Effective filtering area:	Actual filter dimensions ($W \times H \times D$):

TEST DATA			
Test airflow rate:	Test air temp:	Test air relative humidity: %	Test aerosol: **DEHS** Loading dust: **ISO 12103-A2**

RESULTS				
Initial pressure drop:	**Final test pressure drop:**	A_{50} (gravimetric efficiency at 50g):	**Test dust capacity**	**Remark:**

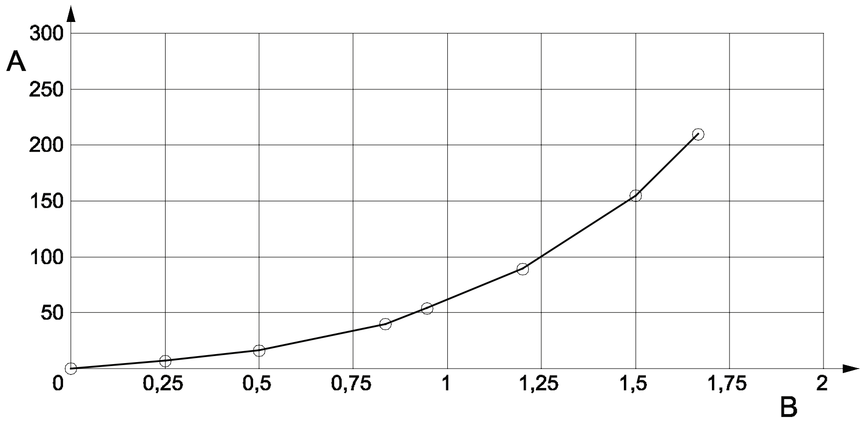
Efficiency versus DEHS-particles

	Particle Size[b]			
Efficiency	**0,4 µm**	**0,6 µm**	**0,8 µm**	**1,2 µm**
Filter				
Initial (E_0)	±	±	±	±
Conditioned[a] (Initial - ΔE_C)				
Dust loaded 50g	±	±	±	±
Dust loaded (final dp)	±	±	±	±
Media				
Initial	±	±	±	±
Conditioned	±	±	±	±
ΔE_C (Initial-Conditioned)				

[a] The conditioned filter efficiency is calculated from the media test: conditioned efficiency (filter) = E_0 (filter) - ΔE_C

[b] See the attached Interpretation of Test Report.

Pressure vs. airflow



Key

A pressure drop

B airflow

NOTE The performance results are only valid for the tested item and cannot by themselves be quantitatively applied to predict filter performance in service.

Figure 15 — Summary section of performance report

Table 9 — Initial particulate efficiency and loaded particulate efficiency inclusive of uncertainty

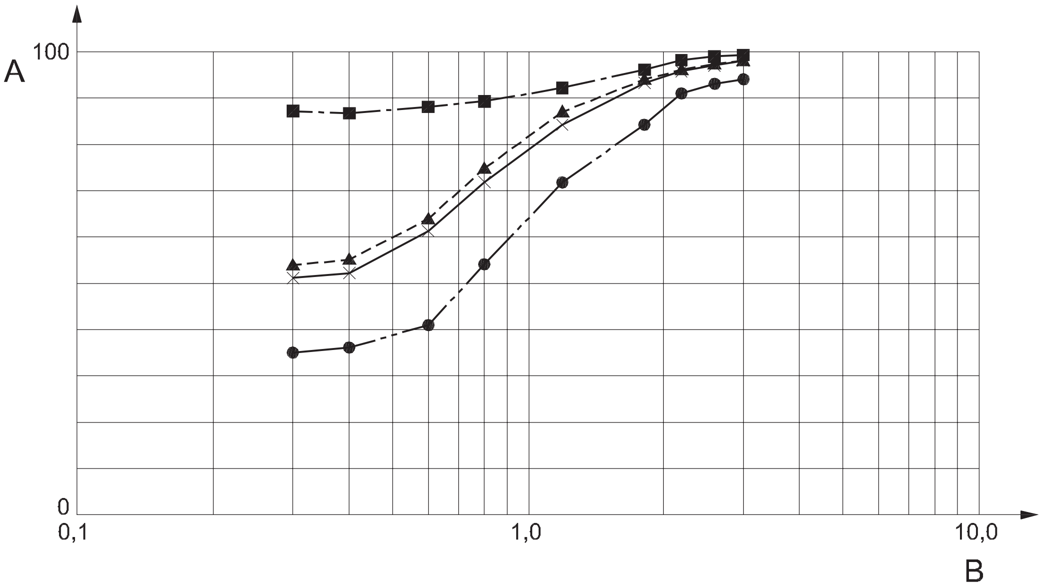
ISO 29461-1, Initial and loaded efficiency incl. uncertainty					
Air filter:					
Test no.:					
Test aerosol:					
Air flow rate:					
Particle size (µm)		**Efficiency** %			
		Pressure drop and dust fed			**Remark**
Interval	**Mean**	Pa (in WG) 0 g	Pa (in WG) 50 g	Final Pa (in WG) g	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
-		±	±	±	
NOTE The uncertainty of the measured efficiencies is reported on a 95 % confidence level.					

Report any correction of efficiency based on release of particles from filter.

Air filter.......................

Initial and dust loaded particulate efficiency

ISO 29461-1



Test no: ....

Test aerosol: ....

Loading dust: ....

Airflow rate: ....

Final test pressure drop: ....

Key

A	Efficiency (%)
B	Particle size (µm)
—×—	Initial
▲- - -	50 g
■-·—	Final pressure drop
●-·-—	Conditioned

Figure 16 — Initial and dust loaded efficiencies

Table 10 — Airflow rate and pressure drop of clean filter

ISO 29461-1 – Airflow rate and pressure drop of clean filter												
Air filter:												
Test no.:												
Airflow rate:												
Date		**Airflow meter**				**Filter**						
		T_f °C	p_{sf} kPa	Δp_f Pa	q_m kg/m^3	T °C	φ %	p_a kPa	ρ kg/m^3	q_v m^3/s	Δp Pa	$\Delta p_{1,20}$ Pa
	Clean filter											
yyyy-mm-dd												
	Clean filter pressure drop is proportional to $(q_v)^n$, where n =											

Symbols and units			
p_a	Absolute air pressure upstream of filter, kPa	T_f	Temperature at airflow meter, °C
p_{sf}	Airflow meter static pressure, kPa	ρ	Air density upstream of filter, kg/m^3
q_m	Mass flow rate, kg/m^3	φ	Relative humidity upstream of filter, %
q_v	Airflow rate at filter, m^3/s	Δp	Measured filter pressure drop, Pa
T	Temperature upstream of filter, °C	Δp_f	Airflow meter differential pressure, Pa
		$\Delta p_{1,20}$	Filter pressure drop at nominal air density of 1,20 kg/m^3, Pa

Table 11 — Pressure drop and Gravimetric efficiency after dust loading to final test pressure drop

ISO 29461-1 – Pressure drop and gravimetric efficiency after dust to final test pressure drop									
Air filter:									
Test no.:									
Type of loading dust:									
Airflow rate:									
Date	Δp_1 Pa (in WG)	Δm g	m_{tot} g	Δp_2 Pa (in WG)	m_1 g	m_2 g	Δm_{ff} g	m_d g	A %
yyyy-mm-dd									
yyyy-mm-dd									
yyyy-mm-dd									
yyyy-mm-dd									
yyyy-mm-dd									
yyyy-mm-dd									
Mass of tested device									
Initial mass of tested device:			g						
Final mass of tested device:			g						
Symbols and units									
Gravimetric efficiency, A_{50} [%]									
Dust in duct after device, m_d [g]									
Cumulative mass of dust fed to filter, m_{tot} [g]									
Mass of final filter before dust increment, m_1 [g]									
Mass of final filter after dust increment, m_2 [g]									
Dust increment, Δm [g]									
Mass gain of final filter, Δm_{ff} [g]									
Pressure drop before dust increment, Δp_1 [Pa]									
Pressure drop after dust increment, Δp_2 [Pa]									

Table 12 — Particulate efficiency and pressure drop of untreated filter material

ISO 29461-1 – Efficiency and pressure drop of untreated filter material								
Air filter:								
Test no.:				Test aerosol:				
Airflow rate:				Media velocity:				
Size of material sample:								
Particle size (µm)		**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Average**	
		Efficiency (%)						
		Pressure drop						
Interval	**Mean**	Pa (in WG)	Pa (in WG)	Pa (in WG)	Pa (in WG)	Pa (in WG)	Pa (in WG)	
-		±	±	±	±	±		
-		±	±	±	±	±		
-		±	±	±	±	±		
-		±	±	±	±	±		
-		±	±	±	±	±		
NOTE The uncertainty of the measured efficiencies is reported on a 95 % confidence level								

Table 13 — Particulate efficiency and pressure drop of conditioned filter material

ISO 29461-1 – Efficiency and pressure drop of treated filter material								
Air filter:								
Test no.:				Test aerosol:				
Airflow rate:				Media velocity:				
Size of material sample:								
Particle size (µm)		**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**Average**	
		Efficiency (%)						
		Pressure drop						
Interval	**Mean**	Pa (in WG)	Pa (in WG)	Pa (in WG)	Pa (in WG)	Pa (in WG)	Pa (in WG)	
-		±	±	±	±	±		
-		±	±	±	±	±		
-		±	±	±	±	±		
-		±	±	±	±	±		
-		±	±	±	±	±		
NOTE The uncertainty of the measured efficiencies is reported on a 95 % confidence level								

Annex A

(normative)

Conditioning test procedure

A.1 General

This procedure is used to determine whether the filter particulate efficiency is dependent on the electrostatic removal mechanism and to provide quantitative information about the importance of the electrostatic removal. This is accomplished by measuring the removal efficiency of an untreated filter material and the corresponding efficiency after the effect of the electrostatic removal mechanism has been eliminated or inhibited.

Many types of air filter rely to different extents on the effects of passive electrostatic charges on the fibres to achieve high efficiencies, particularly in the initial stages of their working life, at low resistance to airflow. Exposure to some types of challenge, such as combustion particles, fine particles or oil mist in service may affect the action of these electric charges so that the initial efficiency may drop substantially after an initial period of service. In some cases this is offset or countered by an increase in efficiency ("mechanical efficiency") as dust deposits build up to form a dust cake. In the later stages of operating life the efficiency may increase to equal or exceed the initial efficiency.

The procedure described here quantitatively shows the extent of the electrostatic charge effect on the initial performance on a sample of the filter medium. It indicates the level of efficiency obtainable with the charge effect completely removed and with no compensating increase in mechanical efficiency. Also, the influence of the converted three-dimensional filter structure is not covered by the procedure described here. It should not be assumed that the measured conditioned (discharged) efficiency always represents real life behaviour. The chemical treatment of a filter medium described below may affect the structure of the fibre matrix or chemically affect the fibres or even fully destroy the filter medium. Hence, the procedure described below may not be applicable to all types of filter media.

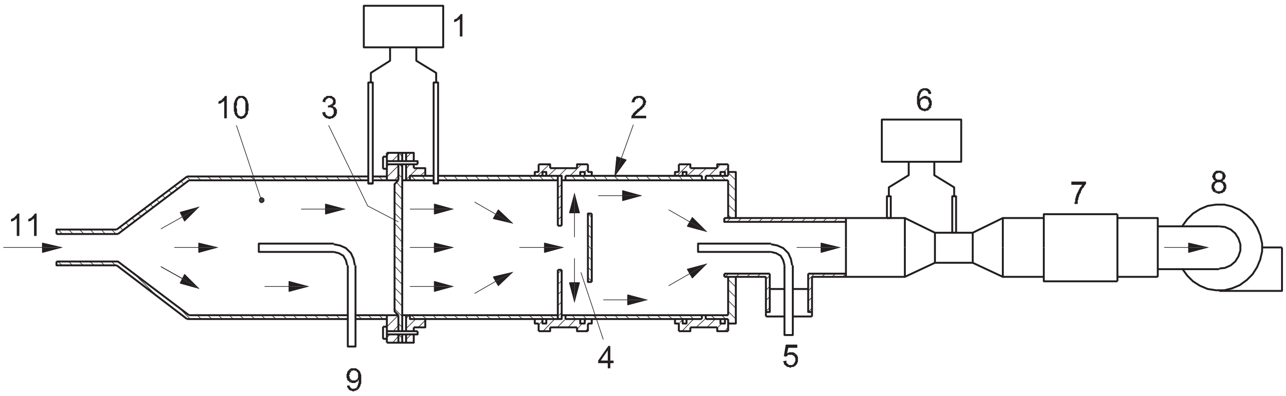
A.2 Test method for conditioning of filter material

A.2.1 Equipment

The described procedure is based on a Standardized treatment with isopropanol (IPA) to evaluate electrostatic influence on filter particulate efficiency.

The isopropanol test is made by first measuring the particulate efficiency of untreated media samples. Next, the samples are treated with IPA vapour (>99,9 % technical grade). If IPA is reused the IPA purity must remain above 99,9 %. After filter samples have been exposed to the IPA vapour, they are placed on a flat, inert surface in a fume cupboard for drying. After the drying period of 15 min the particulate efficiency measurements are repeated. To verify that sample is free from residual IPA the sample is purged for 30 min with clean dry air and the particulate efficiency test is repeated.

The principle of the filter material test equipment is shown in Figure A.1. This system consists of a test duct, a flow meter, a flow control valve, a (downstream) sampling tube and a manometer. The filter sample to be tested is fixed to the test tube by means of a flange. The test tube also includes a mixing section, which ensures a representative sampling downstream of the filter. The sampling tubes are connected to the sampling system of the optical particle counter. Air and test aerosol could be taken from the main duct system, which means that the normal aerosol generation system can be used.

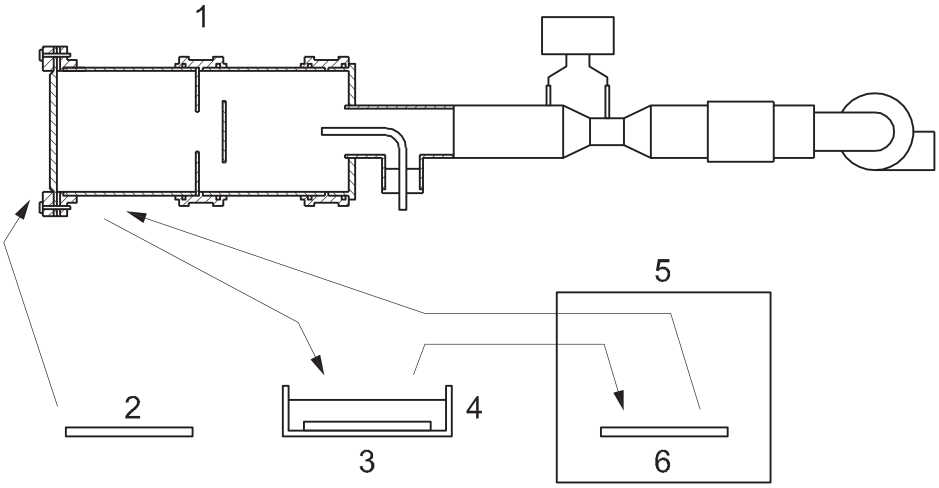


Key

1	manometer	7	flow control
2	test duct	8	fan
3	filter sample	9	upstream sampling
4	mixing section	10	upstream duct
5	downstream sampling	11	aerosol
6	flow meter		

Figure A.1 — Filter material test equipment

The isopropanol vapour treatment is made using the system shown in Figure A.2. This system includes a vessel for the isopropanol. The system also includes flat perforated surfaces on which filter samples are placed for drying. The drying of the filter samples should take place in a laboratory fume cupboard.



Key

1	efficiency measurement
2	filter sample
3	isopropanol treatment
4	isopropanol vessel
5	fume cupboard
6	drying

Figure A.2 — Principle of the isopropanol test system

A.2.2 Preparation of test samples

A minimum of three media samples shall be tested. And the total surface of the samples must be ≥600 cm^2. Representative samples shall be supplied by the customer or selected from a second filter, identical with the filter used in the main test. Samples from the filter shall be selected (e.g. by cutting) in such a way that they represent the complete filter. The locations where media samples are to be cut shall be randomized. If flat samples cannot be cut from the filter a small piece from the filter shall be cut out and sealed into a frame fitting into the test system.

Each effective media sample area should be ≥200 cm^2 (0,215 ft^2) and must be ≥100 cm^2 (0,1 075 ft^2). The media area samples could be extended to get more representative samples of the filter but effective media size shall be maximum 0,61 m × 0,61 m (24 in × 24 in).

A.2.3 Measurement of the filter medium efficiency

The test is started by mounting the filter sample in the test equipment. The velocity through the filter sample is adjusted to be the same as the nominal media velocity used in the filter (using effective filtering area). The filter 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 sample. The criteria for test aerosol, size range and particulate efficiency measurement are made according to the main body of this standard.

A.2.4 Isopropanol vapour treatment test

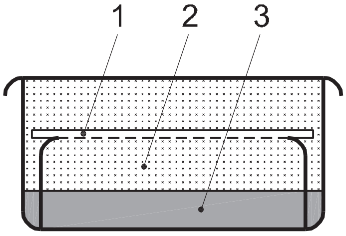
The isopropanol vapour exposure test is carried out as follows:

- Initial particulate efficiency and pressure drop values of the filter samples are measured.
- Filter samples are treated (exposed) with isopropanol vapour for 24 h, see A.2.5.
- Filter samples are placed on a flat inert surface for drying (this should take place in a laboratory fume cupboard). To allow quick evaporation of the IPA the samples should 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 more than ±3 percentage points or the pressure drop has changed by more than ±5 Pa (±0,2 in WG), 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.

A.2.5 Isopropanol vapour treatment method

- The allowed temperature range for the test container and the ambient air is +20 °C to +30 °C.
- 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 40–80 % RH.
- Add IPA into containers to about 10 mm in depth. Well above the liquid surface, place a screen to hold the sample media.
- 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 (see A.2.4).



Key

1 sample

2 IPA vapour

3 liquid IPA

Figure A.3 — Principle of the isopropanol container (vessel and lid)

Isopropanol vessel:

— executor (container with IPA);

— holder with filter media.

A.3 Expression of results

The average efficiencies of the untreated and conditioned filter samples are calculated. The average initial particulate efficiency of the media samples is compared with the initial particulate efficiency measured at the entire filter. If these two efficiencies differ more than 5 percentage points, more media samples shall be tested and the results included in the average calculation of the initial particulate efficiency of the media samples until the two values differ less than 5 percentage points. If this goal can not be reached, a corresponding remark must be made in the test report. The average efficiencies of the untreated and conditioned filter samples are reported together with the aerosol and size range. (DEHS, 0,3 µm to 3 µm). The difference in particulate efficiency from the media tests (initial – conditioned) are calculated by:

$$\Delta E_\mathrm{C} = \text{initial media particulate efficiency } (\mathrm{E}_0) - \text{conditioned media efficiency } [\%] \quad (33)$$

This difference is then used to calculate the conditioned filter efficiency by:

$$\text{conditioned filter efficiency} = E_0 - \Delta E_\mathrm{C} \quad (34)$$

Annex B
(informative)

Shedding from filter elements

The term “shedding” comprises three separate aspects of filter behaviour: re-entrainment of particles, particle bounce and release of fibres or particulate matter from the filter material. Some or all of these phenomena are likely to occur to some extent during the life cycle of an installed filter, especially in dry weather conditions.

Literature about shedding and its effect on filter performances can be found in Bibliography references[14],[16],[17],[18],[19] and.[20]

B.1 Shedding

B.1.1 Re-entrainment of particles

As the quantity of the arrested dust on the filter increases, the following effects may lead to re-entrainment of already captured particles into the air stream:

— An incoming particle may impact on a captured particle and re-entrain it into the air stream.

— The air velocity in the channels through the medium will increase because of the space occupied by captured particles. Furthermore, the filter medium may become compressed by the increased resistance to airflow thereby causing even further increase in velocity in the air channels. The consequent increased fluid drag on deposited particles may re-entrain some of them.

— Movements of the filter medium during operation cause re-arrangement of dust in the filter medium structure. This leads to an immediate re-entrainment of dust. Filter media movements can be caused by a variety of circumstances such as:

1) normal airflow through the filter;

2) periodic (e.g. daily) start/stop operation of the air conditioning plant;

3) varying airflow rates, caused by airflow control;

4) mechanical vibration, caused by the fan or other equipment.

Re-entrainment of particles may be measured and quantified (see Bibliography references[3] and[4]).

This effect is more pronounced for low efficiency filters than for high efficiency filters.

B.1.2 Particle bounce

In an ideal filtration process, each particle would be permanently arrested at the first collision with a filtering surface such as a fibre, or with an already captured particle. For small particles and low air velocities, the energy of adhesion greatly exceeds the kinetic energy of the airborne particle in the air stream, and once captured, such particles are very unlikely to be dislodged from the filter. As particle size and air velocity increase, this is progressively less so; larger particles may “bounce” off a fibre. Thereby they normally lose enough energy to be captured in a subsequent collision with a fibre. However, if no contact with a fibre follows, the particle will be shed, i.e. discharged from the filter, which will result in a corresponding reduction of efficiency for particles of this size range (see Bibliography references[1] and[2]).

A measurement method to quantify this type of shedding is defined in ASHRAE 52.2:1999, using solid KCl particles of relatively big size (>3 µm). Using liquid aerosol, the particle bounce effect cannot be measured at all.

The particle bounce effect is more pronounced for low efficiency filters than for high efficiency filters.

B.1.3 Release of fibres or particulate matter from filter material

Some designs of filter include filter media either containing or generating loose fibres or particulate matter from the filter design materials (e.g. binder). During constant volume filter operation, but especially during variable flow or start-stop operation, these materials can be lost into the air stream. The extent of such shedding depends on the integrity of the media fibre structure and its rigidity and stability in the face of varying air velocities, as well as the stability of the filter design materials (e.g. the binder which holds fibres together), throughout the operating life of the filter. It should be noted, however, that the quantity of fibres or particulate matter shed in this way is normally negligible in comparison with the total amount of dust penetrating through a filter loaded by typical environmental dust burden (see Bibliography references[5] and[6]).

B.2 Testing of shedding effects

Users should be aware of the possibility of filters exhibiting shedding behaviour in practical use. From the user's point of view it would be advantageous to detect any shedding behaviour of a filter. However, such measurements are not that easy to perform.

The gravimetric efficiency measurements for low efficiency filters prescribed in this standard reflect the above described shedding effects only partly, if at all. However, any drop in the value of the gravimetric efficiency or resistance during the course of a filter loading test should be taken as a serious indication that shedding may have occurred.

The particulate efficiency results for higher efficiency filters provided in this standard reflect normally none of the above described shedding effects, as the aerosol used for these filters is a liquid (DEHS) aerosol. Membrane sampling downstream of filters and microscopic analyses of the membranes could determine occurrence of this type of shedding, but such a method is not defined here.

Annex C
(informative)

Commentary

C.1 General

The procedures described in this standard have been developed from those given in ISO/TS 21220. The following gives a brief description of the principles of the test methods and procedures contained in this standard.

C.2 Principle of the test method

C.2.1 Basic

The test is designed for airflow from 0,25 m^3/s (900 m^3/h) up to 1,67 m^3/s (6000 m^3/h). Filter classification is made at air test flow rate specified by the manufacturer.

Two efficiency measurement methods are used in the standard: the “particulate efficiency” and “gravimetric efficiency”. Samples from filter shall be conditioned (discharged) to provide information about the intensity of the electrostatic removal mechanism. Two filters of same quality are needed; one for the main filter test and one for media samples (or partial/complete filter) for the electrostatic condition (discharge) test.

After the determination of the initial particulate efficiency, the filters are loaded with dust in two steps up to final test pressure drop. This may give information of the shedding behaviour of the filter as well as test dust capacity and filtration efficiency with respect to the loading dust (gravimetric efficiency). The measurement methods use different particle size ranges, loading dusts and final test pressure drops.

Table C.1 — Summary of test methods

Test method	**Size range**	**Test aerosol**	**Conditioning**	**Loading dust in two steps (first step 50 g)**	**Final test pressure drop** Pa (in WG)
Particulate efficiency	0,3 µm – 3,0 µm	DEHS	Yes	ISO fine (140 mg/m^3) (4,0 g/1 000 ft^3) [two steps]	625 (2,5)
Gravimetric efficiency	ISO 12103-A2	ISO 12103-A2	Yes	ISO fine (140 mg/m^3) (4,0 g/1 000 ft^3) [two steps]	375 (1,5)

C.2.2 Size range

One size range is used, 0,3 µm to 3,0 µm for particulate efficiency measurement. Gravimetric efficiency (mass) is mostly important for filters with lower efficiency.

C.2.3 Test aerosol

High efficiency filters are not noticeably influenced by the type of test aerosol (liquid/solid). The DEHS aerosol shall be used undiluted without any charge on the particles (charging or neutralization). The aerodynamic, geometric and light scattering sizes are close to each other when measured with optical particle counters. The DEHS (or equivalent) was chosen for the following reasons:

- Easy to generate in size range with simple equipment (Laskin nozzle).
- The response time of DEHS (PAO) generator is fast and testing can start almost immediately.
- Clean to use. No corrosion problem.
- Commonly used in testing of high efficiency filters and *in situ* tests.
- Do not need radioactive source (not allowed in some countries) or corona discharge ionizer.
- Same geometric and aerodynamic particle size.
- Particulate efficiency results close to solid particles in size range 0,3 µm to 1,2 µm.
- The maintenance cost and work is low with DEHS (PAO). No need to rinse the generator, no need to calibrate any neutralizer, etc.
- In most cases DEHS (PAO) does not affect the pressure drop of the filter.

C.2.4 Loading dust

One type of dust is used - ISO fine (ISO 12103-A2). The filters are loaded to final test pressure drop in two steps. The loaded particulate efficiency is then measured to indicate any change in performance.

This loading dust is not representative of the real world, but is used to “simulate” dust loading. The loading could give information of the filter’s mechanical and aerodynamic design but there is no general correlation between synthetic dust capacity and real life capacity and the test dust capacity is not presented in the summary report. The dust loading tests can, to some extent, indicate shedding problems.

ISO “fine” dust is clean and easy to use and the specification of this dust is better defined than for the ASHRAE dust used in earlier air filter standards. The dust will indicate shedding performance better than the ASHRAE dust. The test dust capacity will increase two to five times with the ISO dust. To reduce the required test time, the loading concentration has increased from former values of 70 mg/m^3 (2,0 g/1 000 ft^3) to 140 mg/m^3 (4,0 g/1 000 ft^3).

C.2.5 Conditioning test

Certain types of filter media rely on electrostatic effects to achieve high efficiencies at low resistance to airflow. Exposure to some types of challenge, such as combustion particles, fine particles or oil mist may neutralize such charges with the result that filter efficiency can decrease over time. The exact efficiency is dependent on the media type, the actual particle content of the ambient intake air as well as other environmental factors. It is important for users of filters to be aware of the possibility of performance degradation during operational life.

This procedure is used to determine whether the filter particulate efficiency is dependent on the electrostatic removal mechanism and to provide quantitative information about the importance of the electrostatic removal. This is accomplished by measuring the removal particulate efficiency of an untreated filter material and the corresponding efficiency after the effect of the electrostatic removal mechanism has been eliminated or inhibited.

Conditioning according to the IPA method in Annex A was chosen because:

- the test indicates the minimum particulate efficiency of the filters, which could happen in real applications;
- there have been round robin tests, research works and tests confirming the uniformity of the method and its relevance;
- no or moderate increase in pressure drop of media or filters;

- many years of experience with the method;
- existing Standardized methods.

The procedure was selected because it is well established, reproducible, easily performed and relatively fast. Selection of this approach in the standard is not intended to slow or preclude the development of aerosol-based conditioning procedures by other organizations; an aerosol-based procedure may better reflect filtration changes that occur in actual use.

C.3 Interpretation of test results

This following interpretation of test results shall be included in the test report (see 11.2).

This brief review of the test procedures, including those for addressing the testing of electrostatically charged filters, is provided for those unfamiliar with this ISO procedure. It is intended to assist in understanding and interpreting the results in the test report/summary.

Many types of air filter rely on the effects of passive electrostatic charge on the fibres to achieve high efficiencies, particularly in the initial stages of their working life. Environmental factors encountered in service may affect the action of these electrostatic charges so that the initial particulate efficiency may drop substantially after an initial period of service. In many cases this is offset or countered by an increase in particulate efficiency ("mechanical efficiency") as dust deposits build up to form a dust cake. In the later stages of operating life the efficiency may increase to equal or exceed the initial particulate efficiency. The reported, untreated and conditioned (discharged) efficiency shows the extent of the electrostatically charge effect on initial performance and indicates the level of efficiency reachable when the charge effect is completely removed and there is not a compensating increase of the mechanical efficiency.

The reported untreated and conditioned (discharged) efficiencies show the extent of the electrostatically charge effect on initial performance. It should not be assumed that the measured conditioned (discharged) efficiency represents real life behaviour. It merely indicates the level of particulate efficiency obtainable with the charge effect completely removed and with no compensating increase in mechanical efficiency.

For reasons of consistency filter efficiencies are measured using artificially generated dust clouds of synthetic dusts with closely controlled particle size. The test dust selected for testing a given filter depends on its initial filtration efficiency with respect to 0,4 µm liquid droplets.

In the case of using the industry practice of taping the filter unit into the test duct in combination with the test method, the results may not adequately represent the filter sealing mechanism performance which is a vital component of the filtration system.

The particulate efficiency measurements are repeated after the filter has been loaded with ISO fine loading dust until the resistance has risen to a value of 375 Pa in the case of testing low efficiency filters and up to a value of 625 Pa for the medium and high efficiency filters.

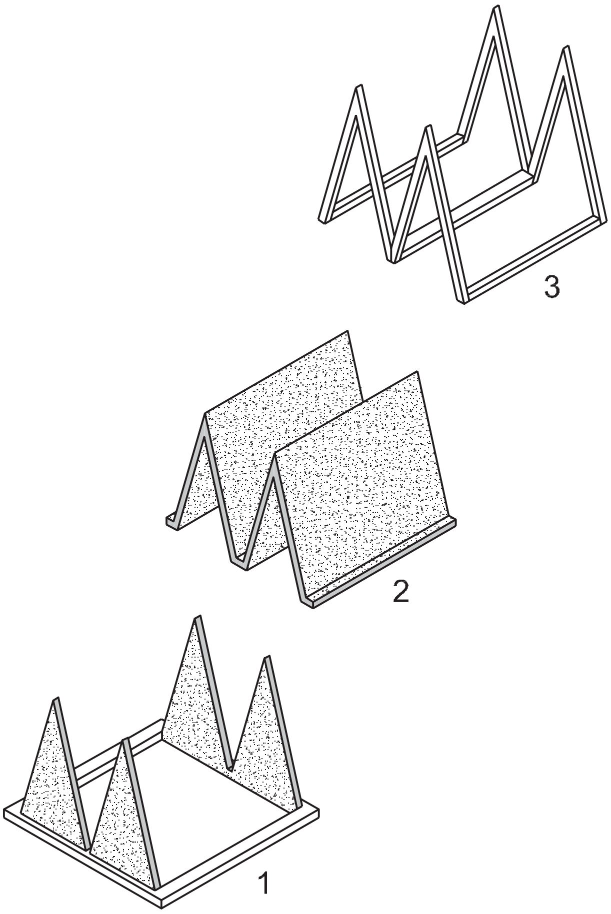
Test dust capacities measured in this way should not be assumed to simulate real life operating conditions as the properties of dusts encountered in service conditions vary very widely. Comparative performances and rankings may be established, but it should always be borne in mind it's the actual conditions on site that will determine the in-service filter performance.

C.4 Flat sheet test (media testing in test duct)

The minimum airflow in the standard is 0,25 m^3/s, which means that flat sheet material using a speed lower than 0,65 m/s cannot be tested directly as a flat sheet in the test duct. For testing at lower velocities through the material in the test duct, it has to be mounted with an extended surface. If the material is fixed to a W-shaped frame system, it can be tested as a common filter. There is no correlation between the W-shape and flat sheet but the method could be used for comparing and evaluating material.

Figure C.1 describes a typical W-form construction that could be used for evaluating filter material. The W-form gives one square metre (1,0 m^2) effective filtering area, and therefore the same figures representing the flow rate (in m^3/s) and the media velocity (in m/s). 0,4 m^3/s gives 0,4 m/s through media.

The filter material to be tested shall be laid on the frame and stretched and fastened to the frame with the help of the counter frames.



Key

1 W-form frame

2 filter material (1 m^2)

3 W-form counter frame

Figure C.1 — Example of W-form frame and details for testing filter material

Annex D
(normative)

Pressure drop calculation

All pressure losses measured during the test should be corrected to a reference air density of 1,198 8 kg/m^3, which corresponds to standard air conditions: temperature 20 °C, barometric pressure 101,325 kPa, relative humidity 50 %. However, as long as the air density is between 1,16 kg/m^3 and 1,24 kg/m^3, no corrections need to be made.

The pressure loss of a filter can be expressed as:

$$\Delta p = c\left(q_\text{v}\right)^n \tag{D.1}$$

$$c = k \times \mu^{2-n} \times \rho^{n-1} \tag{D.2}$$

where

Δp is the pressure loss, Pa

k is a constant;

q_v is the airflow rate, m^3/s

μ is the dynamic viscosity of air, Pa s

n is an exponent;

ρ is the air density, kg/m^3.

The readings of the airflow measuring system shall be convened to the volumetric airflow rate at the conditions prevailing at the inlet of the tested filter. With these airflow rate values and the measured pressure losses, the exponent *n* from Formula (D.1) could be determined by using a least square technique.

With a known value of exponent *n*, the measured pressure losses can be corrected to standard air conditions using the following equation:

$$\Delta p_{1,20} = \Delta p\left(\frac{\mu_{1,20}}{\mu}\right)^{2-n} \times \left(\frac{\rho_{1,20}}{\rho}\right)^{n-1} \tag{D.3}$$

where the un-subscripted quantities refer to the values at the test conditions and the subscripted quantities to values at the standard air conditions and:

$\rho_{1,20}$ = 1,198 8 kg/m^3

$\mu_{1,20}$ = 18,097 × 10^{-6} Pa s

The exponent *n* is usually determined only for a clean filter. During the dust loading phase exponent *n* can change. As it is undesirable to measure pressure loss curves after each dust loading phase, the initial value of exponent *n* may be used during the filter test. The air density ρ (kg/m^3) of temperature T (°C), barometric pressure p (Pa) and relative humidity φ (%) can be obtained by Formula (D.4):

$$\rho = \frac{p \times 0{,}378 p_\mathrm{w}}{287{,}06 \times (T + 273{,}15)} \tag{D.4}$$

where p_w (Pa) is the partial vapour pressure of water in air given by the Formula (D.5):

$$p_\mathrm{w} = \frac{\varphi}{100} p_\mathrm{ws} \tag{D.5}$$

and p_ws (Pa) is the saturation vapour pressure of water in air at temperature T (°C) obtained from Formula (D.6):

$$p_\mathrm{ws} = \exp\left[59{,}484\,085 \times \frac{6\,790{,}498\,5}{(T + 273{,}15)} \times 5{,}028\,02 \times \ln(T + 273{,}15)\right] \tag{D.6}$$

The dynamic viscosity μ (Pa s) at a temperature T (°C) can be obtained from Formula (D.7):

$$\mu = \frac{1{,}455 \times 10^6 \, (T + 273{,}15)^{0{,}5}}{1 + \dfrac{110{,}4}{(T + 273{,}15)}} \tag{D.7}$$

Annex E
(normative)

Net Area Calculation

Estimating effective filtering area of a filter used in air cleaning of rotary machinery.

The information of the media area, provided by the filter manufacturer, shall be checked by measurements and calculation and reported. The filter area shall be calculated according to the guidelines described in this paragraph. If the shape of the pockets/pleats deviates significantly from these schematic drawings, an additional estimation to fit the standard shape should be made. This shall then be commented in the report.

E.1 Pocket filters

Pocket filters typically consist (for a full module, 592 × 592 mm face dimensions) of a set of pockets arranged vertically in a mounting frame. To calculate the net area, the following procedure should be used:

a) Stretch each pocket in the airflow direction so it will expand to its full length (*L*).

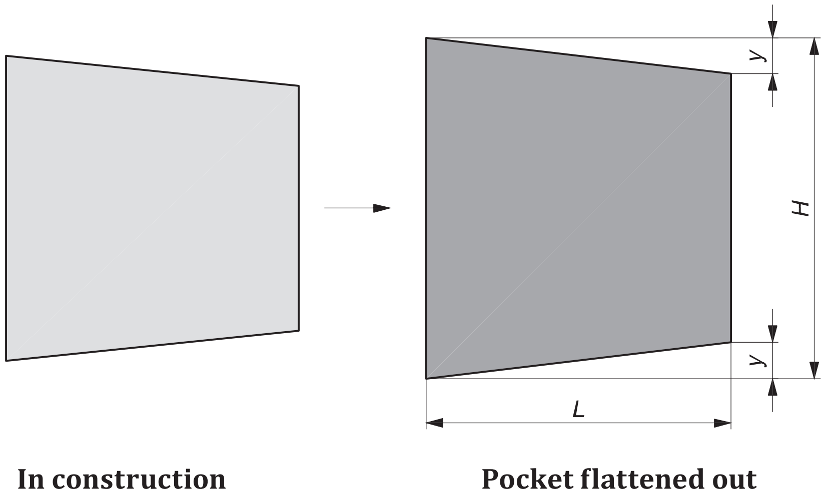
b) Measure the length of each pocket.

c) Measure the shape of the pocket according to Figure E.1, below.

d) Calculate the net area for each pocket.

e) Sum the pocket net areas to the total net area.

f) Estimate the error in measurement as tolerance range of the measured area.



Key

H height of the pocket, inlet side – flattened pocket

L length of pocket

y difference in height on top (and bottom) along the length (*L*) of pocket

Figure E.1 — Pocket filter, area calculation

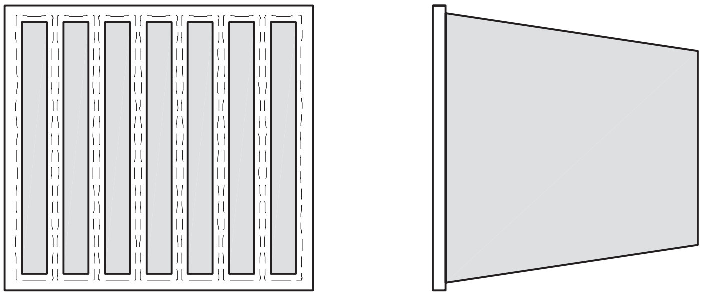
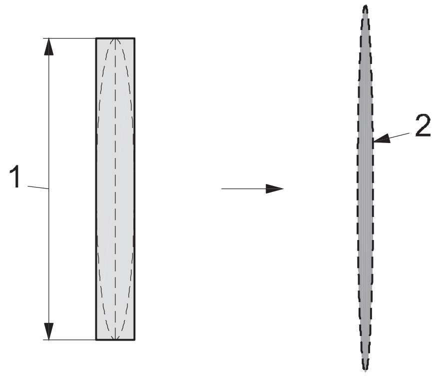


Figure E.2 — Front view (left) and side view (right), pocket filter



Key

1 pocket height in construction

2 pocket flattened out

Figure E.3 — Front view, pocket filter, flattened

Pocket (i) net area:

$$A_\mathrm{i} = 2 \times (H \times L - y \times L) \tag{E.1}$$

For practical reasons, it is allowed to measure the pocket height at $L/2$ if the tapering is linear proportional.

Then the equation becomes:

$$A_\mathrm{i} = 2 \times (H_{L/2} \times L) \qquad [\mathrm{m}^2] \tag{E.2}$$

Total net area:

$$A_\mathrm{tot} = \sum_{1}^{N} A_\mathrm{i} \qquad [\mathrm{m}^2] \tag{E.3}$$

where N is the total number of pockets.

Tolerance range, example

H: ± 0,002 m (2 mm)

L: ± 0,003 m (3 mm)

y: ± 0,001 m (1 mm)

$$A_\mathrm{min} = \Sigma\ [2 \times (\{H - 0{,}002\} \times \{L - 0{,}003\} - \{y + 0{,}01\} \times \{L - 0{,}002\})]\mathrm{i}\ \mathrm{m}^2 \tag{E.4}$$

$$A_\mathrm{max} = \Sigma\ [2 \times (\{H + 0{,}002\} \times \{L + 0{,}003\} - \{y - 0{,}01\} \times \{L + 0{,}002\})]\mathrm{i}\ \mathrm{m}^2 \tag{E.5}$$

Tolerance (–) = $(A_\mathrm{min} - A_\mathrm{tot})$ m^2

Tolerance (+) = $(A_\mathrm{max} - A_\mathrm{tot})$ m^2

Reported result:

$$A_\mathrm{net} = A_\mathrm{tot} \pm \text{Tolerance m}^2 \tag{E.6}$$

E.2 Pleated filters

Pleated filters are normally constructed by mini-pleat technology or with the separator pleating (typically aluminium, plastic or paper). Example of the different type of filters can be seen in Figures E.4 and E.5. A pleated filter can consist of a pleated package that comprises all filter media, or it may be constructed out of several packages that are assembled into a complete filter. To measure and calculate the net area of the filter, the following procedure is used:

a) Measure the effective width (W) of the (each) filter pack (Cross pleating direction).

b) Measure the height (H) of the (each) air filter media pack. This may be difficult to measure (practical reasons). Instead of the height the pleat depth could be measured with, for instance, a small paper strip or calliper device.

c) The effective width (W) that shall be measured must not include sealant (potting) material that covers the air filter media (where obviously no air can penetrate the filter media).

d) Count the number of pleat tips within the effective length (pleat direction).

e) In case of separator filter (rectangular pleat shape) measure the pleat tip width (t).

f) In case of mini-pleated filter (V-shaped pleat shape), t = 0.

g) In the case of a filter consisting of several packages, the total sum of all packages will be the total area of the filter.

h) Estimate the error in measurement as tolerance range of the measured area.

Calculate the pleat (i) net effective area by:

$$A_i = 2 \times (H \times W + t \times W) \tag{E.7}$$

Calculate the total net area by:

$$A_{tot} = \sum_{1}^{N} A_i \qquad [m^2] \tag{E.8}$$

where N is the total number of pleats.

Tolerance range, example

H: ± 0,001 m (1 mm)

W: ± 0,002 m (2 mm)

t: ± 0,000 5 m (0,5 mm)

In case of mini-pleat filter:

$$A_{min} = \Sigma\ [2 \times (\{H - 0{,}001\} \times \{W - 0{,}002\})]\text{i m}^2 \tag{E.9}$$

$$A_{max} = \Sigma\ [2 \times (\{H + 0{,}001\} \times \{W + 0{,}002\})]\text{i m}^2 \tag{E.10}$$

In case of separator filter:

$$A_{min} = \Sigma\ [2 \times (\{H - 0{,}001\} \times \{W - 0{,}002\} + \{t - 0{,}000\ 5\} \times \{W - 0{,}02\})]\text{i m}^2 \tag{E.11}$$

$$A_{max} = \Sigma\ [2 \times (\{H + 0{,}001\} \times \{W + 0{,}002\} + \{t + 0{,}000\ 5\} \times \{W + 0{,}02\})]\text{i m}^2 \tag{E.12}$$

Tolerance (–) = $(A_{min} - A_{tot})$ m^2

Tolerance (+) = $(A_{max} - A_{tot})$ m^2

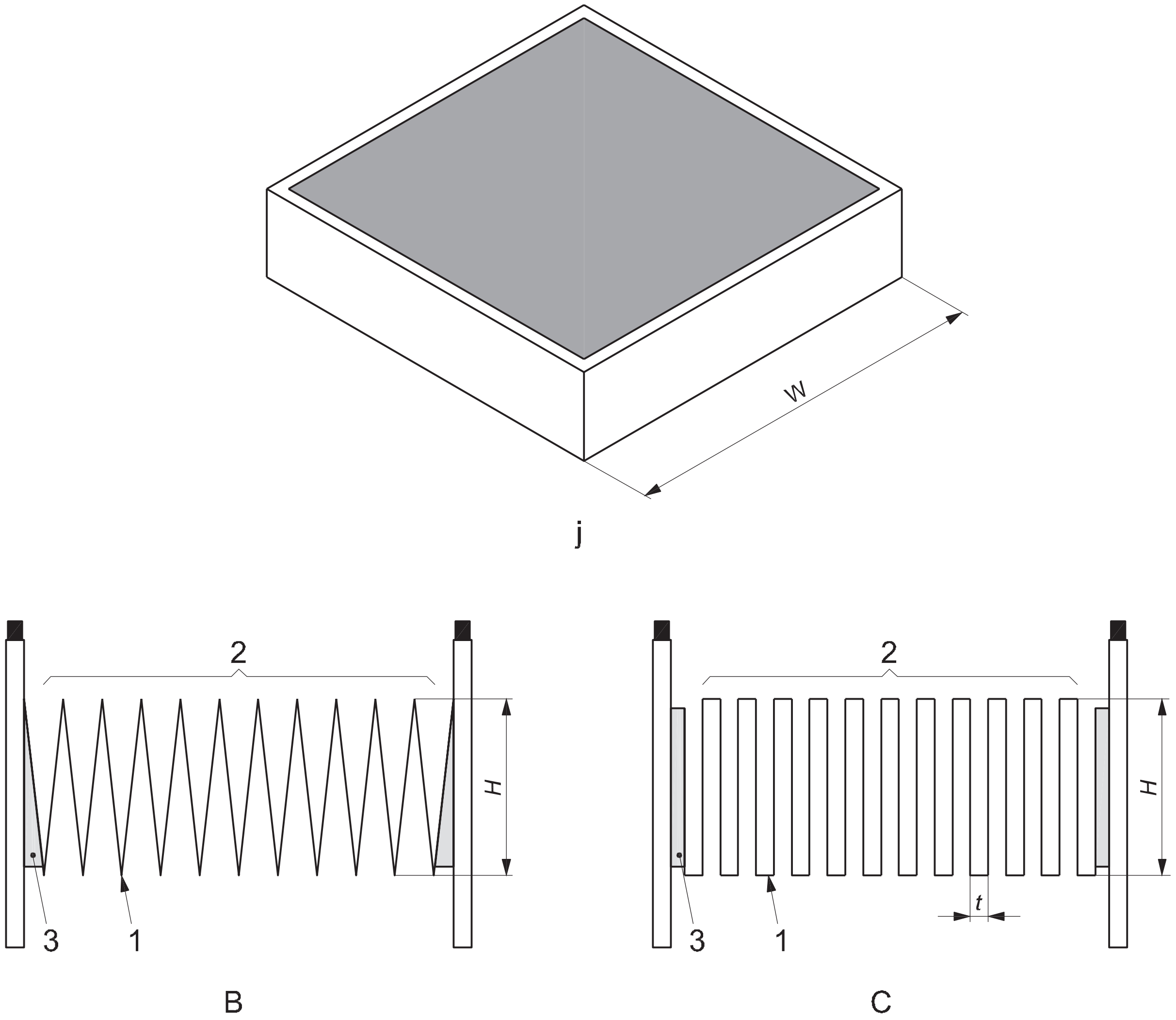
Reported result (one pack filter):

$$A_{net} = A_{tot} \pm \text{Tolerance m}^2 \tag{E.13}$$

Reported result (several pack filter):

$$A_{net} = \Sigma\ A_{tot\ (j)} \pm \text{Tolerance m}^2 \tag{E.14}$$

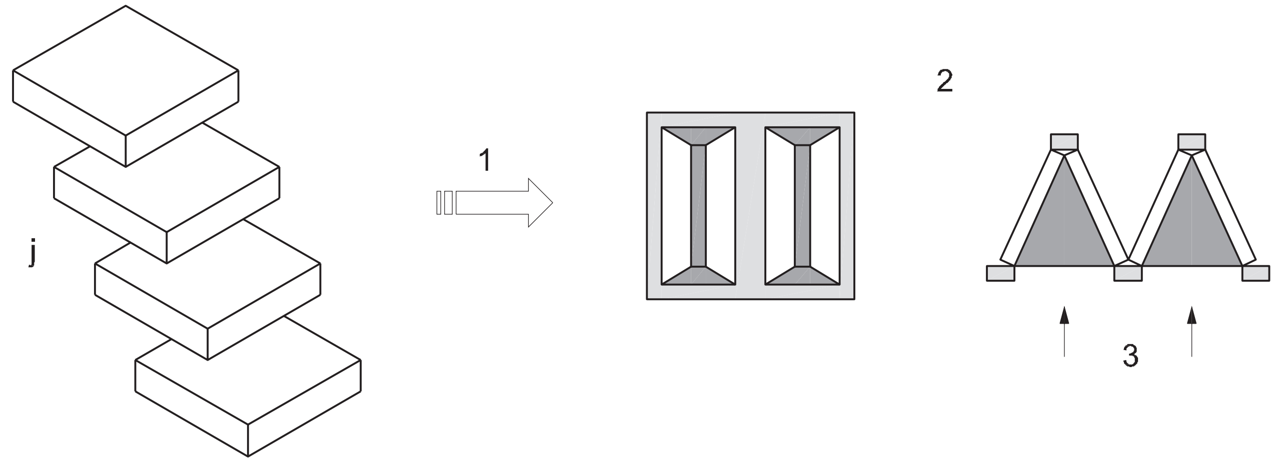
where j is the number of packs (see Figure E.5).



Key

1	pleat tip (*i*)
2	total number of pleat tips (*N*)
3	sealant (potting)
B	minipleat filter
C	separator filter
j	filter pack containing one pleated pack
t	tip width

Figure E.4 — Pleated filter, with one pack - Estimation of net filtering area



Key

1	assembling
2	complete filter
3	airflow direction
j	filter packs (in this case *j* = 4)

Figure E.5 — Pleated filter with several packs- Estimation of net filtering area

E.3 Circular pleated filters

Pleated filters are normally constructed by mini-pleat technology or with the separator pleating (typically aluminium, plastic or paper). A circular (tube shape) pleated filter can consist of a pleated package that comprises all filter media, or it may be constructed out of several packages (tubes) that are assembled into a complete filter. To measure and calculate the net area of the filter following procedure is used:

a) Measure the effective length of the (each) filter pack (L).

b) Measure the effective height (H) of (each) pack.

c) Count the number of pleat tips around the perimeter (pleat direction).

d) In case of separator filter (rectangular pleat shape) measure the pleat tip width (t).

e) In case of mini-pleated filter (V-shaped pleat shape), $t = 0$.

f) In the case of a filter consisting of several packages, the total sum of all packages will be the total area of the filter.

g) Estimate the error in measurement as tolerance range of the measured area:

Calculate the pleat (i) net effective area by:

$$A_\mathrm{i} = 2 \times (H \times L + t \times L) \tag{E.15}$$

Calculate the total net area by:

$$A_\mathrm{tot} = \sum_{1}^{N} A_\mathrm{i} \qquad [\mathrm{m}^2] \tag{E.16}$$

where N is the total number of pleats.

Tolerance range, example

H: ± 0,001 m (1 mm)

W: ± 0,002 m (2 mm)

t: ± 0,0005 m (0,5 mm)

In case of mini-pleat filter:

$$A_{\mathrm{min}} = \Sigma\,[2 \times (\{H - 0{,}001\} \times \{W - 0{,}002\})]\mathrm{i}\ \mathrm{m}^2 \tag{E.17}$$

$$A_{\mathrm{max}} = \Sigma\,[2 \times (\{H + 0{,}001\} \times \{W + 0{,}002\})]\mathrm{i}\ \mathrm{m}^2 \tag{E.18}$$

In case of separator filter:

$$A_{\mathrm{min}} = \Sigma\,[2 \times (\{H - 0{,}001\} \times \{W - 0{,}002\} + \{t - 0{,}0005\} \times \{W - 0{,}02\})]\mathrm{i}\ \mathrm{m}^2 \tag{E.19}$$

$$A_{\mathrm{max}} = \Sigma\,[2 \times (\{H + 0{,}001\} \times \{W + 0{,}002\} + \{t + 0{,}0005\} \times \{W + 0{,}02\})]\mathrm{i}\ \mathrm{m}^2 \tag{E.20}$$

Tolerance (–) = $(A_{\mathrm{min}} - A_{\mathrm{tot}})$ m^2

Tolerance (+) = $(A_{\mathrm{max}} - A_{\mathrm{tot}})$ m^2

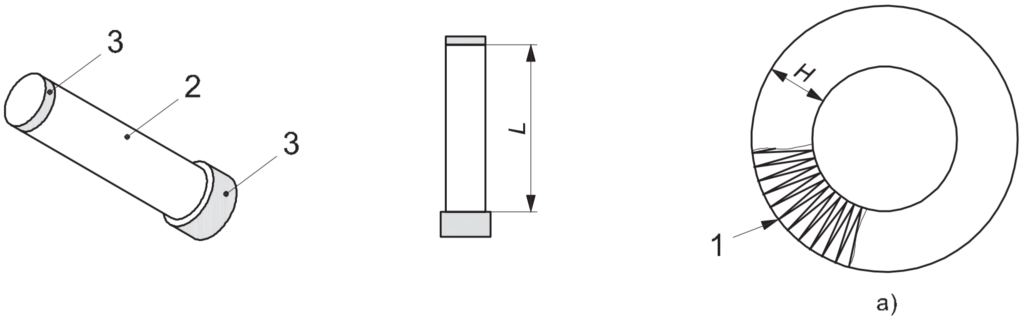
Reported result (one pack filter):

$$A_{\mathrm{net}} = A_{\mathrm{tot}} \pm \text{Tolerance m}^2 \tag{E.21}$$

Reported result (several pack filter):

$$A_{\mathrm{net}} = \Sigma\, A_{\mathrm{tot\,(j)}} \pm \text{Tolerance m}^2 \tag{E.22}$$

where ”j” is the number of packs (see Figure E.5).



Key

1 pleat tip

2 filter media pack

3 end cap

a) top view

Figure E.6 — Circular, pleated filter

E.4 Other constructions

If other air filter constructions with totally different shapes and techniques are checked, it is up to the test institute to describe how the net area, including tolerance range, was determined.

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