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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 11: Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions

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

Partie 11: Mesurage au banc d'essai des émissions de gaz et de particules des gaz d'échappement de moteurs d'engins mobiles non routiers en régime transitoire

Reference number
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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.

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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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-11 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust gas emission measurement*:

- *Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*
- *Part 2: Measurement of gaseous and particulate exhaust emissions at site*
- *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*
- *Part 4: Test cycles for different engine applications*
- *Part 5: Test fuels*
- *Part 6: Report of measuring results and tests*
- *Part 7: Engine family determination*
- *Part 8: Engine group determination*
- *Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*
- *Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*
- *Part 11: Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions*

Introduction

Today's measurement systems depend on the type of test cycle, steady state or transient, and the type of pollutant to be measured. On a steady state cycle, the mass of gaseous emissions can be calculated either from the concentration in the raw exhaust gas and the exhaust flow of the engine, which can easily be determined, or from the concentration in the diluted exhaust gas and the CVS (Constant Volume Sampling) flow of a full flow dilution system. Both equivalent systems are described in ISO 8178-1. For PM, full flow dilution or partial flow dilution systems, in which only a portion of the exhaust gas is diluted, can be used.

On a transient cycle as covered by this International Standard, real-time exhaust flow determination is more difficult. Therefore, the CVS principle has been used for many years due to the fact that 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 flow is kept virtually constant and the emissions (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 on steady state cycles. On the other hand, raw exhaust measurement and partial flow systems can only be applied to transients if sophisticated control systems and calculation algorithms are used.

For most nonroad applications and heavy-duty engines, the CVS system is large and costly. Therefore, ISO 16183 has been developed by ISO/TC 22/SC 5, which defines raw gaseous emissions measurement and partial flow dilution for heavy-duty engines under transient test conditions. Since many nonroad engines are similar to heavy-duty engines in engine size, displacement and power, it is believed that the contents of ISO 16183 can also be applied to nonroad engines.

For the purpose of this International Standard, both full flow dilution and partial flow dilution/raw exhaust methods are considered equivalent and are therefore covered herein.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 11:
Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions

1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust emission from reciprocating internal combustion (RIC) engines under transient conditions on a test bed, necessary for determining one value for each exhaust gas pollutant.

The specific transient test cycle covered by this part of ISO 8178 is applicable to compression-ignition engines for mobile use with a power output between 37 kW and 560 kW, excluding engines for motor vehicles primarily designed for road use. This part of ISO 8178 may be applied to engines used in off-road vehicles and diesel powered off-road industrial equipment as described in 8.3.1.3 of ISO 8178-4. This includes e.g. engines for construction equipment including wheel loaders, bulldozers, crawler tractors, crawler loaders, truck-type loaders, off-highway trucks, hydraulic excavators, agricultural equipment, self propelled agricultural vehicles (including tractors), forestry equipment, fork lift trucks, road maintenance equipment and mobile cranes.

Many of the procedures described below 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.

2 Normative references

The following referenced documents are indispensable for the application 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 8178-1, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

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

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5725-2:1994, *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 14396:2002, *Reciprocating internal combustion engines — Determination and method for the measurement of engine power — Additional requirements for exhaust emission tests in accordance with ISO 8178*

ISO 15550, *Internal combustion engines — Determination and method for the measurement of engine power — General requirements*

ISO 16183:2002, *Heavy duty engines — Measurement of gaseous emissions from raw exhaust gas and of particulate emissions using partial flow dilution systems under transient test conditions*

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

3 Terms and definitions

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

3.1
particulate matter
any material collected on a specified filter medium after diluting exhaust with clean filtered air to a temperature of greater than 315 K (42 °C) and less than or equal to 325 K (52 °C), as measured at a point immediately upstream of the filter

NOTE This is primarily carbon, condensed hydrocarbons, and sulfates with associated water.

3.2
gaseous pollutants
carbon monoxide, hydrocarbons and/or non-methane hydrocarbons, 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 emissions
mass emissions expressed in g/kWh

3.6
steady-state test cycle
test cycle with 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 with a sequence of normalized speed and torque values that vary relatively quickly with time

3.8
rated speed
engine speed at which, according to the statement of the engine manufacturer, the rated or prime power is delivered

NOTE For details see ISO 14396.

3.9
low speed
lowest engine speed where 50 % of the rated or prime power is delivered

3.10
high speed
highest engine speed where 70 % of the rated or prime power is delivered

3.11
reference speed
100 per cent speed value to be used for denormalizing the relative speed values of the NRTC test, as set out in 6.4.2

3.12
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 and takes place in less than 0,1 second

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 may vary dependent 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; in this International Standard, the sampling probe is defined as the reference point.

3.13
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})

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 For the delay time, the sampling probe is defined as the reference point.

3.14
rise time
time between the 10 % and 90 % response of the final reading ($t_{90} - t_{10}$)

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

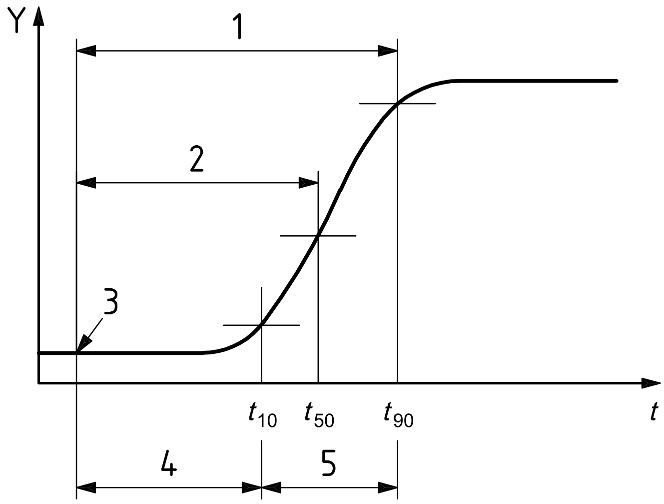
NOTE 2 For the rise time, the sampling probe is defined as the reference point.

3.15
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})

NOTE 1 For the transformation time, the sampling probe is defined as the reference point.

NOTE 2 The transformation time is used for the signal alignment of different measurement instruments.

NOTE 3 3.12 to 3.15 do not apply to full flow dilution systems covered by Clause 10.



Key

Y response

1 response time
2 transformation time
3 step input
4 delay time
5 rise time

Figure 1 — Definitions of system response

4 Symbols and abbreviated terms

4.1 General symbols

Table 1 — List of general symbols

Symbol	Unit	Term
A/F_{st}	—	Stoichiometric air to fuel ratio
c	ppm / Vol%	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

Table 1 (*continued*)

Symbol	Unit	Term
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
$k_\mathrm{h,D}$	—	Humidity correction factor for NO_x for CI 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
n	—	Number of measurements
p_a	kPa	Saturation vapor pressure of the engine intake air
p_b	kPa	Total atmospheric pressure
p_r	kPa	Water vapor pressure after cooling bath
p_s	kPa	Dry atmospheric pressure
P	—	Particle penetration
$q_{m\mathrm{ad}}$	kg/s	Intake air mass flow rate on dry basis
$q_{m\mathrm{aw}}$	kg/s	Intake air mass flow rate on wet basis
$q_{m\mathrm{Ce}}$	kg/s	Carbon mass flow rate in the raw exhaust gas
$q_{m\mathrm{Cf}}$	kg/s	Carbon mass flow rate into the engine
$q_{m\mathrm{Cp}}$	kg/s	Carbon mass flow rate in the partial flow dilution system
$q_{m\mathrm{dew}}$	kg/s	Diluted exhaust gas mass flow rate on wet basis
$q_{m\mathrm{dw}}$	kg/s	Dilution air mass flow rate on wet basis
$q_{m\mathrm{edf}}$	kg/s	Equivalent diluted exhaust gas mass flow rate on wet basis
$q_{m\mathrm{ew}}$	kg/s	Exhaust gas mass flow rate on wet basis
$q_{m\mathrm{ex}}$	kg/s	Sample mass flow rate extracted from dilution tunnel
$q_{m\mathrm{f}}$	kg/s	Fuel mass flow rate
$q_{V\mathrm{s}}$	l/min	System flow rate of exhaust analyser system
$q_{V\mathrm{t}}$	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

Table 1 (*continued*)

Symbol	Unit	Term
r_s	—	Average sample ratio
ρ	kg/m^3	Density
ρ_e	kg/m^3	Exhaust gas density
ρ_{PM}	kg/m^3	Particle density
σ		Standard deviation
T	K	Absolute temperature
T_a	K	Absolute temperature of the intake air
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
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

4.2 Symbols and abbreviations for the fuel composition

w_{ALF} hydrogen content of fuel, % mass

w_{BET} carbon content of fuel, % mass

w_{GAM} sulfur content of fuel, % mass

w_{DEL} nitrogen content of fuel, % mass

w_{EPS} oxygen content of fuel, % 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 $C_\beta H_\alpha O_\varepsilon N_\delta S_\gamma$

4.3 Symbols and abbreviations for the 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 methylester

4.4 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
MW	Molecular Mass
NDIR	Non-Dispersive Infrared (Analyser)
NMC	Non-Methane Cutter
NRTC	Non Road Transient Cycle
% FS	Percent of full scale
SIMS	Soft Ionization Mass Spectrometer
Stk	Stokes number