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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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Contents

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Annexes

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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.

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Gas turbines — Exhaust gas emission —

Part 1:
Measurement and evaluation

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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_2H_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 (ppmC$_1$): The mole fraction of hydrocarbon multiplied by 10^6 measured on a "CH_4" equivalence basis.

1 ppm of methane is indicated as 1 ppmC$_1$ 1).

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 ppmC$_1$, 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.

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1) To convert ppm concentration of any hydrocarbon to an equivalent ppmC$_1$ value, multiply ppm concentration by the number of carbon atoms per molecule of the gas; e.g. 1 ppm propane translates as 3 ppmC$_1$ hydrocarbon; 1 ppm hexane as 6 ppmC$_1$ 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
$EM_{i,15,\mathrm{dry}}$	Same as EM_i, related to an oxygen volumetric concentration of 15 % in dry exhaust gas	mg/m^3
$EM_{i,\mathrm{f}}$	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
$EV_{i,15,\mathrm{dry}}$	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
$V_\mathrm{n,\ dry}$	Volume of dry exhaust gas at normal conditions1)	m^3
$V_\mathrm{n,15,dry}$	Volume of dry exhaust gas at normal conditions related to an oxygen content of 15 %	m^3
$V_\mathrm{n,wet}$	Volume of wet exhaust gas at normal conditions1)	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
$\varphi_{\mathrm{CO_2,dry}}$	Volumetric concentration as percentage of CO_2 in dry exhaust gas	%
$\varphi_{\mathrm{CO_2,stoich,dry}}$	Volumetric concentration as percentage of CO_2 in dry exhaust gas with stoichiometric combustion of the fuel used	%
$\varphi_{\mathrm{H_2O}}$	Volumetric concentration as percentage of water vapour in exhaust gas	%

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Table 1 — *(concluded)*

Symbol	Term	Unit
$\varphi_{i,\text{dry}}$	Volumetric concentration in dry exhaust gas	cm^3/m^3
$\varphi_{i,\text{wet}}$	Volumetric concentration in wet exhaust gas, equal to V_i/V_{tot}	cm^3/m^3
$\varphi_{O_2,\text{dry}}$	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_2O	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 hydrocarbon products
VOC	Volatile organic compounds

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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 ($\varphi_{i,\text{wet}}$) or to dry exhaust gas ($\varphi_{i,\text{dry}}$);
- 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_2O:	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.

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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 ± 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.

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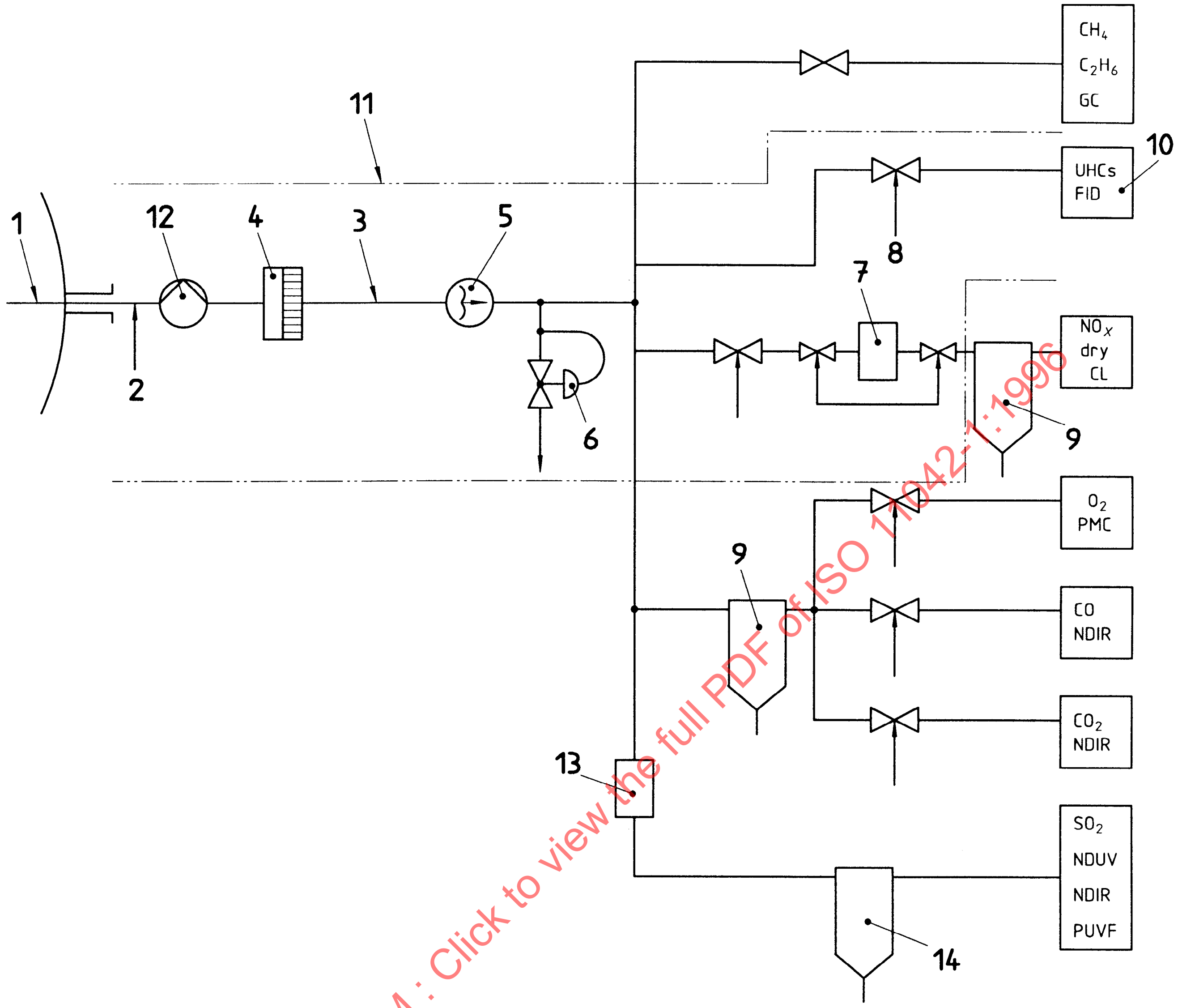

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Key

1 Probe
2 Gas inlet for system check
3 Sample line
4 Filter
5 Sample pump
6 Back-pressure regulator
7 $NO_2 \rightarrow NO$ converter
8 Gas inlet for instrument calibration
9 Chiller/separator (operating at $\leqslant 3$ °C)
10 Analyser
11 Heated section
12 Dump pump to vent (if required)
13 $SO_x \rightarrow SO_2$ 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 chromatograph1) (GC)
NH_3	Chemiluminescence2) 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 O_3 is measured. This method is not sensitive to NO_2 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 NO_2 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 % CO_2 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.

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No.	Term	Requirement
10	Converter	This shall be designed and operated in such a manner as to reduce NO_2 present in the sample to NO. The converter shall not affect the NO originally in the sample. The converter efficiency expressed as $\eta = 100\,[\varphi_{NO}\,(\text{after converter}) - \varphi_{NO}]/\varphi_{NO_2}$ shall not be less than 90 %. This efficiency value shall be used to correct the measured sample's NO_2 value, i.e. $\varphi_{NO}\,(\text{after converter}) - \varphi_{NO}$ to that which would have been obtained if the efficiency had been 100 %.

1) It is recommended as being consistent with good practice that such correction procedures should be adopted in all cases. Also other corrections may be required due to the particular equipment used.

7.3 Specification for CO and CO_2 analysers

7.3.1 Measurement technique

Carbon monoxide and carbon dioxide shall be measured using non-dispersive infrared (NDIR) analysers. These analysers utilize differential energy absorption in parallel reference and sample gas cells. The required ranges of sensitivity are obtained by use of stacked sample cells or changes in electronic circuitry, or both. Interference from gases with overlapping absorption bands may be minimized by gas absorption filters and/or optical filters, preferably the latter.

7.3.2 Principal performance specifications for CO and CO_2 analysers

The principal performance specifications determined for the instruments operated in an environment as specified by the manufacturer shall be as given in tables 5 and 6.

7.3.3 Special requirements for CO and CO_2 analysers

7.3.3.1 Operational aspects

The preferred mode of operation is for analysis of the sample on a dry basis, in which case the pressure of the sample at the analyser inlet shall be measured and kept constant to within 0,2 kPa throughout the calibration and the test procedure. In this mode of operation, the CO and CO_2 analysers may be used in serial arrangement with the appropriate SO_2 and/or O_2 analyser, whenever the latter constituents are measured.

Table 5 — Principal performance specifications for CO analysers

No.	Term	Requirement
1	Total range	In appropriate ranges up to 2 500 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 ± 2 ppm, whichever is greater.
4	Stability	Better than ± 2 % of full scale of range used or ± 2 ppm, whichever is greater, over a period of 2 h.
5	Zero drift	Less than ± 1 % of full scale of range used or ± 2 ppm, whichever is greater, over a period of 2 h.
6	Noise	0,5 Hz and greater; less than ± 1 % of full scale used or ± 1 ppm, whichever is greater.
7	Interference	To be limited with respect to indicated CO concentration as follows: 1) less than 500 ppm for each % of ethylene concentration; 2) less than 2 ppm for each % of CO_2 concentration; 3) in case of analysis of the sample in its untreated (wet) condition only: less than 2 ppm for each % of water vapour. 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.

1) It is recommended as being consistent with good practice that such correction procedures should be adopted in all cases.

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Table 6 — Principal performance specifications for CO_2 analysers

No.	Term	Requirement
1	Total range	0 % to 20 % in appropriate ranges.
2	Resolution	Better than 0,5 % of full scale of range used or 100 ppm, whichever is greater.
3	Repeatability	Better than ± 1 % of full scale of range used or ± 100 ppm, whichever is greater.
4	Stability	Better than ± 2 % of full scale of range used or ± 100 ppm, whichever is greater, over a period of 2 h.
5	Zero drift	Less than ± 1 % of full scale of range used or ± 100 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 ± 100 ppm, whichever is greater.
7	Interference	In case of analysis of the sample in its untreated (wet) condition only: less than 20 ppm for each % of water vapour.
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.

7.3.3.2 Sample temperature

In the case of the (preferred) measurement of CO and CO_2 on a dry basis (with the sample train equipped with water traps according to 6.2) the sample cell within the analyser shall be maintained at a temperature of not less than 313 K (40 °C), with a stability of ± 2 K. If agreed upon by the parties involved, and when a light hydrocarbon fuel is used, analysis of the sample in its "wet" condition is allowed. In this case the sample cell and all other components in contact with the sample in this sub-system shall be maintained at a temperature of not less than 323 K (50 °C), with a stability of ± 2 K. An H_2O interference correction shall be applied.

7.4 Specification for sulfur oxide analysers

7.4.1 Measurement technique

Sulfur oxides shall preferably be calculated by using the fuel analysis. Therefore it shall be assumed that all the sulfur present in the fuel is completely oxidized to SO_2.

Measurement of SO_2 shall be considered only if the expected concentration of SO_2 exceeds the lower limit of detection of 3,4 mg SO_2 per 1 m^3 dry exhaust gas.

7.4.2 Principal performance specifications for SO_x analysers

7.4.2.1 Measurement

The measurement of SO_2 shall be by the non-dispersive infrared (NDIR) or by the non-dispersive ultraviolet (NDUV) technique.

7.4.2.2 Effect of other gases

NDIR measurement is interfered with by CO_2, H_2O and hydrocarbons. NDUV measurement is only interfered with by hydrocarbons.

7.4.2.3 Principal performance specifications

The principal performance specifications determined for the instruments operated in an environment as specified by the manufacturer shall be as given in table 7.

Table 7 — Principal performance specifications for SO_2 analysers

No.	Term	Requirement
1	Total range	0 ppm to 50 ppm and, in appropriate ranges, up to 1 000 ppm.
2	Resolution	Better than 2 % of full scale of range used or ± 2 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 ± 3 % of full scale of range used or ± 1 ppm, whichever is greater, over a period of 2 h.
5	Zero drift	Less than ± 2 % 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 ± 2 % of full scale of range used or ± 0,05 ppm, whichever is greater, over a period of 2 h.

No.	Term	Requirement
7	Interference	For samples containing CO_2, H_2O and UHC, shall be limited as follows: — < 1 % reading for each % of CO_2 concentration (by volume); — < 2 % reading for each % of water vapour concentration (by volume); — < 1 % reading for each 10 ppm of UHC, or the resulting interference shall be ⩽ 4 % reading. The most important influence on the reading is caused by the water content. To keep the water content of the gas sample constant, the pressure in the cooler shall be controlled in a range of ± 0,2 kPa. To avoid interference with ammonia in plants with catalytic reduction (SCR) of NO_x, the SO_2 concentration shall be measured before the mixing with ammonia.[1]
8	Response time	Shall not exceed 50 s from entry of the sample into the analyser to attaining 90 % of the final reading.
9	Linearity	The linearity response with SO_2 in N_2 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.

[1] For the NDIR method all three interfering components have to be considered. For the NDUV method, only UHC has to be considered. If the interference limitations for one, two or all of the above mentioned components cannot be met, appropriate correction factors shall be determined, reported and applied.

7.5 Specification for UHC analysers

7.5.1 Measurement technique

The measurement of unburned and partially burned hydrocarbons including all hydrocarbon species shall be by the flame ionization detection technique.

When the unburned hydrocarbon gases are subsequently burned in an independently controlled flame, ionization proportional to the number of carbon-hydrogen bonds broken is produced.

This technique yields a total of all hydrocarbons present. For requirements stated as volatile organic compounds it is necessary to differentiate between the individual species of hydrocarbons in order to exclude those hydrocarbons not contributing to the VOCs.

NOTE 4 The ambient hydrocarbon level will, in some circumstances, be very significant or even higher than that measured in the turbine exhaust. The exhaust test probe can be used to sample ambient air before or after regular tests. Where significant readings are encountered and a simultaneous reading desired, a sample line to a location near the gas turbine inlet can be added. This sample line need not be heated since hydrocarbons are wet samples and the sample temperature is the same as the unheated line.

7.5.2 Principal performance specifications for UHC analysers

The principal performance specifications determined for the instruments operated in an environment as specified by the manufacturer shall be as given in table 8.

Table 8 — Principal performance specifications for UHC analysers

No.	Term	Requirement
1	Total range	0 ppmC_1 to 1 500 ppmC_1 in appropriate ranges, including the smallest range of 0 ppm to 10 ppm. To minimize errors in readings it is desirable that enough ranges be available so that hydrocarbon emissions can be measured at no less than 50 % of the full scale deflection (FSD) of the calibrated scale.
2	Resolution	Better than 0,5 % of full scale of range used or ± 0,5 ppmC_1, whichever is greater.
3	Repeatability	Better than ± 1 % of full scale of range used or ± 0,5 ppmC_1, whichever is greater.
4	Stability	Better than ± 2 % of full scale of range used or ± 1 ppmC_1, whichever is greater.
5	Zero drift	Less than ± 1 % of FSD or ± 0,5 ppmC_1, 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 ± 0,5 ppmC_1, whichever is greater.
7	Interference	See 7.5.3.
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, with propane in air, 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.

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7.5.3 Interference and relative hydrocarbon response

The following requirements shall be adhered to.

7.5.3.1 The gases used for the analyser shall be a standard mixture of 40 % hydrogen and 60 % helium as this reduces the variation in detector output caused by

- different levels of oxygen and
- different hydrocarbon species

which are characteristic of a gas turbine exhaust gas composition under different engine operating conditions. Instead of helium, nitrogen also can be used.

7.5.3.2 For operation of the flame, air is required which has only a limited residual content of organic substances. The volumetric concentration of organic substances (CH_4) shall be less than 10 % of the full scale deflection used, but in no case greater than 10 ppmC_1. It is consistent with good practice to use artificial air.

7.5.3.3 To measure the change in output caused by variation of oxygen in the sample, a comparison shall be made of readings obtained from the following gases:

a) 500 ppmC_1 in zero air, which is the equivalent of 500/3 ppm propane in zero air;

b) 500 ppmC_1 in nitrogen, which is the equivalent of 500/3 ppm propane in nitrogen.

The difference in the readings shall be less than 2 %.

7.5.3.4 To measure the change in output caused by different hydrocarbon species, a comparison shall be made of readings obtained from the following gases:

a) 500 ppmC_1 propane in zero air;

b) 500 ppmC_1 propylene in zero air;

c) 500 ppmC_1 toluene in zero air;

d) 500 ppmC_1 *n*-hexane in zero air.

There shall be less than 5 % variation in readings expressed as CH_4.

7.5.4 Determination of VOCs

7.5.4.1 General

For a volatile organic compound limit, the total unburned hydrocarbons shall be determined and the amount of methane (CH_4) and ethane (C_2H_6) components shall be subtracted. This is done using a gas chromatograph or a gas chromatograph in combination with a flame ionization detector.

There are two types: "direct" and "subtraction" analysers.

7.5.4.2 Direct analysers

These consist of an automated gas chromatograph with an FID detector. The sample is separated into two parts: air and the sum of methane and ethane. The column is then backflushed which gives a third part consisting of all the VOCs. Since the methane, ethane and VOCs are separated from the air, no oxygen synergism occurs. The two columns may be used with suitable flow switching to improve the separation and speed up the analysis.

This type is recommended where measurement of UHCs and VOCs is required.

7.5.4.3 Subtraction analysers

If the method described in 7.5.4.2 is not available the following may be used. This method uses two systems simultaneously: a gas chromatograph for the determination of the proportional amount of methane and ethane included in the sample and an FID for total unburned hydrocarbons. The VOCs are obtained by subtraction of the methane and ethane from the UHCs.

7.6 Specification for ammonia analysers

In cases where ammonia (NH_3) is present in the exhaust gas, e.g. when ammonia is used in SCR units, it is necessary to measure ammonia.

7.6.1 Measurement technique

Ammonia measurement is based on the different behaviour of two designs of NO_2 to NO converter which are used in conjunction with the chemiluminescence instrument specified in 7.2. Because of their different materials, stainless steel and carbon, the two converter designs react differently with NO_2 and NH_3 components in the exhaust.

Stainless steel converters normally operate at approximately 700 °C. At that temperature NH_3 completely oxidizes to NO according to the reaction:

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \qquad \ldots (1)$$

Note that this measurement produces incorrect NO_x results.

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Carbon converters operate at 300 °C, a temperature at which NH_3 is not oxidized. A conversion from NO_2 to NO occurs according to the following reaction:

$$NO_2 + C \rightarrow NO + CO \qquad \ldots (2)$$

The flow diagram for the two converters used with the chemiluminescence instrument is shown in figure 2. Alternatively, two complete chemiluminescence analyser and converter systems can be used.

7.6.2 Operation

The different behaviour of the two different converters is used to determine the NH_3 content of the exhaust. See figure 2. The operation and specifications of the converters and the chemiluminescence instrument shall be the same as described in 7.2.2. The converters shall be designed and operated to oxidize NH_3 and reduce NO_2 in the sample to NO.

7.6.3 Converter efficiency correction

The efficiency value shall be used to correct the reading if the measured values are closed to the required limits. The converter efficiency is expressed either as

$$\eta_{NH_3} = \frac{100\left[\varphi_{NO}\ (\text{after converter}) - \varphi_{NO}\right]}{\varphi_{NH_3}} \qquad \ldots (3)$$

or

$$\eta_{NO_2} = \frac{100\left[\varphi_{NO}\ (\text{after converter}) - \varphi_{NO}\right]}{\varphi_{NO_2}} \qquad \ldots (4)$$

7.7 Specification for oxygen analysers

7.7.1 Measurement technique

The measurement of oxygen shall be by the paramagnetic principle.

O_2 molecules, owing to their paramagnetic property, are attracted in an inhomogeneous magnetic field in the direction of higher field strength.

If two gases having different O_2 contents are brought together in a magnetic field, a pressure difference is generated between them.

One of the gases is the sample gas, the other one is a reference gas. For gas turbine exhaust gas measurements a gas with 20,95 % O_2 in N_2 is used as the reference gas. This gas is introduced to the measuring chamber via two ducts (see figure 3). One of the ducts mixes reference gas with the sample gas in the area of the magnetic field. Since both ducts are connected, the pressure difference Δp, which is proportional to the O_2 content of the sample gas, produces a flow which is converted by a microflow sensor into an electrical signal.

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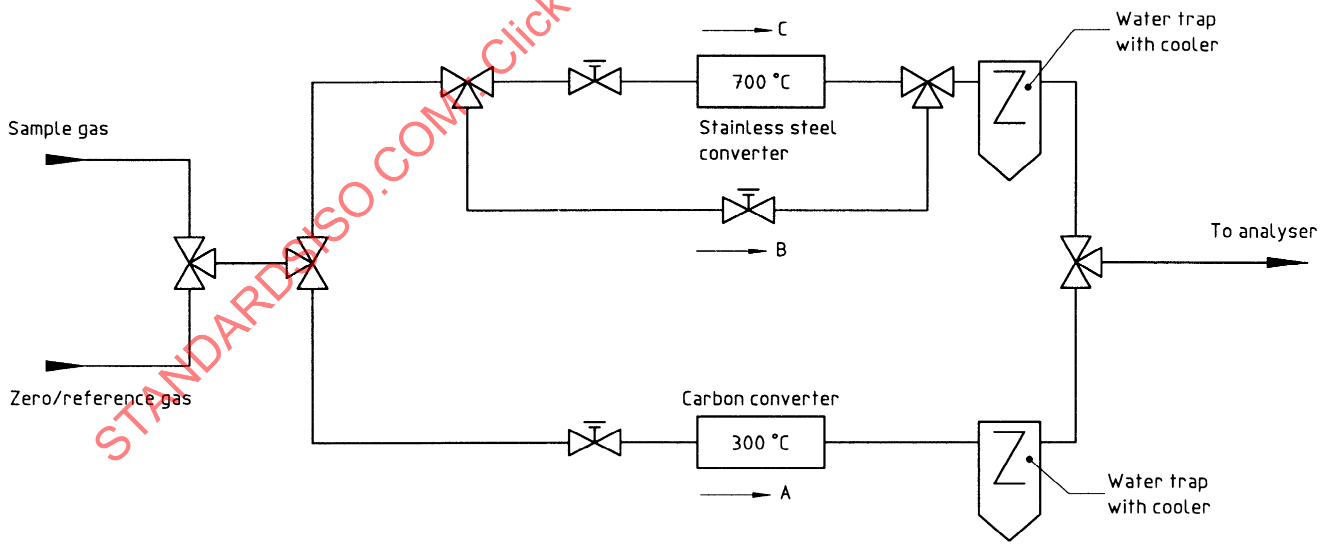

Key

A	NO_x measurement
B	NO measurement
C	$NO_x + NH_3$ measurement
A – B	NO_2 content
C – A	NH_3 content

Figure 2 — Flow diagram of a converter system for NO_x/NH_3 measurements

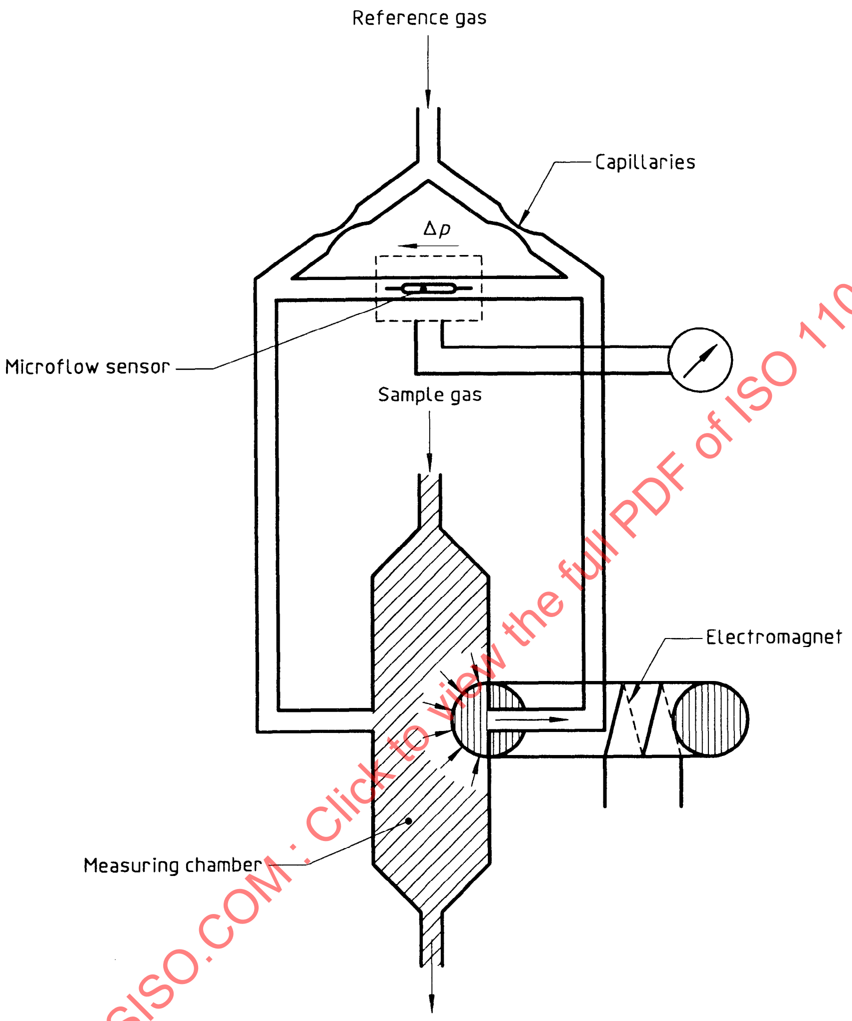

Figure 3 — Typical functional diagram of the O_2 analyser

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7.7.2 Principal performance specifications

The principal performance specifications determined for the instruments operated in an environment as specified by the manufacturer shall be as given in table 9.

Table 9 — Principal performance specifications for oxygen analysers

No.	Term	Requirement
1	Total range	0 % to 25 % in appropriate ranges.
2	Resolution	Better than ± 0,2 % of full scale of range used or ± 0,05 %, whichever is greater.
3	Repeatability	Better than ± 0,2 % of full scale of range used or ± 0,05 %, whichever is greater.
4	Stability	Better than ± 2 % of full scale of range used or ± 0,05 %, whichever is greater, over a period of 2 h.
5	Zero drift	Better than ± 0,2 % of full scale of range used or ± 0,05 %, whichever is greater.
6	Noise	0,5 Hz and greater; less than ± 0,2 % of full scale of range used or ± 0,05 %, whichever is greater, over a period of 2 h.
7	Interference	See 7.7.3.
8	Response time	Same as 7.2.2.
9	Linearity	Same as 7.2.2.

7.7.3 Special requirements

Most gases exhibit some paramagnetism which can affect oxygen readings. These effects are likely to be negligible in relation to overall measurement accuracy, but may be taken into account if agreed between the interested parties.

7.8 Specification for smoke analysers

7.8.1 Measurement technique

In the following, the method according to ISO 5063 is used.

Smoke measurements are not intended to be measurements of solid particles. In the event of agreement between the interested parties that such measurements should be taken, relevant methods are referred to in 7.9.

The degree of smoke intensity for gas turbines is specified using the smoke spot number, also known as Bacharach number, where the smoke scale ranges from 0 to 9, with the lower values corresponding to a logarithmically lower value of smoke.

7.8.2 Apparatus

7.8.2.1 Pump (manual), permitting suction of a volume of 160 cm^3 ± 5 % through the effective filtering surface of 6 mm diameter by one single operation of the pump (i.e. approximately 570 cm^3 ± 5 % per square centimetre of effective filtering surface); the stroke of the pump should be about 200 mm.

NOTE 5 If the smoke sample temperature deviates from normal ambient, it is recommended that a volume correction be added to the readings by measuring the sample temperature and using a correction curve to adjust the smoke spot reading to a normal value of 570 cm^3/cm^2 of effective filtering surface.

The tightening of the device for holding the filter paper, which should be done before introducing the paper into the slot provided, should ensure a sufficiently tight seal to enable the pump to be initially operated and heated up without the occurrence of any condensation.

7.8.2.2 Sampling tube, having an external diameter of 6 mm and fulfilling the requirements of 7.8.2.1.

7.8.2.3 Filter paper, having a reflectance of (85 ± 2,5) % determined photometrically. For this measurement the filter paper is placed on a white surface having a reflectance ⩾ 75 %.

The passage of clean air through the new filter paper, at a flow of 3 $dm^3/min/cm^2$ of effective filtering surface should result in a pressure drop of between 2 kPa and 10 kPa (20 mbar and 100 mbar).

7.8.2.4 Grey scale, comprising 10 grades numbered from 0 to 9 distributed over equal intervals from white to dark grey. These grades exist as printed samples or are obtained by other means on a paper or plastic base having a reflectance of (85 ± 2,5) % determined photometrically.

The identification number of each grade is equal to one-tenth of the reduction, expressed as a percentage, of the reflected incident light on the corresponding sample.

The number 0 corresponds to the paper base and the number 6, for instance, to a reduction of the reflected incident light of 60 %.

The tolerance on the reflectance for each of the points of the scale shall be at most 3 % of the value of the said reflectance.

If the scale is protected by a transparent plastic cover, its construction shall be such that the test spot and the standard grades are observed through the same thickness of protective substance. The grades of the standard smoke scale have a diameter of about 20 mm and a central circular window of 6 mm diameter.

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7.8.3 Determination of the smoke number

Unscrew the paper fixing device, insert the filter paper in the slot provided on the pump and retighten the device.

Introduce the sampling probe perpendicularly to the direction of the gas flow. Ensure gas-tightness between the sampling probe and the wall of the duct in which sampling is done.

Sampling may be carried out either with a manual pump or with an electromechanical pump.

When using the manual pump, carry out ten suctions. Each suction shall be regular and shall be of between 2 s and 3 s duration. The end of the suction is indicated when the operator no longer senses the reaction of the piston.

Withdraw the sampling probe from the gas, unscrew the fixing device and carefully withdraw the filter paper.

Visually compare the test spot with the standard grades by placing the band of paper against the back of the standard scale. Examine the spot through the central window of the standard grades. Note the number of the scale whose shade is the closest to that of the test spot. For the scale intervals between 0 and 4, it is necessary to evaluate the intermediate grades with particular attention.

A sufficient number of samples shall be taken at different positions in the exhaust duct to ensure that representative results are achieved.

7.9 Specification for solid particle analysers

7.9.1 Preamble

If the parties involved agree to carry out the measurement of solid particles it shall be done according to the following.

The solid particle load of the exhaust gas (and of the air taken in by the compressor) shall be measured by gravimetric analysis. A representative sample of the particle-laden gas/air is taken from the overall flow, the particles are separated from the sample, and the accumulated mass of particles is weighed and related to the amount of gas/air sampled. If agreed upon by the parties involved, additional analysis of the solid particle sample can be done, e.g. particle size distribution, chemical analysis. In this case, the appropriate method is subject to special agreement not covered by this part of ISO 11042.

Optical methods, e.g. continuous measuring of optical transmission or of the scattered light, although generally accepted for continuous emission control, with respect to mass-related particle load suffer from the transmission/scattering depending on particle size, size distribution, particle shape, particle density and some optical properties of the particle material. They may be used after appropriate calibration and on the assumption that the relevant properties, once established and checked, are stable.

7.9.2 Location of sampling probe and arrangement of sampling system

The solid particle sample train shall be installed separate from the sample train (see 6.2) for the gaseous constituents.

The sample train is built with the main separator inside (see figure 4) or outside (see figure 5) the gas/air duct.

As stainless steel may not be suitable under certain conditions the following parts of the sample train shall be made of corrosion and temperature resistant material such as glass: the sampling probe, the bend, the transport tube and the separator casing. The main separator consists of a filter. A preseparator, e.g. a cyclone, is required only with very high particle loads that would otherwise overload the filter in less than the sampling time. The filter medium shall withstand the sample temperature under consideration, shall be chemically stable and shall be fine enough for "total" filtration.

7.9.3 Principal performance considerations

7.9.3.1 General

The performance of the solid particle analysing system (SPAS) depends on appropriate

- aquisition,
- transport,
- separation and
- metering

of a representative sample.

Unless demonstrated by previous tests and agreed upon by the parties involved, samples shall be considered representative of the mean flow only when the number of sampling stations is at least 4/m^2 of the cross-sectional area. The number of sampling stations shall be between twelve and twenty.

Also the sampling stations shall be located at least $8 \times D_h$ (D_h = hydraulic diameter) downstream and $2 \times D_h$ upstream of any type of consecutive flow disturbance (bend, expansion, contraction etc.).

If these conditions cannot be achieved in practice then the distances shall be $2 \times D_h$ and $1 \times D_h$, respectively. In this case the number of sampling stations shall be increased.

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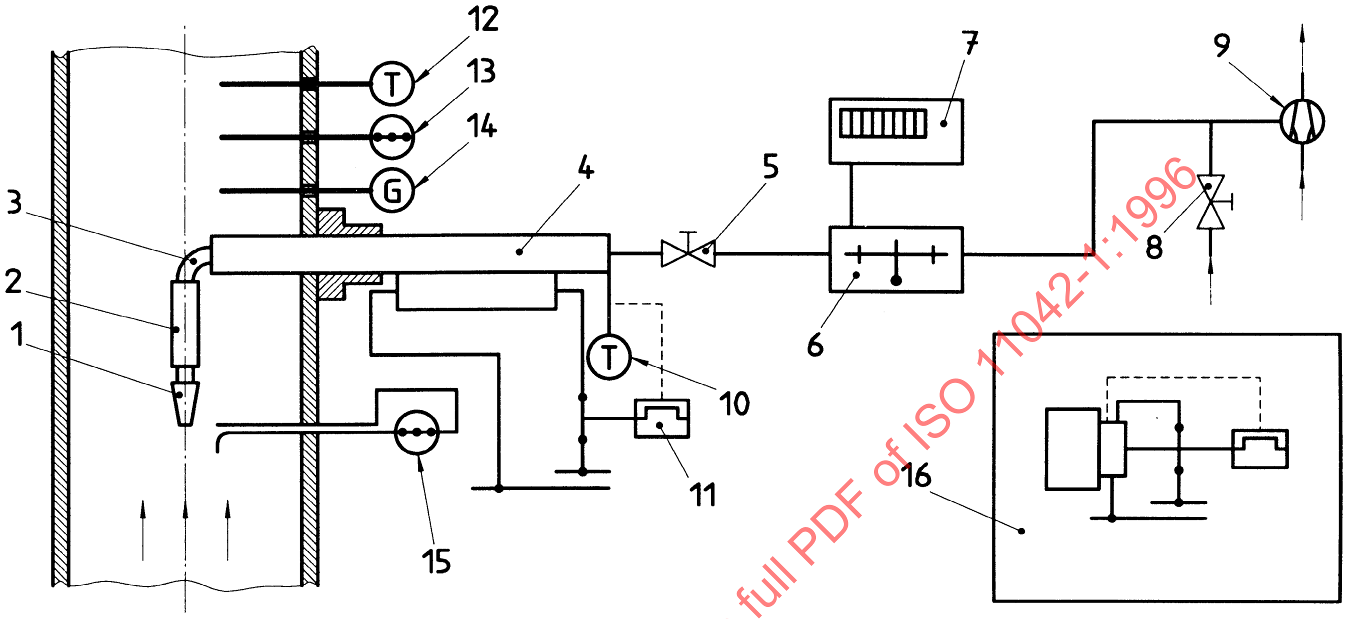

Key

1 Sampling probe
2 Separator
3 Bend
4 Temperature-controlled transport tube
5 Start/stop valve
6 Throttling device } flow meter
7 Transmitter/indicator
8 Suction control
9 Ejector, blower
10 Sample temperature measurement
11 Temperature control device
12 Temperature probe
13 Pressure probe
14 Sample train for gaseous constituents
15 Velocity measurement (near sampling probe)
16 Separator preheating device

Figure 4 — Sample train for measurement of solid particle concentration by weight
(main separator inside duct)

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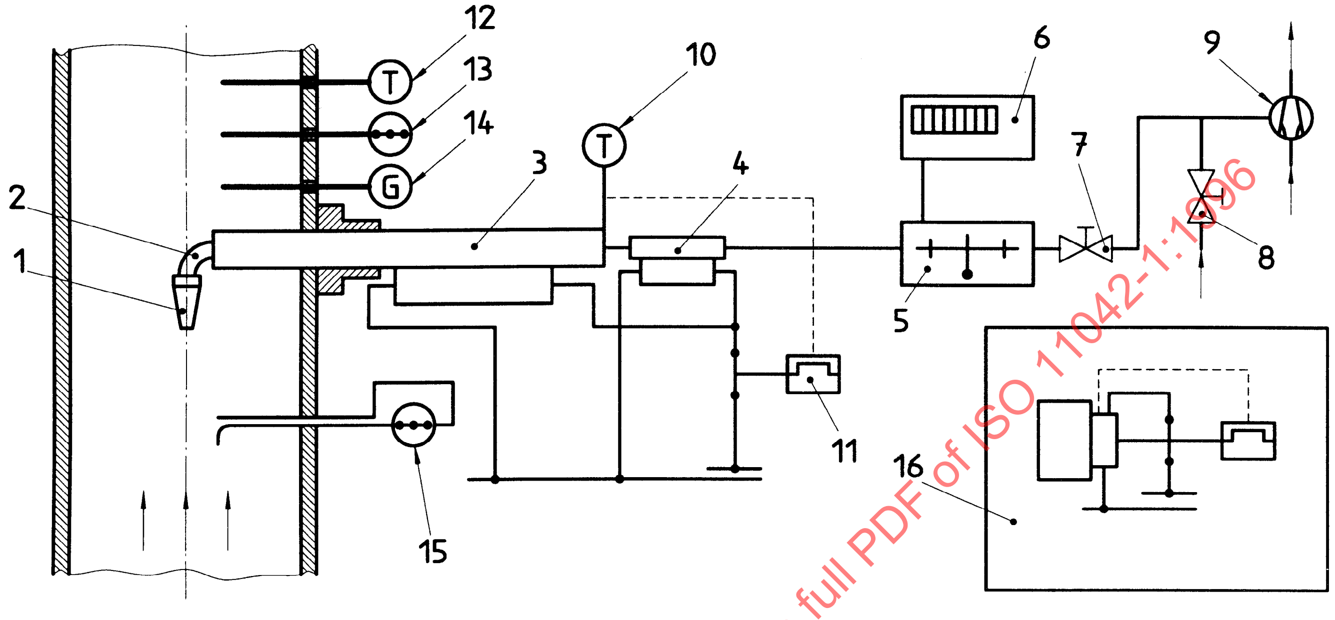

Key

1 Sampling probe
2 Bend
3 Temperature-controlled transport tube
4 Separator
5 Throttling device } flow meter
6 Transmitter/indicator } flow meter
7 Start/stop valve
8 Suction control
9 Ejector, blower
10 Sample temperature measurement
11 Temperature control device
12 Temperature probe
13 Pressure probe
14 Sample train for gaseous constituents
15 Velocity measurement (near sampling probe)
16 Separator preheating device

Figure 5 — Sample train for measurement of solid particle concentration by weight
(main separator outside duct)

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7.9.3.2 Acquisition

Single-hole sampling probes shall be used. The sampling probe shall be designed and the SPAS operated in such a way as to limit the error due to anisokinetic sampling to ± 10 % for particles with an aerodynamic diameter smaller than 5 µm. The probe shall be positioned such as to deviate not more than ± 10° from isoaxial sampling. Probe designs considered consistent with good practice are given in figure 6.

The appropriate choice of the effective diameter depends on the volume flow rate of the particle-laden gas to be sampled. Under ideal isokinetic conditions (velocity, v, in the probe tip equal to velocity, w, of undisturbed flow in the duct) we have

$$d_{\text{eff}} = \sqrt{\frac{4q_V}{\pi w}} \qquad \ldots (5)$$

where

d_{eff} is the effective probe diameter, in metres;

q_V is the volume flow of the exhaust gas, in cubic metres per second;

w is the gas velocity, in metres per second.

The error due to anisokinetic sampling shall be estimated using figure 7 (after Belyaev and Levin) with the relevant Stokes' number

$$St_{\text{W}} = \frac{d_{\text{pa}}^2\, \rho_{\text{pa}}\, C}{18\mu} \cdot \frac{w}{d_{\text{eff}}} \qquad \ldots (6)$$

where

d_{pa} is the particle diameter, in metres;

ρ_{pa} is the density of the particle material, in kilograms per cubic metre;

μ is the dynamic viscosity of the gas, in pascal seconds;

w is the gas velocity, in metres per second;

d_{eff} is the effective probe diameter, in metres;

C is Cunningham's slip correction factor.

Cunningham's slip correction factor is calculated as follows:

$$C = 1 + J\,\frac{\Lambda}{d_{\text{pa}}} \qquad \ldots (7)$$

This factor corrects for the reduction of the resistance to flow, J, of a particle as compared to Stokes' law, when the ratio of the mean free path of the gas molecules, Λ, to the particle diameter d_{pa} (the Knudsen number) approaches unity.

According to Grassmann[3], J is calculated as follows:

$$J = 1{,}764 + 0{,}562\exp(-0{,}785\,\frac{d_{\text{pa}}}{\Lambda}) \qquad \ldots (8)$$

7.9.3.3 Transport

The bend and the transport tube shall be designed and the SPAS operated in such a way as to minimize transport losses due to Brownian diffusion, gravitational settling, inertial deposition, electrostatic collection and/or thermophoretic effects. It is consistent with good practice to make tubes as short as possible, to arrange them vertically and, if possible, without bends, to use grounded metallic tubes and to avoid temperature gradients. The tube diameter shall not be smaller than 5 mm. An example of an appropriate arrangement of probe, bend, tube and separator for the main-separator-inside-duct technique is given in figure 8.

7.9.3.4 Separation

The separation of the particles from the sample shall be "total". It is consistent with good practice to use as a filter quartz fibres of diameter ⩽ 10 µm packed tightly inside a glass fibre cartridge. Provisions shall be made for capturing residual fines in an additional barrier filter, behind the main separator.

7.9.3.5 Metering

Metering of the sample volume flow shall be done by continuous flow meters according to established standards. The mass of the particles shall be measured by weighing the filter and the filter cartridge, carefully dried, before and after exposure.

Care shall be taken to include the mass of the particles that have been deposited inside the passage according to 7.9.3.3.

Weighing shall be done to an accuracy of 1 % whenever the sampled mass is more than 100 mg, or at least 0,1 mg for smaller masses sampled. The volume flow rate (and the corresponding probe diameter according to 7.9.3.2) shall be such that a sufficient mass of particles is captured within a sampling time of 2 h.

The lower limit of solid particle load of a gas stream that can be resolved by the SPAS is between 1 mg/m³ and 5 mg/m³.

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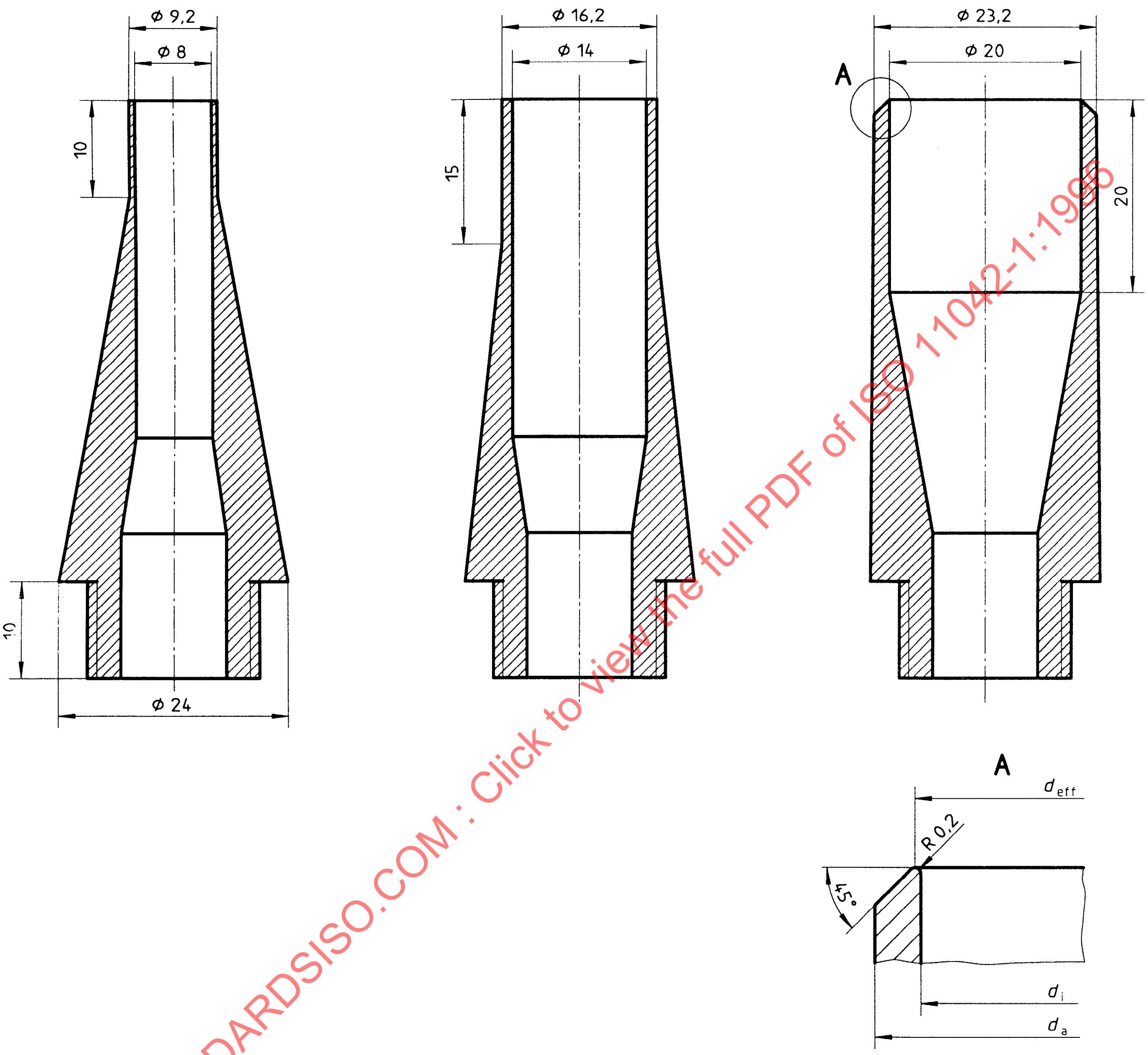
Dimensions in millimetres



NOTE — The effective diameter d_{eff} shall be such that 5mm $\leqslant d_{\text{eff}} \leqslant$ 30 mm.

Figure 6 — Examples of solid particle sampling probes

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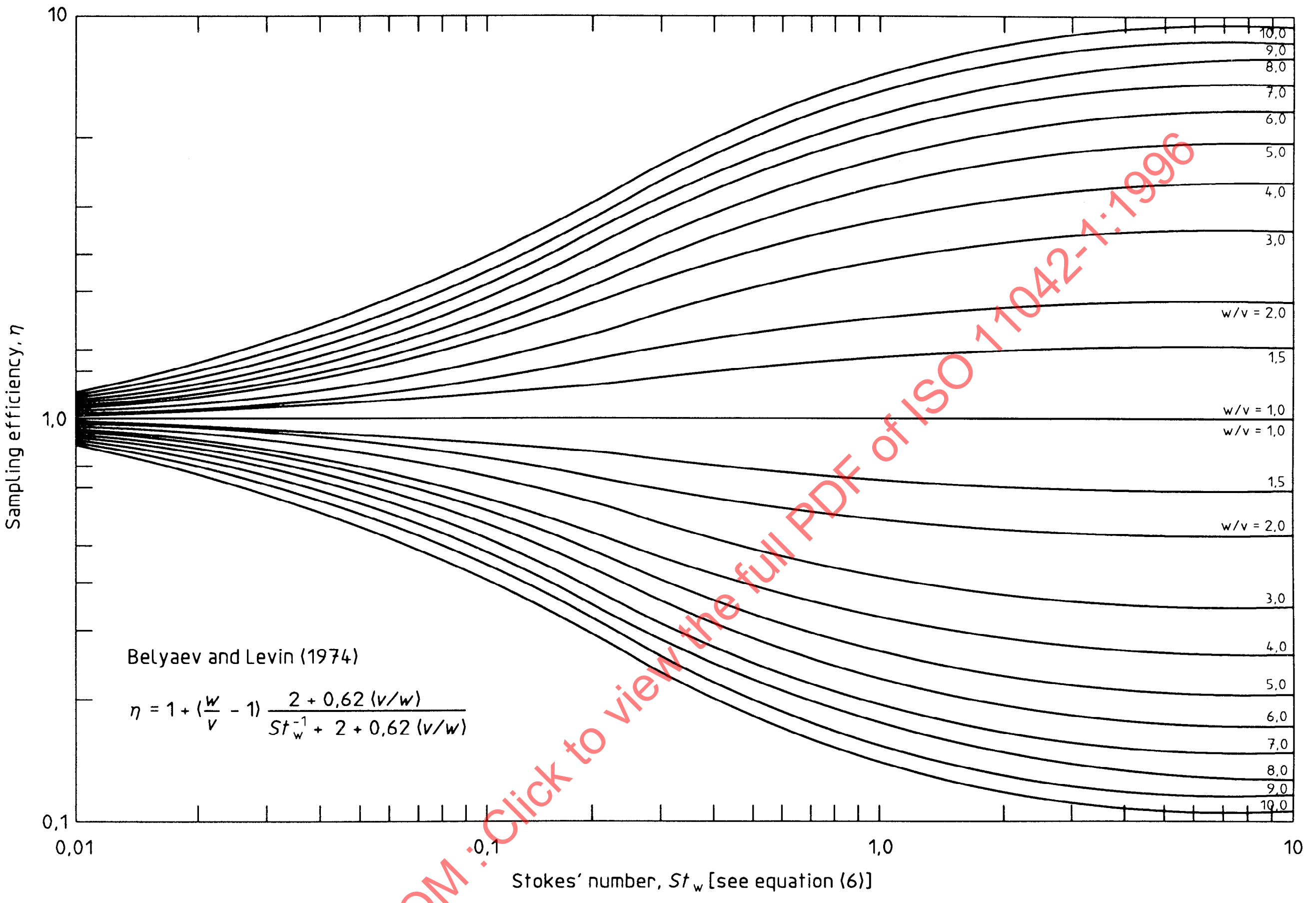

Figure 7 — Sampling efficiency according to Belyaev and Levin's equation

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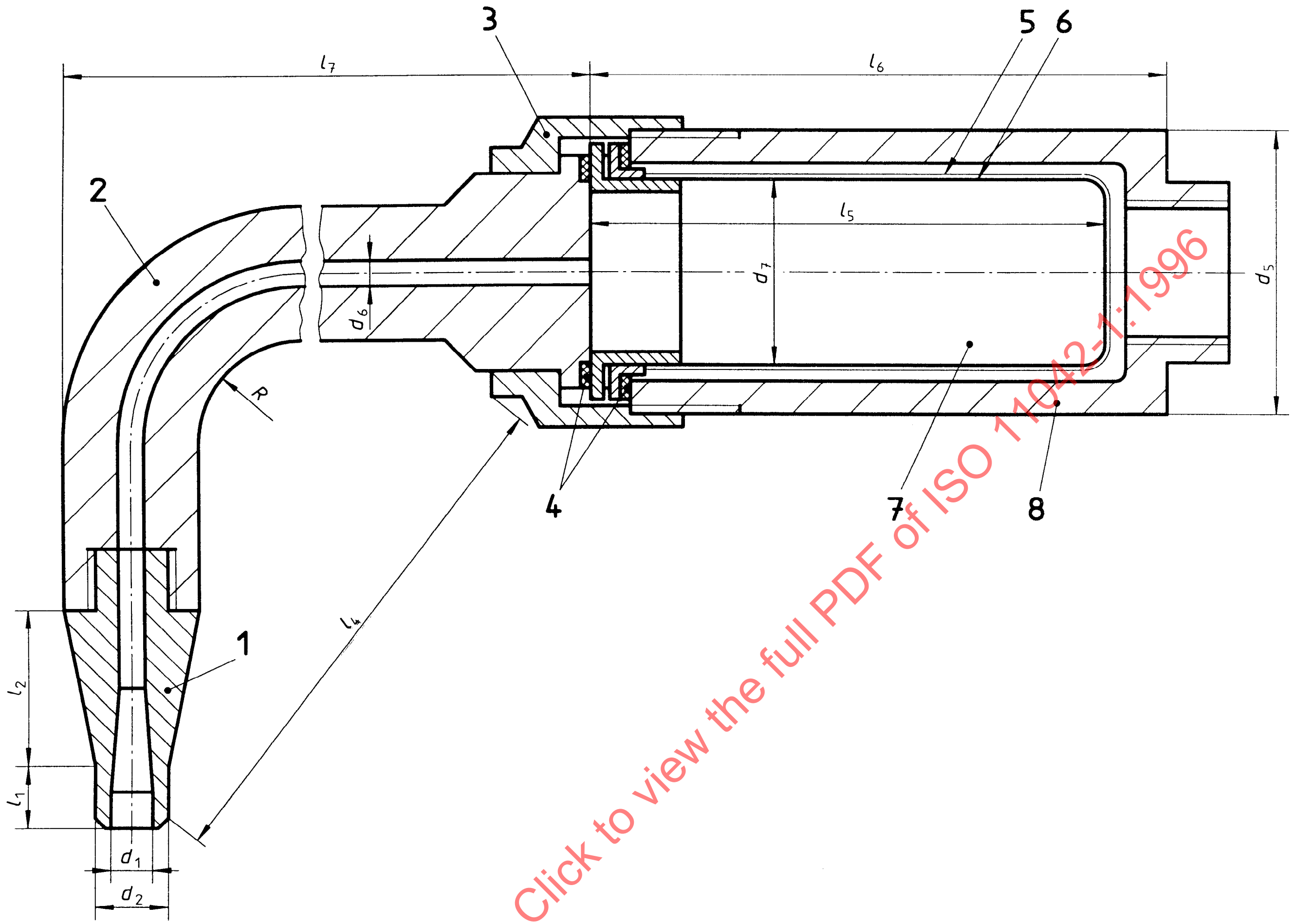

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Key

1 Probe
2 Bend
3 Joint
4 Sealing
5 Support cage
6 Glass fibre cartridge
7 Quartz fibres (packed)
8 Separator casing

$d_5 < 50$ mm
$d_6 > 5$ mm
$d_7 = 30$ mm; diameter of the cartridge
$l_4 > 2d_R$
$l_5 = 70$ mm; length of the cartridge
$l_6 \approx 80$ mm
$l_7 \geqslant l_6$

NOTES

— The probe may be connected to the separator by a straight tube, and the bend arranged downstream of the separator.

— The length l_1 of the cylindrical part at the probe tip shall be $l_1 \geqslant d_{\text{eff}}/2$.

Figure 8 — Example of probe, bend, tube and separator assembly

8 Quality of measurement

8.1 Preamble

Quality of measurement is influenced by measurement system design and installation, calibration procedures and measurement test procedures. System design and measurement test procedures are covered in the preceding sections.

Verification that the exhaust sample is representative of the exhaust stream may be made by a carbon balance which compares the carbon input in the fuel with the carbon measured in the exhaust stream, exclusive of smoke.

8.2 Methods for calibration

Instrument calibration shall be carried out by comparison with a calibration gas. The calibration gas shall have a certificate of mixture preparation according to ISO 6141. It is consistent with good practice to provide calibration gas mixtures with the relevant constituent in nitrogen at concentration levels of approximately 60 % and 90 % of the full scale of the metering ranges of the analyser.

The manufacturer of the calibration gases has to make sure that these gases are provided with the accuracies listed in table 10.

Carbon monoxide and carbon dioxide calibration gases may be blended singly or used as dual-component mixtures. Three-component mixtures of carbon monoxide, carbon dioxide and propane in zero air may be used, provided the stability of the mixture is assured.

Zero gas as specified for the HC analyser shall be zero air which includes "artificial" air with 20 % to 22 % O_2 blended with N_2. For the remainder of the analysers pure nitrogen shall be used as the zero gas. Impurities in both kinds of zero gas shall be restricted to be less than the following concentrations.

C	1 ppm
CO	1 ppm
CO_2	100 ppm
NO_x	1 ppm
SO_2	1 ppm

The user shall ensure that commercial gases supplied to him do in fact meet this specification, or are so specified by the vendor.

9 Conversion of data

9.1 General

The gaseous components are considered to be ideal gases; hence the molar concentration is proportional to the ratio of the partial pressure to the total pressure and to the volume fraction.

The volumetric concentration shall be presented in % or in cm^3/m^3 (ppm).

Smoke measured as Bacharach number as well as solid particle concentrations are not converted.

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Table 10 — Concentration accuracies for calibration gases

Analyser	Gas	Accuracy[1)]
HC	Propane in (10 ± 1) % O_2; balance, N_2	± 2 % or ± 0,05 ppm[2)]
HC	Propane in (20,95 ± 1) % O_2; balance, N_2	± 2 % or ± 0,05 ppm[2)]
HC	Propylene in zero air	± 2 % or ± 0,05 ppm[2)]
HC	Toluene in zero air	± 2 % or ± 0,05 ppm[2)]
HC	*n*-hexane in zero air	± 2 % or ± 0,05 ppm[2)]
CO	CO in N_2	± 2 % or ± 2 ppm[2)]
CO_2	CO_2 in N_2	± 1 % or ± 100 ppm[2)]
NO_x	NO in N_2	± 1 % or ± 1 ppm[2)]
O_2	O_2 in N_2	± 0,2 % or ± 100 ppm[2)]
SO_2	SO_2 in N_2	± 1 % or ± 1 ppm[2)]

1) Taken over the 95 % confidence interval.
2) Whichever is greater.

9.2 Conversion between wet and dry exhaust gas

The measurements are considered to be "dry" when the water content of the gas sample has been condensed out; otherwise, they are considered to be "wet". The water content represents the difference between the "wet" and the "dry" results and is obtained by calculation or measurement to be agreed upon by the interested parties. Humidity of the air in the compressor inlet, water content in the fuel, water formed by combustion of the fuel, as well as water or steam injection shall be considered. The conversion is carried out by using the following equation:

$$\varphi_{i,\mathrm{dry}} = \varphi_{i,\mathrm{wet}} \cdot \frac{1}{1 - \varphi_{\mathrm{H_2O}}} \qquad \dots (9)$$

9.3 Conversion to the particular exhaust gas oxygen level

To relate measurements to a standardized exhaust gas the following correction can be applied to give reference to a particular exhaust gas oxygen level.

The emission value as the volumetric concentration of the component i related to an oxygen volumetric concentration of e.g. 15 % in dry exhaust gas is given by:

$$EV_{i,15,\mathrm{dry}} = \frac{20{,}95 - 15}{20{,}95 - \varphi_{\mathrm{O_2,dry}}} \cdot \varphi_{i,\mathrm{dry}} \qquad \dots (10)$$

whereby the oxygen content of the dry ambient air is in accordance with ISO 2533.

Theoretically this correction can be applied to other oxygen levels and for "wet" and "dry" gases.

9.4 Conversion to the constituent mass flow related to the dry exhaust gas volume flow at normal conditions and to a specific oxygen content

The exhaust gas emission value as constituent concentration related to the dry exhaust gas at normal conditions and with an oxygen content of e.g. 15 % is given by:

$$EM_{i,15,\mathrm{dry}} = EV_{i,15,\mathrm{dry}} \cdot \frac{M_i}{V_{\mathrm{mn}}} = EV_{i,15,\mathrm{dry}} \cdot \rho_{\mathrm{n}} \qquad \dots (11)$$

Molar masses (M_i) and normal reference densities (ρ_n) are given in table C.1.

The above emission values have the unit mg/m^3, if the molar mass is in kg/kmol and the concentration in cm^3/m^3.

In the case of NO$_x$ the unit is mg NO$_2$/m^3, in the case of SO$_x$ the unit is mg SO$_2$/m^3 and in the case of UHC the unit is mg CH$_4$/m^3.

9.5 Conversion to power output related values

The power output related emission values given by

$$EM_{i,P} = \frac{q_{m_i}}{P} \qquad \dots (12)$$

are calculated by using the equation

$$\frac{q_{m_i}}{P} = \varphi_{i,\mathrm{wet}} \cdot \frac{M_i}{M_{\mathrm{tot}}} \cdot \frac{q_{m_{\mathrm{g7}}}}{P} \qquad \dots (13)$$

When the values of $\varphi_{i,\mathrm{wet}}$ are given in cm^3/m^3, those of $q_{m_{\mathrm{g7}}}$ in kg/s and those of P in kW, then the equation

$$EM_{i,P} = \varphi_{i,\mathrm{wet}} \cdot \frac{M_i}{M_{\mathrm{tot}}} \cdot \frac{q_{m_{\mathrm{g7}}}}{P} \cdot 3{,}6 \qquad \dots (14)$$

yields the power output related values in g/kWh.

NOTE 6 The molar mass M_{tot} is taken from a calculation assuming complete combustion and is based on the composition of the fuel. Any steam or water injection should be reasonably considered.

For example, the combustion of pure methane (CH$_4$) as a reference gaseous fuel with an amount of air with 60 % relative humidity at 101,3 kPa and 288,15 K (15 °C) resulting in an oxygen concentration of 15 % related to dry exhaust gas at standard conditions produces a wet exhaust gas with M_{tot} = 28,463 kg/kmol.

The combustion of pure *n*-dodecane (C$_{12}$H$_{26}$) as a reference liquid fuel under the same conditions produces a wet exhaust gas with M_{tot} = 28,753 kg/kmol.

9.6 Conversion to consumed fuel energy related values

The consumed fuel energy related emission values are calculated as follows:

$$EM_{i,\mathrm{f}} = EM_{i,P} \cdot \frac{P}{q_{m_\mathrm{f}} \cdot e_\mathrm{n}} \qquad \dots (15)$$

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Annex A
(informative)

Typical example of test results and their evaluation

Table A.1 — Record of emission test

Identification No.			
	Test engineer's name: Company/Organization:		
Gas turbine			
101 **102** **103**	Manufacturer: Type: Serial No.:		
Location			
104 **105**	Place: Country:		
Fuel type			
106	(For details see separate data sheet)		
Date/time of test			
107 **108** **109**	Date: Time at start of test: Time at end of test:		
Measuring instruments used			
110	O_2	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	
111	CO_2	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	
112	NO_x	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	
113	CO	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	
114	SO_x	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	
115	Smoke	Measuring instrument	Serial No.:
		— type: — standard measuring ranges (see ISO 5063)	
116	UHCs	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	
117	VOCs	Measuring instrument	Serial No.:
		— type: — measuring ranges used:	

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Table A.1 *(concluded)*

Identification No.	Table of measurements							
		Unit	1	2	3	4	5	Mean value
200	Test No.							
201	Time	min						
202	Time taken to measure one point	min						
Ambient conditions								
203	Air temperature	°C						
204	Air pressure	kPa						
205	Relative air humidity	%						
Operating data								
206	Power output (mechanical/electrical)	kW						
207	Fuel mass flow	kg/s						
208	Exhaust gas mass flow (by measurement or calculation)	kg/s						
209	Exhaust gas mean temperature	°C						
	Additional information as to 5.1, see separate sheet							
Measured/calculated gas volumetric concentrations 1)								
			wet/dry	wet/dry	wet/dry	wet/dry	wet/dry	
			measured/ calculated	measured/ calculated	measured/ calculated	measured/ calculated	measured/ calculated	
210	O_2	%						
211	CO_2	%						
212	H_2O	%						
213	NO	cm^3/m^3						
214	NO_x	cm^3/m^3						
215	CO	cm^3/m^3						
216	SO_x	cm^3/m^3						
217	UHC (as CH_4)	cm^3/m^3						
Smoke number								
218	Bacharach spot number	—						

1) Depending on the measuring procedure used the volumetric concentration shall be listed relative to either "dry" or "wet" exhaust gas. The value shall be calculated and listed above using equation 9 in 9.2. Both values are needed for the evaluations in table A.2. This means that the volumetric concentration of water shall be determined, by combustion calculation.

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Table A.2 — Evaluation

Identification No.	Term	Unit	Calculation	1	2	3	4	5	Mean value
Conversion between wet and dry exhaust gas Note: This calculation is only required if the measured volumetric concentrations are related to the wet exhaust gas.									
300	$\varphi_{i,\mathrm{dry}}$ = volumetric concentration of component i in dry exhaust gas $\varphi_{i,\mathrm{dry}} = \varphi_{i,\mathrm{wet}} \cdot \frac{1}{1-\varphi_{\mathrm{H_2O}}}$								
301	$\varphi_{\mathrm{H_2O}}$	1	**212**/100						
302	$\frac{1}{1-\varphi_{\mathrm{H_2O}}}$	1	$\frac{1}{1-\mathbf{301}}$						
303	$\varphi_{\mathrm{O_2,dry}}$	%	**302** × **210**						
304	$\varphi_{\mathrm{CO_2,dry}}$	%	**302** × **211**						
305	$\varphi_{\mathrm{NO,dry}}$	$\mathrm{cm^3/m^3}$	**302** × **213**						
306	$\varphi_{\mathrm{NO}_x,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**302** × **214**						
307	$\varphi_{\mathrm{CO,dry}}$	$\mathrm{cm^3/m^3}$	**302** × **215**						
308	$\varphi_{\mathrm{SO}_x,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**302** × **216**						
309	$\varphi_{\mathrm{UHC,dry}}$	$\mathrm{cm^3/m^3}$	**302** × **217**						
Conversion of the exhaust gas volumetric concentration to a dry reference exhaust gas with an oxygen content of 15 %									
400	$EV_{i,15,\mathrm{dry}}$ = exhaust gas emission value as volumetric concentration related to an oxygen volume content of 15 % in dry exhaust gas $EV_{i,15,\mathrm{dry}} = \frac{20{,}95-15}{20{,}95-\mathbf{303}} \cdot \varphi_{i,\mathrm{dry}}$								
401	$\frac{20{,}95-15}{20{,}95-\varphi_{\mathrm{O_2,dry}}}$	1	$\frac{5{,}95}{20{,}95-\mathbf{303}}$						
402	$EV_{\mathrm{NO},15,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**401** × **305**						
403	$EV_{\mathrm{NO}_x,15,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**401** × **306**						
404	$EV_{\mathrm{CO},15,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**401** × **307**						
405	$EV_{\mathrm{SO}_x,15,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**401** × **308**						
406	$EV_{\mathrm{UHC},15,\mathrm{dry}}$	$\mathrm{cm^3/m^3}$	**401** × **309**						
Conversion of the volumetric concentration $EV_{i,15,\mathrm{dry}}$ to a mass per reference volume at standard conditions									
500	$EM_{i,15,\mathrm{dry}}$ = exhaust gas emission value as pollutant concentration related to reference gas volume at standard conditions $EM_{i,15,\mathrm{dry}} = EV_{i,15,\mathrm{dry}}(M_i/V_{\mathrm{mn}})$								
501	$EM_{\mathrm{NO},15,\mathrm{dry}}$	$\mathrm{mg/m^3}$	1,338 7 × **402**						
502	$EM_{\mathrm{NO}_x,15,\mathrm{dry}}$ (as NO_2)	$\mathrm{mg/m^3}$	2,052 55 × **403**						
503	$EM_{\mathrm{CO},15,\mathrm{dry}}$	$\mathrm{mg/m^3}$	1,249 7 × **404**						
504	$EM_{\mathrm{SO}_x,15,\mathrm{dry}}$ (as SO_2)	$\mathrm{mg/m^3}$	2,858 × **405**						
505	$EM_{\mathrm{UHC},15,\mathrm{dry}}$ (UHCs as CH_4)	$\mathrm{mg/m^3}$	0,715 7 × **406**						

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Table A.2 *(concluded)*

Identification No.	Term	Unit	Calculation	1	2	3	4	5	Mean value
Calculation of power output related emission values									
600	$EM_{i,P}$ = power output related emission value $EM_{i,P} = 3{,}6\varphi_{i,\text{wet}} \times \frac{M_i}{M_\text{tot}} \times \frac{q_{m\text{g}7}}{P}$								
601	N_2	%	$100 - \mathbf{210}_\text{wet} - \mathbf{211}_\text{wet} - \mathbf{212}$						
602	M_tot	kg/kmol	[(**210** × 31,998 8) + (**211** × 44,009 8) + (**212** × 18,015 2) + (**601** × 28,158)]/100						
603	$\frac{q_{m\text{g}7}}{P}$	$\frac{\text{kg}}{\text{kW} \cdot \text{s}}$	$\frac{\mathbf{208}}{\mathbf{206}}$						
604	$EM_{\text{NO},P}$	g/kWh	$\mathbf{213}_\text{wet} \times \frac{108{,}02}{\mathbf{602}} \times \mathbf{603}$						
605	$EM_{\text{NO}_x,P}$	g/kWh	$\mathbf{214}_\text{wet} \times \frac{165{,}64}{\mathbf{602}} \times \mathbf{603}$						
606	$EM_{\text{CO},P}$	g/kWh	$\mathbf{215}_\text{wet} \times \frac{100{,}84}{\mathbf{602}} \times \mathbf{603}$						
607	$EM_{\text{SO}_x,P}$	g/kWh	$\mathbf{216}_\text{wet} \times \frac{230{,}61}{\mathbf{602}} \times \mathbf{603}$						
608	$EM_{\text{UHC},P}$	g/kWh	$\mathbf{217}_\text{wet} \times \frac{57{,}75}{\mathbf{602}} \times \mathbf{603}$						

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