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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 2: Measurement of gaseous and particulate exhaust emissions under field conditions

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

Partie 2: Mesurage des émissions de gaz et de particules sur site

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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.

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

This third edition cancels and replaces the second edition (ISO 8178-2:2008), which has been technically revised.

The main changes are as follows:

— Clause 4 has been amended to update requirements applicable for discrete-mode steady-state tests in the field when it is intended to either conduct measurements at a single operating point or conduct a weighted cycle-based test, reflecting changes in other parts of the ISO 8178 series;

— Clause 5 has been expanded to set out requirements for measurement of gaseous emissions performance of engines during typical in-service operation under field conditions using portable emission measurement systems (PEMS) and moving average window data evaluation.

A list of all 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.

Introduction

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 size of 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 a laboratory test using a dynamometer is not possible, testing at site or under appropriate conditions can be a viable alternative.

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 this document are appropriate. It should be recognized that data obtained under these circumstances may not agree completely with previous or future data, obtained in a laboratory or in the field, due to the variability and uncontrolled nature of testing in the field.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 2: Measurement of gaseous and particulate exhaust emissions under field conditions

1 Scope

This document specifies the measurement and evaluation methods for gaseous and particulate exhaust emissions from reciprocating internal combustion engines (RIC engines) in the field.

This document is applicable when the emissions from RIC engines used in non-road machinery, industrial equipment, marine installations, generating sets, diesel rail traction or similar machinery applications need to be measured in the field. Clause 4 applies for the conduct of discrete-mode steady-state gaseous or particulate emission measurements at a single operating point or conduct a weighted cycle-based test in the field. Clause 5 applies where it is necessary to assess gaseous emissions performance of engines during typical in-service operation under field conditions using portable emission measurement systems (PEMS).

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 8178-1:2020, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement systems of gaseous and particulate emissions*

ISO 8178-4:2020, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 4: Steady-state and transient test cycles for different engine applications*

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

ISO 8178-6, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 6: Report of measuring results and test*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 27145-4, *Road vehicles — Implementation of World-Wide Harmonized On-Board Diagnostics (WWH-OBD) communication requirements — Part 4: Connection between vehicle and test equipment*

ISO 15765-4, *Road vehicles — Diagnostic communication over Controller Area Network (DoCAN) — Part 4: Requirements for emissions-related systems*

ISO 13400, *Road vehicles — Diagnostic communication over Internet Protocol (DoIP)*

ISO 15031-3, *Road vehicles — Communication between vehicle and external equipment for emissions-related diagnostics — Part 3: Diagnostic connector and related electrical circuits: Specification and use*

SAE J1939-73, *Application layer – diagnostics*

ASTM E 29-06b, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8178-1, ISO 8178-4 and the following apply.

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

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

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

3.1.1
event
data measured in an in-service test for the gaseous pollutant emissions calculations obtained in a time increment Δt equal to the data sampling period

3.1.2
field conditions
conditions under which the engine under test is installed in, and coupled with, the actual equipment or vehicle, which is driven by the engine, and conditions under which the equipment or vehicle is allowed to function in normal use

3.1.3
moving average window
period, measured in cumulative amount of work or CO_2, over which each integration of gaseous pollutant emissions is performed

3.1.4
operating sequence
elapsed time of uninterrupted machinery operation and continuous data sampling during an in-service test

3.1.5
portable emission measurement system
PEMS
emission measurement system that is transportable and suitable for conducting in-service measurements

3.1.6
proxy power
value obtained by simple linear interpolation based on certain assumptions for the sole purpose of identifying non-working events when there is no torque signal from an Electronic Control Unit (ECU)

3.1.7
reference mass of CO_2
amount of cumulative CO_2 measured during a prior bench-test of the engine type or, where applicable, engine family, which is used to determine the size of the moving average CO_2 window

3.1.8
reference work
amount of cumulative work measured during a prior bench-test of the engine type or, where applicable, engine family, which is used to determine the size of the moving average work window

3.2 Symbols

3.2.1 General symbols

Symbol	Term	Unit
D_{max}	Maximum averaging window duration	s
e_{gas}	Brake specific gaseous pollutant emissions	g/kWh
f_a	Laboratory atmospheric factor	—
f_{CF}	Conformity factor	—
f_{CFC}	Certification ratio	—
f_{CFI}	In-service ratio	—
f_{WF}	Weighting factor	—
K_{veline}	Simplified engine-family-specific CO_2 constant	—
L	Limit value	g/kWh
m	Mass emission of gaseous pollutant	g
m_{CO2}	Mass of CO_2 for the test cycle	g
m_{CO2ref}	Reference mass of CO_2	g
N_{mode}	Number of mode in test cycle	—
p_b	Total barometric pressure	kPa
p_S	Dry atmospheric pressure	kPa
P	Uncorrected brake power	kW
P_{aux}	Declared total power absorbed by auxiliaries fitted for the test and not required by Annex B of ISO 8178-4:2020	kW
P_{max}	Maximum measured or declared power	kW
$P_{proxy,i}$	Instantaneous proxy power (see Annex F)	kW
P_m	Measured power	kW
q_{mCO2}	Mean CO_2 mass flow rate	g/h
r_{NOx}	NO_x response factor of zirconium dioxide analyser	—
r_{NO2}	NO_2 response factor of zirconium dioxide analyser	—
$r_{NO2,max}$	Maximum NO_2/NO_x concentration ratio	—
t	Time	s
t_{ref}	Reference time	s
T	Temperature	°C
T_a	Absolute temperature	K
W	Work	kWh
W_{act}	Actual work	kWh
W_{ref}	Reference work	kWh

3.2.2 Symbols for measured chemical components

Symbol	Component
CO	Carbon monoxide
CO_2	Carbon dioxide
HC	Hydrocarbons
NH_3	Ammonia
NMHC	Non-methane hydrocarbons
NO_2	Nitrogen Dioxide

Symbol	Component
NO_x	Oxides of nitrogen
PM	Particulate matter
PN	Particulate number
THC	Total hydrocarbons

3.3 Abbreviated terms

ECU	Electronic Control Unit
EFM	Exhaust Flow Meter
LSI-NRTC	Large Spark-Ignition Non-Road Transient Cycle
NRMM	Non-Road Mobile Machinery
NRSC	Non-Road Steady-State Cycle
NRTC	Non-Road Transient Cycle
RMC NRSC	Ramped Modal Non-Road Steady-State Cycle
ZRDO	Zirconium dioxide (analyser)

4 Discrete-mode steady-state tests in the field when it is intended to either conduct measurements at a single operating point or conduct a weighted cycle-based test

4.1 General

Testing conducted according to Clause 4 shall in general follow the requirements set out in ISO 8178-1:2020 and ISO 8178-4 for discrete-mode steady-state testing. Deviations from the requirements of those parts are limited to those set-out in Clause 4. This clause shall not be used for transient testing.

4.2 Test conditions

4.2.1 General requirements

Field measurements according to Clause 4 shall be conducted only when test-bed measurement is not appropriate because the required measurement cannot be performed on the test-bed.

NOTE When testing under field conditions the test cycles specified in ISO 8178-4:2020 might not be fully reproduceable, there might be differences in engine operating parameters from laboratory conditions and there might be differences in the accuracy of emission measurement equipment. Consequently, it is not expected that the emission results obtained when testing according to Clause 5 will be directly comparable to the values obtained on the test bed.

4.2.2 Engine test conditions

4.2.2.1 Ambient conditions

The temperature of the engine intake air, expressed in °C and the dry atmospheric pressure, p_s, expressed in kilopascal (kPa), shall be measured and recorded, and the parameter, f_a, shall be determined according to ISO 8178-4:2020, 5.1.1 and recorded. The calculation of f_a requires the absolute temperature, T_a, of the intake air to be expressed in Kelvin (K).

With the agreement of the parties concerned, taking into consideration the purpose for which the test is being conducted, the range of f_a and intake air temperature may be outside of the range given in ISO 8178-4:2020, 5.1.2.

NOTE f_a is calculated using intake air temperature, not ambient air temperature.

The humidity of the engine intake air shall be measured and the absolute humidity determined.

4.2.2.2 Engines with charge air cooling

The temperature of the cooling medium and the temperature of the charge air shall be recorded.

4.2.2.3 Engine parameters

The engine parameters necessary to complete the emission calculations and ensure the validity of the test in accordance with this document shall be determined from measured values and recorded in appropriate units.

Where it is not practicable to measure a parameter using instrumentation in conformance with the requirements of ISO 8178-1, alternative methods of measurement may be utilized with the agreement of the parties concerned. This may include using signals from an engine control unit or the machinery in which the engine is installed.

Other parameters may be measured and recorded according to the agreement of the parties concerned.

4.2.3 Power

Terms of power are defined in ISO 14396, as applied in ISO 8178-4:2020. The basis of specific emission measurement, expressed in g/kWh, is uncorrected brake power. Power, engine speed and torque values may differ at field compared to the test-bed conditions. Therefore, the emission values expressed in g/kWh differ at field compared to those under test-bed conditions. If the 100 % load of the test-bed measurement cannot be reached, the maximum power output to be measured is limited by maximum allowed engine speed and maximum allowed torque.

In cases where a direct measurement of torque is not possible, the power output shall be calculated based on other available data including signals from the engine ECU or fuel rack position. The method of calculation and estimation shall be agreed between parties involved.

Subclause 5.2 of ISO 8178-4:2020 shall be used to account for auxiliaries, to the extent possible, taking into consideration that it might not be practical to remove auxiliaries from an installed engine, nor disconnect the engine from the driven machinery. Where there is a risk that the auxiliaries that would normally be removed for testing according to ISO 8178-4 might absorb more than 5 % of the maximum observed power, agreement between the parties concerned shall be sought prior to the test.

4.2.4 Engine air intake system

The engine shall be equipped with an air intake system presenting an air inlet restriction within the limit specified by the manufacturer.

4.2.5 Charge air cooler

Where applicable, the engine shall be equipped with a charge air cooling system with sufficient capacity to maintain the engine at the normal operating temperatures prescribed by the manufacturer.

4.2.6 Engine exhaust system

The engine shall be equipped with an exhaust system presenting an exhaust back pressure within the limit specified by the manufacturer.

4.2.7 Engines with exhaust after-treatment systems

4.2.7.1 Use of reagent

In the case of an engine equipped with an exhaust after-treatment system that requires the consumption of a reagent, the reagent used for all tests shall be within the specification prescribed by the manufacturer, be recorded and presented with the results of the tests.

4.2.7.2 Regeneration

In the case of an engine equipped with an exhaust after-treatment system that regenerates on an infrequent (periodic) basis, as described in ISO 8178-4:2020, 5.5.1.2.2, emission results shall be adjusted to account for regeneration events. In this case, the average emission depends on the frequency of the regeneration event in terms of fraction of tests during which the regeneration occurs, and the extent to which the emissions increase during regeneration. The method for determination of emissions during regeneration and the corresponding adjustment shall be agreed by the parties concerned.

4.2.8 Crankcase emissions

Where the parties involved require crankcase emissions that are normally discharged to ambient atmosphere to be included, the emissions shall be added to the exhaust emissions during all emission testing either physically or mathematically. Methods to achieve this are set out in ISO 8178-4:2020, 5.5.2.

4.2.9 Cooling system

The engine shall be equipped with a cooling system with sufficient capacity to maintain the engine at normal operating temperatures prescribed by the manufacturer.

4.2.10 Lubricating oil

Specifications of the lubricating oil used for the test shall conform with the requirements of the manufacturer, be recorded and presented with the results of the test.

4.2.11 Test fuels

Fuel characteristics influence the engine exhaust gas emission. Therefore, in all cases, the characteristics of the fuel used for the test shall be verified as required, recorded and declared with the results of the test. The characteristics to be recorded shall be those listed in the appropriate universal data sheet in ISO 8178-5. A certificate of analysis of the fuel that includes these characteristics shall satisfy this requirement.

Unless otherwise agreed, the test fuel shall be either the appropriate reference fuel given in ISO 8178-5 or the typical fuel for the engine in its field application.

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

4.3 Installation of sampling probes and equipment

Provisions that shall be taken for the proper installation of the sampling probes and measuring equipment are described in ISO 8178-1:2020, 5.2 and 8.1.1. Modifications to suit field installation conditions are permitted under the following conditions:

a) The space available for the necessary instrumentation shall be large enough to meet the requirements for safety and working ambient conditions.

b) The engine exhaust shall be routed using short connectors, preferably flexible, at the end of the engine's exhaust pipe downstream of any aftertreatment device, if used.

c) Flexible connectors that do not exceed a length of three times their largest inside diameter may be used to enlarge or reduce the exhaust-pipe diameter to match that of the test equipment.

d) Rigid stainless steel raw exhaust tubing shall be used to connect between flexible connectors. The tubing may be straight or bent to accommodate equipment geometry. "T" or "Y" stainless steel fittings may be used to join exhaust from multiple tailpipes.

e) Connectors and tubing shall not increase back pressure so much that it exceeds the manufacturer's maximum specified exhaust restriction.

f) Where there is a risk that the measurement might be distorted by condensation, action shall be taken to avoid this. This may include additional heating or insulation.

4.4 Measurement equipment and data to be measured

4.4.1 General

The emission of gaseous and particulate pollutants by the engine submitted for testing shall be measured using methods set out in ISO 8178-1:2020, Clause 5.

That clause describes the analytical systems for the gaseous pollutants and the particulate dilution and sampling systems used in the test cell. The same principles shall also be applied to field measurement systems. Field analytical systems shall be installed in a manner to minimize the impact of field ambient conditions such as temperature, pressure, humidity, physical orientation, mechanical shock and vibration, electromagnetic radiation, and background emissions.

The types of systems to be used for testing shall be declared prior to the test and shall be agreed upon by the parties involved.

4.4.2 Zirconium dioxide (ZRDO) NO_x analyser

A zirconium dioxide (ZRDO) NO_x analyser used under conditions that provide a NO_x response factor not less than 0,9 may be used to perform measurements in the field for the purposes, and under the conditions, set out in this clause:

a) As a monitoring device to confirm activation of a NO_x emission control system;

b) To perform a spot-check verification measurement at site where the parties concerned have agreed that the use of an instrument set out in ISO 8178-1:2020, 7.3.6 is not necessary;

c) Where the analyser has been demonstrated to meet the requirements of 4.4.3 under operating conditions similar to those of the intended test and the parties concerned have also agreed to use of that analyser.

Prior to performing any measurement with a ZRDO NO_x analyser, the parties concerned shall evaluate the uncertainties associated with the use of that analyser for the intended measurement. The following points shall be included in that evaluation:

a) Location of sensor(s) within exhaust system;

b) Potential interference by NH_3 that may increase measured result, and which may be dependent upon various factors including, but not limited to:

    1. Design of engine including after-treatment system, where installed;

    2. Age and deterioration of after-treatment system, where installed;

    3. Design characteristics of ZRDO NO_x analyser;

    4. Exhaust gas temperature.

NOTE A ZRDO NO_x analyser generally has a positive response to NH_3. Consequently, where NH_3 is present in the exhaust (for example downstream of a selective catalytic reduction (SCR) NO_x after-treatment system), it will create interference and the value measured by the ZRDO NO_x analyser will be a function of both NO_x and NH_3 concentration in the exhaust gas.

When using a ZRDO NO_x analyser, the following requirements shall be met:

a) The sensor of the analyser shall be mounted directly in the exhaust gas flow for making measurements on a wet basis;

b) Prior to conducting an emission test, the analyser shall be warmed-up and stabilized in accordance with the specifications of the instrument manufacturer and a zero and span check performed as specified in Clause K.1;

c) At the conclusion of the emission test, a post-test zero and span check shall be performed and drift verified according to ISO 8178-4:2020, 8.7.4.

d) The NO_x response factor shall be calculated as specified in Clause K.2.

4.4.3 Alternative measurement procedures

Other systems or analysers may be accepted, if it is found that they yield equivalent results using the general measurement principles and system equivalency set out in ISO 8178-1:2020, Clause 5, or if parties involved agree to the use of such a system or analyser.

4.4.4 Torque and speed

When performing measurements at a single steady-state operating point, each combination of torque and speed shall be agreed by the parties concerned and measurements reported on a point-by-point basis.

When performing a steady-state discrete-mode weighted cycle-based test, the engine shall be operated with the torque and speed sequence applied according to the relevant test cycles described in ISO 8178-1:2020. In cases where the relevant test cycle is not possible, e.g. due to the characteristic of the load or because of the torsional vibration of the plant, the required test point shall be replaced by a point as close as possible, by agreement with all parties involved.

The instrumentation for torque and speed measurement shall enable the determination of the shaft power to be within the given limits. Additional calculations and comparison with test-bed measurement results might be necessary.

Signals from the engine's ECU may be used in place of values measured by individual instruments, provided the signals are correctly filtered and in case of a signal that changes with time, time-aligned with the emissions signals from the instruments in accordance with the principles set out in Clause D.3. Any combination of ECU signals, with or without other measurements, may be used to estimate engine speed and torque for use in brake-specific emission calculations, provided the overall performance of any speed or torque estimator meets the performance specifications in ISO 8178-1:2020, Table 4.

Other available data including fuel rack position may be used for this purpose. In this case the method of calculation and estimation shall be agreed between parties involved.

4.4.5 Exhaust gas flow

The principal methods applicable for determining the exhaust gas flow and the required accuracy and linearity requirements are described in ISO 8178-1:2020, 6.4.3 and 6.4.4.

4.4.6 Accuracy of the data to be measured

4.4.6.1 Exhaust gas analyser

Measurement instruments shall meet the specifications set out in ISO 8178-1:2020, 5.3 and the requirements on calibration and performance checks set out in ISO 8178-1:2020, 9.1.

Special attention shall be given to perform the following actions:

a) the vacuum-side leak verification as set out in ISO 8178-1:2020, 9.3;

b) the response and updating-recording verification of the gas analyser as set out in ISO 8178-1:2020, 9.1.5.

The minimum frequency for gas analyser linearity verification and NO_2-to-NO converter conversion verification set out in ISO-8178-1:2020, Tables 6 and 7 may be increased to 3 months.

4.4.6.2 Other measuring equipment

The requirements set out in ISO 8178-1:2020, Clauses 6 and 9 shall be met. The calibration of all measuring instruments shall be traceable to national (international) standards. The instruments shall be calibrated as required by internal audit procedures, by the instrument manufacturer, according to ISO/IEC 17025.

In practical cases it is often impossible to measure the fuel consumption at site. In such cases, especially those concerning gas or heavy fuel, an estimation using a method other than chemical balance, with a corresponding estimated error shall be made.

The consequences of such an error on the final emissions shall be calculated and reported with the results of the emission measurement. The acceptance of test results established using such estimation shall be determined by the parties concerned.

4.4.7 Determination of the gaseous components

The analytical measuring equipment and the methods are described in ISO 8178-1:2020, Clauses 5 and 7. For field measurements, the non-methane hydrocarbon analysis according to ISO 8178-1:2020, 7.3.5.2 (gas chromatography) is not applicable in most cases, as this method needs laboratory equipment.

For the measurement of non-methane hydrocarbons (NMHC), the hydrocarbon cutter method of ISO 8178-1:2020, 7.3.5.3, should preferably be applied. Alternatively, a factor of 0,98 THC may be used for diesel engines.

4.4.8 Determination of the particulates

The determination of particulate matter (PM) or number (PN) and the equipment needed shall be as specified in ISO 8178-1:2020, Clauses 5 and 8. However, the reference filter weighing time may be exceeded.

The weighing chamber and analytical balance specifications according to ISO 8178-1:2020, 8.1.5 also apply to the measurement at site and under field conditions. In cases where the weighing chamber is not located near the measurement site, it shall be ensured that the loading of the filter does not change during the transport from or to the weighing chamber [e.g. caused by mechanical vibrations, evaporation at temperatures above 52 °C (325 K)]. It is permissible to collect and store particulate samples from several tests before transporting them to the weighing chamber, but this storage time should be minimized.

PM measurement might prove difficult under field conditions, especially on-board ships, locomotives and non-road mobile machinery. It is therefore acceptable to use alternative particulate sample media or measurement procedures, if their equivalency is proven in accordance with 4.4.3, including non-filtering techniques. This includes particulate deposition on an inert substrate using electrostatic,

