Reciprocating internal combustion engines — Exhaust emission measurement —

Part 1: 
Test-bed measurement of gaseous and particulate exhaust 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
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Bibliography
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 2.

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 8178-1 was prepared by Technical Committee ISO/TC 70, Internal combustion engines, Subcommittee SC 8, Exhaust gas emission measurement.

This second edition cancels and replaces the first edition (ISO 8178-1:1996), which has been technically revised.

ISO 8178 consists of the following parts, under the general title Reciprocating internal combustion engines — Exhaust 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 test

— 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

This part of ISO 8178 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 a map of an engine’s emissions characteristics which, through use of the proper weighting factors, can be used as an indication of that engine’s emission levels under various applications. The emission results are expressed in units of grams per kilowatt-hour and represent the mass rate of emissions per unit of work accomplished.

Although this part of ISO 8178 is designed for non-automotive engines, it shares many principles with particulate and gaseous emission measurements that have been in use for many years for on-road engines. One test procedure that shares many of these principles is the full-flow dilution method as currently specified for certification of 1985 and later heavy-duty truck engines in the USA. Another is the procedure for direct measurement of the gaseous emissions in the undiluted exhaust gas, as currently specified for the certification of heavy-duty truck engines in Japan and Europe.

Many of the procedures described in this part of ISO 8178 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 off-road engines is more complicated than the same task for on-road engines due to the diversity of off-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. Off-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, the tests must be made at site or under appropriate conditions.
Reciprocating internal combustion engines — Exhaust emission measurement —

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

1 Scope

This part of ISO 8178 specifies the measurement and evaluation methods for gaseous and particulate exhaust emissions from reciprocating internal combustion (RIC) engines under steady-state conditions 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 part of ISO 8178 is applicable to RIC engines for mobile, transportable and stationary use, excluding engines for motor vehicles primarily designed for road use. This part of ISO 8178 may be applied to engines used, for example, for earth-moving machines, generating sets and for other applications.

In limited instances, the engine can be tested on the test bed in accordance with ISO 8178-2, the field test document. 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 part of ISO 8178. Therefore, it is recommended that this option be exercised only with engines built in very limited quantities such as very large marine or generating set engines.

For engines used in machinery covered by additional requirements (e.g. occupational health and safety regulations, regulations for powerplants), 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.

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 31-0:1992, Quantities and units — Part 0: General principles


3 Terms and definitions

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

3.1 particulates
material collected on a specified filter medium after diluting exhaust gases 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 primary filter

NOTE 1 Particulates consist primarily of carbon, condensed hydrocarbons, and sulfates and associated water.

NOTE 2 Particulates defined in this part of ISO 8178 are substantially different in composition and weight from particulates or dust sampled directly from the undiluted exhaust gas using a hot filter method (e.g. ISO 9096). Particulates measurement as described in this part of ISO 8178 is conclusively proven to be effective for fuel sulphur levels up to 0,8 %.

NOTE 3 The filter temperature requirement has been changed compared to ISO 8178-1:1996 to reflect the latest legal requirements in the USA and European Union. Existing systems built in compliance with the requirements of ISO 8178-1:1996 may still be used.
3.2 partial-flow dilution method
process of separating a part of the raw exhaust from the total exhaust flow, then mixing with an appropriate amount of dilution air prior to passing through the particulate sampling filter

NOTE See 17.2.1, Figures 10 to 18.

3.3 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 (see 17.2.2, Figure 19).

3.4 isokinetic sampling
process of controlling the flow of the exhaust sample by maintaining the mean sample velocity at the probe equal to the exhaust stream mean velocity

3.5 non-isokinetic sampling
process of controlling the flow of the exhaust sample independently of the exhaust stream velocity

3.6 multiple-filter method
process of using one pair of filters for each of the individual test cycle modes

NOTE The modal weighting factors are accounted for after sampling during the data evaluation phase of the test.

3.7 single-filter method
process of using one pair of filters for all test cycle modes

NOTE Modal weighting factors must 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.

3.8 specific emissions
mass emissions expressed in grams per kilowatt-hour

NOTE For many engine types within the scope of this part of ISO 8178, the auxiliaries which will be fitted to the engine in service will not be known at the time of manufacture or certification.

When it is not appropriate to test the engine in the conditions as defined in ISO 14396 (e.g. if the engine and transmission form a single integral unit), the engine can only be tested with other auxiliaries fitted. In this case the dynamometer settings should be determined in accordance with 5.3 and 12.5. The auxiliary losses should not exceed 5 % of the maximum observed power. Losses exceeding 5 % must be approved by the parties involved prior to the test.

3.9 brake power
observed power measured at the crankshaft or its equivalent, the engine being equipped only with the standard auxiliaries necessary for its operation on the test bed

NOTE See 5.3 and ISO 14396.

3.10 auxiliaries
equipment and devices listed in ISO 14396
4 Symbols and abbreviations

4.1 General symbols

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<th>Term</th>
<th>Unit</th>
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<tr>
<td>$A/F_{st}$</td>
<td>Stoichiometric air-to-fuel ratio</td>
<td>1</td>
</tr>
<tr>
<td>$A_p$</td>
<td>Cross-sectional area of the isokinetic sampling probe</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$A_t$</td>
<td>Atomic mass</td>
<td>g</td>
</tr>
<tr>
<td>$A_x$</td>
<td>Cross-sectional area of the exhaust pipe</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$c_c$</td>
<td>Background corrected concentration</td>
<td>ppm% (V/V)</td>
</tr>
<tr>
<td>$c_d$</td>
<td>Concentration in the dilution air</td>
<td>ppm% (V/V)</td>
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<tr>
<td>$c_x$</td>
<td>Concentration in the exhaust (with suffix of the component nominating)</td>
<td>ppm% (V/V)</td>
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<td>Dilution factor</td>
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<td>$E_{CO2}$</td>
<td>CO$_2$ quench of NO$_x$ analyser</td>
<td>%</td>
</tr>
<tr>
<td>$E_E$</td>
<td>Ethane efficiency</td>
<td>%</td>
</tr>
<tr>
<td>$E_{H2O}$</td>
<td>Water quench of NO$_x$ analyser</td>
<td>%</td>
</tr>
<tr>
<td>$E_M$</td>
<td>Methane efficiency</td>
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</tr>
<tr>
<td>$E_{NOx}$</td>
<td>Efficiency of NO$_x$ converter</td>
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</tr>
<tr>
<td>$e_{PT}$</td>
<td>Particulate emission</td>
<td>g/kW h</td>
</tr>
<tr>
<td>$e_x$</td>
<td>Gas emission (with subscript denoting compound)</td>
<td>g/kW h</td>
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<td>$\lambda$</td>
<td>Excess air factor ((kg dry air) / ([kg fuel] * $[A/F_{st}]$))</td>
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<td>Excess air factor at reference conditions</td>
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<td>Carbon factor</td>
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<td>$f_{fd}$</td>
<td>Fuel specific factor for exhaust flow calculation on dry basis</td>
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<td>Fuel specific factor used for the calculations of wet concentrations from dry concentrations</td>
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<tr>
<td>$H_a$</td>
<td>Absolute humidity of the intake air (g water / kg dry air)</td>
<td>g/kg</td>
</tr>
<tr>
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<td>Absolute humidity of the dilution air (g water / kg dry air)</td>
<td>g/kg</td>
</tr>
<tr>
<td>$i$</td>
<td>Subscript denoting an individual mode</td>
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<td>Fuel specific factor for the carbon balance calculation</td>
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<td>Humidity correction factor for NO$_x$ for diesel engines</td>
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<td>Humidity correction factor for particulates</td>
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<td>Dry to wet correction factor for the intake air</td>
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<tr>
<td>$k_{we}$</td>
<td>Dry to wet correction factor for the diluted exhaust gas</td>
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<tr>
<td>$k_{wr}$</td>
<td>Dry to wet correction factor for the raw exhaust gas</td>
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<tr>
<td>$M$</td>
<td>Percent torque related to the maximum torque for the test engine speed</td>
<td>%</td>
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<tr>
<td>$M_i$</td>
<td>Molecular mass</td>
<td>g</td>
</tr>
<tr>
<td>$m_{d}$</td>
<td>Mass of the dilution air sample passed through the particulate sampling filters</td>
<td>kg</td>
</tr>
<tr>
<td>$m_{f,d}$</td>
<td>Particulate sample mass of the dilution air collected</td>
<td>mg</td>
</tr>
<tr>
<td>$m_{f}$</td>
<td>Particulate sample mass collected</td>
<td>mg</td>
</tr>
<tr>
<td>$m_{sep}$</td>
<td>Mass of the diluted exhaust sample passed through the particulate sampling filters</td>
<td>kg</td>
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<tr>
<td>$P_A$</td>
<td>Absolute outlet pressure at pump outlet</td>
<td>kPa</td>
</tr>
<tr>
<td>Symbol</td>
<td>Term</td>
<td>Unit</td>
</tr>
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<tr>
<td>$p_a$</td>
<td>Saturation vapour pressure of the engine intake air</td>
<td>kPa</td>
</tr>
<tr>
<td>$p_b$</td>
<td>Total barometric pressure</td>
<td>kPa</td>
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<tr>
<td>$p_d$</td>
<td>Saturation vapour pressure of the dilution air</td>
<td>kPa</td>
</tr>
<tr>
<td>$p_y$</td>
<td>Water vapour pressure after cooler</td>
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</tr>
<tr>
<td>$p_s$</td>
<td>Dry atmospheric pressure</td>
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<tr>
<td>$P$</td>
<td>Uncorrected brake power</td>
<td>kW</td>
</tr>
<tr>
<td>$P_{\text{aux}}$</td>
<td>Declared total power absorbed by auxiliaries fitted for the test and not required by ISO 14396</td>
<td>kW</td>
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<tr>
<td>$P_m$</td>
<td>Maximum measured or declared power at the test engine speed under test conditions (see 12.5)</td>
<td>kW</td>
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<td>$q_{\text{mad}}$</td>
<td>Intake air mass flow rate on dry basis</td>
<td>kg/h</td>
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<tr>
<td>$q_{\text{maw}}$</td>
<td>Intake air mass flow rate on wet basis</td>
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<td>Dilution air mass flow rate on wet basis</td>
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<td>$q_{\text{medw}}$</td>
<td>Equivalent diluted exhaust gas mass flow rate on wet basis</td>
<td>kg/h</td>
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<td>$q_{\text{neww}}$</td>
<td>Exhaust gas mass flow rate on wet basis</td>
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<td>Fuel mass flow rate</td>
<td>kg/h</td>
</tr>
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<td>$q_{\text{medew}}$</td>
<td>Diluted exhaust gas mass flow rate on wet basis</td>
<td>kg/h</td>
</tr>
<tr>
<td>$q_{\text{mgas}}$</td>
<td>Emission mass flow rate of individual gas</td>
<td>g/h</td>
</tr>
<tr>
<td>$q_{\text{mPT}}$</td>
<td>Particle mass flow rate</td>
<td>g/h</td>
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<td>$r_d$</td>
<td>Dilution ratio</td>
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<td>$r_a$</td>
<td>Ratio of cross-sectional areas of isokinetic probe and exhaust pipe</td>
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<tr>
<td>$R_a$</td>
<td>Relative humidity of the intake air</td>
<td>%</td>
</tr>
<tr>
<td>$R_d$</td>
<td>Relative humidity of the dilution air</td>
<td>%</td>
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<tr>
<td>$r_h$</td>
<td>FID response factor</td>
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<td>FID response factor for methanol</td>
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<td>$r_x$</td>
<td>Ratio of the SSV throat to inlet absolute, static pressure</td>
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<td>$r_y$</td>
<td>Ratio of the SSV throat diameter, $d$, to the inlet pipe inner diameter</td>
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<tr>
<td>$\rho$</td>
<td>Density</td>
<td>kg/m³</td>
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<tr>
<td>$S$</td>
<td>Dynamometer setting</td>
<td>kW</td>
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<td>$T_a$</td>
<td>Absolute temperature of the intake air</td>
<td>K</td>
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<td>$T_d$</td>
<td>Absolute dewpoint temperature</td>
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<td>Absolute reference temperature (of combustion air: 298 K)</td>
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<td>Effective weighting factor</td>
<td>1</td>
</tr>
</tbody>
</table>

### 4.2 Symbols for fuel composition

- $w_{\text{ALF}}$ - H content of fuel, % mass
- $w_{\text{BET}}$ - C content of fuel, % mass
- $w_{\text{GAM}}$ - S content of fuel, % mass
- $w_{\text{DEL}}$ - N content of fuel, % mass
\( \omega_{\text{EPS}} \)  O content of fuel, % mass
\( \alpha \)  molar ratio (H/C)
\( \beta \)  molar ratio (C/C)
\( \gamma \)  molar ratio (S/C)
\( \delta \)  molar ratio (N/C)
\( \epsilon \)  molar ratio (O/C)

NOTE The conversion between mass content and molar ratio is given in Equations A.3 to A.12 of Annex A.

### 4.3 Symbols and abbreviations for the chemical components

- **ACN**: acetonitrile
- **C1**: carbon 1 equivalent hydrocarbon
- **CH\(_4\)**: methane
- **C\(_2\)H\(_6\)**: ethane
- **C\(_3\)H\(_8\)**: propane
- **CH\(_3\)OH**: methanol
- **CO**: carbon monoxide
- **CO\(_2\)**: carbon dioxide
- **DNPH**: dinitrophenyl hydrazine
- **DOP**: dioctyl phthalate
- **HC**: hydrocarbons
- **HCHO**: formaldehyde
- **H\(_2\)O**: water
- **NH\(_3\)**: ammonia
- **NMHC**: non-methane hydrocarbons
- **NO**: nitric oxide
- **NO\(_2\)**: nitrogen dioxide
- **NO\(_x\)**: oxides of nitrogen
- **N\(_2\)O**: dinitrogen oxide
- **O\(_2\)**: oxygen
- **RME**: rapeseed oil methylester
- **SO\(_2\)**: sulphur dioxide
- **SO\(_3\)**: sulphur trioxide
4.4 Abbreviations

CFV critical flow venturi
CLD chemiluminescent detector
CVS constant volume sample
ECS electrochemical sensor
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
PDP positive displacement pump
PMD paramagnetic detector
PT particulates
UVD ultraviolet detector
ZRDO zirconium dioxide sensor

5 Test conditions

5.1 Engine test conditions

5.1.1 Test condition parameter

The absolute temperature \( T_a \) of the engine intake air expressed in Kelvin and the dry atmospheric pressure \( p_s \) expressed in kilopascals shall be measured, and the parameter \( f_a \) shall be determined according to the following provisions.

a) Compression-ignition engines

Naturally aspirated and mechanically pressure-charged engines:

\[
f_a = \left( \frac{99}{P_s} \right) \times \left( \frac{T_a}{298} \right)^{0.7}
\]

(1)

Turbocharged engines with or without cooling of the intake air:

\[
f_a = \left( \frac{99}{P_s} \right)^{0.7} \times \left( \frac{T_a}{298} \right)^{1.5}
\]

(2)
b) Spark-ignition engines

\[
f_a = \left( \frac{99}{P_s} \right)^{12} \times \left( \frac{T_a}{298} \right)^{0.6}
\]

(3)

NOTE Formulae (1) to (3) are identical with the exhaust emissions legislation from ECE, EEC and EPA, but different from the ISO power correction formulae.

5.1.2 Test validity

For a test to be recognized as valid, the parameter \(f_a\) shall be such that

\[
0.93 \leq f_a \leq 1.07
\]

(4)

Tests should be conducted with the parameter \(f_a\) between 0.96 and 1.06.

5.2 Engines with charge air cooling

The charge air temperature shall be recorded and shall be, at the speed of the declared rated power and full load, within ± 5 K of the maximum charge air temperature specified by the manufacturer. 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 rated 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.

5.3 Power

The basis of specific emissions measurement is uncorrected brake power as defined in ISO 14396. The engine shall be submitted with auxiliaries needed for operating the engine (e.g. fan, water pump). If it is impossible or inappropriate to install the auxiliaries on the test bench, the power absorbed by them shall be determined and subtracted from the measured engine power.

Certain auxiliaries necessary only for the operation of the machine and which may be mounted on the engine should be removed for the test. The following incomplete list is given as an example:

— air compressor for brakes,
— power steering compressor,
— air conditioning compressor,
— pumps for hydraulic actuators.

For further details, see 3.9 and ISO 14396.

Where auxiliaries have not been removed, the power absorbed by them at the test speeds shall be determined in order to calculate the dynamometer settings in accordance with 12.5, except for engines where such auxiliaries form an integral part of the engine (e.g. cooling fans for air-cooled engines).
5.4 Specific test conditions

5.4.1 Engine air inlet system

An engine air intake system or a test shop system shall be used, presenting an air intake restriction within ± 300 Pa of the maximum value specified by the manufacturer for a clean air cleaner at the speed of rated power and full load.

If the engine is equipped with an integral air inlet system, it shall be used for testing.

NOTE The restrictions are to be set at rated speed and full load.

5.4.2 Engine exhaust system

An engine exhaust system or a test shop system shall be used, presenting an exhaust backpressure within ± 650 Pa of the maximum value specified by the manufacturer at the speed of rated power and full load. The exhaust system shall conform to the requirements for exhaust gas sampling, as set out in 7.5.5, 17.2.1, EP and 17.2.2, EP.

If the engine is equipped with an integral exhaust system, it shall be used for testing.

If the engine is equipped with an exhaust aftertreatment 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 aftertreatment device. The distance from the exhaust manifold flange or turbocharger outlet to the exhaust aftertreatment 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 the same criteria as above, and may be set with a valve. The aftertreatment container may be removed during dummy tests and during engine mapping, and replaced with an equivalent container having an inactive catalyst support.

NOTE The restrictions are to be set at rated speed and full load.

5.4.3 Cooling system

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

5.4.4 Lubricating oil

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

5.4.5 Adjustable carburettors

For engines with limited adjustable carburettors, test of the engines shall be performed at both extremes of the adjustment.

5.4.6 Crankcase breather

When it is required to measure the crankcase emissions of an open crankcase system as part of the total emissions from the engine, they shall be introduced into the exhaust system downstream of any aftertreatment system, if used, and upstream of the sampling point. Sufficient distance shall be allowed to ensure mixing of the crankcase emissions with the exhaust gas.
6 Test fuels

Fuel characteristics influence the engine exhaust gas emission. Therefore, the characteristics of the fuel used for the test should be determined, recorded and presented with the results of the test. Where fuels designated in ISO 8178-5 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 are those listed in the appropriate universal data sheets in ISO 8178-5.

The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded.

The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties involved, the fuel shall be selected in accordance with Table 1. When a suitable reference fuel is not available, a fuel with properties very close to the reference fuel may be used. The characteristics of the fuel shall be declared.

<table>
<thead>
<tr>
<th>Test purpose</th>
<th>Interested parties</th>
<th>Fuel selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type approval (Certification)</td>
<td>1. Certification body</td>
<td>Reference fuel, if one is defined</td>
</tr>
<tr>
<td></td>
<td>2. Manufacturer or supplier</td>
<td>Commercial fuel if no reference fuel is defined</td>
</tr>
<tr>
<td>Acceptance test</td>
<td>1. Manufacturer or supplier</td>
<td>Commercial fuel as specified by the manufacturer a</td>
</tr>
<tr>
<td></td>
<td>2. Customer or inspector</td>
<td></td>
</tr>
<tr>
<td>Research/development</td>
<td>One or more of the following:</td>
<td>To suit the purpose of the test.</td>
</tr>
<tr>
<td></td>
<td>manufacturer, research organization,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fuel and lubricant supplier, etc.</td>
<td></td>
</tr>
</tbody>
</table>

a Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily comply with limits specified when using reference fuels.

7 Measurement equipment and data to be measured

7.1 General

The emission of gaseous and particulate components by the engine submitted for testing shall be measured by the methods described in Clauses 16 and 17. These clauses describe the recommended analytical systems for the gaseous emissions (Clause 16) and the recommended particulate dilution and sampling systems (Clause 17).

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 part of ISO 8178. “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, or the C1 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 the standard, the determination of equivalency shall be based upon the calculation of repeatability and reproducibility, as described in ISO 5725-1 and ISO 5725-2.

The following equipment shall be used for emissions tests of engines on engine dynamometers. This part of ISO 8178 does not contain details of flow, pressure, and temperature measuring equipment. Instead, only the accuracy requirements of such equipment necessary for conducting an emissions test are given in 7.4.
7.2 Dynamometer specification

An engine dynamometer with adequate characteristics to perform the appropriate test cycle described in ISO 8178-4 shall be used.

The instrumentation for torque and speed measurement shall allow the measurement accuracy of the shaft power within the given limits. Additional calculations may be necessary. The accuracy of the measuring equipment shall be such that the maximum tolerances of the figures given in 7.4 are not exceeded.

7.3 Exhaust gas flow

7.3.1 General

The exhaust gas flow shall be determined by one of the methods given in 7.3.2 to 7.3.6.

7.3.2 Direct measurement method

Direct measurement of the exhaust flow may be done by systems such as the following:

- pressure differential devices, like flow nozzle (see ISO 5167);
- ultrasonic flowmeter;
- vortex flowmeter.

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.

The flowmeters shall meet the accuracy specifications of 7.4.

7.3.3 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 7.4 shall be used. The calculation of the exhaust gas flow is as follows:

\[ q_{mEW} = q_{mAW} + q_{mf} \]  \hspace{1cm} (5)

7.3.4 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, as given with the following formulae (see A.3.2.3.1):

\[ q_{mEW} = q_{mf} \times \left( \frac{w_{Bet} \times w_{Bet} \times 1.4}{f_{C} \times f_{C}} \right) \times \left( \frac{1.4 \times w_{Bet} + w_{ALF} \times 0.08936 - 1}{1.293 + f_{fd}} \right) \times \left( \frac{w_{ALF} \times 0.08936 - 1}{1 \times \frac{H_{a}}{1000} + 1} \right) \]  \hspace{1cm} (6)

where

- \( f_{fd} \) is according to Equations A.20 to A.23;
- \( H_{a} \) is the g water per kg dry air;

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The formula for the calculation of the fuel consumption is according to Equation A.64:

\[ f_c = (c_{CO2d} - c_{CO2ad}) \times 0.544 \frac{c_{COd}}{18.522} + \frac{c_{HCw}}{17.355} \]  

(7)

where

- \( c_{CO2d} \) is the dry CO₂ concentration in the raw exhaust [%];
- \( c_{CO2ad} \) is the dry CO₂ concentration in the ambient air [%];
- \( c_{COd} \) is the dry CO concentration in the raw exhaust [ppm];
- \( c_{HCw} \) is the wet HC concentration in the raw exhaust [ppm].

**NOTE** Optionally, the oxygen balance method may be used. See A.3.3.

### 7.3.5 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 calculation of the exhaust gas flow is as follows:

\[ q_{new} = \frac{q_{rt} \times \rho_{ew}}{60 \times (c_{mix} - c_a)} \]  

(8)

where

- \( q_{new} \) is the exhaust mass flow [kg/s];
- \( q_{rt} \) is the tracer gas flow rate [cm³/min];
- \( c_{mix} \) is the concentration of the tracer gas after mixing [ppm];
- \( \rho_{ew} \) is the density of the exhaust gas [kg/m³];
- \( c_a \) is the background concentration of the tracer gas in the intake air [ppm].

The background concentration of the tracer gas \( (c_a) \) 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.
The total system shall meet the accuracy specifications for the exhaust gas flow, and shall be calibrated according to 8.6.

### 7.3.6 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 instantaneous exhaust gas mass flow is as follows:

\[
g_{\text{mew}} = g_{\text{maw}} \times \left(1 + \frac{1}{A/F_{\text{st}} \times \lambda}\right) \tag{9}
\]

where

\[
A/F_{\text{st}} = \frac{138.0 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right)}{12,011 \times \beta + 1,007 \times 94 \times \alpha + 15,999 \times 4 \times \varepsilon + 14,006 \times 7 \times \delta + 32,065 \times \gamma} \tag{10}
\]

\[
\lambda = \frac{\beta \left(100 - \frac{c_{\text{CO}} \times 10^{-4}}{2} - c_{\text{HC}} \times 10^{-4}\right) + \left(\frac{\alpha}{4} \times \frac{1 - \frac{2 \times c_{\text{CO}} \times 10^{-4}}{3,5 \times c_{\text{CO2}}} - \frac{\varepsilon}{2} - \frac{\delta}{2}}{1 + \frac{c_{\text{CO}} \times 10^{-4}}{3,5 \times c_{\text{CO2}}} \times \left(c_{\text{CO2}} + c_{\text{CO}} \times 10^{-4} + c_{\text{HC}} \times 10^{-4}\right)}\right)}{4,764 \times \left(\beta + \frac{\alpha}{4} - \frac{\varepsilon}{2} + \gamma\right) \times \left(c_{\text{CO2}} + c_{\text{CO}} \times 10^{-4} + c_{\text{HC}} \times 10^{-4}\right)} \tag{11}
\]

where

- \(A/F_{\text{st}}\) is the stoichiometric air-to-fuel ratio [kg/kg];
- \(\lambda\) is the excess air ratio;
- \(c_{\text{CO2}}\) is the dry CO\(_2\) concentration [%];
- \(c_{\text{CO}}\) is the dry CO concentration [ppm];
- \(c_{\text{HC}}\) is the HC concentration [ppm].

**NOTE** Fuel composition \(C_\beta H_\alpha S_\gamma N_\delta O_\varepsilon\) with \(\beta = 1\). For fuels without carbon (e.g. hydrogen) Equations (10) and (11) cannot be used.

The air flowmeter shall meet the accuracy specifications of 7.4, the CO\(_2\) analyser used shall meet the specifications of 7.5.4.2, 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 7.5.4.12 may be used for the measurement of the excess air ratio.

### 7.3.7 Total dilute exhaust gas flow

When using a full-flow dilution system, the total flow of the dilute exhaust \((q_{\text{mdew}})\) shall be measured with a PDP or CFV (see 17.2.2). The accuracy shall conform to the provisions of 9.2.

### 7.4 Accuracy

The calibration of all measuring instruments shall be traceable to national (international) standards and comply with the requirements given in Tables 2 and 3.

**NOTE** Calibration requirements for analysers are given in 8.5.