BS EN 15058:2017

BSI Standards Publication

# Stationary source emissions — Determination of the mass concentration of carbon monoxide — Standard reference method: non-dispersive infrared spectrometry

bsi.

**National foreword**

This British Standard is the UK implementation of EN 15058:2017. It supersedes BS EN 15058:2006 which is withdrawn.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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# EN 15058

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Supersedes EN 15058:2006

English Version

# Stationary source emissions - Determination of the mass concentration of carbon monoxide - Standard reference method: non-dispersive infrared spectrometry

Émissions de sources fixes - Détermination de la concentration massique de monoxyde de carbone - Méthode de référence normalisée : spectrométrie infrarouge non dispersive

Emissionen aus stationären Quellen - Bestimmung der Massenkonzentration von Kohlenmonoxid - Standardreferenzverfahren: Nicht-dispersive Infrarotspektrometrie

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

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# Contents Page

## European foreword

This document (EN 15058:2017) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This document supersedes EN 15058:2006.

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of an identical text or by endorsement, at the latest by July 2017, and conflicting national standards shall be withdrawn at the latest by July 2017.

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

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# 1 Scope

This European Standard specifies the standard reference method (SRM) based on the infrared (IR) absorption principle. It includes the sampling and the gas conditioning system, and allows the determination of the carbon monoxide CO in flue gases emitted to the atmosphere from ducts and stacks.

This European Standard specifies the characteristics to be determined and the performance criteria to be fulfilled by portable automated measuring systems (P-AMS) using the IR measurement method. It applies for periodic monitoring and for 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 (AM) to the SRM by application of EN 14793:2017.

This European Standard has been validated during field tests on waste incineration, co-incineration and large combustion plants and on a recognized test bench. It has been validated for CO concentrations with sampling periods of 30 min in the range of 0 $mg/m^3$ to 400 $mg/m^3$ for large combustion plants and 0 $mg/m^3$ to 740 $mg/m^3$ for waste and co-incineration. Directive 2010/75/EU lays down emission values which are expressed in $mg/m^3$, on dry basis at a specified value of oxygen and at standard conditions (273 K and 101,3 kPa).

NOTE 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 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*

EN 15267-4:2017, *Air quality — Certification of automated measuring systems — Part 4: Performance criteria and test procedures for automated measuring systems for periodic measurements of emissions from stationary sources*

EN ISO 14956:2002, *Air quality - Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty (ISO 14956:2002)*

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 14793:2016]

**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**
**portable automated measuring system**
**P-AMS**
automated measuring system which is in a condition or application to be moved from one to another measurement site to obtain measurement results for a short measurement period

Note 1 to entry: The measurement period is typically 8 h for a day.

Note 2 to entry: The P-AMS can be configured at the measurement site for the special application but can be also set-up in a van or mobile container. The probe and the sample gas lines are installed often just before the measurement task is started.

[SOURCE: EN 15267-4:2017]

**3.8**
**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 system (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: Calibration should not be confused with adjustment of a measuring system.

**3.9**
**adjustment**
set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured

Note 1 to entry: The adjustment can be made directly on the instrument or using a suitable calculation procedure.

**3.10**
**span gas**
test gas used to adjust and check a specific point on the response line of the measuring system

**3.11**
**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.

**3.12**
**interference**
negative or positive effect upon the response of the measuring system, due to a component of the sample that is not the measurand

**3.13**
**influence quantity**
quantity that is not the measurand but that affects the result of the measurement

Note 1 to entry: Influence quantities are e.g. presence of interfering gases; ambient temperature, pressure of the gas sample.

**3.14**
**ambient temperature**
temperature of the air around the measuring system

**3.15**
**emission limit value**
**ELV**
limit value given in regulations such as EU Directives, ordinances, administrative regulations, permits, licences, authorisations or consents

Note 1 to entry: ELV can be stated as concentration limits expressed as half-hourly, hourly and daily averaged values, or mass flow limits expressed as hourly, daily, weekly, monthly or annually aggregated values.

**3.16**
**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]

**3.17**
**measurement plane**
plane normal to the centreline of the duct at the sampling position

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

[SOURCE: EN 15259:2007]

**3.18**
**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]

**3.19**
**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]

**3.20**
**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]

**3.21**
**performance characteristic**
one of the quantities (described by values, tolerances, range) assigned to equipment in order to define its performance

**3.22**
**response time**
duration between the instant when an input quantity value of a measuring instrument or measuring system is subjected to an abrupt change between two specified constant quantity values and the instant when a corresponding indication settles within specified limits around its final steady value

Note 1 to entry: By convention time taken for the output signal to pass from 0 % to 90 % of the final variation of indication.

**3.23**
**short-term zero drift**
difference between two zero readings at the beginning and at the end of the measurement period

**3.24**
**short-term span drift**
difference between two span readings at the beginning and at the end of the measurement period

**3.25**
**lack of fit**
systematic deviation, within the measurement range, between the measurement result obtained by applying the calibration function to the observed response of the measuring system measuring test gases and the corresponding accepted value of such test gases

Note 1 to entry: Lack of fit can be a function of the measurement result.

Note 2 to entry: The expression “lack of fit” is often replaced in everyday language by “linearity” or “deviation from linearity”.

**3.26**
**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 %.

**3.27**
**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 %.

**3.28**
**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 are called field reproducibility conditions and 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 %.

**3.29**
**residence time in the measuring system**
time period for the sample gas to be transported from the inlet of the probe to the inlet of the measurement cell

**3.30**
**uncertainty**
parameter associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand

**3.31**
**standard uncertainty**
***u***
uncertainty of the result of a measurement expressed as a standard deviation

**3.32**
**combined uncertainty**
$\boldsymbol{u_c}$
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)

**3.33**
**expanded uncertainty**
***U***
quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

$$U = k \times u_c$$

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.

**3.34**
**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.

| | |
|---|---|
| $A(t_0)$ | (result given by the analyser after adjustment at $t_0$ at span point – result given by the analyser after adjustment at $t_0$ at zero point) / (calibration gas concentration at span point – calibration gas concentration at zero point) |
| $B(t_0)$ | result given by the analyser after adjustment at $t_0$ at zero point |
| $C$ | measured concentration |
| $C_{corr}$ | measured concentration corrected for drift |
| Drift($A$) | {[(result given by the analyser during the drift check at $t_{end}$ at span point – result given by the analyser during the drift check at $t_{end}$ at zero point) / (calibration gas concentration at span point – calibration gas concentration at zero point)] – $A(t_0)$} / ($t_{end} - t_0$) |
| Drift($B$) | (result given by the analyser during the drift check at $t_{end}$ at zero point – result given by the analyser after adjustment at $t_0$ at zero point) / ($t_{end} - t_0$) |
| $f$ | volume fraction |
| $k$ | coverage factor |
| $M_{mol}$ | molar mass |
| $s_R$ | reproducibility standard deviation |
| $s_{r,limit}$ | maximum allowable repeatability standard deviation |
| $t$ | time |
| $t_0$ | time of adjustment |
| $t_{end}$ | time of check for drift at the end of the measurement period |
| $u$ | standard uncertainty |
| $u_c$ | combined uncertainty |
| $U$ | expanded uncertainty |
| $V_{mol}$ | molar volume |

### 4.2 Abbreviated terms

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

| | |
|---|---|
| AM | alternative method |
| AMS | automated measuring system |
| P-AMS | portable automated measuring system |
| PTFE | polytetrafluoroethene |
| PFA | perfluoroalkoxy |
| SRM | standard reference method |

## 5 Principle

### 5.1 General

This European Standard describes the standard reference method (SRM) for sampling, and determining the carbon monoxide (CO) concentration in ducts and stacks emitted to atmosphere by means of an automatic analyser using the IR absorption principle. The specific components and the requirements for the sampling system and the IR analyser are described in Clause 6 and Clause 7. A number of performance characteristics with associated performance criteria are specified for the analyser. These performance characteristics determined according to EN 15267-4:2017 and the expanded uncertainty of the method shall meet the performance criteria given in this European Standard. Requirements and recommendations for quality assurance and quality control are given in Clause 10 for measurements in the field.

### 5.2 Measuring principle

The attenuation of infrared light passing through a sample cell is a measure of the concentration of CO in the cell, according to the Lambert-Beer law. Not only CO but also most hetero-atomic molecules absorb infrared light, in particular water and $CO_2$ have broad bands that can interfere with the measurement of CO. Different technical solutions have been developed to suppress cross-sensitivity in order to design automatic monitoring systems with acceptable performance.

For example, the Non Dispersive Infra-Red (NDIR) method is suitable for CO measurements**:** gas concentration is measured electro-optically by its absorption of a specific wavelength in the infrared (IR). The IR light is directed through the sample chamber towards the detector. In parallel there is another chamber with an enclosed reference gas, typically nitrogen. The detector has an optical filter in front of it that eliminates all light except the wavelength that the selected gas molecules can absorb. Ideally other gas molecules do not absorb light at this wavelength, and do not affect the amount of light reaching the detector to compensate for interfering components. For instance, $CO_2$ and $H_2O$ often initiate cross sensitivity in the infrared spectrum. Different technical solutions have been developed to suppress, cross-sensitivity, instability and drift in order to design automatic monitoring systems with acceptable properties (e.g. Gas Filter Correlation technique).

Special attention shall be paid to IR radiation absorbing-gases such as water vapour, carbon dioxide, nitrous oxide and hydrocarbons.

IR analysers are associated to an extractive sampling system and a gas conditioning system. A sample of gas is taken from the stack with a sampling probe and conveyed to the analyser through the sample gas line and gas conditioning system. The values from the analyser are recorded and/or stored by means of electronic data processing systems.

# 6 Description of the measuring system

## 6.1 General

A volume is extracted from the flue gas for a fixed period of time at a controlled flow rate. The sampling system consists of:

— a sampling probe;

— a filter;

— a sample gas line;

— a conditioning system.

A filter removes the dust in the sampled volume before the sample is conditioned and passed to the analyser.

Different sampling and conditioning configurations are available in order to avoid the water vapour condensation in the measuring system.

Possible configurations are:

— Configuration 1: removal of water vapour by condensation using a cooling system;

— Configuration 2: removal of water vapour through elimination using a permeation drier;

— Configuration 3: dilution with dry, clean, ambient air or nitrogen of the gas to be characterized;

— Configuration 4: heating of the complete sampling system from the nozzle to the heated analyser at a temperature above the dew point".

Configurations 1 to 3 require that the user shall check that the dew point temperature or the outlet temperature of the conditioning system is lower or equal to 4 °C at the inlet of the analyser.

For configuration 4 the user may correct the results for the remaining water content in order to report results on a dry basis (see Annex B in EN 14790:2017).

It is important that all parts of the sampling equipment upstream of the analyser are made of materials that do not react with or absorb CO.

The temperature of all components of the sampling equipment coming into contact with the wet sample gas shall be maintained at a sufficiently high temperature to avoid any condensation.

Conditions and layout of the sampling equipment contribute to the combined uncertainty of the measurement. In order to minimize this contribution to the combined measurement uncertainty, performance criteria for the sampling equipment and sampling conditions are given in 6.2 and in Clause 7.

Some other sample gas conditioning systems may exist and could be acceptable, provided they fulfil the requirements of this European Standard and have been validated with success during the certification process. For example, some systems put gas in depression using a simple Sonic nozzle in the collection probe in order to create a partial vacuum (between 50 hPa absolute and 100 hPa absolute) so that the head of collection and the sample gas line does not need to be heated and water vapour condensation is avoided.

NOTE $NO_x$ converter can produce CO. Therefore, it is not appropriate to place a CO analyser downstream the $NO_x$ converter.

## 6.2 Sampling and sample gas conditioning system

### 6.2.1 Sampling probe

In order to reach the measurement points in 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.

NOTE 2 A sealable connection can be installed on the probe in order to introduce test gases for adjustment.

### 6.2.2 Filter

The filter and filter holder shall be made of an inert material (e.g. ceramic or sinter metal filter with an appropriate pore size). It shall be heated above the sample water and acid dew point temperature, whichever is the greater. The particle filter shall be changed or cleaned periodically depending on the dust loading in the measurement plane.

NOTE Overloading of the particle filter can increase the pressure drop in the sample gas line.

### 6.2.3 Sample gas line

The sample gas line shall be heated up to the conditioning system. It shall be made of a suitable corrosion resistant material (e.g. stainless steel, borosilicate glass, ceramic or titanium could be used; PTFE or PFA is only suitable for flue gas temperature lower than 200 °C).

### 6.2.4 Sample gas conditioning system

#### 6.2.4.1 Sample gas cooler (configuration 1) and permeation drier (configuration 2)

The sample gas cooler or the permeation drier are used before the gas enters the analyser in order to separate water vapour from the flue gas.

Due to ammonium-salt deposition on the permeation tube, the permeation system shall be used when the $NH_3$ concentration is outside the range specified by the manufacturer.

#### 6.2.4.2 Dilution system (configuration 3)

The dilution technique is an alternative to hot gas monitoring or sample gas drying. The flue gas is diluted with dry, clean, ambient air or nitrogen. The dilution gas shall be dry and free from nitrogen oxides. The dilution ratio shall be chosen according to the objectives of the measurement and shall be compatible with the range of the analytical unit. It shall remain constant through the period of the test.

The contribution of the dilution system to the uncertainty shall be added to the uncertainty budget.

NOTE 1 Analysers that are used in combination with dilution probes work with measurement ranges, which are typical for ambient air analysers (0 $mg/m^3$ – 1 $mg/m^3$ – 5 $mg/m^3$ – 10 $mg/m^3$ – 25 $mg/m^3$).

NOTE 2 Configuration 3 was not included in the validation of the method in the field.

#### 6.2.4.3 Heated line and heated analyser (configuration 4)

To avoid condensation, the sample gas line up to the analyser and the analyser itself shall be heated.

The concentrations are given on wet basis and shall be corrected so that they are expressed on dry basis. The correction shall be made from the water vapour concentration in the flue gases and the uncertainty attached to this correction shall be added to the uncertainty budget (see Clause 8).

NOTE Configuration 4 was not included in the validation of the method in the field.

### 6.2.5 Sample gas pump

When a pump is not an integral part of the analyser, an external pump is necessary to draw the sampled gas through the apparatus. It shall be capable of operating according to the specified flow requirements of the manufacturer of the analyser and pressure conditions required for the reaction chamber. The pump shall be resistant to corrosion and consistent with the requirements of the analyser to which it is connected. The whole sampling system associated to the analyser, including the pump, has to meet the criterion in Table 1 related to the influence of gas pressure.

NOTE The quantity of sample gas required can vary between 15 l/h and 500 I/h, depending upon the analyser and the expected response time.

### 6.2.6 Secondary filter

The secondary filter is used to separate fine dust, with a pore size of 1 µm to 2 µm. For example it may be made of glass-fibre, sintered ceramic, stainless steel or PTFE.

NOTE No additional secondary filter is necessary when they are part of the analyser itself.

### 6.2.7 Flow controller and flow meter

This apparatus sets the required sample gas flow. A corrosion resistant material shall be used. The sample gas flow rate into the analyser shall be maintained within the analyser manufacturer's requirements. A controlled pressure drop across restrictors is usually employed to maintain flow rate control into the IR analyser.

NOTE No additional flow controller or flow meter is necessary when they are part of the analyser itself.

## 6.3 Analyser equipment

### 6.3.1 General

The main parts of the analyser are typically:

— source of infrared radiation;

— optics to focus the radiation through the measuring cell to the infrared detector;

— way of modulating the infrared beam;

— means to select a suitable wavelength or wavelengths to measure the gas;

— measuring cell that the sample gas enters. There may be a reference cell in some designs;

— infrared detector;

— amplifier and signal processing system to give an electrical output proportional to the CO concentration.

The standard of construction and vibration/corrosion resistance shall be suited to industrial environments and to the composition of the flue gas.

In Annex B schematic diagrams are given of two types of non-dispersive infrared analysers.

#### 6.3.2 Pressure and temperature effects

The output signal of the analyser is proportional to the density of CO (number of CO molecules) present in the absorption cell and depends on the absolute pressure and temperature in the absorption cell. The effects of variations of pressure and temperature in the absorption cell should be taken into account by the manufacturer.

#### 6.3.3 Sampling pump for the analyser

The sampling pump can be separate or part of the analyser. In any case, it shall be capable of operating within the specified flow requirements of the manufacturer of the analyser and pressure conditions required for the IR absorption cell.

#### 6.3.4 Interferences due to infrared absorbing gases

##### 6.3.4.1 General

As various gases absorb infrared radiation, interference from these gases can occur when their infrared absorption bands coincide or overlap the CO infrared absorption bands. The degree of interference varies among individual IR analysers. In general, gas correlation spectrophotometers are less sensitive to the influence of interferents.

##### 6.3.4.2 Water vapour

The primary interferent is water vapour. However water vapour interference should be minimised by using sampling and conditioning configuration 1 or 2.

##### 6.3.4.3 Other interferents

Other known interferents are carbon dioxide, hydrocarbons and $N_2O$. Knowledge of the gas composition and the cross sensitivity of the analyser is useful to ensure that none of the compounds interferes with the measurement.

## 7 Performance characteristics of the SRM

Table 1 gives an overview of the performance characteristics of the whole measurement method including the analyser and the sampling and sample gas conditioning system. These performance characteristics shall be determined in a general performance test according to the test procedures described in EN 15267-4:2017, by an independent test laboratory accredited or recognized by the competent authorities for the implementation of tests procedures of EN 15267-4:2017.

The independent test-laboratory shall check the conformity of the analyser with its sampling and sample gas conditioning system to fulfil the performance criterion attached to each performance characteristics. The maximum allowable deviations as absolute values of the measured values are given as mass concentrations or as percentages of the upper limit of the range.

**Table 1 — Performance characteristics of the SRM and associated performance criteria**

| Performance characteristic | Performance criterion | Performance characteristic to be included in calculation of combined uncertainty |
|---|---|---|
| Response time | ≤ 200 s | |
| Repeatability standard deviation at zero point | ≤ 2,0 % [a] | X [b] |
| Repeatability standard deviation at span point | ≤ 2,0 % [a] | X [b] |
| Reproducibility standard deviation | ≤ 3,3 % [a] | X [b] |
| Lack of fit | ≤ 2,0 % [a] | X |
| Short-term zero drift | ≤ 2,0 % [a, c] | X |
| Short-term span drift | ≤ 2,0 % [a, c] | X |
| Influence of ambient temperature change from 5 °C to 25 °C and from 40 °C to 20 °C at zero point | ≤ 5,0 % [a, c] | X |
| Influence of ambient temperature change from 5 °C to 25 °C and from 40 °C to 20 °C at span point | ≤ 5,0 % [a, c] | X |
| Influence of sample gas pressure at span point, for a pressure change $\Delta p$ of 3 kPa | ≤ 2,0 % [a] | X |
| Influence of sample gas flow on extractive P-AMS for a given specification by the manufacturer | ≤ 2,0 % [a] | X |
| Influence of vibration | ≤ 2,0 % [a] | X |
| Influence of voltage, at −15 % below and at +10 % above nominal supply voltage | ≤ 2,0 % [a] | X |
| Cross-sensitivity | ≤ 4,0 % [a, d] | X |
| Leakage in the sample gas line and sample gas conditioning system | ≤ 2,0 % of the measured value | X [e] |

[a] Percentage value of the upper limit of the certification range.

[b] The repeatability in the laboratory or the reproducibility in the field shall be used, whichever is greater. If the repeatability in the laboratory is used, only one of both values shall be included in the calculation: the first possibility is to choose the repeatability standard deviation got from laboratory tests corresponding to the closest concentration to the actual concentration in stack, or the higher (relative) standard deviation of repeatability independently of the concentration measured in stack.

[c] Consider either a combination of drift effect in the laboratory and effect of temperature in the laboratory or drift in the field whatever is the greatest, because drift in the field combines mainly intrinsic drift of the P-AMS and the drift due to temperature.

[d] The sums of contributions to uncertainty producing positive and negative effects are calculated separately. The maximum of their absolute value shall be compared with the performance criterion.

[e] If the leak test is performed under severe conditions of depression, then leak can be considered as negligible in normal conditions of use.

# 8 Suitability of the measuring system for the measurement task

An uncertainty budget shall be established by the user to determine for which measurement range the analyser and its associated sampling and sample gas conditioning system fulfil the requirements for a maximum allowable expanded uncertainty.

The relative expanded uncertainty, calculated on dry basis and before correction to the oxygen reference concentration, shall not exceed 6,0 % of the daily emission limit value (ELV) or the lower limit value fixed to the plant by the local authorities.

The measurement range that could be covered by the measuring system can be extended if the user demonstrates that the uncertainty with the actual variation range of influence quantities and values of interferents at a particular plant is lower than the maximum allowable expanded uncertainty.

Table 1 indicates which performance characteristics have to be included in the calculation of the combined uncertainty.

The principle of calculation of the combined uncertainty is based on the law of 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, including the uncertainty of the calibration gas

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

— calculate the combined uncertainty of the measured value, reported as a dry gas value at actual concentration of oxygen.

NOTE When the concentration of a measured component has to be expressed at an oxygen reference concentration (e.g. 3 % or 11 %), the correction of oxygen can bring an additional uncertainty which could be significant if the difference between the oxygen measured value and the oxygen reference value is too large. Annex C provides information on the contribution of oxygen correction to the uncertainty linked to the concentration.

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

# 9 Field operation

## 9.1 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, measurements 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.

## 9.2 Sampling strategy

### 9.2.1 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).

### 9.2.2 Measurement section and measurement plane

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

### 9.2.3 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 CO 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.

### 9.2.4 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.

## 9.3 Choice of the measuring system

To choose an appropriate analyser, sample gas line and conditioning system, the following characteristics of flue gases shall be considered before a field campaign:

— flue gas moisture content and dew point;

— temperature of exhaust gases;

— dust loading;

— expected concentration range of CO and emission limit values;

— expected concentration of potentially interfering substances.

The measurement range shall be adapted to the measurement objective. Generally, this means that the measurement range is large enough to cover the peak emission and at least 150 % of the half-hourly ELV.

To avoid long response times, the sample gas line should be as short as possible. If necessary a bypass pump should be used.

Use a heated filter appropriate to the dust loading.

## 9.4 Setting of the measuring system on site

### 9.4.1 General

The complete measuring system, including the sampling system, the sample gas conditioning system and the analyser, shall be connected according to the manufacturer's instructions and the nozzle of the probe placed at the measurement points in the duct (see 9.2).

The sample gas conditioning system, sampling probe, filter, connection tube and analyser shall be stabilized at the required temperature. At the same time, a constant pressure shall be achieved in the measuring chamber of the analyser.

After pre-heating, the flow passing through the sampling system and the analyser shall be adjusted to the chosen flow rate to be used during measurement.

When both the analyser and the sampling system have been set-up, and before zero and span adjustments, the proper functioning of the analyser and sampling system shall be checked.

Any data recording and data processing system used shall be shall be adapted to the measurement objective and to the response time of the measuring system; generally, data are recorded at least every 60 s. For CO, where peaks can occur a higher resolution can be used.

### 9.4.2 Preliminary zero and span check, and adjustments

#### 9.4.2.1 Test gases

The zero gas shall be a gas containing no significant amount of carbon monoxide (for example, nitrogen or purified air).

The span gases used to adjust the analyser shall have concentrations traceable to SI units. The expanded uncertainty on the analytical certificate of the span gas shall not exceed 2,0 % for CO.

When the analyser is used for regulatory purposes, the span gas shall have a known concentration of approximately the half-hourly ELV, or 50 % to 90 % of the selected range of the analyser.

#### 9.4.2.2 Adjustment of the analyser

At the beginning of the measurement period, zero and span gases shall be supplied to the analyser directly, without passing through the sampling system. Adjustments shall be made until the correct zero and span gas values are given by the data sampling system:

— check and adjust the zero value;

— check and adjust the span value;

— in case of adjustments, check again zero to see if there is no significant change.

#### 9.4.2.3 Check of the sampling system including the leak test

Before starting the measurement, check that there is no significant leakage in the sampling system by use of one of the two following procedures or any other relevant procedure validated during the general performance test (see Clause 7):

— zero and span gas are supplied to the analyser through the sampling system, as close as possible to the nozzle (in front of the filter if possible); differences between the readings at zero and at span point shall not exceed 2,0 % of the span value;

— assemble the complete sampling system; close the nozzle and 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.

NOTE The leak test can be carried out before the adjustment of the analyser.

### 9.4.3 Zero and span checks after measurement

At the end of the measurement period and at least once a day, zero and span checks shall be performed at the inlet of the analyser by supplying test gases.

The results of these checks shall be documented. In case of deviation between checks after measurement and preliminary adjustments, values of deviation shall be indicated in the measurement report.

If the span or zero drifts are greater than 2,0 % of the span value, it is necessary to correct both for zero and span drifts (see in Annex E for a procedure of correction of data for drift effect).

The drift of zero and span shall be lower than 5,0 % of the span value; otherwise, the results shall be rejected.

The concentration $C_{corr}$ corrected according to time $t$ for the concentration $C$ given by the analyser shall be calculated according to Formula (1):

$$C_{corr} = \frac{C - \left(B\left(t_0\right) + \text{Drift}\left(B\right) \times t\right)}{\left(A\left(t_0\right) + \text{Drift}\left(A\right) \times t\right)} \quad (1)$$

where

$A(t_0)$ is (result given by the analyser after adjustment at $t_0$ at span point – result given by the analyser after adjustment at $t_0$ at zero point) / (calibration gas concentration at span point – calibration gas concentration at zero point);

$B(t_0)$ is the result given by the analyser after adjustment at $t_0$ at zero point;

Drift*(A)* is {[(result given by the analyser during the drift check at $t_{end}$ at span point – result given by the analyser during the drift check at $t_{end}$ at zero point) / (calibration gas concentration at span point – calibration gas concentration at zero point)] – $A(t_0)$} / ($t_{end} - t_0$);

Drift($B$) is (result given by the analyser during the drift check at $t_{end}$ at zero point – result given by the analyser after adjustment at $t_0$ at zero point) / ($t_{end} - t_0$);

$t_{end} - t_0$ is the duration of the measurement period in minutes (duration between adjustment and check for drift at the end of the measurement period).

An example of drift check and of drift correction is given in Annex E.

# 10 Ongoing quality control

## 10.1 Introduction

Quality control is critically important in order to ensure that the uncertainty of the measured values for carbon monoxide is kept within the stated limits during extended automatic monitoring periods in the field. This means that maintenance, as well as zero and span adjustment procedures shall be followed, as they are essential for obtaining accurate and traceable data.

## 10.2 Frequency of checks

Table 2 shows the required minimum frequency of checks. The test laboratory shall implement the relevant European Standards for the determination of performance characteristics.

**Table 2 — Frequency of checks**

| Checks | Frequency | Action criteria |
|---|---|---|
| Cleaning or changing of particulate filters [a] at the sampling inlet and at the analyser inlet | Every campaign, if needed [a] | |
| Leak test | Every campaign | As specified in 9.4.2.3 |
| Zero and span adjustment | Every campaign | As specified in 9.4.2.2 |
| Drift | Every campaign | As specified in 9.4.3 |
| Regular maintenance of several parts of the analyser | As required by manufacturer | As specified by the manufacturer |
| Lack of fit | At least every year and after repair of the analyser | As specified in Table 1 |

[a] The particle filter shall be changed periodically depending on the dust loading at the measurement site. During this filter change the filter housing shall be cleaned. Overloading of the particle filter may increase the pressure drop in the measurement line.

## 11 Expression of results

The measurement results shall be expressed as mass concentrations.

A volume fraction $f$ (e.g. in $10^{-6}$ which is often expressed as ppm) is converted to a mass concentration $C$ (e.g. in mg/m$^3$) by Formula (2):

$$C = f \frac{M_{\text{mol}}}{V_{\text{mol}}} \tag{2}$$

where:

$M_{\text{mol}}(\text{CO}) = 28\,\text{g/mol}$

$V_{\text{mol}} = 22,4\,\text{l/mol}$

If the measurement result has to be converted to reference conditions the corresponding equations in Annex C of EN 15259 shall be used.

## 12 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 (3)) and the reproducibility standard deviation (see Formula (4)) defined in EN 14793:2017, expressed in mass concentration for this standard reference method are:

$$s_{r,\text{limit}}(C) = 0{,}0106\,C + 2{,}2\,\frac{\text{mg}}{\text{m}^3} \tag{3}$$

$$s_R(C) = 0{,}0118\,C + 2{,}94\,\frac{\text{mg}}{\text{m}^3} \tag{4}$$

where $C$ is the mass concentration in milligrams per cubic meter.

## 13 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 point(s) in the measurement plane;

c) information about the analyser and description of the sampling and conditioning line;

d) operating range;

e) details of the quality and the concentration of the calibration gases used;

f) details on the adjustment performed before and after actual sampling

g) measurement results with sampling date, time and duration;

h) information on flue gas characteristics (temperature, velocity, moisture, pressure).

# 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 doubles 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 — Flue gas characteristics during field tests**

| Field test | Installation | Fuel | Flue gas characteristics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | T<br>°C | $O_2$<br>% | $NO_x$<br>mg/m³ | $SO_2$<br>mg/m³ | CO<br>mg/m³ | $H_2O$<br>% | PM<br>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 $i^{\mathrm{th}}$ 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):

$$U = t_{0,95;np-1}\, s_R \quad \text{(A.3)}$$

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

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 | Mass concentration | | Number of teams | Number of double measurements | Repeatability standard deviation $s_r$ | Repeatability $r$ | |
|---|---|---|---|---|---|---|---|
| | Range mg/m³ | Average mg/m³ | | | mg/m³ | mg/m³ | % |
| 1A | 16 to 20 | 18 | 5 | 2 | 0,24 | 0,76 | 4,3 |
| 1B | 57 to 69 | 64 | 5 | 2 | 0,34 | 1,08 | 1,7 |
| 1C | 95 to 106 | 100 | 5 | 2 | 0,42 | 1,33 | 1,3 |
| 1D | 205 to 211 | 209 | 5 | 2 | 0,65 | 2,08 | 1,0 |
| 1E | 338 to 353 | 345 | 5 | 2 | 0,95 | 3,03 | 0,9 |
| 1F | 213 to 278 | 256 | 5 | 1 | 0,75 | 2,95 | 1,2 |
| 1G | 41 to 53 | 44 | 5 | 1 | 0,30 | 1,16 | 2,6 |
| 2 | 7,2 to 15 | 9,5 | 4 | 16 | 2,7 | 8,29 | 86,9 |
| 3 | [a] | | | | | | |
| 4 | 95 to 183 | 144 | 4 | 12 | 2,9 | 9,19 | 6,4 |
| 5 | 264 to 441 | 328 | 3 | 12 | 4,8 | 15,55 | 4,7 |
| 6 | 3,8 to 5,6 | 4,5 | 4 | 12 | 1,2 | 3,82 | 84,8 |

[a] below the detection limit

The following functions expressed as mass concentrations in mg/m³ were determined:

$$s_r(C) = 0,0088C + 1,83\,\frac{\text{mg}}{\text{m}^3} \tag{A.5}$$

$$s_{r,\text{limit}}(C) = 0,0106C + 2,2\,\frac{\text{mg}}{\text{m}^3} \tag{A.6}$$

$$r(C) = 0,0283C + 5,7\,\frac{\text{mg}}{\text{m}^3} \tag{A.7}$$

where $C$ is the mass concentration expressed in mg/m³.

### A.3.3 Reproducibility

**Table A.3 — Reproducibility in the field**

| Field test | Concentration | | Number of teams | Number of double measurements | Reproducibility standard deviation | Estimate of the expanded uncertainty | Reproducibility | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $s_R$ | $U$ | $R$ | |
| | Range mg/m³ | Average mg/m³ | | | mg/m³ | mg/m³ | mg/m³ | % |
| 1A | 16 to 20 | 18 | 5 | 2 | 1,3 | 3,0 | 4,2 | 23 |
| 1B | 57 to 69 | 64 | 5 | 2 | 2,2 | 4,9 | 7,0 | 11 |
| 1C | 95 to 106 | 100 | 5 | 2 | 1,8 | 4,0 | 5,7 | 6 |
| 1D | 205 to 211 | 209 | 5 | 2 | 2,4 | 5,4 | 7,7 | 4 |
| 1E | 338 to 353 | 345 | 5 | 2 | 2,5 | 5,7 | 8,1 | 2 |
| 1F | 213 to 278 | 256 | 5 | 1 | 23 | 64 | 90,3 | 35 |
| 1G | 41 to 53 | 44 | 5 | 1 | 4,8 | 13 | 18,7 | 42 |
| 2 | 7,2 to 14,3 | 9,5 | 4 | 16 | 3,5 | 7,6 | 10,7 | 112 |
| 3 | [a] | | | | | | | |
| 4 | 57 to 149 | 93 | 4 | 12 | 4,8 | 11 | 15,6 | 17 |
| 5 | 264 to 441 | 328 | 3 | 12 | 6,6 | 15 | 21,2 | 6 |
| 6 | 3,8 to 5,6 | 4,5 | 4 | 12 | 2,0 | 4,5 | 6,4 | 141 |

[a] below the detection limit

The following functions expressed as mass concentrations in mg/m³ were determined:

$$s_R(C) = 0,0118C + 2,94\,\frac{\text{mg}}{\text{m}^3} \tag{A.8}$$

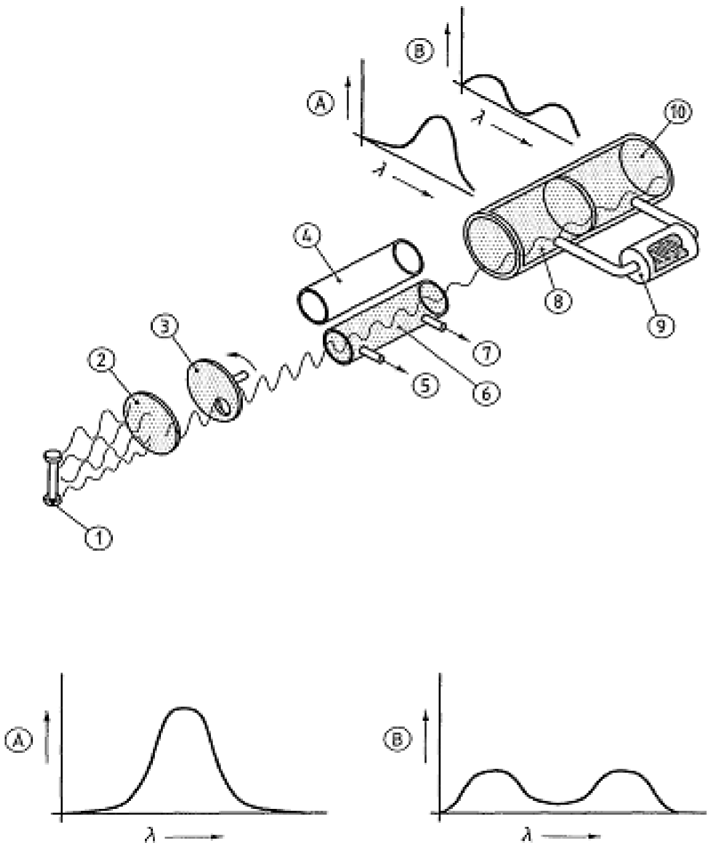
$$U(C) = 0,029C + 7,2\,\frac{\text{mg}}{\text{m}^3} \tag{A.9}$$

$$R(C) = 0,041C + 10,2\,\frac{\text{mg}}{\text{m}^3} \tag{A.10}$$

where $C$ is the mass concentration expressed in mg/m³.

# Annex B
(informative)

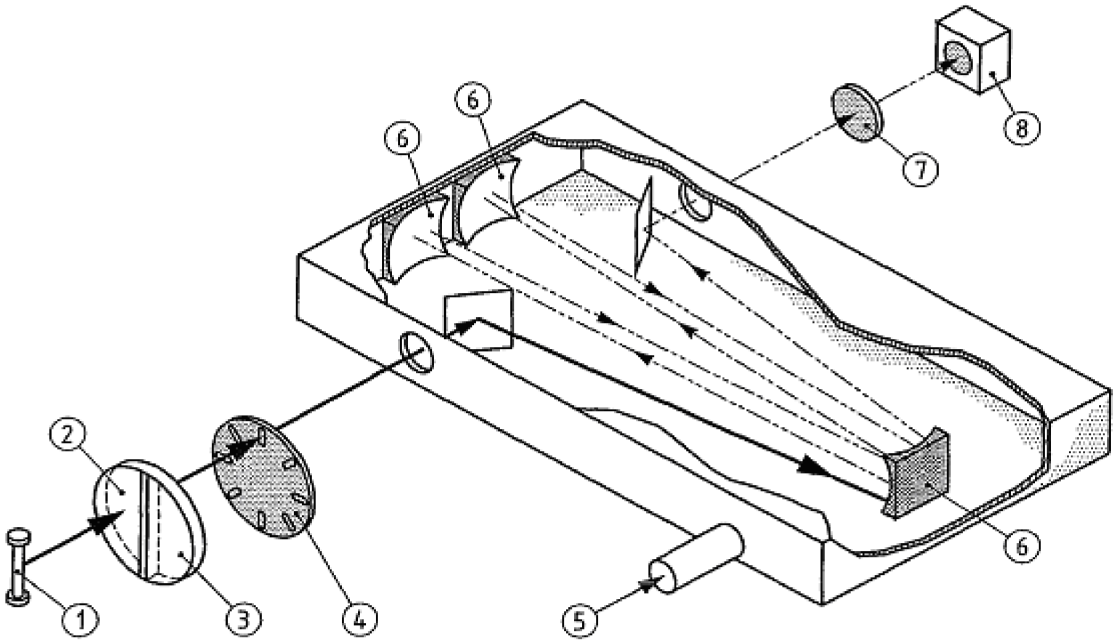
# Schematics of non-dispersive infrared spectrometer




**Key**

1 IR lamp
2 light filter
3 chopper
4 reference cell
5 gas in
6 sample cell
7 gas out
8 first chamber
9 microflow sensor
10 second chamber
A light absorption in first chamber
B light absorption in second chamber
λ wavelength

**Figure B.1 — Example of a dual cell analyser**




**Key**

1 IR source
2 neutral filter ($N_2$)
3 gas filter cell (CO)
4 modulator
5 sample gas
6 mirror
7 filter
8 detector

**Figure B.2 — Example of a gas filter correlation analyser**

# Annex C
(informative)

# Calculation of the uncertainty associated with a concentration expressed on dry gas and at an oxygen reference concentration

## C.1 Uncertainty associated with a concentration expressed on dry gas

The concentration of a measured component expressed for dry gas is calculated according to Formula (C.1):

$$C_{\mathrm{dry}} = C_{\mathrm{wet}} \frac{100\,\%}{100\,\% - h_{\mathrm{m}}} \tag{C.1}$$

where

$C_{\mathrm{dry}}$ is the concentration expressed on dry basis;

$C_{\mathrm{wet}}$ is the concentration expressed on wet basis;

$h_{\mathrm{m}}$ is the volume fraction of water vapour.

The uncertainty associated with a concentration expressed on dry gas is calculated according to Formula (C.2):

$$u^2\left(C_{\mathrm{dry}}\right) = \left(C_{\mathrm{dry}}\right)^2 \times \left( \frac{u^2\left(C_{\mathrm{wet}}\right)}{\left(C_{\mathrm{wet}}\right)^2} + \frac{u^2\left(h_{\mathrm{m}}\right)}{\left(100\,\% - h_{\mathrm{m}}\right)^2} \right) \tag{C.2}$$

where :

$u\left(C_{\mathrm{dry}}\right)$ is the uncertainty associated with a concentration expressed on dry gas;

$u\left(C_{\mathrm{wet}}\right)$ is the uncertainty associated with a concentration expressed on wet gas;

$u\left(h_{\mathrm{m}}\right)$ is the uncertainty associated with the water vapour volume fraction.

**Table C.1 — Calculation of the uncertainty on dry gas**

| | |
|---|---|
| Concentration $C_{wet}$ of the measured component: | 100 mg/m³ on wet basis |
| Standard uncertainty of the concentration $u(C_{wet})$: | 6 % of measured value |
| Standard uncertainty of the water vapour content $u(h_m)$: | 10 % of measured value |

| **Water vapour content** | **Concentration on dry basis** | **Standard uncertainty** | **Relative standard uncertainty** |
|---|---|---|---|
| $h_m$ | $C_{dry}$ | $u(C_{dry})$ | $u_{rel}(C_{dry})$ |
| % | mg/m³ | mg/m³ | % |
| 1 | 101,01 | 6,06 | **6,00** |
| 2 | 102,04 | 6,13 | **6,00** |
| 3 | 103,09 | 6,19 | **6,01** |
| 4 | 104,17 | 6,27 | **6,01** |
| 5 | 105,26 | 6,34 | **6,02** |
| 6 | 106,38 | 6,42 | **6,03** |
| 7 | 107,53 | 6,50 | **6,05** |
| 8 | 108,70 | 6,59 | **6,06** |
| 9 | 109,89 | 6,68 | **6,08** |
| 10 | 111,11 | 6,78 | **6,10** |
| 11 | 112,36 | 6,88 | **6,13** |
| 12 | 113,64 | 6,99 | **6,15** |
| 13 | 114,94 | 7,11 | **6,18** |
| 14 | 116,28 | 7,23 | **6,22** |
| 15 | 117,65 | 7,36 | **6,25** |
| 16 | 119,05 | 7,49 | **6,30** |
| 17 | 120,48 | 7,64 | **6,34** |
| 18 | 121,95 | 7,79 | **6,39** |
| 19 | 123,46 | 7,95 | **6,44** |
| 20 | 125,00 | 8,13 | **6,50** |
| 21 | 126,58 | 8,31 | **6,56** |
| 22 | 128,21 | 8,50 | **6,63** |
| 23 | 129,87 | 8,70 | **6,70** |
| 24 | 131,58 | 8,92 | **6,78** |
| 25 | 133,33 | 9,15 | **6,86** |
| 26 | 135,14 | 9,40 | **6,95** |
| 27 | 136,99 | 9,66 | **7,05** |

| | | | |
|---|---|---|---|
| 28 | 138,89 | 9,93 | **7,15** |
| 29 | 140,85 | 10,22 | **7,26** |
| 30 | 142,86 | 10,53 | **7,37** |
| 31 | 144,93 | 10,86 | **7,50** |
| 32 | 147,06 | 11,21 | **7,63** |
| 33 | 149,25 | 11,59 | **7,76** |
| 34 | 151,52 | 11,98 | **7,91** |
| 35 | 153,85 | 12,40 | **8,06** |

## C.2 Uncertainty associated with a concentration expressed at a oxygen reference concentration

The concentration of a measured component for oxygen reference conditions is calculated according to Formula (C.3):

$$C_{\mathrm{corr}} = C_{\mathrm{m}} \times \frac{21\% - \left(o_{\mathrm{ref}}\right)_{\mathrm{dry}}}{21\% - \left(o_{\mathrm{m}}\right)_{\mathrm{dry}}} \tag{C.3}$$

where

$C_{\mathrm{corr}}$ is the concentration expressed at oxygen reference conditions;

$\left(o_{\mathrm{ref}}\right)_{\mathrm{dry}}$ is the oxygen reference concentration expressed as a volume fraction on dry basis;

$C_{\mathrm{m}}$ is the measured concentration at the actual volume fraction of oxygen;

$\left(o_{\mathrm{m}}\right)_{\mathrm{dry}}$ is the actual volume fraction of oxygen in the dry flue gas.

The uncertainty associated with a concentration expressed on dry gas is calculated according to Formula (C.4):

$$u^2\left(C_{\mathrm{corr}}\right) = \left(C_{\mathrm{corr}}\right)^2 \times \left( \frac{u^2\left(C_{\mathrm{m}}\right)}{\left(C_{\mathrm{m}}\right)^2} + \frac{u^2\left(\left(o_{\mathrm{m}}\right)_{\mathrm{dry}}\right)}{\left(21\% - \left(o_{\mathrm{m}}\right)_{\mathrm{dry}}\right)^2} \right) \tag{C.4}$$

where

$u\left(C_{\mathrm{corr}}\right)$ is the uncertainty associated with a concentration expressed at a oxygen reference concentration;

$u\left(C_{\mathrm{m}}\right)$ is the uncertainty associated with a concentration at the actual volume fraction of oxygen;

$u\left(\left(o_{\mathrm{m}}\right)_{\mathrm{dry}}\right)$ is the uncertainty associated with the actual volume fraction of oxygen in the flue gas on dry basis.

The uncertainty associated to the concentration expressed at a reference oxygen volume fraction depends on the uncertainty of the measurement carried out at the actual oxygen volume fraction, and on the uncertainty of measurement of oxygen. It increases with the oxygen volume fraction in the sample gas as shown in Table C.2.

**Table C.2 — Calculation of the uncertainty of a concentration expressed at an oxygen reference concentration**

| | |
|---|---|
| Concentration $C_m$ of the measured component: | 100 mg/m³ at actual oxygen content |
| Standard uncertainty of the concentration $u(C_m)$: | 4,7 % of the measured value |
| Relative standard uncertainty of the oxygen content $u_{rel}(o_m)$: | 2,5 % |
| Oxygen reference volume concentration $o_{ref}$: | 11 % |

| **Oxygen volume content** | **Concentration at $o_{ref}$ = 11 %** (calculated with $o_m$) | **Standard uncertainty** | **Relative standard uncertainty** |
|---|---|---|---|
| $o_m$ | $C_{corr}$ | $u(C_{corr})$ | $u_{rel}(C_{corr})$ |
| % | mg/m³ | mg/m³ | % |
| 5 | **62,50** | 2,98 | **4,76** |
| 6 | **66,67** | 3,20 | **4,81** |
| 7 | **71,43** | 3,47 | **4,86** |
| 8 | **76,92** | 3,80 | **4,95** |
| 9 | **83,33** | 4,22 | **5,06** |
| 10 | **90,91** | 4,75 | **5,22** |
| 11 | **100,00** | 5,45 | **5,45** |
| 12 | **111,11** | 6,40 | **5,76** |
| 13 | **125,00** | 7,77 | **6,21** |
| 14 | **142,86** | 9,80 | **6,86** |
| 15 | **166,67** | 13,03 | **7,82** |
| 16 | **200,00** | 18,56 | **9,28** |
| 17 | **250,00** | 29,05 | **11,62** |
| 18 | **333,33** | 52,40 | **15,72** |
| 19 | **500,00** | 121,05 | **24,21** |
| 20 | **1000,00** | 502,20 | **50,22** |

# Annex D
(informative)

# Example of assessment of compliance of non-dispersive infrared method for CO with requirements on emission measurements

## D.1 General

This informative annex gives an example of the calculation of the uncertainty budget established for configuration 1 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

### D.2.1 Model equation

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 model equation for the concentration $C_{\mathrm{CO}}$ can be generally expressed as a sum of individual contributions $C_i$ as given by Formula (D.1):

$$C_{\mathrm{CO}} = \sum_{i=1}^{N} C_i \qquad \text{(D.1)}$$

The individual contributions $C_i$ represent the volume concentration indicated by the analyser and additional corrections due to deviations caused by the performance characteristics of the analyser and the influence quantities such as given by Table D.1.

**Table D.1 — Parameters and signal and uncertainty contributions**

| Number<br>$i$ | Parameter | Signal contribution<br>$C_i$ | Uncertainty contribution<br>$u_i$ |
|---|---|---|---|
| 1 | volume concentration indicated by the analyser | $C_{\text{read}}$ | $u_{\text{read}}$ |
| 2 | repeatability | $C_{\text{r}}$ | $u_{\text{r}} = s_{\text{r}}$ |
| 3 | lack of fit | $C_{\text{lof}}$ | $u_{\text{lof}}$ |
| 4 | short-term zero drift | $C_{\text{d,z}}$ | $u_{\text{d,z}}$ |
| 5 | short-term span drift | $C_{\text{d,s}}$ | $u_{\text{d,s}}$ |
| 6 | influence of ambient temperature at zero [a] | $C_{\text{t,z}}$ | $u_{\text{t,z}}$ |
| 7 | influence of ambient temperature at span [a] | $C_{\text{t,s}}$ | $u_{\text{t,s}}$ |
| 8 | influence of sample gas pressure | $C_{\text{p}}$ | $u_{\text{p}}$ |
| 9 | influence of sample gas flow | $C_{\text{f}}$ | $u_{\text{f}}$ |
| 10 | influence of supply voltage | $C_{\text{v}}$ | $u_{\text{v}}$ |
| 11 | cross-sensitivity (interference) | $C_{\text{i}}$ | $u_{\text{i}}$ |
| 12 | adjustment (calibration gas) | $C_{\text{adj}}$ | $u_{\text{adj}}$ |
| [a] choose the most appropriate of both according to the level of concentration measured | | | |

### D.2.2 Combined uncertainty

The combined uncertainty $u_{\text{c}}\left(C_{\text{CO}}\right)$ of the concentration $C_{\text{CO}}$ is obtained by application of the law of propagation of uncertainty on Formula (D.1) which leads to a quadratic summation of the uncertainty contributions $u_i$ listed in Table D.1:

$$u_{\text{c}}\left(C_{\text{CO}}\right) = \sqrt{\sum_{i=1}^{N}\left[\left(\frac{\partial C_{\text{CO}}}{\partial C_i}\right)^2 u^2\left(C_i\right)\right]} = \sqrt{\sum_{i=1}^{N} u^2\left(C_i\right)} = \sqrt{\sum_{i=1}^{N} u_i^2} \qquad \text{(D.2)}$$

The uncertainty contributions $u_i$ are quantified on the basis of available performance characteristics of the measurement system, data from the dispersion of repeated measurements, data describing the range of influence quantities or data provided in calibration certificates. If an uncertainty contribution is not expressed as a standard uncertainty (standard deviation), a conversion to a standard uncertainty is required.

### D.2.3 Expanded uncertainty

In general, the uncertainty associated to a result of measurement is expressed as an expanded uncertainty which corresponds to the combined uncertainty multiplied by a coverage factor $k$. Since most of the values of the uncertainty components $u_i$ are determined from test data, where the probability distribution of values is rectangular for most parameters and a normal distribution for a few parameters, a factor $k = 2{,}0$ is used for a level of confidence of approximately 95 % since the number of measurements to determine the uncertainty contributions and the associated number of degrees of freedom is sufficiently high or a rectangular distribution is assumed.

The expanded uncertainty $U\left(C_{\mathrm{CO}}\right)$ of the concentration $C_{\mathrm{CO}}$ is determined using Formula (D.3):

$$U\left(C_{\mathrm{CO}}\right) = 2,0\,u_{\mathrm{c}}\left(C_{\mathrm{CO}}\right) \tag{D.3}$$

### D.2.4 Determination of uncertainty contributions in case of rectangular distributions

In the case of rectangular distributions the standard uncertainty $u_i$ is calculated according to EN ISO 14956 by Formula (D.4):

$$u_i = \sqrt{\frac{\left(C_{i,\max} - C_{i,\mathrm{adj}}\right)^2 + \left(C_{i,\min} - C_{i,\mathrm{adj}}\right)\left(C_{i,\max} - C_{i,\mathrm{adj}}\right) + \left(C_{i,\min} - C_{i,\mathrm{adj}}\right)^2}{3}} \tag{D.4}$$

where

$C_{i,\min}$ is the minimum value of the average reading influenced by parameter *i*;

$C_{i,\max}$ is the maximum value of the average reading influenced by parameter *i*;

$C_{i,\mathrm{adj}}$ is the value of the average reading during adjustment.

Formula (D.4) can be simplified in the following cases:

— if the value $C_{i,\mathrm{adj}}$ is at the centre of the interval bounded by the maximum value $C_{i,\max}$ and the minimum value $C_{i,\min}$ of all values $C_i$, then the standard uncertainty $u_i$ is given by Formula (D.5):

$$u_i = \frac{\left(C_{i,\max} - C_{i,\min}\right)}{\sqrt{12}} \tag{D.5}$$

If the absolute value of the deviation above and below the central value is expressed by $\Delta C_i$ (see Formula (D.6)), then the standard uncertainty $u_i$ is given by Formula (D.7):

$$\left|C_{i,\max} - C_{i,\mathrm{adj}}\right| = \left|C_{i,\min} - C_{i,\mathrm{adj}}\right| = \Delta C_i \tag{D.6}$$

$$u_i = \frac{\Delta C_i}{\sqrt{3}} \tag{D.7}$$

— if the value of $C_{i,\mathrm{adj}}$ is the same as either $C_{i,\min}$ or $C_{i,\max}$, then the standard uncertainty $u_i$ is given by Formula (D.8):

$$u_i = \frac{\left(C_{i,\max} - C_{i,\min}\right)}{\sqrt{3}} \tag{D.8}$$

### D.2.5 Determination of uncertainty contributions by use of sensitivity coefficients

The contribution $C_i$ to the measured value caused by a parameter *i* can be calculated by use of the value $X_i$ of the parameter and a corresponding sensitivity coefficient $b_i$ of this parameter as shown by Formula (D.9):

$$C_i = b_i\, X_i \tag{D.9}$$

The contribution of a variation of the parameter to the total uncertainty of the measured values can be calculated from the range of values of the parameter in the considered application and the sensitivity coefficient of this parameter determined in the laboratory test of the analyser by use of Formula (D.10):

$$u_i = |b_i| u(X_i) \quad \text{(D.10)}$$

where

$u_i$ is the uncertainty contribution to the total uncertainty of the measured values caused by a variation of the parameter *i*;

$b_i$ is the sensitivity coefficient of the parameter *i*;

$u(X_i)$ is the standard uncertainty due to variation of the parameter *i*.

The variation of the parameter *i* can be converted to a standard uncertainty by use of Formula (D.4) to Formula (D.8).

## D.3 Example of an uncertainty calculation

### D.3.1 Site specific conditions

Table D.2 gives the specific conditions at the site, that is to say the values and the variation ranges of the influence quantities used in this example.

**Table D.2 — Site specific conditions and values or ranges of influence parameters applied for the example**

| Specific conditions | Value or range |
|---|---|
| Range of analyser | 0 mg/m³ to 100 mg/m³ |
| Studied concentration of CO (limit value of CO for the site) expressed in standard conditions of temperature and pressure and at oxygen reference volume concentration | 50 mg/m³ |
| oxygen reference volume concentration | 11 % |
| Conditions in the field | |
| Sample volume flow | 60 l/h ± 5 l/h |
| Temperature during adjustment | 285 K |
| Fluctuations of ambient temperature during measurement | 283 K to 308 K |
| Voltage variation | 230 V × (1 ± 5 %) |
| Gas pressure during adjustment | 99 kPa |
| Gas pressure variation | 99 kPa to 100 kPa |
| $CO_2$ volume concentration variations | 8 % to12 % |
| $N_2O$ concentration variations | negligible |
| $CH_4$ concentration variations | 0 mg/m³ to 10 mg/m³ |
| Calibration gas (concentration of CO in $N_2$, without interferent) | 80 mg/m³ × (1 ± 2 %) |

### D.3.2 Performance characteristics

Table D.3 gives the performance characteristics of the method used in this example. These parameters can have an influence on the response of the analyser and include the metrological performance of the analyser and the effect of influence quantities (environmental conditions like ambient temperature, voltage, pressure and chemical interferents).

**Table D.3 — Performance characteristics**

| Performance characteristic | Performance criteria | Results of laboratory and field tests |
|---|---|---|
| Response time | ≤ 200 s | 120 s |
| Repeatability standard deviation in the laboratory at zero point | ≤ 1,0 % [a] | 0,3 % [a] |
| Repeatability standard deviation in the laboratory at span point | ≤ 2,0 % [a] | 0,45 % [a] |
| Lack of fit | ≤ 2,0 % [a] | 0,6 % [a] |
| Short-term zero drift | ≤ 2,0 % [a] | 0,01 % [a] |
| Short-term span drift | ≤ 2,0 % [a] | 0,5 % [a] |
| Influence of ambient temperature change from 5 °C to 25 °C and from 40 °C to 20 °C at zero point | ≤ 5,0 % [a] | 0,5 % [a] |
| Influence of ambient temperature change from 5 °C to 25 °C and from 40 °C to 20 °C at span point | ≤ 5,0 % [a] | 1,0 % [a] |
| Influence of sample gas pressure at span point, for a pressure change $\Delta p$ of 3 kPa | ≤ 2,0 % [a] | 0,4 % of the measured value |
| Influence of sample volume flow, for flow change of 10 l/h | ≤ 2,0 % [a] | 0,2 % [a] |
| Influence of voltage, for a voltage change of 10 V at span point | ≤ 2,0 % [a] | 0,12 % [a] |
| Cross-sensitivity | Total : ≤ 4,0 % [a] | |
| $CO_2$ (15 %) | | –0,8 mg/m³ |
| $N_2O$ (20 mg/m³) | | 1,0 mg/m³ |
| $CH_4$ (50 mg/m³) | | 2,0 mg/m³ |
| Adjustment with calibration gases | | 2,0 % of the measured value |

[a] expressed in percent of the range

### D.3.3 Determination of the uncertainty contributions

The relevant uncertainty contributions are determined as follows:

a) Volume concentration indicated by the analyser

The uncertainty $u_{read}$ related to the reading of the concentration is due to the resolution of the analyser and of the data acquisition. It can be considered as negligible.

b) Repeatability

The standard uncertainty $u_r$ due to repeatability is equal to the repeatability standard deviation $s_r$ calculated from the results of the repetitions of the measurements.

Several tests can be carried out at different concentrations but only one of the values is included in the calculation of the uncertainty budget e.g.

— the repeatability standard deviation corresponding to the closest concentration measured in stack;

— the highest (relative) repeatability standard deviation whatever is the concentration measured in stack.

c) Lack of fit

If $C_{lof,max}$ is the maximum deviation between measured values and the corresponding values given by the linear regression achieved during the laboratory test, then it can be assumed that the lack of fit has an equal probability to take any value in the interval $[-C_{lof,max}\,;\,+C_{lof,max}]$. The standard uncertainty $u_{lof}$ is calculated by application of a rectangular probability distribution according to Formula (D.11):

$$u_{lof} = \frac{C_{lof,max}}{\sqrt{3}} \tag{D.11}$$

d) Short-term zero drift

It can be assumed that the zero drift $C_{d,z}$ has an equal probability to take any value in the interval $[-C_{d,z}\,;\,+C_{d,z}]$. The standard uncertainty $u_{d,z}$ is calculated by application of a rectangular probability distribution according to Formula (D.12):

$$u_{d,z} = \frac{C_{d,z}}{\sqrt{3}} \tag{D.12}$$

e) Short-term span drift

It can be assumed that the span drift $C_{d,s}$ has an equal probability to take any value in the interval $[-C_{d,s}\,;\,+C_{d,s}]$. The standard uncertainty $u_{d,s}$ is calculated by application of a rectangular probability distribution according to Formula (D.13):

$$u_{d,s} = \frac{C_{d,s}}{\sqrt{3}} \tag{D.13}$$

f) Cross-sensitivity (interference)

Particularly with chemical components, deviations created by different interferents occur at the same time in the same proportion, i.e. the standard uncertainties of those substances are correlated. To avoid underestimation of additive effects and overestimation of effects by compensation, EN ISO 14956 recommends to determine the sum of all standard uncertainties of interferents with a positive impact on the measured value and the sum of all standard uncertainties of interferents with a negative impact on the measured value and to retain the highest sum as the representative value for all interferents.

Cross-sensitivity is tested in the laboratory test for one concentration of an interferent and is supposed to be proportional to the value of the interferent. The correction $C_{i,j}$ of the cross-sensitivity of an interferent $j$ is also proportional to its variation $X_{i,j}$:

$$C_{i,j} = b_{i,j}\, X_{i,j} \tag{D.14}$$

where $b_{i,j}$ is the (constant) sensitivity coefficient of interferent $j$ determined in the laboratory test.

In general, the concentration of the interferent in the calibration gas used for adjustment of the analyser is equal to zero.

If the maximum deviation $C_{ip,j}$ of the measured value caused by interferent $j$ or the maximum value $X_{ip,j}$ of interferent $j$ with a positive impact on the measured value are known only, then it can be assumed that a deviation caused by this interferent has an equal probability to take any value in the interval between zero and the maximum value. In this case the corresponding standard uncertainty $u_{ip,j}$ is given by Formula (D.15):

$$u_{ip,j} = \frac{C_{ip,j}}{\sqrt{3}} = \left|b_{ip,j}\right| \frac{X_{ip,j}}{\sqrt{3}} \tag{D.15}$$

If the value $X_{ip,j,adj}$ during the adjustment of the analyser and the minimum and maximum value, $X_{ip,j,min}$ and $X_{ip,j,max}$, during the measurement period are known, then the standard uncertainty of interferent $j$ with a positive impact on the measured value can be calculated on the basis of Formulae (D.4) and (D.10)by use of Formula (D.16):

$$u_{ip,j} = \left|b_{ip,j}\right| \sqrt{\frac{\left(X_{ip,j,max} - X_{ip,j,adj}\right)^2 + \left(X_{ip,j,min} - X_{ip,j,adj}\right)\left(X_{ip,j,max} - X_{ip,j,adj}\right) + \left(X_{ip,j,min} - X_{ip,j,adj}\right)^2}{3}} \tag{D.16}$$

If the value $X_{ip,j,adj}$ during the adjustment of the analyser is zero, then the standard uncertainty of interferent $j$ with a positive impact on the measured value is given by Formula (D.17):

$$u_{ip,j} = \left|b_{ip,j}\right| \sqrt{\frac{\left(X_{ip,j,max}\right)^2 + \left(X_{ip,j,min}\right)\left(X_{ip,j,max}\right) + \left(X_{ip,j,min}\right)^2}{3}} \tag{D.17}$$

The sum of all standard uncertainties of interferents with a positive impact on the measured value is calculated by Formula (D.18):

$$u_{ip} = \sum_{j=1}^{p} u_{ip,j} \tag{D.18}$$

The standard uncertainties $u_{in,j}$ and the sum $u_{in}$ of all standard uncertainties of interferents with a negative impact on the measured value are calculated in the same manner as the uncertainties of interferents with a positive impact:

$$u_{in} = \sum_{j=1}^{n} u_{in,j} \quad \text{(D.19)}$$

The standard uncertainty $u_i$ due to cross-sensitivity caused by correlated interferents is the maximum value of $u_{ip}$ and $u_{in}$:

$$u_i = \max\left(u_{ip}; u_{in}\right) \quad \text{(D.20)}$$

Uncorrelated interferents are treated individually.

g) Influence quantities

Influence quantities such as ambient temperature, atmospheric pressure, sample gas flow and supply voltage are tested in the laboratory test for one value of the quantity and the effects of the influence quantities are supposed to be proportional to the value of the quantity. The correction $C_i$ of the effect of an influence quantity $i$ is also proportional to its variation $X_i$ (see Formula (D.21):

$$C_i = b_i X_i \quad \text{(D.21)}$$

where $b_i$ is the (constant) sensitivity coefficient of influence quantity $i$ determined in the laboratory test.

The calculation of the standard uncertainty associated with the correction of deviations caused by variations of influence quantities depends on the value $X_{i,adj}$ of the influence quantity during the adjustment of the analyser and the minimum and maximum value, $X_{i,min}$ and $X_{i,max}$, of the influence quantity during the measurement period. The uncertainty can be calculated by use of Formulae (D.4) to (D.10) either by use of the sensitivity coefficient and the deviations of the values of the influence quantity or directly from the deviations of the measured values.

h) Adjustment

The standard uncertainty $u_{adj}$ is calculated from the uncertainty of the calibration gas. In general, the uncertainty given by manufacturer is an expanded uncertainty $U_{cal}$. For a level of confidence of 95 % the standard uncertainty $u_{adj}$ is approximately given by Formula (D.22):

$$u_{adj} = \frac{U_{cal}}{2{,}0} \quad \text{(D.22)}$$

If the expanded uncertainty is expressed as a relative uncertainty $U_{cal,rel}$ in form of a percentage value, the standard uncertainty of the correction at the concentration $C_{CO}$ is given by Formula (D.23):

$$u_{adj} = \frac{U_{cal,rel}\, C_{CO}}{2{,}0} \quad \text{(D.23)}$$

## D.3.4 Result of uncertainty calculation

### D.3.4.1 Standard uncertainties

Table D.4 presents the results of the uncertainty calculation based on the data presented in Table D.2 and Table D.3.

**Table D.4 — Results of uncertainties calculation**

| Parameter | Standard uncertainty | Value of standard uncertainty at limit value (in mg/m³) |
|---|---|---|
| Repeatability in the laboratory at span | $u_r$ | $\lvert 0{,}45\% \rvert \times 100 = 0{,}45$ |
| Lack of fit | $u_{lof}$ | $\frac{\lvert 0{,}6\,\% \rvert \times 100}{\sqrt{3}} = 0{,}35$ |
| Short-term zero drift | $u_{d,z}$ | $\frac{\lvert 0{,}01\% \rvert \times 100}{\sqrt{3}} = 0{,}006$ |
| Short-term span drift | $u_{d,s}$ | $\frac{\lvert 0{,}5\,\% \rvert \times 100}{\sqrt{3}} = 0{,}29$ |
| Influence of ambient temperature | $u_{t,s}$ | $\left\lvert \frac{1\%}{20} \right\rvert \times 100 \times \sqrt{\frac{(308\text{-}285)^2 + (308\text{-}285)(283\text{-}285) + (283\text{-}285)^2}{3}} = 0{,}64$ |
| Influence of sample gas pressure | $u_p$ | $\left\lvert \frac{0{,}4\,\%}{3} \right\rvert \times 50 \times \frac{100\text{-}99}{\sqrt{3}} = 0{,}04$ |
| Influence of sample gas flow | $u_f$ | $\left\lvert \frac{0{,}2\,\%}{10} \right\rvert \times 100 \times \frac{5 \times 2}{\sqrt{3}} = 0{,}12$ |
| Influence of supply voltage | $u_v$ | $\left\lvert \frac{0{,}12\ \%}{10} \right\rvert \times 100 \times \frac{(230/100 \times 5)}{\sqrt{3}} = 0{,}08$ |
| Interferent: $CO_2$ | $u_{i,CO2}$ | $\frac{\lvert -0{,}8 \rvert}{15} \times \sqrt{\frac{12^2 + 12 \times 8 + 8^2}{3}} = 0{,}54$ |
| Interferent: $CH_4$ | $u_{i,CH4}$ | $\frac{2}{50} \times \sqrt{\frac{10^2}{3}} = 0{,}23$ |
| Uncertainty of calibration gas | $u_{adj}$ | $\frac{\lvert 2\% \rvert \times 50}{2} = 0{,}5$ |

### D.3.4.2 Combined uncertainty

The sum of the standard uncertainties of interferents with a negative impact on the measured value is greater than the sum of all standard uncertainties of interferents with a positive impact on the measured value:

$$u_{\mathrm{i}} = \max\left(u_{\mathrm{ip}}\,;u_{\mathrm{in}}\right) = 0,54\,\frac{\mathrm{mg}}{\mathrm{m}^3}$$

According to Formula (D.2) the combined uncertainty of the CO concentration is given by:

$$u_{\mathrm{c}}\left(C_{\mathrm{CO}}\right) = \sqrt{\sum_{i=1}^{N} u_i^2} = \sqrt{u_{\mathrm{r}}^2 + u_{\mathrm{lof}}^2 + u_{\mathrm{d,z}}^2 + u_{\mathrm{d,s}}^2 + u_{\mathrm{t,s}}^2 + u_{\mathrm{f}}^2 + u_{\mathrm{p}}^2 + u_{\mathrm{v}}^2 + u_{\mathrm{i}}^2 + u_{\mathrm{adj}}^2}$$

$$= \sqrt{0,35^2 + 0,45^2 + 0,006^2 + 0,29^2 + 0,64^2 + 0,12^2 + 0,04^2 + 0,08^2 + 0,54^2 + 0,5^2}\ \mathrm{mg/m^3}$$

$$= \sqrt{1,3827}\ \mathrm{mg/m^3} = 1,18\,\mathrm{mg/m^3}$$

### D.3.4.3 Expanded uncertainty

The absolute and relative expanded uncertainty for $k = 2$ are given by:

$$U\left(C_{\mathrm{CO}}\right) = 2,36\,\mathrm{mg/m^3}$$

$$U_{\mathrm{rel}}\left(C_{\mathrm{CO}}\right) = 4,7\,\%$$

### D.3.4.4 Evaluation of the compliance with the required measurement quality

The performance criterion on cross-sensitivity is met for the sum of interferents with a positive impact on the measured values as well as for the sum of interferents with a negative impact:

$$C_{\mathrm{ip}} = 0,23\,\% < 4\%$$

$$\left|C_{\mathrm{in}}\right| = 0,54\,\% < 4\,\%$$

All values of the performance characteristics obtained in the laboratory and field tests comply with the performance criteria. Therefore, the measurement method fulfils the requirements.

# Annex E
(informative)

# Example of correction of data from drift effect

Table E.1 shows a spreadsheet example based on the correction procedure given in 9.4.3.

**Table E.1 —Spreadsheet example of correction of data from drift effect**

| | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|
| | Input data | | | | | | | |
| 3 | | concentration unit | | mg/m³ | | | | |
| 4 | | | calibration gas concentration | concentration given by the analyser | | | | |
| 5 | | | | adjustment at $t_0$ (before measurement) | check at $t_f$ (end of measurement) | | | |
| 6 | | span point | 900 | 898 | 900 | | | :to be filled |
| 7 | | zero point | 0 | 3 | 1 | | | : list choice |
| 8 | | time | | 10:00:00 | 15:00:00 | | | |
| 9 | | duration (h) | | 5:00:00 (F8-E8) | | | | |
| 10 | | duration (min) | | 300 (HOUR(E9)*60+ MINUTE(E9) | | | | |
| 11 | | | | | | | | |
| 12 | | | | | | | | |
| 13 | Calculation of zero and span drift | | | | | | | |
| 14 | | | | adjustment | check | deviation | | |
| 15 | | A: span point | | 0,99444 (E6-E7)/(D6-D7) | 0,99889 (F6-F7)/(D6-D7) | 0,00444 (F15-E15) | | |
| 16 | | $B_{corr}$: zero point corrected of span | | 3,017 (E7/E15) | 1,001 (F7/F15) | –2,016 (F16-E16) | | |
| 17 | | | | | | | | |
| 18 | | drift at zero point | –0,22 % ((G16)/D6) | | | | | |
| 19 | | drift at span point | 0,44 % ((D6*G15)/D6 ) | | | | | |
| 20 | | | | | | | | |
| 21 | *If the drift at zero or at the span point is greater than 2 % of the selected span point* | | | | | | | |
| 22 | | | | | | | | |
| 23 | Equation to calculate the concentration $C_{corr}$ corrected according to time $t$ for the concentration $C$ given by the analyser | | | | | | | |
| 24 | | | | | | | | |
| 25 | | | | value at $t_0$ | drift per min | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 26 | | A (span point) | | 0,994444<br>(E15) | 0,00001481<br>(G15/E10) | | | |
| 27 | | B (zero point not corrected of span) | | 3,000000<br>(E7) | –0,006667<br>((F7-E7)/E10) | | | |
| 28 | | | | | | | | |
| 29 | $C_{corr} = [C - (B(t_0) + \text{Drift}(B) \times t)] / [A(t_0) + \text{Drift}(A) \times t]$ | | | | | | | |
| 30 | $C_{corr} = [C - (\text{E27} + \text{F27} \times t)] / [\text{E26} + \text{F26} \times t]$ | | | | | | | |
| 31 | : | | | | | | | |
| 32 | ➔ $C_{corr} = (C-(3{,}000000-0{,}006667*t))/(0{,}994444+0{,}00001481*t)$ | | | | | | | |
| 33 | *To apply the formula in a calculation file:* | | | | | | | |
| 34 | *– copy cell C32 above;*<br>*– in the calculation file click on "edition – special paste – values" in the first cell dedicated to a corrected value;*<br>*– insert before formula "=" then the concentration value measured and replace "t" by its value in min.* | | | | | | | |
| 35 | | | | | | | | |

# Annex F
(informative)

# Significant technical changes

**Table F.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, plan and report. Normative reference to EN 15267–4:2017 related to performance criteria and test procedures for portable automated measuring systems for monitoring emissions from stationary sources has been added. |
| 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. |
| 6 | Two new sampling and conditioning configurations have been added:<br>— configuration 3: dilution with dry, clean, ambient air or nitrogen of the gas to be characterized;<br>— configuration 4: maintaining the temperature of the measurement line up to the heated analyser. |
| 6.3 | This clause corresponds to the previous Clause 6. |
| 7 | The performance characteristics shall be determined in a general performance test according to the test procedures described in EN 15267–4:2017. |
| 7, Table 1 | Sensitivity to atmospheric pressure has been withdrawn. |
| 9.2 | For determination of homogeneity reference to the EN 15259 has been added |
| 9.4.2.1 | The test gases shall have concentrations traceable to SI units |
| 9.4.3 | Equation to calculate the concentration corrected when drift occurs has been added |
| 11 | Expression of results have been modify to be in line with EN 15259 |
| 12 | 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 C | An annex giving the procedure to calculate the uncertainty associated with a concentration expressed on dry gas and at a oxygen reference concentration, has been added |
| Annex D | The presentation of the calculation of the uncertainty budget has been improved |
| Annex E | Typing errors of the table to determine the drift have been corrected |

# Bibliography

[1] Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)

[2] EN 14790:2017, *Stationary source emissions – Determination of the water vapour in ducts – Standard reference method*

[3] 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*

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

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

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