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

Part 1:
Gas-phase air cleaning media

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

Partie 1: Médias de filtration moléculaire (GPACM)

Reference number
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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is 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 using adsorption for gas removal relies to a large extent on the performance of a solid gas-phase air cleaning media (GPACM) incorporated in the device. Still applications, device performance and media performance are often poorly understood by the user and supplier 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 this part of ISO 10121. This part of 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, in-duct sorptive media gas-phase air-cleaning devices by ASHRAE[2] and for adsorptive media by ASHRAE[3] and ASTM.[5] No international standard for general filtration exists today.

This part of ISO 10121 provides methods, test equipment, data interpretation and reporting for three different types of gas-phase air cleaning media (GPACM) intended for use in gas-phase air cleaning devices (GPACD) for 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 proper analysis equipment for common test gases
- Annex C describes the design of the test stand except the normative sample holder.
- Annex D describes the normative test setup and normative section of the test stand for the three different media configurations.

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

The ISO 10121 series 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.
- ISO 10121-2 aims to give a standardized interface between suppliers of air cleaning devices and end customers seeking the best performing and most economical way to employ gas-phase filtration.

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

Part 1:
Gas-phase air cleaning media

1 Scope

This part of ISO 10121 aims to provide an objective laboratory test method, a suggested apparatus, normative test sections and normative tests for evaluation of three different solid gas-phase air cleaning media (GPACM) or GPACM configurations for use in gas-phase air cleaning devices intended for general filtration applications. This part of ISO 10121 is specifically intended for challenge testing and not for general material evaluation or pore system characterization. The three different types of GPACM identified in this part of ISO 10121 are GPACM-LF (particles of different shape and size intended for e.g. Loose Fill applications), GPACM-FL (FLat sheet fabric intended for e.g. flat one layer, pleated or bag type devices) and GPACM-TS (three dimensional structures that are many times thicker than flat sheet and e.g. used as finished elements in a device). The tests are conducted in an air stream and the GPACM configurations are challenged with test gases under steady-state conditions. Since elevated gas challenge concentrations (relative to general ventilation applications) are used, test data should be used to compare GPACM within the same configuration and not for the purpose of predicting performance in a real situation. It is also not implied that different GPACM configurations can be directly compared. The primary intention is to be able to compare like GPACM configurations to like, not between GPACM configurations. Testing of complete devices is described in ISO 10121-2.

To ensure objectivity for test equipment suppliers, no specific design of the test apparatus is defined: an example is illustrated in Annex C (informative). Instead normative demands for media sample holder design, apparatus properties and validation tests are specified.

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 10121-2, *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)*

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

ASTM D2854, *Standard Test Method for Apparent Density of Activated Carbon*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29464 and the following 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 surface 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 GPAC Media or Device

Note 1 to entry: See *penetration* (3.33).

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 filter 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 GPAC Media or Device 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 (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 or origin.

[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_{END} - t_{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 GPAC Media or Device 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 opposite of adsorption.

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

3.19
efficiency vs. time curve
plot of the GPAC Media or Device 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 GPAC Media or Device

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 mm × 300 mm × 300 mm up to approximately 610 mm × 610 mm × 610 mm or 2 feet × 2 feet × 2 feet.

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

3.24
GPAC media or device face area
cross-sectional area of the GPAC Media or Device also including a header frame or other support structures if so equipped when viewed from the direction of air flow using exact dimensions

3.25
gas-phase air cleaning media
GPACM
solid 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
GPACM-LF
adsorbent in the form of particles of different shape and size intended for e.g. loose fill applications

3.27
GPACM-FL
adsorbent in the form of flat sheet that is flexible, thin, and nominally 2-dimensional

EXAMPLE Woven or nonwoven fabrics, wet laid papers, smooth pads, felts etc. normally handled as roll goods.

3.28
GPACM-TS
adsorbent in the form of a three dimensional structure that is many times thicker than flat sheet and e.g. used as a finished element in a device

EXAMPLE Flexible open cell structures, i.e. of thicker impregnated foam, corrugated pads etc. and air permeable rigid structures, i.e. of bonded particles, honeycomb trays, extruded monoliths, etc.

3.29
initial efficiency
E_i
efficiency calculated as the intersection of vertical efficiency axis by extrapolation of a linear fit of efficiency vs. time from the values between 2 to 12 minutes of the E vs. time graph generated during testing of a GPAC Media or Device

3.30
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

3.31
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.

3.32
ppm(v)

parts per million by volume concentration measure normally used to record pollution levels in, e.g. work place safety

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

3.33
penetration

P

ratio of contaminant concentration downstream of the filter to the upstream (challenge) concentration

Note 1 to entry: Sometimes expressed as a percentage.

Note 2 to entry: Related to efficiency (E) by the expression: $E = (1 - P) \times 100\ \%$.

[SOURCE: ISO 29464:2011; 3.2.51]

3.34
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)

3.35
pores

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]

3.36
pressure drop

Δp

difference in pressure between two points in an airflow system at specified conditions, especially when measured across a GPAC Media or Device

3.37
removal efficiency

E

fraction or percentage of a challenge contaminant that is retained by a GPAC Media or Device at a given time

3.38
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]

3.39
residence time
t_r
relative time that an increment of fluid (or contaminant) is within the boundaries of the media volume

EXAMPLE An example of the media volume is 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 [tR = V (total bed volume) / Q (air flow rate)].

[SOURCE: ISO 29464:2011; 3.2.71]

3.40
rise time
t_{Rn}
time between initial injection of contaminant and reaching 95 % of the challenge concentration for an empty duct (t_0 - t_{VO}) measured at the downstream sampling location for a specific test (n), challenge gas and gas flow

3.41
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 compounds present in the air stream, e.g. gases and vapours.

3.42
sorption
process in which fluid molecules (gas or liquid) are removed by the GPACM by absorption or adsorption

3.43
space velocity
sv
measure of residence time of the airflow to pass through the adsorbent bed

EXAMPLE sv = volumetric flow rate/total volume of the bed.

Note 1 to entry: [sv] = (residence time)$^{-1}$.

3.44
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	concentration
C_D	downstream concentration [ppb, ppm] measured at a position Y mm after the media sample or device
C_U	upstream concentration [ppb, ppm] measured at a position X mm before the media sample or device
d_{pa}	the average particle diameter of a loose fill adsorbent

E_C	removal efficiency [%] for the device measured at the challenge concentration selected during the capacity test
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 media or 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_s	the total integrated amount [g], [mol] of challenge compound accumulated by the GPAC media or device during the whole challenge test
m_{sD}	the integrated amount in moles or gram of challenge compound accumulated during measurement at the downstream position
m_{sU}	the integrated amount in moles or gram of challenge compound accumulated during measurement at the upstream position
n_p	the number of pores along the (shortest) diameter of a GPACM-TS sample
p_D	downstream pressure [Pa] measured at a position Y mm after the media sample or device
p_U	upstream pressure [Pa] measured at a position X mm before the media sample or device
Q	air flow rate; flow used in test (given by 5.4 or 5.5) [m^3/h] measured at a position Z mm from the media sample or device
Q_A	the average air flow rate calculated from individual measurements evenly distributed over the test period.
RH_D	downstream relative humidity [%] measured at a position Y mm after the media sample or device
RH_U	upstream relative humidity [%] measured at a position X mm before the media sample or device
t	time
t_0	start time. The time when C_U (contamination concentration upstream) equals the selected challenge concentration for an empty sample holder or duct
t_{DC}	decay time for challenge concentration used in the capacity measurement
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_{RC}	rise time for challenge concentration used in the capacity measurement
t_{VC}	time noted at challenge gas valve closure
t_{VO}	time noted at challenge gas valve opening
T_D	downstream temperature [°C] measured at a position Y mm after the media sample or device
T_U	upstream temperature [°C] measured at a position X mm before the media sample or device
v_f	face velocity [m/s] calculated from flow and cross sectional area of media sample or device
X	a position X positioned sufficiently far ahead of the device to allow undisturbed measurements, determined in the validation, Annex A. At the position X the concentration of challenge compound is sufficiently mixed and represents the upstream concentration that the GPACM sample will be challenged with.

x	the minimum recommended distance from the highest part of the sample holder with the same diameter as the upstream side of the sample
Y	a position Y positioned sufficiently far after the device to allow undisturbed measurements, determined in the validation section, Annex A. At the position Y the concentration of penetrating challenge compound is sufficiently mixed and represents the average downstream concentration after the GPACM sample.
y	the minimum recommended distance from the downstream side of the sample to the lowest part of the sample holder with the same diameter as the sample.
Z	a position Z positioned sufficiently far from the media or device to permit a reliable flow measurement using an orifice device, determined in the validation, Annex A.
Δp	pressure drop measured over the tested media sample or device [Pa]

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 different GPACM configurations

5.1 General

This part of ISO 10121shows how to measure four key parameters that reflect the performance of a GPACM. 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);

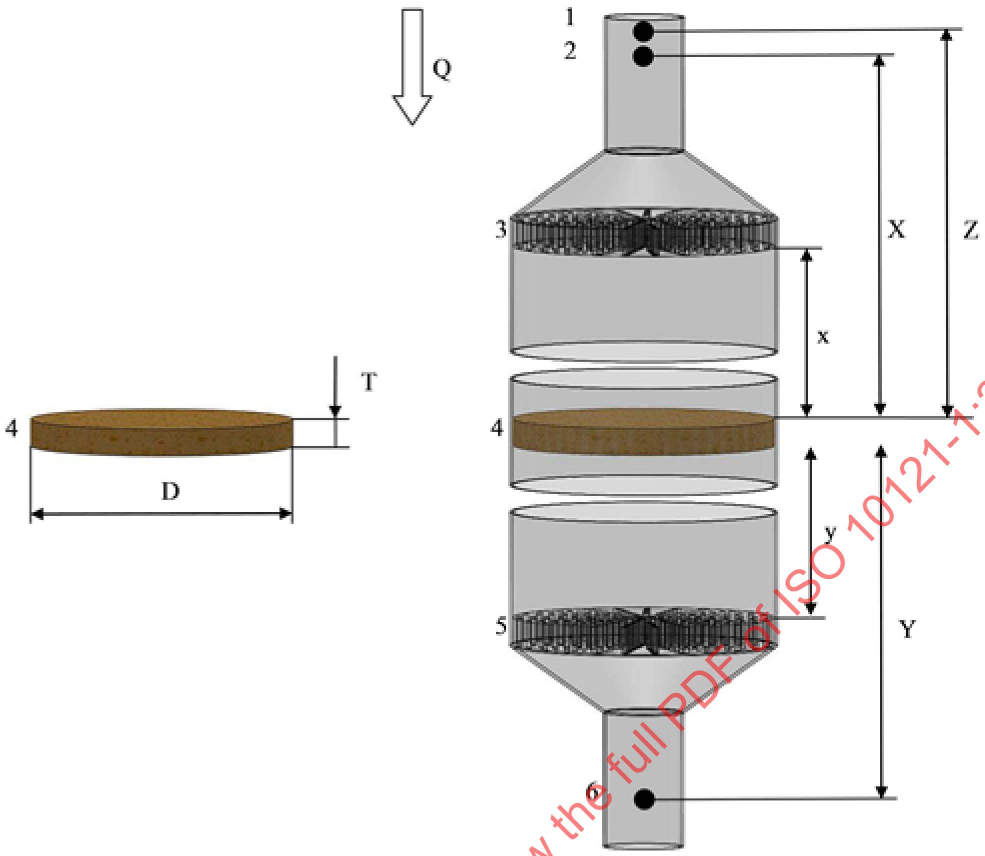
- affected by other gases present, by temperature, by humidity and by the air flow;
- different for different particle sizes of loose fill samples occupying the same volume;
- different for identical materials subjected to different face velocities and/or material thicknesses.

In order to perform tests at sufficiently short test times the concentration is strongly increased to accelerate the test. In this part of ISO 10121 two concentration levels are suggested for the determination of capacity in 5.4.

Clause 5 describes the normative part of the test stand and normative sample holder for different GPACM, normative parameters for generation of the challenge air stream and test gases for benchmark purposes. Clause 6 describes in detail the test sequence for conditioning and for determination of pressure drop, removal efficiency, capacity and retentivity in this order.

5.2 Test setup and normative GPACM sample holder

The GPACM sample holder shall be installed without leakages or bypass. The air stream should be uniformly mixed and with equal velocity and upstream concentration over the cross section. A schematic view of the sample holder is shown in Figure 1. 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 sample holders should be vertical and the flow direction is most logically from top to bottom as indicated in Figure 1. In this way bed disturbances due to the flow are avoided. However, if spring loaded screens are used to hold the material the flow direction may be from bottom to top as well. This part of ISO 10121 exemplifies the procedure of measuring a single sample. A test stand with multiple parallel sample holders is often used and may be advantageous. The procedure can easily be expanded to work with multiple measurements as discussed in 6.1.



Key

1 Q, air flow rate sampling at point Z
2 upstream sampling point for T_U, RH_U, p_U and C_U at point X
3 diffusor at a distance x from the media sample surface
4 GPAC media sample of diameter D and thickness T, see Annex D
5 diffusor at a distance y from the media sample surface
6 downstream sampling point for T_D, RH_D, p_D and C_D at point Y

Figure 1 — Schematic view of a sample holder showing ducting, measurement parameters and sampling points (normative parameters are given in Annex D)

Media are used in different configurations depending on the configuration and construction of the intended device. To cover most applications three different GPACM configurations are defined. The three different types identified in this part of ISO 10121 are GPACM-LF (particles of different shape and size intended for e.g. Loose Fill applications), GPACM-FL (FLat sheet fabric intended for e.g. flat one layer, pleated or bag type devices) and GPACM-TS (three dimensional structures that are many times thicker than flat sheets and e.g. used as finished elements in a device). For each of these three GPACM configurations normative measures of the sample holder are given in Annex D. Annex D also contain specific normative information for the use of each sample holder including sample (bed) thickness and sample face velocity as well as the prescribed sampling and filling procedure.

It is also common to test parts of devices e.g. cut out sections from a complete GPACD. These may be tested according to ISO 10121-2 with flow adjusted to the remaining cross section of the sample. Since a unique adaptor plate is used depending on size and type of GPACD no normative test section can be defined. This test is therefore not part of this part of ISO 10121.

The test equipment supporting the normative sample holder 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. A schematic design is however shown in Annex C. Gas generation and analysis techniques are suggested in Annex B. It is the user of this part of ISO 10121 that should select the solution best fitted with regard to equipment availability and other technical concerns e.g. single or multiple parallel sample capacity. 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 shall be demonstrated by the tests provided in the validation section.

5.3 Raw data, sampling accuracy and normative generation parameters

Ideally all measurement parameters in Figure 1 should be measured continuously with a computerised logging system. The sampling frequency should be fast enough to produce sufficient resolution in the adsorption and desorption data. 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)	5000 - 100000	±1,5 %	±3 %	5min, 1h, 4h, 12h[a, b]
C_D	n.a.	ppb(v)	100 - 100000	±1,5 %	n.a.	1 min[b]
T_U	23 or selected in 5.5	°C	n.a.[c]	±0,5°C	±0,5°C	same as C_D
T_D	n.a.				n.a.	
RH_U	50 or selected in 5.5	%	n.a.[c]	±1 % RH	±3 % RH	same as C_D
RH_D	n.a.				*n.a.*	
p_U, p_D	-	mbar	-	±5 %	±5	same as C_D
Δp	specific for media and sample holder	Pa	-	±2		same as C_D
Q, air flow rate	given in Annex D for 5.4 or user selected in 5.5	m^3/h	n.a.	±5 %	±3 %	same as C_D
v_f, face velocity		m/s	n.a.			
residence time		s	n.a.	n.a.	n.a.	n.a.

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

[b] A longer interval may be used if at least 100 pts can be generated down to 50 % eff. 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 measurements than every 5 min.

[c] Useful informative ranges of T and RH are 15–45 and 30–95 respectively.

5.4 Test parameters for the standardized benchmark test

5.4.1 General

For generally applicable benchmark purposes two concentration levels and three gases are suggested and common for all the GPACM configurations defined in this part of ISO 10121. These are given in Table 2 below. All other parameters are normatively specified but different for different GPACM configurations given in Annex D. The whole test setup is selected as a best compromise between measurement errors, the resolution of available measurement techniques and acceptable testing times.

5.4.2 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 the media is challenged enough to show a decaying efficiency. To ensure that the test is challenging the media enough to produce useful data a minimum permissible end efficiency is also given. Data obtained can be used for comparison of different samples within the same GPACM configuration providing that the compared data for BOTH were measured at either 9 or 90 ppm(v) with the same challenge gas, same sample holder and with the same test option i.e. the same face velocity and material height.

5.4.3 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 approximate the actual application better. 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 at the real application.

5.4.4 Filters for acids and bases tested with SO_2 and NH_3 respectively

For inorganic acids and bases no concentration dependent difference is expected at 9 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 adsorbent systems. In addition, the uptake of SO_2 is often dependent on relative humidity. For an SO_2 application where the expected temperature or relative humidity is far from the normative value, it is recommended to use actual application parameters and test according to 5.5.

Table 2 specifies challenge gases, concentrations and test demands for the capacity determination, according to 6.3.

Table 2 — Challenge gases, concentrations and test demands for the standardized benchmark test

Parameter	Selected gas	Challenge level	Unit	Reference analysis technique	Min permissible end efficiency within 12 h [b]	Retentivity test
ACID	SO_2[a]	9/90[b]	ppm(v)	UV fluorescence	$50\ \% > E_{End} > 10\ \%$	optional
BASE	NH_3	9/90 [b]	ppm(v)	chemiluminescence[c]	$50\ \% > E_{End} > 10\ \%$	optional
VOC	toluene	9/(90) [b]	ppm(v)	PID[c] or FID[c]	$50\ \% > E_{End} > 10\ \%$	compulsory

[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 according to 5.5 and Annex B

[b] The lower or higher concentration is selected depending on filter type and the requirements of the application. The lower concentration is preferred for toluene while the higher concentration may be needed for all gases to reach the minimum permissible end efficiency after 12 h.

[c] 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 documented correlation versus the reference technique

5.4.5 Retentivity test

For devices tested with toluene a retentivity determination is compulsory, see 6.4. 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 6h. For tests with sulfur dioxide or ammonia a retentivity test is highly recommended.

5.5 Test parameters selected between user and supplier

5.5.1 General

The normative setup specifies all variables except face velocity, material thickness, challenge gas, challenge concentration, temperature, relative humidity and test duration. These parameters depend on the specific application and should be agreed upon between supplier and user in each specific case.

5.5.2 Face velocity and material thickness

These are construction parameters of a device. In testing media for a specific application it is therefore better to use the actual face velocity, actual material thickness and for loose fill applications the actual size distribution in order to mimic the actual performance. The air flow rate and residence time are derived from the face velocity, material thickness and sample cross sectional area as specified in Annex D.

5.5.3 Challenge gas

The **challenge gas selection** needs to conform to the intended application. If possible, the best choice is to use the same gas as in the real application. Otherwise, the gases used in 5.4 may be used. Several known pollutant gases are also suggested in Annex B.

5.5.4 Challenge concentration

The **challenge concentration** is always a compromise and pose a risk for under or over estimating the real life media performance. For removal of **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 material 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 media 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 selected challenge concentration need to be assessed in each individual case.

5.5.5 Temperature and relative humidity

The temperature, at least theoretically, affects the rate of chemical reactions e.g. in the chemisorption reaction of impregnated carbons. The relative humidity need to be over a certain minimum value for a chemical reactions involving water to proceed. In the case of unimpregnated carbons used for VOC removal the relative humidity can have a quite strong influence if the pore system become partially or completely blocked by water. For applications where the expected temperature or relative humidity is far from the normative values for the standardized benchmark test given in Table 1, it is recommended to use actual application parameters for the test.

5.5.6 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 weeks. However, media testing is almost exclusively performed to give a fast indication of best candidates for a GPACD. The complete GPACD is then more extensively tested.

6 Test sequence

6.1 General

This test sequence should be used for testing of all GPACM configurations. A full test consists of three consecutive parts 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 shall always be performed. Depending on the needs of the user and of the specific GPACM to be tested not all key parameters may need to be determined. It is optional to perform 6.4 for acids and bases (Table 2). However, any and all parts performed shall conform to the normative part of this part of ISO 10121.

A validation of test stand, generation equipment and analysers shall be performed before the test starts. In particular, if only one analyser is used, the lag times, t_R and t_D, between upstream and downstream measurements shall be previously determined (Clause 7) for the concentration and flow used in 6.3 and 6.4. It is common and often beneficial to use a test stand with multiple GPACM sample holders. The test sequence in Clause 6 is described for a single sample holder but may easily be duplicated in appropriate sections for a multiple test. Most common in multiple sample setups is to measure in an endless cycle from upstream, downstream sample 1, downstream sample 2 etc. However, the supplier shall be able to demonstrate that the data are not altered due to the multiple setups and to allow that the time between samples exceed the time for actual manoeuvring of valves and flushing tube dead volumes in addition to the individual rise times and decay times as explained in 7.2.

6.2 Conditioning and pressure drop determination

Before any performance measurements are made the GPACM sample holder should be conditioned with clean air without challenge gas at the correct test air flow rate calculated from the face velocity and the sample cross sectional area as per Annex D. The conditioning should be maintained until temperature and humidity becomes stable over the device (equilibrium time). The pressure drop for the empty holder at the rated air flow shall be measured and recorded. It should be noted that the determined Δp values are affected by the sample holder design and the data should only be used to compare like GPACM configurations to like, not between GPACM configurations.

6.2.1 Procedure

1) Select correct flow, challenge compound and challenge concentration C_U for the device to be tested according to 5.4 or 5.5 and Annex D.

2) Calibrate analysis equipment according to Annex A or manufacturer’s recommendations.

3) Prepare the test stand and seal it without introducing a GPACM but with the correct sample holder mounted.

4) Prepare and start challenge gas source and stabilize it to the desired upstream concentration. When stability is reached, measure C_U for at least 10 min. Note also Δp for the empty holder.

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

6) Introduce the GPACM into the sample holder.

7) Increase air flow to the desired air flow rate.

8) Let the flow stabilize and record the pressure drop Δp.

9) 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

Calculate Δp as the difference between Δp of sample in sample holder and Δp of the empty sample holder. No other calculations besides in point 9 above.

6.2.3 Reporting and graphs

Note the value of Δp on page 1 in the test report Clause 8.

6.3 Capacity determination

The capacity determination test shall be made at 9 or 90 ppm as per 5.4 or at a selected value according to 5.5. The goal of this test is to determine the capacity of the media. In this test it is recommended to measure downstream continuously with only periodical upstream measurements to check the stability, e.g. for 10 min of every hour of the test or repeatedly in a multiple sample holder setup. The most suitable interval will of course depend on the expected total test time, selected end point, the concentration difference over the GPACM, t_{RC} and t_{DC}. The end point or end efficiency is selected by supplier and user depending on the application according to 5.5. For the standardised benchmark test in 5.4 the end efficiency should reach a value between 50 % and 10 % within the 12 h test time.

6.3.1 Procedure (continued from 6.2.1)

10) The capacity test can be started directly after 6.2.1. The settings to reach C_U after t_{RC} shall be previously determined in 7.2. The GPACM should already be mounted in the sample holder, at the rated air flow and in equilibrium.

11) Prepare and start challenge gas source with the settings for C_U.

12) Monitor T_U, T_D, RH_U, RH_D, ΔP and Q every 1 min (or longer if at least 100 data points can be generated down to 50 % eff)

13) Turn source ON and wait t_{RC}. Note the starting time t_0.

14) Measure C_D until the level is sufficiently stable or at least for 20 min in the case of a single sample setup or for a time sufficient to give a stable reading in a multiple setup.

15) Switch to C_U and start to measure. Note the concentration increase but discard the readings during t_{RC}.

16) Measure C_U until the level is sufficiently stable or at least for 10 min in the case of a single sample setup or for a time sufficient to give a stable reading in a multiple setup.

17) Switch to C_D and start to measure. Note the concentration decrease but discard the readings during t_{DC}.

18) Measure C_D for a longer time period, e.g. 20 min depending on the expected total test time and if a single or multiple sample setup is used.

19) Repeat 15 to 18 for the remainder of the test until the desired end point is reached and is stable for at least 10 min.

20) If a desorption test is planned this can only be performed correctly if it continues directly after this test.

21) Continue with the procedure for desorption in 6.4 without terminating this test -OR- Note capacity, test time t_{END} and end removal efficiency E_{END}.

22) Turn source OFF and terminate the test.

6.3.2 Calculations

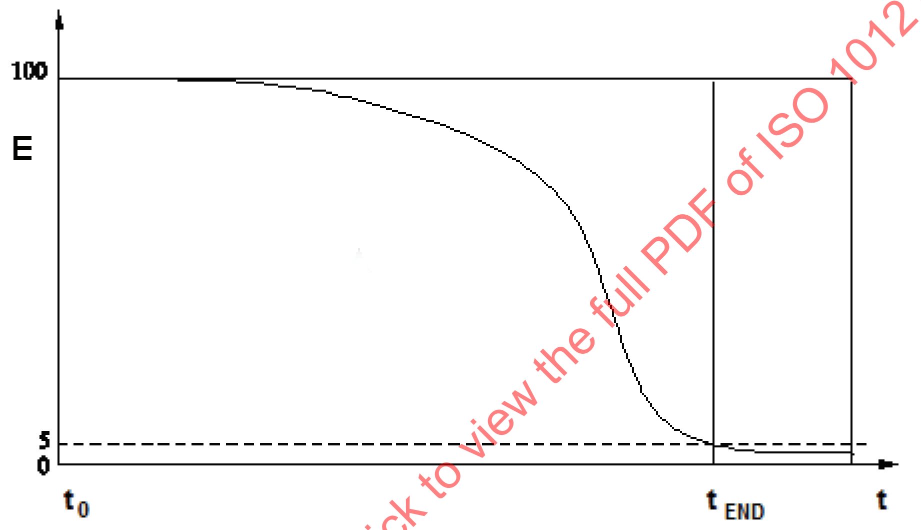
From the data acquisition system a raw data table containing date, time, test time, C_U, C_D, T_U, T_D, RH_U, RH_D, ΔP and Q should be created. For validation purposes (Clause 7) it is also useful to monitor the generation equipment, e.g. the signal from a mass flow valve. It is also advantageous to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

6.3.2.1 Calculation of efficiency

From the raw data table removal efficiency, E_C, is calculated as:

$$E_C[\%]=\frac{(C_U-C_D)}{C_U}x100 \quad (1)$$

and plotted against time, see Figure 2.



Key

E efficiency %

t time

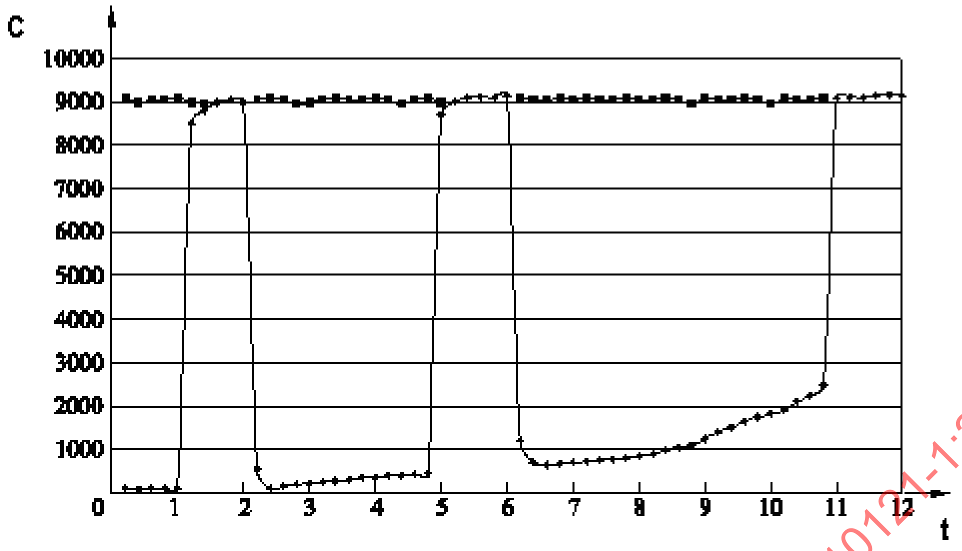
t_0 start time

t_{END} end time

Figure 2 — Example of an efficiency vs. time graph

6.3.2.2 Calculation of capacity

Capacity (m_S) is the mass of contaminant sorbed by the GPACM. The total amount m_S will be calculated in increments due to the fact that the procedure in 6.3.1 uses only one analyser which makes it necessary to use an interpolated average for the concentration not measured. 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 one hour and then every sixth hour and as illustrated by Figure 3.



Key

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

Figure 3 — Example of a concentration graph when using a single analyser for C_U and C_D

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

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:

$$m_s = \sum_{0}^{1}((C_{kU} - C_D(t))Q_A(t)k)\Delta t + \sum_{1}^{2}((C_U(t) - C_{kD})Q_A(t)k)\Delta t + \sum_{2}^{5}((C_{kU} - C_D(t))Q_A(t)k)\Delta t + \sum_{5}^{6}((C_U(t) - C_{kD})Q_A(t)k)\Delta t + \sum_{6}^{11}((C_{kU} - C_D(t))Q_A(t)k)\Delta t \tag{3}$$

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.

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. If multiple samples are tested there will be a number of downstream data sets that should be separated and treated separately according to the above equations.

6.3.3 Reporting and graphs

The capacity measurements are presented as:

- The initial value of E_C [%], Ei [%] is calculated as the intersection of vertical efficiency axis by extrapolation of a linear fit of efficiency vs. time from the values between 2 to 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 as far as available below 50 % are noted on page 1 in the test report.
- E_C versus m_s [g], in the test report, Clause 8.
- E_C versus time (h), in the test report, Clause 8.
- C_D versus time (h), in the test report, Clause 8.

In addition, for verification of the correct test the following raw data or graphs should be archived at the test lab and be available upon request:

- T_U and T_D versus 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.

6.4 Retentivity determination

6.4.1 General

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 VOC's. The test should continue until the downstream concentration is < 5 %. of the original challenge concentration or for maximum 6 h whatever occurs first.

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}) is agreed between user and supplier.

6.4.2 Procedure (continued from 6.3.1)

23) Turn source OFF, note time t_{VC} 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 are below 90 %.

24) Measure C_D until the desired end point is reached.

25) Note desorption test time t_{END} and end concentration C_D.

26) Shut down the test completely.

6.4.3 Calculations

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

$$m_r = m_s - \int_{t_{VC}}^{t_{END}} (C_D(t)Q(t)k)dt \tag{4}$$

6.4.4 Reporting and graphs

- Note the value of m_r on page 1 in the test report.
- Show the m_r 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 checklists 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 or if multiple parallel sample holders are used, then the lag time for changing concentration in the system shall 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 correct flow, challenge compound and challenge concentration C_U for the device to be tested according to 5.4 or 5.5 and Annex D.

2) Prepare the test stand and seal it without introducing a GPACM but with the correct sample holder mounted.

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_{V0}). (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}.

7.2.2 Calculations

The values to be used in the capacity determination test are:

— 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 used. These data can be reused at a later test provided that nothing has been changed in the set-up. However, it is strongly recommended to check these values on a regular basis as part of the QA work.

— t_{RC} gives the time until a GPACM is subjected to the correct upstream concentration and the actual challenge starts i.e. t_0.

— t_{RC} gives the delay 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 and for safe introduction of the GPACM sample holder in the test stand.

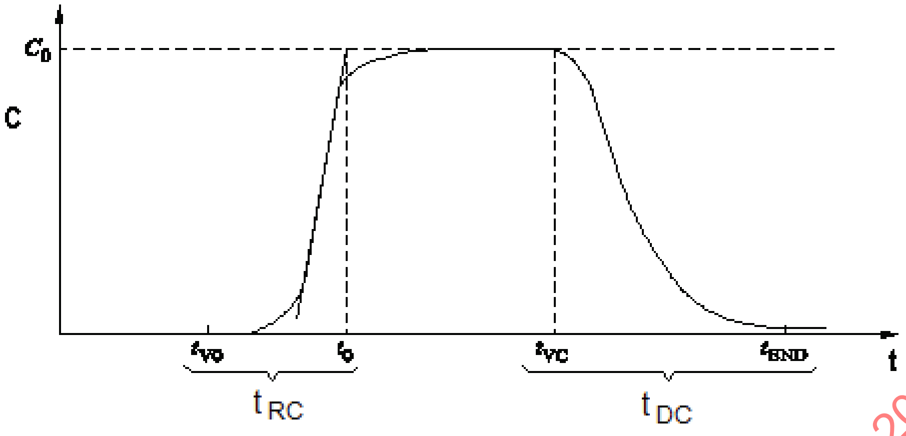
— t_{DC} gives the time until the values of C_D downstream of the GPACM reflects the actual penetration through the device and not remaining adsorption from walls and test tubing, for example after an upstream measurement. Recorded values should therefore be discarded during t_{DC} in the data logging software.

— t_{DC} for certain gases at low concentrations e.g. ammonia at 100 ppb can take several hours.

— t_{RC} and t_{DC} shall also be taken into account between samples if a multiple sample holder setup is used

7.2.3 Reporting and graphs

The values of t_{RC} and t_{DC} should be included in the test report, Clause 8.



Key

t	time
C	concentration
t_{V0}	time noted at challenge gas valve opening
t_0	start 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}	rise time for challenge concentration (RC)
t_{DC}	decay time for challenge concentration (DC)

Figure 4 — 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 italic text. The graphs show actual data of a similar test and can be used as a guideline on how to present data. The parts of the report referring to an optional retentivity test should be excluded if this part is not performed.

8.2 Test report example

ISO 10121-1 TEST REPORT			
Report n.	*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:			

ISO 10121-1 TEST REPORT			
name of customer		Address	*insert applicable info*
Phone	*insert applicable info*	Web	*insert applicable info*

TESTED MEDIA (GPACM):

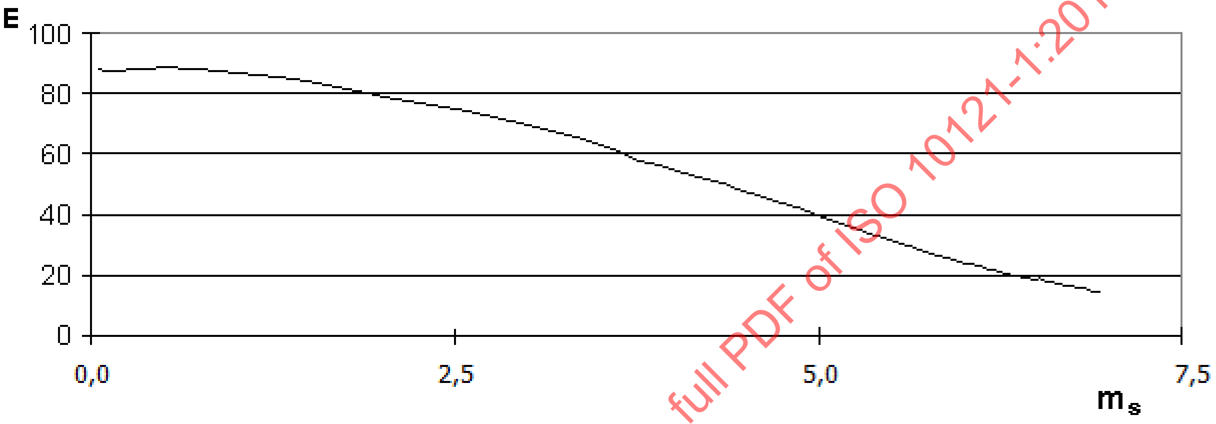
Manufacturer	*name of manufacturer*	Address	*insert applicable info*
Phone	*insert applicable info*	Web	*insert applicable info*
Product name	*insert applicable info*	Lot number (if available)	*insert applicable info*
Product grade	*AC-VOC*	Batch number (if available)	*insert applicable info*
Particle dimensions [mm] or [mesh] if LF	*4 × 8*		
Average particle size range	*insert applicable info*	Max particle size	*insert applicable info*
Sample information	*insert applicable info*	Other identifications	*insert applicable info*

TESTING CONDITIONS:

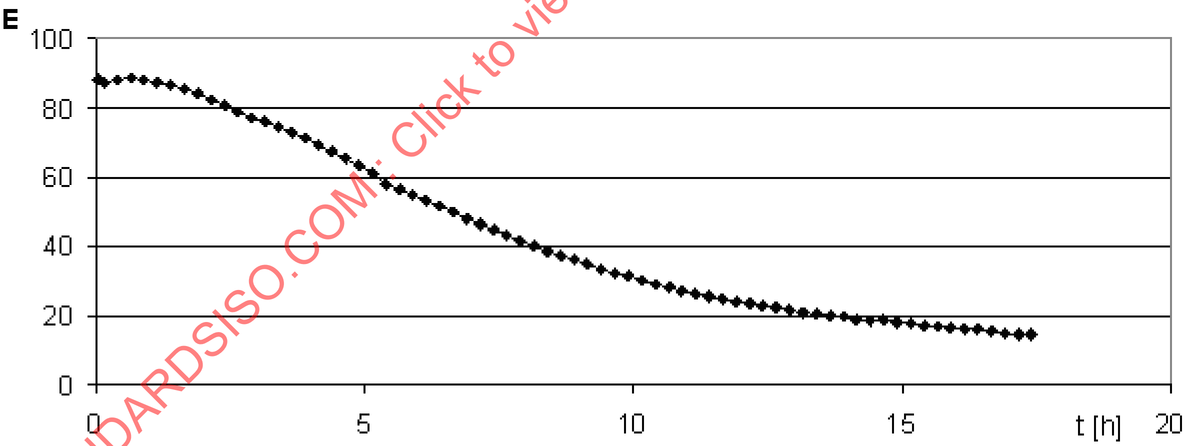
Face velocity v_f [mm/s]	*260*	Configuration used		*GPACM-LF*	
Sample diameter, D [mm]	*50*	x [mm]		Challenge conc [ppb]	*9100*
Sample thickness, T [mm]	*26*	y [mm]		sample mass [g]	*48,3*
Test gas	*toluene*	Temp [°C]	*23*	RH [%]	*50*
Analyser	*insert applicable info*	Model	*insert applicable info*		
static air pressure [mbar]	*insert applicable info*	t_{RC} [s]	*40*	t_{DC} [s]	*30*

SUMMARY OF TESTING RESULTS:

Δp [Pa]	64	Δp empty [Pa]	*12*	Ei Initial Eff. (challenge) [%]	*88*
Test duration T_{END} [h]		*11,2*		E_{END} End efficiency [%]	*18*

<table>
<tr><td colspan="10">ISO 10121-1 TEST REPORT</td></tr>
<tr><td rowspan="2">$\boldsymbol{m_s}$, Capacity [g] and time (h) @</td><td>eff 95 %</td><td><i>n.a.</i></td><td><i>n.a</i></td><td>eff 90 %</td><td><i>n.a.</i></td><td><i>n.a.</i></td><td>eff 70 %</td><td><i>2,6</i></td><td><i>4,5</i></td></tr>
<tr><td>eff 50 %</td><td><i>4,5</i></td><td><i>7</i></td><td>eff 30 %</td><td><i>5,5</i></td><td><i>10</i></td><td>total</td><td><i>7,3</i></td><td><i>11,2</i></td></tr>
<tr><td colspan="2">$\boldsymbol{m_r}$, retentivity [g]</td><td colspan="2"><i>4,0</i></td><td colspan="4">residence time $\boldsymbol{t_r}$ [s]</td><td colspan="2"><i>0,1</i></td></tr>
<tr><td colspan="10">Comment:</td></tr>
<tr><td colspan="10">CAPACITY DETERMINATION GRAPHS:</td></tr>
<tr><td colspan="10">


a) Example of capacity test, E vs. m_s, (see 6.3)



b) Example of capacity test, E vs. t, (see 6.3)

Figure 5 — Capacity determination graphs
</td></tr>
<tr><td colspan="10">RETENTIVITY DETERMINATION GRAPH:</td></tr>
</table>

ISO 10121-1 TEST REPORT

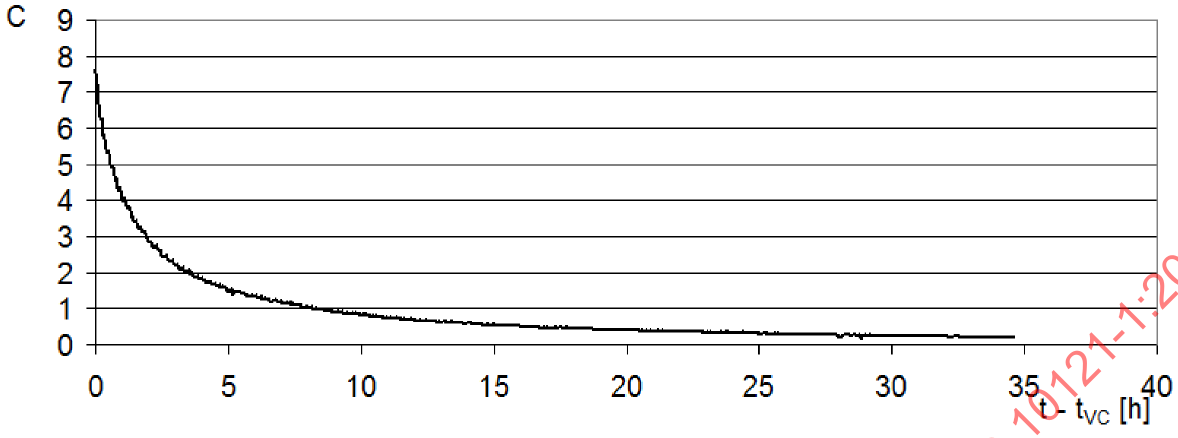
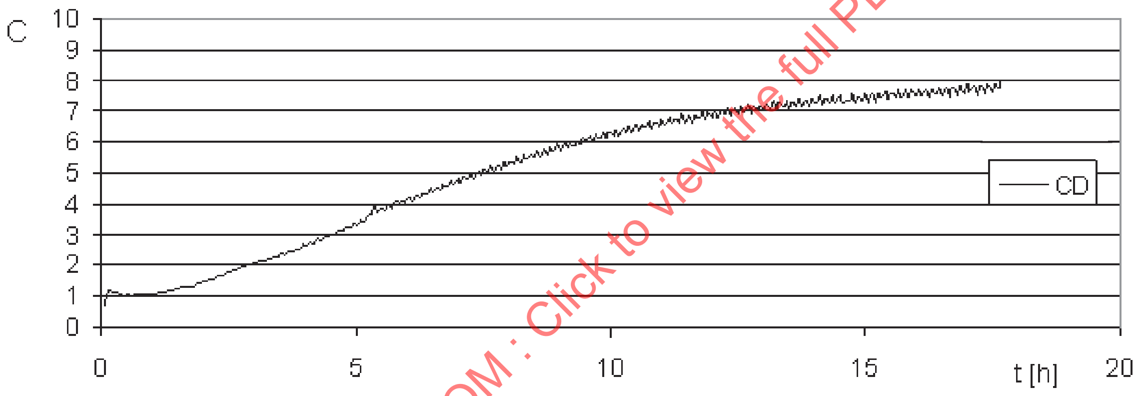
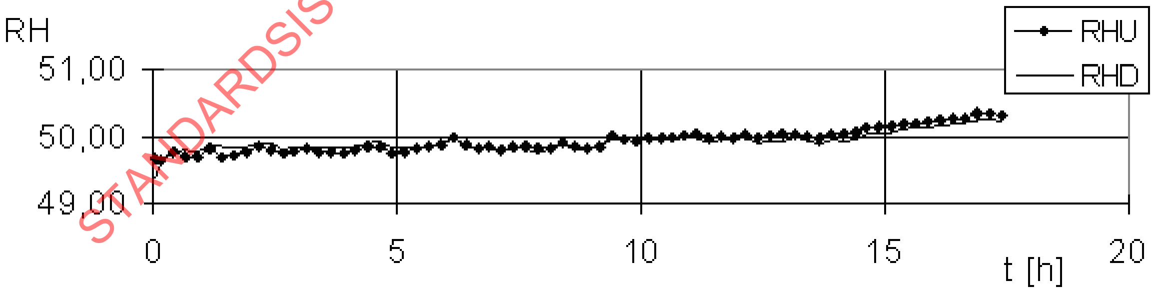


Figure 6 — Example of retentivity test, C vs. t, (see 6.4)

TEST VERIFICATION GRAPHS



a) Example verification of measured concentration



b) Example verification of relative humidity accuracy and oscillation

Figure 7 — Test verification graphs

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 which includes but is not limited to the following.

— Proper training of personnel shall be ensured.

- All chemicals should be handled according to local regulations for personal safety, e.g. TLV levels, handling, storage and transport.
- Technical data sheets and MSDS for chemicals used shall 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 e.g. using stands or wall mounts to prevent fall and unintended outlet of content.
- 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.
- Leak monitors and gas 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 e.g. hydrogen sulphide, 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 shall also be recognized that all challenge gas penetrating the GPACM are 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, *Accuracy 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 clauses in this part of ISO 10121.

Table A.1 — Uncertainty of measurements of sensors

Clause	Device	Requirement	Comment
Clauses 6 and 7	Measuring Uncertainty Airflow	±2 %	Relative to actual reading
Clauses 6 and 7	Measuring Uncertainty Pressure Drop	±2 %	Relative to actual reading
Clauses 6 and 7	Measuring Uncertainty Temperature	±0,5 °C	Relative to actual reading
	Determining Uncertainty in Gas sensor/analyser used	±1,5 %	Relative to actual reading
Clauses 6 and 7	Measuring Uncertainty Relative Humidity	±1 %	Relative to actual reading
Clauses 6 and 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 checklist 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
Clauses 5 and 7	Temperature control,	23 °C ± 0,5 °C	Check with calibrated thermometer

[a] Recommended filter classes as given in EN 779:2012 and ISO 29463-1:2011.

Table A.2 *(continued)*

Clause	Parameter or Test Item	Requirement	Comment
Clauses 5 and 7	Humidity control (relative)	50 % ± 3 % R.H.	Check with calibrated humidity sensor
7	Leakage of duct and test chamber	< 0,2 % of test flow given in 5.5 or Annex D at 500 Pa	Check according to accepted state of the art methods
7	Cleanliness of test air, background contamination	< 1 % of challenging concentration	Check empty duct without gas challenge
7	Cleanliness of test air, particles	Particle cleanliness > F7 + ISO 25E [a]	Check empty duct without gas challenge
Clauses 5 and 7	Airflow sensor, to be achieved in the test bench	±2 % measuring uncertainty	±2 % repeatability
Clauses 5,6, and 7	Airflow control	Range: 5–30 cm/s	The test stand and sample holder should be validated 10 cm/s/h. This face velocity has to be kept within a tolerance of 3 % for at least 12 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		
	Sampling tubes: materials and properties		No out-gassing, chemically resistant materials
	Challenge gas injection - concentration	±3 % of set point, stable over 1 h	check using 90 ppm_V ACID, BASE and VOC gas
	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 6.1 for a detailed description
5	Documentation of performance profile		All results achieved during validation shall be documented

[a] Recommended filter classes as given in EN 779:2012 and ISO 29463-1:2011.

Table A.3 — Routine operation

Clause	Item	Requirement	Frequency	Comment
6	Compare up- and downstream sampling with the sample holder to be used mounted without media (empty)	Ratio C_D/C_U between 0,98 and 1,02	daily	
5	Pressure drop of empty sample holder		each test	
7	Background concentration (excluding methane and NO)	< 1 % of cumulative concentration of challenging agent	daily	For each analyser used
5	Calibration of detectors and analysers		each test	
6	Spatial homogeneity of challenge compound concentration	±5 %	after each modification of test bench	
6	Stability of challenge 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	< 0,2 % 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 shall 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 shall 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 shall 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 shall be made regarding decommissioning and equipment cleanout between tests. It shall be recognized that all surfaces exposed to contaminant adsorb test species and hazardous reaction products may also be produced. Examples of challenge species and suitable concentration levels are given in Tables B.1, B.2, B.3 and B.4.

B.1.2 Liquid Species

Liquid species shall be vaporized before injection into the test equipment. Suitable methods vary with test species, but shall 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)
Sulfur Dioxide	9 ± 5 % or 90 ± 5 %
Nitrogen Dioxide	9 ± 5 % or 90 ± 5 %
Nitrogen Oxide	9 ± 5 % or 90 ± 5 %
Hydrogen Sulphide	9 ± 5 % or 90 ± 5 %
Acetic acid	9 ± 5 % or 90 ± 5 %

Table B.2 — Alkaline (basic) gases

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

Table B.3 — VOC gases

Compound	Suggested challenge concentrations ppm(v)
Toluene	9 ± 5 % or 90 ± 5 %
Isopropanol	9 ± 5 % or 90 ± 5 %
Isobutanol	9 ± 5 % or 90 ± 5 %
Hexane	9 ± 5 % or 90 ± 5 %
Tetrachloroethylene	9 ± 5 % or 90 ± 5 %
Formaldehyde	9 ± 5 % or 90 ± 5 %
Mercaptans	9 ± 5 % or 90 ± 5 %
Ethanol	9 ± 5 % or 90 ± 5 %
MEK	9 ± 5 % or 90 ± 5 %
acetone	9 ± 5 % or 90 ± 5 %
n-butane[a]	9 ± 5 % or 90 ± 5 %
a n-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	9 ± 5 % or 90 ± 5 %
Chlorine	9 ± 5 % or 90 ± 5 %
Carbon monoxide	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 shall be selected carefully with regard to the contaminant characteristics. Similarly the sample rate and accuracy of detectors and measurement equipment can vary widely.

Methods recommend for the simplified test includes FID for organic substances, chemiluminescence detectors for NO_x 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 tube (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
CPE	Controlled Potential Electrolysis
PAS	Photo Acoustic emission
NDIR	Non-diffraction Infrared Absorption
UV	Ultra-violet Absorption
UVL	Ultra-violet Luminescence
PID	Photo-ionization detector
FID	Flame-ionization detector
FTIR	Fourier Transform Infrared Spectroscopy
NPD	Nitrogen Phosphorous Detector for GC

B.2.2 Suggested analysers to the tabulated challenge species

Tables B.5, B.6, B.7 and B.8 suggest analysis techniques for the challenge species given in Tables B.1, B.2, B.3 and B.4 respectively.

Table B.5 — Acid gases

Compound	Suggested technique
Sulfur Dioxide	UVL, (CPR)
Nitrogen Oxide	CLS (NO, NO_2 and NO_x 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	FID, NPD

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, (CPE)
Chlorine	CPE, UV
Carbon monoxide	CPE, PAS, NDIR, FTIR
Carbon dioxide	CPE, PAS, NDIR, FTIR

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