INTERNATIONAL STANDARD

ISO 8178-5

Third 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
ISO 8178-5:2015(E)

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Foreword

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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).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

This third edition cancels and replaces the second edition (ISO 8178-5:2008), of which it constitutes a minor revision.

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*[1)]

— *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*

1) ISO 8178-4 is currently under revision and foreseen to be published with above new title in 2016.

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 configurations 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.

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.

It is applicable to reciprocating internal combustion engines for mobile, transportable and stationary installations excluding engines for 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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, *Petroleum products — Fuels (class F) classification — Part 1: Categories of marine fuels*

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

3 Terms and definitions

For the purposes of this 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 1 to entry: The historical methods of Conradson and Ramsbottom have largely been replaced by the carbon residue (micro) method.

[SOURCE: 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 1 to entry: 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 to10 year intervals. The current formula is given in ISO 4264. It is not applicable to fuels containing an ignition-improving additive.

[SOURCE: 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 1 to entry: 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.

[SOURCE: 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

[SOURCE: ISO 1998-1:1998, 1.05.005]

Note 1 to entry: 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 1 to entry: It is often referred to as “automotive diesel fuel”.

[SOURCE: 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 1 to entry: 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

[SOURCE: 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 1 to entry: 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.

[SOURCE: 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 abbreviated terms

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 kilogrammes dry air per kilogramme 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 13 (Universal analytical data sheet — Engine 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 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:

— fuel consumption of the engine (BSFC);

— fuel sulfur content (FSC);

— S ⇒ SO4 conversion rate (CR);

— weight increase by water absorption standardized to $H_2SO_4 \cdot 6{,}651H_2O$.

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 in Formula (1):

$$\text{Sulfur}_{PM} = \text{BSFC} \times \frac{\text{FSC}}{1{,}000{,}000} \times \frac{\text{CR}}{100} \times 6{,}795\ 296 \quad (1)$$

where

Sulfur_{PM} is the brake specific contribution of fuel sulfur to PM, expressed in grams per kilowatt-hour (g/kw-h);

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);

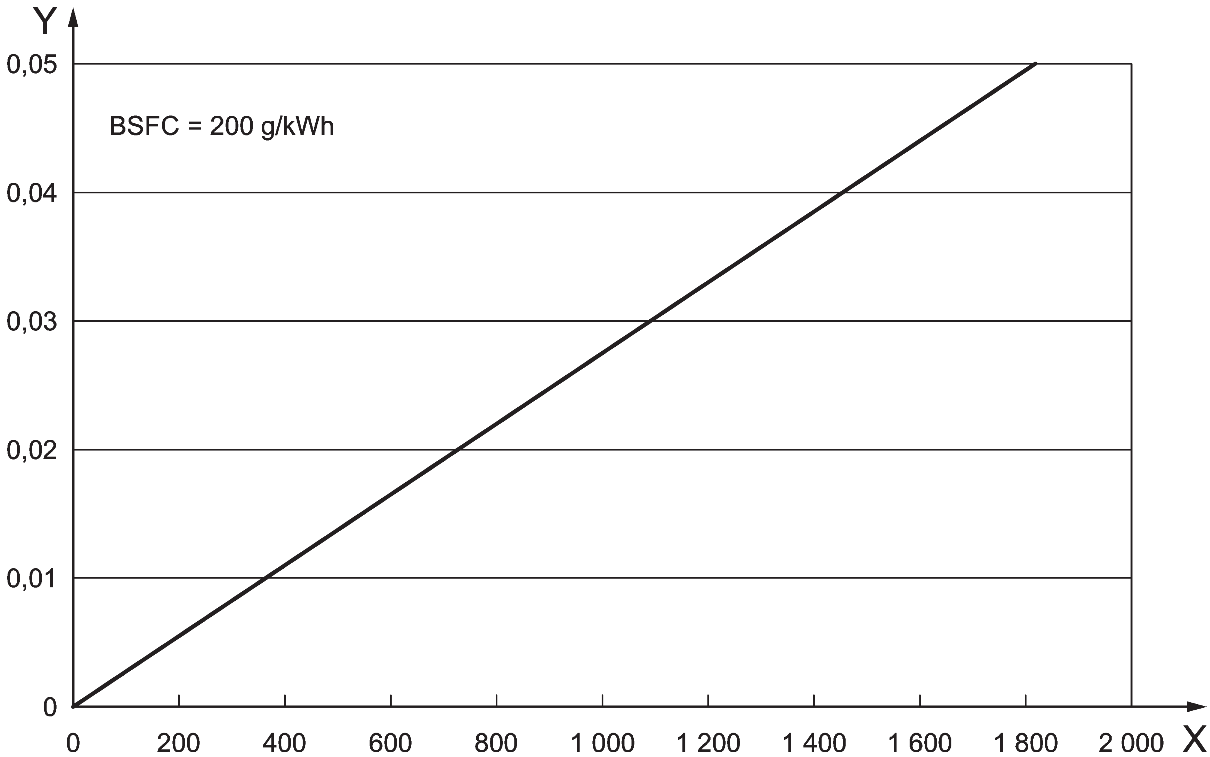
CR is the $S \Rightarrow SO_4$ conversion rate, expressed in percent %;

6,795 296 is the $S \Rightarrow H_2SO_4 \cdot 6{,}651H_2O$ conversion factor.

This is based on the assumption that 1,221 6 grams of water is associated with each gram of H_2SO_4 because of the dew point temperature of 9,5°C in the weighing environment. This corresponds to $6{,}651H_2O$.

The relationship between fuel sulfur content and sulfate emission is shown in Figure 1 for an engine without aftertreatment and a S to 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.

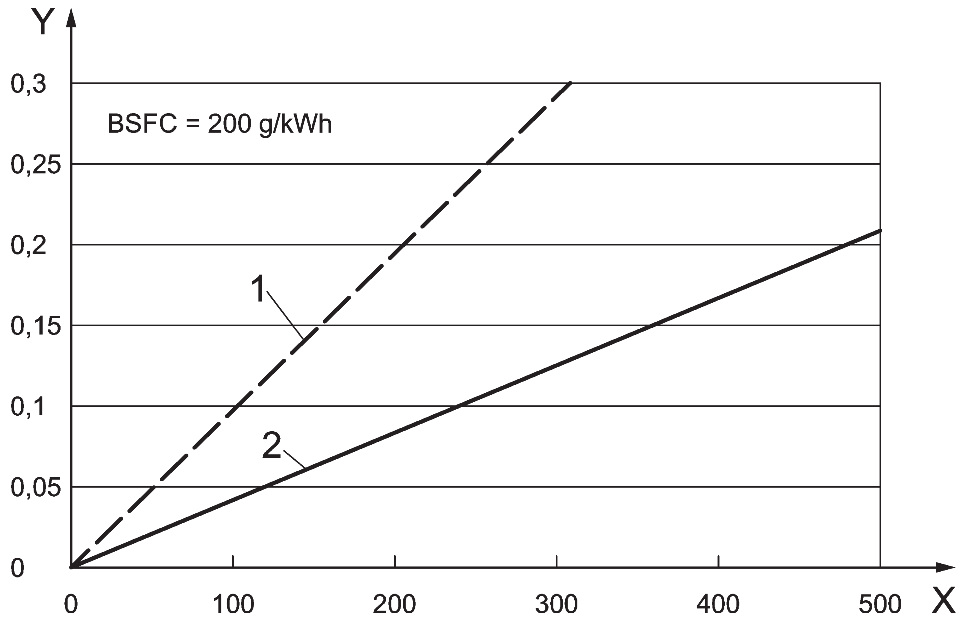


Key

X sulfur content, in mg/kg

Y sulfur PM, in g/kWh

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



Key

X sulfur content, in mg/kg

Y sulfur PM, in g/kWh

1 70 % conversion

2 30 % conversion

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

5.2.2 Specific considerations for marine fuels

For marine fuels (distillate and residual fuel oils), sulfur and nitrogen have a significant impact on PM and NO_x emissions, respectively.

Typically, the sulfur content is higher than for onroad or nonroad diesel fuels by a factor of approximately 10, as shown in Table 21. Even without any aftertreatment system, the PM sulfur level will be approximately 0,4 g/kWh for a 2 % sulfur fuel. In addition, the high ash, vanadium and sediment fractions will significantly contribute to the total PM emission. As a consequence, the inherent engine PM emission, which is mainly soot, is only a very small fraction of the total PM emission. In the application of aftertreatment systems, 5.2.1 should be carefully considered.

The average nitrogen content of residual fuel oil is currently around 0,4 %, but steadily increasing. In some cases, nitrogen contents between 0,8 % and 1,0 % have been reported. Assuming a 55 % conversion rate at a nitrogen level of 0,8 % will increase the NO_x emission of the engine by more than 2 g/kW-h. This is a significant portion of the total NO_x emission, and has therefore to be carefully taken into account.

5.2.3 Other fuel properties

There are other fuel parameters that have a significant influence on emissions and fuel consumption of an engine. Contrary to the sulfur influence, their magnitude is less predictable and unambiguous, but there is always a general trend that is valid for all engines. The most important of these parameters are the cetane number, density, poly-aromatic content, total aromatics content and distillation characteristics. Their influence is briefly summarized, below.

For NO_x, total aromatics is the predominant parameter whereas the effect of poly-aromatics and density is less significant. This can be explained by an increase of the flame temperature with higher

