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Heavy-duty engines — Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions

Moteurs de poids lourds — Détermination, sur cycle transitoire, des émissions de polluants gazeux par mesure des concentrations dans les gaz d'échappement bruts et des émissions de particules en utilisant un système de dilution partielle

Reference number
ISO 16183:2002(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16183 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 5, *Engine tests*.

Annexes A, B and C form a normative part of this International Standard. Annex D is for information only.

Introduction

Today's emission measurement systems depend on the type of test cycle — steady-state or transient — and the type of pollutant to be measured.

In a steady-state cycle, the mass of gaseous emissions is calculated from the concentration in the raw exhaust gas and the exhaust flow of the engine, which can easily be determined. For particulate matter (PM), partial-flow dilution systems, in which only a portion of the exhaust gas is diluted, are widely used.

In a transient cycle, real time exhaust flow determination is more difficult. Therefore, the constant volume sampling (CVS) principle has been used for many years because exhaust mass flow measurement is not required with this system. The total exhaust gas is diluted, the total flow as the sum of dilution air and exhaust gas volume is kept virtually constant, and the emissions (both gaseous and PM) are measured in the diluted exhaust gas. The space and cost requirements of such a system are considerably higher than for the partial-flow dilution systems used in steady-state cycles. Nevertheless, raw exhaust measurement and partial flow systems can only be applied to transients if sophisticated control systems and calculation algorithms are used.

The mass emission determination in a raw exhaust sample and the measurement of the exhaust gas mass flow rate is a state-of-the-art procedure for light duty vehicle development on chassis dynamometers. There it is called modal analysis. However, it is usually done in conjunction with the mass emission evaluation on a full-flow CVS with bag analysis, where quality of the modal results can easily be verified by comparison with the CVS bag results. For heavy-duty engines, the CVS system is a large and costly system.

The aim of this International Standard is to provide an optional, stand-alone measurement procedure. By the nature of the transient mass emission calculation, small changes could result in large deviations of the final results, for example, by a wrongly performed time alignment caused by a wrong response time determination or by a system fault resulting in a change of the response time behaviour of the system. Therefore, the quality assurance procedure of a carbon dioxide-based carbon balance check, in line with highly sophisticated verification procedures for the partial flow particulate measurement, have been established in this International Standard.

NOTE CVS systems are covered in detail in various exhaust emissions regulations for both light- and heavy-duty vehicles as well as by ISO 8178-1. They are therefore not included in this International Standard. Since they are considered to be the reference systems for exhaust emission measurement on transient cycles, extensive studies have been commissioned by ISO/TC 22/SC 5/WG 2 on the correlation between CVS systems and the systems covered by this International Standard, with the results having been taken into consideration in its development.

Heavy-duty engines — Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions

1 Scope

This International Standard specifies methods for the measurement and evaluation of gaseous and particulate exhaust emissions from heavy-duty engines under transient conditions on a test bed. The procedures it defines can be applied to any transient test cycle that does not require extreme system response times; it can therefore be used as an option to the regulated measurement equipment of certification test cycles — usually CVS-type systems — with the approval of the certification agency [among certification test cycles in place are the European transient cycle (ETC) and the US heavy-duty transient cycle (FTP)].

This International Standard is applicable to heavy-duty engines for commercial vehicles primarily designed for road use, but can also be applied to passenger car engines and to engines used for non-road applications. The test equipment specified in this International Standard can also be used in steady-state test cycles, however, if so, the calculation procedures will need to be replaced by those applicable to the particular test cycle.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*

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 8178-5:1998, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 5: Test fuels*

SAE paper 770141, *Optimization of Flame Ionization Detector for the Determination of Hydrocarbons in Diluted Automobile Exhaust*, Glenn D. Reschke

SAE J 1936:1989, *Chemical methods for the measurement of non-regulated diesel emissions*

SAE J 1937:1995, *Engine testing with low-temperature charge air-cooler systems in a dynamometer test cell*

3 Terms, definitions, symbols and abbreviations

For the purposes of this International Standard, the following terms and definitions, and symbols and abbreviations (see Table 1), apply.

3.1
particulate matter
PM
any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature of $\leqslant$ 325 K (52 °C), as measured at a point immediately upstream of the filter; it is primarily carbon, condensed hydrocarbons, and sulfates with associated water

NOTE Regulatory agencies choosing to use ISO 16183 could adapt this definition to their particular needs. For example, US regulations after 2007 will define particulate matter at a temperature greater than 42 °C and less than 52 °C.

3.2
gaseous pollutant
gas considered to be polluting to the atmosphere: carbon monoxide, hydrocarbons or non-methane hydrocarbons, or both these, oxides of nitrogen [expressed in nitrogen dioxide (NO_2) equivalent], formaldehyde and methanol

3.3
partial-flow dilution method
process of separating a part of the raw exhaust from the total exhaust flow, then mixing it with an appropriate amount of dilution air prior to the particulate sampling filter

3.4
full-flow dilution method
process of mixing dilution air with the total exhaust flow prior to separating a fraction of the diluted exhaust stream for analysis

NOTE It is common in many full flow dilution systems to dilute this fraction of pre-diluted exhaust a second time to obtain appropriate sample temperatures at the particulate filter.

3.5
specific emission
mass emission expressed in grams per kilowatt hour

3.6
steady-state test cycle
test cycle comprising a sequence of engine test modes in which the engine is given sufficient time to achieve defined speed, torque and stability criteria at each mode

3.7
transient test cycle
test cycle comprising a sequence of normalized speed and torque values that vary relatively quickly with time

3.8
response time
difference in time between a rapid change of the component to be measured at the reference point and the appropriate change in the response of the measuring system, whereby the change of the measured component is at least 60 % FS (full scale) and takes place within less than 0,1 s

See Figure 1.

NOTE 1 The system response time, t_{90}, consists of the delay time to the system and of the rise time of the system.

NOTE 2 The response time can vary, depending on where the reference point for the change of the component to be measured is defined: either at the sampling probe or directly at the port entrance of the analyser. For the purposes of this International Standard, the sampling probe is defined as the reference point.

3.9
delay time
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}

See Figure 1.

NOTE 1 For the gaseous components, this is basically the transport time of the measured component from the sampling probe to the detector.

NOTE 2 The delay time can vary, depending on where the reference point for the change of the component to be measured is defined: either at the sampling probe or directly at the port entrance of the analyser. For the purposes of this International Standard, the sampling probe is defined as the reference point.

3.10
rise time
time between the 10 % and 90 % response of the final reading ($t_{90} - t_{10}$)

See Figure 1.

NOTE 1 This is the instrument response after the component to be measured has reached the instrument.

NOTE 2 The rise time can vary, depending on where the reference point for the change of the component to be measured is defined: either at the sampling probe or directly at the port entrance of the analyser. For the purposes of this International Standard, the sampling probe is defined as the reference point.

3.11
transformation time
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}

See Figure 1.

NOTE 1 The transformation time is used for the signal alignment of different measurement instruments.

NOTE 2 The transformation time can vary, depending on where the reference point for the change of the component to be measured is defined: either at the sampling probe or directly at the port entrance of the analyser. For the purposes of this International Standard, the sampling probe is defined as the reference point.

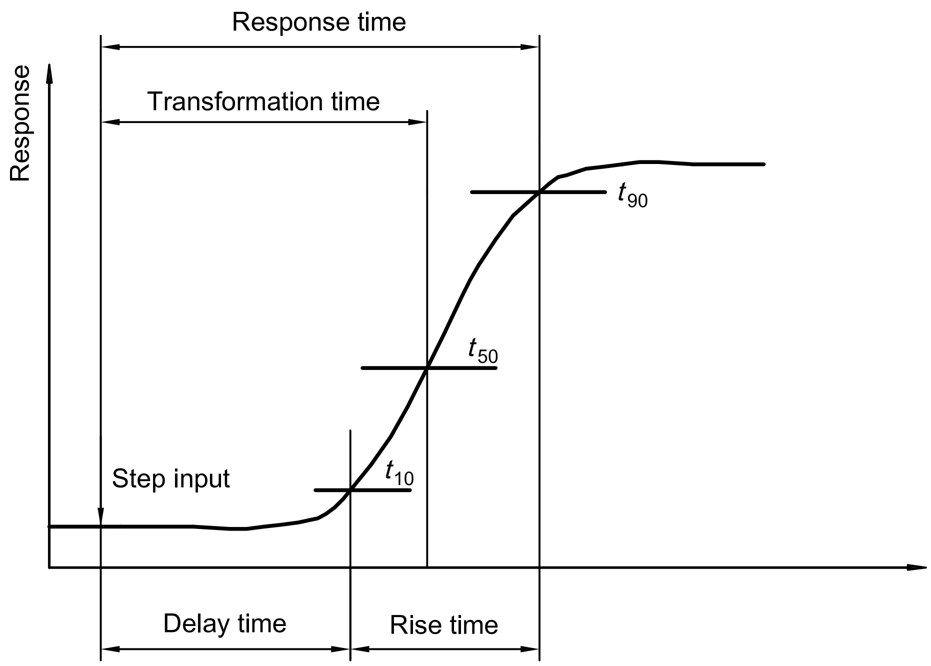

Figure 1 — Definitions of system response

Table 1 — General symbols and abbreviations used in this International Standard

Symbol/Abbreviation	Unit	Meaning
A/F_{st}	—	Stoichiometric air-to-fuel ratio
c	ppm [a] (µl/l) or % by volume	Concentration
C_c	—	Slip factor
d_e	m	Exhaust pipe diameter
d_p	m	Sampling probe diameter
d_{PM}	m	Particle diameter
f	Hz	Data sampling rate
f_a	—	Laboratory atmospheric factor
E_{CO2}	%	CO_2 quench of NO_x analyser
E_E	%	Ethane efficiency
E_{H2O}	%	Water quench of NO_x analyser
E_M	%	Methane efficiency
E_{NOx}	%	Efficiency of NO_x converter
η	Pa·s	Dynamic viscosity of exhaust gas
H_a	g/kg	Absolute humidity of the intake air
i	—	Subscript denoting an instantaneous measurement (e.g. 1 Hz)
k_f	—	Fuel specific factor
$k_{h,D}$	—	Humidity correction factor for NO_x for CI engines
$k_{h,G}$	—	Humidity correction factor for NO_x for SI engines
k_w	—	Dry to wet correction factor for the raw exhaust gas
λ	—	Excess air ratio
m_{edf}	kg	Mass of equivalent diluted exhaust gas over the cycle
m_f	mg	Particulate sample mass collected
m_{gas}	g	Mass of gaseous emissions (over the test cycle)
m_{PM}	g	Mass of particulate emissions (over the test cycle)
m_{se}	kg	Exhaust sample mass over the cycle
m_{sed}	kg	Mass of diluted exhaust gas passing the dilution tunnel
m_{sep}	kg	Mass of diluted exhaust gas passing the particulate collection filters
M_{gas}	g/kWh	Specific emission of gaseous emissions
M_{PM}	g/kWh	Specific emission of particulate emissions
$M_{r,e}$	—	Molecular mass [b] of exhaust
$M_{r,gas}$	—	Molecular mass of exhaust component

Table 1 *(continued)*

Symbol/Abbreviation	Unit	Meaning
n	—	Number of measurements
p_a	kPa	Saturation vapour pressure of the engine intake air
p_b	kPa	Total atmospheric pressure
p_r	kPa	Water vapour pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
P	—	Particle penetration
q_{mad}	kg/s	Intake air mass flow rate on dry basis
q_{maw}	kg/s	Intake air mass flow rate on wet basis
q_{mCe}	kg/s	Carbon mass flow rate in the raw exhaust gas
q_{mCf}	kg/s	Carbon mass flow rate into the engine
q_{mCp}	kg/s	Carbon mass flow rate in the partial-flow dilution system
q_{mdew}	kg/s	Diluted exhaust gas mass flow rate on wet basis
q_{mdw}	kg/s	Dilution air mass flow rate on wet basis
q_{medf}	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
q_{mew}	kg/s	Exhaust gas mass flow rate on wet basis
q_{mex}	kg/s	Sample mass flow rate extracted from dilution tunnel
q_{mf}	kg/s	Fuel mass flow rate
q_{mp}	kg/s	Sample flow of exhaust gas into partial-flow dilution system
q_{vs}	l/min	System flow rate of exhaust analyser system
q_{vt}	cm³/min	Tracer gas flow rate
r_d	—	Dilution ratio
r_h	—	Hydrocarbon response factor of the FID
r_m	—	Methanol response factor of the FID
r_s	—	Average sample ratio
ρ_e	kg/m³	Exhaust gas density (wet, at 273 K and 101,3 kPa)
ρ_{gas}	kg/m³	Density of exhaust component (at 273 K and 101,3 kPa)
ρ_{PM}	kg/m³	Particle density (at 273 K and 101 kPa)
σ		Standard deviation
T	K	Absolute temperature
T_a	K	Absolute temperature of the intake air
T_e	K	Exhaust gas temperature
t_{10}	s	Time between step input and 10 % of final reading
t_{50}	s	Time between step input and 50 % of final reading
t_{90}	s	Time between step input and 90 % of final reading
τ	s	Particle relaxation time
u	—	Ratio between densities of gas component and exhaust gas
V_s	l	Total volume of exhaust analyser system

Table 1 *(continued)*

Symbol/Abbreviation	Unit	Meaning
W_{act}	kWh	Actual cycle work of the respective test cycle
υ_e	m/s	Gas velocity in the exhaust pipe
υ_p	m/s	Gas velocity in the sampling probe
Symbols specific to fuel composition		
w_{ALF}	—	Hydrogen content of fuel, % by mass
w_{BET}	—	Carbon content of fuel, % by mass
w_{GAM}	—	Sulfur content of fuel, % by mass
w_{DEL}	—	Nitrogen content of fuel, % by mass
w_{EPS}	—	Oxygen content of fuel, % by mass
α	—	Molar hydrogen ratio (H/C)
β	—	Molar carbon ratio (C/C)
γ	—	Molar sulfur ratio (S/C)
δ	—	Molar nitrogen ratio (N/C)
ε	—	Molar oxygen ratio (O/C)
Referring to a fuel $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$		
Symbols and abbreviations for chemical components		
ACN	—	Acetonitrile
C1	—	Carbon 1 equivalent hydrocarbon
CH_4	—	Methane
CH_3OH	—	Methanol
C_2H_6	—	Ethane
C_3H_8	—	Propane
CO	—	Carbon monoxide
CO_2	—	Carbon dioxide
DNPH	—	Dinitrophenyl hydrazine
DOP	—	Di-octylphtalate
HC	—	Hydrocarbons
HCHO	—	Formaldehyde
H_2O	—	Water
NMHC	—	Non-methane hydrocarbons
NO_x	—	Oxides of nitrogen
NO	—	Nitric oxide
NO_2	—	Nitrogen dioxide
PM	—	Particulate matter
RME	—	Rapeseed oil methyl ester

Table 1 *(continued)*

Symbol/Abbreviation	Unit	Meaning
Other abbreviations		
CLD	—	Chemiluminescent detector
FID	—	Flame ionization detector
FTIR	—	Fourier transform infrared (analyser)
GC	—	Gas chromatograph
HCLD	—	Heated chemiluminescent detector
HFID	—	Heated flame ionization detector
HPLC	—	High pressure liquid chromatograph
NDIR	—	Non-dispersive infrared (analyser)
NMC	—	Non-methane cutter
% FS	—	Percentage of full scale
SIMS	—	Soft ionization mass spectrometer
St	—	Stokes number

[a] "Parts per million (ppm)" is a deprecated unit, i.e. not accepted by the International System of Units, SI. It is used exceptionally in this International Standard, immediately followed by the SI unit of equivalent value in parentheses, in order to correspond to other, closely related and already published standards. The accepted SI form for the expression of a volume fraction is in units of microlitres per litre (µl/l), or, alternatively, as 10^{-6} or as a percentage by volume (% by volume); for mass fractions it is expressed in micrograms per gram (µg/g). See ISO 31-0:1992, 2.3.3, and ISO 31-8-15:1992.

[b] Formerly called molecular weight.

4 Test conditions

4.1 Engine test conditions

4.1.1 Test condition parameter

The absolute temperature (T_a) of the engine air at the inlet to the engine, expressed in kelvin, and the dry atmospheric pressure (p_s), expressed in kilopascals, shall be measured, and the parameter f_a determined in accordance with the following provisions. In multi-cylinder engines having distinct groups of intake manifolds, such as in a "vee" engine configuration, the average temperature of the distinct groups shall be taken.

a) For compression-ignition engines:

— Naturally aspirated and mechanically supercharged engines

$$f_a = \left(\frac{99}{p_s}\right) \times \left(\frac{T_a}{298}\right)^{0,7} \tag{1}$$

— Turbocharged engines, with or without cooling of the intake air

$$f_a = \left(\frac{99}{p_s}\right)^{0,7} \times \left(\frac{T_a}{298}\right)^{1,5} \tag{2}$$

b) For spark-ignition engines:

$$f_a = \left(\frac{99}{p_s}\right)^{1,2} \times \left(\frac{T_a}{298}\right)^{0,6} \tag{3}$$

4.1.2 Test validity

For a test to be recognized as valid, f_a shall be such that $0{,}96 \leqslant f_a \leqslant 1{,}06$.

4.2 Engines with charge air cooling

The charge air temperature shall be recorded and be within ± 5 K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. The temperature of the cooling medium shall be at least 293 K (20 °C).

If a test shop system or external blower is used, the charge air temperature shall be set to within ± 5 K of the maximum charge air temperature specified by the manufacturer at the speed of the declared maximum power and full load. Coolant temperature and coolant flow rate of the charge air cooler at the above set point shall not be changed for the whole test cycle. The charge air cooler volume shall be based upon good engineering practice and typical vehicle/machinery applications.

Optionally, the setting of the charge air cooler may be done in accordance with SAE J 1937.

4.3 Power

The basis of specific emissions measurement is uncorrected net or gross power, depending on the regulation.

Certain auxiliaries necessary only for the operation of the vehicle that can be mounted on the engine should be removed for the test.

EXAMPLE Air compressor for brakes, power steering compressor, air conditioning compressor or pumps for hydraulic actuators.

Where such auxiliaries have not been removed, the power absorbed by them shall be determined in order to adjust the set values and calculate the work produced by the engine over the test cycle.

4.4 Engine air intake system

An engine air intake system shall be used presenting an air intake restriction within ± 300 Pa of the value specified by the engine manufacturer for a clean air cleaner and in accordance with the respective regulation.

4.5 Engine exhaust system

A vehicle exhaust system or a test shop system shall be used presenting an exhaust backpressure within ± 650 Pa of the value specified by the engine manufacturer and in accordance with the respective regulation. The exhaust system shall conform to the requirements for exhaust gas sampling in 5.6.2 and 7.2.3, EP.

If the engine is equipped with an exhaust after-treatment device, the exhaust pipe shall have the same diameter as found in-use for at least four pipe diameters upstream to the inlet of the beginning of the expansion section containing the after-treatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust after-treatment device shall be the same as in the vehicle configuration or within the distance specifications of the manufacturer. The exhaust backpressure or restriction shall follow these same criteria, and may be set with a valve. The after-treatment container may be removed during dummy tests and during engine mapping and replaced with an equivalent container having an inactive catalyst support.

4.6 Cooling system

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer shall be used.

4.7 Lubricating oil

The lubricating oil shall be as specified by the manufacturer; the specifications of the lubricating oil used for the test shall be recorded and presented with the results of the test.

4.8 Test fuel

Fuel characteristics influence the engine exhaust gas emission. Therefore, the characteristics of the fuel used for the test should be determined, recorded and declared with the results of the test. Where fuels designated as reference fuels are used, the reference code and the analysis of the fuel shall be provided. For all other fuels, the characteristics to be recorded shall be those listed in the appropriate universal data sheet of ISO 8178-5.

The fuel temperature shall be in accordance with the manufacturer's recommendations.

5 Determination of gaseous and particulate components

5.1 General

For the purpose of this International Standard, the gaseous components are measured in the raw exhaust gas on a real time basis, and the particulates are determined using a partial-flow dilution system.

The instantaneous concentration signals of the gaseous components are used for the calculation of the mass emissions by multiplication with the instantaneous exhaust mass flow rate. The exhaust mass flow rate may be measured directly or calculated in accordance with 5.4.4 (intake air and fuel flow measurement), 5.4.5 (tracer method) or 5.4.6 (intake air and air/fuel ratio measurement). Special attention shall be paid to the response times of the different instruments. These differences shall be accounted for by time aligning the signals in accordance with 5.5.3.

For particulates, the exhaust mass flow rate signals given in 5.4 are used for controlling the partial-flow dilution system in order that a sample proportional to the exhaust mass flow rate can be taken. The quality of proportionality is checked by applying a regression analysis between sample and exhaust flow in accordance with 5.6.2.

The complete test set up is shown schematically in Figure 2.

5.2 Equivalence

The emission of gaseous and particulate components by the engine submitted for testing shall be measured in accordance with clauses 6 and 7. These describe the recommended analytical systems for the gaseous emissions (see clause 6) and the recommended particulate dilution and sampling systems (see clause 7).

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 systems accepted by this International Standard. *Results* refers to the specific cycle weighted emissions value. The correlation testing is to be performed at the same laboratory, on the same test cell, and the same engine, and is preferably to be run concurrently. The test cycle to be used shall be the appropriate cycle on which the engine will be run. The equivalency of the sample pair averages shall be determined by “t”-test statistics as given in Annex A, obtained under these laboratory cell and engine conditions. Outliers shall be determined in accordance with ISO 5725-2 and excluded from the database. 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 the introduction of a new system into the standard, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility in accordance with ISO 5725-2.