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Test methods for assessing the performance of gas-phase air cleaning media and devices for general ventilation —

Part 2:
Gas-phase air cleaning devices (GPACD)

Méthodes d'essai pour l'évaluation de la performance des médias et des dispositifs de filtration moléculaire pour la ventilation générale —

Partie 2: Dispositifs de filtration moléculaire (GPACD)

Reference number
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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.

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

ISO 10121-2 was prepared by Technical Committee ISO/TC 142, *Cleaning equipment for air and other gases*.

ISO 10121 consists of the following parts, under the general title *Test methods for assessing the performance of gas-phase air cleaning media and devices for general ventilation*:

— *Part 1: Gas-phase air cleaning media (GPACM)*

— *Part 2: Gas-phase air cleaning devices (GPACD)*

Introduction

There is an increasing use and need for gas-phase filtration in general filtration applications. This demand can be expected to increase rapidly due to the increasing pollution problems in the world together with an increasing awareness that solutions to the problems are available in the form of filtration devices or, phrased more technically, gas-phase air cleaning devices (GPACD). The performance of devices relies to a large extent on the performance of a gas-phase air cleaning media (GPACM) incorporated in the device. Still applications and device performance are often poorly understood by the users and suppliers of such media and devices. Media tests may also be adequate to offer data for real applications if actual low concentrations (< 100 ppb) and longer exposure times (>weeks) can be used in the test, provided that the geometrical configuration, packing density and flow conditions of the small-scale test specimen are equal to those used in the real applications. Such tests are however not included in the scope of ISO 10121. ISO 10121 attempts to increase understanding and communication by supplying a more standardized interface between media suppliers, device suppliers and end users. At present, standards exist for general ventilation in Japan[1] by JIS, automotive filters by ISO[4], in-duct sorptive media gas-phase air-cleaning devices by ASHRAE[7] and for adsorptive media by ASHRAE[8] and ASTM[9]. No international standard for general filtration exists today.

This part of ISO 10121 prescribes methods, test equipment, data interpretation and reporting for gas-phase air cleaning devices intended for the removal of gas-phase contamination from air in general ventilation applications.

In addition, information is given in a number of annexes:

- Annex A describes the normative validation procedure in detail in a tabulated form.
- Annex B gives a list of possible test gases, generation sources and suggests suitable analysis equipment for common test gases in addition to reference techniques given for the simplified benchmark setup in Clause 5.5.
- Annex C discusses different test stand designs.

A general introduction to molecular filtration and molecular filtration testing can be found in the scientific literature.

ISO 10121 aims to provide laboratory test methods for media and devices which are used for removal of gas-phase contaminants from air in general ventilation. It consists of two parts:

- ISO 10121-1 covers three different media configurations and is targeted towards giving a standardized interface between media suppliers and producers of air cleaning devices. It may also be used between media suppliers and end customers with regards to loose fill media properties.
- This part of ISO 10121 aims to give a standardized interface between suppliers of air cleaning devices and end customers seeking the most cost efficient way to employ gas-phase filtration.

Test methods for assessing the performance of gas-phase air cleaning media and devices for general ventilation —

Part 2:
Gas-phase air cleaning devices (GPACD)

1 Scope

This part of ISO 10121 aims to provide an objective test method to estimate the performance of any full size gas filtration device (GPACD) for general filtration regardless of media or technique used in the device. In fact, the goal of this part of ISO 10121 is to avoid relating the test data to internal parameters altogether. The benefit with this approach is that customers of GPACDs will be able to concentrate on price/performance and suppliers will have access to a normative and objective test standard that will not require the release of proprietary information or reverse engineering of the product.

To ensure objectivity for test equipment suppliers, no specific design of the test apparatus is specified. Instead requirements of apparatus properties and validation tests are specified. However, different design examples in present use are outlined. This part of ISO 10121 can also be used with technologies such as scrubbers, absorbers, non-sorptive devices or packed columns as long as they fit into the test apparatus, can be meaningfully judged by the test method and are intended for general ventilation applications, both residential and non residential. Nuclear and military applications are specifically excluded.

2 Normative references

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

ISO 29464:2011, *Cleaning equipment for air and other gases — Terminology*

EN 15805:2009, *Particulate air filters for general ventilation — Standardised dimensions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29464 and the followings apply.

3.1
absorption
transport and dissolution of a sorbate into an absorbent

3.2
adsorbate
molecular compound in gaseous or vapour phase that will be retained by the adsorbent material of the media

3.3
adsorbent
material that collects adsorbates on its surface through physical or chemical processes

3.4
adsorption
process in which the molecules of a gas adhere by physical or chemical processes to the exposed surfaces of solid substances, both the outer surface and inner pore surface, with which they come into contact

3.5
breakthrough
amount of gaseous contaminant in the effluent of a GPACD

Note 1 to entry: See "penetration".

3.6
breakthrough vs. time curve
plot of contaminant penetration versus time for a particular challenge concentration and airflow

[Source: ISO 29464:2011; 3.2.67]

3.7
bypass
proportion of the challenge air stream that passes around the GPACD without contacting the media

[Source: ISO 29464:2011; 3.2.64]

3.8
capacity
m_s
amount (mass or moles) of a selected sorbate that can be contained in the filter media of a GPACD at given test conditions, and a specific end point

Note 1 to entry: Capacity can also be negative during desorption.

3.9
challenge concentration
concentration of the test contaminant(s) of interest in the air stream prior to filtration cf. challenge air stream

3.10
challenge compound
chemical compound that is being used as the contaminant of interest for any given test

3.11
challenge air stream
test contaminant(s) of interest diluted to the specified concentration(s) of the test prior to filtration

[Source: ISO 29464:2011; 3.2.16]

3.12
channeling
disproportionate or uneven flow of gas through passages of lower resistance due to inconsistencies in the design or production of a GPACD, particularly in packed granular beds

[Source: ISO 29464:2011; 3.2.17]

3.13
chemisorption
chemical adsorption
trapping of gaseous or vapour contaminants on an adsorbent involving chemical reaction on the adsorbent surface

[Source: ISO 29464:2011; 3.2.19]

3.14
concentration
C_n
quantity of one substance dispersed in a defined amount of another

Note 1 to entry: Indices "n" denote location.

[Source: ISO 29464:2011; 3.2.21]

3.15
contaminant
substance (solid, liquid, or gas) that negatively affects the intended use of a fluid

[Source: ISO 29464:2011; 3.2.23]

3.16
decay time
t_{Dn}
time required for the gas contaminant monitoring instrument to record a reduction from greater than 95 % of the challenge concentration to less than 5 % of the challenge concentration ($t_{\mathrm{END}} - t_{\mathrm{VC}}$) at the downstream sampling point for a specific test (n), challenge gas and gas flow after stopping the injection of the contaminant with no GPACD present

3.17
desorption
process in which adsorbate molecules leave the surface of the adsorbent and re-enter the air stream

Note 1 to entry: Desorption is the oppsite of adsorption.

3.18
downstream
area following the filter in the direction of fluid flow

3.19
efficiency vs. time curve
plot of the GPACD removal efficiency against time over the duration of a challenge test for a particular challenge concentration and airflow

[Source: ISO 29464:2011; 3.2.31]

3.20
efficiency vs. capacity curve
plot of the GPACD removal efficiency against the integrated capacity over the duration of a challenge test for a particular challenge concentration and airflow

[Source: ISO 29464:2011; 3.2.28]

3.21
face velocity
air flow rate divided by the cross sectional area of the GPACD

3.22
gas
substance whose vapour pressure is greater than the ambient pressure at ambient temperature

[Source: ISO 29464:2011; 3.2.44]

3.23
gas-phase air cleaning device
GPACD
assembly of a fixed size enabling the removal of specific gas- or vapour-phase contaminants

Note 1 to entry: It is normally box shaped or fits into a box of dimensions between 300 × 300 × 300 mm up to approximately 610 × 610 × 610 mm or 2 × 2 × 2 feet.

[Source: ISO 29464:2011; 3.2.45, modified – NOTE has been modified.]

3.24
GPACD face area
cross-sectional area of the GPACD also including a header frame if so equipped when viewed from the direction of air flow using exact dimensions

3.25
gas-phase air cleaning media
GPACM
media or media configuration used for filtering a contaminant

EXAMPLE a porous film or fibrous layer; a bead shaped, granular or pelletized adsorbent (or chemisorbent); a support structure of fabric, foam or monoliths containing adsorbent in the form of small sized particles, granules, spheres or powder; a woven or nonwoven fabric completely made from an adsorbent material

3.26
initial efficiency
efficiency of an unexposed filter or GPACD calculated as soon after the start of a test as is possible

Note 1 to entry: For gas-phase, this should be calculated as soon as a steady reading can be obtained.

3.27
molecular contamination
contamination present in gas or vapour phase in an air stream and excluding compounds in particulate (solid) phase regardless of their chemical nature

3.28
ppb(v)
parts per billion by volume
concentration measure normally used to record ambient levels of outdoor pollution

Note 1 to entry: Units are mm^3/m^3.

3.29
ppm(v)
parts per million by volume
concentration measure normally used to record pollution levels in, for example, work place safety

Note 1 to entry: Units are cm^3/m^3 and ml/m^3.

3.30
penetration
P
ratio of contaminant concentration downstream of the filter to the upstream (challenge) concentration, sometimes expressed as a percentage

Note 1 to entry: Related to efficiency (E) by the expression: $E = (1 - P) \times 100\ \%$.

[Source: ISO 29464:2011; 3.2.51]

3.31
physisorption
physical adsorption
attraction of an adsorbate to the surface, both outer surface and inner pore surface, of an adsorbent by physical forces (Van der Waals forces)

[Source: ISO 29464:2011; 3.2.52]

3.32
pore

minute passageways through which fluid may pass or that expose to the fluid stream the internal surfaces of an adsorbent media

[Source: ISO 29464:2011; 3.2.55]

3.33
pressure drop

Δp

difference in pressure between two points in an airflow system at specified conditions, especially when measured across a GPACD

3.34
removal efficiency

E

fraction or percentage of a challenge contaminant that is removed by a GPACD at a given time

3.35
retentivity

m_r

measure of the ability of an adsorbent or GPACD to resist desorption of an adsorbate

Note 1 to entry: Computed as the residual capacity (fraction remaining) after purging the adsorbent with clean, conditioned air only, following challenge breakthrough.

[Source: ISO 29464:2011; 3.2.61, modified – NOTE has been added]

3.36
residence time

t_r

relative time that an increment of fluid (or contaminant) is within the boundaries of the media volume (e.g. a bed of granules or a non-woven sheet)

Note 1 to entry: In typical use and in this part of ISO 10121, this value neglects the fact that the media and possible support structures occupy a significant portion of the volume of the bed [$t_\mathrm{R} = V$ (total bed volume) $/Q$ (air flow rate)].

[Source: ISO 29464:2011; 3.2.71]

3.37
rise time

t_Rn

time between initial injection of contaminant and reaching 95 % of the challenge concentration for an empty duct ($t_0 - t_\mathrm{VO}$) measured at the downstream sampling location for a specific test (n), challenge gas and gas flow

3.38
sorbate

molecular compounds that are retained in the adsorbent of the device

Note 1 to entry: The sorbate will refer to both intended compounds like the selected challenge gas in a test or pollution in real service but also any other compound present in the air stream e.g. gases and vapours.

3.39
sorption

process in which fluid molecules (gas or liquid) are removed by a GPACD media by absorption or adsorption

3.40
vapour
substance whose vapour pressure is less than the ambient pressure at ambient temperature, but is present in the gas phase through evaporation or sublimation

[Source: ISO 29464:2011; 3.2.74]

4 Symbols and abbreviated terms

4.1 Symbols

C_U	upstream concentration [ppb, ppm] measured at a position *X* mm before the device
C_D	downstream concentration [ppb, ppm] measured at a position *Y* mm after the device
Δp	pressure drop measured over the tested device [Pa]
E_I	initial removal efficiency [%] for the device measured at a low (< 1 ppm) challenge concentration during the initial efficiency test in 6.3
E_C	removal efficiency [%] for the device measured at the challenge concentration selected during the capacity test in 6.4
E_END	efficiency recorded at stop test time or value agreed between user and supplier [%]
m_r	retentivity [g],[mol]; the amount withheld by the device after ventilating with clean air at the same flow selected during the capacity test until C_D reaches a specified value close to zero.
m_sEI	the integrated amount in moles or grams of challenge compound accumulated during the initial efficiency test in Formula (2)
m_sU	the integrated amount in moles or gram of challenge compound accumulated during measurement at the upstream position in Formula (3)
m_sD	the integrated amount in moles or grams of challenge compound accumulated during measurement at the downstream position in Formula (3)
m_s	the total integrated amount [g], [mol] of challenge compound accumulated during the whole challenge test
p_U	upstream pressure [Pa] measured at a position *X* mm before the device
p_D	downstream pressure [Pa] measured at a position *Y* mm after the device
Q	flow used in test (normally the rated flow for the tested device) [$\mathrm{m^3/h}$] measured at a position *Z* mm after the device
RH_U	upstream relative humidity [%] measured at a position *X* mm before the device
RH_D	downstream relative humidity [%] measured at a position *Y* mm after the device
t_0	start time. The time when C_U (contamination concentration upstream) equals the selected challenge concentration for an empty duct
t_END	time when a test is stopped. The time when a desired concentration or other termination criteria have been met in any of the prescribed test procedures (agreed between user and supplier)

t_{DC}	decay time for challenge concentration
t_{DE}	decay time for initial efficiency concentration
t_{RC}	rise time for challenge concentration
t_{RE}	rise time for initial efficiency concentration
t_{VC}	time noted at challenge gas valve closure
t_{VO}	time noted at challenge gas valve opening
T_U	upstream temperature [°C] measured at a position X mm before the device
T_D	downstream temperature [°C] measured at a position Y mm after the device
v_f	face velocity [m/s] calculated from flow and cross sectional area of device
X	a position X positioned sufficiently far ahead of the device to allow undisturbed measurements, determined in the validation, Annex A. At the distance X, the concentration of challenge compound is sufficiently mixed and uniform over the cross sectional area of the duct while not being so close to the device that the device itself obscures the flow, pressure drop or concentration.
Y	a position Y positioned sufficiently far after the device to allow undisturbed measurements, determined in the validation section, Annex A. At the distance Y the concentration of penetrating challenge compound is sufficiently mixed and uniform to represent the average of the device and not being so close to the device that the device itself obscures the flow, pressure drop or concentration.
Z	a position Z positioned sufficiently far after the device to permit a reliable flow measurement using an orifice device, determined in the validation, Annex A

4.2 Abbreviated terms

ASHRAE	American Society of Heating Refrigerating and Air-conditioning Engineers
ASTM	ASTM International, formerly known as the American Society for Testing and Materials (ASTM)
HEPA	High Efficiency Particulate Air (filter)
JIS	Japanese Industrial Standards
JSA	Japanese Standards Association
MSDS	Material Safety Data Sheet
NMP	n-Methyl –2-pyrrolidone
TLV	threshold limit value. Amount of a chemical substance is a level to which it is believed a worker can be exposed day after day for a working lifetime without adverse health effects.
VOC	Volatile Organic Compound

5 Testing of GPACDs

5.1 General

This part of ISO 10121 shows how to measure four key parameters that reflect the performance of a GPACD. The four parameters are:

- pressure drop, Δp
- capacity, m_s
- removal efficiency, E
- retentivity, m_r

These parameters are:

- linked to each other;
- different for different gases (exception: Δp is not affected);
- different for different concentrations of the same gas (exception: Δp is not affected);
- affected by other gases present, by temperature, by humidity and by the air flow.

The ideal case would be to test at the exact parameter values and concentration present in the intended application, but then the test time would be as long as the real service life, e.g. years. One way to accelerate the test is to increase the concentration. In this part of ISO 10121 an increased concentration should be agreed between user and supplier. Alternatively, for general benchmark purposes three concentrations are used, one mildly increased for determination of the removal efficiency and two strongly increased for determination of capacity. Besides the key performance parameters other important factors must also be considered. Particles may be emitted downstream, at least during initial start-up, for GPACDs employing loose fill granular and pelletized adsorbents or adsorbent fibres and possibly for other media types as well. This may pose a problem depending on the sensitivity of the specific application and on available particle filtration after the GPACD. Others factors that may be considered are gaseous emissions, corrosion resistance, weight and depth requirements.

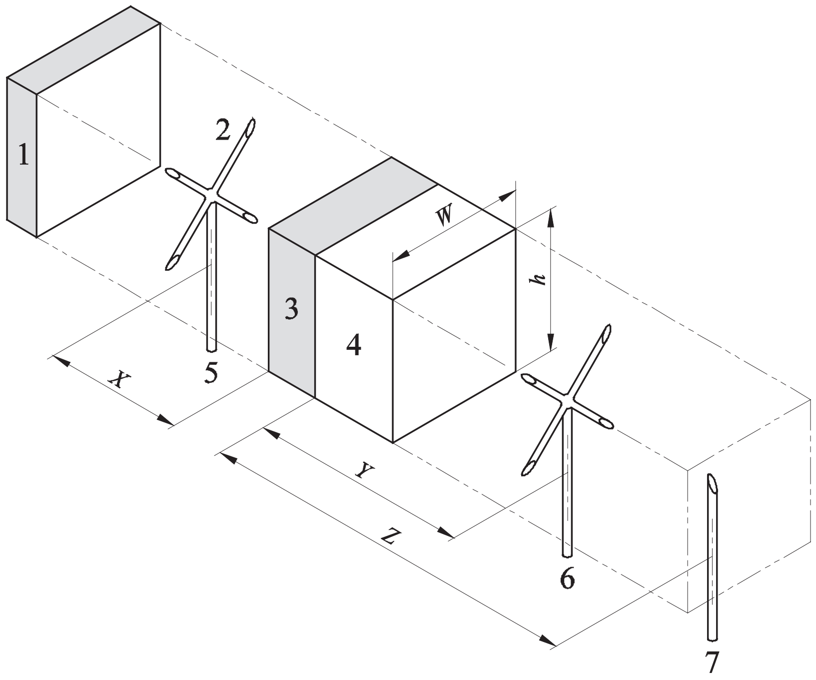
This clause will describe the normative part of the test stand, normative parameters for generation of the challenge air stream and suggest test gases for benchmark purposes and for the case when the pollution in the real application is not yet defined. Clause 6 describes in detail the test sequence for conditioning and for determination of pressure drop, initial removal efficiency, capacity and retentivity in this order.

5.2 Test setup and normative section of test stand

The test equipment can be designed in various ways and it is not the purpose of this part of ISO 10121 to enforce a particular engineering solution or analysis technique. Several designs and analysis techniques are described in the informative annexes. It is the user of this part of ISO 10121 that should select the solution best fitted with regard to equipment availability and other concerns. There are some key parameters that WILL SEVERELY SKEW THE DATA or make benchmark testing impossible unless they are controlled within specified limits. These parameters are displayed in the normative test section in Figure 1 and Table 1. The adherence to these levels must be demonstrated by the tests provided in the validation section.

The GPACD must be installed without leakages or bypass. The air stream should be uniformly mixed and with equal velocity and upstream concentration over the cross section. Recorded parameters are concentration C, pressure p, temperature T and relative humidity RH in two positions. The air flow is recorded at a third position.

The inner dimension (ID) of the duct, width and height as indicated in Figure 1, should be 610 × 610 mm along the whole GPACD section. Devices in actual (full) size must always be tested. Flat adaptor plates are used for GPACD < 610 × 610 mm. In addition, a duct with internal dimension (ID) 300 × 300 mm is permitted for testing of a full size 300 × 300 mm GPACD. Acceptable sizes of GPACD for testing are 300 × 300 mm to 610 × 610 mm. The length of the GPACD section shall be greater that the inner dimension (ID) of the duct, ideally 1–3 × ID. Any changes in duct diameter before and after the GPACD section should be designed so that the flow is uniform over the entire GPACD cross section.



Key

1	diffusor and Δ*p* device
2	sampling points – should be of “fork” type or similar with multiple inlet points to make a compounded sample over the whole cross section
3	GPACD under test
4	GPACD section of test duct
5	upstream sampling point for T_U, RH_U, p_U and C_U at *X* mm before the GPACD
6	Downstream sampling point for T_D, RH_D, p_D and C_D at *Y* mm after the GPACD
7	*Q*, air flow rate sampling point at *Z* mm after the GPACD
W	internal width of the test duct along the GPACD section, 3+4
h	internal height of the test duct along the GPACD section, 3+4

Figure 1 — Normative section of test stand showing ducting, measurement parameters and sampling points

5.3 Raw data, sampling accuracy and normative generation parameters

Ideally all measurement parameters in Figure 1 should be measured continuously with a computerized logging system. The sampling frequency should be fast enough to produce smoothly changing data and not overlook any events. In Table 1 below normative generation parameters in addition to prescribed accuracy are given.

Table 1 — Normative generation parameters, measurement frequency and demands on accuracy during test

Parameter	Normative generation parameters	Unit	Range	Absolute accuracy	Permissible oscillation during test	Measurement frequency
C_U	selected in 5.4 or 5.5	ppb(v)	100 – 100000	± 1,5 %	± 3 %	5min, 1 h, 4 h, 12 h[a]
C_D	n.a.	ppb(v)	1–2 % of C_U – 100 000	± 1,5 %	± 3 %	1 min[b] (or longer if at least 100 pts can be generated down to 50 % efficiency)
T_U	selected in 5.4 or 5.5	°C	n.a.	± 0,5°C	± 0,5°C	same as C_D
T_D	n.a.				n.a.	
RH_U	selected in 5.4 or 5.5	%	n.a.	± 1 % RH	± 3 % RH	same as C_D
RH_D	n.a.				n.a.	
p_U, p_D	–	Pa	–	± 5	± 5	same as C_D
Δp ($p_U - p_D$)	device specific	Pa	–	± 2	± 2	same as C_D
Q, air flow rate	rated air flow (5.4) or face velocity 2,5 m/s (5.5)	m^3/h	n.a.	± 5 %	± 3 %	same as C_D
v_f, face velocity		m/s	n.a.			

[a] Upstream concentration needs, at a minimum, to be measured before and after an individual test sequence.

[b] Measurement duration may need to be longer for concentration to permit low level detection using *ex situ* equipment, e.g. Tenax tubes, resulting in less frequent measurments than every 5 min.

Temperature and relative humidity are normatively specified for benchmark tests (see 5.5) but may also be changed to fit a specific GPACD or application (see 5.4).

5.4 Test parameters selected between user and supplier

5.4.1 General

The normative setup specifies all variables except rated air flow, challenge gas, challenge concentration, temperature, relative humidity and test duration. These parameters will depend on the specification and purpose of the device under test and should be agreed upon between supplier and user.

5.4.2 Air flow rate and face velocity

The **rated air flow** for a GPACD is a construction parameter and the device will not perform as expected if the air flow is different. Typically a device will exhibit improved performance at a lower than rated air flow and reduced performance at a higher than rated air flow.

5.4.3 Challenge gas

The challenge gas selection needs to conform to the intended functionality of the GPACD, e.g. it must be established if the device is designed to remove the selected challenge gas. If possible, the best choice is to use the same gas as in the intended real application. Several known pollutant gases are suggested in Annex B.

5.4.4 Challenge concentration

The challenge concentration will always be a compromise and pose a risk for under- or over-estimating the real life performance of a GPACD. For a GPACD designed to remove organic compounds by physisorption, the measured performance is a direct function of the selected challenge concentration as described by an adsorption vs. concentration isotherm. In addition, a device that performs best in a high concentration test may not be the best in the low concentrations of a real installation. Therefore the lowest practical possible challenge concentration should be used for both the initial efficiency and capacity portions of the test. For a GPACD designed to remove acid or alkaline compounds by chemisorption, a concentration dependence of capacity is not normally seen for challenge concentrations in the normative range if only a chemisorptive mechanism is available. However, organic acids and bases may also be removed by physisorption and also catalytic reactions are known, both phenomena adding to the capacity given by pure chemisorption. The effects of the selected challenge concentration need to be assessed in each individual case.

5.4.5 Temperature and relative humidity

The air temperature can affect the rate of chemical reactions in chemisorption and the ease of physisorption of VOCs. The relative humidity needs to be over a certain minimum value for chemical reactions involving water to proceed. In the case of adsorbents for VOC removal through physisorption, the relative humidity can have quite a strong influence due to competition for adsorption sites between the water in the air and the contaminants. For applications where the expected temperature and/or relative humidity is far from the normative values given in 5.5, it is recommended to use actual application parameters for the test.

5.4.6 Test duration

This is a function of the gas, gas concentration, adsorbent and selected end point of the test. It is possible to define tests with duration from one hour to several months.

Selection of the four parameters above must be agreed upon in each specific case. However, for a first screening of suitable devices for general filtration a simplified benchmark setup is suggested below.

5.5 Simplified benchmark setup

5.5.1 General

For benchmark purposes, a set face velocity, temperature, and relative humidity, along with three concentration levels and three gases are suggested as a best compromise between measurement errors, the resolution of available measurement techniques and acceptable testing times. These are given in Table 2 below. The intention of this setup is to aid in an initial screening of different GPACDs and to establish a performance baseline. It must be stated that this test may not be sufficient enough to determine the best device in a specific application.

5.5.2 Initial removal efficiency test

A low concentration must be used in the determination of the initial efficiency. Ideally one would use the actual concentration of the application, but most likely one would need to increase the concentration due to technical or economic limitations in low level generation and analysis. To ensure that the test does not begin to saturate the filter, a maximum permissible efficiency decay is given. This test will take between 1 h and 3 h.

5.5.3 Challenge test concentration

To ensure that the challenge test can be performed with a test time between 1 h and 12 h, two high concentrations are given: 9 ppm(v) and 90 ppm(v). The higher concentration may be needed in order to ensure that a device is challenged enough to show an efficiency decay of > 10 %. To ensure that the test is challenging the filter enough to produce useful data, a minimum permissible efficiency decay is also given. Data obtained can be used for comparison between different GPACDs providing that the compared data for BOTH were measured at either 9 ppm(v) or 90 ppm(v) with the same gas and at the same face velocity.

5.5.4 Filters for VOC tested with toluene

The goal is to select the lower concentration for toluene whenever possible since the data produced from this concentration will better mirror the actual application. At higher concentrations the isotherms from different adsorbents may change ranking due to pore volume and show an "empty" and easily desorbed capacity not available in the real application. The higher concentration will be needed for very heavy devices with more than 50 kg (100 lbs) of adsorbent. It often gives more useful data to use the lower concentration and to stop the test at a higher end efficiency than to use the higher concentration and run the whole curve down to zero end efficiency.

5.5.5 Filters for acids and bases tested with SO_2 and NH_3, respectively

For acids and bases no direct concentration difference is expected at 9 ppm(v) or 90 ppm(v), so the higher concentration may be used for convenience. However, use caution and consult available data for the adsorbent, this may not be true for all present and future adsorbent systems.

Table 2 — Challenge gases and concentrations for the simplified benchmark test

<table>
<tr><th colspan="9">Challenge gas and concentration for the initial efficiency determination (6.3)</th></tr>
<tr><th>Parameter</th><th>Selected gas</th><th>Challenge level</th><th>Unit</th><th>Reference analysis technique</th><th>Face velocity [m/s]</th><th>T_U [°C]</th><th>RH_U [%]</th><th>Maximum permissible efficiency decay during test[b]</th></tr>
<tr><td>Acid</td><td>SO_2[a]</td><td>450</td><td>ppb(v)</td><td>UV fluorescence[d]</td><td>2,5</td><td>23</td><td>50</td><td>5 %</td></tr>
<tr><td>Base</td><td>NH_3</td><td>450</td><td>ppb(v)</td><td>chemiluminescence[d]</td><td>2,5</td><td>23</td><td>50</td><td>5 %</td></tr>
<tr><td>VOC</td><td>toluene</td><td>5</td><td>ppm(v)</td><td>PID[d] or FID[d]</td><td>2,5</td><td>23</td><td>50</td><td>5 %</td></tr>
<tr><th colspan="9">Challenge gas and concentration for the capacity determination (6.4)</th></tr>
<tr><th>Parameter</th><th>Selected gas</th><th>Challenge level</th><th>Unit</th><th>Reference analysis technique</th><th>Face velocity [m/s]</th><th>T_U [°C]</th><th>RH_U [%]</th><th>Minimum permissible efficiency decay after 12 h[c]</th></tr>
<tr><td>Acid</td><td>SO_2[a]</td><td>9/90[c]</td><td>ppm(v)</td><td>UV fluorescence[d]</td><td>2,5</td><td>23</td><td>50</td><td>>10 %</td></tr>
<tr><td>Base</td><td>NH_3</td><td>9/90 [c]</td><td>ppm(v)</td><td>chemiluminescence[d]</td><td>2,5</td><td>23</td><td>50</td><td>>10 %</td></tr>
<tr><td>VOC</td><td>toluene</td><td>9/(90)[c]</td><td>ppm(v)</td><td>PID[d] or FID[d]</td><td>2,5</td><td>23</td><td>50</td><td>>10 %</td></tr>
</table>

[a] For other acid gases SO_2 may not be representative. In applications for H_2S, NO, NO_2, etc. it may be better to test with the gas in question.

[b] A test for initial efficiency should not decay during the test but this may be the case if the selected low concentration is well beyond challenge capacity of the filter. Therefore, a maximum permissible efficiency decay during the initial efficiecy test is given. A GPACD not filling this demand may still be tested according to 5.4.

[c] The lower or higher concentration is selected depending on filter type/ weight/ purpose/ data sheet. The lower concentration is preferred for toluene while the higher concentration may be needed for all gases to reach the minimum permissible efficiency decay after 12 h.

[d] The reference techniques are the ones preferred in this part of ISO 10121. However, other techniques may be used provided that the test supplier can show doccumented correlation versus the reference technique.

5.5.6 Retentivity test

For devices tested with toluene a retentivity determination is recommended, see 6.5. This test is performed directly after the challenge test simply by keeping the same air flow but with the challenge gas switched off. The decaying downstream concentration is then recorded until the concentration is < 5 % of the original challenge concentration or to a test time of maximum 6 h.

6 Test sequence

6.1 General

This test sequence should be used for testing with both application specific gases and with the simplified benchmark setup. A full test consists of four consecutive parts, one each for the determination of the four key parameters. The first part involves, besides determining Δp, conditioning of the device to be tested. This is necessary before any further test and must always be performed. Depending on the needs of the user and of the specific GPACD to be tested, not all key parameters may need to be determined. It is optional to perform all three remaining parts or a subset of these but at least 6.4 “Capacity determination” should be performed. However, any and all parts performed must conform to the normative part of this part of ISO 10121.

A validation of test stand, generation equipment and analysers must be performed before the test starts (see Clause 7 and Annex A). In particular, if only one analyser is used, the lag times, t_R and t_D, between upstream and downstream measurements must be previously determined for the concentration and flow used in 6.3 and 6.4.

6.2 Conditioning and pressure drop determination

Before any performance measurements are made the device should be conditioned with clean air without challenge gas at correct air flow rate, temperature and relative humidity until a stable and minimal temperature and humidity gradient over the device is reached. The pressure drop at the rated air flow shall be measured and recorded. In addition, the relationship between pressure drop and flow rate shall be determined and reported for 50 %, 75 %, 100 % and 125 % of rated air flow. It should be noted that the Δp values are affected by the test duct and any adaptor plates used in addition to other flow restrictions not caused by the tested device. A duct having minimal flow restrictions should be used and the pressure drop through the duct without the filter should be documented for possible correction of the measured pressure drop across the filter. Probable deviations should be commented in the report.

6.2.1 Procedure

- 1. Select the desired air flow rate (i.e the rated air flow of the device or the air flow for the specific application), temperature, relative humidity, challenge compound and challenge concentration C_U for the device to be tested according to 5.4 or 5.5.
- 2. Calibrate analysis equipment according to Annex A or manufacturer’s recommendations.
- 3. Prepare the test stand and seal it without introducing a GPACD. Prepare the challenge gas source and check that selected challenge gas concentrations can be achieved within the normative accuracy at the desired air flow rate. Determine the rise and decay times according to Clause 7 unless previously known for identical conditions.
- 4. Turn the source off (to exhaust) and let the concentration reach zero.
- 5. Record the pressure drop of the empty duct at each of the flow rates at which the GPACD will be tested. Return to the desired air flow rate.
- 6. Introduce the GPACD into the test stand.
- 7. Increase air flow to the desired air flow rate i.e. the rated air flow of the device or the air flow for the specific application.
- 8. Let the flow stabilize and record the pressure drop Δp.
- 9. Change the air flow to the next percentage increment of the design/rated air flow.

- 10. Repeat steps 8 and 9 for 50 %, 75 % and 125 % of the air flow.
- 11. Return the air flow to the 100 % setting.
- 12. Monitor *T* and *RH* every 1 min. The equilibrium time is reached when the relative difference between readings from the same probe is stabilized within 1 % for RH_U and RH_D and within 0,2 °C for T_U and T_D for at least 15 min for all four parameters. When this is reached, the unit is ready for further testing.

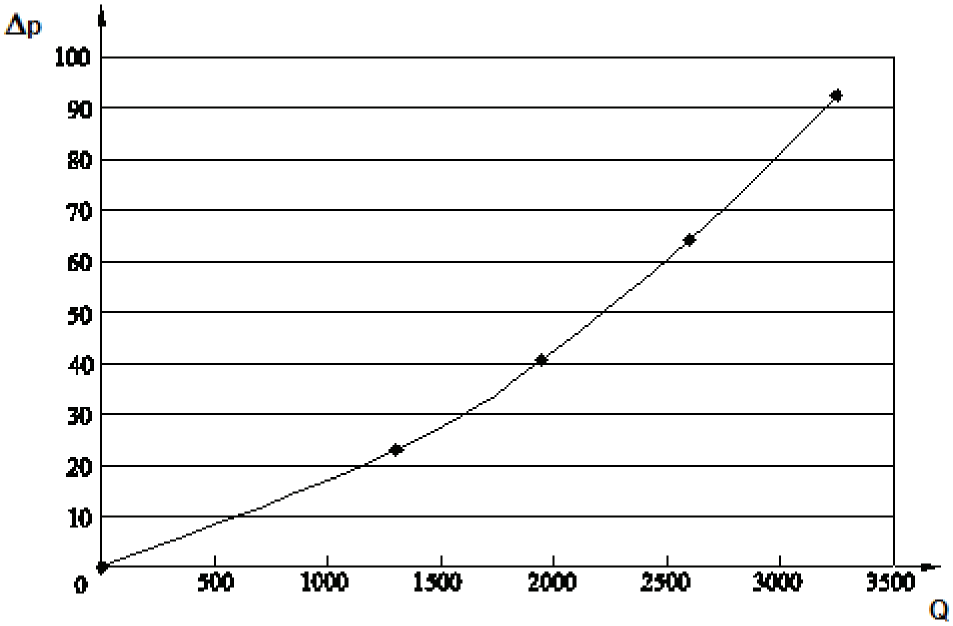
6.2.2 Calculations

No calculations besides those in step 12 above.

6.2.3 Reporting and graphs

Plotting pressure drop against flow rate yields a graph whose slope can be used to compare products in terms of their resistance to flow.

- Plot the pressure drop Δ*p* for the GPACD versus air flow rate in the test report, Clause 8.



Key

—◆— GPACD

Q air flow [m^3/h]

Δ*p* pressure drop [Pa]

Figure 2 — Example of a pressure drop vs. air flow graph

6.3 Initial removal efficiency

Many GPACDs designed for general ventilation need to be optimized for minimum pressure drop, which often results in the fact that they may have less than 100 % efficiency already from the start. Therefore, the second part of the test sequence estimates the beginning efficiency of the GPACD at conditions as close to the application as is practical. The second part of the test should be performed at a concentration low enough to resemble the real application. For the initial removal efficiency test, an application specific gas is selected according to the realistic concentration level and property of gas such as odour threshold, or the simplified benchmark test is used (see 5.5, Table 2). The goal of this test is to determine the removal efficiency at realistic concentrations. However, if the determined efficiency values during the repetitions of this test show a clear trend of decreasing, this is an indication that the selected concentration and flow conditions are not representative of an initial efficiency measurement but rather a capacity test. A lower value for C_U must then be used and the test repeated with a new GPACD sample since the first one is already partially saturated. The maximum permissible efficiency decay is given in 5.5, Table 2. This test will normally continue for around or less than 3 h.

6.3.1 Procedure (continued from 6.2.1)

- 13. From the procedure in 6.2.1 the GPACD should be mounted in the test stand, at the desired air flow and in equilibrium. The settings to reach C_U after the rise time t_{RE} must be previously determined as in 7.2.
- 14. Monitor T_U, T_D, RH_U, RH_D, Δp and Q every 5 min or more frequently.
- 15. Turn challenge gas source ON and wait t_{RE}. Note the test start time t_0.
- 16. Switch to C_D and start to measure. Since the GPACD was introduced with the source off, the downstream concentration is valid directly and it is not necessary to wait the decay time t_{DE}.
- 17. Measure C_D until the readings have stabilized or at least for 10 min.
- 18. Switch to C_U and start to measure. Note the concentration increase but discard the readings during t_{RE}.
- 19. Measure C_U until the level is sufficiently stable or at least for 10 min.
- 20. Switch to C_D and start to measure. Note the concentration decrease but discard the readings during t_{DE}.
- 21. Measure C_D until the readings have stabilized or at least for 10 min.
- 22. Repeat 18–21 for two more cycles producing a total of 4 groups of C_D values and 3 groups of C_U values.
- 23. Note t_{END}.
- 24. Turn challenge gas source OFF.

6.3.2 Calculations

The initial removal efficiency (E_I) cannot be described unless the selection of challenge gas, its concentration and flow are given and these values should be reported together with the value on page 1 of the test report:

$$E_I = \frac{(C_U - C_D)}{C_U} \times 100\,\% \tag{1}$$

Use the values produced in 17–22, remove any outliers and produce 7 averages. If the 4 C_D values and 3 C_U values are consistent then reduce them to an average value for C_U and for C_D and calculate E_I.

EXAMPLE The challenge concentration was set to 500 ppb of toluene at a flow of 1 250 m^3/h. The test is started at t_0. The average values for C_U and for C_D are 495 ppb and 25 ppb, respectively.

Thus, $E_I = (495 - 25)/495 \times 100 = 94{,}9\ \%$.

The determination of E_I will consume some of the GPACD capacity. This capacity must be determined. Due to the short test duration and the low challenge, the average concentrations may be used without integration:

$$m_{\mathrm{s}E_\mathrm{I}}\left[\mathrm{g}\right]=\left(C_\mathrm{U}\left[\frac{\mathrm{ml}}{\mathrm{m}^3}\right]-C_\mathrm{D}\left[\frac{\mathrm{ml}}{\mathrm{m}^3}\right]\right)Q_\mathrm{A}\left[\frac{\mathrm{m}^3}{\mathrm{h}}\right]k\left[\frac{\mathrm{mg}}{\mathrm{ml}}\right]1\,000\,\frac{\left(t_\mathrm{END}\left[\mathrm{min}\right]-t_0\left[\mathrm{min}\right]\right)}{60} \tag{2}$$

where

Q_A is the calculated average value of the air flow measurements;

k is the temperature, absolute pressure, and gas dependent constant to transform ppm into mg/ m^3. It is equivalent to the gas density of the challenge gas at the temperature and absolute pressure at which the test is conducted.

6.3.3 Reporting and graphs

- — Note the value of E_I on page 1 of the test report.
- — Plot the data with upstream and downstream concentrations in the test report, Clause 8.

6.4 Capacity determination

The capacity determination test will be made at a higher concentration, typically around 10 ppm but definitely below 100 ppm, or according to the simplified benchmark test given in 5.5, Table 2. The goal of this test is to determine the capacity of the device. In this test it is recommended to measure downstream continuously with only periodical upstream measurements to check the stability, e.g for 1 h after every 5 h of the test. The most suitable interval will of course depend on the expected total test time, selected end point, the concentration difference over the GPACD, t_RC and t_DC. The end point or end efficiency is selected by supplier and user. Typical selections are at 90 %, 50 % or 30 % end removal efficiency.

6.4.1 Procedure (continued from 6.2.1 or 6.3.1)

- — 25. The capacity test can be started directly after either 6.2.1 or 6.3.1. The settings to reach C_U after t_RC must be previously determined as in 7.2. The GPACD should already be mounted in the test stand, at the desired air flow and in equilibrium.
- — 26. Prepare and start challenge gas source with the settings for C_U.
- — 27. Monitor T_U, T_D, RH_U, RH_D, Δp and Q every 5 min or more frequently.
- — 28. Turn source ON and wait t_RC. Note the starting time t_0.
- — 29. Measure C_D until the readings have stabilized or at least for 20 min.
- — 30. Switch to C_U and start to measure. Note the concentration increase but discard the readings during t_RC.
- — 31. Measure C_U until the level is sufficiently stable or at least for 30 min or 1 h.
- — 32. Switch to C_D and start to measure. Note the concentration decrease but discard the readings during t_DC.
- — 33. Measure C_D for a longer time period, e.g. 3,5 h, 5 h or 11 h depending on the expected total test time.
- — 34. Repeat 30–33 for the remainder of the test until the desired end point is reached and is stable for at least 10 min.
- — 35. Note capacity test time t_END and end removal efficiency E_END.
- — 36. If a retentivity test is planned this MUST continue directly after this test.

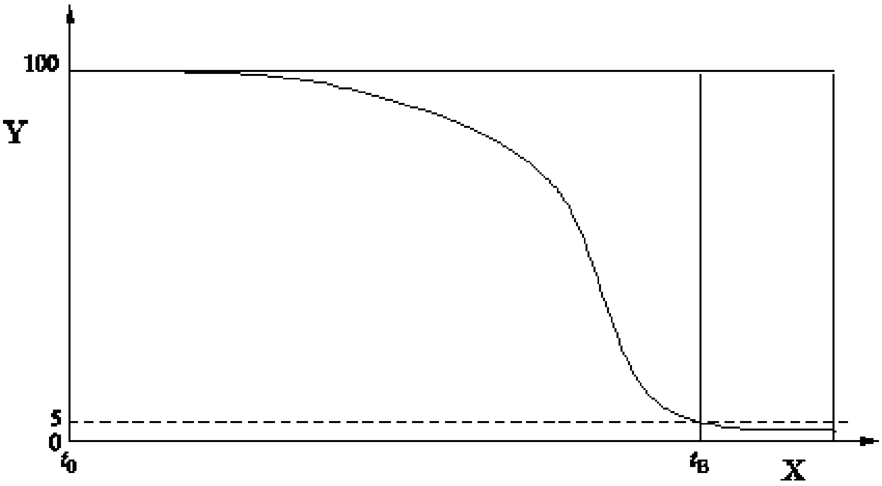
- — 37a. Continue with the procedure for desorption in 6.5.1 without terminating this test, OR
- — 37b. Turn source OFF and terminate the test.

6.4.2 Calculations

From the data acquisition system a raw data table containing date, time, test time, C_U, C_D, T_U, T_D, RH_U, RH_D, Δp and Q should be created. For validation purposes (Clause 7), it is also useful to monitor the generation equipment, e.g. the signal from a mass flow valve. It is also advantageous to have the above information, or at least the concentration vs. time t, available as a chart on the measurement computer.

Calculation of efficiency:

From the raw data table removal efficiency, E_C, is calculated according to Formula (1) and plotted against time, see Figure 3.



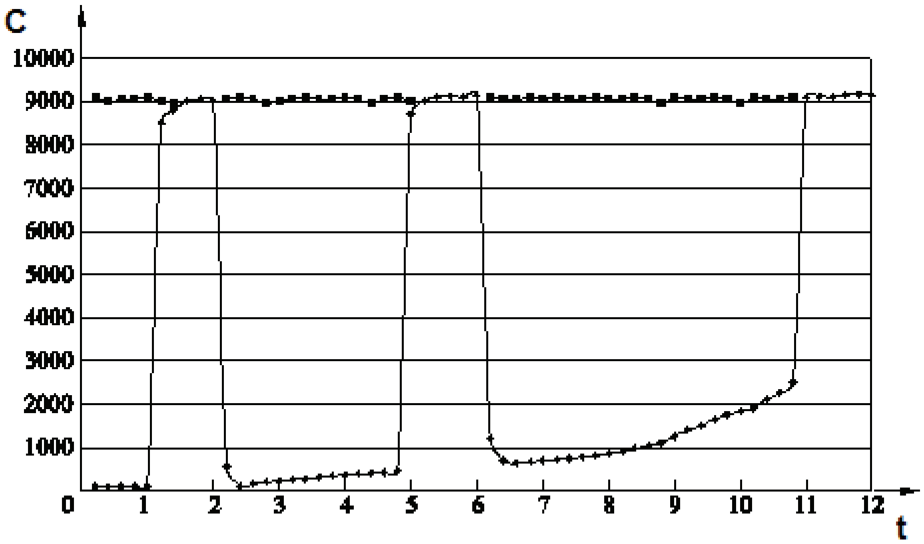
Key

X	time, t
Y	efficiency, E [%]
t_0	start time
t_E	end time

Figure 3 — Example of an efficiency vs. time graph

Calculation of capacity:

Capacity (m_S) is the mass of contaminant sorbed by the GPACD. The total amount m_S will be calculated in increments because the procedure in 6.4.1 uses only one analyser, which makes it necessary to use an interpolated average for the concentration not measured. Note that if two analysers are used interpolation will not be necessary. The interpolated values should also be used in place of the discarded values during periods of t_{RC} and t_{DC}. It is also assumed that one of the concentrations (C_U or C_D) and the flow are measured continuously, e.g. every 3 min. In the equations below time is given in hours and the example is shown for 1 h upstream measurement after 1 h and then every sixth hour and as illustrated by Figure 4.



Key

t	time [h]
C	concentration [ppb]
——■——	*C* (interpolated upstream concentration)
——◆——	C_D and C_u (measured with a single analyser)

Figure 4 — Example of a concentration graph when using a single analyser for C_U and C_D

$$m_s = m_{sE_I} + m_{sD(0<t<1)} + m_{sU(1<t<2)} + m_{sD(2<t<5)} + m_{sU(5<t<6)} + m_{sD(6<t<11)} \tag{3}$$

C_U is linearly interpolated when C_D is measured and C_D is linearly interpolated when C_U is measured as indicated by C_{kU} and C_{kD}, respectively:

$$\begin{aligned} m_s = m_{sE_I} &+ \sum_0^1 \left((C_{kU} - C_D(t)) Q(t) k \right) \Delta t + \sum_1^2 \left((C_U(t) - C_{kD}) Q(t) k \right) \Delta t + \\ &\sum_2^5 \left((C_{kU} - C_D(t)) Q(t) k \right) \Delta t + \sum_5^6 \left((C_U(t) - C_{kD}) Q(t) k \right) \Delta t + \sum_6^{11} \left((C_{kU} - C_D(t)) Q(t) k \right) \Delta t \end{aligned} \tag{4}$$

In this way the total capacity is calculated. To achieve a correct linear interpolation, this should be done between two three point running averages of the data sets. Despite the perhaps daunting equations, the actual work on the computer is to copy and paste the average values in the empty sections of each concentration column. If two analysers are available then only one integration is needed.

6.4.3 Reporting and graphs

The capacity measurements are presented as follows.

- The initial value of E_C [%] is calculated as the intersection of vertical efficiency axis by extrapolation of a linear fit of efficiency vs. time from the values between 2 min and 12 min of the E_C vs. time graph generated in 6.4.2. and noted on page 1 in the test report.
- Specific values for m_s corresponding to efficiency at 95 %, 90 %, 70 %, 50 % and 30 % as far as available are noted on page 1 in the test report.
- E_C vs. m_s [g], in the test report, Clause 8.
- E_C vs. time (h), in the test report, Clause 8.

In addition, for verification of the correct test the following graphs are made in the test report, Clause 8:

- C_U and C_D vs. time (h);
- T_U and T_D vs. time (h) in the range of 21 °C to 25 °C with 0,5 °C graduation or narrower;
- RH_U and RH_D versus time (h) in the range of 45 % to 55 % with 0,5 % graduation or narrower;
- air flow rate (Q) and the mass flow valve setting for the challenge compound versus time (h) in appropriate resolution;
- Δp versus time (h) in appropriate resolution.

6.5 Retentivity determination

The last part of the test is performed directly after the capacity test and is made at zero concentration of challenge compound (i.e. source OFF). The purpose of this test is to determine possible desorption. Desorption is a typical behaviour of a GPACD designed to remove VOCs. In the simplified benchmark setup, the test should continue until the downstream concentration is < 5 % of the original challenge concentration or for maximum 6 h, whichever occurs first. When test parameters are specifically selected, an even lower limit or longer time may be agreed between the supplier and user.

It should be noted that it is entirely possible and of interest to test desorption properties at an end point or breakthrough point much earlier than at total exhaustion. The test duration and selected end point (E_END or t_END) are agreed between user and supplier.

6.5.1 Procedure (continued from 6.4.1)

- 38. Turn source OFF, note time t_VO and continue to measure C_D while proceeding with the desorption test. Note the concentration decrease but discard the readings during t_DC since they are significantly influenced by wall adsorption, etc. if the removal efficiency is below 90 %.
- 39. Measure C_D until the desired end point is reached.
- 40. Note desorption test time t_END and end concentration C_D.
- 41. Shut down the test completely.

6.5.2 Calculations

From the capacity determination the total capacity uptake at the desired challenge concentration is determined. The retentivity, m_r, is determined as:

$$m_\mathrm{r} = m_\mathrm{s} - \int_{0}^{t_\mathrm{END}} \left(C_\mathrm{D}(t) Q(t) k \right) \mathrm{d}t \qquad (5)$$

6.5.3 Reporting and graphs

- Note the value of m_r on page 1 in the test report.
- Show the C_D vs. time graph in the test report, Clause 8.

- END OF TEST SEQUENCE -

7 Validation of test setup

7.1 General

Many components need to be addressed with special care regarding their manufacturing, calibration and adjustment, to make sure that the test set-up meets the requirements of this part of ISO 10121. As this part of ISO 10121 is performance based rather than defining specific equipment, it is the duty of the builder and user of such test equipment to prove the required performance.

The normative Annex A describes tabulated check lists covering the most important controls to be performed. These include determining the accuracy of sensors and routines for validation and for routine operation. The especially important determination of lag times that are gas and concentration specific is described in detail below.

7.2 Determination of rise time and decay time

If only one analyser is used, then the lag time for changing concentration in the system must be determined. Lag time determination is performed without the device to be tested but for each gas, at each concentration and air flow rate.

The results of the tests in Clause 6 depend on correct concentration measurements. There will always be a certain lag time after a concentration change until the new desired level is within ±5 % of the target value. This depends on the challenge gas, its concentration and the reactivity and area of inner wall surfaces of the test stand. The following procedure ensures that concentration data from transition phases can be discarded.

7.2.1 Procedure

— 1. Select the desired air flow rate (i.e. the rated air flow of the device or the air flow for the specific application), challenge compound and challenge concentration C_U for the device to be tested according to 5.4 or 5.5.

— 2. Prepare the test stand and seal it without introducing a GPACD.

— 3. Prepare and start challenge gas source and stabilize it to the desired upstream concentration.

— 4. Turn the source off (to exhaust) and let the concentration reach zero.

— 5. Turn source ON and record the time (t_{VO}). (VO = valve open).

— 6. Allow the challenge concentration to reach C_U at the downstream sampling point and record the time (t_0).

— 7. When C_U looks sufficiently stable, turn source OFF and record t_{VC} (VC = valve closed).

— 8. Allow concentration at C_D to reach zero within at least < 5 % of C_U and record t_{END}.

— 9. Repeat steps 1–8 for the lower concentration C_U selected for the initial efficiency measurement.

7.2.2 Calculations

Values to be used in the initial efficiency test:

— Calculate the rise time $t_{RE} = (t_0 - t_{VO})$.

— Calculate the decay time $t_{DE} = (t_{END} - t_{VC})$.

Values to be used in the capacity determination test:

— Calculate the rise time $t_{RC} = (t_0 - t_{VO})$.

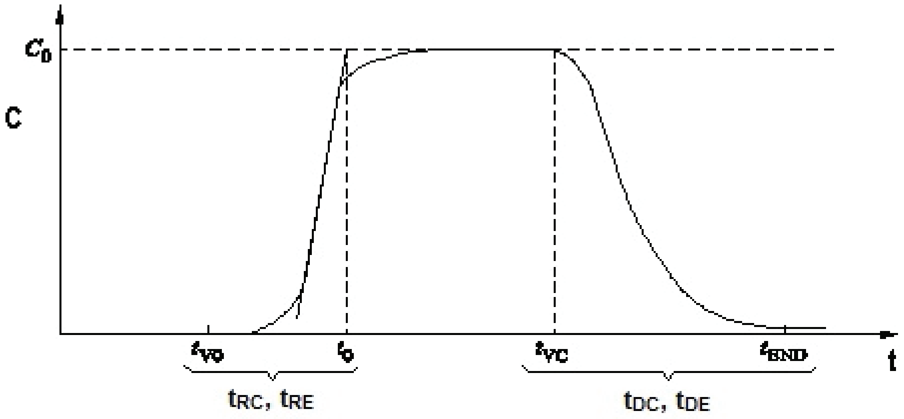
- Calculate the decay time $t_{DC} = (t_{END} - t_{VC})$.

The above data are specific for the selected challenge gas, its concentration and air flow rate used. These data can be reused at a later test provided that nothing has been changed in the set-up.

- t_{RC} gives the time until a GPACD is subjected to the correct upstream concentration and the actual challenge starts, i.e. t_0.
- t_{RC} can also be used for the decay time when switching between C_D data and C_U data at high removal efficiency for which the values during t_{RC} should be discarded in the data logging software.
- t_{DC} gives the time until the test stand is completely free from challenge gas, which is important for zero measurements, retentivity tests and for safe introduction of the GPACD in the test stand.
- t_{DC} gives the time until the values of C_D downstream of the GPACD reflect the actual penetration through the device and not remaining adsorption from walls and test tubing, for example after an upstream measurement or after the challenge gas source is turned off at the start of a retentivity test. Recorded values should therefore be discarded during t_{DC} in the data logging software.
- t_{DC} for certain gases at low concentrations, e.g. ammonia at 100 ppb, can take several hours.

7.2.3 Reporting and graphs

- The concentration vs. time graph should be included in the end of the test report, Clause 8:



Key

t	time
C	concentration
t_{VO}	time noted at challenge gas valve opening
t_0	start time – the time when C_U (contamination concentration upstream) equals the selected challenge concentration for an empty duct
t_{VC}	time noted at challenge gas valve closure
t_{END}	time when a test is stopped
t_{RC}, t_{RE}	rise time for challenge concentration (RC) or initial efficiency concentration (RE)
t_{DC}, t_{DE}	decay time for challenge concentration (DC) or initial efficiency concentration (DE)

Figure 5 — Example of an experimental plot to determine rise time and decay time

8 Evaluation and report

8.1 Test report introduction

The test sequence is described in Clause 6. For each part of the test, a subclause “Reporting and graphs” describes the information that should be included in the test report shown below. The report contains exemplary information and example graphs. Text to be changed is shown in italics. The graphs show actual data of a test conducted according to this part of ISO 10121 and can be used as a guideline on how to present data. The parts of the report referring to the optional initial efficiency test and the optional retentivity test should be excluded if these parts are not performed.

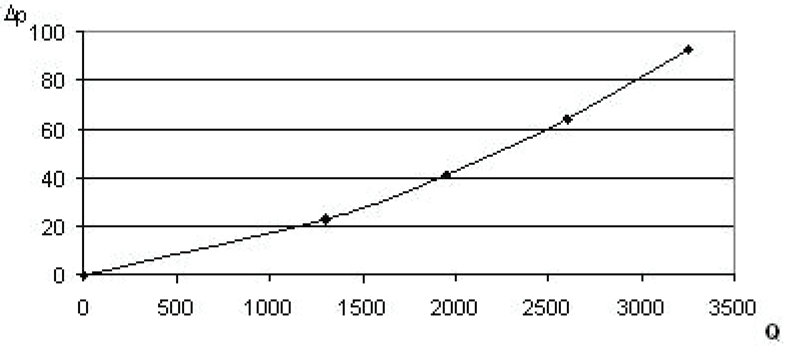
8.2 Test report example

ISO 10121-2 **TEST REPORT**							
Report no.	*insert applicable info*	Date received	*insert applicable info*				
Date tested	*insert applicable info*	Date report	*insert applicable info*				
TEST SUPPLIER:							
Test organization	*name of test organization*	Address	*insert applicable info*				
Phone	*insert applicable info*	Web	*insert applicable info*				
Operator	*insert applicable info*	Supervisor	*insert applicable info*				
TEST CUSTOMER:							
name of customer	Address	*insert applicable info*					
Phone	*insert applicable info*	Web	*insert applicable info*				
TESTED DEVICE:							
Manufacturer	*name of manufacturer*	Address	*insert applicable info*				
Phone	*insert applicable info*	Web	*insert applicable info*				
Model	*GPACD*	Serial no	*insert applicable info*				
Gas type	*VOC*	Type	*4vee cell type*				
Rated flow [m^3/h]	*2600*	Dimensions [mm]	*610 × 610 × 292*				
Pressure drop [Pa]	*100*	GPACD mass [g]	*5200*				
Adsorbent	*activated carbon*	Other identifications	*black*				
TESTING CONDITIONS:							
Air flow [m^3/h]	*2000*	Initial eff. conc. [ppb]	*460*				
Face vel. [m/s]	*1,5*	Challenge conc. [ppb]	*9100*				
Test gas	*toluene*	Temp [°C]	*23*	*RH* [%]	*50*		
Analyser	*name of supplier*	Model	*PID type x9*				
t_{RE} [s]	*20*	t_{DE} [s]	*20*	t_{RC} [s]	*40*	t_{DC} [s]	*30*

SUMMARY OF TESTING RESULT:						
E_I [%]		*84,5*	**Initial E_C [%]**			*88*
m_S, capacity [g] @	efficiency 95 %	-	efficiency 90 %	-	efficiency 70 %	*303*
	efficiency 50 %	*435*	efficiency 30 %	*558*	total	*635*
m_r, retentivity [g]	*391*		**Δp [Pa]**		*112*	

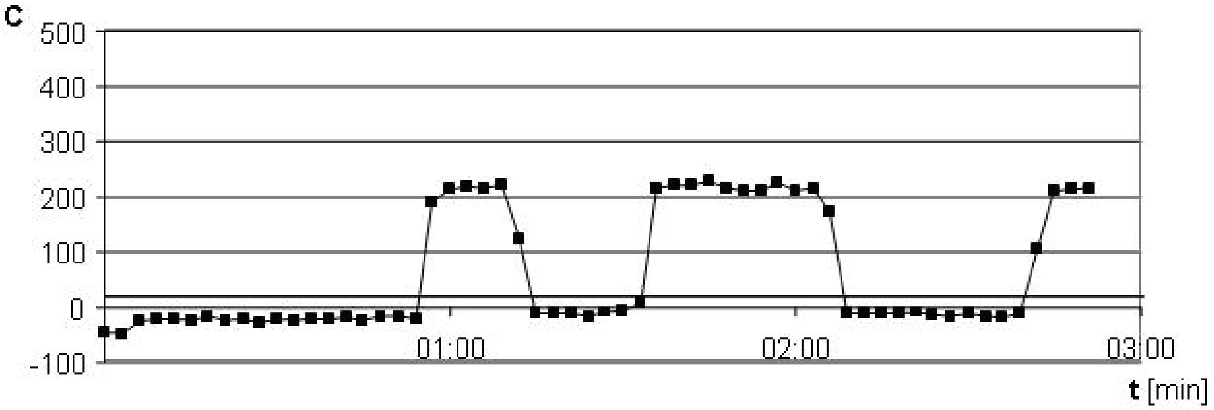
PRESSURE DROP GRAPH:

Example of pressure drop curve, Δp vs. Q, see 6.2



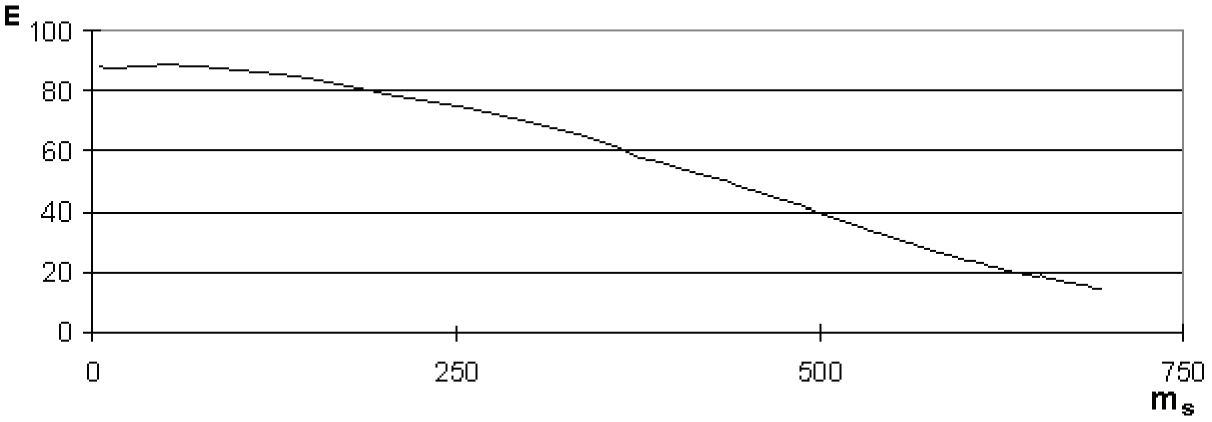
INITIAL REMOVAL EFFICIENCY TEST GRAPH:

Example of initial efficiency test, C vs. t, see 6.3

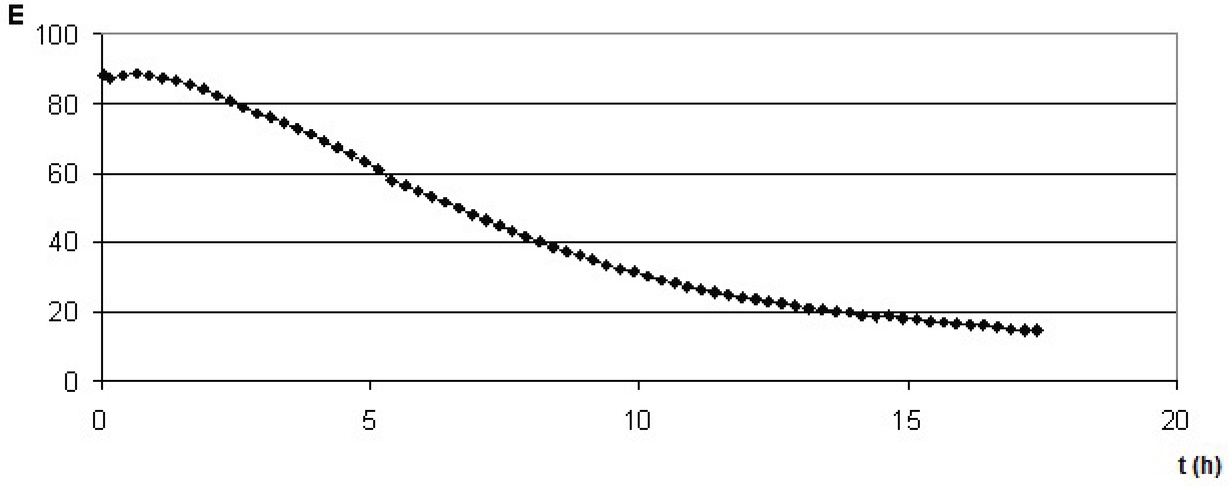


CAPACITY DETERMINATION GRAPHS:

Example of capacity test, E vs. m_S, see 6.4

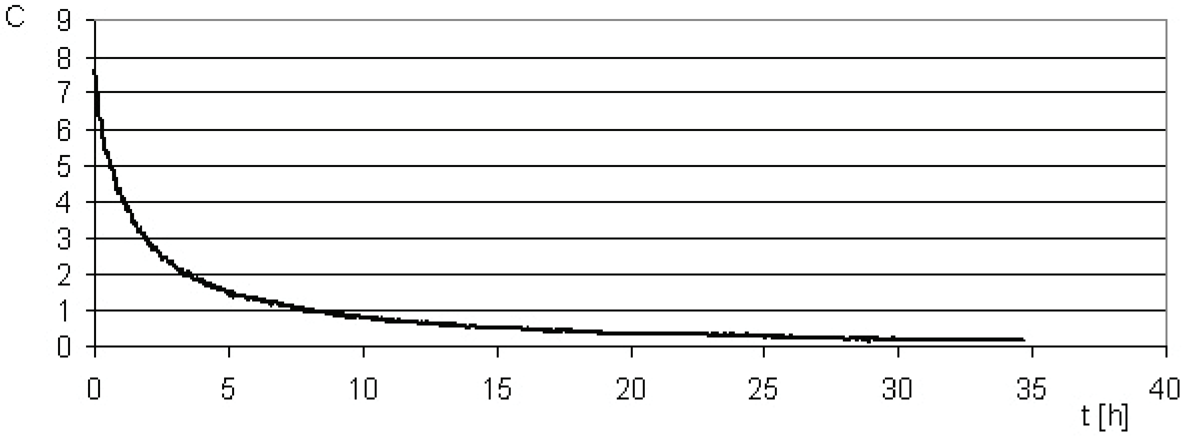


Example of capacity test, *E* vs. *t*, see 6.4



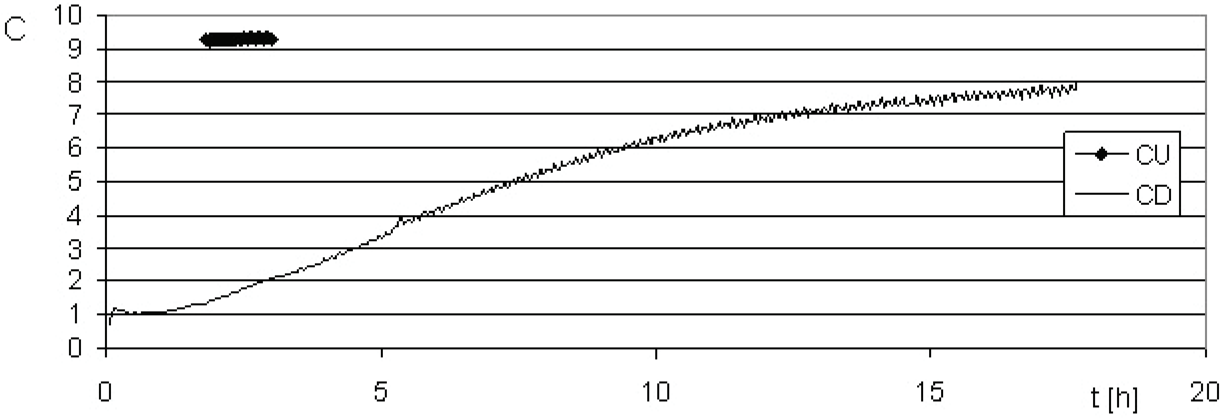
RETENTIVITY DETERMINATION GRAPH:

Example of retentivity test, *C* vs. *t*, see 6.5

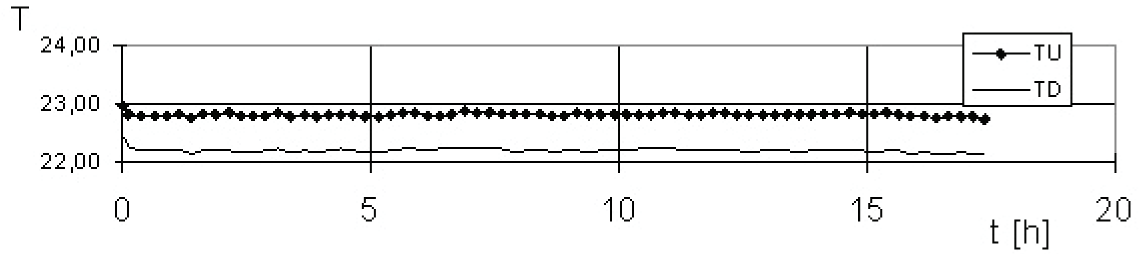


TEST VERIFICATION GRAPHS:

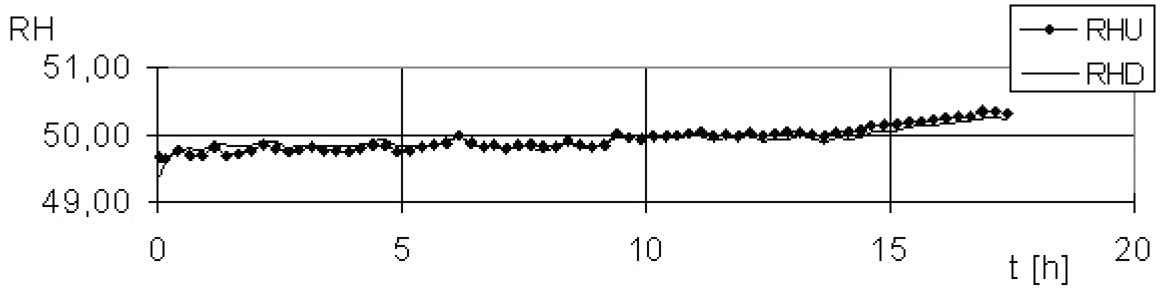
Example verification of measured concentration



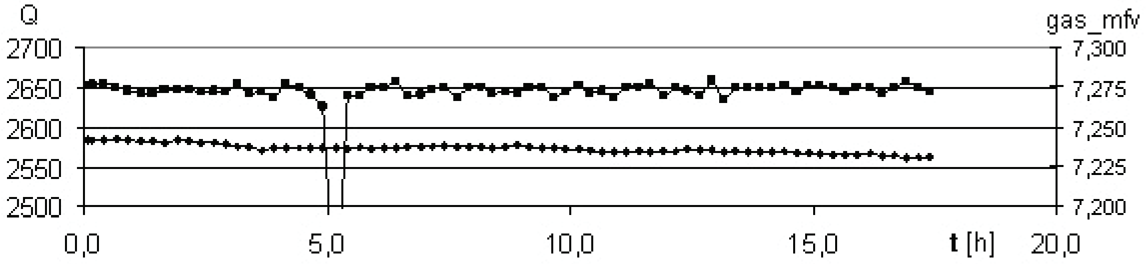
Example verification of temperature accuracy and oscillation



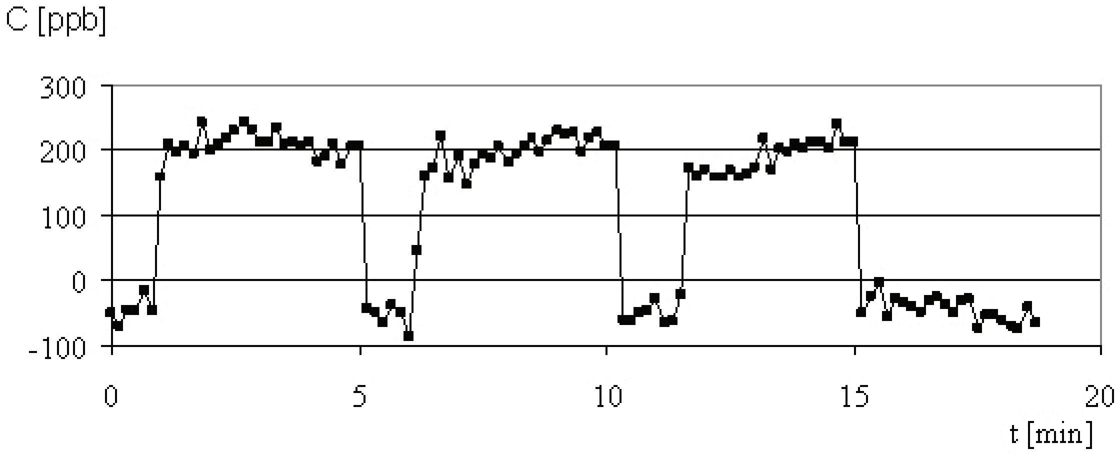
Example verification of relative humidity accuracy and oscillation



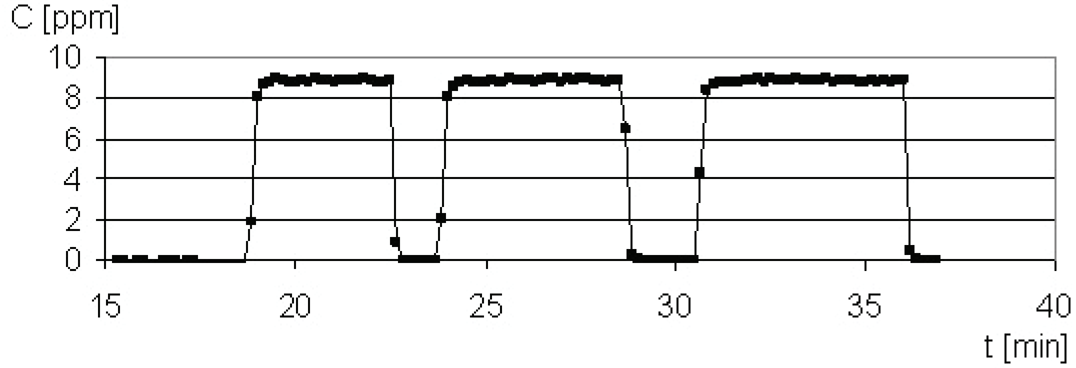
Example verification of air flow rate and mfv setting



Example graph for determination of rise and decay time for the initial efficiency test



Example graph for determination of rise and decay time for the capacity determination test



9 Safety features

All work utilizing hazardous chemicals at elevated concentrations poses a severe risk to personnel and environment. It is an absolute requirement that the test supplier considers and acts to provide a safe work area that includes but is not limited to the following.

- Proper training of personnel must be ensured.
- All chemicals should be handled according to local regulations for handling storage and transport.
- Technical data sheets and MSDS for chemicals used must be available at the point of use.
- All chemicals used should be checked for toxicity, fire and explosion hazard in technical data sheets and MSDS documentation.
- All pressure vessels should be handled and stored with correct procedures.
- Containers with a substantial amount of challenge compound, e.g pressure vessels or flasks of VOC, should be stored and used according to local safety regulations and most commonly in ventilated enclosures so that the content of a ruptured vessel is not allowed to enter the work area.
- The complete test stand and all tubing and duct work should be tested for leakage.
- Safety monitors (sensors) should be installed in the work positions where challenge compound may enter the work area.
- Before conducting challenge test with severely toxic compounds like hydrogen sulphide, arsine, phosphine, PCBs and dioxines, the value of the test data should be weighed against the risks. One should also consider using other compounds with similar adsorptive behaviour for capacity determination and perhaps limit the use of the toxic compounds to low concentration efficiency measurements.
- It must also be realized that all challenge gas penetrating the GPACD will be present in the exhaust air. Depending on the toxicity of a compound and its concentration and local regulations, proper actions should be taken.

The above list is intended to put focus on problems that may appear during testing. However, this part of ISO 10121 does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this part of ISO 10121 to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Annex A
(normative)

Test equipment requirements, equipment validation and routine operation

The following tables contain the components, which need to be addressed with special care regarding their manufacturing, calibration and adjustment, to make sure that the test set-up meets the requirements of this part of ISO 10121. As this part of ISO 10121 is performance based rather than defining specific equipment, it is the duty of the builder and user of such test equipment to prove the required performance.

Table A.1, *Uncertainty of measurements of sensors,* contains information regarding the required accuracy of the instrumentation used to determine the general process parameters. The criteria are typically met by controlled and traceable calibration.

Table A.2, *Validation,* contains system properties defined mainly by the design of the test bench. These properties have to be checked once to show that the concept, the design and the construction are fit to meet the basic performance requirements. These criteria are typically verified by determining the appropriate characteristics.

Table A.3, *Routine operation,* lists tests, adjustments and calibrations, which have to be performed regularly and controlled, to prove and maintain the permanent capability of the test equipment to produce reliable and reproducible measurements.

The numbers in the first column refer to the related clause in this part of ISO 10121.

Table A.1 — Uncertainty of measurements of sensors

Clause	Device	Requirement	Comment
6.7	Measuring uncertainty airflow	± 2 %	Relative to actual reading
6.7	Measuring uncertainty pressure drop	± 2 %	Relative to actual reading
6.7	Measuring uncertainty temperature	± 0,5 °C	Relative to actual reading
	Determining uncertainty in gas sensor/analyser used	± 1,5 %	Relative to actual reading
6.7	Measuring uncertainty relative humidity	± 1 %	Relative to actual reading
6.7	Measuring uncertainty ambient pressure	± 3 mbar	Relative to actual reading

The order in which the tests in the following table are performed is relevant. The test sequence as shown in the check list may be used as a guideline.

Table A.2 — Validation

Clause	Parameter or test item	Requirement	Comment
5	Test bench conductive and grounded		Check electrical potential
5.7	Temperature control	23 °C ± 0.5 °C	Check with calibrated thermometer
5.7	Humidity control (relative)	50 % ± 3 % RH	Check with calibrated humidity sensor
7	Leakage of duct and test chamber	< 100 l/min at 500 Pa	Check according to accepted state of the art methods

Table A.2 *(continued)*

Clause	Parameter or test item	Requirement	Comment
7	Cleanliness of test air, background contamination	< 2,5 % of challenge concentration	Check empty duct without gas challenge
7	Cleanliness of test air, particles	Particle cleanliness > F7 + H12	Check empty duct without gas challenge
5.7	Airflow sensor, to be achieved in the test bench	± 2 % measuring uncertainty	± 2 % repeatability
5.7	Airflow control	Typical range: 1000 m^3/h – 4000 m^3/h	The test bench has to be validated at a minimum of 1000 m^3/h. This airflow has to be kept within a tolerance of 3 % for at least 3 h.
6	Range of pressure drop, maximum 1000–4000 Pa	Range at least 10 % > maximum Δp	Recommendation: use more than one sensor to cover the full range.
6	Pressure drop sensor – uncertainty	± 2 %	Of full range value
6	Pressure drop sensor – repeatability	± 2 %	
5	Sample fixture: allow sample to be sealed without leaks		
	Gas sampling upstream: centre of sample face area, close to sample	determine X	determined according to …..
	Gas sampling downstream: centre of sample face area, allow sufficient distance to sample	determine Y	determined according to …..
	Sampling tubes: materials and properties		No out-gassing, chemically resistant materials
	Challenge gas injection – concentration	± 5 % of set point, stable over 1 h	check using 90 ppm(v) acid, base and VOC gas
	Challenge gas injection – homogeneous distribution	± 5 % over complete test chamber cross section at 90 ppm(v) concentration of butane	Scan at least nine sampling locations (Divide cross section into nine equal squares and locate probe at the centre of each square) according to ISO/TS 21220 or ISO/TS 11155-1:2001, 4.2.1
	Challenge gas stability has to be checked for every Mass Flow Controller used for gas dosage	See above	
	Gas detectors – calibration	Calibration gas with a purity of ≥ 99,5 %	
	Gas detectors – sampling flow	± 5 % of set value	Use high precision flow meters
	Gas detectors – cross sensitivity	Check for potential cross sensitivities	Operator manual (Special care required with FIDs and Infrared Spectrometers
	Calibration gas; accuracy, shelf life and dilution	agree with certificate	check supplier certificate and recommendation
6	Determine the equipment response/delay time (different for different agents, test set-ups and detectors)	N/A	Time between gas injection and full detector signal see 6.2 for a detailed description
5	Documentation of performance profile		All results achieved during validation shall be documented

Table A.3 — Routine operation

Clause	Item	Requirement	Frequency	Comment
6	Compare up- and downstream sampling	Ratio C_D/C_U between 0,95 und 1,05	daily	No GPACD should be mounted in duct
5	Pressure drop of empty duct		Each test	
7	Background concentration	< 1 % of cumulative concentration of challenging agent	daily	For each analyser used
5	Calibration of detectors and analysers		Each test	
6	Spatial homogeneity of concentration of agents	± 5 %	After each modification of test bench	
6	Stability of agent concentration	± 5 %	After change, service or repair of mass flow controllers	
5	Monitor C_U, C_D, T_U, T_D, RH_U, RH_D, Δp and Q every min during 5 data points recorded for empty test stand	Accuracy in agreement with 5.3, Table 1	Before each test	
6	Leak test of duct work	< 100 l/min at 500 Pa	Annually	
6	Calibration of airflow measurement	± 3 %	Quarterly	
6	Calibration of pressure drop sensors	± 2 %	Quarterly	
6	Calibration of temperature and humidity sensors	± 1 %	Quarterly	
6	Repeatability	± 5 %	Annually	
6	Cleaning of test bench and components		As needed	

Annex B
(informative)

Challenge gases, generation sources and analysis techniques

B.1 Challenge gases and generation sources

Injection of contaminants must be carried out safely. Quantities injected may be tailored to specific requirements, and suitable accelerated test concentrations are listed.

B.1.1 Gaseous species

Gas-phase injection can be achieved by direct injection of the gas from cylinders, but care must be taken to ensure that excessively high concentrations cannot build up inadvertently. To this end it is advisable to use, where available, pre-diluted cylinders. However, for full size filters tested at rated air flows, non diluted cylinders may be necessary to achieve acceptable exposure times and also for economical reasons. Especially for non diluted gases, separate ventilated enclosures for the gas cylinders should be used. In addition, gas detectors and shut off valves must be used appropriately for the safe operation of the equipment.

Gaseous effluent from the equipment should be treated to reduce contaminant to safe levels before discharge to atmosphere following local regulations. Proper consideration must be made regarding decommissioning and equipment cleanout between tests. It must be recognized that all surfaces exposed to contaminant will adsorb test species and hazardous reaction products may also be produced.

B.1.2 Liquid species

Liquid species must be vaporized before injection into the test equipment. Suitable methods will vary with test species, but must provide a stable flow rate to provide constant upstream concentration to the limits indicated in the table. Typical techniques involve spray nozzles and/or heated surfaces.

B.1.3 Tabulated challenge species

Table B.1 — Acid gases

Compound	Suggested challenge concentrations, ppm(v)
Sulphur dioxide	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Nitrogen dioxide	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Nitrogen oxide	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Hydrogen sulphide	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Acetic acid	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %

Table B.2 — Alkaline (basic) gases

Compound	Suggested challenge concentrations, ppm(v)
Ammonia	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
NMP	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %

Table B.3 — VOC gases

Compound	Suggested challenge concentrations, ppm(v)
Toluene	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Isopropanol	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Isobutanol	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Hexane	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Tetrachloroethylene	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Formaldehyde	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Mercaptans	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Ethanol	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Butane[a]	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %

[a] Butane is included since it is previously used in DIN standards even if it is not a common contaminant.

Table B.4 — Other gases

Compound	Suggested challenge concentrations, ppm(v)
Ozone	0,9 ± 5 %
Chlorine	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Carbon monoxide	0,9 ± 5 %, 9 ± 5 % or 90 ± 5 %
Carbon dioxide	900 ± 5 % or 9000 ± 5 %

B.2 Gas detection equipment

No single device can detect all the species covered by this part of ISO 10121 and the equipment must be selected carefully with regard to the contaminant characteristics. Similarly the sample rate and accuracy of detectors and measurement equipment can vary widely.

Methods recommended for the simplified test include FID for organic substances, chemiluminscence detectors for NOx and ammonia and UV-Fluorescence Detectors for SO_2. FTIRs can be used for a large range of agents.

Online FID may not reach concentrations low enough to be useful in a specific case. If an online FID is too low in sensitivity downstream, *ex situ* equipment, e.g. Tenax tubes (GC-MS/FID) or gas absorption tubes (ion chromatograph), can be used.

B.2.1 Typical analyser (online) methods

CPR	colorimetric detection on chemically impregnated paper reel type analyser
IMS	ion mobility spectroscopy
MGD	mass gain detector (of condensed organic build-up) using different types of piezoelectric resonators
P-GC	portable gas chromatograph equipment
ECS	sensors of electrochemical cell type
ICS	ion chromatography monitoring system
CLS	chemiluminescence monitoring system

CP	controlled potential electrolysis
PAS	photo acoustic emission
NDIR	non-diffraction infrared absorption
UV	ultraviolet absorption
UVL	ultraviolet luminescence
PID	photo-ionization detector
FID	flame-ionization detector
FTIR	Fourier transform infrared spectroscopy

B.2.2 Suggested analysers to the tabulated challenge species

Table B.5 — Acid gases

Compound	Suggested technique
Sulfur dioxide	UVL, (CPR)
Nitrogen oxide	CLS (NO, NO_2 and NOx should be monitored together in order to detect possible conversion of one species to the other), (CPR)
Nitrogen dioxide	
Hydrogen sulfide	UVL, (CPR)
Acetic acid	PAS, (FID)

Table B.6 — Alkaline (basic) gases

Compound	Suggested technique
Ammonia	CLS, PAS, CPR
NMP	

Table B.7 — VOC gases

Compound	Suggested technique
Toluene	PAS, PID, FID,UV
Isopropanol	PAS, PID, FID
Isobutanol	PAS, PID, FID
Hexane	PAS, FID
Tetrachloroethylene	PAS, PID, (FID)
Formaldehyde	PAS, CPE
Mercaptans	PAS,(UVL)
Ethanol	PAS, FID
Butane	PAS, FID

Table B.8 — Other gases

Compound	Suggested technique
Ozone	UV, (CPR)
Chlorine	CPR, UV
Carbon monoxide	CPR, PAS, NDIR
Carbon dioxide	CPR, PAS, NDIR

B.2.3 *Ex situ* techniques

Besides the listed analyser techniques, there is an abundance of *ex situ* analysis techniques that can be used to analyse many specific substances. These are often present in industrial applications but may be of interest also in testing of general filtration. The information below was originally compounded for the detection of airborne molecular contamination (AMC) in cleanrooms within ISO 14644-8. To perform these analyses a suitable sampling technique is needed to extract the sample from the duct and an *ex situ* analysis technique that is selective and with an acceptable detection limit.

B.2.3.1 Typical sampling methods for *ex situ* analysis

These may include, but are not limited to:

DIFF	passive diffusive sampler
FC	filter collector
IMP	impinger set in series filled with suitable solvent
SB	sample bag for direct collection of duct air
SOR	sorbent tube
WW	witness wafer or plate used as sample collector
VPD	vapour phase decomposition
DSE	droplet scanning extraction
DT	diffusion tube

B.2.3.2 Typical *ex situ* analysis methods

These may include, but are not limited to:

AA	atomic absorption spectroscopy
AA-F	atomic absorption spectroscopy – flame
AA-GF	atomic absorption spectroscopy – graphite furnace
AES	atomic emission spectroscopy
CL	chemiluminescence
CZE	capillary zone electrophoresis
GC-MS	gas chromatography – mass spectroscopy
IC	ion chromatography

ICP-MS	inductively coupled plasma – mass spectroscopy
MS	mass spectroscopy
UVS	ultraviolet spectroscopy
FTIR	Fourier transform infrared spectroscopy
VPD	vapour phase decomposition
TXRF	total reflection X-ray fluorescence spectroscopy
VPD-TXRF	vapour phase decomposition – total reflection X-ray fluorescence
DSE-TXRF	droplet scanning extraction – total reflection X-ray fluorescence
TOF-SIMS	time of flight – secondary ion mass spectrometry
API-MS	atmospheric pressure ionization – mass spectroscopy

B.2.3.3 Suggested sampling and *ex situ* analysis techniques at different concentration ranges

Table B.9 — Sampling and analysis techniques at different concentration ranges

Compound	**AMC ISO Class n (10^{-n} g/m^3)**					
	0	**1**	**2**	**3**	**4**	**5**
ACID	IMP, IC				IMP, IC, CPR	
BASE						
ORGANIC	SOR, SB; GC-MS					
IN-ORGANIC	IMP; AA, AA-F, AA-CF, UVspec, ICP-MS					

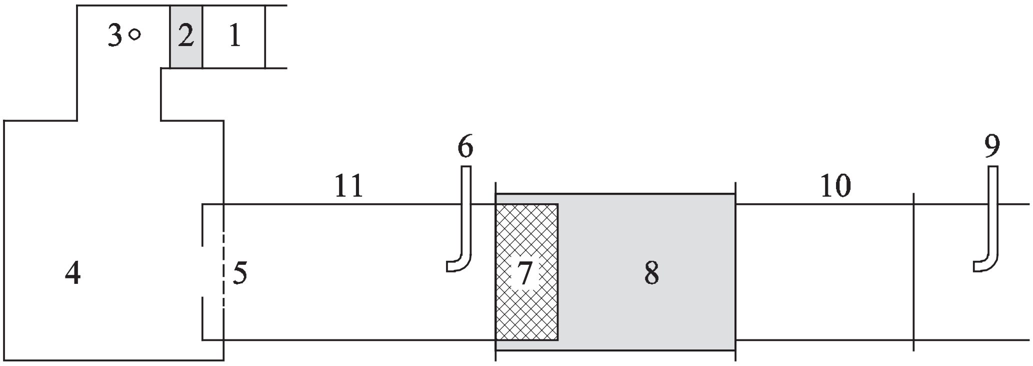
Compound	**Species concentration, g/m^3**						
	6	**7**	**8**	**9**	**10**	**11**	**12**
ACID	IMP, IC, CPR, DIFF		IMP, IC, DIFF	IMP, IC, DIFF, CZE	IMP, CZE		
BASE			IMP, IC, DIFF, IMS		IMP, IC, CZE?		
ORGANIC	SOR; GC-MS						
IN-ORGANIC	IMP; AA, AA-F, AA-CF, UVspec, ICP-MS			IMP, UVspec ICP-MS	ICP-MS		

Annex C
(informative)

Test equipment designs

C.1 Schematic test stand design

By way of example Figure C.1 show the ductwork required for a typical test stand used in this part of ISO 10121. The inlet air is filtered and purified using standard HEPA and activated carbon units. This air is then contaminated with test gas by injecting vaporized chemical species directly into the mixing chamber. Note that the lining of the chamber and the following downstream ductwork and fittings will require protection from the corrosive effect of the contaminant. These surfaces will also act as sinks and potential sources of secondary, unwanted contamination of the test gas, especially if the test facility is used for a variety of chemical species, and so should be smooth, chemically resistive, and easily cleaned. The test is aimed at testing the GPACD as well as any sealing arrangement, though not the chemical stability of seals other than to note any deterioration during the test cycle. Because test chemicals may be toxic or corrosive, the best solution is to minimize leakage into the laboratory or environment by operating the test ducting under negative pressure relative to the surrounding facilities. If a pressurized system is used, it must be carefully constructed and maintained to prevent leakage.



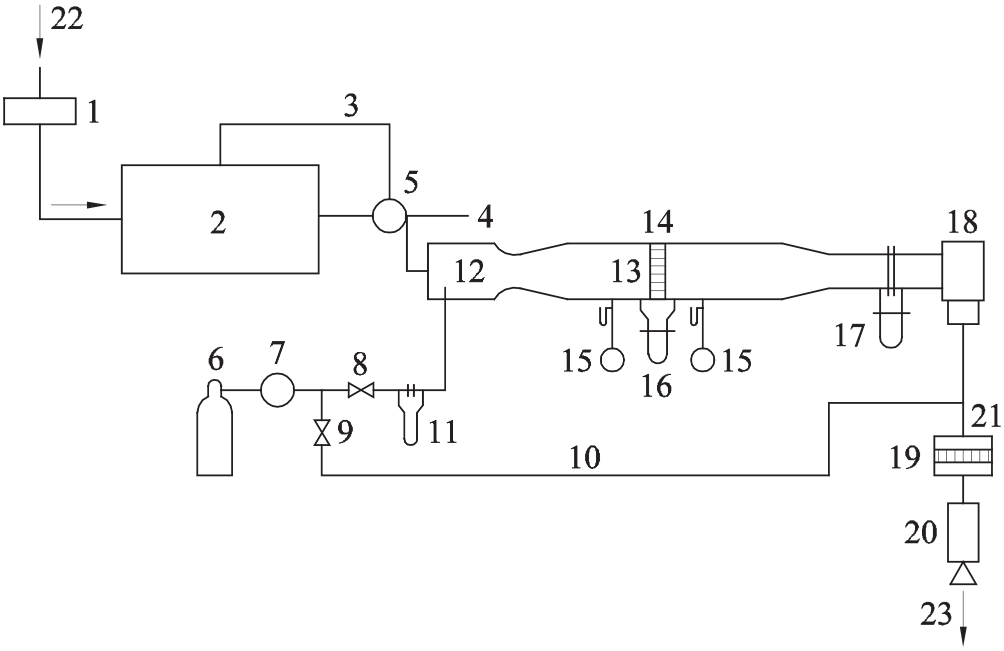
Key

1	HEPA filter
2	GPACD to clean supply air
3	challenge injection point
4	mixing chamber
5	perforated plate (diffusor and Δp device)
6	upstream sample point
7	GPACD under test
8	GPACD section
9	downstream sample point
10	downstream duct
11	upstream duct

Figure C.1 — Example of typical test equipment design

C.2 Examples of test stands in use

Already there are test stands in active use that resemble the above schematic design to a lesser or greater extent. Two different designs are incorporated and presented below. See Figures C.2 and C.3 from JIS[1] and ISO[4], respectively.

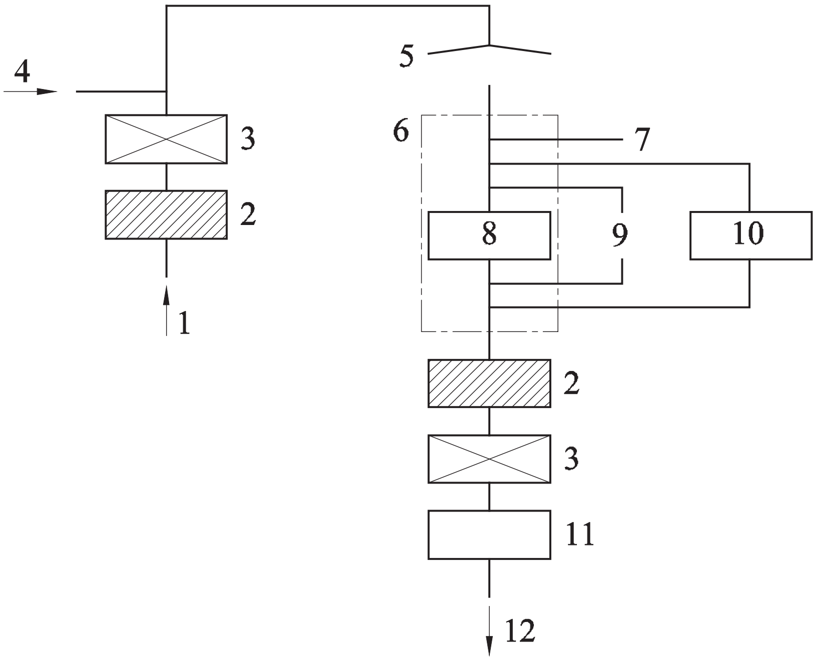


Key

1	air cleaner
2	test air regulator (impurity removal and temperature and humidity regulation)
3	temperature and humidity detection control circuit
4	excess air exhaust duct
5	temperature and humidity detecting part
6	test gas generator
7	gas pressure regulator
8	gas flow rate control valve
9	gas by-pass flow rate control valve
10	gas by-pass pipe
11	high concentration test gas flowmeter
12	gas dispersion duct
13	square duct
14	specimen
15	test gas sampling hole
16	manometer
17	orifice flowmeter
18	blower
19	exhaust gas processing air cleaner
20	throttle apparatus
21	damper
22	air
23	exhaust

Figure C.2 — Test stand design from JIS B 9901:1997 (E)

The design in JIS B 9901:1997 shows a complete system with four main parts. A system to condition clean air with controlled temperature and humidity is illustrated by items 1–5. This is followed by a challenge gas preparation system by items 6–12. The actual test duct with fan (blower) is shown by items 13–18 and finally an exhaust cleaning system comprises items 19–23.



Key

1	conditioned air
2	gaseous clean-up filter
3	particle clean-up filter
4	contaminant injection
5	mixer/diffuser
6	test section
7	temperature and humidity measurement device
8	test filter
9	differential pressure measurement
10	gas measurement device
11	flow measurement device
12	exhaust air

Figure C.3 — Test stand design from ISO 11155-2:2009 for automotive cabin air filters

The normative test stand configuration of ISO 11155-2:2009 for testing of automotive cabin air filters contains the schematic steps for cleaning an already conditioned air stream, introducing contamination and testing in a test duct. The test duct part is similar to the ones shown in Figures C.1 and C.2.

The guidelines discussed in the schematic design and these two examples should constitute a good foundation for a successful test stand design. However, any and all designs used must fulfil the demands given in Clause 5.

Bibliography

[1] JIS B 9901:1997 (E), *Gas removal — Method of test for performance of gas-removal filters*

[2] ISO 10121-1, *Test method for assessing the performance of gas-phase air cleaning media and devices for general ventilation — Part 1: Gas-phase air cleaning media*

[3] ISO/TS 11155-1:2001, *Road vehicles — Air filters for passenger compartments — Part 1: Test for particulate filtration*

[4] ISO 11155-2:2009, *Road vehicles — Air filters for passenger compartments — Part 2: Test for gaseous filtration*

[5] ISO 14644-8, *Cleanrooms and associated controlled environments — Part 8: Classification of air cleanliness by chemical concentration (ACC)*

[6] ISO/TS 21220, *Particulate air filters for general ventilation — Determination of filtration performance*

[7] ANSI/ASHRAE Standard 145.2:2011, *Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Air-Cleaning Devices*

[8] ANSI/ASHRAE Standard 145.1:2008, *Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Loose Granular Media*

[9] ASTM D 5160-95, *Standard Guide for Gas-Phase Adsorption Testing of Activated Carbon*

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