BS ISO 8178-1:2020

BSI Standards Publication

Reciprocating internal combustion engines — Exhaust emission measurement

Part 1: Test-bed measurement systems of gaseous and particulate emissions

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National foreword

This British Standard is the UK implementation of ISO 8178-1:2020. It supersedes BS ISO 8178-1:2017, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee MCE/14/-/3, RIC Engines - Performance and emissions.

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

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© The British Standards Institution 2020
Published by BSI Standards Limited 2020

ISBN 978 0 539 06183 3

ICS 13.040.50; 27.020

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2020.

Amendments/corrigenda issued since publication

Date	Text affected

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INTERNATIONAL STANDARD

ISO 8178-1

Fourth edition
2020-06

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 1: Test-bed measurement systems of gaseous and particulate emissions

Moteurs alternatifs à combustion interne — Mesurage des émissions de gaz d'échappement —

Partie 1: Mesurage des émissions de gaz et de particules au banc d'essai

Reference number
ISO 8178-1:2020(E)

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Published in Switzerland

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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.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement.*

This fourth edition cancels and replaces the third edition (ISO 8178-1:2017), which has been technically revised.

The main changes compared to the previous edition are as follows:

— addition of provision to use alternative systems for ammonia analysis;

— improvement of weighing chamber and analytical balance specifications;

— insertion of general section on measurement instruments;

— revision of particle number measurement system requirements;

— addition concentration and expiration date for analytical gases;

— revision of the annex on carbon flow check;

— addition of the 1980 international gravity formula.

A list of all the parts in the ISO 8178 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

This document is intended for use as a measurement procedure to determine the gaseous and particulate emission levels of reciprocating internal combustion (RIC) engines for non-automotive use. Its purpose is to provide an engine's emissions characteristics which, through use of proper weighting factors and test cycles, can be used as an indication of that engine's emission levels under various applications and for different fuels. The emission results are expressed in units of grams per kilowatt-hour and represent the rate of emissions per unit of work accomplished.

Many of the procedures described in this document are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

Evaluating emissions from non-road engines is more complicated than the same task for on-road engines due to the diversity of non-road applications. For example, on-road applications primarily consist of moving a load from one point to another on a paved roadway. The constraints of the paved roadways, maximum acceptable pavement loads and maximum allowable grades of fuel, narrow the scope of on-road vehicle and engine sizes. Non-road engines and vehicles include a wider range of size, including the engines that power the equipment. Many of the engines are large enough to preclude the application of test equipment and methods that were acceptable for on-road purposes. In cases where the application of dynamometers is not possible, testing at site or under appropriate conditions can be a viable alternative.

In limited instances, the engine can be tested on the test bed in accordance with ISO 8178-2, to test in field conditions. This can only occur with the agreement of the parties involved. It should be recognized that data obtained under these circumstances may not agree completely with previous or future data obtained under the auspices of this document.

For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations, regulations for power plants), additional test conditions and special evaluation methods may apply.

Where it is not possible to use a test bed or where information is required on the actual emissions produced by an in-service engine, the site test procedures and calculation methods specified in ISO 8178-2 are appropriate.

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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 1: Test-bed measurement systems of gaseous and particulate emissions

1 Scope

This document specifies the measurement methods for gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines on a test bed, necessary for determining one weighted value for each exhaust gas pollutant. Various combinations of engine load and speed reflect different engine applications (see ISO 8178-4).

This document is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for motor vehicles primarily designed for road use. This document can be applied to engines used, for example, for earth-moving machines, generating sets and for other applications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 8178-4:2020, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Test cycles for different engine applications*

ASTM F1471–93, *Standard Test Method for Air Cleaning Performance of a High-Efficiency Particulate Air-Filter System*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
accuracy
absolute difference between the reference quantity, y_{ref}, and the arithmetic mean of the ten y_i, y values

Note 1 to entry: See the example of an accuracy calculation in Annex D.

Note 2 to entry: It is recommended that the instrument accuracy be within the specifications in Table 5.

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3.2
aqueous condensation
precipitation of water-containing constituents from a gas phase to a liquid phase

Note 1 to entry: Aqueous condensation is a function of humidity, pressure, temperature, and concentrations of other constituents such as sulphuric acid. These parameters vary as a function of engine intake-air humidity, dilution-air humidity, engine air-to-fuel ratio, and fuel composition - including the amount of hydrogen and sulphur in the fuel.

3.3
atmospheric pressure
wet, absolute, atmospheric static pressure

Note 1 to entry: If the atmospheric pressure is measured in a duct, negligible pressure losses shall be ensured between the atmosphere and the measurement location, and changes in the duct's static pressure resulting from the flow shall be accounted for.

3.4
calibration
process of setting a measurement system's response so that its output agrees with a range of reference signals

Note 1 to entry: Contrast with *verification* (3.51).

3.5
calibration gas
purified gas mixture used to calibrate gas analysers

Note 1 to entry: Calibration gases shall meet the specifications of 9.2.1. Note that calibration gases and *span gases* (3.37) are qualitatively the same, but differ in terms of their primary function. Various performance *verification* (3.51) checks for gas analysers and sample handling components might refer to either calibration gases or span gases.

3.6
certification
process of obtaining a certificate of conformity

3.7
conversion efficiency of non-methane cutter
conversion efficienty of NMC
E
efficiency of the conversion of an NMC that is used for the removal of the *non-methane hydrocarbons* (3.21) from the sample gas by oxidizing all hydrocarbons except methane

Note 1 to entry: Ideally, the conversion for methane is 0 % (E_{CH4} = 0) and for the other hydrocarbons represented by ethane is 100 % (E_{C2H6} = 100 %). For the accurate measurement of *NMHC* (3.21), the two efficiencies shall be determined and used for the calculation of the NMHC emission mass flow rate for methane and ethane. Contrast with *penetration fraction* (3.27).

3.8
delay time
difference in time between the change of the component to be measured at the reference point and a system response of 10 % of the final reading (t_{10}) with the sampling *probe* (3.28) being defined as the reference point

Note 1 to entry: For the gaseous components, this is the transport time of the measured component from the sampling probe to the detector (see Figure 1).

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3.9
dew point
measure of humidity stated as the equilibrium temperature at which water condenses under a given pressure from moist air with a given absolute humidity

Note 1 to entry: Dew point is specified as a temperature in °C or K, and is valid only for the pressure at which it is measured.

3.10
drift
difference between a zero or *calibration* (3.4) signal and the respective value reported by a measurement instrument immediately after it was used in an emission test

3.11
exhaust aftertreatment system
catalyst, particulate filter, $deNO_x$ system, combined $deNO_x$ particulate filter or any other emission-reducing device that is installed downstream of the engine

Note 1 to entry: This definition excludes exhaust gas recirculation (EGR) and turbochargers, which are considered an integral part of the engine.

3.12
full flow dilution
method of mixing the exhaust gas flow with dilution air prior to separating a fraction of the diluted exhaust gas flow for analysis

3.13
good engineering judgement
judgement made consistent with generally accepted scientific and engineering principles and available relevant information

3.14
HEPA filter
high-efficiency particulate air filter that is rated to achieve a minimum initial particle-removal efficiency of 99,97 % using ASTM F1471–93 or an equivalent standard

3.15
hydrocarbon
HC
hydrocarbon group on which the emission standards are based for each type of fuel and engine

EXAMPLE *THC* (3.47), *NMHC* (3.21) as applicable.

3.16
internationally recognized-traceable standard
international standard which includes but is not limited to the list quoted in Table 1

Table 1 — Internationally recognized-traceable standard

Internationally recognized standard	Where copies of the documents may be purchased
American Society for Testing and Materials (ASTM)	American Society for Testing and Materials, 100 Barr Harbour Dr., P.O. Box C700, West Conshohocken, PA 19428 or www.astm.com
International Organization for Standardization (ISO)	International Organization for Standardization, Case Postale 56, CH-1211 Geneva 20, Switzerland or www.iso.org
National Institute of Standards and Technology (NIST)	Government Printing Office, Washington, DC 20402 or download them free from the Internet at www.nist.gov
Society of Automotive Engineering (SAE)	Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096 or www.sae.org

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Table 1 *(continued)*

Internationally recognized standard	Where copies of the documents may be purchased
Institute of Petroleum	Energy Institute, 61 New Cavendish Street, London, W1G 7AR, UK, +44 (0)20 7467 7100 or www.energyinst.org.uk
The National Metrology Institute of Japan (NMIJ)	AIST Tsukuba Headquarters, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan or www.nmij.jp/english/info/
Japanese Industrial Standards (JIS)	Japanese Standards Association (JSA), 4-1-12 Akasaka, Minato-ku, 107-8440, Japan or www.jsa.org.jp/default_english.asp

3.17
isokinetic sampling
process of controlling the flow of the exhaust sample by maintaining the mean sample velocity at the *probe* (3.28) equal to the exhaust stream mean velocity

3.18
linearity
degree to which measured values agree with respective reference values

Note 1 to entry: Linearity is quantified using a linear regression of pairs of measured values and reference values over a range of values expected or observed during testing.

3.19
multiple-filter method
process of using one filter for each of the individual *test cycle* (3.44) modes

Note 1 to entry: The modal weighting factors are accounted for after sampling during the data evaluation phase of the test.

3.20
noise
two times the root-mean-square of the ten standard deviations (that is, $N = 2 \times y_{\mathrm{RMS}(\sigma)}$) when the reference signal is a zero-quantity signal

Note 1 to entry: See the example of a root-mean-square calculation in Annex D. It is recommended that the instrument noise be within the specifications in Table 5.

3.21
non-methane hydrocarbons
NMHC
sum of all *hydrocarbon* (3.15) species except methane

3.22
operator demand
engine operator's input to control engine output

Note 1 to entry: The "operator" may be a person (i.e., manual), or a governor (i.e., automatic) that mechanically or electronically signals an input that demands engine output. Input may be from an accelerator pedal or signal, a throttle-control lever or signal, a fuel lever or signal, a speed lever or signal, or a governor setpoint or signal. Output means engine power, *P*, which is the product of engine speed, *n*, and engine torque, *T*.

3.23
oxides of nitrogen
NO_x
compounds containing only nitrogen and oxygen as measured by the *procedures* (3.29) specified in this document

Note 1 to entry: Oxides of nitrogen are expressed quantitatively as if the NO is in the form of NO_2, such that an effective molar mass is used for all oxides of nitrogen equivalent to that of NO_2.

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3.24
partial pressure
pressure, p, attributable to a single gas in a gas mixture

Note 1 to entry: For an ideal gas, the partial pressure divided by the total pressure is equal to the constituent's molar concentration, x.

3.25
partial flow dilution
method of analysing the exhaust gas whereby a part of the total exhaust gas flow is separated and then mixed with an appropriate amount of dilution air prior to reaching the particulate sampling filter

3.26
particulate matter
PM
material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature and a point as specified in 8.1.4, primarily carbon, condensed *hydrocarbons* (3.15), and sulphates with associated water

3.27
penetration fraction
PF
deviation from ideal functioning of a non-methane cutter

Note 1 to entry: See *conversion efficiency of non-methane cutter* (NMC), E (3.7).

Note 2 to entry: An ideal non-methane cutter would have a methane penetration factor, $f_{\mathrm{PF\ CH4}}$, of 1,000 (that is, a methane conversion efficiency E_{CH4} of 0), and the penetration fraction for all other *hydrocarbons* (3.15) would be 0,000, as represented by $f_{\mathrm{PF\ C2H6}}$ (that is, an ethane conversion efficiency E_{C2H6} of 1). The relationship is: $f_{\mathrm{PF\ CH4}} = 1 - E_{\mathrm{CH4}}$ and $f_{\mathrm{PF\ C2H6}} = 1 - E_{\mathrm{C2H6}}$.

3.28
probe
first section of the transfer tube which transfers the sample to next component in the sampling system

3.29
procedures
all aspects of engine testing, including the equipment specifications, *calibrations* (3.4), calculations and other protocols and specifications needed to measure emissions, unless otherwise specified

3.30
ramped-modal test
test cycle (3.44) with a sequence of steady state engine test modes with defined speed and torque criteria at each mode and defined speed and torque ramps between these modes

3.31
regeneration
event during which emissions levels change while the aftertreatment performance is being restored by design

Note 1 to entry: Two types of regeneration can occur: continuous regeneration (see ISO 8178-4:2020, 5.5.1.2.1) and infrequent (periodic) regeneration (see ISO 8178-4:2020, 5.5.1.2.2);

3.32
repeatability
two times the standard deviation of the ten errors, i.e. $r = 2\sigma_{\varepsilon}$

Note 1 to entry: See the example of a standard-deviation calculation in Annex D. It is recommended that the instrument repeatability be within the specifications shown in Table 5.

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3.33
response time
difference in time between the change of the component to be measured at the reference point and a system response of 90 % of the final reading (t_{90}) with the sampling *probe* (3.28) being defined as the reference point, whereby the change of the measured component is at least 60 % full scale (FS) and the devices for gas switching shall be specified to perform the gas switching in less than 0,1 s

Note 1 to entry: The system response time consists of the *delay time* (3.8) to the system and of the *rise time* (3.34) of the system.

3.34
rise time
difference in time of the 10 % and 90 % response of the final reading ($t_{90} - t_{10}$)

3.35
single-filter method
process of using one filter for all *test cycle* (3.44) modes

Note 1 to entry: Modal weighting factors shall be accounted for during the particulate sampling phase of the test cycle by adjusting sample flow rate and/or sampling time. This method dictates that particular attention be given to sampling duration and flow rates.

3.36
span, verb
adjust an instrument so that it gives a proper response to a *calibration* (3.4) standard that represents between 75 % and 100 % of the maximum value in the instrument range or expected range of use

3.37
span gas
purified gas mixture used to *span* (3.36) gas analysers

Note 1 to entry: Span gases shall meet the specifications of 9.2.1. Note that *calibration gases* (3.5) and span gases are qualitatively the same, but differ in terms of their primary function. Various performance *verification* (3.51) checks for gas analysers and sample handling components might refer to either calibration gases or span gases.

3.38
span response
mean response, including *noise* (3.20), to a *span gas* (3.37) during a 30 s time interval

3.39
specific emissions
mass emissions expressed in g/kWh

3.40
stand-alone
having no dependencies

3.41
steady-state
relating to emission tests in which engine speed and load are held at a finite set of nominally constant values

Note 1 to entry: Steady-state tests are either discrete-mode tests or ramped-modal tests (3.30).

3.42
stoichiometric
relating to the particular ratio of air and fuel such that if the fuel were fully oxidized, there would be no remaining fuel or oxygen

3.43
storage medium
particulate filter, sample bag, or any other storage device used for batch sampling

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3.44
test cycle
duty cycle
sequence of test points each with a defined speed and torque to be followed by the engine under steady state or transient operating conditions

Note 1 to entry: Duty cycles are specified in ISO 8178-4:2020, Annexes A to C. A single duty cycle may consist of one or more *test intervals* (3.45).

3.45
test interval
duration of time over which brake-specific emissions are determined

Note 1 to entry: In cases where multiple test intervals occur over a *duty cycle* (3.44), the regulation can specify additional calculations that weigh and combine results to arrive at composite values for comparison against the applicable emission limits.

3.46
tolerance
interval in which 95 % of a set of recorded values of a certain quantity lies, with the remaining 5 % of the recorded values deviating from the tolerance interval, using the specified recording frequencies and time intervals to determine if a quantity is within the applicable tolerance

3.47
total hydrocarbon
THC
combined mass of organic compounds measured by the specified procedure for measuring total hydrocarbon

Note 1 to entry: Total hydrocarbon is expressed as a *hydrocarbon* (3.15) with a hydrogen-to-carbon mass ratio of 1,85 (Diesel), 1,93 (petrol (E10)), 2,525 (LPG), 4,0 (NG/biomethane) or 2,74 (ethanol (E85)).

3.48
transformation time
difference in time between the change of the component to be measured at the reference point and a system response of 50 % of the final reading (t_{50}) with the sampling *probe* (3.28) being defined as the reference point

Note 1 to entry: The transformation time is used for the signal alignment of different measurement instruments (see Figure 1).

3.49
transient test cycle
test cycle (3.44) with a sequence of normalized speed and torque values that vary relatively quickly with time

Note 1 to entry: See ISO 8178-4:2020, 7.6.

3.50
updating-recording
frequency at which the analyser provides new, current values

3.51
verification
evaluation of whether or not a measurement system's outputs agree with a range of applied reference signals to within one or more predetermined thresholds for acceptance

Note 1 to entry: Contrast with *calibration* (3.4).

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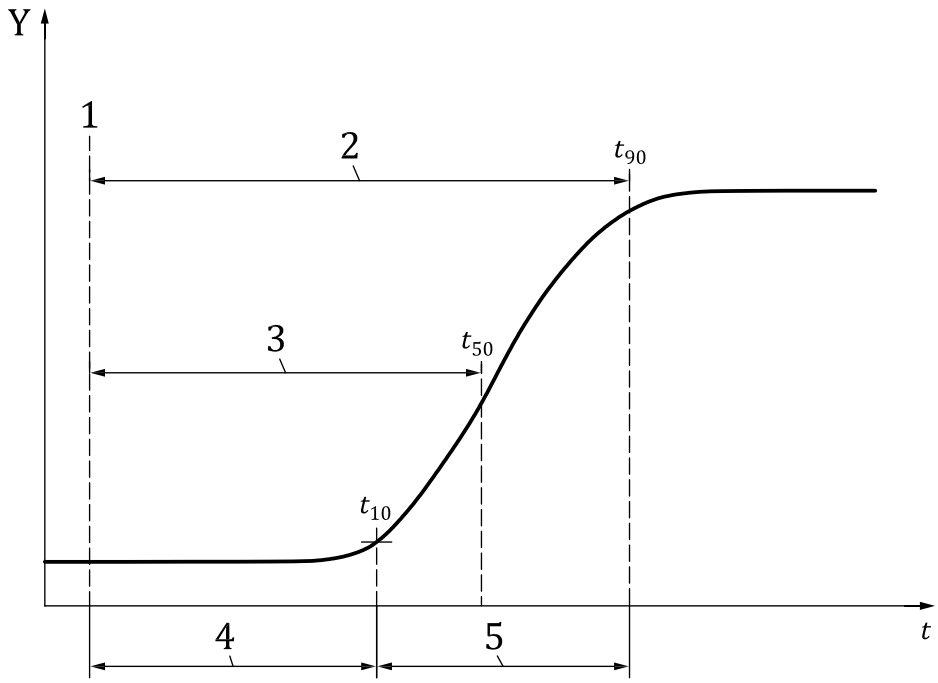
3.52
zero, verb
adjust an instrument, so it gives a *zero response* (3.54) to a zero *calibration* (3.4) standard, such as purified nitrogen or purified air

3.53
zero gas
gas that yields a *zero response* (3.54) in an analyser

Note 1 to entry: This may either be purified nitrogen, purified air, a combination of purified air and purified nitrogen.

3.54
zero response
mean response, including *noise* (3.20), to a *zero gas* (3.53) during a 30 s time interval



Key

1	step input time	5	*rise time* (3.34)
2	*response time* (3.33)	t	time
3	*transformation time* (3.48)	Y	response
4	*delay time* (3.8)		

Figure 1 — Definitions of system response: delay time, response time, rise time and transformation time

4 Symbols and abbreviated terms

4.1 General symbols

For the purposes of this document, the general symbols given in Table 2 apply.

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Table 2 — General symbols

Symbol	Term	Unit
a_0	y intercept of the regression line	—
a_1	Slope of the regression line	—
C_d	CFV discharge coefficient [-]	—
d	Diameter	m
E	Conversion efficiency	%
E_E	Ethane efficiency	%
F	F-test statistics	
f_{PF}	Penetration fraction	%
H_m	Highest expected water vapour concentration	%
m	Mass	kg
m_{ex}	Total mass of diluted exhaust	kg
m_f	Particulate sample mass collected	mg
m_{PM}	Mass of particulate emissions over the test cycle	g
m_{sed}	Mass of diluted exhaust gas passing the dilution tunnel	kg
μ	Dynamic viscosity of exhaust gas	Pa*s
n	Engine speed	min^{-1}
P	Power	kW
p	Pressure	kPa
p_a	Absolute pressure	kPa
p_{total}	Total atmospheric pressure	kPa
q_{ex}	Particle number sample mass flow rate	kg/s
q_{maw}	Intake air mass flow rate on wet basis	kg/s
q_{mdew}	Diluted exhaust gas mass flow rate on wet basis	kg/s
q_{mdw}	Dilution air mass flow rate on wet basis	kg/s
q_{mew}	Exhaust gas mass flow rate on wet basis	kg/s
q_{mf}	Fuel mass flow rate	kg/s
q_{mp}	Sample flow of exhaust gas into partial flow dilution system	kg/s
q_{VCSV}	Air flow rate	m^3/s
q_{sw}	Mass flow rate fed back into dilution tunnel to compensate for particle number sample extraction	kg/s
q_V	Volume flow rate	m^3/s
R	molar gas constant	J/(mol K)
Re	Reynolds number	—
r^2	Coefficient of determination	—
r_d	Dilution ratio	—
r_m	Methanol response factor of the FID	—
r_x	Ratio of the SSV throat to inlet absolute, static pressure	—
r_y	Ratio of the SSV throat diameter, d, to the inlet pipe inner diameter (d_{in})	—
ρ	Density	kg/m^3
S_{EE}	Standard error of estimate of y on x	—
σ	Standard deviation	
T	Temperature	°C
T	Engine torque	Nm
$T_{chiller}$	Absolute chiller temperature	K

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Table 2 *(continued)*

Symbol	Term	Unit
T_{dew}	Absolute dew point temperature	K
t	Time	s
t_0	Time between step input and 0 % of final reading	s
t_{10}	Time between step input and 10 % of final reading	s
t_{50}	Time between step input and 50 % of final reading	s
t_{90}	Time between step input and 90 % of final reading	s
V	Volume	m^3
ν	Kinematic viscosity	m^2/s
W	Work	kWh
x	Concentration	µmol/mol or %

4.2 Symbols for fuel composition

w_H hydrogen content of fuel, % mass

w_C carbon content of fuel, % mass

w_S sulphur content of fuel, % mass

w_N nitrogen content of fuel, % mass

w_O oxygen content of fuel, % mass

α molar hydrogen-to-carbon ratio (H/C)

β molar carbon-to-carbon ratio (C/C)

γ molar sulphur-to-carbon ratio (S/C)

δ molar nitrogen-to-carbon ratio (N/C)

ε molar oxygen-to-carbon ratio (O/C)

NOTE The conversion between mass content and molar ratio is given in ISO 8178-4:2020, Formula D.3.

4.3 Symbols and abbreviated terms for the chemical components

ACN Acetonitrile

C_x Carbon x equivalent hydrocarbon

C_2H_6 Ethane

C_3H_8 Propane

CH_3OH Methanol

CH_4 Methane

CO Carbon monoxide

CO_2 Carbon dioxide

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DNPH	Dinitrophenyl hydrazine
H	Atomic hydrogen
H_2	Molecular hydrogen
H_2O	Water
HCHO	Formaldehyde
He	Helium
N_2	Molecular nitrogen
N_2O	Nitrous oxide
NH_3	Ammonia
NO	Nitric oxide
NO_2	Nitrogen dioxide
O_2	Oxygen
S	Sulphur
SO_2	Sulphur dioxide

4.4 Abbreviated terms

ASTM	American Society for Testing and Materials
CFV	Critical flow venturi
CI	Compression-ignition
CLD	Chemiluminescent detector
CVS	Constant volume sampling
deNOx	NO_x after-treatment system
DAF	Dilution air filter
DC	Damping chamber
DPT	Differential pressure transducer
DT	Dilution tunnel
EDL	Electrode-less discharge lamp
EFC	Electronic flow compensation
EGR	Exhaust gas recirculation
EP	Exhaust pipe
ET	Evaporation tube
FC	Flow controller

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FD	Flow divider
FH	Filter holder
FID	Flame ionization detector
FL	Flow meter
FM	Flow measurement device
FS	Full scale
FTIR	Fourier transform infrared (analyser)
GC	Gas chromatograph
HCLD	Heated chemiluminescent detector
HE	Heat exchanger
HEPA	High-efficiency particulate air
HFID	Heated flame ionization detector
HSL	Heated sampling line
HPLC	High-performance liquid chromatograph
IR	Infrared
ISO	International Organization for Standardization
LPG	Liquefied Petroleum Gas
NDIR	Non-dispersive infrared (analyser)
NDUV	Non-dispersive ultraviolet (analyser)
NDUV-RAS	Non-dispersive ultraviolet – resonant absorption spectroscopy
NMC	Non-methane cutter
OT	Outlet tube
PCF	Particle pre-classifier
PDP	Positive displacement pump
PF	Penetration fraction
PFD	Partial flow dilution
PM	Particulate matter
PMD	Paramagnetic detector
PN	Particle number
PNC	Particle number counter
PND	Particle number diluter

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PSP	Particulate Sampling probes
PTFE	Polytetrafluoroethylene (commonly known as Teflon®[a])

[a] Teflon® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

PTS	Particle transfer system
PTT	Particle transfer tube
QCL	Quantum cascade laser (analyser)
RIC	Reciprocating internal combustion (engines)
RTD	Resistive temperature detector
SAE	Society of Automotive Engineers
SSV	Subsonic venturi
TDL	Tunable diode laser (analyser)
UFM	Ultrasonic flow meter
UV	Ultraviolet
V	Valve
VPR	Volatile particle remover

5 General measurement principles

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in Clauses 6 to 8. These clauses describe the engine and ambient related measurement systems (Clause 6), the analytical systems for the gaseous emissions (Clause 7) and the particulate sampling systems (Clause 8). The system calibration procedures are described in Clause 9.

Test cycles and emissions calculations are not part of this document. They are included in ISO 8178-4.

Other systems or analysers may be accepted if they yield equivalent results. The determination of system equivalency shall be based on a seven-sample pair (or larger) correlation study between the system under consideration and one of the accepted systems of this document. “Results” refers to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, test cell, and on the same engine. The tests should be run concurrently. The test cycle to be used shall be the appropriate cycle as found in ISO 8178-4. The equivalency of the sample pair averages shall be determined by *F*-test and *t*-test statistics (see Annex D), with outliers excluded, obtained under the laboratory cell and the engine conditions described above. The systems to be used for correlation testing shall be declared prior to the test and shall be agreed upon by the parties involved.

For introduction of a new system into this document, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725-2.

5.1 Principle of emission measurement

To measure the brake-specific emissions the engine shall be operated over the test cycles defined in ISO 8178-4, as applicable. The measurement of brake-specific emissions requires the determination of the mass of pollutants in the exhaust and the corresponding engine work.

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5.1.1 Mass of constituent

The total mass of each constituent shall be determined over the applicable test cycle by using the following methods:

5.1.1.1 Continuous sampling

In continuous sampling, the constituent's concentration is measured continuously from raw or dilute exhaust. This concentration is multiplied by the continuous (raw or diluted) exhaust flow rate at the emission sampling location to determine the constituent's flow rate. The constituent's emission is continuously summed over the test interval. This sum is the total mass of the emitted constituent.

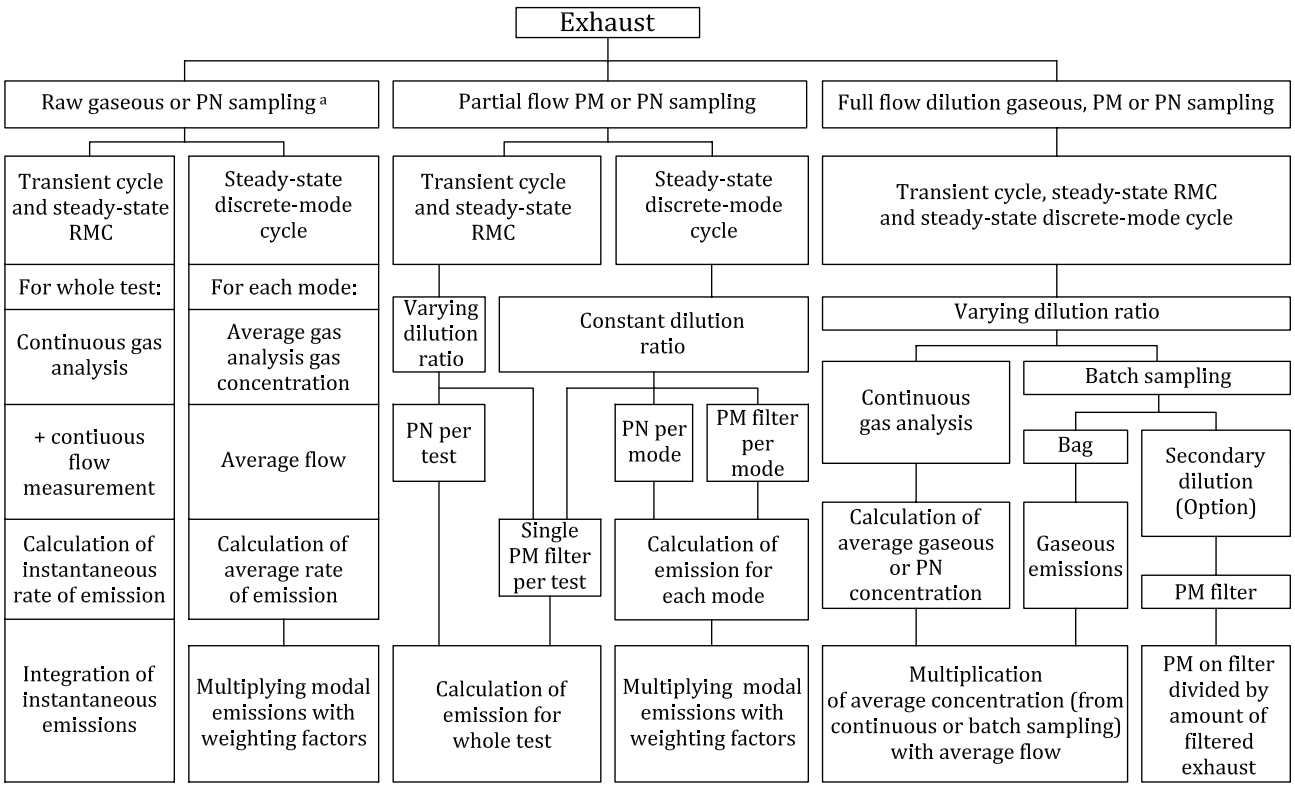
5.1.1.2 Batch sampling

In batch sampling, a sample of raw or dilute exhaust is continuously extracted and stored for later measurement. The extracted sample shall be proportional to the raw or dilute exhaust flow rate. Examples of batch sampling are collecting diluted gaseous emissions in a bag and collecting PM on a filter. In principal the method of emission calculation is done as follows: the batch sampled concentrations are multiplied by the total mass or mass flow (raw or dilute) from which it was extracted during the test cycle. This product is the total mass or mass flow of the emitted constituent. To calculate the PM concentration, the PM deposited onto a filter from proportionally extracted exhaust shall be divided by the amount of filtered exhaust.

5.1.1.3 Combined sampling

Any combination of continuous and batch sampling is permitted (e.g. PM with batch sampling and gaseous emissions with continuous sampling).

Figure 2 illustrates the two aspects of the test procedures for measuring emissions: the equipment with the sampling lines in raw and diluted exhaust gas and the operations requested to calculate the pollutant emissions in steady-state and transient test cycles.



a A proportional or constant diluter should be applied for PN measurement (see Figure 14).

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NOTE The term "Partial flow PM sampling" includes the partial flow dilution to extract only raw exhaust with constant or varying dilution ratio.

Figure 2 — Test procedures for emission mass measurement

5.2 Exhaust sampling and dilution

5.2.1 General sampling requirements

5.2.1.1 Probe design and construction

A probe is the first fitting in a sampling system. It protrudes into a raw or diluted exhaust stream to extract a sample, such that its inside and outside surfaces are in contact with the exhaust. A sample is transported out of a probe into a transfer tube.

Sample probes shall be made with inside surfaces of stainless steel or, for raw exhaust sampling, with any non-reactive material capable of withstanding raw exhaust temperatures. Sample probes shall be located where constituents are mixed to their mean sample concentration and where interference with other probes is minimised. All probes should remain free from influences of boundary layers, wakes, and eddies – especially near the outlet of a raw-exhaust tailpipe where unintended dilution might occur. Purging or back-flushing of a probe shall not influence another probe during testing. A single probe to extract a sample of more than one constituent may be used as long as the probe meets all the specifications for each constituent.

5.2.1.2 Transfer tubes

Transfer tubes that transport an extracted sample from a probe to an analyser, storage medium, or dilution system shall be minimized in length by locating analysers, storage media, and dilution systems as close to the probes as practical. The number of bends in transfer tubes shall be minimized and that the radius of any unavoidable bend shall be maximized.

5.2.1.3 Sampling methods

For continuous and batch sampling, introduced in 5.1.1, the following conditions apply:

a) when extracting from a constant flow rate, the sample shall also be carried out at a constant flow rate;

b) for batch sampling, when extracting from a varying flow rate, the sample flow rate shall be varied in proportion to the varying flow rate;

c) proportional sampling shall be validated as described in ISO 8178-4:2020, 8.2.1.

Gaseous constituents may be measured raw or diluted whereas PM and PN measurements require dilution.

5.2.2 Gas sampling

5.2.2.1 Sampling probes

Either single-port or multi-port probes are used for sampling gaseous emissions. The probes may be oriented in any direction relative to the raw or diluted exhaust flow. For some probes, the sample temperatures shall be controlled, as follows:

a) for probes that extract NO_x from diluted exhaust, the probe's wall temperature shall be controlled to prevent aqueous condensation;

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b) for probes that extract hydrocarbons from the diluted exhaust, the probe wall temperature should be controlled to approximately 191 °C to minimise contamination.

5.2.2.2 Transfer tubes

Transfer tubes with inside surfaces of stainless steel, PTFE, Viton®[1)], or any other material that has better properties for emission sampling shall be used. A non-reactive material capable of withstanding exhaust temperatures shall be used. In-line filters may be used if the filter and its housing meet the same temperature requirements as the transfer tubes, as follows:

a) for NO_x transfer tubes upstream of either an NO_2-to-NO converter that meets the specifications of 9.4 or a chiller that meets the specifications of 9.5.9.3 a sample temperature that prevents aqueous condensation shall be maintained;

b) for THC transfer tubes a wall temperature tolerance throughout the entire line of (191 ± 11) °C shall be maintained. If sampled from raw exhaust, an unheated, insulated transfer tube may be connected directly to a probe. The length and insulation of the transfer tube shall be designed to cool the highest expected raw exhaust temperature to no lower than 191 °C, as measured at the transfer tube outlet. For dilute sampling a transition zone between the probe and transfer tube of up to 0,92 m in length is allowed to transition the wall temperature to (191 ± 11) °C.

5.2.2.3 Sample-conditioning components

5.2.2.3.1 Sample dryers

The instrument that is used for removing moisture shall meet the minimum requirements in the following paragraph. The moisture content of 0,8 volume % H_2O is used in ISO 8178-4:2020, Formula (43).

For the highest expected water vapour concentration H_m, the water removal technique shall maintain CLD humidity at ≤5 g water/kg dry air (or about 0,8 volume % H_2O), which is 100 % relative humidity at 3,9 °C and 101,3 kPa. This humidity specification is also equivalent to about 25 % relative humidity at 25 °C and 101,3 kPa. This may be demonstrated by measuring the temperature at the outlet of a thermal dehumidifier, or by measuring humidity at a point just upstream of the CLD.

Either type of sample dryer described in this subclause to decrease the effects of water on gaseous emission measurements may be used.

a) If an osmotic-membrane dryer upstream of any gaseous analyser or storage medium is used, it shall meet the temperature specifications in 5.2.2.2. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of an osmotic-membrane dryer shall be monitored. The amount of water shall be calculated as specified in ISO 8178-4:2020, H.3.2 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the dryer's lowest absolute pressure expected during testing.

b) A thermal chiller upstream of a THC measurement system for compression-ignition engines may not be used. If a thermal chiller upstream of an NO_2-to-NO converter or in a sampling system without an NO_2-to-NO converter is used, the chiller shall meet the NO_2 loss-performance check specified in 9.5.9.3. The dew point, T_{dew}, and absolute pressure, p_{total}, downstream of a thermal chiller shall be monitored. The amount of water shall be calculated as specified in ISO 8178-4:2020, Annex H.3.2 by using continuously recorded values of T_{dew} and p_{total} or their peak values observed during a test or their alarm set points. Lacking a direct measurement, the nominal p_{total} is given by the thermal chiller's lowest absolute pressure expected during testing. If it is valid to assume the degree of saturation in the thermal chiller, T_{dew} based on the known chiller efficiency and continuous monitoring of chiller temperature, $T_{chiller}$ may be calculated. If values of $T_{chiller}$ are not

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continuously recorded, its peak value observed during a test, or its alarm setpoint, may be used as a constant value to determine a constant amount of water according to ISO 8178-4:2020, H.3.2. If it is valid to assume that $T_{chiller}$ is equal to T_{dew}, $T_{chiller}$ may be used in lieu of T_{dew} according to ISO 8178-4:2020, Annex H. If it is valid to assume a constant temperature offset between $T_{chiller}$ and T_{dew}, due to a known and fixed amount of sample reheat between the chiller outlet and the temperature measurement location, this assumed temperature offset value may be factored in into emission calculations. The validity of any assumptions allowed by this subclause shall be shown by engineering analysis or by data.

5.2.2.3.2 Sample pumps

Sample pumps upstream of an analyser or storage medium for any gas shall be used. Sample pumps with inside surfaces of stainless steel, PTFE, or any other material having better properties for emission sampling shall be used. For some sample pumps, temperatures shall be controlled, as follows:

a) if a NO_x sample pump upstream of either an NO_2-to-NO converter that meets the specification of 9.4 or a chiller that meets the specification of 9.5.9.3 is used, it shall be heated to prevent aqueous condensation;

b) if a THC sample pump upstream of a THC analyser or storage medium is used, its inner surfaces shall be heated to a tolerance of (191 ± 11) °C.

5.2.2.3.3 Ammonia scrubbers

Ammonia scrubbers may be used for any or all gaseous sampling system to prevent NH_3 interference, poisoning of NO_2-to-NO converter, and deposits in the sampling system or analysers. Follow the ammonia scrubber manufacturer recommendations or use good engineering in applying ammonia scrubbers.

5.2.2.3.4 Sample storage media

In the case of bag sampling, gas volumes shall be stored in sufficiently clean containers that minimally off-gas or allow permeation of gases. Good engineering judgment shall be used to determine acceptable thresholds of storage media cleanliness and permeation. To clean a container, it may be repeatedly purged and evacuated and may be heated. A flexible container (such as a bag) within a temperature-controlled environment, or a temperature controlled rigid container that is initially evacuated or has a volume that can be displaced, such as a piston and cylinder arrangement, shall be used. Containers meeting the specifications in Table 3 shall be used.

Table 3 — Gaseous batch sampling container materials

CO, CO_2, 0_2, CH_4,C_2H_6, C_3H_8, NO, NO_2[a]	polyvinyl fluoride (PVF)[b], polyvinylidene fluoride[b], polytetrafluoroethylene[c], or stainless steel[c]
THC, NMHC	polytetrafluoroethylen[d] or stainless steel[d]

[a] As long as aqueous condensation in storage container is prevented.

[b] Up to 40 °C.

[c] Up to 202 °C.

[d] At (191 ± 11) °C.

5.2.3 Raw sampling for gaseous emissions

The gaseous emissions sampling probes shall be fitted at least 0,5 m or three times the diameter of the exhaust pipe – whichever is the larger – upstream of the exit of the exhaust gas system but sufficiently close to the engine so as to ensure an exhaust gas temperature of at least 70 °C at the probe.

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In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emissions from all cylinders.

In multi-cylinder engines having distinct groups of manifolds, such as in a "V" engine configuration, instead of taking a sample for the combined flow it is permissible to acquire a sample from each group individually and combine flows and concentrations. Methods may be chosen based on good engineering practice and shall comply with either one of the following requirements:

a) Simultaneous determination of both concentration and exhaust mass flow within each group. The determination may be performed for all groups simultaneously or the test may be repeated for each group sequentially. The emissions shall be calculated for each group from the concentration and exhaust mass flow. The overall result shall be determined by mathematical combination of the emissions from each group.

b) Methods that do not comply with the requirements of section a). In this case it shall be demonstrated to the satisfaction of the parties concerned that the resulting error in the engine emission calculation will not exceed 2 %.

If the composition of the exhaust gas is influenced by any exhaust aftertreatment system, the exhaust sample shall be taken downstream of this device.

For engines with water injection into exhaust system for the purpose of cooling, or noise reduction, the inlet of the probe shall be located so as to avoid ingestion of water, for example a hatted probe may be used.

For spark-ignition engines, sampling may be done in the high-pressure side of the muffler, but as far from the exhaust port as possible. A mixing chamber may be optionally inserted between the muffler outlet and the sample probe. The internal volume of the mixing chamber shall be not less than 10 times the cylinder displacement of the engine under test and should have roughly equal dimensions in height, width and depth. The mixing chamber size should be kept as small as practicable and should be coupled as close as possible to the engine. The exhaust line leaving the mixing chamber should extend at least 610 mm beyond the sample probe location and be of sufficient size to minimize back pressure. The temperature of the inner surface of the mixing chamber shall be maintained above the dew point of the exhaust gases and a minimum temperature of 65 °C is recommended.

5.2.4 Dilute sampling for gaseous emissions

When a full-flow dilution system is used for the determination of the particulates, the gaseous emissions may also be determined in the diluted exhaust gas. The sampling probes shall be close to the particulate sampling probe (PSP) in the dilution tunnel (DT) (see 8.3.3).

For compression-ignition engines, HC and NO_x shall be measured by direct sampling from the dilution tunnel. Alternatively, if the relative temperatures (5.2.2) are met, sampling in a bag and subsequent measurement of the concentration may be used. CO and CO_2 may optionally be determined by direct measurement or by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

For spark-ignition engines and gas-fuelled engines, all components may optionally be measured directly in the dilution tunnel, or by sampling into a bag and subsequent measurement of the concentration in the sampling bag.

5.2.5 Dilution system

Dilution may be accomplished by a full flow or partial flow dilution system. When dilution is applied the exhaust may be diluted with ambient air, purified air, or nitrogen. For gaseous emissions measurement the temperature of the diluent shall be at least 15 °C. For PM sampling the temperature of the diluent is specified in 5.2.5.3 for CVS and 5.2.5.1 for PFD with varying dilution ratio. The flow capacity of the dilution system shall be large enough to completely eliminate water condensation in the dilution and sampling systems. De-humidifying the dilution air before entering the dilution system is permitted, if

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the air humidity is high. The dilution tunnel walls may be heated or insulated as well as the bulk stream tubing downstream of the tunnel to prevent aqueous condensation.

Before a diluent is mixed with exhaust, it may be preconditioned by increasing or decreasing its temperature or humidity. Constituents may be removed from the diluent to reduce their background concentrations. The following provisions apply to removing constituents or accounting for background concentrations:

a) constituent concentrations in the diluent may be measured and compensated for background effects on test results. See ISO 8178-4:2020, Clause 9 and H.6.1 for calculations that compensate for background concentrations;

b) to account for background PM the following options are available:

   1) for removing background PM, the diluent shall be filtered with high-efficiency particulate air (HEPA) filters that have an initial minimum collection efficiency specification of 99,97 % using ASTM F1471–93 or an equivalent standard;

   2) for correcting for background PM without HEPA filtration, the background PM shall not contribute more than 50 % of the net PM collected on the sample filter;

   3) background correction of net PM with HEPA filtration is permitted without restriction;

c) the following changes to the requirements of 5.2, Clause 7 and Clause 8 are permitted for taking a background sample of dilution air and measuring gaseous or particulate pollutants therein:

   1) it shall not be required to use proportional sampling;

   2) unheated sampling systems may be used;

   3) continuous sampling may be used irrespective of the use of batch sampling for diluted emissions;

   4) batch sampling may be used irrespective of the use of continuous sampling for diluted emissions.

5.2.5.1 Partial-flow dilution system

The temperature of the diluents (ambient air, purified air, or nitrogen as quoted in 5.2.5) shall be maintained between 20 °C to 52 °C in close proximity to the entrance into the dilution tunnel.

The partial flow dilution system has to be designed to extract a proportional raw exhaust sample from the engine exhaust stream, thus responding to excursions in the exhaust stream flow rate, and introduce dilution air to this sample to achieve a temperature at the test filter as prescribed by 8.1.4. For this it is essential that the dilution ratio be determined such that the accuracy requirements of 9.8.6.1 are fulfilled.

To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flow meter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flow meter inlet measured. The PFD system may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel.

The minimum dilution ratio shall be within the range of 5:1 to 7:1 based on the maximum engine exhaust mass flow rate during the test cycle or test interval.

The residence time in the system shall be between 0,5 s and 5 s, as measured from the point of diluent introduction to the filter holder(s).

The partial-flow system shall be designed to extract a raw exhaust sample from the engine exhaust stream, introduce dilution air into this sample and subsequently measure the particulates in the diluted sample. From that it is essential that the dilution ratio be determined very accurately.

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Splitting of the exhaust stream and the following dilution process may be done by different dilution system types. For subsequent collection of the particulates, the entire dilute exhaust gas or only a portion of the dilute exhaust gas is passed to the particulate sampling system (see Figures E.1 to E.8). The first method is referred to as total-sampling type, the second method as fractional-sampling type. The calculation of the dilution ratio depends upon the type of system used. Examples of partial-flow dilution system layouts are shown in Annex E.

5.2.5.2 Applicability

PFD may be used to extract a proportional raw exhaust sample for any batch or continuous PM and gaseous emission sampling over any transient duty cycle, any discrete steady-state duty cycle or any ramped-modal steady state duty cycle.

The system may be used also for a previously diluted exhaust where, via a constant dilution-ratio, an already proportional flow is diluted (see Figure 8). This is the way of performing secondary dilution from a CVS tunnel to achieve the necessary overall dilution ratio for PM sampling.

The particulate sampling probe shall be fitted close to and upstream of the gaseous probe as defined in 5.2.2.1. See Annex E.

5.2.5.3 Full-flow dilution system

Full-flow dilution; constant-volume sampling (CVS). The full flow of raw exhaust is diluted in a dilution tunnel. Constant flow may be maintained by maintaining the temperature and pressure at the flow meter within the limits. For non-constant flow the flow shall be measured directly to allow for proportional sampling. The system shall be designed as follows (see example in Figure 9):

a) A tunnel with inside surfaces of stainless steel shall be used. The entire dilution tunnel shall be electrically grounded; thin walled and insulated if needed to reduce temperature difference between walls and exhaust gas.

b) The exhaust system backpressure shall not be artificially lowered by the dilution air inlet system. The static pressure at the location where raw exhaust is introduced into the tunnel shall be maintained within ±1,2 kPa of atmospheric pressure.

c) To support mixing the raw exhaust shall be introduced into the tunnel by directing it downstream along the centreline of the tunnel. A fraction of dilution air maybe introduced radially from the tunnel's inner surface to minimize exhaust interaction with the tunnel walls.

d) Diluent. For PM sampling the temperature of the diluents (ambient air, purified air, or nitrogen as quoted in 5.2.5) shall be maintained between 20 °C to 52 °C in close proximity to the entrance into the dilution tunnel.

e) The Reynolds number, *Re*, shall be at least 4 000 for the diluted exhaust stream, where *Re* is based on the inside diameter of the dilution tunnel. *Re* is defined in 9.8.4.2 and in ISO 8178-4:2020, H.8.4. Verification of adequate mixing shall be performed while traversing a sampling probe across the tunnel's diameter, vertically and horizontally. If the analyser response indicates any deviation exceeding ±2 % of the mean measured concentration, the CVS shall be operated at a higher flow rate or a mixing plate or orifice shall be installed to improve mixing.

f) Flow measurement preconditioning. The diluted exhaust may be conditioned before measuring its flow rate, as long as this conditioning takes place downstream of heated HC or PM sample probes, as follows:

   1) flow straighteners, pulsation dampeners, or both of these may be used;

   2) a filter may be used;

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3) a heat exchanger may be used to control the temperature upstream of any flow meter but steps shall be taken to prevent aqueous condensation.

g) Aqueous condensation. To ensure that a flow is measured that corresponds to a measured concentration, either aqueous condensation shall be prevented between the sample probe location and the flow meter inlet in the dilution tunnel or aqueous condensation shall be allowed to occur and humidity at the flow meter inlet measured. The dilution tunnel walls or bulk stream tubing downstream of the tunnel may be heated or insulated to prevent aqueous condensation. Aqueous condensation shall be prevented throughout the dilution tunnel. Certain exhaust components can be reduced or eliminated by the presence of moisture.

For PM sampling, the already proportional flow coming from CVS goes through secondary dilution (one or more) to achieve the requested overall dilution ratio as shown in Figure 11.

h) The minimum overall dilution ratio shall be within the range of 5:1 to 7:1 and at least 2:1 for the primary dilution stage based on the maximum engine exhaust flow rate during the test cycle or test interval.

i) The overall residence time in the system shall be between 0,5 s and 5 s, as measured from the point of diluent introduction to the filter holder(s).

j) The residence time in the secondary dilution system, if present, shall be at least 0,5 s, as measured from the point of secondary diluent introduction to the filter holder(s).

5.2.6 Dilute sampling for particulate emissions

To determine the mass of the particulates, a particulate sampling system, particulate sampling filters, a microgram balance, and a temperature- and humidity-controlled weighing chamber are required. For particulate sampling, the following two methods may be applied.

The multiple-filter method dictates that one filter is used for each of the individual modes of the test cycle. This method allows more lenient sample procedures but uses more filters.

The single-filter method uses one filter for all modes of the test cycle. Attention shall be paid to sampling times and flows during the sampling phase of the test; however, only one filter will be required for the test cycle.

5.3 Measurement instruments

5.3.1 General

5.3.1.1 Overview

This subclause specifies measurement instruments and associated system requirements related to emission testing. This includes laboratory instruments for measuring engine parameters, ambient conditions, flow-related parameters, and emission concentrations (raw or diluted).

5.3.1.2 Instrument types

Any instrument mentioned in ISO 8178 (all parts) shall be used as described in the standard itself (see Table 7 for measurement quantities provided by these instruments). Whenever an instrument mentioned in this document is used in a way that is not specified, or another instrument is used in its place, the requirements for equivalency provisions shall apply as specified in Clause 5. Where more than one instrument for a particular measurement is specified, one of them will be identified by the type approval or certification authority upon application as the reference for showing that an alternative procedure is equivalent to the specified procedure.

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5.3.1.3 Redundant systems

Data from multiple instruments to calculate test results for a single test may be used for all measurement instruments described in this subclause, with prior approval of the type approval or certification authority. Results from all measurements shall be recorded and the raw data shall be retained. This requirement applies whether or not the measurements are actually used in the calculations.

5.3.2 Data recording and control

The test system shall be able to update data, record data and control systems related to operator demand, the dynamometer, sampling equipment, and measurement instruments. Data acquisition and control systems shall be used that can record at the specified minimum frequencies, as shown in Table 4 (this table does not apply to discrete-mode testing).

Table 4 — Data recording and control minimum frequencies

Applicable test protocol subclause in ISO 8178-4:2020	Measured values	Minimum command and control frequency[a]	Minimum recording frequency[b, c]
7.4	Speed and torque during an engine step-map	1 Hz	1 mean value per step
7.4	Speed and torque during an engine sweep-map	5 Hz	1 Hz means
8.6.3	Transient duty cycle reference and feedback speeds and torques	5 Hz	1 Hz means
8.6.2	Steady-state and ramped-modal duty cycle reference and feedback speeds and torques	1 Hz	1 Hz
8.4 8.7	Continuous concentrations of raw analysers	N/A	1 Hz
8.4 8.7	Continuous concentrations of dilute analysers	N/A	1 Hz
8.4 8.7	Batch concentrations of raw or dilute analysers	N/A	1 mean value per test interval
7.4 8.2.1	Diluted exhaust flow rate from a CVS with a heat exchanger upstream of the flow measurement	N/A	1 Hz
7.4 8.2.1	Diluted exhaust flow rate from a CVS without a heat exchanger upstream of the flow measurement	5 Hz	1 Hz means
7.4 8.2.1	Intake-air[d], fuel[d], and raw exhaust flow rate	N/A	1 Hz means

[a] CFVs that are not using active control are exempt from meeting this requirement due to their operating principle.

[b] 1 Hz means are data reported from the instrument at a higher frequency, but recorded as a series of 1 s mean values at a rate of 1 Hz.

[c] For CFVs in a CVS, the minimum recording frequency is 1 Hz. For CFVs used to control sampling from a CFV CVS, the minimum recording frequency is not applicable.

[d] If used for instantaneous raw exhaust flow determination.

[e] This is not applicable to CVS dilution air.

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Table 4 *(continued)*

Applicable test protocol subclause in ISO 8178-4:2020	Measured values	Minimum command and control frequency[a]	Minimum recording frequency[b, c]
7.4 8.2.1	Dilution air flow if actively controlled (for example, a partial flow PM sampling system)[e]	5 Hz	1 Hz means
7.4 8.2.1	Sample flow from a CVS with a heat exchanger	1 Hz	1 Hz
7.4 8.2.1	Sample flow from a CVS without a heat exchanger	5 Hz	1 Hz mean

[a] CFVs that are not using active control are exempt from meeting this requirement due to their operating principle.

[b] 1 Hz means are data reported from the instrument at a higher frequency, but recorded as a series of 1 s mean values at a rate of 1 Hz.

[c] For CFVs in a CVS, the minimum recording frequency is 1 Hz. For CFVs used to control sampling from a CFV CVS, the minimum recording frequency is not applicable.

[d] If used for instantaneous raw exhaust flow determination.

[e] This is not applicable to CVS dilution air.

5.3.3 Performance specifications for measurement instruments

5.3.3.1 Overview

The calibration of all measuring instruments shall be traceable to national (international) standards.

The test system as a whole shall meet all the applicable calibrations, verifications, and test-validation criteria specified in Clause 9, including the requirements of the linearity check of 9.1.4 and ISO 8178-4:2020, 8.2. Instruments shall meet the specifications in Table 5 for all ranges to be used for testing. Furthermore, any documentation received from instrument manufacturers showing that instruments meet the specifications in Table 5 shall be kept.

5.3.3.2 Component requirements

Table 5 shows the specifications of transducers of torque, speed, and pressure, sensors of temperature and dew point, and other instruments. The overall system for measuring the given physical and/or chemical quantity shall meet the linearity verification in 9.1.4. For gaseous emissions measurements, analysers may be used, that have compensation algorithms that are functions of other measured gaseous components, and of the fuel properties for the specific engine test. Any compensation algorithm shall only provide offset compensation without affecting any gain (that is, no bias).

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Table 5 — Recommended performance specifications for measurement instruments

Measurement Instrument	Measured quantity symbol	Complete System Rise time ($t_{10\text{-}90}$) and Fall time ($t_{90\text{-}10}$)[a]	Recording update frequency	Accuracy[b]	Repeatability[b]	Noise[b]
Engine speed transducer	n	1 s	1 Hz means	2,0 % of pt. or 0,5 % of max.	1,0 % of pt. or 0,25 % of max.	0,05 % of max
Engine torque transducer	T	1 s	1 Hz means	2,0 % of pt. or 1,0 % of max.	1,0 % of pt. or 0,5 % of max	0,05 % of max
Electrical work (active-power meter)	W	1 s	1 Hz means	2,0 % of pt. or 0,5 % of max.	1,0 % of pt. or 0,25 % of max	0,05 % of max
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	2,0 % of pt. or 1,0 % of max.	1,0 % of pt. or 0,50 % of max.	0,1 % of max
Atmospheric pressure meter used for PM-stabilization and balance environments	p_a	50 s	5 times per hour	50 Pa	25 Pa	5 Pa
General purpose atmospheric pressure meter	p_a	50 s	5 times per hour	250 Pa	100 Pa	50 Pa
Temperature sensor for PM-stabilization and balance environments	T	50 s	0,1 Hz	0,25 K	0,1 K	0,1 K
Other temperature sensor (not a part of another instrument)	T	10 s	0,5 Hz	0,4 % of pt. K or 0,2 % of max. K	0,2 % of pt. K or 0,1 % of max. K	0,1 % of max
Dew point sensor for PM-stabilization and balance environments	T_{dew}	50 s	0,1 Hz	0,25 K	0,1 K	0,02 K
Other dew point sensor	T_{dew}	50 s	0,1 Hz	1 K	0,5 K	0,1 K
Fuel flow meter[c] (Fuel totalizer)		5 s (N/A)	1 Hz (N/A)	2,0 % of pt. or 1,5 % of max.	1,0 % of pt. or 0,75 % of max.	0,5 % of max.
Total diluted exhaust meter (CVS)[c] (With heat exchanger before meter)		1 s (5 s)	1 Hz means (1 Hz)	2,0 % of pt. or 1,5 % of max.	1,0 % of pt. or 0,75 % of max.	1,0 % of max.
Dilution air, inlet air, exhaust, and sample flow meters[c]		1 s	1 Hz means of 5 Hz samples	2,5 % of pt. or 1,5 % of max.	1,25 % of pt. or 0,75 % of max.	1,0 % of max.
Continuous gas analyser	x	5 s	1 Hz	2,0 % of pt. or 2,0 % of meas.	1,0 % of pt. or 1,0 % of meas	1,0 % of max.

[a] The performance specifications identified in the table apply separately for rise time and fall time.

[b] Accuracy, repeatability, and noise are all determined with the same collected data as described in 5.3, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

[c] The procedure for accuracy, repeatability and noise measurement described in Clause 3 may be modified for flow meters to allow noise to be measured at the lowest calibrated value instead of zero flow rate.

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Table 5 *(continued)*

Measurement Instrument	Measured quantity symbol	Complete System Rise time ($t_{10\text{-}90}$) and Fall time ($t_{90\text{-}10}$)[a]	Recording update frequency	Accuracy[b]	Repeatability[b]	Noise[b]
Batch gas analyser	x	—	—	2,0 % of pt. or 2,0 % of meas.	1,0 % of pt. or 1,0 % of meas	1,0 % of max.
Gravimetric PM balance	m_f	—	—	See 8.1.5.2	0,5 µg	—

[a] The performance specifications identified in the table apply separately for rise time and fall time.

[b] Accuracy, repeatability, and noise are all determined with the same collected data as described in 5.3, and based on absolute values. "pt." refers to the overall flow-weighted mean value expected at the standard; "max." refers to the peak value expected at the standard over any test interval, not the maximum of the instrument's range; "meas" refers to the actual flow-weighted mean measured over any test interval.

[c] The procedure for accuracy, repeatability and noise measurement described in Clause 3 may be modified for flow meters to allow noise to be measured at the lowest calibrated value instead of zero flow rate.

6 Engine and ambient related measurement equipment

6.1 Dynamometer specification

An engine dynamometer shall be used that has adequate characteristics to perform the applicable test cycle described in ISO 8178-4:2020 including the ability to meet the appropriate cycle validation criteria, if applicable.

The following are examples of dynamometers that may be used:

a) eddy-current or water-brake dynamometer;

b) alternating-current or direct-current motoring dynamometer;

c) one or more dynamometers.

6.2 Speed and torque sensors

Measurement instruments for work inputs and outputs during engine operation shall meet the specifications in this subclause. Sensors, transducers, and meters should meet the specifications in Table 5. Overall systems for measuring work inputs and outputs shall meet the linearity verifications in 9.1.4.

6.2.1 Shaft work

Work and power shall be calculated from outputs of speed and torque transducers according to 6.2. Overall systems for measuring speed and torque shall meet the calibration and verifications in 9.9 and 9.1.4.

Torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for as needed, based on good engineering judgment.

6.2.2 Speed sensors

A magnetic or optical shaft-position detector with a resolution of at least 60 counts per revolution, in combination with a frequency counter that rejects common-mode noise should be used. Other sensors with an equivalent resolution may be used.

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6.2.3 Torque sensors

A variety of methods to determine engine torque may be used. As needed, and based on good engineering judgment, torque induced by the inertia of accelerating and decelerating components connected to the flywheel, such as the drive shaft and dynamometer rotor, shall be compensated for.

When using a load cell, the torque signal shall be transferred to the engine axis and the inertia of the dynamometer shall be considered. The actual engine torque is the torque read on the load cell plus the moment of inertia of the brake multiplied by the angular acceleration. The control system has to perform such a calculation in real time.

Torque shall be measured either by mounting a strain gage or similar instrument in-line between the engine and dynamometer or by measuring torque by mounting a strain gage or similar instrument on a lever arm connected to the dynamometer housing. Torque may be calculated from internal dynamometer signals, such as armature current, as long as this measurement is calibrated as described in 9.9.1.

6.2.4 Engine accessories

The work of engine accessories required to fuel, lubricate, or heat the engine, circulate liquid coolant to the engine, or to operate after-treatment devices shall be accounted for and they shall be installed in accordance with ISO 8178-4:2020, 5.2.

6.3 Pressure transducers, temperature sensors, and dew point sensors

Overall systems for measuring pressure, temperature, and dew point shall meet the calibration in 9.10.

Pressure transducers shall be located in a temperature-controlled environment, or they shall compensate for temperature changes over their expected operating range. Transducer materials shall be compatible with the fluid being measured.

Temperature measurement may be done by systems such as the following:

— thermistors;

— thermocouples;

— resistive temperature detectors (RTDs).

Pressure meters may include:

a) either capacitance-type, quartz crystal, or laser-interferometer transducers for atmospheric pressure or other precision pressure measurements;

b) either strain gage or capacitance-type pressure transducers for other applications;

c) other pressure-measurement instruments, such as manometers.

Dew point meters may include:

a) chilled-surface hygrometers which include chilled mirror detectors and chilled surface acoustic wave (SAW) for PM-stabilization environments;

b) thin-film capacitance sensors, for other applications;

c) other dew point sensors, such as a wet-bulb/dry-bulb psychrometer.

6.4 Flow related measurements

For any type of flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this

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may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, straightening fins, orifice plates (or pneumatic pulsation dampeners for the fuel flow meter) to establish a steady and predictable velocity profile upstream of the meter.

6.4.1 Fuel flow

Overall system for measuring fuel flow shall meet the calibration in 9.11.1. In any fuel flow measurement, fuel that bypasses the engine or returns from the engine to the fuel storage tank shall be accounted for.

A fuel flow meter that measures mass directly, such as one that relies on gravimetric or inertial measurement principles should be used. This may involve using a meter with one or more scales for weighing fuel or using a Coriolis meter.

The fuel flow shall be conditioned as needed to prevent any gas bubbles in the fuel from affecting the fuel meter.

6.4.2 Intake air flow

Overall system for measuring intake-air flow shall meet the calibration and linearity verification in 9.11.2 and 9.1.4.

The intake flow meter may include a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer.

Flow conditioning shall be carried out as described in the beginning of 6.4.

6.4.3 Raw exhaust flow

The overall system for measuring raw exhaust flow shall meet the linearity requirements in 9.1.4. Any raw-exhaust meter shall be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states and calibrated according to 9.11.3.

6.4.3.1 Flow meter response time

For the purpose of controlling of a partial flow dilution system to extract a proportional raw exhaust sample, a flow meter response time faster than indicated in Table 5 is required. For partial flow dilution systems with online control, the flow meter response time shall meet the specifications in ISO 8178-4:2020, 8.2.1.2.

Any direct exhaust meter shall be designed to appropriately compensate for changes in the raw exhaust's thermodynamic, fluid, and compositional states. The raw-exhaust flow measurement may involve using an ultrasonic flow meter, a subsonic venturi, an averaging Pitot tube, a hot-wire anemometer, a vortex flowmeter, or other measurement principle. This would generally not involve a laminar flow element or a thermal-mass meter.

Precautions shall be taken to avoid measurement errors which will impact on emission value errors. Such precautions include the careful installation of the device in the engine exhaust system according to the instrument manufacturers' recommendations and to good engineering practice. In particular, engine performance and emissions shall not be affected by the installation of the device.

6.4.3.2 Exhaust cooling

This subclause applies to cooling of the exhaust gas after it leaves the engine. It does not refer to cooling of the exhaust gas that may occur in normal engine operation due to the design of the engine, including, but not limited to, water-cooled exhaust manifolds or turbochargers.

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The raw exhaust may be cooled upstream of a raw-exhaust flow meter, as long as all the following provisions are observed:

a) No sampling of PM should be carried out downstream of the cooling.

b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, no sampling of NMHC should be carried out downstream of the cooling for:

— compression-ignition engines;

— 2-stroke spark-ignition engines;

— 4-stroke spark-ignition engines below 19 kW.

c) The cooling shall not cause aqueous condensation.

6.4.3.3 Application

The measured raw exhaust flow may be used as follows:

a) The actual value of calculated raw exhaust shall be used in the following cases:

1) Multiply raw exhaust flow rate with continuously sampled concentrations.

2) Multiply total raw exhaust with batch sampled concentrations.

b) In the following cases, a raw exhaust flow meter signal that does not give the actual value of raw exhaust may be used, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

1) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

2) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

An intake-air flow meter signal may be used instead of the exhaust flow signal in the following cases, as long as it is linearly proportional to the exhaust flow rate's actual calculated value:

a) For feedback control of a proportional sampling system, such as a partial-flow dilution system.

b) For multiplying with continuously sampled gas concentrations, if the same signal is used in a chemical-balance calculation to determine work from brake-specific fuel consumption and fuel consumed.

6.4.4 Indirect exhaust flow

6.4.4.1 Air and fuel measurement method

This involves measurement of the air flow and the fuel flow. Air flowmeters and fuel flowmeters with an accuracy defined in addition to 5.3 shall be used. The instantaneous exhaust gas flow shall be the sum of time-aligned instantaneous air mass flow and fuel mass flow.

6.4.4.2 Fuel flow and carbon balance method

This involves exhaust mass calculation from fuel consumption, fuel composition and exhaust gas concentrations using the carbon balance method. The calculation of the exhaust gas flow shall be in accordance with ISO 8178-4:2020, D.3.2.3.1.

For aftertreatment systems that use urea for NO_x reduction, the method may be used without taking urea consumption into account.

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For aftertreatment systems requiring active regeneration, this method does not provide adequate accuracy, unless air- and fuel mass flow of active regeneration system are considered.

6.4.4.3 Tracer measurement method

This involves measurement of the concentration of a tracer gas in the exhaust.

A known amount of an inert gas (e.g. pure helium) shall be injected into the exhaust gas flow as a tracer. The gas is mixed and diluted by the exhaust gas, but shall not react in the exhaust pipe. The concentration of the gas shall then be measured in the exhaust gas sample.

In order to ensure complete mixing of the tracer gas, the exhaust gas sampling probe shall be located at least 1 m or 30 times the diameter of the exhaust pipe – whichever is larger – downstream of the tracer gas injection point. The sampling probe may be located closer to the injection point if complete mixing is verified by comparing the tracer gas concentration with the reference concentration when the tracer gas is injected upstream of the engine.

The tracer gas flow rate shall be set so that the trace gas concentration after mixing becomes lower than the full scale of the trace gas analyser.

The background concentration of the tracer gas c_b may be determined by averaging the background concentration measured immediately before the test run and after the test run. When the background concentration is less than 1 % of the concentration of the tracer gas after mixing (c_{mix}) at maximum exhaust flow, the background concentration may be neglected.

6.4.4.4 Air flow and air-to-fuel ratio measurement method

This involves exhaust mass calculation from the air flow and the air-to-fuel ratio. The calculation of the exhaust gas flow shall be as follows:

The air flowmeter shall meet the accuracy specifications of Table 5. The CO_2 analyser used shall meet the specifications of 7.3.2, and the total system shall meet the accuracy specifications for the exhaust gas flow.

Optionally, air-to-fuel ratio measurement equipment, such as a zirconia-type sensor, which meets the specifications of 7.3.12 may be used for the measurement of the excess air ratio.

6.4.5 Dilution air and diluted exhaust flow meters

6.4.5.1 Application

Instantaneous diluted exhaust flow rates or total diluted exhaust flow over a test interval shall be determined by using a diluted exhaust flow meter. Raw exhaust flow rates or total raw exhaust flow over a test interval may be calculated from the difference between a diluted exhaust flow meter and a dilution air meter.

6.4.5.2 Component requirements

It is recommended that the diluted exhaust flow meter meets the specifications in Table 5. The overall system for measuring diluted exhaust flow shall meet the calibration and verifications in 9.8. The following meters may be used:

a) For constant-volume sampling (CVS) of the total flow of diluted exhaust, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (UFM) may be used. Combined with an upstream heat exchanger, either a CFV or a PDP will also function as a passive flow controller by keeping the diluted exhaust temperature constant in a CVS system.

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b) For the partial flow dilution (PFD) system the combination of any flow meter with any active flow control system to maintain proportional sampling of exhaust constituents may be used. The total flow of diluted exhaust, or one or more sample flows, or a combination of these flow controls may be controlled to maintain proportional sampling.

For any other dilution system, a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer may be used.

For any type of diluted exhaust flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

6.4.5.3 Exhaust cooling

This subclause applies to cooling of the exhaust gas after it leaves the engine. It does not refer to cooling of the exhaust gas that may occur in normal engine operation due to the design of the engine, including, but not limited to, water-cooled exhaust manifolds or turbochargers.

Diluted exhaust upstream of a dilute flow meter may be cooled, as long as all the following provisions are observed:

a) PM shall not be sampled downstream of the cooling.

b) If cooling causes exhaust temperatures above 202 °C to decrease to below 180 °C, NMHC shall not be sampled downstream of the cooling.

c) If cooling causes aqueous condensation, NO_x shall not be sampled downstream of the cooling unless the cooler meets the performance verification in 9.5.9.3.

d) If cooling causes aqueous condensation before the flow reaches a flow meter, dew point, T_{dew} and pressure p_{total} shall be measured at the flow meter inlet. These values shall be used in emission calculations according ISO 8178-4:2020, Annex H.

6.4.6 Sample flow meter for batch sampling

A sample flow meter shall be used to determine sample flow rates or total flow sampled into a batch sampling system over a test interval. The difference between two flow meters may be used to calculate sample flow into a dilution tunnel e.g. for partial flow dilution PM measurement and secondary dilution flow PM measurement or total raw exhaust flow over a test interval, e.g. by subtracting dilution air flow from total CVS flow.

Specifications for differential flow measurement to extract a proportional raw exhaust sample is given in 9.8.6.1 and the calibration of differential flow measurement is given in 9.8.6.2.

It is recommended to use a sample flow meter that meets the specifications in Table 5. A sample flow meter may involve a laminar flow element, an ultrasonic flow meter, a subsonic venturi, a critical-flow venturi (CFV) or multiple critical-flow venturis arranged in parallel, a positive-displacement meter, a thermal-mass meter, an averaging Pitot tube, or a hot-wire anemometer. Note that the overall system for measuring sample flow shall meet the linearity verification in 9.1.4. For the special case where CFVs are used for both the diluted exhaust and sample-flow measurements and their upstream pressures and temperatures remain similar during testing, the flow rate of the sample-flow CFV need not be quantified. In this special case, the sample-flow CFV inherently flow-weights the batch sample relative to the diluted exhaust CFV.

Overall system for the sample flow meter shall meet the calibration in 9.11.3.

For any type of sample flow meter, the flow shall be conditioned as needed to prevent wakes, eddies, circulating flows, or flow pulsations from affecting the accuracy or repeatability of the meter. For some

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meters, this may be accomplished by using a sufficient length of straight tubing (such as a length equal to at least 10 pipe diameters) or by using specially designed tubing bends, orifice plates or straightening fins to establish a predictable velocity profile upstream of the meter.

6.4.7 Use of gas dividers

A gas divider may be used to blend calibration gases.

If a gas divider is used, it shall blend gases to the specifications of 9.2 and to the concentrations expected during testing. Critical-flow gas dividers, capillary-tube gas dividers, or thermal-mass-meter gas dividers may be used. Viscosity corrections shall be applied as necessary (if not done by gas divider internal software) to appropriately ensure correct gas division. The gas-divider system shall meet the linearity verification in 9.1.4.5. Optionally, the blending device may be checked with an instrument which by nature is linear, e.g. using NO gas with a CLD. The span value of the instrument shall be adjusted with the span gas directly connected to the instrument. The gas divider shall be checked at the settings used and the nominal value shall be compared to the measured concentration of the instrument.

7 Determination of the gaseous components

7.1 General specifications

The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components.

7.2 Gas drying

Exhaust gases may be measured wet or dry. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

Sample dryers shall meet the specifications in 5.2.2.3.1.

7.3 Analysers

7.3.1 General

7.3.2 to 7.3.12 define the measurement principles to be used. A detailed description of the measurement systems is given in 7.4. The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearizing circuits is permitted.

7.3.2 Carbon monoxide (CO) and carbon dioxide (CO_2) analysis

A Non-dispersive infrared (NDIR) analyser shall be used to measure CO and CO_2 concentrations in raw or diluted exhaust for either batch or continuous sampling.

The NDIR-based system shall meet the calibration and verifications in 9.5.8.

7.3.3 Oxygen (O_2) analysis

A paramagnetic detection (PMD) analyser shall be used to measure O_2 concentration in raw or diluted exhaust for batch or continuous sampling.

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7.3.4 Hydrocarbon (HC) analysis

7.3.4.1 General

A heated flame-ionization detector (HFID) analyser shall be used to measure hydrocarbon concentrations in raw or diluted exhaust for either batch or continuous sampling. Hydrocarbon concentrations shall be determined on a carbon number basis of one, C_1. Methane and non-methane hydrocarbon values shall be determined as described in 7.3.5.1. Heated FID analysers shall maintain all surfaces that are exposed to emissions at a temperature of (191 ± 11) °C.

For methanol-fuelled engines, the temperature requirements of 7.3.11.3 apply. Optionally, for gas-fuelled engines and for the dilute testing of spark-ignition engines, the hydrocarbon analyser may be of the non-heated flame ionization detector (FID) type.

7.3.4.2 FID fuel and burner air

FID fuel and burner air shall meet the specifications of 9.2. The FID fuel and burner air shall not mix before entering the FID analyser to ensure that the FID analyser operates with a diffusion flame and not a premixed flame.

7.3.5 Non-methane hydrocarbon (NMHC) analysis

7.3.5.1 General

FID analysers measure total hydrocarbons (THC). To determine non-methane hydrocarbons (NMHC), methane, CH_4, shall be quantified either with a non-methane cutter and a FID analyser as described in 7.3.5.3, or with a gas chromatograph as described in 7.3.5.2. For a FID analyser used to determine NMHC, its response factor to CH_4, $f_{RF\ CH4}$, shall be determined as described in 9.5. NMHC-related calculations are described in ISO 8178-4:2020, Clause 9 and Annex H.

For engines operated only on Diesel fuel, it is allowed to assume that 2 % of measured total hydrocarbons is methane, instead of measuring methane.

7.3.5.2 Gas chromatographic (GC) method

A gas chromatograph may be used to measure CH_4 concentrations of diluted exhaust for batch sampling. While also a non-methane cutter may be used to measure CH_4, as described in 7.3.5.3 a reference procedure based on a gas chromatograph shall be used for comparison with any proposed alternate measurement procedure in Annex B.

7.3.5.3 Non-methane cutter (NMC) method

A non-methane cutter may be used to measure CH_4 with a FID analyser. A non-methane cutter oxidizes all non-methane hydrocarbons to CO_2 and H_2O. A non-methane cutter may be used for raw or diluted exhaust for batch or continuous sampling.

Non-methane-cutter performance shall be determined as described in 9.5.7 and the results shall be used to calculate NMHC emission in ISO 8178-4:2020, Clause 9 and Annex H.

The non-methane cutter shall be configured with a bypass line for the verification described in 9.5.7.

A non-methane cutter may be optimised to maximize the penetration of CH_4 and the oxidation of all other hydrocarbons. A sample may be humidified and a sample may be diluted with purified air or oxygen (O_2) upstream of non-methane cutter to optimize its performance. Any sample humidification and dilution shall be accounted for in emission calculations.

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7.3.6 Oxides of nitrogen (NO_x) analysis

The following measurement instruments are specified for NO_x measurement and either instrument may be used provided it meets the criteria specified in 7.3.6.1 to 7.3.6.4, respectively. The chemiluminescent detector shall be used as the reference procedure for comparison with any proposed alternate measurement procedure in Annex B.

7.3.6.1 CLD

The CLD-based system shall meet the quench verification in 9.5.9.1. A heated or unheated CLD may be used, and a CLD that operates at atmospheric pressure or under a vacuum may be used.

An internal or external NO_2-to-NO converter that meets the verification in 9.4 shall be placed upstream of the CLD, while the converter shall be configured with a bypass to facilitate this verification.

A heated CLD may be used to improve CLD response time.

7.3.6.1.1 Humidity effects

All CLD temperatures shall be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a CLD, one of the following configurations shall be used:

a) a CLD connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in 9.4;

b) a CLD connected downstream of any dryer or thermal chiller that meets the verification in 9.5.9.3.

7.3.6.2 NDUV

A non-dispersive ultraviolet (NDUV) analyser is used to measure NO_x concentration in raw or diluted exhaust for batch or continuous sampling.

If the NDUV analyser measures only NO, an internal or external NO_2-to-NO converter that meets the verification in 9.4 shall be placed upstream of the NDUV analyser. The converter shall be configured with a bypass to facilitate this verification.

7.3.6.2.1 Humidity effects

All NDUV temperatures shall be maintained to prevent aqueous condensation. To remove humidity from a sample upstream of a NDUV, one of the following configurations shall be used:

a) a NDUV connected downstream of any dryer or chiller that is downstream of an NO_2-to-NO converter that meets the verification in 9.4;

b) a NDUV connected downstream of any dryer or thermal chiller that meets the verification in 9.5.9.3.

7.3.6.3 NDUV-RAS

Alternatively, an NDUV-RAS (non-dispersive ultraviolet - resonant absorption spectroscopy) analyser may be used to measure oxides of nitrogen without the use of a NO_2-to-NO converter. The NDUV-RAS analyser determines NO concentrations by means of gas filter and interference filter correlation measurements of light, emitted by a gas-filled electrode-less discharge lamp (EDL) in a very narrow spectral range NO_2 concentration is determined with the same set-up by means of interference filter correlation measurements. If the NDUV-RAS analyser measures only NO, a NO_2-to-NO converter with bypass capability shall be placed upstream of the analyser.

In order to prevent humidity effects, either the temperature of all gas feeding parts the NDUV-RAS analyser shall be maintained above the exhaust's dew point, or a dryer or gas cooler shall be connected upstream of the analyser. If the NDUV-RAS analyser is connected to a NO_2-to-NO converter, the gas cooler shall be connected between the converter and the analyser in order to avoid NO_2 losses in the cooler.

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7.3.6.4 Laser infrared analyser

A laser infrared analyser may be used for NO_x measurement in accordance with the instrument supplier's instructions. The NO_x concentration may be determined by summing NO and NO_2 concentrations, since conventional engines and aftertreatment systems do not emit significant amounts of other NO_x species. The temperature of the sample line shall be maintained to prevent water condensation.

Examples of infrared laser analysers are pulsed-mode high resolution narrow band mid-infrared analysers such as analysers using QCL (quantum cascade laser).

7.3.7 Sulphur dioxide (SO_2) analysis

7.3.7.1 Calculation

The SO_2 emission shall be calculated from the sulphur content of the fuel used, since experience has shown that using the direct measurement method for SO_2 does not give more precise results:

$$q_{mSO2} = q_{mf} \times w_{GAM} \times 20 \quad (1)$$

where

q_{mSO2} is SO_2 mass flow rate, kg/s;

q_{mf} is fuel mass flow rate, kg/s;

w_{GAM} is S content of fuel, % mass.

NOTE The application of the calculation method for SO_2 assumes a 100 % sulphur conversion and is limited to engines without aftertreatment systems.

7.3.7.2 Measurement

If an aftertreatment system is used, SO_2 shall be measured in accordance with the instructions of the instrument suppliers with prior agreement of the parties involved. Condensation shall be avoided.

Sulphur dioxide analysers shall be of the FTIR, NDIR or NDUV types.

7.3.8 Ammonia (NH_3) analysis

A FTIR (Fourier transform infrared) analyser, NDUV or laser infrared analyser may be used in accordance with 7.4.3.

7.3.9 Dinitrogen oxide (N_2O) analysis

An FTIR analyser, an NDIR (non-dispersive infrared) analyser, laser infrared analyser or NDUV analyser may be used in accordance with the instrument supplier's instructions.

7.3.10 Formaldehyde (HCHO) analysis

Formaldehyde shall be determined by passing an exhaust sample, preferably from the diluted exhaust gas, through an impinger containing an acetonitrile (ACN) solution of DNPH reagent or through a silica cartridge coated with 2.4-DNPH. The sample collected shall be analysed by a high-performance liquid chromatograph (HPLC) using UV detection at 365 nm.

Optionally, an FTIR or NDIR analyser may be used in accordance with the instrument supplier's instructions.

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7.3.11 Methanol (CH_3OH) analysis

7.3.11.1 General

An FTIR analyser may be used in accordance with the instrument supplier's instructions. Since the technology has not been fully demonstrated for exhaust measurements, prior agreement of the parties involved is required.

7.3.11.2 Gas chromatographic (GC) method

Methanol shall be determined by passing an exhaust sample through an impinger containing de-ionized water. The sample shall be analysed by a GC with FID.

7.3.11.3 HFID method

The HFID calibrated on propane shall be operated at 112 °C ± 10 °C. The methanol response factor shall be determined at several concentrations in the range of concentrations in the sample, according to 9.5.10.

To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

7.3.12 Air-to-fuel measurement

The air-to-fuel measurement equipment used to determine the exhaust gas flow as specified in 6.4.4.4 shall be a wide range air-to-fuel ratio sensor or lambda sensor of zirconia type.

The sensor shall be mounted directly on the exhaust pipe where the exhaust gas temperature is high enough to eliminate water condensation.

The accuracy of the sensor with incorporated electronics shall be as follows:

— ±3 % of reading for $\lambda < 2$;

— ±5 % of reading for $2 \leq \lambda < 5$;

— ±10 % of reading for $5 \leq \lambda$.

To fulfil the accuracy specified above, the sensor shall be calibrated as specified by the instrument manufacturer.

7.4 Measurement system

7.4.1 General

7.4.2 to 7.4.6 and Figure 3 to Figure 6 contain detailed descriptions of the typical sampling and analysing systems. Since various configurations can produce equivalent results, exact conformance with these figures is not required. However, conformance with the basic requirements such as sampling line heating is mandatory. Additional components such as instruments, valves, solenoids, pumps, filters and switches may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on certain systems may be excluded if their exclusion is based upon good engineering judgement.

7.4.2 Analytical system

An analytical system for the determination of the gaseous emissions in the raw or diluted exhaust gas is described, based on the use of the analyzers in 7.3. Annex F provides examples of the exhaust gas analysis system.

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For the raw exhaust gas (see Figure F.1 as an example), the sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

For the diluted exhaust gas (see Figure F.2 as an example), the sample for the hydrocarbons shall be taken with a sampling probe other than that used with the sample for the other components, unless a common sample pump is used for all analysers and the sample line system design reflects good engineering practice. Care shall be taken that no condensation of exhaust components (including water and sulphuric acid) occurs at any point of the analytical system.

All components in the sampling gas path shall be maintained at the temperatures specified for the respective systems.

7.4.3 Ammonia analysis

Four measurement principles are specified for ammonia (NH_3) measurement and either principle may be used provided it meets the criteria specified in 7.4.3.1 to 7.4.3.2, respectively. Gas dryers shall not be permitted for NH_3 measurement.

7.4.3.1 In-situ measurement devices

7.4.3.1.1 Laser infrared analyser

7.4.3.1.1.1 Measurement principle

The Laser Infrared Analyser employs the single line spectroscopy principle. The NH_3 absorption line is chosen in the near infrared spectral range and scanned by a single-mode laser.

7.4.3.1.1.2 Installation

The analyser shall be installed either directly in the exhaust pipe (in-situ) or within an analyser cabinet using extractive sampling in accordance with the instrument manufacturers' instructions. If installed in an analyser cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to a temperature between 110 °C and 202 °C in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimized, or compensation techniques be used.

If applicable, sheath air used in conjunction with in-situ measurement for protection of the instrument, shall not affect the concentration of any exhaust component measured downstream of the device, or sampling of other exhaust components shall be made upstream of the device.

7.4.3.1.1.3 Cross interference

The spectral resolution of the laser shall be within 0,5 cm^{-1} in order to minimize cross interference from other gases present in the exhaust gas.

7.4.3.2 Extractive measurement devices

7.4.3.2.1 Fourier transform infrared (FTIR) analyser

7.4.3.2.1.1 Measurement principle

The FTIR employs the broad waveband infrared spectroscopy principle. It allows simultaneous measurement of exhaust components whose standardized spectra are available in the instrument. The

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absorption spectrum (intensity/wavelength) is calculated from the measured interferogram (intensity/time) by means of the Fourier transform method.

7.4.3.2.1.2 Installation and sampling

The FTIR shall be installed in accordance with the instrument manufacturer's instructions. The NH_3 wavelength shall be selected for evaluation. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated a temperature between 110 °C and 202 °C in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

7.4.3.2.1.3 Cross interference

The spectral resolution of the NH_3 wavelength shall be within 0,5 cm^{-1} in order to minimize cross interference from other gases present in the exhaust gas.

7.4.3.2.2 NDUV

7.4.3.2.2.1 Measurement principle

The method is called Non Dispersive Ultra Violet Resonance Absorption Spectroscopy (NDUV), since the method is based on purely physical principle, no auxiliary gases or equipment is necessary.

The main element of the photometer is an electrode-less discharge lamp. It produces a sharply structured radiation in the ultraviolet range, enabling the measurement of several components such as NH_3.

The photometric system has a dual beam in time design set up to produce a measuring and a reference beam by filter correlation technique.

In order to achieve a high stability of the measuring signal the dual beam in time design is combined with a dual beam in space design. The detector signals processing fosters an almost negligible amount of zero point drift rate.

In the calibration mode of the analyser a sealed-off quartz cell is tilted into the beam path to obtain an exact calibration value, since any reflection and absorption losses of the cell windows are cancelled out. Since the gas filling of the cell is very stable, this calibration method leads to long term stability of the photometer.

7.4.3.2.2.2 Installation

The analyser shall be installed within an analyser cabinet using extractive sampling in accordance with the instrument manufacturer’s instructions.

The analyser location shall be capable of supporting the weight specified by the manufacturer.

If installed in an analyser cabinet, the sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated a temperature between 110 °C and 202 °C.

In addition, the sampling line shall be as short as possible.

Influence from exhaust temperature and pressure, installation environment and vibrations on the measurement shall be minimized.

The gas analyser shall be protected from cold, heat, temperature variations, and strong air currents, accumulation of dust, corrosive atmosphere and vibrations.

Adequate air circulation shall be provided to avoid heat build-up.

The complete surface shall be used to dissipate the heat losses.

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7.4.3.2.2.3 Cross sensitivity

An appropriate spectral range needs to be chosen in order to minimize cross interferences of accompanying gases. Typical components causing cross sensitivities on the NH_3 measurement are SO_2, NO_2 and NO.

Additionally, further methods can be applied to reduce the cross sensitivities.

a) usage of interference filters;

b) cross sensitivity compensation by measuring cross sensitivity components and using the measurement signal for compensation.

7.4.3.2.3 Laser Infrared Analyser

7.4.3.2.3.1 Measurement principle

An infrared laser such as a tunable diode laser (TDL) or a quantum cascade laser (QCL) can emit coherent light in the near-infrared region or in mid-infrared region respectively where nitrogen compounds including NH_3 have strong absorption. This laser optics can give a pulsed-mode high resolution narrow band near-infrared or mid-infrared spectrum. Therefore, laser infrared analysers can reduce interference caused by the spectral overlap of co-existing gases in engine exhaust.

7.4.3.2.3.2 Installation and sampling

The laser infrared analyser shall be installed in accordance with the instrument manufacturer's instructions. The sample path (sampling line, pre-filter(s) and valves) shall be made of stainless steel or PTFE and shall be heated to a temperature between 110 °C and 202 °C in order to minimize NH_3 losses and sampling artefacts. In addition, the sampling line shall be as short as practically possible.

7.4.3.2.3.3 Interference verification for NH_3 laser infrared analysers (Cross interference)

a) Scope and frequency:

   If NH_3 is measured using laser infrared analyser, the amount of interference shall be verified after initial analyser installation and after major maintenance.

b) Measurement principles for interference verification:

   Interference gases can positively interfere with certain laser infrared analyser by causing a response similar to NH_3. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, simultaneously conduct these other measurements to test the compensation algorithms during the analyser interference verification.

   Good engineering judgment shall be used to determine interference gases for laser infrared analyser. Note that interference species, with the exception of H_2O, are dependent on the NH_3 infrared absorption band chosen by the instrument manufacturer. For each analyser determine the NH_3 infrared absorption band. For each NH_3 infrared absorption band, good engineering judgment shall be used to determine interference gases to use in the verification.

7.4.3.3 Emissions test procedure

7.4.3.3.1 Checking the analysers

Prior to the emissions test, the analyser range shall be selected. Emission analysers with automatic or manual range switching shall be permitted. During the test cycle, the range of the analysers shall not be switched.

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Zero and span response shall be determined, if the provisions of 7.4.3.3.4.2 do not apply for the instrument. For the span response, a NH_3 gas that meets the specifications of 7.4.3.4.2.7 shall be used. The use of reference cells that contain NH_3 span gas is permitted.

7.4.3.3.2 Collection of emission relevant data

At the start of the test sequence, the NH_3 data collection shall be started, simultaneously. The NH_3 concentration shall be measured continuously and stored with at least 1 Hz on a computer system.

7.4.3.3.3 Operations after test

At the completion of the test, sampling shall continue until system response times have elapsed. Determination of analyser's drift in accordance with 7.4.3.3.4.1 shall only be required if the information in 7.4.3.3.4.2 is not available.

7.4.3.3.4 Analyser drift

7.4.3.3.4.1 Drift verification

As soon as practical but no later than 30 minutes after the test cycle is complete or during the soak period, the zero and span responses of the analyser shall be determined. The difference between the pre-test and post-test results shall be less than 2 % of full scale.

7.4.3.3.4.2 Drift verification exemption

Determination of analyser drift is not required in the following situations:

a) if the zero and span drift specified by the instrument manufacturer in 7.4.3.4.2.3 and 7.4.3.4.2.4 meets the requirements of 7.4.3.3.4.1;

b) the time interval for zero and span drift specified by the instrument manufacturer in points 7.4.3.4.2.3 and 7.4.3.4.2.4 exceeds the duration of the test.

7.4.3.4 Analyser specification and verification

7.4.3.4.1 Linearity requirements

The analyser shall comply with the linearity requirements specified in Table 7. The linearity verification in accordance with 9.1.4 shall be performed at least at the minimum frequency set out in Table 6. With the prior approval of the Type Approval Authority, less than 10 reference points are permitted, if an equivalent accuracy can be demonstrated.

For the linearity verification, a NH_3 gas that meets the specifications of 7.4.3.4.2.7 shall be used. The use of reference cells that contain NH_3 span gas shall be permitted.

Instruments, whose signals are used for compensation algorithms, shall meet the linearity requirements specified in Table 7. Linearity verification shall be done as required by internal audit procedures or by the instrument manufacturer. The implementation of a quality management system, such as in accordance with ISO 9000, is advised.

7.4.3.4.2 Analyser specifications

The analyser shall have a measuring range and response time appropriate for the accuracy required to measure the concentration of NH_3 under transient and steady state conditions.

7.4.3.4.2.1 Minimum detection limit

The analyser shall have a minimum detection limit of <2 µmol/mol under all conditions of testing.

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