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Stationary source emissions — Determination of the water vapour in ducts — Standard reference method

bsi.

National foreword

This British Standard is the UK implementation of EN 14790:2017. It supersedes BS EN 14790:2005 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EH/2/1, Stationary source emission.

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

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Stationary source emissions - Determination of the water vapour in ducts - Standard reference method

Emissions de sources fixes - Détermination de la vapeur d'eau dans les conduits - Méthode de référence normalisée

Emissionen aus stationären Quellen - Bestimmung von Wasserdampf in Kanälen - Standardreferenzverfahren

This European Standard was approved by CEN on 26 September 2016.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Contents

European foreword

This document (EN 14790:2017) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This document supersedes EN 14790:2005.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2017, and conflicting national standards shall be withdrawn at the latest by July 2017.

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

Annex E provides details of significant technical changes between this document and the previous edition.

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

1 Scope

This European Standard specifies the standard reference method (SRM) based on a sampling system with a condensation/adsorption technique to determine the water vapour concentration in the flue gases emitted to atmosphere from ducts and stacks.

This European Standard specifies the performance characteristics to be determined and performance criteria to be fulfilled by measuring systems based on the measurement method. It applies to periodic monitoring and to the calibration or control of automated measuring systems (AMS) permanently installed on a stack, for regulatory or other purposes.

This European Standard specifies criteria for demonstration of equivalence of an alternative method to the SRM by application of EN 14793:2017.

This European Standard is applicable in the range of water vapour content from 4 % to 40 % as volume concentrations and of water vapour mass concentration from 29 g/m^3 to 250 g/m^3 as a wet gas, although for a given temperature the upper limit of the method is related to the maximum pressure of water in air or in the gas.

In this European Standard all the concentrations are expressed at standard conditions (273 K and 101,3 kPa).

NOTE 1 For saturated conditions the condensation/adsorption method is not applicable. Some guidance is given in this European Standard to deal with flue gas when droplets are present.

This European Standard has been validated during field tests on waste incineration, co-incineration and large combustion plants. It has been validated for sampling periods of 30 min in the volume concentration range of 7 % to 26 %.

NOTE 2 The characteristics of installations, the conditions during field tests and the values of repeatability and reproducibility in the field are given in Annex A.

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.

EN 1911, *Stationary source emissions - Determination of mass concentration of gaseous chlorides expressed as HCl - Standard reference method*

EN 14791:2017, *Stationary source emissions — Determination of mass concentration of sulphur oxides — Standard reference method*

EN 14793:2017, *Stationary source emission – Demonstration of equivalence of an alternative method with a reference method*

EN 15259:2007, *Air quality - Measurement of stationary source emissions - Requirements for measurement sections and sites and for the measurement objective, plan and report*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
standard reference method
SRM
reference method prescribed by European or national legislation

[SOURCE: EN 15259:2007]

3.2
reference method
RM
measurement method taken as a reference by convention, which gives the accepted reference value of the measurand

Note 1 to entry: A reference method is fully described.

Note 2 to entry: A reference method can be a manual or an automated method.

Note 3 to entry: Alternative methods can be used if equivalence to the reference method has been demonstrated.

[SOURCE: EN 15259:2007]

3.3
measurement method
method described in a written procedure containing all the means and procedures required to sample and analyse, namely field of application, principle and/or reactions, definitions, equipment, procedures, presentation of results, other requirements and measurement report

[SOURCE: EN 14793:2017]

3.4
alternative method
AM
measurement method which complies with the criteria given by this European Standard with respect to the reference method

Note 1 to entry: An alternative method can consist of a simplification of the reference method.

[SOURCE: EN 14793:2017]

3.5
measuring system
set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

[SOURCE: JCGM 200:2012]

3.6
automated measuring system
AMS

entirety of all measuring instruments and additional devices for obtaining a result of measurement

Note 1 to entry: Apart from the actual measuring device (the analyser), an AMS includes facilities for taking samples (e.g. probe, sample gas lines, flow meters and regulator, delivery pump) and for sample conditioning (e.g. dust filter, pre-separator for interferents, cooler, converter). This definition also includes testing and adjusting devices that are required for functional checks and, if applicable, for commissioning.

Note 2 to entry: The term “automated measuring system” (AMS) is typically used in Europe. The term “continuous emission monitoring system” (CEMS) is also typically used in the UK and USA.

[SOURCE: EN 15267-4:2017]

3.7
calibration

set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring method or measuring system, and the corresponding values given by the applicable reference

Note 1 to entry: In case of automated measuring systems (AMS) permanently installed on a stack the applicable reference is the standard reference method (SRM) used to establish the calibration function of the AMS.

Note 2 to entry: In case of manual methods the applicable reference can be reference materials used as calibration standards to establish the relationship between the output signal of the analytical device and the reference values.

Note 3 to entry: Calibration should not be confused with adjustment of a measuring system.

3.8
measurand

particular quantity subject to measurement

[SOURCE: EN 15259:2007]

Note 1 to entry: The measurand is a quantifiable property of the stack gas under test, for example mass concentration of a measured component, temperature, velocity, mass flow, oxygen content and water vapour content.

3.9
measurement site

place on the waste gas duct in the area of the measurement plane(s) consisting of structures and technical equipment, for example working platforms, measurement ports, energy supply

Note 1 to entry: Measurement site is also known as sampling site.

[SOURCE: EN 15259:2007]

3.10
measurement plane

plane normal to the centre line of the duct at the sampling position

Note 1 to entry: Measurement plane is also known as sampling plane.

[SOURCE: EN 15259:2007]

3.11
measurement port
opening in the waste gas duct along the measurement line, through which access to the waste gas is gained

Note 1 to entry: Measurement port is also known as sampling port or access port.

[SOURCE: EN 15259:2007]

3.12
measurement line
line in the measurement plane along which the measurement points are located, bounded by the inner duct wall

Note 1 to entry: Measurement line is also known as sampling line.

[SOURCE: EN 15259:2007]

3.13
measurement point
position in the measurement plane at which the sample stream is extracted or the measurement data are obtained directly

Note 1 to entry: Measurement point is also known as sampling point.

[SOURCE: EN 15259:2007]

3.14
absorber
device in which water vapour is absorbed

3.15
droplets
small liquid particles of condensed water vapour or water liquid in the flue gas (e.g. coming from a scrubber)

Note 1 to entry: In adiabatic equilibrium conditions, droplets could arise only if a gas stream is saturated with water.

3.16
dew point
temperature below which the condensation of water vapour begins at the given pressure condition of the flue gas

3.17
vapour pressure
pressure of water in vapour form

3.18
performance characteristic
one of the quantities (described by values, tolerances, range) assigned to equipment in order to define its performance

3.19
repeatability in the laboratory

closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement

Note 1 to entry: Repeatability conditions include:

- same measurement method;
- same laboratory;
- same measuring system, used under the same conditions;
- same location;
- repetition over a short period of time.

Note 2 to entry: Repeatability can be expressed quantitatively in terms of the dispersion characteristics of the results.

Note 3 to entry: In this European Standard the repeatability is expressed as a value with a level of confidence of 95 %.

3.20
repeatability in the field

closeness of the agreement between the results of simultaneous measurements of the same measurand carried out with two sets of equipment under the same conditions of measurement

Note 1 to entry: These conditions include:

- same measurement method;
- two sets of equipment, the performances of which are fulfilling the requirements of the measurement method, used under the same conditions;
- same location;
- implemented by the same laboratory;
- typically calculated on short periods of time in order to avoid the effect of changes of influence parameters (e.g. 30 min).

Note 2 to entry: Repeatability can be expressed quantitatively in terms of the dispersion characteristics of the results.

Note 3 to entry: In this European Standard the repeatability under field conditions is expressed as a value with a level of confidence of 95 %.

3.21
reproducibility in the field

closeness of the agreement between the results of simultaneous measurements of the same measurand carried out with several sets of equipment under the same conditions of measurement

Note 1 to entry: These conditions include:

- same measurement method;
- several sets of equipment, the performances of which are fulfilling the requirements of the measurement method, used under the same conditions;
- same location;
- implemented by several laboratories.

Note 2 to entry: Reproducibility can be expressed quantitatively in terms of the dispersion characteristics of the results.

Note 3 to entry: In this European Standard the reproducibility under field conditions is expressed as a value with a level of confidence of 95 %.

3.22
uncertainty

parameter associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand

3.23
standard uncertainty

u

uncertainty of the result of a measurement expressed as a standard deviation

3.24
combined uncertainty

$\boldsymbol{u_{\mathrm{C}}}$

standard uncertainty attached to the measurement result calculated by combination of several standard uncertainties according to the principles laid down in ISO/IEC Guide 98-3 (GUM)

3.25
expanded uncertainty

U

quantity defining a level of confidence about the result of a measurement that may be expected to encompass a specific fraction of the distribution of values that could reasonably be attributed to a measurand

$$U = k \times u_{\mathrm{c}}$$

Note 1 to entry: In this European Standard, the expanded uncertainty is calculated with a coverage factor of $k = 2$, and with a level of confidence of 95 %.

Note 2 to entry: The expression overall uncertainty is sometimes used to express the expanded uncertainty.

3.26
uncertainty budget

calculation table combining all the sources of uncertainty according to EN ISO 14956 or ISO/IEC Guide 98-3 in order to calculate the combined uncertainty of the method at a specified value

4 Symbols and abbreviations

4.1 Symbols

For the purposes of this document, the following symbols apply.

C	measured volume concentration
C_w	water vapour mass concentration on dry basis
h_m	measured water vapour content on wet basis expressed as volume concentration
k	coverage factor
m_w	mass of water vapour trapped in the trapping system
M_w	molecular weight of water, 18,01534 g/mol rounded to 18 g/mol
p_m	absolute pressure at the gas volume meter
$p_\mathrm{s}(T_\mathrm{m})$	saturation vapour pressure of water at the temperature T_m of the gas volume meter
p_ref	standard pressure, 101,3 kPa
s_R	reproducibility standard deviation
$s_{r,\mathrm{limit}}$	maximum allowable repeatability standard deviation
T_i	ith temperature reading
T_m	mean absolute temperature of the sampled gas at the gas volume meter
T_ref	standard temperature, 273 K
u	standard uncertainty
u_c	combined uncertainty
U	expanded uncertainty
V_1	gas volume reading from the gas volume meter at the beginning of the sampling period, at actual conditions of temperature, pressure and humidity
V_2	gas volume reading from the gas volume meter at the end of the sampling period, at actual conditions of temperature, pressure and humidity
V_m	difference between the readings at the gas volume meter at the beginning and at the end of the sampling period
$V_\mathrm{m,ref}$	measured dry gas volume, corrected to standard conditions
V_mol	molar volume at standard conditions, in m^3/mol at p_ref and T_ref

4.2 Abbreviated terms

For the purposes of this document, the following abbreviated terms apply.

AM	alternative method
AMS	automated measuring system
PTFE	Polytetrafluoroethene
SRM	standard reference method

5 Principle

5.1 General

This European Standard describes the standard reference method (SRM) for determining the water-vapour content emitted to atmosphere from ducts and stacks. The specific components and the requirements for the measuring system are described in Clause 6. A number of performance characteristics, together with associated performance criteria are specified for the measurement method (see Table 1 in Clause 7). The expanded uncertainty of the method shall meet the specifications given in this European Standard.

The measurement method described hereafter is appropriate when the flue gas is free of droplets.

Within the scope of this European Standard, it is assumed that gas streams in stacks or ducts are more or less in adiabatic (thermodynamic) equilibrium. In those conditions, droplets can arise only if a gas stream is saturated with water. When no droplets are present in the gas stream, the gas stream is then assumed to be unsaturated with water. A gas sample is extracted at a constant rate from the stack. The water vapour of that sample is subsequently trapped by adsorption or by condensation plus adsorption; the mass of the vapour is then determined by weighing the mass gain of the trapping system.

When droplets are present in the gas stream, the implementation of the measurement method described in this European Standard leads to an overestimation of the water vapour content. If the measured value is equal to or higher than the expected value shown in the table in Annex B for saturated conditions at the temperature and pressure of the flue gas, that means that the presence of droplets can lead to biased results; such results shall be rejected.

In such cases, the evidence suggests that the gas stream is saturated with water vapour. Under these conditions, the method is abridged to a determination of the gas temperature. Then, the water vapour concentration is calculated from the theoretical mass of water vapour per unit of standard gas volume at liquid-gas equilibrium, given the actual temperature, pressure and composition of the gas stream.

5.2 Adsorption or condensation/adsorption method

A measured quantity of sampled gas is extracted from the gas stream through a trapping system, which meets the specifications of efficiency (see 8.5.2). The mass gain of the trapping system is measured in order to determine the mass or the volume water vapour content, on the basis of the volume sampled.

5.3 Temperature method

This method applies when gases are water saturated.

A temperature probe is placed in the gas stream saturated with water vapour, until it reaches equilibrium. The amount of water vapour present in the gas is subsequently derived from the temperature, using a water liquid-gas equilibrium chart or table (see Annex B).

6 Description of the measuring system

6.1 General

A known volume of flue gas is extracted representatively from a duct or chimney during a certain period of time at a controlled flow rate. A filter removes the dust in the sampled volume; thereafter the gas stream is passed through a trapping system. It is important that all parts of the sampling equipment upstream of the trapping system are heated and that the components shall not react with or absorb water vapour (e.g. stainless steel, borosilicate glass, quartz glass, PTFE or titanium are suitable materials).

An example of suitable sampling trains is shown in Annex C. The user can choose between a trapping system made up with either:

— adsorption system (Figure C.1) or

— condensation and adsorption system (Figure C.2).

The choice shall be made to fulfil the efficiency that is required in 8.5.2.

6.2 Sampling probe

In order to reach the measurement points of the measurement plane, probes of different lengths and inner diameters may be used. The design and configuration of the probe used shall ensure the residence time of the sample gas within the probe is minimised in order to reduce the response time of the measuring system.

NOTE 1 The probe can be marked before sampling in order to demonstrate that the measurement points in the measurement plane have been reached.

The sampling probe shall be surrounded by a heating jacket capable of producing a controlled temperature of at least 120 °C and 20 °C higher than the (acid) dew point of gases and shall be protected and positioned using an outer tube.

NOTE 2 It is possible to perform the sampling of SO_2 and water vapour simultaneously with the same probe (without nozzle providing no droplets are present).

NOTE 3 It is possible to perform the sampling of HCl and water vapour simultaneously with the same probe (without nozzle providing no droplets are present).

6.3 Filter housing

The filter housing shall be made of materials inert to water vapour and shall have the possibility to be connected with the probe thereby avoiding leaks.

The filter housing may be located either:

— in the duct or chimney, mounted directly behind the entry nozzle (in-stack filtration) or

— outside the duct or chimney, mounted directly behind the suction tube (out-stack filtration).

The filter housing shall be connected to the probe without any cold path between the two.

In special cases where the sample gas temperature is greater than 200 °C, the heating jacket around the sampling probe, filter housing and connector fine may be omitted. However the temperature in the sampled gas just after the filter housing should not fall below the acid dew point temperature.

6.4 Particle filter

Particle filters and filter housings of different designs may be used, but the residence time of the sample gas should be minimised.

6.5 Trapping system

The trapping system shall be made up with:

- adsorption system or
- condensation and adsorption system.

The set-up of the trapping system shall be as follows:

a) When using the adsorption system alone, it shall consist of at least one cartridge, impinger or absorber, filled with a suitable drying agent, for example coloured silica gel.

b) The condensation and adsorption system shall consist of two stages:

   1) the first one shall be a condensation stage with an optional cooling system;

   2) the second one shall be an adsorption stage as described in a).

The temperature at the outlet of the condensation system shall be as low as possible.

The efficiency of the sampling system shall be checked according to the procedure described in 8.5.2.

The trapping efficiency can be increased by increasing the residence time of sampled gases in the trapping system and/or by improving the efficiency of the cooling system. The sampled volume should be sufficient to reach an appropriate accuracy of the measurement (see 6.8 and Clause 7).

Condensation of water shall be avoided in all parts of the sampling system that are not weighed.

6.6 Cooling system (optional)

Any kind of cooling system may be used to condense water vapour in the sampled flue gas (e.g. crushed ice or cryogenic system).

6.7 Sample gas pump

A leak-free pump capable of drawing sample gas at a set flow-rate is required.

NOTE 1 A rotameter (optional) could make easier the adjustment of the nominal sampling flow-rate.

NOTE 2 A small surge tank can be used between the pump and rotameter to eliminate the pulsation effect of the diaphragm pump on the rotameter.

NOTE 3 A regulating valve (optional) would also be useful for adjusting the sample gas flow-rate.

6.8 Gas volume meter

Two variants of gas volume meter may be used:

- dry-gas volume meter; or
- wet-gas volume meter.

The gas volume meter (wet or dry) shall have a relative expanded uncertainty not exceeding 5,0 % of the measured volume (at actual conditions).

The gas volume meter shall be equipped with a temperature measuring device with a relative expanded uncertainty not exceeding 2,0 % and shall be associated to an absolute pressure measurement with a relative expanded uncertainty not exceeding 2,0 %. The absolute pressure can be determined from the relative pressure and the ambient pressure.

When using a dry gas volume meter, a condenser and/or a gas drying system shall be used which can achieve a residual water vapour content of less than 10,0 g/m^3 (equivalent to a dew point of 10,5 °C or a volume content of 1,25 %).

NOTE For example, a glass cartridge or adsorption bottle packed with silica gel (1 mm to 3 mm particle size) which has been previously dried at least at 110 °C for at least 2 h.

When using a wet gas volume meter, a correction shall be applied for water vapour, using the table in Annex B.

6.9 Barometer

Barometer capable of measuring atmospheric pressure present at the measurement site, with an expanded uncertainty that does not exceed 1 kPa.

6.10 Balance

The resolution of the balance shall be equal or better than 0,1 g or 2,0 % of the water weight to be measured.

6.11 Temperature measurement

The uncertainty of the calibrated thermometer for flue gas temperature determination with a measurement range from 273 K to 373 K shall not exceed 2,5 K. That thermometer shall have a low thermal inertia, in order to be rapidly in thermal equilibrium with the stack gas.

7 Performance characteristics of the SRM

Table 1 gives an overview of the performance characteristics and the associated performance criteria of the whole measurement method.

The laboratory implementing the method shall demonstrate that:

— performance characteristics of the method meet the performance criteria given in Table 1 and

— the relative expanded uncertainty calculated by combining values of selected performance characteristics by means of an uncertainty budget does not exceed 20,0 % at the measured value.

Table 1 — Performance characteristics of the SRM to be determined in the laboratory (L) and in the field (F) and associated performance criteria

Performance characteristic	L	F	Performance criterion
Gas volume meter:			
standard uncertainty of the sample volume [a]	X		≤ 2,5 % of the volume of sampled gas
standard uncertainty of temperature [a]	X		≤ 2,0 % of the absolute temperature
standard uncertainty of absolute pressure [a]	X		≤ 2,0 % of the absolute pressure
Leak in the sample gas line		X	≤ 2,0 % of the nominal flow rate
Weighing of collected water:			
uncertainty associated to the balance [b]	X	X	
uncertainty associated to weighing in the field [c]		X	

[a] The uncertainties of sample volume, temperature and absolute pressure are a combination of uncertainties due to calibration, resolution or reading, drift between two consecutive calibrations and standard deviation of the mean when several values have been collected to get the result. When a barometer is used, see 6.9.

[b] The uncertainty contributions of the balance can be for example resolution, repeatability and uncertainty of calibration of the balance. See 6.10.

[c] When weighing is carried out in the field, variations of ambient conditions can be an uncertainty source, for example temperature variations, air currents and vibrations.

The principle of calculation of the combined uncertainty is based on the law on propagation of uncertainty laid down in ISO/IEC Guide 98-3 (GUM):

— determine the standard uncertainties attached to the performance characteristics to be included in the calculation of the uncertainty budget according to ISO/IEC Guide 98-3;

— calculate the uncertainty budget by combining all the standard uncertainties according to ISO/IEC Guide 98-3;

— values of standard uncertainty that are less than 5 % relative of the maximum standard uncertainty may be neglected;

— calculate the combined uncertainty at the measured value.

An example of the calculation of an uncertainty budget is given in Annex D.

8 Field operation

8.1 Measurement planning

Emission measurements at a plant shall be carried out such that the results are representative for the emissions from this plant and comparable with results obtained for other comparable plants. Therefore, water vapour measurements, often used to bring correction to measurement results and to express them on dry conditions, shall be planned in accordance with EN 15259.

Before carrying out any measurements, the purpose of the sampling and the sampling procedures shall be discussed with the plant personnel concerned. The nature of the plant process, e.g. steady-state or cyclic, can affect the sampling programme. If the process can be performed in a steady-state, it is important that this is maintained during sampling.

Dates, starting times, duration of survey and sampling periods as well as plant operating conditions during these periods shall be agreed with the plant management.

If no suitable location exists in the plant, and/or that measurements have been carried out during non-steady-state conditions of the plant, which leads to an increase of the uncertainty of the measurements, it shall be stated in the measurement report.

8.2 Sampling strategy

8.2.1 General

Sampling requires a suitable measurement section and measurement plane.

The measurement plane shall be easily reached from convenient measurement ports and a safe working platform (see EN 15259).

8.2.2 Measurement section and measurement plane

The measurement section and measurement plane shall meet the requirements of EN 15259.

8.2.3 Minimum number and location of measurement points

It is necessary to ensure that the gas concentrations measured are representative of the average conditions inside the waste gas duct. Measurements may be performed at one representative measurement point or at any measurement point, if the corresponding requirements on the distribution of the water vapour volume concentration or any other relevant component specified in 8.3 of EN 15259 are fulfilled. In all other cases the measurements shall be performed as grid measurements. In that case, EN 15259 specifies the minimum number of measurement points to be used and the location in the measurement plane for circular and rectangular ducts.

8.2.4 Measurement ports and working platform

Measurement ports shall be provided for access to the measurement points selected in accordance with EN 15259.

Examples of suitable measurement ports are given in EN 15259.

For safety and practical reasons, the working platform shall comply with the requirements of EN 15259.

8.3 Assembling the equipment

When using a condensation system with impingers or absorbers, these shall be filled with water, the volume of which is less than half the content of the absorber.

The water can be replaced by the appropriate absorption solution used in EN 14791, EN 1911 or in any other European Standards using water in the preparation of the absorption solution, when the operator wants to collect water vapour with the same sampling train as for another component such as SO_2 or HCl. When using an adsorption system, fill the last impinger or absorber or cartridge with a drying agent.

NOTE This European Standard has only been validated with silica gel even if this commonly used drying agent can absorb carbon dioxide; this error has been accepted.

Assemble the trapping system, including junctions. Weigh and record the elements of the trapping system including junctions, with a resolution equal or better than 0,1 g or 2,0 % of the water weight to be measured. Then assemble the whole sampling train.

If applicable, turn on the probe heater and the filter heating system to a controlled temperature of at least 120 °C and 20 °C higher than the (acid) dew point of gases, to prevent water condensation in front of the condenser. Allow time for the temperatures to stabilize.

8.4 Leak test

Before starting the measurement, check that there is no significant leakage in the sampling system by use of the following procedure or any other relevant procedure:

— assemble the complete sampling system, including charging the filter housing and absorbers;

— close the nozzle inlet;

— switch on the pump;

— after reaching minimum pressure, read or measure the flow rate with an appropriate measuring device;

— the leak flow rate shall not exceed 2,0 % of the expected sample gas flow rate used during measurement.

Perform the leak test at the operating temperature unless this conflicts with safety requirements.

In addition, the integrity of the sampling system can also be tested during sampling by continuously measuring the concentration of a suitable stack gas component (e.g. O_2) directly in the stack and downstream the sampling system. Any systematic difference between those concentrations indicates a leak in the sampling system.

8.5 Performing sampling

8.5.1 Introduction of the sampling probe in the duct

After the leak test, insert the sampling probe through the measurement port and place the probe at the measurement points within the measurement plane.

Seal the resultant space around the sampling probe and the measurement port with an appropriate material such that ambient air is not induced into the duct (nor should any flue gas escape from the duct). In cases where large pressure differences exist between the ambient air and sample gas, care shall be taken that no condensate leaves the absorber.

Control the jacket and filter housing temperatures.

8.5.2 Sampling

Start the sample gas pump and adjust the regulating valve to give the desired sample gas volume flow rate.

Record the reading on the gas meter V_1 and the time.

Record the reading of the temperature device T_i and the absolute pressure p_{m} at the gas volume meter at least 5 min after starting sampling and at the end of the sampling period.

NOTE 1 For a sampling system shown in Figure C.1, with a gas volume meter placed downstream the pump, absolute pressure on the gas volume meter is close to atmospheric pressure.

During the whole sampling, check that the trapping capability of the trapping system is not exceeded. This can be achieved either by:

— measuring the temperature at the outlet of trapping system, which shall not be greater than 4 °C, or

- checking visually that the amount of silica gel having faded in the last impinger or cartridge does not exceed 50 %.

At the end of the sampling period, switch off the sample gas pump, record the time and the reading on the gas volume meter V_2.

NOTE 2 If the used gas volume meter records volumetric differences, the difference $V_m = (V_2 - V_1)$ can be used directly at the end of sampling instead of V_1 and V_2.

Disassemble the sampling train (adsorption system). When using a cooling bath, the outside of the trapping system is thoroughly wiped (e.g. with a dry cloth) before weighing. Next, determine the increase in weight of the whole trapping system. Record the weighing results.

8.6 Repeatability of the weighing

To determine the repeatability of the weighing in the field in order to take into account the influence of environmental conditions:

- carry out 10 independent weightings of the trapping system;
- calculate the mean value and the standard deviation.

8.7 Procedure for gas streams saturated with water (droplets present)

When droplets are present, the method produces values for water vapour which are larger than those would be expected for saturated conditions at the temperature of flue gas. Under such conditions the result is consequently biased; therefore water vapour concentration can be determined by using the table of Annex B. This table shows the water vapour concentration for saturated gases for the corresponding average temperature of the flue gas in the measurement plane.

In order to measure the temperature, the probe is inserted at a representative point in the stack. Care shall be taken to wait for the stabilization of the recorded temperature.

9 Water vapour determination

Calculate the mean value of the absolute temperature T_m at the gas volume meter according to Formula (1):

$$T_\mathrm{m} = \frac{1}{n}\sum_{i=1}^{n} T_i \qquad (1)$$

where

T_i is the ith temperature reading taken during sampling, in Kelvin;

n is the number of the temperature readings.

Calculate the dry gas volume $V_{m,ref}$ measured at the gas volume meter, at standard conditions, in cubic meter,

- according to Formula (2) if a dry-gas volume meter is used:

$$V_\mathrm{m,ref} = \left(V_2 - V_1\right) \times \frac{T_\mathrm{ref}}{T_\mathrm{m}} \times \frac{p_\mathrm{m}}{p_\mathrm{ref}} \qquad (2)$$

- according to Formula (3) if a wet-gas volume meter is used:

$$V_{\mathrm{m,ref}} = \left(V_2 - V_1\right) \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{p_{\mathrm{m}} - p_{\mathrm{s}}\left(T_{\mathrm{m}}\right)}{p_{\mathrm{ref}}} \qquad (3)$$

where

$V_{\mathrm{m,ref}}$ is the measured dry gas volume, corrected to standard conditions, in m^3;

V_1 is the gas volume reading from the gas volume meter at the beginning of the sampling period, at actual conditions of temperature, pressure and humidity, in m^3;

V_2 is the gas volume reading from the gas volume meter at the end of the sampling period, at actual conditions of temperature, pressure and humidity, in m^3;

T_{m} is the mean absolute temperature of the sampled gas at the gas volume meter, in K;

T_{ref} is the standard temperature, 273 K;

p_{m} is the absolute pressure at the gas volume meter, in kPa;

$p_{\mathrm{s}}(T_{\mathrm{m}})$ is the saturation vapour pressure of water at the temperature T_{m} of the gas volume meter, in kPa;

p_{ref} is the standard pressure, 101,3 kPa.

The water vapour mass concentration at standard conditions of temperature and pressure and on dry basis is given by Formula (4):

$$C_{\mathrm{w}} = \frac{m_{\mathrm{w}}}{V_{\mathrm{m,ref}}} \qquad (4)$$

where

C_{w} is the water vapour mass concentration on dry basis, in g/m^3;

$V_{\mathrm{m,ref}}$ is the measured dry gas volume, corrected to standard conditions, in m^3;

m_{w} is the mass of water vapour trapped in the trapping system, in g.

The water vapour content expressed as volume concentration in percent on wet basis is given by Formula (5):

$$h_{\mathrm{m}} = \frac{\dfrac{m_{\mathrm{w}} \times V_{\mathrm{mol}}}{M_{\mathrm{w}}}}{\dfrac{m_{\mathrm{w}} \times V_{\mathrm{mol}}}{M_{\mathrm{w}}} + V_{\mathrm{m,ref}}} \tag{5}$$

where

h_{m} is the measured water vapour content on wet basis expressed as volume concentration, in % (m^3 of water vapour in m^3 of wet gas);

$V_{\mathrm{m,ref}}$ is the measured dry gas volume, corrected to standard conditions, in m^3;

m_{w} is the mass of water vapour collected in the trapping system, in g;

M_{w} is the molecular weight of water, 18,01534 g/mol rounded to 18 g/mol;

V_{mol} is the molar volume at standard conditions, in m^3/mol at p_{ref} and T_{ref}.

10 Equivalence of an alternative method

In order to show that an alternative method is equivalent to the standard reference method specified in this European Standard, follow the procedures described in EN 14793:2017.

The maximum allowable repeatability standard deviation (see Formula (6)) and the reproducibility standard deviation (see Formula (7)) expressed as a volume concentration in percent for the standard reference method are:

$$s_{r,\mathrm{limit}}(C) = 0{,}0262\,C + 0{,}30\,\% \tag{6}$$

$$s_R(C) = 0{,}03\,C + 0{,}367\,\% \tag{7}$$

where *C* is the measured volume concentration in percent.

11 Measurement report

The measurement report shall fulfil the requirements of EN 15259 and shall include the following information:

a) information about the personnel involved in the measurement;

b) description of the location of the measurement points in the measurement plane;

c) characteristics of the sampling equipment;

d) for each measurement: sampling date, time and duration as well as identification of samples;

e) measurement results: sample gas volume, concentrations.

Annex A
(informative)

Validation of the method in the field

A.1 General

The method has been validated during six field tests, on waste incineration installations, co-incineration installations and large combustion plants. Each test was performed by at least four different European measuring teams originating from 10 member countries.

A.2 Characteristics of installations

The following field tests were performed:

— 1st field test: INERIS bench-loop at Verneuil en Halatte (France); the bench-loop simulates combustion or waste incineration exhaust gases. Five teams took part in the 1st field test. Double measurements were not performed simultaneously but sequentially. Five different flue gas matrices were generated. Within each matrix, two sequential measurements were performed. Two additional sequential measurements were performed in flue gas matrices where the flue gas concentrations varied. There were a total of 12 measurements performed by all the teams.

— 2nd field test: waste incinerator in Denmark. Four teams took part to the field test and performed double measurements simultaneously. A total of 16 measurements were performed by all the teams.

— 3rd field test: waste incinerator in Italy. Four teams took part to the field test. Two pairs of two teams performed double measurements simultaneously and the four teams performed single measurements simultaneously. A total of six double measurements were performed by each pair of two teams while a total of 12 single measurements were performed by all teams.

— 4th field test: co-incinerator combined heat and power installation in Sweden. The fluidised bed boilers operate on fuel mixes of wood chips, demolition waste, peat and coal. Two pairs of two teams performed double measurements simultaneously and the four teams performed single measurements simultaneously. A total of six double measurements were performed by each pair of two teams while a total of 12 single measurements were performed by all the teams.

— 5th field test: co-incinerator cement plant in Germany. The fuel could be coal, heavy oil and secondary fuel (e.g. paper, plastics, textiles, and tires). Four teams took part to the field test and performed double measurements simultaneously. All the teams performed a total of 16 double measurements.

— 6th field test: coal fired power plant in Germany. Four teams performed their double measurements simultaneously. The total amount of double measurements performed by all teams was 12.

An overview of the flue gas characteristics is given in Table A.1.

Table A.1 — Example of flue gas characteristics during field tests

Field test	Installation	Fuel	Flue gas characteristics						
			T °C	O_2 %	NO_x mg/m³	SO_2 mg/m³	CO mg/m³	H_2O %	PM mg/m³
1	Power plant [a]	Natural gas	< 150	3 to 13	10 to 1 300	10 to 2 000	20 to 400	10 to 21	< 1
2	Waste incinerator	Municipal waste	90 to 110	8 to 11	180 to 250	25 to 250	5 to 15	13 to 19	1 to 5
3	Waste incinerator	Municipal waste	85 to 105	16 to 18	61 to 78	5 to 50	0 to 2	8 to 12	1 to 5
4	Co-incinerator	Wood, waste, coal	70 to 80	4 to 6	4 to 70	0 to 10	50 to 150	8 to 12	0 to 20
5	Co-incinerator	Coal, oil, waste	140 to 170	4 to 6	440 to 1060	60 to 170	260 to 740	23 to 26	5 to 10
6	Power plant	Coal	130 to 140	8,9 to 9,2	110 to 140	1 000 to 1 130	3 to 6	5,5 to 8	< 50

[a] Bench-loop: flue gas simulation.

A.3 Repeatability and reproducibility in the field

A.3.1 General

Repeatability standard deviation s_r and reproducibility standard deviation s_R are determined from data obtained during inter-laboratory tests at the plants described in A.2.

Repeatability standard deviation s_r (see Formula (A.1)), and repeatability in the field r (see Formula (A.2)) are calculated according to ISO 5725-2 and ISO 5725-6 from the results of the double measurements implemented by the same laboratory (see Table A.2):

$$s_{\mathrm{r}} = \sqrt{\frac{\sum\left(x_i - \overline{x}\right)^2}{n-1}} \tag{A.1}$$

$$r = \sqrt{2}\, t_{0{,}95;\mathrm{n}-1}\, s_{\mathrm{r}} \tag{A.2}$$

where

s_r is the repeatability standard deviation;

x_i is the i^{th} measured signal;

$\overline{x}$ is the average of the measured signals x_i;

$t_{0,95;n-1}$ is the student factor for a level of confidence of 95 % and a degree of freedom of n–1 with n the number of double measurements;

r is the repeatability in the field.

Reproducibility standard deviation s_R used to estimate of the expanded uncertainty U (see Formula (A.3)) and reproducibility in the field R (see Formula (A.4)) are calculated according to ISO 5725-2, from the results of parallel measurements performed simultaneously by several laboratories (see Table A.3):

$$U = t_{0,95;np-1}\, s_R \tag{A.3}$$

$$R = \sqrt{2}\, t_{0,95;np-1}\, s_R \tag{A.4}$$

where

U	is an estimate of the expanded uncertainty;
s_R	is the reproducibility standard deviation;
$t_{0,95;np-1}$	is the student factor for a level of confidence of 95 % and a degree of freedom of $np-1$ with n the number of measurements and p the number of laboratories;
R	is the reproducibility in the field.

A.3.2 Repeatability

Table A.2 — Repeatability in the field

Field test	Volume concentration		Number of teams	Number of double measurements	Repeatability standard deviation s_r	Repeatability r	
	Range %	Average %			%	absolute %	relative %
1A	8,9 to 10,9	9,7	5	2	0,43	1,4	14
1B	7,3 to 9,1	8,4	5	2	0,36	1,1	13
1C	10,7 to 13,1	11,8	5	2	0,55	1,8	15
1D	13,1 to 16,0	14,4	5	2	0,69	2,2	15
1E	22,0 to 25,1	22,7	5	2	1,17	3,7	16
1F	15,4 to 20,3	17,7	5	1	0,88	3,5	20
1G	15,0 to 20,3	17,2	5	1	0,86	3,4	20
2	13,9 to 18,2	17	4	16	0,81	2,5	14
3	8,2 to 11,7	10,4	4	12	0,57	1,8	17
4	8,5 to 11,6	9,6	4	12	0,56	1,7	18
5	21,2 to 25,7	22,5	3	12	0,56	1,8	8
6	5,5 to 7,8	6,0	3	12	0,16	0,5	8

The following functions expressed as volume concentrations in percent were determined:

$$s_r\left(C\right) = 0,0218\,C + 0,247\,\% \tag{A.5}$$

$$s_{r,\text{limit}}\left(C\right) = 0,0262\,C + 0,30\,\% \tag{A.6}$$

$$r\left(C\right) = 0,071\,C + 0,7\,\% \tag{A.7}$$

where *C* is the volume concentration expressed in percent.

A.3.3 Reproducibility

Table A.3 — Reproducibility in the field

Field test	**Volume concentration**		**Number of teams**	**Number of double measurements**	**Reproducibility standard deviation**	**Estimate of expanded uncertainty**		**Reproducibility**	
					s_R	U		R	
	Range %	Average %			%	absolute %	relative %	absolute %	relative %
1A	8,9 to 10,9	9,7	5	2	0,83	1,9	19,6	2,7	27
1B	7,3 to 9,1	8,4	5	2	0,55	1,2	14,3	1,8	21
1C	10,7 to 13,1	11,8	5	2	0,77	1,7	14,4	2,5	21
1D	13,1 to 16,0	14,4	5	2	1,00	2,4	16, 7	3,4	23
1E	22,0 to 25,1	22,7	5	2	1,70	3,8	16,8	5,4	24
1F	15,4 to 20,3	17,7	5	1	2,00	5,4	30,5	7,7	44
1G	15,0 to 20,3	17,2	5	1	2,10	5,8	33,8	8,3	48
2	13,9 to 18,2	17	4	16	0,99	2,1	12,4	3,0	18
3	8,2 to 11,7	10,4	4	12	0,67	1,5	14,4	2,1	20
4	8,5 to 11,6	10,1	4	12	0,72	1,6	15,8	2,3	22
5	21,2 to 25,7	22,5	3	12	0,96	2,1	9,3	3,0	13
6	5,5 to 7,8	6,0	3	12	0,48	1,1	18,3	1,5	25

The following functions expressed as volume concentrations in percent were determined:

$$s_R\left(C\right) = 0,03\,C + 0,367\,\% \tag{A.8}$$

$$U\left(C\right) = 0,066\,C + 0,9\,\% \tag{A.9}$$

$$R\left(C\right) = 0,093\,C + 1,27\,\% \tag{A.10}$$

where *C* is the volume concentration expressed in percent.

Annex B
(normative)

Determination of water vapour concentration for water saturated gas, at p_{ref} = 101,325 kPa

Table B.1 — Saturated water vapour concentration as a function of saturation temperature

Saturation temperature	**Saturated vapour pressure**	**Saturated water vapour concentration**					
°C	hPa	g/kg (wet)	g/m^3 (wet at T and p_{ref})	g/m^3 (dry at T and p_{ref})	% (absolute; wet)	g/m^3 (wet)	g/m^3 (dry)
0	6,1	3,78	4,87	4,90	0,61	4,9	4,9
1	6,6	4,06	5,22	5,25	0,65	5,2	5,3
2	7,1	4,36	5,59	5,63	0,70	5,6	5,7
3	7,6	4,69	5,98	6,02	0,75	6,0	6,1
4	8,2	5,03	6,39	6,44	0,81	6,5	6,5
5	8,8	5,40	6,83	6,89	0,86	7,0	7,0
6	9,4	5,79	7,30	7,36	0,93	7,5	7,5
7	10,1	6,20	7,79	7,87	0,99	8,0	8,1
8	10,8	6,64	8,31	8,40	1,06	8,6	8,6
9	11,5	7,11	8,86	8,96	1,14	9,2	9,3
10	12,3	7,61	9,44	9,56	1,22	9,8	9,9
11	13,2	8,13	10,06	10,19	1,30	10,5	10,6
12	14,1	8,69	10,71	10,86	1,39	11,2	11,3
13	15,1	9,29	11,40	11,57	1,48	11,9	12,1
14	16,1	9,92	12,12	12,32	1,58	12,7	13,0
15	17,1	10,58	12,89	13,11	1,69	13,6	13,8
16	18,3	11,29	13,70	13,95	1,80	14,5	14,8
17	19,5	12,04	14,55	14,83	1,92	15,5	15,8
18	20,7	12,83	15,44	15,76	2,05	16,5	16,8
19	22,1	13,67	16,38	16,75	2,18	17,5	17,9
20	23,5	14,55	17,38	17,79	2,32	18,7	19,1
21	25,0	15,49	18,42	18,89	2,47	19,8	20,3
22	26,6	16,47	19,52	20,04	2,62	21,1	21,7
23	28,2	17,52	20,67	21,26	2,79	22,4	23,1
24	30,0	18,62	21,88	22,55	2,96	23,8	24,5
25	31,9	19,78	23,15	23,91	3,14	25,3	26,1

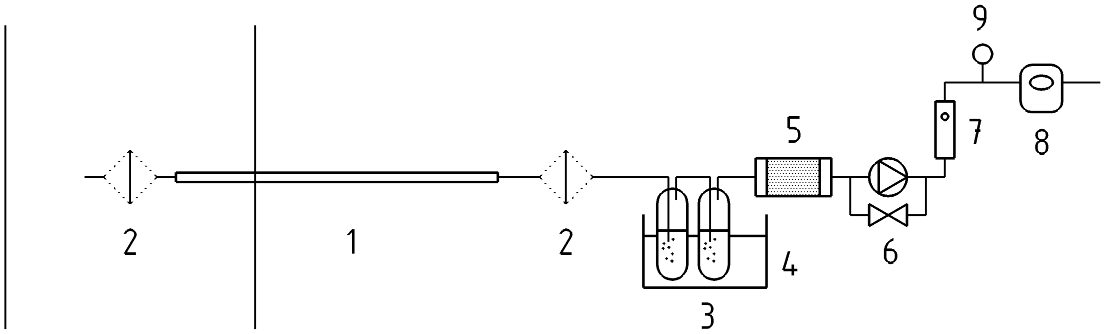
Saturation temperature	Saturated vapour pressure	Saturated water vapour concentration					
°C	hPa	g/kg (wet)	g/m^3 (wet at T and p_{ref})	g/m^3 (dry at T and p_{ref})	% (absolute; wet)	g/m^3 (wet)	g/m^3 (dry)
26	33,8	21,01	24,49	25,34	3,34	26,8	27,8
27	35,8	22,30	25,89	26,84	3,54	28,5	29,5
28	38,0	23,67	27,36	28,43	3,75	30,2	31,3
29	40,3	25,10	28,90	30,10	3,98	32,0	33,3
30	42,7	26,62	30,52	31,86	4,21	33,9	35,4
31	45,2	28,21	32,21	33,71	4,46	35,9	37,5
32	47,8	29,89	33,98	35,66	4,72	38,0	39,8
33	50,6	31,66	35,83	37,71	4,99	40,2	42,3
34	53,5	33,52	37,77	39,87	5,28	42,5	44,8
35	56,6	35,47	39,80	42,15	5,58	44,9	47,6
36	59,8	37,53	41,92	44,54	5,90	47,4	50,4
37	63,1	39,69	44,13	47,07	6,23	50,1	53,4
38	66,7	41,97	46,45	49,72	6,58	52,9	56,6
39	70,4	44,35	48,86	52,51	6,94	55,8	60,0
40	74,2	46,86	51,39	55,45	7,33	58,9	63,6
41	78,3	49,50	54,02	58,54	7,73	62,1	67,3
42	82,5	52,27	56,77	61,80	8,14	65,5	71,3
43	87,0	55,17	59,63	65,23	8,58	69,0	75,5
44	91,6	58,23	62,62	68,84	9,04	72,7	79,9
45	96,5	61,43	65,73	72,65	9,52	76,6	84,6
46	101,6	64,79	68,97	76,66	10,02	80,6	89,6
47	106,9	68,31	72,35	80,88	10,55	84,8	94,8
48	112,4	72,01	75,87	85,33	11,09	89,2	100,3
49	118,2	75,89	79,52	90,02	11,66	93,8	106,2
50	124,2	79,96	83,33	94,97	12,26	98,6	112,4
51	131	84,22	87,29	100,2	12,88	103,6	118,9
52	137	88,69	91,40	105,7	13,53	108,8	125,8
53	144	93,38	95,68	111,5	14,21	114,3	133,2
54	151	98,29	100,1	117,7	14,91	119,9	140,9
55	159	103,4	104,7	124,2	15,65	125,8	149,2
56	166	108,8	109,5	131,0	16,41	132,0	157,9

Saturation temperature	**Saturated vapour pressure**	**Saturated water vapour concentration**					
°C	hPa	g/kg (wet)	g/m³ (wet at *T* and p_{ref})	g/m³ (dry at *T* and p_{ref})	% (absolute; wet)	g/m³ (wet)	g/m³ (dry)
57	174	114,5	114,5	138,3	17,21	138,4	167,2
58	183	120,4	119,7	140,0	18,04	145,1	177,0
59	192	126,6	125,0	154,2	18,91	152,1	187,5
60	201	133,2	130,6	162,8	19,81	159,3	198,6
61	210	140,0	136,3	172,0	20,74	166,8	210,5
62	220	147,1	142,3	181,8	21,71	174,6	223,1
63	230	154,6	148,5	192,2	22,73	182,8	236,5
64	241	162,5	154,9	203,2	23,78	191,2	250,9
65	252	170,7	161,5	215,0	24,87	200,0	266,2
66	263	179,4	168,4	227,6	26,00	209,1	282,6
67	275	188,4	175,5	241,0	27,18	218,6	300,2
68	288	197,9	182,9	255,4	28,40	228,4	319,0
69	301	207,9	190,5	270,9	29,67	238,6	339,3
70	314	218,3	198,4	287,4	30,99	245,2	361,1
71	328	229,3	206,5	305,2	32,35	264,2	384,6
72	342	240,8	214,9	324,5	33,77	271,6	410,0
73	357	252,8	223,6	345,2	35,23	283,4	437,5
74	372	265,5	232,6	367,7	36,75	295,6	467,3
75	388	278,8	241,8	392,1	38,33	308,2	499,8
76	405	292,8	251,4	418,7	39,96	321,4	535,2
77	422	307,4	261,3	447,7	41,65	334,9	574,0
78	440	322,9	271,4	479,5	43,39	349,0	616,5
79	458	339,1	281,9	514,5	45,20	363,5	663,4
80	477	356,2	292,8	553,2	47,07	378,6	715,2
81	497	374,1	303,9	596,0	49,01	394,1	772,9
82	517	393,0	315,5	643,9	51,01	410,2	837,3
83	538	413,0	327,3	697,5	53,07	426,8	909,5
84	559	434,0	339,5	758,0	55,21	444,4	991,3
85	582	456,1	352,1	826,8	57,41	461,7	1 084
86	605	479,5	365,1	905,7	69,69	480,0	1 191
87	629	504,1	378,4	996,9	62,04	499,0	1 314

Saturation temperature	**Saturated vapour pressure**	**Saturated water vapour concentration**					
°C	hPa	g/kg (wet)	g/m³ (wet at *T* and p_{ref})	g/m³ (dry at *T* and p_{ref})	% (absolute; wet)	g/m³ (wet)	g/m³ (dry)
88	653	530,2	352,1	1 104	64,47	518,5	1 459
89	679	557,8	406,2	1 230	66,97	538,6	1 631
90	705	587,0	420,7	1 382	69,56	559,4	1 838
91	732	617,9	435,6	1 568	72,22	580,8	2 091
92	760	650,7	450,9	1 801	74,97	602,9	2 409
93	788	685,5	466,7	2 102	77,80	625,6	2 818
94	818	722,4	482,8	2 503	80,71	649,1	3 365
95	848	761,7	495,4	3 067	83,71	673,2	4 133
96	880	803,6	516,5	3 914	86,81	698,1	5 293
97	912	848,3	534,0	5 333	89,99	723,7	7 230
98	945	895,9	551,9	8 189	93,26	750,0	11 128
99	979	946,9	570,3	16 915	96,63	777,1	23 059

Annex C
(informative)

Type of sampling equipment

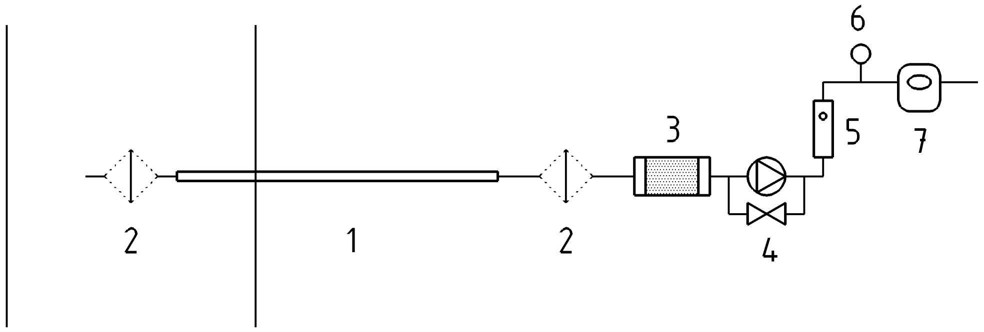


Key

1	heated probe
2	heated filter (in-stack or out-stack)
3	impingers or absorbers
4	cooling bath (optional)
5	adsorption cartridge
6	pump
7	gas flow meter
8	gas volume meter
9	temperature and pressure measurement

NOTE If the pressure drop in the gas meter is lower than 100 Pa, the absolute pressure is equal to the atmospheric pressure.

Figure C.1 — Trapping system with two stages: condensation and adsorption



Key

1	heated probe
2	heated filter (in-stack or out-stack)
3	adsorption cartridge
4	pump
5	gas flow meter
6	temperature and pressure measurement
7	gas volume meter

Figure C.2 — Trapping system with one adsorption stage

Annex D
(informative)

Example of assessment of compliance of standard reference method for water vapour with given uncertainty requirements

D.1 General

This informative annex gives an example of the calculation of the uncertainty budget established to demonstrate compliance with given uncertainty requirements.

The following procedure for calculating the measurement uncertainty is based on the law of propagation of uncertainty as described in EN ISO 14956 or ISO/IEC Guide 98-3 (GUM). The individual standard uncertainties, the combined standard uncertainty and the expanded uncertainty are determined according to the requirements of EN ISO 14956 or ISO/IEC Guide 98-3.

D.2 Elements required for the uncertainty determinations

In the first step, the model equation is established. The model equation describes the mathematical relationship between the measurand and all the parameters that influence the result of measurement. These parameters are called input quantities. It is necessary to clearly define the measurand and the input quantities.

The model function is used to calculate the result of measurement on the basis of the values assigned to the input quantities and to obtain the combined uncertainty of the result of measurement by application of the law of propagation of uncertainty.

The expanded uncertainty U_c is obtained by multiplying a coverage factor k with the combined uncertainty u_c. The value of the coverage factor k is chosen on the basis of the level of confidence required. In most cases, k is taken equal to 2 for a level of confidence of approximately 95 %.

D.3 Example of an uncertainty calculation

D.3.1 Specific conditions in the field

Table D.1 gives one example of the specific conditions of the site, that is to say the values and the variation range of the influence parameters.

Table D.1 — Example of measurement conditions

Specific conditions	Value
Volume concentration on wet basis:	17,9 %
Water collected in the trapping system [a]: – weight of water collected in the condensation system – weight of water trapped in adsorption system	 17,2 g 2,0 g
Volume of gas sampled in 30 min	0,120 m^3
Nominal flow rate Q	240 l/h
Mean absolute temperature at the gas volume meter [b]	296 K
Mean absolute pressure at the gas volume meter [c]	100 281 Pa

[a] A calibrated balance is used to determine water vapour collected in the condensation system and in the adsorption system. The procedure consists in weighing the trapping system before and after sampling.

Repeatability of the weighing in the field has been estimated by 10 independent weighing of a trapping system: the standard deviation is equal to 0,78 g.

[b] The mean temperature is calculated from data recording of temperature measurements (one measurement per 30 s leads to 60 measurements in 30 min):

- standard deviation of measurements is equal to 3,1 K.
- drift: no drift between two calibrations.

[c] The mean absolute pressure is calculated from five measurements of the static relative pressure at the gas meter and one measurement of the atmospheric pressure during the sampling period.

Table D.2 gives one example of the measured values of relative pressure.

Table D.2 — Measured values of relative pressure

Measurement	Relative pressure p_{rel} at gas meter Pa
1	70,5
2	68,0
3	65,0
4	69,0
5	70,5
Mean	68,6
Standard deviation	2,27

Barometric pressure: 100 212 Pa

Mean absolute pressure: 100 281 Pa

D.3.2 Performance characteristics

Table D.3 shows the performance characteristics of the method related to the parameters which can have an influence on the response of the analyser.

Table D.3 — Example of performance characteristics

Performance characteristic	Performance criterion	Results obtained in laboratory or field
Weighing of water vapour collected:		
— expanded uncertainty of the balance		0,8 g
— standard deviation (average value)		0,3 g
— resolution		0,02 g
Gas volume meter:		
Expanded uncertainty	≤ 5,0 % of the measured value	
— expanded uncertainty of calibration		1 % of the measured value
— drift between two adjustments		2 % of the measured value
— reading		0,002 m^3
Temperature at the gas volume meter:		
Expanded uncertainty	≤ 2,0 % of the measured value	
— expanded uncertainty of calibration		0,50 K
— standard deviation (average value)		3,1 K for 60 measurements
— drift between two calibrations		negligible
— resolution		0,01 K
Absolute pressure at the gas volume meter:		
Expanded uncertainty	≤ 2,0 % of the measured value	
Relative pressure at gas volume meter:		
— expanded uncertainty of calibration		1,5 Pa
— standard deviation (average value)		2,27 Pa
— drift between two calibrations		0,5 Pa
— resolution		0,3 Pa
Atmospheric pressure:		
— expanded uncertainty of calibration		170 Pa
— drift between two calibrations		60 Pa
— resolution		10 Pa
Leakage in the sample gas line	≤ 2,0 % of the nominal flow rate	1,5 % of the nominal flow rate

D.3.3 Model equation and application of the rule of the uncertainty propagation

D.3.3.1 Water vapour content

The measured water vapour content is calculated by Formula (D.1):

$$h_{\mathrm{m}} = \frac{\dfrac{m_{\mathrm{w}} \times V_{\mathrm{mol}}}{M_{\mathrm{w}}}}{\dfrac{m_{\mathrm{w}} \times V_{\mathrm{mol}}}{M_{\mathrm{w}}} + V_{\mathrm{m,ref}}} = \frac{\dfrac{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}}\right) \times V_{\mathrm{mol}}}{M_{\mathrm{w}}}}{\dfrac{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}}\right) \times V_{\mathrm{mol}}}{M_{\mathrm{w}}} + V_{\mathrm{m,ref}}} \qquad \text{(D.1)}$$

where $V_{\mathrm{m,ref}}$ is given by Formula (D.2)

$$V_{\mathrm{m,ref}} = V_{\mathrm{m}} \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{p_{\mathrm{m}}}{p_{\mathrm{ref}}} = V_{\mathrm{m}} \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{p_{\mathrm{rel}} + p_{\mathrm{atm}}}{p_{\mathrm{ref}}} \qquad \text{(D.2)}$$

and

h_{m}	is the measured water vapour content on wet basis expressed as volume concentration, in % (m^3 of water vapour in m^3 of wet gas);
m_{w}	is the total mass of water vapour collected in the trapping system, in g;
$m_{\mathrm{w,c}}$	is the mass of water vapour collected in the condensation stage, in g;
$m_{\mathrm{w,a}}$	is the mass of water vapour collected in the adsorption stage, in g;
M_{w}	is the molecular weight of water, 18 g/mol;
V_{mol}	is the molar volume at standard conditions, in m^3/mol (constant value of $21{,}1 \times 10^{-3}$ m^3/mol at 273 K and 101,3 kPa);
$V_{\mathrm{m,ref}}$	is the measured dry gas volume, corrected to standard conditions, in m^3;
V_{m}	is the sampled gas volume calculated by difference between the gas volume at the end and at the beginning of the sampling period, in m^3 (the value at the beginning of the sampling period corresponds to a reading of an indicator; the value at the end of the sampling period corresponds to the reading of a measured value);
T_{m}	is the mean temperature of the sampled gas at the gas volume meter, in K;
T_{ref}	is the standard temperature, 273 K;
p_{m}	is the absolute pressure at the gas volume meter which is equal to the sum of relative pressure measured at the gas volume meter and the atmospheric pressure, in kPa;
p_{rel}	is the relative pressure measured at the gas volume meter, in kPa;
p_{atm}	is the atmospheric pressure, in kPa;
p_{ref}	is the standard pressure, 101,3 kPa.

D.3.3.2 Effect of the collection efficiency

The efficiency of the sampling system can be checked by placing an additional absorber system after the “normal” trapping system. The weight of the water collected in it is determined with the same weighing procedure and with the same uncertainty than the water collected in the “normal” trapping system. The efficiency of the sampling system can also be checked by calculating the ratio between the measured water vapour concentration and the remaining water vapour concentration at the exit of the adsorption stage. When the result has been corrected for the remaining water vapour at the outlet of the adsorption stage, then it is possible to consider that $100\,\%/\varepsilon = 1$.

The collection efficiency is calculated according to Formula (D.3):

$$\varepsilon = \frac{m_{\text{w,c}} + m_{\text{w,a}}}{\left(m_{\text{w,c}} + m_{\text{w,a}}\right) + m_{\text{w,add}}} \tag{D.3}$$

where

ε	collection efficiency, in %;
$m_{\text{w,c}}$	is the mass of water vapour collected in the condensation stage, in g;
$m_{\text{w,a}}$	is the mass of water vapour collected in the adsorption stage, in g;
$m_{\text{w,c}} + m_{\text{w,a}}$	is the weight of the water vapour collected in the “normal” trapping system;
$m_{\text{w,add}}$	is the weight of the water vapour collected in the additional absorber.

The mass of water vapour in sampling gas from the duct is then equal to $\left(m_{\text{w,c}} + m_{\text{w,a}}\right)/\varepsilon$.

D.3.3.3 Calculation of the combined uncertainty of the water vapour content taking into account the collection efficiency

The model equation for the calculation of the water vapour content taking into account the collection efficiency is given by Formula (D.4):

$$h_{\text{m}} = \frac{\dfrac{m_{\text{w}} \times V_{\text{mol}}}{M_{\text{w}}}}{\dfrac{m_{\text{w}} \times V_{\text{mol}}}{M_{\text{w}}} + V_{\text{m,ref}}} = \frac{\dfrac{\left(m_{\text{w,c}} + m_{\text{w,a}}\right) \times V_{\text{mol}}}{\varepsilon \times M_{\text{w}}}}{\dfrac{\left(m_{\text{w,c}} + m_{\text{w,a}}\right) \times V_{\text{mol}}}{\varepsilon \times M_{\text{w}}} + V_{\text{m,ref}}} \tag{D.4}$$

With the assumption that the uncertainties of V_{mol} and M_{w} are negligible, the combined uncertainty of the water vapour content taking into account the collection efficiency is given by Formula (D.5):

$$\begin{aligned} u^2\left(h_{\text{m}}\right) = {} & \left(\frac{\partial h_{\text{m}}}{\partial m_{\text{w,c}}}\right)^2 \times u^2\left(m_{\text{w,c}}\right) + \left(\frac{\partial h_{\text{m}}}{\partial m_{\text{w,a}}}\right)^2 \times u^2\left(m_{\text{w,a}}\right) \\ & + \left(\frac{\partial h_{\text{m}}}{\partial \varepsilon}\right)^2 \times u^2\left(\varepsilon\right) + \left(\frac{\partial h_{\text{m}}}{\partial V_{\text{m,ref)}}}\right)^2 \times u^2\left(V_{\text{m,ref}}\right) \end{aligned} \tag{D.5}$$

D.3.3.4 Calculation of sensitivity coefficients

The sensitivity coefficients are given by Formula (D.6) to Formula (D.9):

$$\frac{\partial h_{\mathrm{m}}}{\partial m_{\mathrm{w,c}}}=\frac{h_{\mathrm{m}}\times V_{\mathrm{m,ref}}}{\frac{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)\times V_{\mathrm{mol}}}{\varepsilon\times M_{\mathrm{w}}}+V_{\mathrm{m,ref}}}\times\frac{1}{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)} \qquad \text{(D.6)}$$

$$\frac{\partial h_{\mathrm{m}}}{\partial m_{\mathrm{w,a}}}=\frac{h_{\mathrm{m}}\times V_{\mathrm{m,ref}}}{\frac{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)\times V_{\mathrm{mol}}}{\varepsilon\times M_{\mathrm{w}}}+V_{\mathrm{m,ref}}}\times\frac{1}{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)} \qquad \text{(D.7)}$$

$$\frac{\partial h_{\mathrm{m}}}{\partial \varepsilon}=\frac{-h_{\mathrm{m}}\times V_{\mathrm{m,ref}}\times\frac{1}{\varepsilon}}{\frac{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)\times V_{\mathrm{mol}}}{\varepsilon\times M_{\mathrm{w}}}+V_{\mathrm{m,ref}}} \qquad \text{(D.8)}$$

$$\frac{\partial h_{\mathrm{m}}}{\partial V_{\mathrm{m,ref}}}=\frac{-h_{\mathrm{m}}}{\frac{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)\times V_{\mathrm{mol}}}{\varepsilon\times M_{\mathrm{w}}}+V_{\mathrm{m,ref}}} \qquad \text{(D.9)}$$

Formula (D.5) is equivalent to Formula (D.10):

$$\frac{u^{2}\left(h_{\mathrm{m}}\right)}{\left(h_{\mathrm{m}}\right)^{2}}=\left(\frac{V_{\mathrm{m,ref}}}{\frac{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)\times V_{\mathrm{mol}}}{\varepsilon\times M_{\mathrm{w}}}+V_{\mathrm{m,ref}}}\right)^{2}\times\left(\left(\frac{u\left(m_{\mathrm{w,c}}\right)}{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)}\right)^{2}+\left(\frac{u\left(m_{\mathrm{w,a}}\right)}{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)}\right)^{2}+\left(\frac{u\left(\varepsilon\right)}{\varepsilon}\right)^{2}+\left(\frac{u\left(V_{\mathrm{m,ref}}\right)}{V_{\mathrm{m,ref}}}\right)^{2}\right) \qquad \text{(D.10)}$$

D.3.3.5 Calculation of the standard uncertainty of the collection efficiency

The collection efficiency is given by Formula (D.11):

$$\varepsilon=\frac{m_{\mathrm{wc(cs)}}+m_{\mathrm{wc(as)}}}{\left(m_{\mathrm{wc(cs)}}+m_{\mathrm{wc(as)}}\right)+m_{\mathrm{wc(add)}}} \qquad \text{(D.11)}$$

where $m_{\mathrm{w,add}}$ is given by Formula (D.12):

$$m_{\mathrm{w,add}}=\frac{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a)}}\right)\times\left(1-\varepsilon\right)}{\varepsilon} \qquad \text{(D.12)}$$

The standard uncertainty of the collection efficiency is given by Formula (D.13):

$$u^{2}\left(\varepsilon\right)=\left(\frac{\partial\varepsilon}{\partial m_{\mathrm{w,add)}}}\right)^{2}\times u^{2}\left(m_{\mathrm{w,add}}\right)+\left(\frac{\partial\varepsilon}{\partial m_{\mathrm{w,c}}}\right)^{2}\times u^{2}\left(m_{\mathrm{w,c)}}\right)+\left(\frac{\partial\varepsilon}{\partial m_{\mathrm{w,a)}}}\right)^{2}\times u^{2}\left(m_{\mathrm{w,a}}\right) \qquad \text{(D.13)}$$

The sensitivity coefficients are given by Formula (D.14) to Formula (D.16):

$$\frac{\partial\varepsilon}{\partial m_{\mathrm{w,c}}}=\frac{m_{\mathrm{w,add}}}{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}+m_{\mathrm{w,add}}\right)^{2}}=\frac{\varepsilon\times\left(1-\varepsilon\right)}{\left(m_{\mathrm{w,c}}+m_{\mathrm{w,a}}\right)} \qquad \text{(D.14)}$$

$$\frac{\partial \varepsilon}{\partial m_{\mathrm{w,a}}} = \frac{m_{\mathrm{w,add}}}{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}} + m_{\mathrm{w,add}}\right)^2} = \frac{\varepsilon \times (1-\varepsilon)}{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}}\right)} \tag{D.15}$$

$$\frac{\partial \varepsilon}{\partial m_{\mathrm{w,add}}} = \frac{-\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}}\right)}{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}} + m_{\mathrm{w,add}}\right)^2} = \frac{-\varepsilon \times (1-\varepsilon)}{m_{\mathrm{w,add}}} \tag{D.16}$$

Formula (D.13) is equivalent to Formula (D.17):

$$\frac{u^2(\varepsilon)}{\varepsilon^2} = (1-\varepsilon)^2 \times \left(\frac{u^2\left(m_{\mathrm{w,cs}}\right)}{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}}\right)^2} + \frac{u^2\left(m_{\mathrm{w,a}}\right)}{\left(m_{\mathrm{w,c}} + m_{\mathrm{w,a}}\right)^2} + \frac{u^2\left(m_{\mathrm{w,add}}\right)}{\left(m_{\mathrm{w,add}}\right)^2} \right) \tag{D.17}$$

D.3.3.6 Calculation of the standard uncertainty of measured dry gas volume corrected to standard conditions

The measured dry gas volume corrected to standard conditions is given by Formula (D.18):

$$V_{\mathrm{m,ref}} = V_{\mathrm{m}} \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{p_{\mathrm{m}}}{p_{\mathrm{ref}}} = V_{\mathrm{m}} \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{p_{\mathrm{rel}} + p_{\mathrm{atm}}}{p_{\mathrm{ref}}} \tag{D.18}$$

With the assumption that uncertainties of T_{ref} and p_{ref} are negligible, the combined uncertainty of the measured dry gas volume is given by Formula (D.19):

$$\begin{aligned} u^2\left(V_{\mathrm{m,ref}}\right) = {} & \left(\frac{\partial V_{\mathrm{m,ref}}}{\partial V_{\mathrm{m}}}\right)^2 \times u^2\left(V_{\mathrm{m}}\right) + \cdot \left(\frac{\partial V_{\mathrm{m,ref}}}{\partial T_{\mathrm{m}}}\right)^2 \times u^2\left(T_{\mathrm{m}}\right) \\ & + \left(\frac{\partial V_{\mathrm{m,ref}}}{\partial p_{\mathrm{rel}}}\right)^2 \times u^2\left(p_{\mathrm{rel}}\right) + \left(\frac{\partial V_{\mathrm{m,ref}}}{\partial p_{\mathrm{atm}}}\right)^2 \times u^2\left(p_{\mathrm{atm}}\right) \end{aligned} \tag{D.19}$$

The sensitivity coefficients are given by Formula (D.20) to Formula (D.23):

$$\frac{\partial V_{\mathrm{m,ref}}}{\partial V_{\mathrm{m}}} = \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{p_{\mathrm{m}}}{p_{\mathrm{ref}}} = \frac{V_{\mathrm{m,ref}}}{V_{\mathrm{m}}} \tag{D.20}$$

$$\frac{\partial V_{\mathrm{m,ref}}}{\partial T_{\mathrm{m}}} = -V_{\mathrm{m}} \times T_{\mathrm{ref}} \times \frac{p_{\mathrm{m}}}{p_{\mathrm{ref}}} \times \frac{1}{T_{\mathrm{m}}^2} = -\frac{V_{\mathrm{m,ref}}}{T_{\mathrm{m}}} \tag{D.21}$$

$$\frac{\partial V_{\mathrm{m,ref}}}{\partial p_{\mathrm{rel}}} = V_{\mathrm{m}} \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{1}{p_{\mathrm{ref}}} = \frac{V_{\mathrm{m,ref}}}{p_{\mathrm{rel}} + p_{\mathrm{atm}}} = \frac{V_{\mathrm{m,ref}}}{p_{\mathrm{m}}} \tag{D.22}$$

$$\frac{\partial V_{\mathrm{m,ref}}}{\partial p_{\mathrm{atm}}} = V_{\mathrm{m}} \times \frac{T_{\mathrm{ref}}}{T_{\mathrm{m}}} \times \frac{1}{p_{\mathrm{ref}}} = \frac{V_{\mathrm{m,ref}}}{p_{\mathrm{rel}} + p_{\mathrm{atm}}} = \frac{V_{\mathrm{m,ref}}}{p_{\mathrm{m}}} \tag{D.23}$$

Formula (D.19) is equivalent to Formula (D.24):

$$\frac{u^2\left(V_{\mathrm{m,ref}}\right)}{\left(V_{\mathrm{m,ref}}\right)^2} = \frac{u^2\left(V_{\mathrm{m}}\right)}{\left(V_{\mathrm{m}}\right)^2} + \frac{u^2\left(T_{\mathrm{m}}\right)}{\left(T_{\mathrm{m}}\right)^2} + \frac{u^2\left(p_{\mathrm{rel}}\right)}{\left(p_{\mathrm{rel}} + p_{\mathrm{atm}}\right)^2} + \frac{u^2\left(p_{\mathrm{atm}}\right)}{\left(p_{\mathrm{rel}} + p_{\mathrm{atm}}\right)^2} \tag{D.24}$$

D.3.3.7 Calculation of the combined uncertainty of the water vapour content

Formula (D.10) is equivalent to Formula (D.25):

$$\begin{aligned}\frac{u^2(h_\mathrm{m})}{(h_\mathrm{m})^2} = {} & \left(\frac{V_\mathrm{m,ref}}{\dfrac{(m_\mathrm{w,c}+m_\mathrm{w,a})\times V_\mathrm{mol}}{\varepsilon\times M_\mathrm{w}}+V_\mathrm{m,ref}}\right)^2 \times \left(\left(\frac{u(m_\mathrm{w,c})}{(m_\mathrm{w,c}+m_\mathrm{w,a})}\right)^2+\left(\frac{u(m_\mathrm{w,a})}{(m_\mathrm{w,c}+m_\mathrm{w,a})}\right)^2\right. \\ & +(1-\varepsilon)^2\left(\left(\frac{u(m_\mathrm{w,c})}{m_\mathrm{w,c}+m_\mathrm{w,a}}\right)^2+\left(\frac{u(m_\mathrm{w,a})}{m_\mathrm{w,c}+m_\mathrm{w,a}}\right)^2+\left(\frac{u(m_\mathrm{w,add})}{m_\mathrm{w,add}}\right)^2\right) \\ & \left.+\left(\frac{u(V_\mathrm{m})}{V_\mathrm{m}}\right)^2+\left(\frac{u(T_\mathrm{m})}{T_\mathrm{m}}\right)^2+\left(\frac{u(p_\mathrm{rel})}{p_\mathrm{m}}\right)^2+\left(\frac{u(p_\mathrm{atm})}{p_\mathrm{m}}\right)^2\right)\end{aligned} \tag{D.25}$$

D.3.3.8 Results of standard uncertainties calculations

The values of $m_\mathrm{w,c}$, $m_\mathrm{w,a}$ and $m_\mathrm{w,add}$ are determined by weighing the trapping systems before and after sampling:

$$m_\mathrm{w,c} = m_\mathrm{w,c,2} - m_\mathrm{w,c,1} \tag{D.26}$$

$$m_\mathrm{w,a} = m_\mathrm{w,a,2} - m_\mathrm{w,a,1} \tag{D.27}$$

$$m_\mathrm{w,add} = m_\mathrm{w,add,2} - m_\mathrm{w,add,1} \tag{D.28}$$

Uncertainties associated to the weighing before and after sampling are equal. As the weighing of the water vapour collected in each system is equal to a difference of two weighings, systematic errors are cancelled. Therefore, the individual standard uncertainties are given by Formula (D.29):

$$u(m_\mathrm{w,c}) = u(m_\mathrm{w,a}) = u(m_\mathrm{w,add}) = 2\times u(m) \tag{D.29}$$

where the weighing uncertainty $u(m)$ depends on the uncertainty of the balance, the uncertainty associated to the resolution and the uncertainty associated to the mean.

Calculation of standard uncertainties in Table D.4 is based on Formula (D.30) to Formula (D.34):

$$u^2(m_\mathrm{w,c}) = u^2(m_\mathrm{w,a}) = u^2(m_\mathrm{w,add}) = 2\times\left(u_\mathrm{cal}^2(m)+u_\mathrm{res}^2(m)+u_\mathrm{mean}^2(m)\right) \tag{D.30}$$

$$u^2(V_\mathrm{m}) = u_\mathrm{cal}^2(V_\mathrm{m})+u_\mathrm{dr}^2(V_\mathrm{m})+2u_\mathrm{read}^2(V_\mathrm{m}) \tag{D.31}$$

$$u^2(T_\mathrm{m}) = u_\mathrm{cal}^2(T_\mathrm{m})+u_\mathrm{res}^2(T_\mathrm{m})+u_\mathrm{dr}^2(T_\mathrm{m})+u_\mathrm{mean}^2(T_\mathrm{m}) \tag{D.32}$$

$$u^2(p_\mathrm{rel}) = u_\mathrm{cal}^2(p_\mathrm{rel})+u_\mathrm{dr}^2(p_\mathrm{rel})+u_\mathrm{res}^2(p_\mathrm{rel})+u_\mathrm{mean}^2(p_\mathrm{rel}) \tag{D.33}$$

$$u^2(p_\mathrm{atm}) = u_\mathrm{cal}^2(p_\mathrm{atm})+u_\mathrm{dr}^2(p_\mathrm{atm})+u_\mathrm{res}^2(p_\mathrm{atm}) \tag{D.34}$$

Table D.4 — Results of uncertainty calculations

Performance characteristic	Formula	Standard uncertainty	Relative standard uncertainty
Weighing of water vapour collected	(D.30)	$u(m_{\mathrm{w,c}})$ $u(m_{\mathrm{w,a}})$ $u(m_{\mathrm{w,add}})$	
− calibration		$u_{\mathrm{cal}}(m) = 0{,}4\,\mathrm{g}$	
− standard deviation		$u_{\mathrm{mean}}(m) = 0{,}3\,\mathrm{g}$	
− resolution		$u_{\mathrm{res}}(m) = \dfrac{0{,}02\,\mathrm{g}}{2\sqrt{3}} = 0{,}006\,\mathrm{g}$	
		$u(m_{\mathrm{w,c}}) = 0{,}71\ \mathrm{g}$ $u(m_{\mathrm{w,a}}) = 0{,}71\ \mathrm{g}$ $u(m_{\mathrm{w,add}}) = 0{,}71\ \mathrm{g}$	$\dfrac{u(m_{\mathrm{w,c}})}{m_{\mathrm{w,c}} + m_{\mathrm{w,a}}} = \dfrac{0,71}{(17,2+2)} = 3,7\times10^{-2}$ $\dfrac{u(m_{\mathrm{w,a}})}{m_{\mathrm{w,c}} + m_{\mathrm{w,a}}} = \dfrac{0,71}{(17,2+2)} = 3,7\times10^{-2}$ $\dfrac{u(m_{\mathrm{w,add}})}{m_{\mathrm{w,add}}} = 1,8$
Volume of sampled gas	(D.31)	$u(V_{\mathrm{m}})$	
− calibration		$u_{\mathrm{cal}}(V_{\mathrm{m}}) = \dfrac{\frac{1}{100}\times 0{,}120\,\mathrm{m}^3}{2} = 0{,}0006\,\mathrm{m}^3$	
− drift		$u_{\mathrm{dr}}(V_{\mathrm{m}}) = \dfrac{\frac{2}{100}\times 0{,}120\,\mathrm{m}^3}{\sqrt{3}} = 0{,}0014\,\mathrm{m}^3$	
− reading		$u_{\mathrm{read}}(V_{\mathrm{m}}) = \dfrac{0{,}002\,\mathrm{m}^3}{2\sqrt{3}} = 0{,}0006\,\mathrm{m}^3$	
		$u(V_{\mathrm{m}}) = 0{,}00191\ \mathrm{m}^3$	$\dfrac{u(V_{\mathrm{m}})}{V_{\mathrm{m}}} = \dfrac{0,00191}{0,120} = 1,6\times10^{-2}$
Temperature at the gas volume meter	(D.32)	$u(T_{\mathrm{m}})$	
− calibration		$u_{\mathrm{cal}}(T_{\mathrm{m}}) = \dfrac{0{,}5\,\mathrm{K}}{2} = 0{,}25\,\mathrm{K}$	
− drift		$u_{\mathrm{dr}}(T_{\mathrm{m}}) = 0\,\mathrm{K}$ (negligible)	

– resolution		$u_{\text{res}}\left(T_{\text{m}}\right)=\dfrac{0{,}01\,\text{K}}{2\sqrt{3}}=0{,}003\,\text{K}$	
– standard deviation of the mean		$u_{\text{mean}}\left(T_{\text{m}}\right)=\dfrac{3{,}1\,\text{K}}{\sqrt{60}}=0{,}40\,\text{K}$	
		$u(T_{\text{m}})$ = 0,47 K	$\dfrac{u\left(T_{\text{m}}\right)}{T_{\text{m}}}=\dfrac{0{,}47}{296}=1{,}6\times10^{-3}$
Relative pressure at the gas meter	(D.33)	$u(p_{\text{rel}})$	
– calibration of the manometer		$u_{\text{cal}}\left(p_{\text{rel}}\right)=\dfrac{1{,}5\,\text{Pa}}{2}=0{,}75\,\text{Pa}$	
– drift between two calibrations		$u_{\text{dr}}\left(p_{\text{rel}}\right)=\dfrac{0{,}5\,\text{Pa}}{2\sqrt{3}}=0{,}15\,\text{Pa}$	
– resolution of manometer		$u_{\text{res}}\left(p_{\text{rel}}\right)=\dfrac{0{,}3\,\text{Pa}}{2\sqrt{3}}=0{,}087\,\text{Pa}$	
– standard deviation of the mean		$u_{\text{mean}}\left(p_{\text{rel}}\right)=\dfrac{2{,}28\,\text{Pa}}{\sqrt{5}}=1{,}02\,\text{Pa}$	
		$u(p_{\text{rel}})$ = 1,31 Pa	$\dfrac{u\left(p_{\text{rel}}\right)}{p_{\text{m}}}=\dfrac{1{,}28}{100\,281}=1{,}3\times10^{-5}$
Atmospheric pressure	(D.34)	$u(p_{\text{atm}})$	
– calibration		$u_{\text{cal}}\left(p_{\text{atm}}\right)=\dfrac{170\,\text{Pa}}{2}=85\,\text{Pa}$	
– drift		$u_{\text{dr}}\left(p_{\text{atm}}\right)=\dfrac{60\,\text{Pa}}{\sqrt{3}}=35\,\text{Pa}$	
– resolution of the barometer		$u_{\text{res}}\left(p_{\text{atm}}\right)=\dfrac{10\,\text{Pa}}{2\sqrt{3}}=2{,}89\,\text{Pa}$	
		$u(p_{\text{atm}})$ = 91,8 Pa	$\dfrac{u\left(p_{\text{atm}}\right)}{p_{\text{m}}}=\dfrac{91{,}8}{100\,281}=9{,}2\times10^{-4}$

D.3.4 Estimation of the combined uncertainty

The result of the calculation of the combined uncertainty according to Formula (D.25) is:

– standard uncertainty as volume concentration: $u(h_\mathrm{m}) = 1{,}0\ \%$

– relative standard uncertainty: $u_\mathrm{rel}(h_\mathrm{m}) = 5{,}4\ \%$

– expanded uncertainty as volume concentration ($k = 2$): $U(h_\mathrm{m}) = 2{,}0\ \%$

– relative expanded uncertainty ($k = 2$): $U_\mathrm{rel}(h_\mathrm{m}) = 10{,}8\ \%$

If the result of measurement is not corrected for the collection efficiency ε, the uncertainty shall be increased by adding the value of correction to the expanded uncertainty as an error:

$$U(h_\mathrm{m,nc}) = U(h_\mathrm{m}) + C(\varepsilon) \tag{D.35}$$

where $U(h_\mathrm{m,nc})$ is the expanded uncertainty of the result of measurement when collection efficiency is not taken into account.

The correction $C(\varepsilon)$ is equal to the difference between the result of measurement when collection efficiency is taken into account and the result of measurement when collection efficiency is not taken into account according to Formula (D.36):

$$C(\varepsilon) = \frac{\dfrac{(m_\mathrm{w,c} + m_\mathrm{w,a}) \times V_\mathrm{mol}}{\varepsilon \times M_\mathrm{w}}}{\dfrac{(m_\mathrm{w,c} + m_\mathrm{w,a}) \times V_\mathrm{mol}}{\varepsilon \times M_\mathrm{w}} + V_\mathrm{m,ref}} - \frac{\dfrac{(m_\mathrm{w,c} + m_\mathrm{w,a}) \times V_\mathrm{mol}}{M_\mathrm{w}}}{\dfrac{(m_\mathrm{w,c} + m_\mathrm{w,a}) \times V_\mathrm{mol}}{M_\mathrm{w}} + V_\mathrm{m,ref}} \tag{D.36}$$

In this example the correction is calculated as $C(\varepsilon) = 0{,}30\ \%$ as a volume concentration.

Then, the uncertainty of the result of measurement when collection efficiency is not taken into account is equal to:

– standard uncertainty as volume concentration: $u(h_\mathrm{m,nc}) = 1{,}2\ \%$

– relative standard uncertainty: $u_\mathrm{rel}(h_\mathrm{m,nc}) = 6{,}4\ \%$

– expanded uncertainty as volume concentration ($k = 2$): $U(h_\mathrm{m,nc}) = 2{,}3\ \%$

– relative expanded uncertainty ($k = 2$): $U_\mathrm{rel}(h_\mathrm{m,nc}) = 12{,}5\ \%$

Annex E
(informative)

Significant technical changes

Table E.1 — Significant technical changes

Clause	Technical change
1	Directive 2000/76/EC has been replaced by Directive 2010/75/EU
2	Normative reference to EN 13284–1 has been replaced by EN 15259 related to requirements for measurement sections and sites and for the measurement objective and plan.
3	Definitions have been reviewed taking into account EN 15259 definitions and new version of VIM (2012). Detection limit is no more considered in the list of definition and in performance characteristics (repeatability at zero is more suitable).
4	Symbols and abbreviations used in the main section of the document have been added.
8.1	Requirements on measurement planning with reference to the EN 15259 have been added.
8.2	For determination of homogeneity reference to the EN 15259 has been added.
9	Symbols have been adapted to EN 15259.
10	According to the new rules fixed in the EN 14793:2017, $s_{r,limit}$ has been recalculated.
Annex A	An estimate of the uncertainty calculated through the determination of reproducibility has been added and replace the expression “reproducibility confidence interval”.
Annex D	The presentation of the calculation of the uncertainty budget has been improved.

Bibliography

[1] ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

[2] ISO 5725-6, *Accuracy (trueness and precision) of measurement methods and results — Part 6: Use in practice of accuracy values*

[3] JCGM 200:2012, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

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