INTERNATIONAL STANDARD

ISO 8178-5

Second edition
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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 5:
Test fuels

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

Partie 5: Carburants d'essai

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.

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 8178-5 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 8178-5:1997), 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 under field conditions*

— *Part 3: Definitions and methods of measurement of exhaust gas smoke under steady-state conditions*

— *Part 4: Steady-state 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

In comparison with engines for on-road applications, engines for off-road use are made in a much wider range of power output and configuration and are used in a great number of different applications.

Since fuel properties vary widely from country to country a broad range of different fuels is listed in this part of ISO 8178 — both reference fuels and commercial fuels.

Reference fuels are usually representative of specific commercial fuels but with considerably tighter specifications. Their use is primarily recommended for test bed measurements described in ISO 8178-1 and ISO 8178-11.

For measurements typically at site where emissions with commercial fuels, whether listed or not in this part of ISO 8178 are to be determined, uniform analytical data sheets (see Clause 5) are recommended for the determination of the fuel properties to be declared with the exhaust emission results.

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 5: Test fuels

1 Scope

This part of ISO 8178 specifies fuels whose use is recommended for performing the exhaust emission test cycles given in ISO 8178-4 and ISO 8178-11.

It is applicable to reciprocating internal combustion engines for mobile, transportable and stationary installations excluding engines for motor vehicles primarily designed for road use. This part of ISO 8178 may be applied to engines used, e.g. earth-moving machines and generating sets, and for other applications.

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 2160:1998, *Petroleum products — Corrosiveness to copper — Copper strip test*

ISO 2719:2002, *Determination of flash point — Pensky-Martens closed cup method*

ISO 3007:1999, *Petroleum products and crude petroleum — Determination of vapour pressure — Reid method*

ISO 3015:1992, *Petroleum products — Determination of cloud point*

ISO 3016:1994, *Petroleum products — Determination of pour point*

ISO 3104:1994, *Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity*

ISO 3105:1994, *Glass capillary kinematic viscometers — Specifications and operating instructions*

ISO 3405:2000, *Petroleum products — Determination of distillation characteristics at atmospheric pressure*

ISO 3675:1998, *Crude petroleum and liquid petroleum products — Laboratory determination of density or relative density — Hydrometer method*

ISO 3733:1999, *Petroleum products and bituminous materials — Determination of water — Distillation method*

ISO 3735:1999, *Crude petroleum and fuel oils — Determination of sediment — Extraction method*

ISO 3830:1993, *Petroleum products — Determination of lead content of gasoline — Iodine monochloride method*

ISO 3837:1993, *Liquid petroleum products — Determination of hydrocarbon types — Fluorescent indicator absorption method*

ISO 3993:1984, *Liquefied petroleum gas and light hydrocarbons — Determination of density or relative density — Pressure hydrometer method*

ISO 4256:1996, *Liquefied petroleum gases — Determination of gauge vapour pressure — LPG method*

ISO 4260:1987, *Petroleum products and hydrocarbons — Determination of sulfur content — Wickbold combustion method*

ISO 4262:1993, *Petroleum products — Determination of carbon residue — Ramsbottom method*

ISO 4264:2007, *Petroleum products — Calculation of cetane index of middle-distillate fuels by the four-variable equation*

ISO 5163:2005, *Petroleum products — Determination of knock characteristics of motor and aviation fuels — Motor method*

ISO 5164:2005, *Petroleum products — Determination of knock characteristics of motor fuels — Research method*

ISO 5165:1998, *Petroleum products — Determination of the ignition quality of diesel fuels — Cetane engine method*

ISO 6245:2001, *Petroleum products — Determination of ash*

ISO 6246:1995, *Petroleum products — Gum content of light and middle distillate fuels — Jet evaporation method*

ISO 6326-5:1989, *Natural gas — Determination of sulfur compounds — Part 5: Lingener combustion method*

ISO 6615:1993, *Petroleum products — Determination of carbon residue — Conradson method*

ISO 6974 (all parts), *Natural gas — Determination of composition with defined uncertainty by gas chromatography*

ISO 7536:1994, *Petroleum products — Determination of oxidation stability of gasoline — Induction period method*

ISO 7941:1988, *Commercial proprane and butane — Analysis by gas chromatography*

ISO 8178-1:2006, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions*

ISO 8216-1:2005, *Petroleum products — Fuels (class F) — Classification — Part 1: Categories of marine fuels*

ISO 8217:2005, *Petroleum products — Fuels (class F) — Specifications of marine fuels*

ISO 8691:1994, *Petroleum products — Low levels of vanadium in liquid fuels — Determination by flameless atomic absorption spectrometry after ashing*

ISO 8754:2003, *Petroleum products — Determination of sulfur content — Energy-dispersive X-ray fluorescence spectrometry*

ISO 8973:1997, *Liquefied petroleum gases — Calculation for density and vapour pressure*

ISO 10307-1, *Petroleum products — Total sediment in residual fuel oils — Part 1: Determination by hot filtration*

ISO 10307-2, *Petroleum products — Total sediment in residual fuel oils — Part 2: Determination using standard procedures for ageing*

ISO 10370, *Petroleum products — Determination of carbon residue — Micro method*

ISO 10478:1994, *Petroleum products — Determination of aluminium and silicon in fuel oils — Inductively coupled plasma emission and atomic absorption spectroscopy methods*

ISO 13757:1996, *Liquefied petroleum gases — Determination of oily residues — High-temperature method*

ISO 14597:1997, *Petroleum products — Determination of vanadium and nickel content — Wavelength-dispersive X-ray fluorescence spectrometry*

EN 116:1997, *Diesel and domestic heating fuels — Determination of cold filter plugging point*

EN 238:1996, *Liquid petroleum products — Determination of the benzene content by infrared spectrometry*

3 Terms and definitions

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

NOTE Also see any applicable definitions contained in the standards listed in the tables in Annex B.

3.1
carbon residue
residue remaining after controlled thermal decomposition of a product under a restricted supply of oxygen (air)

NOTE The historical methods of Conradson and Ramsbottom have largely been replaced by the carbon residue (micro) method.

[ISO 1998-2:1998, 2.50.001]

3.2
cetane index
number, calculated to represent the approximate cetane number of a product from its density and distillation characteristics

NOTE The formula used for calculation is reproduced from statistical analysis of a very large representative sample of world-wide diesel fuels, on which cetane number and distillation data are known, and thus is subject to change at 5 to 10 year intervals. The current formula is given in ISO 4264. It is not applicable to fuels containing an ignition-improving additive.

[ISO 1998-2:1998, 2.30.111]

3.3
cetane number
number on a conventional scale, indicating the ignition quality of a diesel fuel under standardized conditions

NOTE It is expressed as the percentage by volume of hexadecane (cetane) in a reference mixture having the same ignition delay as the fuel for analysis. The higher the cetane number, the shorter the delay.

[ISO 1998-2:1998, 2.30.110]

3.4
crude oil
naturally occurring form of petroleum, mainly occurring in a porous underground formation such as sandstone

[ISO 1998-1:1998, 1.05.005]

NOTE Hydrocarbon mixture, generally in a liquid state, which may also include compounds of sulfur, nitrogen, oxygen, metals and other elements.

3.5
diesel fuel
gas-oil that has been specially formulated for use in medium and high-speed diesel engines, mostly used in the transportation market

NOTE It is often referred to as “automotive diesel fuel”.

[ISO 1998-1:1998, 1.20.131]

3.6
diesel index
number which characterizes the ignition performance of diesel fuel and residual oils, calculated from the density and the aniline point

NOTE No longer widely used for distillate fuels due to inaccuracy of this method, but applicable to some blended distillate residual fuel oils. See also 3.2, cetane index.

3.7
liquefied petroleum gas
LPG
mixture of light hydrocarbons, consisting predominantly of propane, propene, butanes and butenes, that may be stored and handled in the liquid phase under moderate conditions of pressure and at ambient temperature

[ISO 1998-1:1998, 1.15.080]

3.8
octane number
number on a conventional scale expressing the knock-resistance of a fuel for spark-ignition engines

NOTE It is determined in test engines by comparison with reference fuels. There are several methods of test; consequently the octane number should be accompanied by reference to the method used.

[ISO 1998-2:1998, 2.30.100]

3.9
oxygenate
oxygen containing organic compound which may be used as a fuel or fuel supplement, such as various alcohols and ethers

4 Symbols and abbreviations

The symbols and abbreviations used in this part of ISO 8178 are identical with those given in ISO 8178-1:2006 (Clause 4 and Annex A). Those which are essential for this part of ISO 8178 are repeated below in order to facilitate comprehension.

Symbol SI	Definition	Unit
λ	Excess air factor (in kilograms dry air per kilogram of fuel)	kg/kg
k_f	Fuel specific factor for exhaust flow calculation on wet basis	—
k_{CB}	Fuel specific factor for the carbon balance calculation	—
q_{maw}	Intake air mass flow rate on wet basis [a]	kg/h
q_{mew}	Exhaust gas mass flow rate on wet basis [a]	kg/h
q_{mf}	Fuel mass flow rate	kg/h
w_{ALF}	Mass fraction of hydrogen in the fuel	%
w_{BET}	Mass fraction of carbon in the fuel	%
w_{GAM}	Mass fraction of sulfur in the fuel	%
w_{DEL}	Mass fraction of nitrogen in the fuel	%
w_{EPS}	Mass fraction of oxygen in the fuel	%
z	Fuel factor for calculation of w_{ALF}	—

[a] At reference conditions (T = 273,15 K and p = 101,3 kPa).

5 Choice of fuel

5.1 General

As far as possible, reference fuels should be used for certification of engines.

Reference fuels reflect the characteristics of commercially available fuels in different countries and are therefore different in their properties. Since fuel composition influences exhaust emissions, emission results with different reference fuels are not usually comparable. For lab-to-lab comparison of emissions even the properties of the specified reference fuel are recommended to be as near as possible to identical. This can theoretically best be accomplished by using fuels from the same batch.

For all fuels (reference fuels and others), the analytical data shall be determined and reported with the results of the exhaust measurement.

For non-reference fuels, the data to be determined are listed in the following tables:

— Table 4 (Universal analytical data sheet — Natural gas);

— Table 8 (Universal analytical data sheet — Liquefied petroleum gas);

— Table 12 (Universal analytical data sheet — Motor gasolines);

— Table 17 (Universal analytical data sheet — Diesel fuels);

— Table 19 (Universal analytical data sheet — Distillate fuel oils);

— Table 21 (Universal analytical data sheet — Residual fuel oils);

— Table 22 (Universal analytical data sheet — Crude oil).

An elemental analysis of the fuel shall be carried out when the possibility of an exhaust mass flow measurement or combustion air flow measurement, in combination with the fuel consumption, is not possible. In such cases, the exhaust mass flow can be calculated using the concentration measurement results of the exhaust emission, and using the calculation methods given in ISO 8178-1:2006, Annex A. In cases where the fuel analysis is not available, hydrogen and carbon mass fractions can be obtained by calculation. The recommended methods are given in A.2.1, A.2.2 and A.2.3.

Emissions and exhaust gas flow calculations depend on the fuel composition. The calculation of the fuel specific factors, if applicable, shall be done in accordance with ISO 8178-1:2006, Annex A.

NOTE For non-ISO test methods equivalent to those of ISO International Standards mentioned in this part of ISO 8178, see Annex B.

5.2 Influence of fuel properties on emissions from compression ignition engines

Fuel quality has a significant effect on engine emissions. Certain fuel parameters have a more or less pronounced influence on the emissions level. A short overview on the most influencing parameters is given in 5.2.1 to 5.2.3.

5.2.1 Fuel sulfur

Sulfur naturally occurs in crude oil. The sulfur still contained in the fuel after the refining process is oxidized during the combustion process in the engine to SO_2, which is the primary source of sulfur emission from the engine. Part of the SO_2 is further oxidized to sulfate (SO_4) in the engine exhaust system, the dilution tunnel, or by an exhaust aftertreatment system. Sulfate will react with the water present in the exhaust to form sulfuric acid with associated water that will condense and finally be measured as part of the particulate emission (PM). Consequently, fuel sulfur has a significant influence on the PM emission.

The mass of sulfates emitted from an engine depends on the following parameters:

— the fuel consumption of the engine (BSFC);

— the fuel sulfur content (FSC);

— the S $\Rightarrow$ SO_4 conversion rate (CR);

— the weight increase by water absorption standardized to $H_2SO_4 \cdot 7H_2O$.

Fuel consumption and fuel sulfur content are measurable parameters, whereas the conversion rate can only be predicted, since it may vary from engine to engine. Typically, the conversion rate is approximately 2 % for engines without aftertreatment systems. The following formula has been applied for estimating the sulfur impact on PM, as presented below:

$$\text{Sulfur}_{\text{PM}} = \text{BSFC} \times \frac{\text{FSC}}{100} \times \frac{\text{CR}}{100} \times 6{,}937\,5 \tag{1}$$

where

BSFC is the brake specific fuel consumption, expressed in grams per kilowatt-hour (g/kW·h);

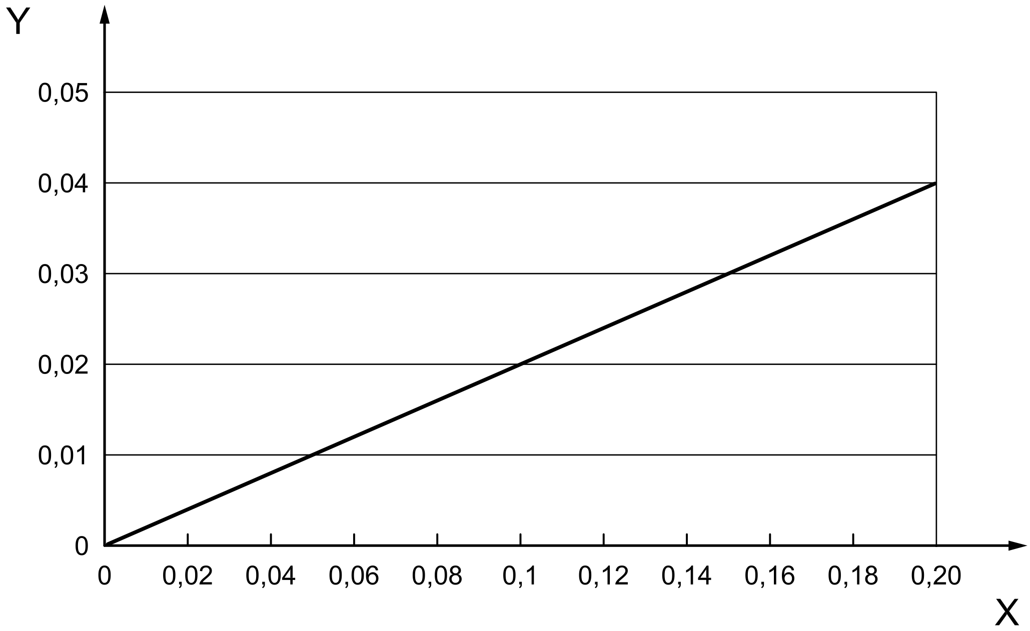
FSC is the fuel sulfur content, expressed in milligrams per kilogram (mg/kg);

CR is the S $\Rightarrow$ SO_4 conversion rate, expressed in percent (%);

6,937 5 is the S $\Rightarrow$ $H_2SO_4 \cdot 7H_2O$ conversion factor.

The relationship between fuel sulfur content and sulfate emission is shown in Figure 1 for an engine without aftertreatment and a S $\Rightarrow$ SO_4 conversion rate of 2 %.

Many aftertreatment systems contain an oxidation catalyst as integral part of the overall aftertreatment system. The major purpose of the oxidation catalyst is to enhance specific chemical reactions necessary for the proper function of the aftertreatment system. Since the oxidation catalyst will also oxidize a considerable amount of SO_2 to SO_4, the aftertreatment system is likely to produce a high amount of additional particulates in the presence of fuel sulfur. When using such aftertreatment systems, the conversion rate can drastically increase to about 30 % to 70 % depending on the efficiency of the catalytic converter. This will have a major impact on the PM emission, as shown in Figure 2 for sulfur levels below 0,05 % (500 ppm).

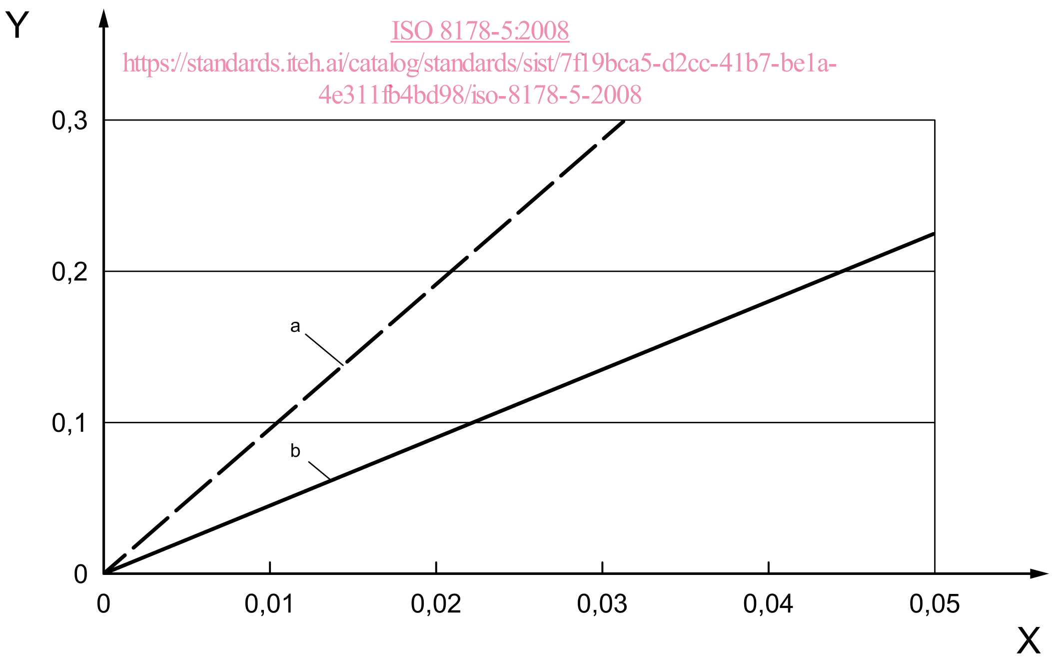


Key

X sulfur content, in mg/kg

Y sulfur PM, in g/kW·h

Figure 1 — Relationship between fuel sulfur and sulfate emission for engines without aftertreatment



Key

X sulfur content, in mg/kg

Y sulfur particulate emission (PM), in g/kW·h

a 70 % conversion.

b 30 % conversion.

Figure 2 — Relationship between fuel sulfur and sulfate emission for engines with aftertreatment

