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METHOD OF TESTING AIR FILTERS USED IN GENERAL VENTILATION FOR DETERMINATION OF FRACTIONAL EFFICIENCY

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FOREWORD

For the last twenty years, the characteristics of general ventilation filters have been established using the ASHRAE 52/76 method which formed the basis for various other standards and recommendations, particularly the recommendation EUROVENT 4/5.

This method which determines the total efficiency (atmospheric dust spot efficiency or synthetic dust weight arrestance) is widely used to compare the characteristics of filters. Nevertheless, the conventional nature of the method is no longer sufficient for a technical approach in filtration. An example is the control of indoor air quality or cleanliness constraints within a process.

Developments in the aerosol technology allow to have access to filter fractional efficiency. The EUROVENT Working Group 4b has developed a new method adapted for a better use of filters in industrial process and in the field of indoor air quality. This new method Eurovent 4/9 has replaced the old Eurovent 4/5 method.

AVANT-PROPOS

Depuis vingt ans les caractéristiques des filtres de ventilation générale sont déterminées par la méthode ASHRAE 52-76 qui a servi de base à de nombreuses normes et recommandations, en particulier la recommandation EUROVENT 4/5.

Cette méthode qui détermine l'efficacité globale (rendement à la tâche ou rendement gravimétrique) est largement utilisée pour comparer les caractéristiques des filtres entre eux.

Néanmoins le caractère conventionnel de la méthode n'est plus suffisant pour une approche technique de la filtration, par exmple pour la maîtrise de la qualité de l'air intérieur ou le respect des contraintes de propreté dans les process.

Les progrès de la métrologie des aérosols permettent maintenant d'accéder aux caractéristiques des filtres en termes d'efficacité spectrale. Le groupe de travail EUROVENT 4b a développé une nouvelle méthode plus adaptée pour une meilleure utilisation des filtres dans les process industriels et dans le domaine de la qualité de l'air dans les locaux.

VORWORT

Für die Bestimmung der Leistungsmerkmale von Luftfiltern für die allgemeine Raumlufttechnik ist in den letzten 20 Jahren die Prüfmethode nach ASHRAE Standard 52/76 maßgeblich die Grundlage für verschiedene andere Normen und Empfehlungen gewesen, insbesondere für das EUROVENT-Dokument 4/5.

Diese Methode dient zur Bestimmung des Gesamt-Wirkungsgrades (Wirkungsgrad gegenüber atmosphärischem Staub oder Abscheidegrad gegenüber synthetischem Staub) und wird weithin verwendet, um die Leistungsmerkmale von Luftfiltern vergleichen zu können. Dieses traditionelle Prüfverfahren ist jedoch nicht mehr hinreichend für die heutigen Anforderungen auf dem Gebiet der Luftfiltration. Beispiele hierfür sind die Anforderungen an die Einhaltung der Raumluftqualität und Reinheitsanforderungen bei Prozessen.

Entwicklungen auf dem Gebiet der Aerosolmessung gestatten es, Fraktionsabscheidegrade zu ermitteln. Die EUROVENT-Arbeitsgruppe 4b hat eine neue Prüfmethode entwickelt, die der Verwendung von Luftfiltern für industrielle Prozesse und für Zwecke der Raumluftqualität eher entspricht.

SUMMARY

1. INTRODUCTION

This document describes a test method based on systems and equipment which have for several years been used for filter testing using LATEX or DEHS as the test aerosols.

The filter collection efficiency is determined by measuring the upstream and downstream concentrations using the laser particle counting method in the particle size range from at least 0,2 μm to 3 μm.

This method can be extended to a wider particle range if new test systems become available giving quick and reliable results.

This document is also a contribution to the European standardisation work of CEN/TC 195.

2. SCOPE - FIELD OF APPLICATION

The aim of this document is to describe a test method for air filters used in general ventilation systems. In the past, the characteristics of such filters were always established using the ASHRAE 52/76 method, which has formed the basis for various other standards and recommendations (e.g. EUROVENT 4/5 and EN 779).

This new method enables one to arrive at a more complete knowledge of filter characteristics, particularly in terms of fractional analysis.

This new test method entails the following objectives :

- To establish filter characteristics in terms of human health risk from given aerosols ;
- To establish filter characteristics in terms of cleanliness constraints within a process ;
- To establish better characteristics for filters in order to be able to transpose test rig characteristics into real ones ;
- To provide technical information in order to establish a baseline for filter ageing ;
- To contribute to the establishment of a quicker and simpler method enabling more control operations to take place on the test rig ;
- To be able to transpose the method, if required, directly into an onsite monitoring of filter set-ups.

This document establishes the requirement concerning the equipment for those tests and defines the analysis and presentation of measuring results.

The performance values obtained in accordance with this standard cannot be used by themselves to predict the service life and behaviour (loss of efficiency, mechanical integrity) of an installed filter. Depending on operating conditions certain electrostatically charged materials could for instance be neutralized and lose efficiency.

The method described applies to air filters used in general ventilation, with a face velocity of at least 0,6 m/s.

3. DEFINITIONS

3.1. Test Air

The air to be used for testing purposes which is filtered by a high efficiency filter and has a relative humidity in compliance with the filter application requirements or being, by definition,below 70 % RH.

3.2. Rated Air Flow Rate

The quantity of air the filter is designed to handle as specified by the manufacturer (expressed in m^3/s for a reference air density of 1,20 kg/m^3).

3.3. Face Area

The area of the inside section of the test duct immediately upstream of the filter under test (nominal values 0,61 x 0,61 m = 0,37 m^2).

3.4. Face Velocity

The air flow rate divided by the face area (expressed in m/s).

3.5. Net Effective Filtering Area

The total filtering surface of the filter in contact with the test air (expressed in m^2).

3.6. Media Velocity

The air flow rate divided by the net effective filtering area (expressed in m/s).

3.7. Initial Pressure Drop

The pressure drop of the clean filter operating at its rated air flow (expressed in Pascals).

3.8. Rated Final Pressure Drop

The maximum operating pressure drop of the filter as recommended by the manufacturer at rated air flow rate (expressed in Pascals).

3.9. Initial Fractional Efficiency

The fractional efficiency of the clean filter operating at the rated air flow rate (expressed in % for each size of selected particles).

3.10. Weighted Fractional Efficiency

The weighted average of the fractional efficiencies for different dust holding levels (expressed in %).

3.11. Average Test Dust Weight Arrestance

The ratio of the amount of dust arrested by the filter to the amount of dust fed to the filter (expressed in %).

3.12. Dust Holding Capacity

The amount of dust fed to the filter multiplied by the average weight arrestance until the final Pressure drop is obtained (expressed in grams).

3.13. HEPA Filter

An air filter with an decontamination factor over 10 000 (according to EUROVENT 4/4) for the rated air flow rate and intended to purify the air upstream of the test circuit.

3.14. Final Air Filter

The air filter used to collect the test dust passing the filter under test.

4. TEST RIG AND EQUIPMENT

4.1. Test Circuit

The test circuit shall be designed in such a way as to obtain a stable aerosol with a homogeneous concentration in the test rig.

The test rig (see Figure 1) consists of several square section duct parts with 610 x 610 mm as nominal dimensions except for the duct part 3 where the filter is installed. This duct part has nominal dimensions between 616 and 622 mm. The length of this duct part shall be 1.1 times the length of the filter, with a minimum length of 1 m.

A HEPA filter housing is placed upstream of duct part 1 in which the aerosol is dispersed.

Duct part 2 includes in the upstream section the mixing orifice in the centre of which the dust feeder is located. Downstream of the dust feeder is a perforated plate intended to achieve a uniform distribution and in the last third of this duct is situated the upstream sampling head. For arrestance tests, this sampling head shall be blanked off.

Duct part 5 is fitted upstream with a final filter for the arrestance test and with the downstream sampling head. The final filter should be mounted in a housing which allows removal of the filter with a minimum disturbance to either the test rig or the filter.

The dimensions of the test rig and the position of the pressure taps are shown in Figure 2.

The test circuit can be operated both in under - or over pressure. However, the over pressure operation (fan upstream) ensures a better relative tightness of the circuit than the operation in under pressure. Circuits shall be then fitted accordingly with a flow rate measuring device suitable for a standardized method.

4.2. Aerosol Generation And Neutralization

The test aerosol for fractional efficiency determination should be DEHS or LATEX particles.

4.2.1. DEHS Test Aerosol

Test aerosol of DEHS (DiEthylHexylsebacate) produced by Laskin nozzle is widely used in filter testing and has replaced the DOP test aerosol.

The system for generating consists of a small container with DEHS liquid and a Laskin nozzle. (see Figure 6.)

The aerosol is generated by feeding a small amount of particle free air through the Laskin nozzle. The atomized droplets are then directly introduced into the test rig, Figure 1. The DEHS aerosol does not need to be neutralized.

The pressure and airflow to the nozzle vary with test flow, temperature of the liquid and the height of the DEHS level.

For a test flow of 1 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.

Before testing regulate the upstream concentration to have a stable concentration below the coincidence level of the particle counter. Any other generator different from the Laskin generator which is able to produce droplets in sufficient concentrations in the size range of 0.1 to 3.0 μm can be used. One such a generator is specified in the French standard NF X 44-060 and compromises of two pressurized containers and a sonic atomizer which is fed by compressed air.

4.2.2. LATEX Test Aerosol

The "latex" particles forming the test aerosol are micro spheres of an industrial produced synthetic resin. The exact designation of that product is homopolymer vinyl acetate and it enables us to cover a particle size range of 0,1 to > 3 μm. This emulsion is diluted in de-ionized water to a concentration of 2 % and then dispersed with a sprayer.

The system for generating the particles consists of a dilution chamber within which the latex solution is sprayed (see Figure 3). After drying in the dilution chamber, the latex particles pass a charge neutralizer intended to make the electrical charge distribution neutral. The atomizer is of the "Collison" type. The compressed air feeding pipe and the nozzle presented in Figure 4 are located in the center of the dilution chamber.

The base of the nozzle is connected with a flexible hose to the container feeding the latex solution.

The atomized droplets impacting on the walls of the dilution chamber flow down to the feeding container, thus ensuring a quasi-constant level of the solution.

The nozzle is fed with compressed air filtered at a pressure of 180 kPa corresponding to a flow rate of 0,083 dm^3/s (0,3 m^3/h).

The dilution chamber is fed with filtered dry air (relative humidity = 10 % at 20°C and efficiency = 99,99 % according to EUROVENT 4/4) at a flow rate of 5,56 dm^3/s (20 m^3/h).

Before testing regulate the upstream concentration to have a stable concentration below the coincidence level of the particle counter.

4.2.3. Neutralization of Latex aerosol

Most aerosol generators produce highly charged aerosols due to mechanical shearing. These charges need to be neutralized to minimize particle deposition due to electric fields. DEHS aerosol will not be changed while Latex aerosol is charged and has to be neutralized

The neutralized particles are then introduced into the test rig at the level of the wall of duct section 1.

The radioactive neutralizer as described in Figure 5 is suitable. It shall consist of a 40 mm diameter cylinder containing three radioactive sources of Americium 241 with an activity of 3,7 MBq each.

A suitable alternative to the radioactive neutralizer is an electrostatic neutralizer capable of producing high numbers of bi-polar ions which effectively neutralize the aerosol.

However, it should be noted that the electrostatic neutralizer may produce large numbers of ultra-fine particles which will contribute to the challenge aerosol.

4.3. Particle Counter

This method requires the use of one optical particle counter with a laser source having a sampling capacity between 0,2 μm and at least > 3 μm with a large counting capacity.

The particle counter shall be periodically calibrated with monodispersed latex particles.

As an alternative to the use of one particle counter for measuring the upstream and downstream concentration one can employ a dual laser system (see Chapter 7).

4.4. Transfer Lines

Two rigid transfer lines with equal length and equivalent geometry (bends and straight lengths) shall connect the upstream downstream isokinetic sampling heads to the particle counter.

Three one-way valves make it possible either to sample the aerosol upstream or downstream of the filter under test, or to have a "blank" by suction through a HEPA filter. These valves must be of a straight-through design.

If the dual-laser system is used the particle counters are directly connected to the isokinetic sampling-heads (but must also be able to sample a blank).

The sampling flow rate shall ensure that the aerosol is not affected by an excessive loss by impaction or sedimentation.

The flow rate can be ensured by the pump of the counter in the case of a particle counter with a high flow rate (0,47 dm^3/s) or by an auxiliary pump in the case of a counter with a smaller flow rate (0,047 dm^3/s for example). The overdriving line shall then be fitted with an isokinetic sampling nozzle directly connected to the particle counter to achieve isokinetic conditions within a tolerance of $\pm$ 10 %.

4.5. Dust Feeder

The purpose of the dust feeder is to supply the synthetic dust to the filter under test at a constant rate over the test period.

If the dust feeder is a linear one, a certain mass of dust previously weighed is loaded into the mobile dust feed tray. The tray is moving regularly and the dust is taken up by a paddle wheel and carried to the slot of the dust pick-up tube of the ejector.

The ejector disperses the dust with compressed air and directs it into the test rig through the dust feeder tube.

The compressed air shall be dry, clean and free from oil.

If the dust feeder is operating by mass loss, the quantity of dust fed is continuously recorded over the dust holding phase together with the pressure drop of the filter under test. Such a device enables to stop the dust holding test for a specified final pressure drop.

5. TEST PROCEDURE

The filter shall be mounted in accordance with the manufacturer's recommendations.

5.1. Initial Pressure Drop

The measurement of the initial pressure drop is recorded at least four air flow rates of 50, 75, 100 and 125 of rated air flow. The pressure drop shall be measured with static pressure taps located as shown in figure 2. Pressure taps are to be provided at four points distributed over the periphery of the duct and connected together by a ring line.

5.2. Initial Fractional Efficiency

The determination of the initial fractional efficiency is done at the rated flow rate.
The aerosol generator is regulated according to the operating conditions stated under paragraph 4.2. ensuring an output compatible with the maximum counting of the particle counter and with the minimum counting required for an accurate determination of the fractional efficiency.

The efficiency measurement is done by a series of 13 counts of one minute conducted successively upstream and downstream of the filter under test and with a one minute purge before each count, or with a one minute sample upstream or dowstream without counting just to equalize the concentration of particles in the transfer lines. The sampling cycle duraction may differ from one minute depending on particle counter and particle concentration.

With the dual-laser-system the measuring is being done in a similar way but in this case only six counts are necessary.

Sampling is done by tapered probes placed in the centre of the upstream and downstream measuring sections. Isokinetic sampling is recommended as closely as possible for all classes of particles.

5.3. Dust Holding Capacity and Weight Arrestance

In order to determine the changes in pressure drop and efficiency the filter is loaded with a test dust.

The ASHRAE-type standardized dust is used (ASHRAE Standard 52.1:1992).

Dust is generated at a concentration of 70 mg/m^3 until a first specified pressure drop is arrived according to 5.4.

After the dust loading test has been completed, the final filter which has been previously weighted is taken out from the test rig and weighed again to determine the mass of dust having passed the filter and hence, calculate the weight arrestance. The final filter must be of a type whose casing does not absorb moisture from the atmosphere. Any final filter must be conditioned for at least 30 minutes before the initial weighing.

5.4. Different Test Phases

Fractional efficiency, arrestance and dust holding capacity measurements are conducted successively to establish the curve of efficiency and arrestance as function of dust loading. The following dust loading phases should be used:

Coarse filters (EU1-EU4) - Arrestance and Dust Holding Capacity
1. After 30 g dust or 10 Pa pressure drop increase, whichever is reached first
2. After 50, 100, 150, 250 Pa final pressure drop (when possible)

Fine filters (EU5-EU9) - Efficiency, Arrestance and Dust Holding Capacity
1. After 30 g dust or 10 Pa pressure drop increase, whichever is reached first
2. After 150, 200, 300, 450 Pa final pressure drop (when possible)

Minimum five measurements (including initial and final tests) shall be made. Intermediate tests shall be made if the above criteria don't give five measurements.

The test is stopped if the weight arrestance decreases below 75 % or if two values are below 85 % of maximum arrestance.

After each dust holding phase, the filter shall be purged to reduce the emission rate of particles "released" by the partly loaded filter.

After each purge phase, a count shall be conducted downstream to evaluate the residual releasing rate for the various particle size ranges.

For a given particle size range, this releasing ratio is expressed by the ratio of the number of "released" particles to the average number of particles coming upstream of the filter during the determination of the fractional efficiency.

This ratio is a direct expression of the error on the true calculated efficiency, taking into account the "released" particles which, if not considered, leads to an under-estimate of the filter fractional efficiency.

The releasing rate can be neglected if the filter is purged until a releasing rate below 2 % is reached for each particle size range..

Example :

n_{ri} : number of "released" particles of the size range i (downstream of the filter during the purging phase).

n_i : number of particles of the size range i during the determination of the fractional efficiency.

N_i : average number of particles of the size range i upstream of the filter during the determination of the fractional efficiency.

Fractional efficiency without releasing :

$$E_i = \frac{N_i - n_i}{N_i} = 1 - \frac{n_i}{N_i}$$

Fractional efficiency with releasing :

$$E_{ri} = \frac{N_i - (n_i + n_{ri})}{N_i} = 1 - \frac{n_i}{N_i} - \frac{n_{ri}}{N_i}$$

$$\frac{n_{ri}}{N_i} = \text{releasing rate}$$

6. EXPRESSION OF THE RESULTS (see Appendix A)

6.1. Flow Rate - Initial Pressure Drop

The curve representing the initial pressure drop as a function of the flow rate shall be plotted for at least four flow rates of 50, 75, 100 125 % of the rated air flow rate.

The reported pressure drop shall be corrected to a reference air density of 1,20 kg/m^3 (see Appendix B).

6.2. Fractional Efficiency

The basic expression of the fractional efficiency for a given particle size range (particles between two diameter values) is the ratio of the number of particles retained by the filter to the number of particles fed upstream of the filter.

The counts shall be conducted upstream and then downstream successively, the counting cycle being as follows for a given particle size range:

Counting Number	1	2	3	4	5	6	7	8	9	10	11	12	13
UPSTREAM	N_1		N_2		N_3		N_4		N_5		N_6		N_7
DOWNSTREAM		n_1		n_2		n_3		n_4		n_5		n_6	

Six "point" fractional efficiencies shall be calculated as follows :
(see Appendix C)

$$E_1 = \left[1 - \frac{n_1}{\left[\frac{N_1+N_2}{2}\right]}\right]100 \qquad E_2 = \left[1 - \frac{n_2}{\left[\frac{N_2+N_3}{2}\right]}\right]100$$

$$E_3 = \left[1 - \frac{n_3}{\left[\frac{N_3+N_4}{2}\right]}\right]100 \qquad E_4 = \left[1 - \frac{n_4}{\left[\frac{N_4+N_5}{2}\right]}\right]100$$

$$E_5 = \left[1 - \frac{n_5}{\left[\frac{N_5+N_6}{2}\right]}\right]100 \qquad E_6 = \left[1 - \frac{n_6}{\left[\frac{N_6+N_7}{2}\right]}\right]100$$

The fractional efficiency shall be equal to the average of those efficiencies, i-e :

$$\bar{E} = \frac{1}{6}\sum_{i+1}^{6} E_i$$

The average values of the fractional efficiencies shall be plotted as a function of the mean diameter. The mean diameter is the diameter corresponding to the middle of the size range of each class.

For the use of the dual-laser system the fractional efficiency shall be calculated as follows :

Counting number	1	2	3	4	5	6
UPSTREAM	N_1	N_2	N_3	N_4	N_5	N_6
DOWNSTREAM	n_1	n_2	n_3	n_4	n_5	n_6

$$E_i = \left[1 - \frac{n_i}{N_i}\right]100 \qquad \bar{E} = \frac{1}{6}\sum_{i+1}^{6} E_i$$

6.3. Weighted Fractional Efficiency

The weighted fractional efficiency is an average fractional efficiency taking into account the different dust holding phases (see Appendix C).

For a series of "n" dust holding phases, the weighted fractional efficiency is given by the following formula

$$E_j = \sum_{i=o}^{n-1}\left[\left(\frac{E_{i,j} + E_{i+1,j}}{2}\right)\frac{M_{i+1}}{M}\right]$$

E_j = The weighted fractional efficiency for the particle size class "j"

$E_{i,j}$= The fractional efficiency for particle sizeclass "j" after the dust holding phase "i".

M_i = Amount of dust fed during the dust holding phase "i"

$$M = \sum_{i=o}^{n-1} M_i$$

$i=0 \quad M_o=0 \quad E_{o,j}$ = initial efficiency

The weighted fractional efficiency shall be plotted as a function of the mean diameter.

6.4. Weight Arrestance And Dust Holding Capacity

The weight arrestance "A" for a given dust holding phase is expressed as follows :

$$A_i = 100\left[1 - \frac{m_i}{M_i}\right]\%$$

m_i : mass of dust passing the filter

M_i : mass of dust fed during the dust holding phase.

The dust holding capacity for a given final pressure drop is equal to the total mass of dust fed multiplied by the average weight arrestance.

The average dust weight arrestance* A_m is given by the following formula :

$$A_m = \frac{1}{M}\left[M_1 A_1 + M_2 A_2 + ... + M_n A_n \right]$$

with M : total mass of dust fed

$M = M_1 + M_2 + ... + M_n$

$M_1, M_2, ... M_n$: dust masses successively fed to reach the following respective final pressure drops :

$\Delta p_1, \Delta p_2, ... \Delta p_n$

(* For the majority of tests, the average arrestance can be expressed directly for the whole test duration without having to calculate the intermediate values of arrestance (A_1, A_2....).)

6.5. Interpolation of measured values

The operator shall try to make the measurements at the stated pressure drops, see 5.4. If these pressure drops are exceeded linear interpolation may be used to estimate the weighted efficiency, arrestance and DHC. The values may also be taken directly from graph over measured values.

6.6. Calculation of Uncertainty

The uncertainty on the average fractional efficiency as defined under paragraph 6.2 corresponds to a two-sided confidence interval of the average value based on a 95 % confidence level.

According to the standard ISO 2854-1976 : « Statistical interpretation of data - Techniques of estimation and tests relating to means an variances ».

$$\bar{E} - t_{(1-\alpha/2)}\frac{\delta}{\sqrt{n}} \leq \bar{E} \leq \bar{E} + t_{(1-\alpha/2)}\frac{\delta}{\sqrt{n}}$$

$\bar{E}$: Average efficiency

$$\bar{E} = \frac{1}{n}\Sigma E_i$$

E_i : point value of the efficiency

$t_{(1-\alpha/2)}$ Value depending on the degree of freedom "v"

v = n - l (see ISO 2854-1976)

n : number of calculated point efficiency values E_i

δ : standard deviation

$$\delta = \sqrt{\frac{\Sigma(E_i - \bar{E})^2}{n-1}}$$

7. CALIBRATION OF THE COUNTER

Optical particle counters give information on the particle concentration and particle size distribution on a quasi real-time basis. Information on the particle size distribution are depending on the calibration of the optical counter.

Differences exist between optical and electronic systems of the various types of counters as well as between their sampling systems.

To avoid these types of problems, the same counter for the upstream and downstream measurements of the filter is recommended to use.

If the dual-laser-system is used (to neglect influences of an unstable aerosol concentration) a proper calibration of both particle counters of the same type is necessary. It has to be ensured that both particle counters have the same counting efficiency for each channel.

7.1.Size Calibration Procedure

The initial calibration of the optical particle counter - in this method, a laser counter - is done with spherical particles of latex polystyrene in single dispersion having a refractive index of 1,59.

The calibration shall be conducted for at least four channels of the measuring range of the device distributed over the whole range.

Each aerosol in single dispersion is successively fed by a calibration atomizer, then dried, neutralized and diluted in a stream of clean air. The optical counter shall then conduct an isokinetic sampling.

The aerosol dilution in the clean airstream shall be such that the error of coincidence is below 5 % (probability to find more than one particle within the sensitive volume of the optical particle counter).

7.2. *Concentration Calibration Procedure*

For each size of aerosol in single dispersion, the calibration control or the internal calibration system of the channel considered shall be adjusted to achieve the maximum counting in the channel corresponding to the standard aerosol.

7.3. *Sample Air Flow Rate*

The air flow rate of the counter shall be checked in compliance with a standardized procedure. In order to obtain a representative isokinetic sample, especially for the larger particles (> 1μm), it is important to know this flow rate.

The calibration of the air flow shall take into account the influence of the pressure drop of the sampling lines.

8. ABBREVIATIONS

ASHRAE	- American Society of Heating, Refrigerating and Air-Conditioning Engineers
CAS	- Chemical Abstract
CEN	- European Committee for Standardization
DEHS	- DiEthylHexylsebacate
DOP	- DioctylPhthalate
DOS	- Dioctylsebacate
HEPA	- High Efficiency Particulate Air Filter
ISO	- International Standards Organisation
MBq	- Mega Becquerel
SAC	- Standard model of alpha radioactive sources

Figure N° 1 : Schematic diagram of the test rig

1 - Duct part of the test rig
2 - Duct part of the test rig
3 - Duct part of the test rig
4 - Duct part of the test rig
5 - Duct part of the test rig
6 - Duct part of the test rig
7 - HEPA Filter
8 - Inlet point for DEHS or LATEX particles
9 - Dust feeding probe
10 - Mixing orifice
11 - Perforated plate
12 - Upstream sampling head
13 - Downstream sampling head
14 - Final filter for the dust weight arrestance test

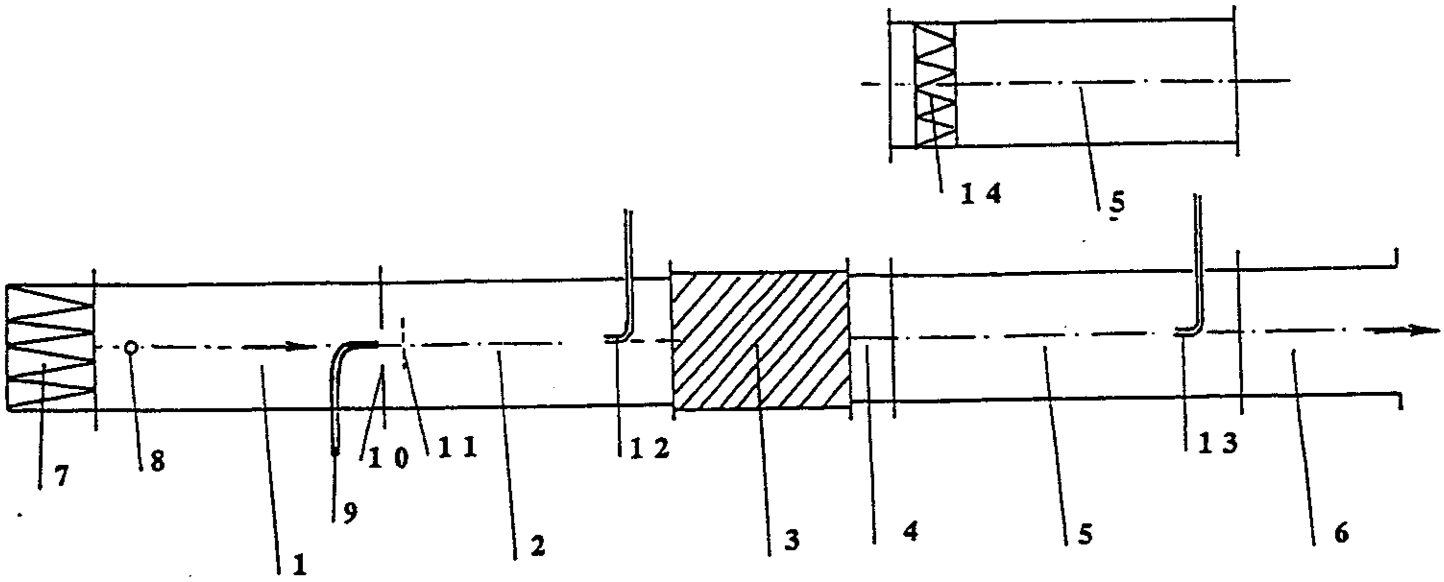


Figure n° 2 :
Dimensions of the test rig in mm

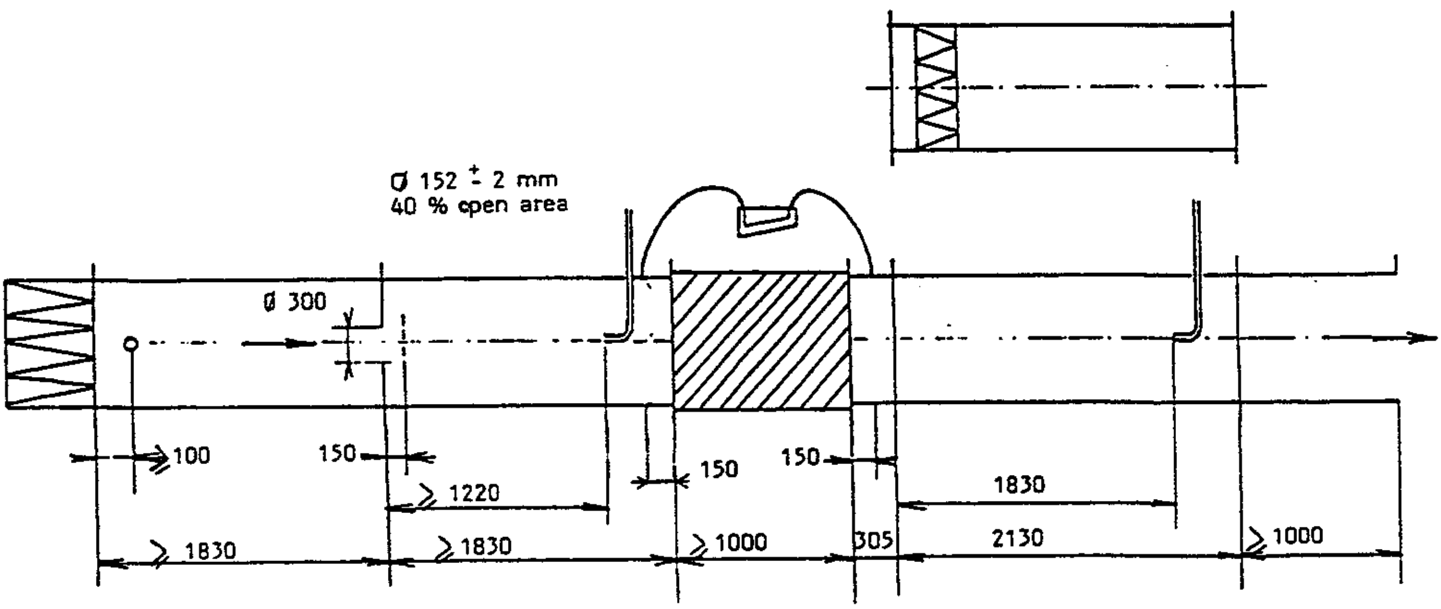


Figure N° 3 : Schematic diagram of the system for latex particle generation

1 - Dilution unit
2 - Latex solution container
3 - Nozzle
4 - Flowmeter
5 - Filter
6 - Filter
7 - Pressure reducer
8 - Needle valve
9 - Rubber tubing
10 - Neutralizer
11 - Test duct

Latex properties : (source : Rhône Poulenc's Research center)
Name : Vinyl acetate homopolymer A018
Density (kg/m3) : 1 050
Refractive index : 1,47

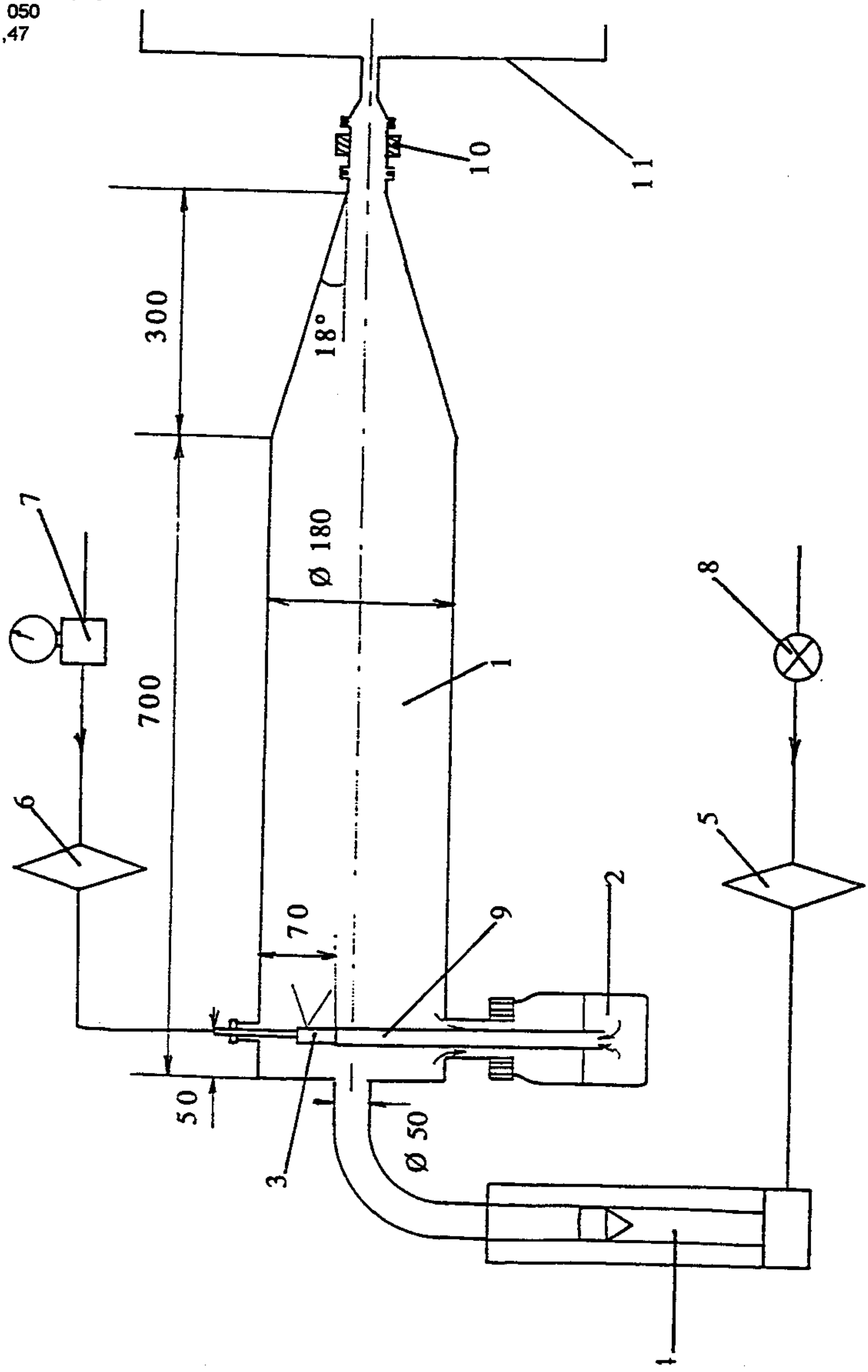
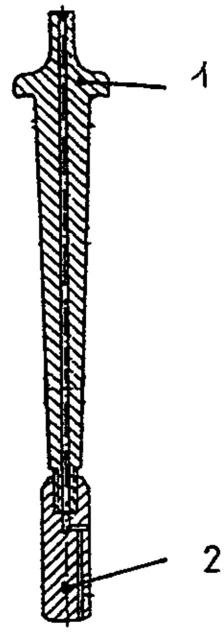


Figure N° 4 : Schematic diagram of the Latex atomiser (dimensions in mm)

1 - Compressed air feeding pipe
2 - Nozzle
3 - Detailed diagram of the nozzle
4 - Three holes ∅ 1,6 equally spaced
5 - Three holes ∅ 0,35



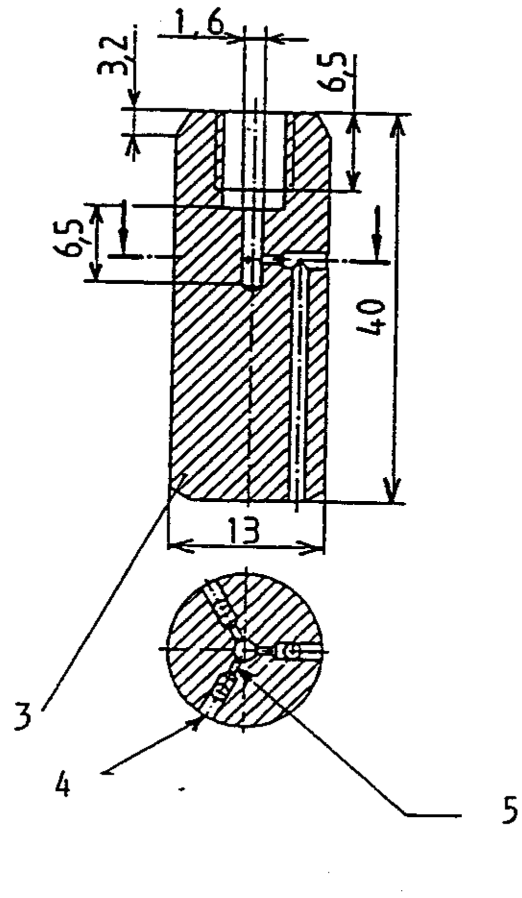
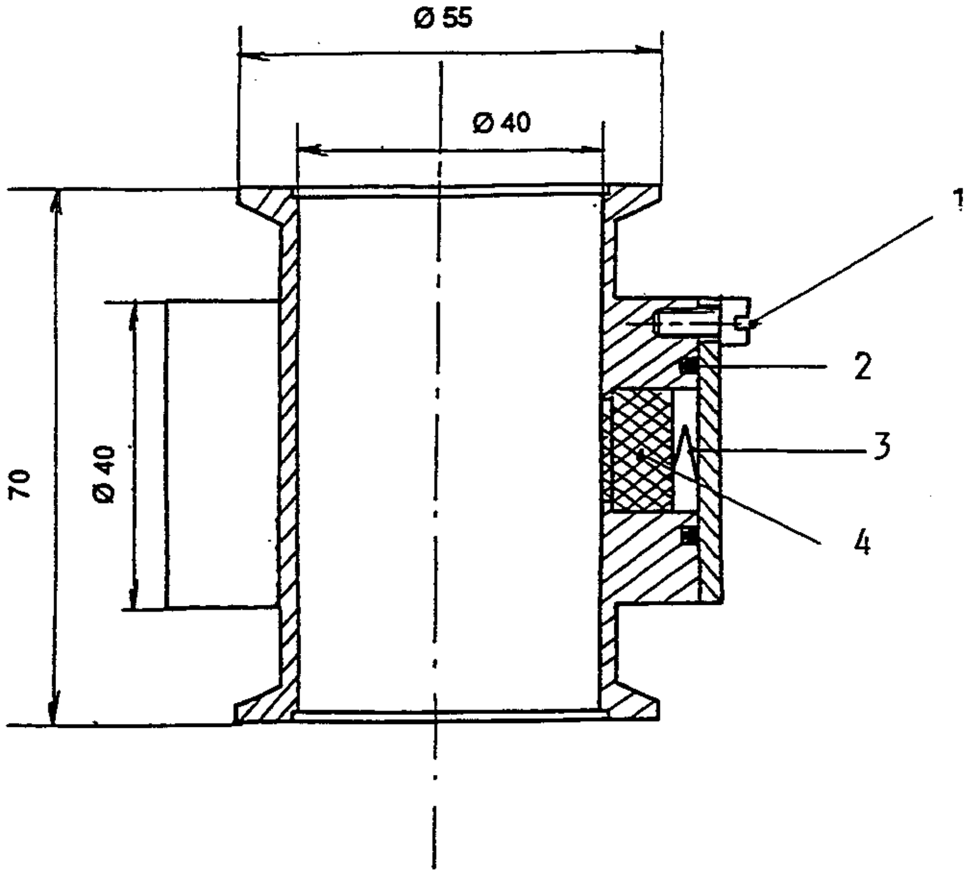


Figure N° 5 : Schematic diagram of the source holder for the aerosol neutralizer (dimensions in mm)

1 -Three fastening screws
2 - O ring seal
3 - Blad spring
4 - SAC 2 sources (3,7 MBq each)
5 - Three equally separated housings for SAC 2 sources



SECTION AA

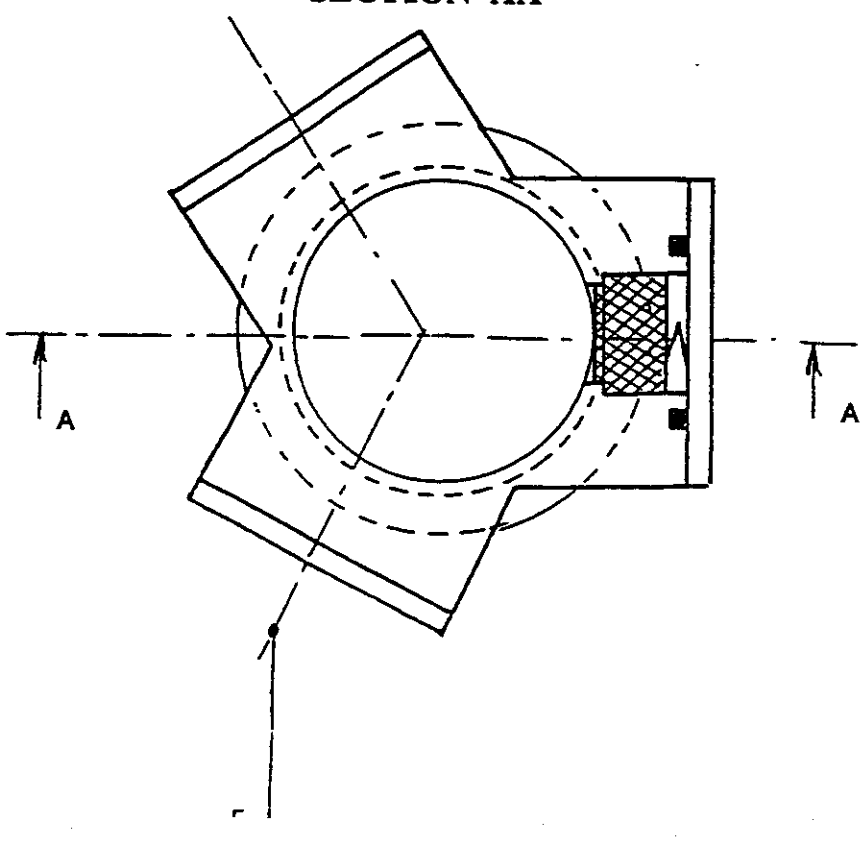
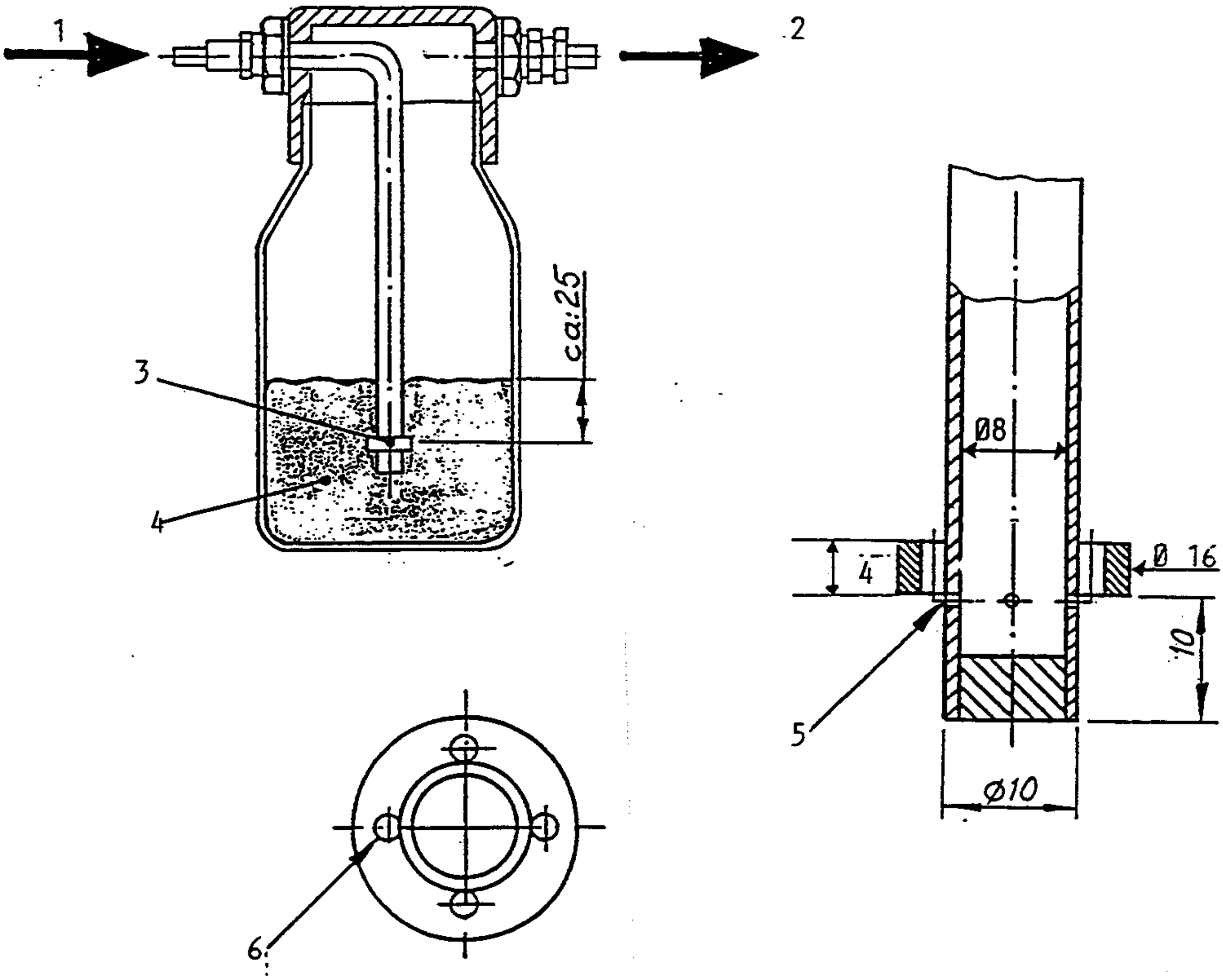


Figure N° 6 : Schematic diagram of DEHS particle generation (dimensions in mm)

1 - Particle free air (pressure 17 kPa)
2 - Aerosol to test rig
3 - Laskin nozzle
4 - DEHS
5 - Four Ø 1,0 holes 900 apart top edge of holes just touching bottom of collar
6 - Four Ø 2,0 holes next to tube in line with radial holes

DEHS is the same as DES Di (2-ethylhexyl) Sebacate or Bis (2-ethylhexyl) Sebacate or DOS (Dioctylsebacate)
DEHS/DES/DOS - formula
$C_{26} H_{50} O_4$
DEHS :

Density (kg/m^3)	915
Flash point (C°)	215
Refractive index	1,451
Viscosity (cst = 10^{-6} m^2/s)	22
CAS no	122 - 62 - 3



APPENDIX A

Test report according EUROVENT document 4/9
Presentation of data

APPENDIX A

TEST REPORT ACCORDING EUROVENT DOCUMENT 4/9

PRESENTATION OF DATA

1. GENERAL

Report N° :
Testing organisation :
Date of test :
Test requested by :

2. FILTER TESTED

Manufacturer :
Model :
Dimensions :
Effective filtering area :
Filter type :
Additional information :

3. TEST RESULTS

The measured and calculated values for pressure drop, arrestance, fractional efficiency and weighted efficiency should be reported in tables and graphs.

3.1 Summary

Test air flow rate (m^3/s) :
Initial pressure drop at test air flow rate (Pa) :
Weighted fractional efficiency (0,4 µm at ΔP = 450 Pa) :
Dust holding capacity (ΔP = 450 Pa) :
Average arrestance (ΔP = 450 Pa) :
Filter class :

3.2 Graphs

- Pressure drop vs dust feed
- Fractional efficiency after different dust loading phases vs. Particle size
- Arrestance vs. Dust feed

3.3 Table

A summary of weighted fractional efficiency vs particle sizes 0.25, 0.4, 0.5, 1.0, 2.0 and 2,5 μm at the different dust loading phases.

The table should also include average arrestance and dust holding capacity values.

APPENDIX B

APPENDIX B

All pressure drop measured during the test should be corrected to a reference air density of 1,20 (1,1987)kg/m^3 which corresponds to air conditions : temperature 20°C, barometric pressure 101,325 kPa, relative humidity 50 %. However, as long as the air density is between 1,16 and 1,24 kg/m^3 no corrections need to be made.

The pressure drop of a filter can be expressed as :

$$\Delta p = c\,(q_V)^n \quad (1)$$

Where

$$c = k\,\mu^{2-n}\,\rho^{n-1} \quad (2)$$

and Δp pressure drop, Pa; q_V air flow rate, m^3/s; n exponent; k constant; μ dynamic viscosity of air, Pa.s; ρ air density, kg/m^3

and	Δp pressure drop, Pa	k constant
	q_V air flow rate, m^3/s	μ dynamic viscosity of air, Pa.s
	n exponent	ρ air density, kg/m^3

The readings of the air flow measuring system shall be convened to volumetric air flow rate at the conditions prevailing at the inlet of the tested filter. With these values of air flow rates and the measured Pressure dropes one can determine exponent n from (1) using a least square technique.

With a known value of exponent n the measured pressure drops can be corrected to reference air conditions using equation (3)

$$\Delta p_o = \Delta p \left(\frac{\mu_o}{\mu}\right)^{2-n} \left(\frac{\rho_o}{\rho}\right)^{n-1} \quad (3)$$

where the unsubscripted quantities refer to the values at the conditions of the test and the subscripted quantities to values at the reference air conditions :

(ρ_o = 1,1987kg/m^3, μ_o = 18,097 . 10^{-6} Pa.s).

The exponent n is usually determined only for a clean filter. During the dust loading phase exponent n an change. As it is undesirable to measure pressure drop 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) at temperature t (°C), barometric pressure p (Pa) and relative humidity φ *(%)* can be obtained by the equation

$$\rho = \frac{p - 0{,}378 p_W}{287{,}06(t + 273{,}15)} \qquad (4)$$

where P_W (Pa) is the partial vapor pressure of water in air given by the equation

$$p_W = \frac{\varphi}{100} p_{WS} \qquad (5)$$

and P_{WS} (Pa) is the saturation vapor pressure of water in air at temperature t (°C) obtained from equation

$$p_{WS} = \exp\left[59{,}484085 - \frac{6790{,}4985}{t + 273{,}15} - 5{,}02802 \, . \, \ln(t + 273{,}15)\right] \qquad (6)$$

The dynamic viscosity μ (Pa.s) at a temperature t (°C) can be obtained from equation

$$\mu = \frac{1{,}455.10^{-6}(t + 273{,}15)^{0{,}5}}{1 + 110{,}4/(t + 273{,}15)} \qquad (7)$$

APPENDIX C

Example of calculation of the fractional efficiency

1. COUNTINGS

Example for determination of initial fractional efficiency.

3 Filter EU7

Particles : latex

Particle counter : LASAIR 210

Sampling rate : 28,3 l/mn

Sampling time : 30 secondes

	UPSTREAM counts						
particle diameter (µm)	**N_1**	**N_2**	**N_3**	**N_4**	**N_5**	**N_6**	**N_7**
0,2 - 0,3	65495	65129	64694	61934	60843	59748	58833
0,3 - 0,5	39659	38767	38100	36267	34951	34066	33516
0,5 - 0,7	20335	19876	19349	18314	17391	17104	16725
0,7 - 1,0	16592	15885	15259	14102	13519	13208	12637
1,0 - 2,0	18097	16141	15580	14403	13626	13308	12868
2,0 - 3,0	5378	4581	4485	3960	3883	3714	3573
3,0 - 5,0	1470	1234	1124	1069	1032	948	912

	DOWNSTREAM counts					
particle diameter (µm)	**n_1**	**n_2**	**n_3**	**n_4**	**n_5**	**n_6**
0,2 - 0,3	29964	29403	28362	27713	27406	26068
0,3 - 0,5	11595	11109	10686	10464	10282	9664
0,5 - 0,7	3160	2986	2875	2729	2707	2491
0,7 - 1,0	1251	1154	1109	1151	1033	973
1,0 - 2,0	445	399	387	348	376	299
2,0 - 3,0	22	26	23	14	24	14
3,0 - 5,0	3	1	2	3	2	5

2. FRACTIONAL EFFICIENCY AND UNCERTAINTY

4.

Example for the size range 0,3 µm - 0,5 µm of the initial fractional efficiency.

counting number	**UPSTREAM particle count**	**DOWNSTREAM particle count**	**efficiency (%)**
1	39659		
2		11595	$E_{0,1} = 70,4$
3	38767		
4		11109	$E_{0,2} = 71,1$
5	38100		
6		10686	$E_{0,3} = 71,3$
7	36267		
8		10464	$E_{0,4} = 70,6$
9	34951		
10		10282	$E_{0,5} = 70,2$
11	34066		
12		9664	$E_{0,6} = 71,4$
13	33516		
average initial fractional efficiency			$\bar{E}_0 = 70,8$

$E_{0,1}, E_{0,2}, E_{0,3}, E_{0,4}, E_{0,5}, E_{0,6}$: "point" fractional efficiencies

$\delta = 0,46$ standard deviation

$n = 6$ number of "point" fractional efficiencies

$\upsilon = 5$ degree of freedom

$t_{1-\frac{\alpha}{2}} = 2,57$ value depending on the degree of freedom

$$t_{1-\frac{\alpha}{2}} \frac{\delta}{\sqrt{n}} = 0,48$$

$\bar{E}_0 = 70,8 \pm 0,5$ % at 95 % confidence level

3. FRACTIONAL EFFICIENCY AFTER HOLDING PHASES (*figure C1*)

The fractional efficiency is calculated after each phase corresponding to sequential pressure losses.

particle diameter (µm)	$\overline{E}_0$ (%)	$\overline{E}_1$ (%)	$\overline{E}_2$ (%)	$\overline{E}_3$ (%)	$\overline{E}_4$ (%)	$\overline{E}_5$ (%)
0,2 - 0,3	54,9	66,1	83,4	89,8	91,9	92,5
0,3 - 0,5	70,8	81,0	91,2	93,7	95,6	95,7
0,5 - 0,7	84,7	93,7	97,2	98,4	98,8	98,9
0,7 - 1,0	92,3	97,1	99,0	99,4	99,5	99,6
1,0 - 2,0	97,5	98,8	99,8	99,9	99,8	99,8
2,0 - 3,0	99,5	99,7	99,9	99,9	99,9	99,8
3,0 - 5,0	99,7	99,8	100	99,9	100	100

$\overline{E}_0$: $\Delta P =$ 120 Pa (initial efficiency)

$\overline{E}_1$: $\Delta P =$ 150 Pa

$\overline{E}_2$: $\Delta P =$ 200 Pa

$\overline{E}_3$: $\Delta P =$ 300 Pa

$\overline{E}_4$: $\Delta P =$ 400 Pa

$\overline{E}_5$: $\Delta P =$ 450 Pa

4. WEIGHTED FRACTIONAL EFFICIENCY (*figure C2*)

$$E_j = \sum_{i=0}^{n-1} \left[\left(\frac{E_{i,j} + E_{i+1,j}}{2} \right) \frac{M_{i+1}}{M} \right]$$

Example for a final pressure drop of 450 Pa.

$n = 5$	$M_1 = 30$ g	$M_2 = 40$ g	$M_3 = 30$ g
	$M_4 = 15$ g	$M_5 = 10$ g	$M = 125$ g

$E_{0,25} = 77{,}5$ %

$E_{0,40} = 87{,}0$ %

$E_{0,60} = 95{,}2$ %

$E_{0,85} = 97{,}8$ %

$E_{1,50} = 99{,}3$ %

$E_{2,50} = 99{,}8$ %

$E_{4,00} = 99{,}9$ %

figure C1. Fractional efficiency after loading phases.

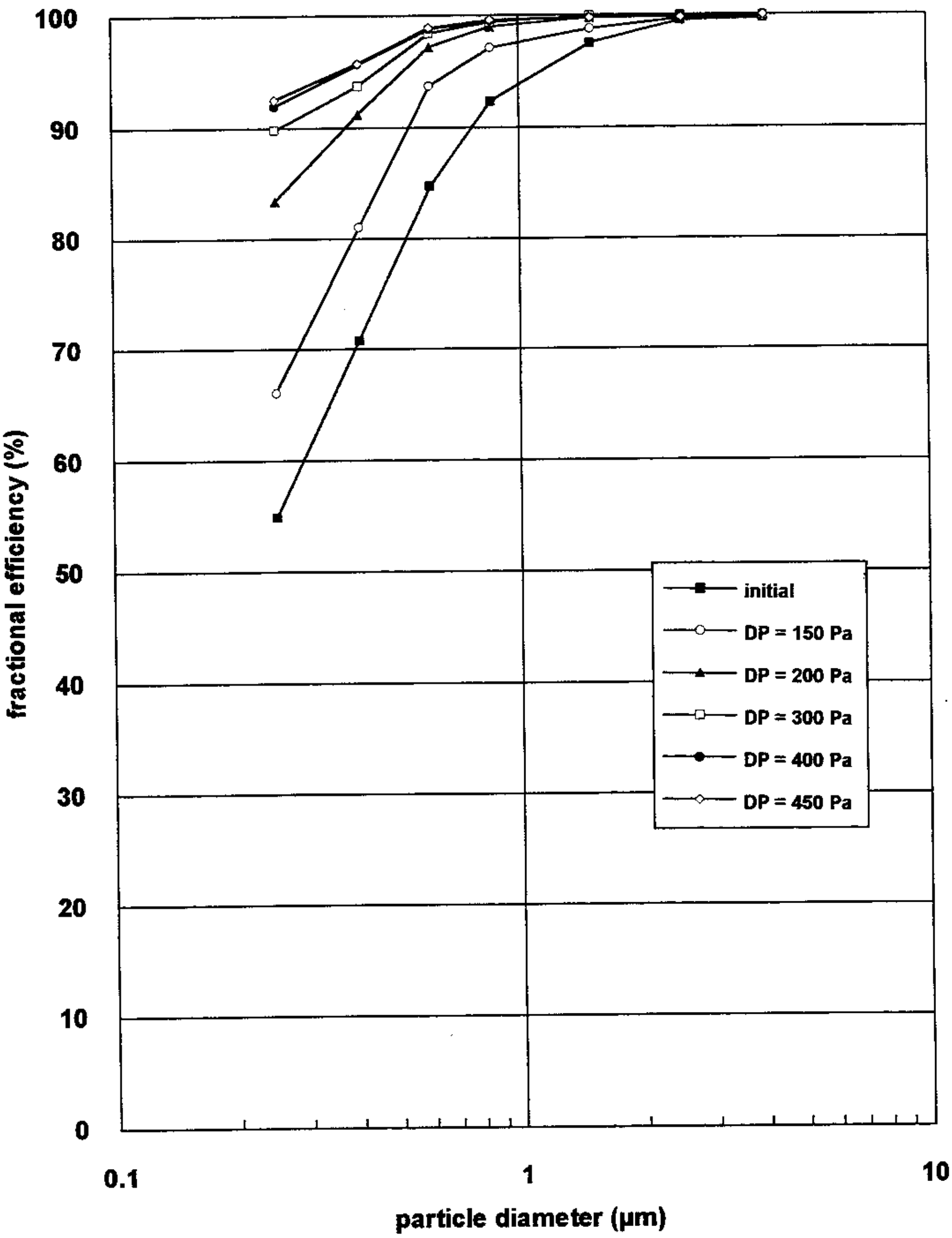
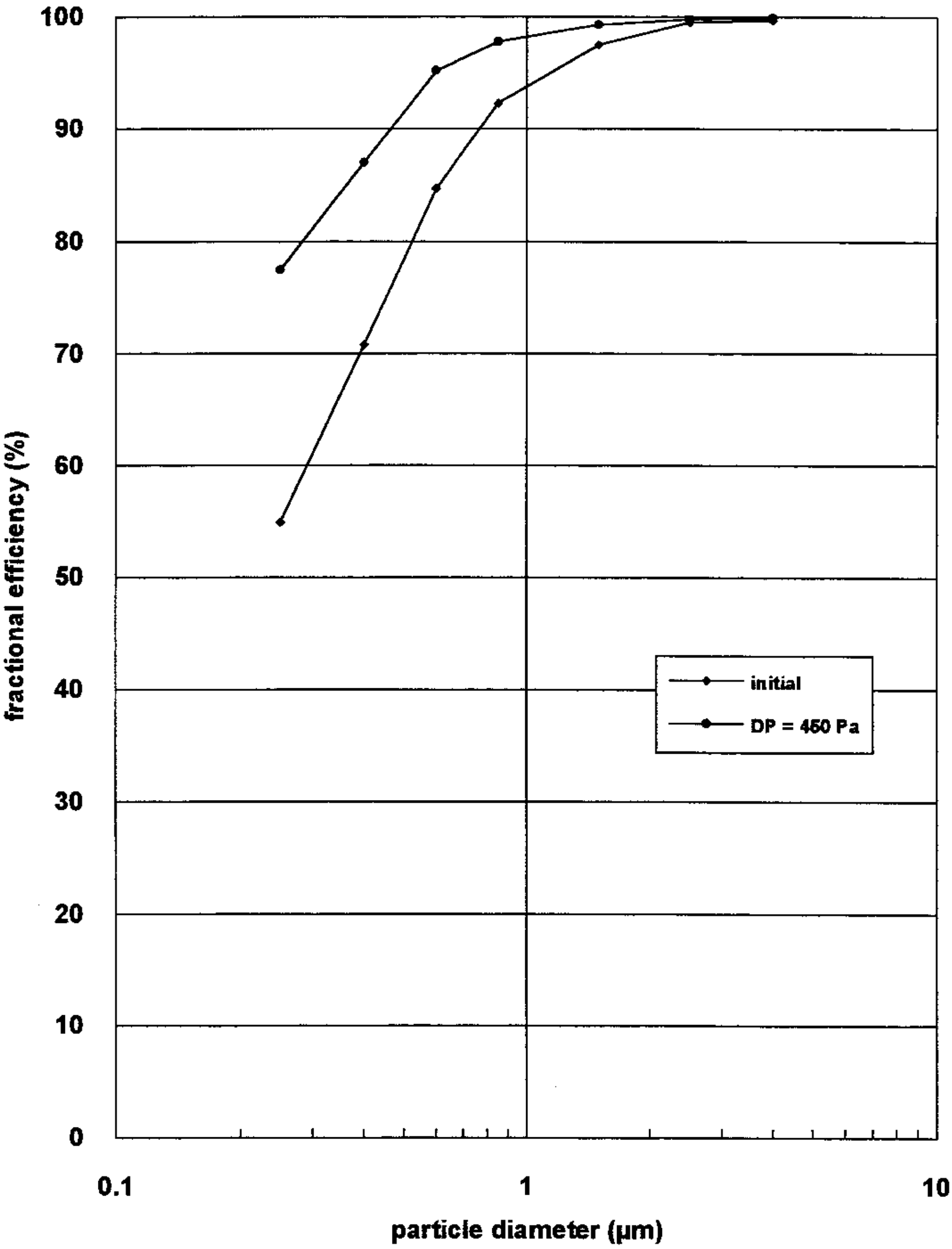


figure C2. Weighted fractional efficiency.



APPENDIX D

APPENDIX D

Fractional Efficiency Classification of FINE - and COARSE - Filters

EUROVENT recommends to group filters in different classes EU1 to EU9 depending on the average efficiency of 0.4 µm particles tested according to EUROVENT 4/9.

- The air flow shall be 0.944m3/s (3400 m3/h). if the manufacturer does not notify any rated air flow rate.
- 250 Pa final pressure drop for Coarse (G) filters (EU1 - EU4).
- 450 Pa final pressure drop for Fine (F) filters (EU5 - EU9).

Classification according to EUROVENT 4/9 and CEN EN 779: 1993

EUROVENT 4/9 class	Average Arrestance % synthetic dust	Average Efficiency % 0.4 µm particles	CEN EN 779* class
EU1	$A_m<65$		G1
EU2	$65\leq A_m<80$		G2
EU3	$80\leq A_m<90$		G3
EU4	$90\leq A_m$		G4
EU5		$40\leq E_m<60$	(F5)
EU6		$60\leq E_m<80$	(F6)
EU7		$80\leq E_m<90$	(F7)
EU8		$90\leq E_m<95$	(F8)
EU9		$95\leq E_m$	(F9)

* In CEN EN 779 the classification system is based on using letters and figures G1, G2, G3, G4 for Coarse filters and F5 ... F9 for Fine filters. The Fine Filters are classified according to the Dust Spot Efficiency, but gives figures comparative to 0.4 µm Efficiency.

Remarks :

- In CEN EN 779 the classification is based on 250 Pa respective 450 Pa final pressure loss while for instance CEN TC/156 recommends a lower final pressure drop for classification of filters (max 150 Pa for G1-G4, 250 Pa for F5-F7 and 350 Pa for F8-F9) in air handling units. The EUROVENT 4/9 also specifies that average efficiency for different particles sizes should be calculated at different final pressure drops.
- Depending on operating conditions certain electrostatically charged filter materials could be neutralised and loose efficiency. The electrostatic effect could be verified by testing a piece of neutralised filtermaterial.