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Gas turbines — Exhaust gas emission — Part 1: Measurement and evaluation

*Turbines à gaz — Émissions de gaz d'échappement —
Partie 1: Mesurage et évaluation*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11042-1 was prepared by Technical Committee ISO/TC 192, *Gas turbines*.

ISO 11042 consists of the following parts, under the general title *Gas turbines — Exhaust gas emission*:

- *Part 1: Measurement and evaluation*
- *Part 2: Automated emission monitoring*

Annexes A to D are for information only.

Gas turbines — Exhaust gas emission —

Part 1: Measurement and evaluation

1 Scope

This part of ISO 11042 establishes the methods used for the measurement and evaluation of the emission of the exhaust gases from gas turbines and defines appropriate emission terms. It presents requirements for the test environment and instrumentation as well as the quality of measurement and correction of data. This allows uniform judgement of the exhaust emissions. The relationship between the various forms of expressing the exhaust emissions is also given.

The constituents to be measured in accordance with this part of ISO 11042 standard should be determined by mutual agreement between the parties involved.

This part of ISO 11042 is applicable for all gas turbines producing mechanical shaft power and/or which are used as drivers for electrical generation excluding application in aircraft. For installations which include an exhaust gas heat recuperation system, the definitions of this part of ISO 11042 can be used as a basis.

This part of ISO 11042 is applicable for gas turbines which utilize the open cycle process. It is also applicable as a basis for gas turbines which utilize the semi-closed cycle and gas turbines equipped with free piston compressors or with special heat sources.

This part of ISO 11042 can be used as an acceptance test for gas turbine exhaust gas emissions.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 11042. At the time of publication, the editions indicated were valid. All standards are subject

to revision, and parties to agreements based on this part of ISO 11042 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2314:1989, *Gas turbines — Acceptance tests*.

ISO 2533:1975, *Standard atmosphere*.

ISO 5063:1978, *Atomizing oil burners of the monobloc type — Testing*.

ISO 6141:1984, *Gas analysis — Calibration gas mixtures — Certificate of mixture preparation*.

3 Definitions

For the purposes of this part of ISO 11042, the following definitions apply.

3.1 emissions: Constituents which enter the environment with the exhaust gas.

In this part of ISO 11042, emissions comprise the following:

nitrogen oxides	NO _x ; sum of NO and NO ₂ , expressed as NO ₂
nitrogen dioxide	NO ₂
carbon monoxide	CO
carbon dioxide	CO ₂
sulfur oxides	SO _x ; sum of SO ₂ and SO ₃ , expressed as SO ₂

unburned or partially burned hydrocarbon products	UHCs; sum of all individual products, expressed as CH ₄
volatile organic compounds	VOCs; UHCs excluding CH ₄ and C ₂ H ₆ but expressed as CH ₄
ammonia	NH ₃
smoke	as measured by the Bacharach method according to ISO 5063
solid particles	all solid particles produced by the combustion process

3.2 accuracy: The closeness with which a measurement approaches the true value established independently.

3.3 calibration gas: High-accuracy reference gas mixture to be used for setting, adjustment and periodic checks of instruments.

3.4 concentration: Volume fraction ϕ_i of the component of interest in the gas mixture, expressed as volume percentage [% (V/V)] or as parts per million (ppm).

3.5 interference: Instrument response due to the presence of a gas or vapour other than the gas or vapour that is to be measured.

3.6 linearity: Ability of an instrument to respond proportionally to an input signal.

3.7 noise: Random variation in instrument output not associated with those characteristics of the sample to which the instrument is responding; distinguishable from its drift characteristics.

3.8 parts per million (ppm): Volumetric concentration of the component i in 10^6 volume parts of gas mixture.

3.9 parts per million carbon (ppmC₁): The mole fraction of hydrocarbon multiplied by 10^6 measured on a "CH₄" equivalence basis.

1 ppm of methane is indicated as 1 ppmC₁¹⁾.

3.10 repeatability: The closeness with which a measurement upon a given invariant sample can be produced on a short-term basis with no adjustment of the instruments.

3.11 resolution: Smallest detectable change in a measurement.

3.12 response: Change in instrument output signal that occurs with change in sample concentration; output signal corresponding to a given sample concentration.

3.13 stability/calibration drift: Time-related deviations of the output signal of the instrument measuring a calibration gas for a given set point.

3.14 relative hydrocarbon response: The different response of the test equipment to the sample hydrocarbon concentrations expressed as equivalent ppmC₁, dependent on the class or admixture of classes of hydrocarbon components.

3.15 zero air: Mixture of oxygen and nitrogen having the same proportion of oxygen as atmospheric air, free from other components.

3.16 zero drift: Time-related deviation of instrument output from zero set point when it is operating on a gas free of the component to be measured.

3.17 zero gas: Gas to be used in establishing the zero, or no-response, adjustment of an instrument.

4 Symbols

See tables 1 and 2.

1) To convert ppm concentration of any hydrocarbon to an equivalent ppmC₁ value, multiply ppm concentration by the number of carbon atoms per molecule of the gas; e.g. 1 ppm propane translates as 3 ppmC₁ hydrocarbon; 1 ppm hexane as 6 ppmC₁ hydrocarbon.

Table 1 — General symbols

Symbol	Term	Unit
e_n	Net specific energy, lower calorific value	kJ/kg
E	Exhaust gas emission value	—
EM_i	Exhaust gas emission value as constituent concentration of component i at 0 °C and 101,3 kPa	mg/m ³
$EM_{i,15,dry}$	Same as EM_i , related to an oxygen volumetric concentration of 15 % in dry exhaust gas	mg/m ³
$EM_{i,f}$	Same as EM_i , related to consumed fuel energy	g/GJ
$EM_{i,P}$	Same as EM_i , related to power supplied	g/kWh
EP	Exhaust gas emission value for solid particles	mg/m ³
ES	Exhaust gas emission value for smoke	—
EV	Exhaust gas emission value as a volumetric concentration	cm ³ /m ³
EV_i	Exhaust gas emission value as a volumetric concentration of component i	cm ³ /m ³
$EV_{i,15,dry}$	Same as EV_i , related to an oxygen volume content of 15 % in dry exhaust gas	cm ³ /m ³
m	Mass	kg
M	Molar mass	kg/kmol
M_{tot}	Total molar mass	kg/kmol
n	Quantity of component	kmol
n_i	Quantity of component i	kmol
n_{tot}	Total quantity of components	kmol
P	Shaft power output of gas turbine	kW
q_m	Mass flow	kg/s
q_v	Volume flow	m ³ /s
V_i	Volume of component i	m ³
V_{mn}	Molar specific volume	m ³ /kmol
$V_{n,dry}$	Volume of dry exhaust gas at normal conditions ¹⁾	m ³
$V_{n,15,dry}$	Volume of dry exhaust gas at normal conditions related to an oxygen content of 15 %	m ³
$V_{n,wet}$	Volume of wet exhaust gas at normal conditions ¹⁾	m ³
V_{tot}	Total volume of components i	m ³
x_i	Partial quantity, equal to n_i/n_{tot}	1
z	Limiting number	1
Z	Real gas factor (compressibility)	1
ρ	Density	kg/m ³
ρ_{pa}	Density of particle material	kg/m ³
$\varphi_{CO_2,dry}$	Volumetric concentration as percentage of CO ₂ in dry exhaust gas	%
$\varphi_{CO_2,stoich,dry}$	Volumetric concentration as percentage of CO ₂ in dry exhaust gas with stoichiometric combustion of the fuel used	%
φ_{H_2O}	Volumetric concentration as percentage of water vapour in exhaust gas	%

Table 1 — (concluded)

Symbol	Term	Unit
$\varphi_{i,dry}$	Volumetric concentration in dry exhaust gas	cm ³ /m ³
$\varphi_{i,wet}$	Volumetric concentration in wet exhaust gas, equal to V_i/V_{tot}	cm ³ /m ³
$\varphi_{O_2,dry}$	Volumetric concentration as percentage of O ₂ in dry exhaust gas	%
NOTES		
1 To identify a particular station along the gas path the subscript g is used, e.g. g7. Subscript 7 identifies the turbine outlet (see ISO 2314).		
2 In this part of ISO 11042, 15 % O ₂ is used as a typical value; alternative oxygen contents may be used by agreement.		
3 The reference temperature of 0 °C is chosen because of available chemical data and evaluation methods.		
1) Normal pressure: $p_n = 101,3$ kPa Normal temperature: $t_n = 0$ °C		

Table 2 — Chemical symbols and abbreviations

Symbol	Compound
CO	Carbon monoxide
CO ₂	Carbon dioxide
H ₂ O	Water
N ₂	Nitrogen
NH ₃	Ammonia
NO	Nitrogen monoxide
NO ₂	Nitrogen dioxide
NO _x	Sum of nitrogen oxides
O ₂	Oxygen
SO ₂	Sulfur dioxide
SO ₃	Sulfur trioxide
SO _x	Sum of sulfur oxides
UHC	Unburned or partially burned hydro-carbon products
VOC	Volatile organic compounds

5 Conditions

5.1 Gas turbine and fuel

In connection with gas turbine emissions, the following shall be indicated for the respective measurement conditions:

- manufacturer of the gas turbine;
- type of gas turbine;
- power output and exhaust gas mass flow and/or fuel flow at the conditions at which the emission measurements are taken;
- ambient conditions, i.e. pressure, temperature and humidity of the surrounding air;

- fuel details;
- equipment in operation which affects the emissions and which is part of the complete system, e.g. catalytic converters, water or steam injection, evaporative coolers, condensors, etc. Relevant details of all flow rates shall be noted.

NOTES

- 1 The definition of the power output, the exhaust gas mass flow rate and/or the fuel flow rate, the measurements and calculations should be defined by agreement between the parties involved (see ISO 2314).
- 2 Exhaust gas emissions are affected by the fuel characteristics (e.g. fuel-bound nitrogen). Therefore, relevant details of the fuel should be noted, including appropriate chemical analysis, temperature, physical properties and flow rates.

5.2 Measured values

The following values shall be measured:

- volumetric concentration of gaseous constituents related to wet exhaust gas ($\varphi_{i,wet}$) or to dry exhaust gas ($\varphi_{i,dry}$);
- exhaust gas emission value for smoke — Bacharach number (*ES*) (smoke number according to ISO 5063);
- gravimetric concentration of solid particles within the wet exhaust gas (*EP*), if specifically agreed upon.

5.3 Standard conditions

Standard conditions shall be:

- pressure: 101,3 kPa

- temperature: 15 °C
- relative humidity: 60 %

(see ISO 2314:1989, 3.2.1).

NOTE 3 A reference temperature of 0 °C is chosen for chemical calculations because of available chemical data and evaluation methods.

6 Measurements

6.1 Determination of constituents in exhaust gas

The constituents are measured or calculated as indicated below.

Total NO _x as NO ₂ :	see 7.2.
CO and CO ₂ :	see 7.3.
SO ₂ :	see 7.4.
SO ₃ :	no recommended method is specified.
Total SO _x as SO ₂ :	shall be calculated using the sulfur content of the fuel.
H ₂ O:	to be measured or calculated (using combustion calculation taking into account air humidity).
UHCs:	see 7.5.
VOCs:	see 7.5.
Ammonia:	see 7.6.
Oxygen:	see 7.7; alternatively a calculation may be adopted upon agreement of the parties.
Smoke:	see 7.8.
Solid particles:	see 7.9; any solid particles in the inlet air which contribute significantly to the particles in the exhaust gas must be subtracted from the reported values.

6.2 Guidelines for the arrangement of the measurement system

6.2.1 General

Basically, three parts shall be considered:

- a) the sampling probe;

- b) the transfer and conditioning system;
- c) the analytical instruments and the data acquisition system.

The measurements shall be performed by continuous flow sampling and be representative of the gas flow.

In the case of a gas turbine installation, the sampling point shall be determined beforehand:

- by modelling, i.e. simulation of the gas veins (dependent on the obstacles and on the gas flow rate — turbulent laminar flow);
- or by determination of the mean velocity within the sleeve which becomes the point representative of the gas sample;
- or by mutual agreement based on an existing standard or on experience.

A single sampling plane, requiring only one set-up, is usually adequate for measuring emissions from the installation with or without supplementary systems operating.

In cases where the gas turbine plant is not provided with any system other than a silencer, a ducting system and a chimney between the engine exhaust and discharge to atmosphere, the sampling site should be selected as close as practical to the exhaust of the engine. In cases where any of the following systems is provided such as a heat recovery system, subsequent firing systems, dilution systems, de-NO_x systems, etc., the sampling site shall be determined by mutual agreement between the parties involved.

The traversing plane shall not be located within the area of exhaust gas discharge to atmosphere in order to allow recirculation of ambient air.

6.2.2 Sampling probe

The sampling probe should provide a representative sample of the exhaust gas. The use of a multihole averaging probe with holes covering equal areas of the cross section of the exhaust duct is recommended for obtaining such a representative sample. A demonstration should be made to ensure that the probe actually measures a sample representative of the main gas flow. This should be done regardless of the type of sampling probe used.

The sampling probe and vacuum pump to be used for the test shall be capable of continuously supplying a sufficient volume of sample gas to the analysers.

If traverse measurements are required to demonstrate representativeness then the probe shall be adequate to allow full assessment of the exhaust channel.

The probe shall be long enough to allow full traverse of the exhaust channel. Procedures to establish probe positions shall be agreed upon between parties involved.

6.2.3 Transfer and conditioning system

The sample transfer lines for samples for measurement of smoke, solid particles and gaseous constituents shall be separate.

A principal system containing the important components is shown in figure 1. When special analytical equipment is used, this arrangement may need modification.

Depending on the operating principle of the analyser the sample shall be conditioned accordingly. In order to avoid condensation of the sample constituents, the entire sample line shall be heated up to temperatures at least 10 K above the condensation temperature of the exhaust gas.

When the sample is processed through a water separator, the sample line shall be heated to at least as far as this device.

For natural gas or light hydrocarbon fuels with a sulfur content of less than 1 % (*m/m*) a minimum temperature of 150 °C (423 K) shall be applied. For this reason, it is recommended that all the equipment, including the pump(s), be heated. The temperature level shall always be kept constant within ± 5 K. For all items in the sampling line the following points apply:

All material in contact with the sample shall be made of non-reactive material (stainless steel or equivalent).

It is recommended as being consistent with good practice to purge PTFE (polytetrafluoroethylene) by means of a continuous flow of pure nitrogen in order to remove residual solvents from the manufacturing process. During this procedure the line shall be heated to the temperature specified for the analysis of the particular component.

All connections and items shall be free of leaks.

All components shall be designed to operate up to required temperatures.

Where long lines are unavoidable, it is recommended to insert a second dump pump which provides sample gas in larger quantities.

The sample transfer time between probe and instruments should be as short as possible, preferably less than 30 s.

6.2.4 Analytical instruments

The instruments used shall be complete with all necessary flow rate control components, such as

regulators, valves, flowmeters etc. Material in contact with the sample shall be corrosion resistant, i.e. stainless steel or carbon-loaded PTFE. The overall temperature of the sample shall be maintained at a value consistent with local pressures and which avoids condensation of water and hydrocarbons.

All the equipment used shall have had the necessary performance checks in accordance with clause 7 of this part of ISO 11042.

6.3 Performing the test, test report, evaluation

The test shall be performed after the gas turbine has reached steady operating conditions as specified in ISO 2314. Variation of ambient humidity expressed as water mass content in dry air should not exceed $\pm 0,5$ g/kg during testing. If ambient conditions vary and exceed the above limitations, corrections may be applied if agreed upon between the parties involved.

The analysers shall be calibrated before and after the test.

The whole system shall be checked prior to testing and at regular intervals. Special checks on the tightness of the assembly shall be performed. All the equipment to be used shall have had the necessary performance checks carried out within the time specified in the manufacturer's specified measurement test procedures.

Multiple measurements (minimum of 3) shall be taken only when the analytical equipment is providing stable readings and at the same time the readings of gas turbine performance shall be taken.

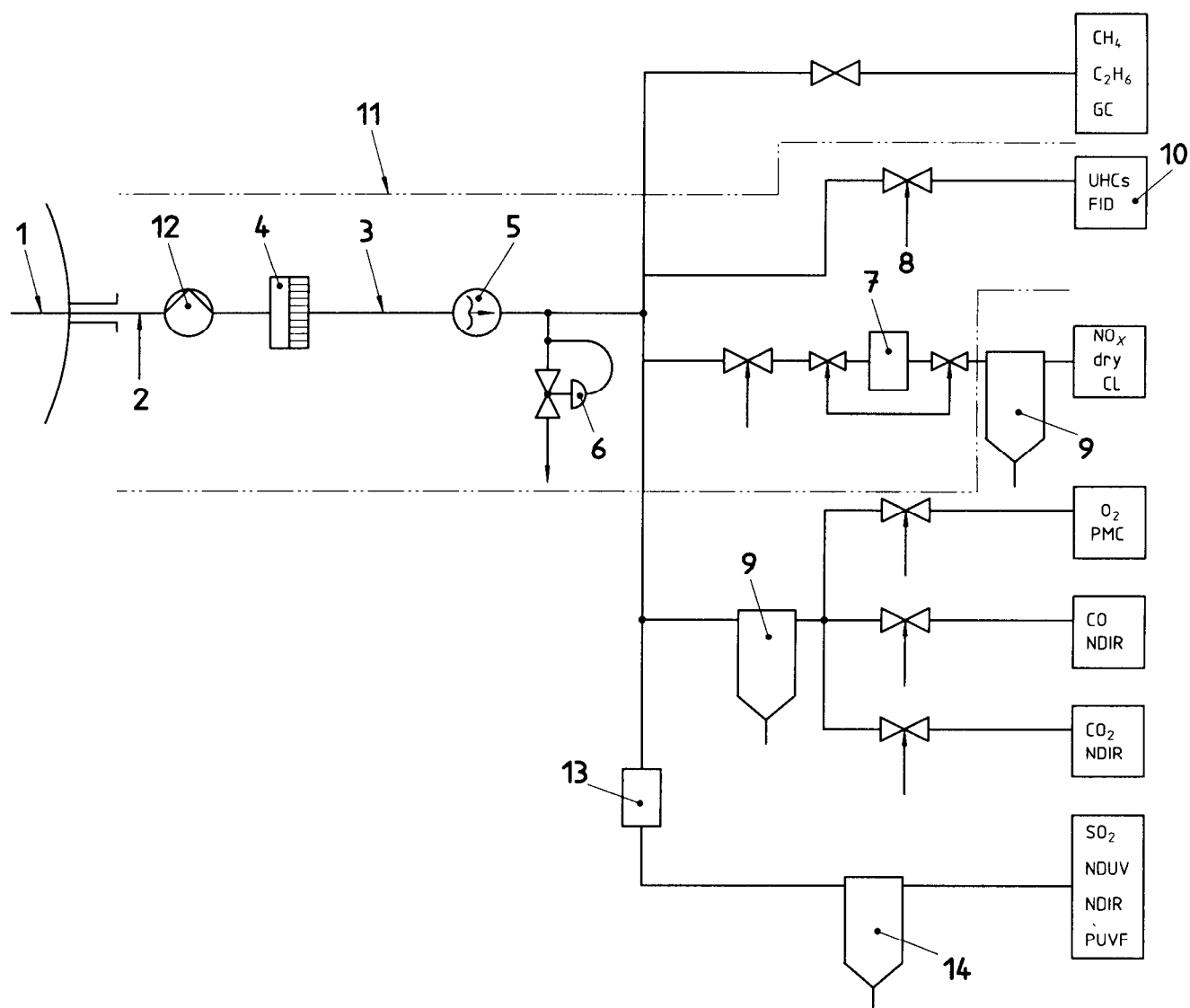
Instruments subject to calibration drift problems due to temperature variations shall be housed in a stable thermal environment.

The arithmetic average value of measurements of three individual test runs constitute a complete test. The minimum sampling time for each measurement shall be at least one minute plus the average system response time. The measurements shall be the average steady state concentration for the sampling time (see 7.9).

Test time for particle measurement shall be extended as required to provide the accuracy agreed upon.

A test report, as shown in table A.1, shall be prepared.

The evaluation may be performed in accordance with the sample calculation as in table A.2. For explanations to table A.2, see clause 9.



Key

- 1 Probe
- 2 Gas inlet for system check
- 3 Sample line
- 4 Filter
- 5 Sample pump
- 6 Back-pressure regulator
- 7 $\text{NO}_2 \rightarrow \text{NO}$ converter
- 8 Gas inlet for instrument calibration
- 9 Chiller/separator (operating at $\leq 3^\circ\text{C}$)
- 10 Analyser
- 11 Heated section
- 12 Dump pump to vent (if required)
- 13 $\text{SO}_x \rightarrow \text{SO}_2$ converter
- 14 Water trap or permeation tube dryer

NOTES

- NO_x can be measured either wet or dry.
- See table 3 for an explanation of the abbreviations.

Figure 1 — Measurement system design for gaseous constituents

7 Instrumentation

7.1 Types of measuring device

Table 3 shows available types of analysers. Detailed specifications are provided for the first named analysers only. The alternative analyser types may be used only by agreement between the interested parties.

Table 3 — Analyser types for measurement of constituents

Constituent	Analyser type
NO _x	Chemiluminescence (CL) or non-dispersive infrared (NDIR) or non-dispersive ultraviolet (NDUV)
CO	Non-dispersive infrared (NDIR)
CO ₂	Non-dispersive infrared (NDIR)
SO ₂	Non-dispersive infrared (NDIR) or non-dispersive ultraviolet (NDUV) or pulsed UV fluorescence (PUVF)
UHCs	Flame ionization detector (FID)
VOCs	Gas chromatograph ¹⁾ (GC)
NH ₃	Chemiluminescence ²⁾ or spectrophotometric (indophenol) method
Smoke	Bacharach method according to ISO 5063 or opacity method
Solid particles	Gravity method or optical method
O ₂	Paramagnetic cell (PMC) or electrochemical cell or zirconia cell
1) Alternative method to be agreed upon. 2) After oxidizing ammonia.	

7.2 Specification for NO_x analysers

7.2.1 Measurement technique

The measurement of concentration of the oxides of nitrogen shall be the chemiluminescence technique in which radiation emitted by the reaction of NO and O₃ is measured. This method is not sensitive to NO₂ and therefore the sample shall be passed through a converter in which NO is made. Both the original NO and the total NO_x concentrations shall be recorded if measured. Thus a measure of the NO₂ can be obtained by subtraction. Only NO_x determination is mandatory.

7.2.2 Principal performance specifications for NO_x analysers

The principal performance specifications determined for the instruments operated in an environment as specified by the manufacturer shall be as given in table 4.

Table 4 — Principal performance specifications for NO_x analysers

No.	Term	Requirement
1	Total range	In appropriate ranges up to 1 000 ppm.
2	Resolution	Better than 0,5 % of full scale of range used or 1 ppm, whichever is greater.
3	Repeatability	Better than ± 1 % of full scale of range used or ± 1 ppm, whichever is greater.
4	Stability	Better than ± 2 % of full scale of range used or ± 1 ppm, whichever is greater, over a period of 2 h.
5	Zero drift	Less than ± 1 % of full scale of range used or ± 1 ppm, whichever is greater, over a period of 2 h.
6	Noise	0,5 Hz and greater; less than ± 1 % of full scale of range used or ± 1 ppm whichever is greater, over a period of 2 h.
7	Interference	For samples containing CO ₂ and water vapour, shall be limited as follows: — less than 0,2 % reading per % CO₂ concentration; — less than 0,5 % reading per % water vapour concentration. If the interference limitation(s) for CO ₂ and/or water vapour cannot be met, appropriate correction factors shall be determined, reported and applied. ¹⁾
8	Response time	Shall not exceed 10 s from entry of the sample into the analyser to attaining 90 % of the final reading.
9	Linearity	The linearity response of each range shall be checked at the 30 %, 60 % and 90 % points using either separate gas mixtures or a gas divider. The maximum deviation of these points from a least squares straight line fit shall be less than ± 2 % of the full scale value.