INTERNATIONAL STANDARD

ISO 8178-5

Fourth 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

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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 fourth edition cancels and replaces the third edition (ISO 8178-5:2015), which has been technically revised.

The main changes compared to the previous edition are as follows:

- the addition of reference fuels from EU Regulation 2017/654 exhaust emission requirements for internal combustion engines in non-road mobile machinery
- the addition of California Air Resources Board (CARB) E10 emissions certification fuel
- the addition of US Environmental Protection Agency Tier 3 E10 emissions certification fuel
- updates of fuel specifications from ISO 8217

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

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 document — 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 document, 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 document 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 document is applicable to engines used, e.g. earth-moving machines and generating sets, and for other applications.

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 4259, *Petroleum and related products – Precision of measurement methods and results – Part 1: Determination of precision data in relation to methods of test*

ISO 6974 (all parts), *Natural gas – Determination of composition and associated uncertainty by gas chromatography*

ISO 6976, *Natural gas — Calculation of calorific values, density, relative density and Wobbe indices from composition*

ISO 8178-1, *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 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*

ASTM D 4815, *A method for the determination of oxygenated compounds in reformulated fuels*

ASTM D 8221-18, *Standard Practice for Determining the Calculated Methane Number (MNC) of Gaseous Fuels Used in Internal Combustion Engines*

EN 228, *Automotive fuels – unleaded petrol – Requirements and test methods*

EN 15376, *Automotive fuels – ethanol as a blending component for petrol – Requirements and test methods*

EN 15489, *Ethanol as a blending component for petrol – Determination of water content – Karl Fischer coulometric titration method*

EN 16726, *Gas infrastructure - Quality of gas - Group H*

3 Terms and definitions

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

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

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

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

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

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* (3.3) 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* (3.5) 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

Note 1 to entry: Crude oil is a hydrocarbon mixture, generally in a liquid state, which may also include compounds of sulfur, nitrogen, oxygen, metals and other elements.

[SOURCE: ISO 1998-1:1998, 1.05.005, modified — Note 1 to entry has been added.]

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, modified — The alternative term "automotive gas-oil" has been removed.]

3.6

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

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

[SOURCE: ISO 1998-1:1998, 1.15.080, modified — The abbreviated term has been added; Note 1 to entry has been added.]

3.7

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]

3.8

oxygenate

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

3.9

natural gas

NG

complex gaseous mixture of hydrocarbons, primarily methane, but generally includes ethane, propane and higher hydrocarbons, and some non-combustible gases such as nitrogen and carbon dioxide

[SOURCE: ISO 14532:2014, 2.1.1.1, modified — Note 1 to entry has been removed.]

3.10

methane number

rating indicating the knocking characteristics of a fuel gas

Note 1 to entry: It is comparable to the octane number for petrol. One expression of the methane number is the volume percentage of methane in a methane-hydrogen mixture, that in a test engine under standard conditions has the same tendency to knock as the fuel gas to be examined.

[SOURCE: ISO 14532:2014, 2.6.6.1]

4 Symbols and abbreviated terms

The symbols and abbreviated terms used in this document are identical with those given in ISO 8178-4:2020, Clause 4. Those which are essential for this document are repeated below in order to facilitate comprehension.

Symbol	Definition	Unit
A/F_{st}	stoichiometric air to fuel ratio	—
λ	excess air factor (in kilogrammes dry air per kilogramme of fuel)	kg/kg
c_{gasd}	concentration of gas on a wet basis	% (V/V)
c_{gasw}	concentration of gas on a dry basis	% (V/V)
k_f	fuel specific factor for exhaust flow calculation on wet basis	—
k_{CB}	fuel specific factor for the carbon balance calculation	—
k_w	dry to wet correction factor for the raw exhaust gas	—
k_{wr}	dry to wet correction factor for the raw exhaust gas	—
k_f	fuel specific factor	—
H_a	absolute humidity of the intake air (g water/kg dry air)	g/kg
p_b	total atmospheric pressure	kPa
p_r	water vapor pressure after cooling bath	KPa
q_{mad}	intake air mass flow rate on dry basis	kg/h
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
q_{ved}	exhaust gas volume flow rate on dry basis	m^3/s
q_{vew}	exhaust gas volume flow rate on wet basis	m^3/s
q_{vH2O}	H_2O volume flow rate	m^3/s
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 identical as far as possible. 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 5 (Universal analytical data sheet — Natural gas);
- Table 9 (Universal analytical data sheet — Liquefied petroleum gas);
- Table 17 (Universal analytical data sheet — Engine gasolines);
- Table 21 (Universal analytical data sheet — Diesel fuels);
- Table 23 (Universal analytical data sheet — Distillate fuel oils);
- Table 25 (Universal analytical data sheet — Residual fuel oils);
- Table 26 (Universal analytical data sheet — Crude oil).

An elemental analysis of the fuel shall be carried out when 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 8178-4:2020, Annex D. 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 Annex A: A.2.2, A.2.3 and A.2.4.

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 8178-4:2020, Annex D.

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

5.2 Influence of fuel properties on emissions from compression ignition engines

5.2.1 General

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 5.2.2 to 5.2.4.

5.2.2 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);
- $S \Rightarrow SO_4$ 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 can vary from engine to engine. Typically, the conversion rate is approximately

2 % for engines without aftertreatment systems. Formula (1) has been applied for estimating the sulfur impact on PM:

$$S_{\mathrm{PM}} = e_{\mathrm{fuel}} \times \frac{X_{\mathrm{FSC}}}{1{,}000{,}000} \times \frac{E}{100} \times 6{,}795\,296 \quad (1)$$

where

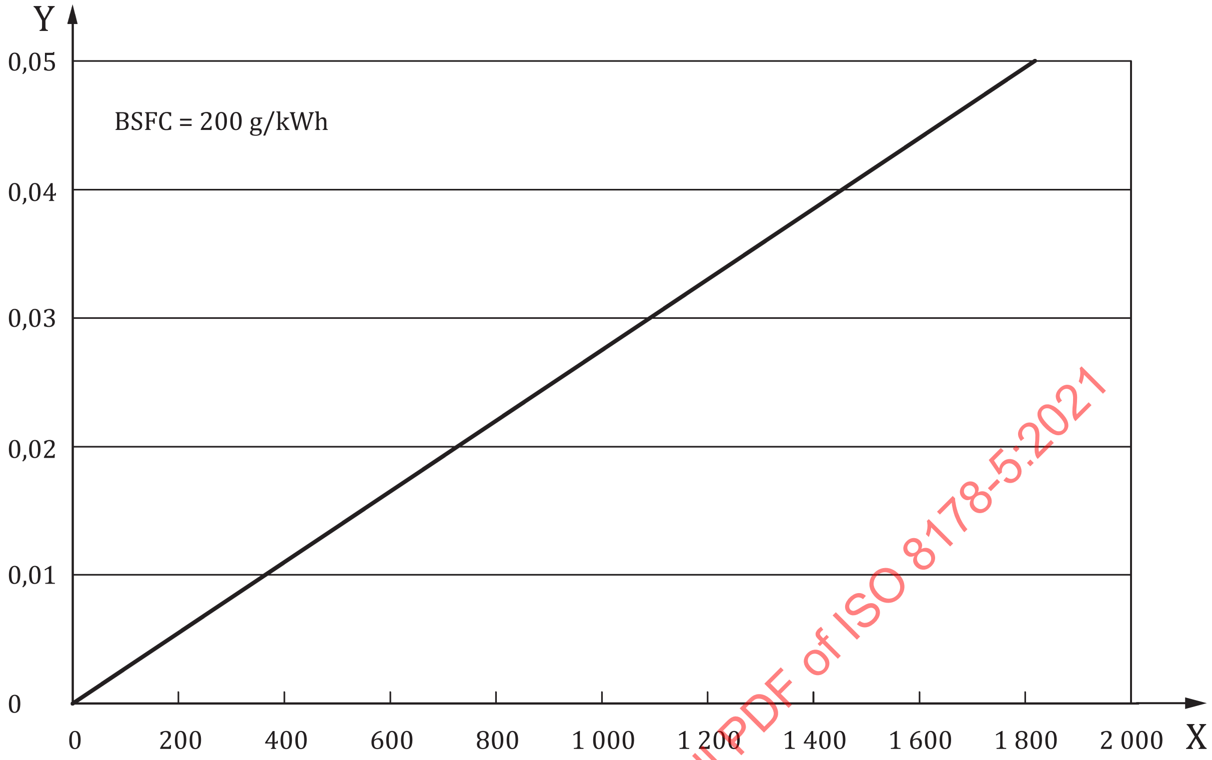
S_{PM}	is the brake specific contribution of fuel sulfur to PM, expressed in grams per kilowatt-hour (g/kw-h);
e_{fuel}	is the brake specific fuel consumption, expressed in grams per kilowatt-hour (g/kW-h);
X_{FSC}	is the fuel sulfur content, expressed in milligrams per kilogram (mg/kg);
E	is the $S \Rightarrow SO_4$ 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 %.

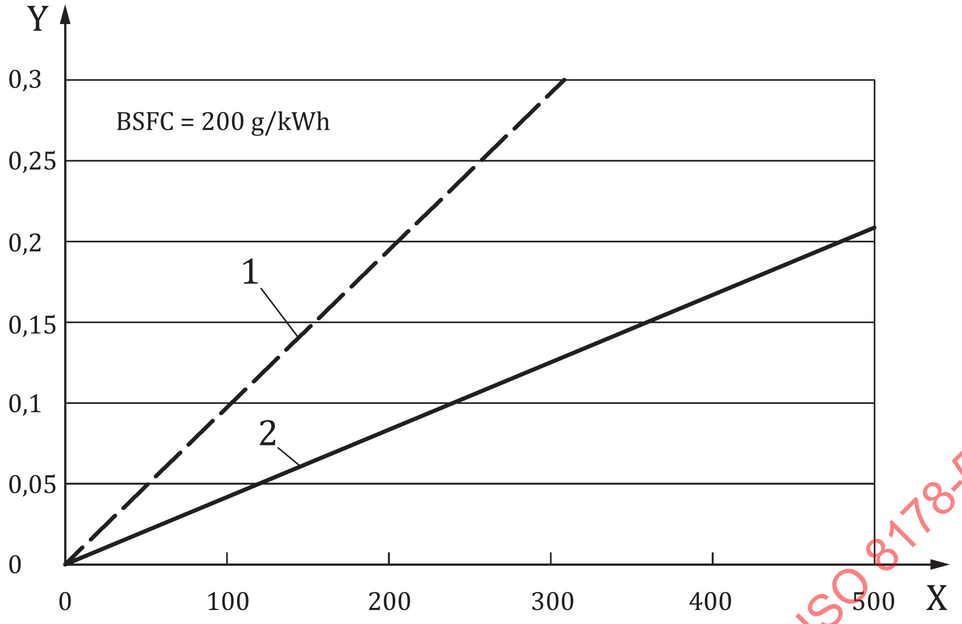
Many aftertreatment systems contain an oxidation catalyst as an integral part of the overall aftertreatment system. The major purpose of the oxidation catalyst is to enhance specific chemical reactions necessary for the proper function of the aftertreatment system. Since the oxidation catalyst will also 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/kW-h

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/kW-h
1	70 % conversion
2	30 % conversion

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

5.2.3 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 that for onroad or nonroad diesel fuels by a factor of approximately 10, as shown in Table 22. 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, 5.2.2 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/kWh. This is a significant portion of the total NO_x emission and shall therefore be carefully taken into account.

5.2.4 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 (CN), 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 aromatics content during combustion, which results in an increased NO_x emission. For PM, density and poly-aromatics are the most significant fuel parameters. In general, NO_x will be reduced by 4 % if aromatics are reduced from 30 % to 10 %. A similar reduction is possible for PM when reducing poly-aromatics from 9 % to 1 %.

Increasing the CN will improve engine cold start and therefore white smoke emission. It has also a favourable influence on NO_x emission particularly at low loads, where reductions of up to 9 % can be achieved if CN is increased from 50 to 58, and fuel consumption with improvements of up to 3 % for the same CN range.

5.3 Influence of fuel properties on emissions from spark ignition (SI) engines

Fuel parameters that have a significant influence on emissions and fuel consumption of an SI engine include octane number, sulfur level, metal-containing additives, oxygenates, olefins and benzene.

Engines are designed and calibrated for a certain octane value or methane number. When a customer uses gasoline with an octane level lower than that required, or accordingly, a natural gas with a lower methane number, knocking can result which could lead to severe engine damage. Engines equipped with knock sensors can handle lower octane or methane number levels by retarding the spark timing.

As mentioned above, sulfur naturally occurs in crude oil. If the sulfur is not removed during the refining process, it will contaminate the fuel. Sulfur has a significant impact on engine emissions by reducing the efficiency of catalysts. Sulfur also adversely affects heated exhaust gas oxygen sensors. Consequently, high sulfur levels will significantly increase HC and NO_x emissions. Also, lean burn technologies, which require NO_x aftertreatment technologies, are extremely sensitive to sulfur.

Metal-containing additives usually form ash and can therefore adversely affect the operation of catalysts and other components, such as oxygen sensors, in an irreversible way that increases emissions. For example, MMT (methylcyclopentadienyl manganese tricarbonyl) is a manganese-based compound marketed as an octane-enhancing fuel additive for gasoline. The combustion products of MMT coat internal engine components, such as spark plugs, can potentially cause misfire which leads to increased emissions, increased fuel consumption and poor engine performance. They also accumulate and partly plug the catalyst causing an increased fuel consumption in addition to reduced emission control.

Oxygenated organic compounds, such as ethanol, are often added to gasoline to increase octane, to extend gasoline supplies, or to induce a lean shift in engine stoichiometry to reduce carbon monoxide emissions. The leaner operation reduces carbon monoxide emissions, especially with carbureted engines without electronic feedback-controlled fuel systems. However increased O_2 levels beyond that for which an open loop engine has been calibrated will typically increase NO_x emissions and combustion temperatures which can lead to premature engine failure.

Olefins are unsaturated hydrocarbons and, in many cases, are also good octane components of gasoline. However, olefins in gasoline can lead to gum and deposit formation and increased emissions of reactive (i.e. ozone-forming) hydrocarbons and toxic compounds.

Benzene is a naturally occurring constituent of crude oil and is also a product of catalytic reforming that produces high octane gasoline streams. It is also a known human carcinogen. The control of benzene levels in gasoline is the most direct way to limit evaporative and exhaust emissions of benzene from SI engines.

Proper volatility of gasoline is critical to the operation of SI engines with respect to both performance and emissions. Volatility is characterized by two measurements, vapour pressure and distillation.

6 Overview of fuels

6.1 Natural gas

6.1.1 Reference natural gas

The referenced natural gases whose use is recommended for certification purposes are the following:

a) EU referenced fuels: see Table 1 and Table 2;

b) USA certification test fuel: see Table 3;

c) Japanese certification test fuel: see Table 4.

6.1.2 Reference natural gas supplied from a pipeline with admixture

The basis of each pipeline reference fuel (G_R, G_{20}, ...) shall be gas drawn from a utility gas distribution network, blended, where necessary to meet the corresponding lambda-shift (S_λ) specification in Table 2, with an admixture of one or more of the following commercially available gases:

a) carbon dioxide;

b) ethane;

c) methane;

d) nitrogen;

e) propane.

The use of calibration gas for this purpose shall not be required.

The value of S_λ of the resulting blend of pipeline gas and admixture gas shall be determined according to Annex D and shall be within the range specified in Table 2 for the specified reference fuel.

The following specification of the test fuels shall be recorded:

a) the admixture gas(es) chosen from the list above;

b) the value of S_λ for the resulting fuel blend;

c) the methane number (MN) determined according to EN 16726 or ASTM D8221-18 of the resulting fuel blend.

The requirements of Annexes C, D, and E shall be met in respect to the determination of the properties of the pipeline and admixture gases, the determination of S_λ and MN for the resulting gas blend, and the verification that the blend was maintained during the test.

In the case that one or more of the gas streams (pipeline gas or admixture gas(es)) contain CO_2 in greater than a de minimis proportion, the calculation of specific CO_2 emissions shall be corrected according to Annex E.

6.1.3 Non-referenced natural gas

Referenced gaseous fuels cannot be used as their use depends on the availability of the gas at site. Their properties, including the fuel(s) analysis, shall be known and reported with the results of the emissions test.

A universal data sheet containing the analytical properties to be reported is given in Table 5.

6.2 Liquefied petroleum gas

6.2.1 Referenced liquefied petroleum gas

The referenced liquefied petroleum gas whose use is recommended for certification purposes is the following:

a) EU reference fuels: see Table 6;

b) USA certification test fuel: see Table 7;

c) Japanese certification test fuel: see Table 8.

6.2.2 Non-referenced liquefied petroleum gas

Often, referenced liquefied petroleum gas cannot be used as its use depends on the availability of the gas at site. The properties, including the gas analysis, shall be known and reported with the results of the emissions test.

A universal data sheet containing the analytical properties to be reported is given in Table 9.

6.3 Engine gasolines

6.3.1 Referenced engine gasolines

The referenced engine gasolines whose use is recommended for certification purposes are the following:

a) EU reference fuels: see Table 10;

b) USA certification test fuel: see Table 11;

c) US EPA E-10 certification test fuel: see Table 12;

d) California CARB LEV III certification test fuel: see Table 13;

e) Japanese certification test fuels: see Table 14;

f) Ethanol E95 (dedicated CI engines): see Table 15;

g) Ethanol E85 Stage V reference fuel: see Table 16.

6.3.2 Non-referenced engine gasolines

If it is necessary to use non-referenced engine gasolines, the properties of the individual fuel shall be reported with the results of the test. Table 17 represents a universal analytical data sheet giving the properties which shall be reported.

6.4 Diesel fuels

6.4.1 Diesel reference fuels

The referenced diesel fuels whose use is recommended for certification purposes are the following:

a) EU reference fuels: see Table 18;

b) USA certification test fuels: see Table 19;

c) Japanese certification test fuel: see Table 20.

6.4.2 Non-referenced diesel fuels

If it is necessary to use non-referenced diesel fuels, the properties of the individual fuel shall be reported with the results of the test. Table 21 represents a universal analytical data sheet giving the properties which shall be reported.

Standards or specifications of commercial fuels may be obtained from the organizations listed in Annex C.

6.5 Distillate fuel oils

As there are no existent reference fuels, it is recommended that the fuel used be in accordance with ISO 8217 (see Table 22).

The fuel's properties, including the elemental analysis, shall be measured and reported with the results of the emission measurement. Table 23 represents a universal analytical data sheet giving the properties which shall be reported.

6.6 Residual fuel oils

As there are no existing reference fuels, it is recommended that the fuel used be in accordance with ISO 8217 (see Table 24).

In cases where it is necessary to run on heavy fuels, the properties of the fuel shall be according to ISO 8216-1 and ISO 8217. The properties of the fuel, including the elementary analysis, shall be determined and reported with the results of the emission measurement. Table 25 represents a universal analytical data sheet giving the properties which shall be reported.

The effect of the ignition quality on exhaust gas emissions, especially NO_x, depends on the engine characteristics and engine speed and load, and is in many cases not negligible. There is a generally recognized need for a standard measurement procedure resulting in a characteristic fuel quality value comparable to the cetane index for pure distillate fuels. A calculation based on the distillation characteristics is not suitable. For the time being, the best approach is to calculate CCAI (calculated carbon aromaticity index) or CII (calculated ignition index) figures for general indication. A.3.2 gives formulae for calculating CCAI and CII.

Another method, which is currently under investigation, is the fuel combustion analyser (FCA). The ignition quality of a fuel is determined as an ignition delay and time delay for the start of the main combustion (both in milliseconds).

By use of calibration fuels, the recorded ignition delay can be converted into an instrument-related cetane number. In addition, the rate of heat release (ROHR) is determined, reflecting the actual heat release process and thus the combustion characteristics of the fuel tested.

The test results appear to reflect the differences in ignition and combustion properties of marine fuels due to variations in their chemical composition. At the present time, a large number of heavy fuels are being tested for the purpose of relating the results obtained from the instruments to the fuel ignition performance as well as correlating the results with engine performance. In co-operation with engine manufacturers, fuel testing laboratories and users of marine heavy fuel, typical limits for satisfactory fuel ignition and combustion quality at which operational disturbances are not encountered, are being established. Results have been published in the CIMAC “Fuel Quality Guide – Ignition and Combustion”.

6.7 Crude oil

Crude oils are non-referenced.

In cases where it is necessary to run the engine with crude oil, the properties of the fuel, including the elemental analysis, shall be measured and reported with the results of the emission measurement. Table 26 is given as a recommendation for a data sheet, of the properties to be reported.

6.8 Alternative fuels

In those cases where alternative fuels are used, the analytical data specified by the producer of the fuel shall be determined and reported together with the report on exhaust emissions.

NOTE Requirements for fatty acid methyl esters can be found in EN 14214.

6.9 Requirements and additional information

For the determination of fuel properties, International Standards shall be used where they exist. Annex B lists standards, established by the standardization organizations, in use in parallel to International Standards. It should be noted that non standards are not always identical in all details to the parallel International Standard.

If supplementary additives are used during the test, they shall be declared and noted in the test report.

If water addition to the engine intake air is used, it shall be declared and taken into account in the calculation of the emission results.

Table 1 — Natural gas — EU reference fuels

Property[c]	**Unit**	**Test method**	G_{23}		G_R		G_{20}		G_{25}	
			min.	max.	min.	max.	min.	max.	min.	max.
Molar fraction of methane	mol %	ISO 6974 (all parts)	91,5	93,5	84	89	99	100	84	88
Molar fraction of ethane	mol %	ISO 6974 (all parts)	—	—	11	15			—	—
Molar fraction of C_{2+} components	mol %	ISO 6974 (all parts)	—	—	—	1	—	—	—	—
Molar fraction of inerts, (except N_2) + C_2 + C_{2+}	mol %	ISO 6974 (all parts)	—	1	—	—	—	1	—	1
Molar fraction of nitrogen	mol %	ISO 6974 (all parts)	6,5	8,5	—	—	—	—	12	16
Mass concentration of sulfur [a]	$\mathrm{mg/m^3}$	ISO 6326-5	—	10	—	10	—	10	—	10
Wobbe Index (net)	$\mathrm{MJ/m^3}$ [b]						47,2	49,2		

NOTE This table is adapted from Reference[204] and[205]

[a] Value to be determined at 293,2 K (20 °C) and 101,3 kPa.

[b] Value to be determined at 273,2 K (0 °C) and 101,3 kPa.

[c] To recalculate standard reference conditions use ISO 6976

Table 2 — Natural gas — The required range of S_λ for each reference fuel - blend of pipeline gas and admixture gas

Reference fuel	Minimum S_λ	Maximum S_λ
G_R [a]	0,87	0,95
G_{20}	0,97	1,03
G_{23}	1,05	1,10
G_{25}	1,12	1,20

[a] The engine shall not be required to be tested on a gas blend with an MN less than 70. In the case that the required range of S_λ for G_R would result in an MN less than 70 the value of S_λ for G_R may be adjusted as necessary until a value of MN no less than 70 is attained.

Table 3 — Natural gas — USA certification test fuel

Property	**Unit**	**Test method**		
			min.	max.
Molar fraction of methane	mol %	ASTM D 1945	87	—
Molar fraction of ethane	mol %	ASTM D 1945	—	5,5

Table 3 *(continued)*

Property	Unit	Test method		
			min.	max.
Molar fraction of propane	mol %	ASTM D 1945	—	1,2
Molar fraction of butane	mole %	ASTM D 1945		0,35
Molar fraction of pentane	mole %	ASTM D 1945		0,13
Molar fraction of C_{6+} components	mol %	ASTM D 1945	—	0,1
Molar fraction of oxygen	mol %	ASTM D 1945		0,1
Molar fraction of inert gases, Σ CO_2 and N_2	mol %	ASTM D 1945	—	5,1

Table 4 — Natural gas — Japanese certification test fuel

Property	Unit	Test method	Equivalent of 13A	
			min.	max.
Total calorific amount	kcal/m^3	JIS K 2301	10 410	11 050
Wobbe index	WI	[a]	13 260	730
Combustion speed index	MCP	[a]	36,8	37,5
Molar fraction of methane	mol %	JIS K 2301	85,0	—
Molar fraction of ethane	mol %	JIS K 2301	—	10,0
Molar fraction of propane	mol %	JIS K 2301	—	6,0
Molar fraction of butane	mol %	JIS K 2301	—	4,0
Molar fraction of C_3 + C_4 components	mol %	JIS K 2301	—	8,0
Molar fraction of C_{5+} components	mol %	JIS K 2301	—	0,1
Molar fraction of other gas (H_2 + O_2 + N_2 + CO + CO_2)	mol %	JIS K 2301	—	14,0
Mass concentration of sulfur	mg/m^3	JIS K 2301	—	10

NOTE This table is adapted from Reference[166].

[a] Wobbe index and Combustion speed index shall be calculated based on the gas composition.

Table 5 — Universal analytical data sheet — Natural gas

Property	Unit	Test method	Result of measurements
Molar fraction of MMmethane	%	ISO 6974 (all parts)	
Molar fraction of C_2 components	%	ISO 6974 (all parts)	
Molar fraction of C_{2+} components	%	ISO 6974 (all parts)	
Molar fraction of C_{6+} components	%	ISO 6974 (all parts)	
Molar fraction of Inerts Σ CO_2 and N_2	%	ISO 6974 (all parts)	
Mass concentration of sulfur	mg/m^3	ISO 6326-5	

Table 6 — Liquefied petroleum gas — EU reference fuel

Property	Unit	Test method	Fuel A	Fuel B
Volume fraction of C_3 components	% by volume	ISO 7941	30 ± 2	85 ± 2
Volume fraction of C_4 components	% by volume	ISO 7941	Balance	Balance

NOTE This table is adapted from Reference[204] and[205]

Table 6 *(continued)*

Property	Unit	Test method	Fuel A	Fuel B
Volume fraction of inerts, <C_3, >C_4	% by volume	ISO 7941	max. 2,0	max. 2,0
Volume fraction of olefins	% by volume	ISO 7941	max.12	max.15
Evaporation residue	mg/kg	ISO 13757	max. 50	max. 50
Water at 0 °C		visual inspection	free	free
Total sulfur content	mg/kg	EN 24260	max. 10	max. 10
Hydrogen sulfide		ISO 8819	none	none
Copper strip corrosion	Rating	ISO 6251	Class 1	Class 1
Odour			characteristic	characteristic
Engine octane number		EN 589	min. 89,0	min. 89,0
NOTE This table is adapted from Reference[204] and[205]				

Table 7 — Liquefied petroleum gas — USA certification test fuel

Property	Unit	Test method	min.	max.
Volume fraction of propane	% by volume	ASTM D 2163	85	—
Volume fraction of butane	% by volume	ASTM D 2163	—	5
Volume fraction of butenes	% by volume	ASTM D 2163	—	2
Volume fraction of pentenes and heavier	% by volume	ASTM D 2163	—	0,5
Volume fraction of propene	%	ASTM D 2163	—	10
Vapor pressure at 38 °C	kPa	ASTM D 1267 and ASTM D 2598	—	1400
Volatility residue	°C	ASTM D 1837	—	-38
Residual matter	ml	ASTM D 2158	—	0,05
Copper strip corrosion	Rating	ASTM D 1838	—	Class 1
Mass concentration of sulfur	mg/kg	ASTM D 2784	—	80
Moisture content	Rating	ASTM D 2713	Pass	—
NOTE This table is adapted from Reference[214]				

Table 8 — Liquefied petroleum gas — Japanese reference fuel

Property	Unit	Test method	min.	max.
Molar fraction of propane and propylene	mol %	JIS K 2240	20	30
Molar fraction of butane and butylene	mol %	JIS K 2240	70	80
Density at 15 °C	g/cm^3	JIS K 2240	0,500	0,620
Vapor pressure at 40 °C	MPa	JIS K 2240	—	1,55
Mass concentration of sulfur	% by mass	JIS K 2240	—	0,02

Table 9 — Universal analytical data sheet — Liquefied petroleum gas

Property	Unit	Test method Text[a]	Result of measurements
Molar fraction of each component	%	ISO 7941	
Mass concentration of sulfur	%	ISO 4260	
Vapour pressure at 40 °C	kPa	ISO 8973 ISO 4256	
Density at 15 °C	g/cm^3	ISO 3993 ISO 8973	

[a] Indicate the method used.

Table 10 — Engine gasolines — EU reference fuels

Property	Unit	Test method [b]	Directive 2002/88/EC		Regulation 2017/654 (E10) [a]	
			min.	max.	min.	max.
Research octane number (RON)	1	ISO 5164 [c]	95	—	91	98
Engine octane number (MON)	1	ISO 5163 [c]	85	—	83	89
Density at 15 °C	kg/m^3	ISO 3675	748	762	743	756
Reid vapour pressure	kPa	EN 12	56	60	—	—
Vapour pressure (DVPE)	kPa	ISO 13016-1	—	—	45	60
Water content	% V/V	ASTM E 1064 ISO 12937				0,05
Distillation		ISO 3405				
Initial boiling point	°C		24	40	18	46
Evaporated at 70°C	% V/V					
Evaporated at 100°C	% V/V		49	57	46	62
Evaporated at 150°C	% V/V		81	87	75	94
Final boiling point	°C		190	215	170	210
Residue	% V/V		—	2	—	2,0
Hydrocarbon analysis						
Volume fraction of olefins	% V/V	ASTM D 1319/ EN 14517/EN 15553	—	10	3	18
Volume fraction of aromatics	% V/V	ASTM D 1319/ EN 14517/ EN 15553	28	40	19,5	35

NOTE This table is adapted from References [156] and [205].

[a] The values quoted in the specifications are ‘true values’. In the establishment of their limit values the terms of ISO 4259 have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[b] Equivalent EN/ISO methods will be adopted when issued for properties listed above.

[c] A correction factor of 0,2 for MON and RON shall be subtracted for the calculation of the final result in accordance with EN 228.

[d] The fuel may contain oxidation inhibitors and metal deactivators normally used to stabilise refinery gasoline streams, but detergent/dispersive additives and solvent oils shall not be added.

[e] Ethanol meeting the specification of EN 15376 is the only oxygenate that shall be intentionally added to the reference fuel.

[f] The actual sulphur content of the fuel used for the Type 1 test shall be reported.

[g] There shall be no intentional addition of compounds containing phosphorus, iron, manganese, or lead to this reference fuel.

[h] The ethanol content and corresponding oxygen content may be zero for engines of category SMB at the choice of the manufacturer. In this case all testing of the engine family, or engine type where no family exists, shall be conducted using petrol with zero ethanol content.

Table 10 *(continued)*

Property	Unit	Test method [b]	Directive 2002/88/EC		Regulation 2017/654 (E10) [a]	
			min.	max.	min.	max.
Volume fraction of benzene	% V/V	EN 12177/ EN 238/ EN 14517	—	1		1,0
Volume fraction of saturates	% V/V	ASTM D 1319/ EN 14517/ EN 15553		Balance		Report
Carbon/hydrogen ratio				Report		Report
Carbon/oxygen ratio						Report
Mass fraction of sulfur [f]	mg/kg	ISO 20846/ ISO 20884	—	100	—	10
Oxygen content [e]	% m/m	EN 1601	—	2,3	3,3	3,7
Lead content	mg/l	EN 237		5	—	5
Phosphorus content [g]	mg/l	ASTM D 3231	—	1,3	—	1,3
Oxidation stability						
Induction period [d]	Min	ISO 7536	480	—	480	—
Mass of existent gum	mg/ml	ISO 6246	—	0,04	—	0,04
Copper corrosion at 50 °C	—	ISO 2160	—	class 1	—	class 1
Ethanol [d]	% V/V	ISO 22854			9,0 [h]	10,2 [h]

NOTE This table is adapted from References [156] and [205].

[a] The values quoted in the specifications are ‘true values’. In the establishment of their limit values the terms of ISO 4259 have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[b] Equivalent EN/ISO methods will be adopted when issued for properties listed above.

[c] A correction factor of 0,2 for MON and RON shall be subtracted for the calculation of the final result in accordance with EN 228.

[d] The fuel may contain oxidation inhibitors and metal deactivators normally used to stabilise refinery gasoline streams, but detergent/dispersive additives and solvent oils shall not be added.

[e] Ethanol meeting the specification of EN 15376 is the only oxygenate that shall be intentionally added to the reference fuel.

[f] The actual sulphur content of the fuel used for the Type 1 test shall be reported.

[g] There shall be no intentional addition of compounds containing phosphorus, iron, manganese, or lead to this reference fuel.

[h] The ethanol content and corresponding oxygen content may be zero for engines of category SMB at the choice of the manufacturer. In this case all testing of the engine family, or engine type where no family exists, shall be conducted using petrol with zero ethanol content.

Table 11 — Engine gasolines (no ethanol) — USA certification test fuel for general testing

Property[a]	Unit	Test method	General testing		Low temperature testing	
			min.	max.	min.	max.
Sensitivity (RON/MON)	1	ASTM D 2699 ASTM D 2700	7,5	—	7,5	—
Dry vapour pressure equivalent	kPa	ASTM D 323	60,0	63,4[b,c]	77,2	81,4
Distillation range:		ASTM D 86				
Evaporated Initial boiling point	°C		24	35	24	36
10 % evaporated (by volume)	°C		49	57	37	48

NOTE This table is adapted from Reference[212].

[a] Gasoline for testing shall have octane values that represent commercially available fuels for the appropriate application.

[b] For testing at altitudes above 1 219 m, the specified volatility range is (52,0 to 55,2) kPa and the specified initial boiling point range is (23,9 to 40,6) °C.

[c] For testing unrelated to evaporative emissions, the specified range is (55,2 to 63,4) kPa.

Table 11 *(continued)*

Property[a]	Unit	Test method	General testing		Low temperature testing	
			min.	max.	min.	max.
50 % evaporated (by volume)	°C		93	110	82	101
90 % evaporated (by volume)	°C		149	163	158	174
Evaporated final boiling point	°C		—	213	—	212
Hydrocarbon analysis		ASTM D 1319				
Olefins	Vol %		—	10	—	17,5
Aromatics	Vol %		—	35	—	30,4
Saturates	Vol %		Remainder		Remainder	
Mass fraction of sulfur	mg/kg		—	80	—	80
Mass concentration of lead	g/l	ASTM D 3237	—	0,013	—	0,013
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,0013	—	0,005

NOTE This table is adapted from Reference[212].

[a] Gasoline for testing shall have octane values that represent commercially available fuels for the appropriate application.

[b] For testing at altitudes above 1 219 m, the specified volatility range is (52,0 to 55,2) kPa and the specified initial boiling point range is (23,9 to 40,6) °C.

[c] For testing unrelated to evaporative emissions, the specified range is (55,2 to 63,4) kPa.

Table 12 — Engine gasolines (10 % ethanol; E10) — USA Environmental Protection Agency certification test fuel for general testing and low temperature testing

Property	Unit	Test method	General testing		Low temperature testing	
			min.	max.	min.	max.
Antiknock Index (R + M)/2		ASTM D 2699 ASTM D 2700	87,0	88,4[a,b]	87,0	88,4[a,b]
Dry vapour pressure equivalent (DVPE)[d]	kPa	ASTM D 323	60,0	63,4[c]	77,2	81,4[c]
Distillation range:		ASTM D 86				
10 % evaporated (by volume)	°C		49	60	43	54
50 % evaporated (by volume)	°C		88	99	88	99
90 % evaporated (by volume)	°C		157	168	157	168
Evaporated final boiling point	°C		193	216	193	216
Residue	millilitre		—	2,0	—	2,0

NOTE This table is adapted from Reference[212].

[a] Gasoline for testing shall have octane values that represent commercially available fuels for the appropriate application.

[b] Octane specifications apply only for testing related to exhaust emissions. For engines or vehicles that require the use of premium fuel the adjusted specification for antiknock index is a minimum value of 91,0; no maximum value applies. All other specifications apply for this high-octane fuel.

[c] For testing at altitudes above 1 219 m, the specified volatility range is (52,4 to 55,2) kPa and the 10 % evaporated range is (49 to 60) °C.

[d] Calculate dry vapor pressure equivalent, p_{DVPE}, based on the measured total vapor pressure, p_{T}, using the following equation: p_{DVPE} (kPa) = 0,956 · p_{T}—2,39 or p_{DVPE} (psi) = 0,956 · p_{T}—0.347. Dry Vapor Pressure Equivalent is intended to be equivalent to Reid Vapor Pressure using a different test method.

[e] ASTM D 5599 prescribes concentration measurements for ethanol and other oxygenates in mass %. Convert results to volume % as specified in Section 14.3 of ASTM D 4815.

Table 12 *(continued)*

Property	Unit	Test method	General testing		Low temperature testing	
			min.	max.	min.	max.
Hydrocarbon analysis		ASTM D 5769				
Total Aromatic Hydrocarbons	Vol %		21,0	25,0	21,0	25,0
C6 Aromatics (benzene)	Vol %		0,5	0,7	0,5	0,7
C7 Aromatics (toluene)	Vol %		5,2	6,4	5,2	6,4
C8 Aromatics	Vol %		5,2	6,4	5,2	6,4
C9 Aromatics	Vol %		5,2	6,4	5,2	6,4
C10 + Aromatics	Vol %		4,4	5,6	4,4	5,6
Olefins	Vol %		3,4	8,6	3,4	8,6
Ethanol blended	Vol %		9,6	10,0	9,6	10,0
Ethanol confirmatory[e]	Vol %	ASTM D 4815 or ASTM D 5599	9,4	10,2	9,4	10,2
Total Content of Oxygenates other than Ethanol	Vol %	ASTM D 4815 or ASTM D 5599	—	0,1	—	0,1
Mass fraction of sulfur	mg/kg	ASTM D 2622, ASTM D 5453 or ASTM D 7039	8,0	11,0	8,0	11,0
Mass concentration of lead	g/l	ASTM D 3237	—	0,0026	—	0,0026
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,0013	—	0,0013
Copper Corrosion		ASTM D 130	—	No. 1	—	No. 1
Solvent-Washed Gum Content	mg/100 milliliter	ASTM D 381	—	3,0	—	3,0
Oxidation Stability	Minute	ASTM D 525	1 000	—	1 000	—

NOTE This table is adapted from Reference[212].

[a] Gasoline for testing shall have octane values that represent commercially available fuels for the appropriate application.

[b] Octane specifications apply only for testing related to exhaust emissions. For engines or vehicles that require the use of premium fuel the adjusted specification for antiknock index is a minimum value of 91,0; no maximum value applies. All other specifications apply for this high-octane fuel.

[c] For testing at altitudes above 1 219 m, the specified volatility range is (52,4 to 55,2) kPa and the 10 % evaporated range is (49 to 60) °C.

[d] Calculate dry vapor pressure equivalent, p_{DVPE}, based on the measured total vapor pressure, p_{T}, using the following equation: p_{DVPE} (kPa) = $0{,}956 \cdot p_{\text{T}} — 2{,}39$ or p_{DVPE} (psi) = $0{,}956 \cdot p_{\text{T}} — 0.347$. Dry Vapor Pressure Equivalent is intended to be equivalent to Reid Vapor Pressure using a different test method.

[e] ASTM D 5599 prescribes concentration measurements for ethanol and other oxygenates in mass %. Convert results to volume % as specified in Section 14.3 of ASTM D 4815.

Table 13 — Engine gasolines (10 % ethanol; E10) — California Air Resources Board (CARB) LEV III certification test fuel

Property	Unit	Test method	min.	max.
Octane (R + M)/2		ASTM D 2699	87,0	88,4[a,b]
Sensitivity (R-M)		ASTM D 2700	91,0	—
			7,5	
RVP	psi	ASTM D 323	6,9	7,2
Distillation range:		ASTM D 86		
10 % point	°C (°F)		54 (130)	66 (150)
50 % point	°C (°F)		96 (205)	102 (215)
90 % point	°C (°F)		154 (310)	160 (320)
Evaporated Point, maximum	°C (°F)		—	199
Residue	Vol %		—	2,0
Hydrocarbon analysis		ASTM D 5580		
Total Aromatic Hydrocarbons	Vol %		19,5	22,5
Benzene	Vol %		0,6	0,8
Multi-substituted Alkyl Aromatic Hydrocarbons	Vol %		13	15
Olefins	Vol %	ASTM D 6550	4,0	6,0
Ethanol	Vol %	ASTM D 4815	9,8	10,2
MTBE	Vol %	ASTM D 7754	—	0,05
Total Oxygen	wt %	ASTM D 4815	3,3	3,7
Mass fraction of sulfur	mg/kg	ASTM D 5453	8,0	11,0
Mass concentration of lead	g/l	ASTM D 3237	—	0,0026
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,0013
Copper Corrosion		ASTM D 130	—	No. 1
Solvent-Washed Gum Content	mg/100 millilitre	ASTM D 381	—	3,0
Oxidation Stability	Minute	ASTM D 525	1 000	—
Specific Gravity	Report[c]			
Heat of Combustion	Report[c]			
Carbon	Report wt. % [c]			
Hydrogen	Report wt. % [c]			

NOTE This table is adapted from Reference[116].

[a] Gasoline for testing shall have octane values that represent commercially available fuels for the appropriate application.

[b] For vehicles/engines that require the use of premium gasoline as part of their warranty, the Octane ((R+M)/2) may be a 91 minimum. All other certification gasoline specifications, as shown in this table, shall be met. For all other vehicles/engines, the Octane ((R+M)/2) shall be 87-88,4.

[c] The fuel producer should report this fuel property to the fuel purchaser. Any generally accepted test method may be used and shall be identified in the report.

Table 14 — Engine gasolines — Japanese certification test fuels

Property	Unit	Test method	Regular Grade		Premium Grade	
			min.	max.	min.	max.
Research octane number (RON)	1	JIS K 2280	90	92	99	101
Engine octane number (MON)	1	JIS K 2280	80	82	86	88
Density at 15 °C	g/cm^3	JIS K 2249	0,72	0,77	0,72	0,77
Reid vapour pressure	kPa	JIS K 2258	56	60	56	60
Distillation		JIS K 2254				

NOTE This table is adapted from Reference[166].

[a] ND = not detectable.

Table 14 *(continued)*

Property	Unit	Test method	Regular Grade		Premium Grade	
			min.	max.	min.	max.
10 % (by volume)	K (°C)		318 (45)	328 (55)	318 (45)	328 (55)
50 % (by volume)	K (°C)		363 (90)	373 (100)	363 (90)	373 (100)
90 % (by volume)	K (°C)		413 (140)	443 (170)	413 (140)	443 (170)
Final boiling point	K (°C)		—	488 (215)	—	488 (215)
Hydrocarbon analysis		JIS K 2536-1, -2, −3, −4, −5, −6				
Olefins	% by volume		15	25	15	25
Aromatics	% by volume		20	45	20	45
Benzene	% by volume		—	1,0	—	1,0
Oxygen	% by mass		—	ND[a]	—	ND
MTBE	% by volume		—	ND	—	ND
Methanol	% by volume		—	ND	—	ND
Ethanol	% by volume		—	ND	—	ND
Kerosine	% by volume		—	ND	—	ND
Mass fraction of sulfur	mg/kg	JIS K 2541-1, -2, −6, −7	—	10	—	10
Mass concentration of lead	g/l	JIS K 2255	—	ND	—	ND
Existent gums per 100 ml	mg	JIS K 2261	—	5	—	5

NOTE This table is adapted from Reference[166].

[a] ND = not detectable.

Table 15 — Ethanol for dedicated compression ignition engines (ED95) [a]

Parameter	Unit	Test method [c]	Limits [b]	
			Minimum	**Maximum**
Total alcohol (Ethanol incl. content on higher saturated alcohols)	% m/m	EN 15721	92,4	

NOTE This table is adapted from Reference[205].

[a] Additives, such as cetane improver as specified by the engine manufacturer, may be added to the ethanol fuel, as long as no negative side effects are known. If these conditions are satisfied, the maximum allowed amount is 10 % m/m.

[b] The values quoted in the specifications are ‘true values’. In establishment of their limit values the terms of ISO 4259 have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[c] Equivalent EN/ISO methods will be adopted when issued for properties listed above.

[d] Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of EN 15489 shall be applied.

Table 15 *(continued)*

Parameter	Unit	Test method [c]	Limits [b]	
			Minimum	Maximum
Other higher saturated mono-alcohols (C_3-C_5)	% m/m	EN 15721		2,0
Methanol	% m/m	EN 15721		0,3
Density 15 °C	kg/m^3	ISO 12185	793,0	815,0
Acidity, calculated as acetic acid	% m/m	EN 15491		0,0025
Appearance			Bright and clear	
Flashpoint	°C	ISO 3679	10	
Dry residue	mg/kg	EN 15691		15
Water content	% m/m	EN 15489 [d] ISO 12937 EN15692		6,5
Aldehydes calculated as acetal-de hyde	% m/m	ISO 1388-4		0,0050
Esters calculated as ethylacetat	% m/m	ASTM D1617		0,1
Sulphur content	mg/kg	EN 15485 EN 15486		10,0
Sulphates	mg/kg	EN 15492		4,0
Particulate contamination	mg/kg	EN 12662		24
Phosphorus	mg/l	EN 15487		0,20
Inorganic chloride	mg/kg	EN 15484 or EN 15492		1,0
Copper	mg/kg	EN 15488		0,100
Electrical Conductivity	µS/cm	DIN 51627-4 or EN 15938		2,50

NOTE This table is adapted from Reference[205].

[a] Additives, such as cetane improver as specified by the engine manufacturer, may be added to the ethanol fuel, as long as no negative side effects are known. If these conditions are satisfied, the maximum allowed amount is 10 % m/m.

[b] The values quoted in the specifications are 'true values'. In establishment of their limit values the terms of ISO 4259 have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[c] Equivalent EN/ISO methods will be adopted when issued for properties listed above.

[d] Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of EN 15489 shall be applied.

Table 16 — Ethanol (E85)

Parameter	Unit	Test method	Limits [a]	
			Minimum	**Maximum**
Research octane number, RON		ISO 5164	95,0	—
Motor octane number, MON		ISO 5163	85,0	—
Density at 15 °C	kg/m^3	ISO 3675	Report	
Vapour pressure	kPa	EN 13016-1 (DVPE)	40,0	60,0
Sulphur content [b]	mg/kg	EN 15485 or EN 15486	—	10
Oxidation stability	Minutes	ISO 7536	360	
Existent gumcontent (solvent washed)	mg/100ml	ISO 6246	—	5
Appearance This shall be determined at ambient temperature or 15 °C whichever is higher		Visual inspection	Clear and bright, visibly free of suspended or precipitated contaminants	
Ethanol and higher alcohols [c]	% v/v	EN 1601 EN 13132 EN 14517 E DIN 51627-3	83	85
Higher alcohols (C_3-C_8)	% v/v	DIN 51627-3	—	2,0
Methanol	% v/v	DIN 51627-3		1,00
Petrol [d]	% v/v	EN 228		Balance
Phosphous	mg/l	EN 15487		0,20 [e]
Water content	% v/v	EN 15489 or EN 15692		0,300
Inorganic chloride content	mg/l	EN 15492		1
pHe		EN 15490	6,5	9,0
Copper strip corrosion (3h at 50 ° C)	Rating	ISO 2160	Class 1	
Acidity, (as acetic acid CH_3COOH)	% m/m (mg/l)	EN 15491	—	0,0050 (40)
Electric Conductivity	µS/cm	DIN 51627-4 or EN 15938	1,5	

NOTE: This table is adapted from Reference[205].

[a] The values quoted in the specifications are ‘true values’. In establishment of their limit values the terms of ISO 4259 have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[b] The actual sulphur content of the fuel used for the emission tests shall be reported.

[c] Ethanol to meet specification of EN 15376 is the only oxygenate that shall be intentionally added to this reference fuel.

[d] The unleaded petrol content can be determined as 100 minus the sum of the % content of water, alcohols, Methyl tert-butyl ether (MTBE) and Ethyl tert-butyl ether (ETBE).

[e] There shall be no intentional addition of compounds containing phosphorus, iron, manganese, or lead to this reference fuel.

Table 16 *(continued)*

Parameter	Unit	Test method	Limits [a]	
			Minimum	Maximum
Carbon/hydrogen ratio			Report	
Carbon/oxygen ration			Report	

NOTE: This table is adapted from Reference[205].

[a] The values quoted in the specifications are ‘true values’. In establishment of their limit values the terms of ISO 4259 have been applied and in fixing a minimum value, a minimum difference of 2R above zero has been taken into account; in fixing a maximum and minimum value, the minimum difference is 4R (R = reproducibility). Notwithstanding this measure, which is necessary for technical reasons, the manufacturer of fuels shall nevertheless aim at a zero value where the stipulated maximum value is 2R and at the mean value in the case of quotations of maximum and minimum limits. Should it be necessary to clarify whether a fuel meets the requirements of the specifications, the terms of ISO 4259 shall be applied.

[b] The actual sulphur content of the fuel used for the emission tests shall be reported.

[c] Ethanol to meet specification of EN 15376 is the only oxygenate that shall be intentionally added to this reference fuel.

[d] The unleaded petrol content can be determined as 100 minus the sum of the % content of water, alcohols, Methyl tert-butyl ether (MTBE) and Ethyl tert-butyl ether (ETBE).

[e] There shall be no intentional addition of compounds containing phosphorus, iron, manganese, or lead to this reference fuel.

Table 17 — Universal analytical data sheet — Engine gasolines

Property	Unit	Test method[a]	Result of measurements
Research octane number (RON)	1	ISO 5164	
Engine octane number (MON)	1	ISO 5163	
Sensitivity (RON/MON)	1	ISO 5163 ISO 5164	
Density at 15 °C	kg/l	ISO 3675	
Reid vapour pressure	kPa	ISO 3007	
Vapour pressure (DVPE)	kPa	EN 13016-1	
Distillation		ISO 3405	
Initial boiling point	°C		
10 % (by volume)	°C		
50 % (by volume)	°C		
90 % (by volume)	°C		
Final boiling point	°C		
Residue			
at 70 °C	%		
at 100 °C	%		
at 180 °C	%		
Hydrocarbon analysis		ISO 3837	
Volume fraction of olefins	%		
Volume fraction of aromatics	%		
Volume fraction of benzene	%	ASTM D 3606 ASTM D 5580 EN 238	
Mass fraction of Sulfur	%	ISO 8754	
Mass concentration of phosphorus	g/l	ASTM D 3231	

[a] Indicate the method used.

[b] See Clause 5.

Table 17 *(continued)*

Property	Unit	Test method[a]	Result of measurements
Mass concentration of lead	g/l	ISO 3830	
Oxidation stability	min	ISO 7536	
Mass of existent gums per 100 ml	mg	ISO 6246	
Copper strip corrosion at 50 °C	—	ISO 2160	
Oxygenates			
Elemental analysis[b]			
Mass fraction of carbon	%	ASTM D 3343	
Mass fraction of hydrogen	%		
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

[a] Indicate the method used.

[b] See Clause 5.

Table 18 — Diesel fuels — EU reference fuels

Property	Unit	Test methods			Low Sulfur		Ultra low sulfur		B7 2017/654	
					min.	max.	min.	max.	min.	max.
Cetane index		ISO 4264							—	—
Cetane number	1	ISO 5165			52	54	—	54	45	56,0
Density at 15 °C	kg/m^3	ISO 3675			833	837	833	837	833	865
Distillation		ISO 3405								
50 % (by volume)	°C				245	—	245	—	245	—
95 % (by volume)	°C				345	350	345	350	345	350
Final boiling point	°C				—	370	—	370	—	370
Flash point	°C	ISO 2719/ EN 22719			55	—	55	—	55	—
Cold filter plugging point	°C	EN 116			—	-5	—	-5	—	-5
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104			2,5	3,5	2,3	3,3	2,3	3,3
Polycyclic aromatic hydrocarbons	% m/m	EN 12916/ IP 391			3,0	6,0	3,0	6,0	2,0	6,0
Mass fraction of sulfur	mg/kg	ISO 14596 ISO 20846 / ASTM D 5453				300	—	10	—	10
Copper corrosion	—	ISO 2160				class 1	—	class 1	—	class 1
Mass fraction of Conradson carbon residue (10 % DR)	%	ISO 10370				0,2	—	0,2	—	0,2
Mass fraction of ash	% m/m	ISO 6245				0,01	—	0,01	—	0,01
Mass fraction of water	% m/m	ISO 12937				0,05	—	0,02	—	0,02
Total contamination	mg/kg	EN 12662							—	24
Lubricity (HFRR @ 60 °C)	µm	ISO 12156-1/ CEC F-06-A-96					—	400	—	400
Neutralization number	mgKOH/g	ASTM D 974			—	0,02	—	0,02	—	0,10
Oxidation stability	mg/ml	ISO 12205			—	0,025	—	0,025	—	0,025
Oxidation stability at 110 °C	H	EN 15751							20,0	—
fatty acid methyl ester (FAME)	% v/v	EN 14078						prohibited	—	7,0

NOTE This table is adapted from References[205], [215] and[157].

Table 19 — Diesel fuels — USA certification tests fuels

Property	Unit	Test method	Fuel 2-D	
			min.	max.
Cetane number	1	ASTM D 613	40	50
Cetane index	1	ASTM D 976	40	50
Gravity	°API	ASTM D 4052	32	37
Distillation		ASTM D 86		
Initial boiling point	°C		171	204
10 % (by volume)	°C		204	238
50 % (by volume)	°C		243	282
90 % (by volume)	°C		293	332
Final boiling point	°C		321	366
Flash point	°C	ASTM D 93	54	—
Kinematic viscosity at 37,88 °C	mm^2/s	ASTM D 445	2	3,2
Mass fraction of sulfur	mg/kg	ASTM D 2622 or alternates as allowed under 40 CFR 80.580	7	15
— ultra low			300	500
— low sulfur			800	2500
— high sulfur				
Volume fraction of aromatics (remainder shall be paraffins, naphthenes, and olefins)	g/kg	ASTM D 5186	100	—

NOTE This table is adapted from Reference [211].

Table 20 — Diesel fuels — Japanese certification test fuel

Property	Unit	Test method	Certification fuel 1[a]		Certification fuel 2[b]	
			min.	max.	min.	max.
Cetane index	—	JIS K 2280	53	57	53	60
Density at 15 °C	g/cm^3	JIS K 2249-1, -2, -3	0,824	0,840	0,815	0,840
Distillation		JIS K 2254				
50 % (by volume)	K (°C)		528 (255)	568 (295)	528 (255)	568 (295)
90 % (by volume)	K (°C)		573 (300)	618 (345)	573 (300)	618 (345)
Final boiling point	K (°C)		—	643 (370)	—	643 (370)
Hydrocarbon analysis						
Total aromatics	% by volume	JPI-5S-49-07[c]	—	25	—	25
Polycyclic aromatics	% by volume	JPI-5S-49-07[c]	—	5,0	—	5,0
Flash point	K (°C)	JIS K 2265-3	331 (58)	—	331 (58)	—
Kinematic viscosity at 30 °C	mm^2/s	JIS K 2283	3,0	4,5	3,0	4,5
Mass fraction of sulfur	mg/kg	JIS K 2541-1,-2,-6,-7	—	10	—	10
Triglyceride	%	Measurement method specified by METI[d] bulletin		0,01[e]		0,01[e]
Fatty acid methyl esters	%			0,1[e]		0,1[e]

NOTE This table adapted from Reference[167].

[a] Test fuel for on road light or middle duty vehicle specified in "Details of Safety Regulation for Road Vehicles, Attachment 42 (MLITe bulletin 2017 No.315)".

[b] Test fuel for on road heavy duty and special vehicle specified in " Details of Safety Regulations for Road Vehicles, Attachment 41 (MLIT bulletin 2017 No.315) and 43 (MLIT bulletin 2014 No. 43), respectively".

[c] Japan Petroleum Institute Standard.

[d] Ministry of Economy, Trade and Industry.

[e] MLIT = Ministry of Land, Infrastructure, Transport and Tourism.

Table 21 — Universal analytical data sheet — Diesel fuels

Property	Unit	Test method[a]	Result of measurements
Cetane number	1	ISO 5165	
Cetane index	1	ISO 4264	
Density at 15 °C	kg/l	ISO 3675	
Distillation		ISO 3405	
Initial boiling point	°C		
10 % (by volume)	°C		
50 % (by volume)	°C		
90 % (by volume)	°C		
Final boiling point	°C		
Volume evaporated	%		
at 250 °C	%		
at 350 °C	%		
Flash point	°C	ISO 2719	
Cold filter plugging point	°C	EN 116	
Pour point		ISO 3016	
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104	
Mass fraction of sulfur	%	ISO 8754	
Volume fraction of aromatics	%	ASTM D 1319[b]	
		ASTM D 5186	
Mass fraction of carbon residue (10 % DR)	%	ISO 6615	
Mass fraction of ash	%	ISO 6245	
Mass fraction of water		ISO 3733	
Neutralization number	mg KOH/g	ASTM D 974	
Oxidation stability			
Induction period	min	ASTM D 525	
Mass of existent gum per 100 ml	mg	ASTM D 381	
Elemental analysis[c]		ASTM D 3343	
Mass fraction of carbon	%		
Mass fraction of hydrogen	%		
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

[a] Indicate the method used.

[b] The validity of this method is limited for high boiling-point fuels, other possible methods are not standardized but could be used.

[c] See Clause 5.

Table 22 — Distillate fuel oils — ISO class F test fuel oils

Property	Unit	Test method	Fuel ISO-F-DMA, DFA		Fuel ISO-F-DMB, DFB	
			min.	max.	min.	max.
Cetane index		ISO 4264	40	—	35	—
Density at 15 °C	kg/m^3	ISO 3675 ISO 12185	—	890,0	—	900,0
Flash point	°C	ISO 2719	60		60	
Pourpoint		ISO 3016				
Winter quality	°C		—	-6	—	0
Summer quality	°C	IP 309, IP612	—	0	—	6
Cold filter plugging point	°C		—	report	—	—
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104	2,00	6,00	2,00	11,0
Mass fraction of sulfur	%	ISO 8754 ISO 14596	—	1,00	—	1,50
Mass fraction of carbon residue, Ramsbottom on 10 % residue	%	ISO 10370	—	0,30	—	—
Mass fraction of carbon residue, Ramsbottom	%	ISO 10370	—	—	—	0,30
Mass fraction of ash	%	ISO 6245	—	0,01	—	0,01
Volume fraction of water	%	ISO 3733	—	—	—	0,3
Mass fraction of sediment	%	ISO 10307-1	—	—	—	0,10
Mass fraction of hydrogen sulfide	mg/kg	IP 570	—	2,00	—	2,00
Acid number	mgKOH/g	ASTM D664	—	0,5	—	0,5
Oxidation stability	g/m^3	ISO 12205	—	25	—	25
Fatty acid methyl ester (FAME)	volume %	ASTM D 7963 IP 579	—	7,0	—	7,0
Cloud point	°C	ISO 3015	—	—	—	—
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C$^{2)}$	µm	ISO 12156-1	—	520	—	520
Visual inspection	—	ISO 8217	clear and bright		[a]	
Property	Unit	Test Method	Fuel ISO-F-DMX		Fuel ISO-F-DMZ, DFZ	
			min.	max.	min.	max.
Cetane index		ISO 4264	45	—	40	—
Density at 15 °C	kg/m^3	ISO 3675 ISO 12185	—	—	—	890,0
Flash point	°C	ISO 2719	43		60	
Cloud point	°C	ISO 3015	—	-16	—	report
Cold filter plugging point	°C	IP 309, IP612	—	—	—	report
Pour point		ISO 3016				
Winter quality	°C		—	—	—	-6
Summer quality	°C		—	—	—	0

NOTE This table is adapted from reference[37]

[a] See ISO 8217

[b] This requirement is applicable to the fuels with a sulfur content below 500 mg/kg (0,05 mass%).

Table 22 *(continued)*

Property	Unit	Test method	Fuel ISO-F-DMA, DFA		Fuel ISO-F-DMB, DFB	
			min.	max.	min.	max.
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104	1,40	5,50	3,00	6,00
Mass fraction of sulfur	%	ISO 8754 ISO 14596	—	1,00	—	1,00
Mass fraction of carbon residue, Ramsbottom on 10 % residue	%	ISO 10370	—	0,30	—	0,30
Mass fraction of carbon residue, Ramsbottom	%	ISO 10370	—	—	—	
Mass fraction of ash	%	ISO 6245	—	0,01	—	0,01
Volume fraction of water	%	ISO 3733	—	—	—	—
Mass fraction of sediment	%	ISO 10307-1	—	—	—	—
Mass fraction of hydrogen sulfide	mg/kg	IP 570	—	2,00	—	2,00
Acid number	mgKOH/g	ASTM D664	—	0,5	—	0,5
Oxidation stability	g/m^3	ISO 12205	—	25	—	25
Fatty acid methyl ester (FAME)	volume %	ASTM D 7963 IP 579	—	—	—	7,0
Cloud point	°C	ISO 3015	—	-16	—	report
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C[b]	µm	ISO 12156-1	—	520	—	520
Visual inspection	—	ISO 8217	clear and bright		clear and bright	

NOTE This table is adapted from reference[37]

[a] See ISO 8217

[b] This requirement is applicable to the fuels with a sulfur content below 500 mg/kg (0,05 mass%).

Table 23 — Universal analytical data sheet — Distillate fuel oils

Property	Unit	Test method	Result of measurements
Cetane number	1	ISO 5165	
Density at 15 °C	kg/l	ISO 3675	
Flash point	°C	ISO 2719	
Pour point	°C	ISO 3016	
Cloud point	°C	ISO 3015	
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104	
Mass fraction of Sulfur	%	ISO 8754	
Mass fraction of carbon residue, micro method on 10 % volume distillation residue	%	ISO 10370	
Mass fraction of carbon residue, micro method	%	ISO 10370	
Mass fraction of ash	%	ISO 6245	
Mass fraction of water	%	ISO 3733	
Mass fraction of sediment	%	ISO 10307-1	

[a] See Clause 5.

Table 23 *(continued)*

Property	Unit	Test method	Result of measurements
Mass fraction of hydrogen sulfide	mg/kg	IP 570	
Acid number	mgKOH/g	ASTM D664	
Cloud point	°C	ISO 3015	
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C[a]	µm	ISO 12156-1	
Visual inspection	—	ISO 8217	
Elemental analysis[b]	%	ASTM D 3343	
Mass fraction of carbon	%		
Mass fraction of hydrogen	%		
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

[a] See Clause 5.

Table 24 — Residual fuel oils — ISO class F test fuel oils

Property	Unit	Test method	Limit	Category ISO-F-										
				RMA	RMB	RMD	RME	RMG				RMK		
				10	30	80	180	180	380	500	700	380	500	700
Density at 15 °C	kg/m^3	ISO 3675 ISO 12185	max.	920,0	960,0	975,0	991,0	991,0				1 010,0		
Kinematic viscosity at 50 °C	mm^2/s	ISO 3104	max.	10,00	30,00	80,00	180,00	180,0	380,0	500,0	700,0	380,0	500,0	700,0
Flash point	°C	ISO 2719	min.	60,0	60,0	60,0	60,0	60,0				60,0		
Pour point (upper)	°C	ISO 3016												
Winter quality			max.	0	0	30	30	30				30		
Summer quality			max.	6	6	30	30	30				30		
CCAI	—	[a]	max.	850	860	860	860	870				870		
Mass fraction of sulfur	%	ISO 8754 ISO 14596	max.		Statutory requirements[b]									
Mass fraction of carbon residue: micro method	%	ISO 10370	max.	2,50	10,00	14,00	15,00	18,00				20,00		
Mass fraction of ash	%	ISO 6245	max.	0,040	0,070	0,070	0,070	0.100				0,150		
Volume fraction of water	%	ISO 3733	max.	0,30	0,50	0,50	0,50	0,50				0,50		
Mass fraction of sediment	%	ISO 10307-2	max.	0,10	0,10	0,10	0,10	0,10				0,10		
Mass fraction of Aluminium + silicon	mg/kg	ISO 10478 IP 501	max.	25	40	40	50	60				60		
Mass fraction of Vanadium	mg/kg	ISO 14597 IP 501	max.	50	150	150	150	350				450		
Mass fraction of hydrogen sulfide	mg/kg	IP 570	max.	2,00	2,00	2,00	2,00	2,00				2,00		
Sodium	mg/kg	IP 501	max.	50	100	100	50	100				100		
Acid number	mg KOH/g	ASTM D664	2,5	2,5	2,5	2,5	2,5	2,5				2,5		

NOTE This table is adapted from reference[37].

[a] See ISO 8217:2017, 6.2.

[b] See ISO 8217:2017, 6.3.

Table 24 *(continued)*

Property	Unit	Test method	Limit		Category ISO-F-									
				RMA	RMB	RMD	RME	RMG				RMK		
				10	30	80	180	180	380	500	700	380	500	700
Used lubricating oils (ULO):	mg/kg	IP 501	—		The fuel shall be free from ULO. A fuel shall be considered to contain ULO when another one of the following conditions is met:									
Calcium and zinc; or					Calcium > 30 and zinc > 15; or									
Calcium and phosphorus					Calcium > 30 and phosphorus > 15									

NOTE This table is adapted from reference[37].

[a] See ISO 8217:2017, 6.2.

[b] See ISO 8217:2017, 6.3.

Table 25 — Universal analytical data sheet — Residual fuel oils

Property	Unit	Test method[a]	Result of measurements
CCAI[b]	1		
Density at 15 °C	kg/l	ISO 3675	
Flash point	°C	ISO 2719	
Pour point	°C	ISO 3016	
Kinematic viscosity at 50 °C	mm^2/s	ISO 3104	
Mass fraction of sulfur	%	ISO 8754	
Mass fraction of carbon residue (10 % DR)	%	ISO 6615 ISO 10370	
Mass fraction of ash	%	ISO 6245	
Volume fraction of water	%	ISO 3733	
Mass fraction of sediment	%	ISO 10307-2	
Mass fraction of aluminium and silicon	mg/kg	ISO 10478	
Mass fraction of vanadium	mg/kg	ISO 8691	
Mass fraction of hydrogen sulfide	mg/kg	IP 570	
Acid number	mg KOH/G	ASTM D 664	
Elemental analysis[c]	%	ASTM D 3343	
Mass fraction of carbon	%		
Mass fraction of hydrogen	%		
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

[a] Indicate the method used.

[b] CCAI = calculated carbon aromaticity index (see A.3.2).

[c] See Clause 5.

Table 26 — Universal analytical data sheet — Crude oil

Property	Unit	Test method[a]	Result of measurements
Density at 15 °C	kg/l	ISO 3675	
Kinematic viscosity at 10 °C	mm^2/s	ISO 3104 ISO 3105	
Mass fraction of sulfur	%	ISO 8754	

[a] Indicate the method used.

Table 26 *(continued)*

Property	Unit	Test method[a]	Result of measurements
Pour point	°C	ISO 3016	
Reid Vapour Pressure	bar	ISO 3007	
Mass fraction of water	%	ISO 3733	

[a] Indicate the method used.

Annex A
(informative)

Calculation of the fuel specific factors

A.1 Fuel specific factors

These factors are used for the calculation from dry concentration to wet concentration according to ISO 8178-4:2020, 9.1.5.

$$c_{\mathrm{w}} = k_{\mathrm{w}} \times c_{\mathrm{d}} \tag{A.1}$$

The dry to wet correction factor k_{wr} is used for converting dry measured concentrations to the wet reference condition. k_{wr} is further the quotient between dry and wet exhaust volume flow:

$$k_{\mathrm{wr}} = \frac{c_{\mathrm{gasw}}}{c_{\mathrm{gasd}}} = \frac{q_{\mathrm{ved}}}{q_{vew}} = 1 - \frac{q_{vH_2O}}{q_{vew}} \tag{A.2}$$

Base on the combustion equation, k_{w} results as follows:

$$k_{\mathrm{wr1}} = \left(1 - \frac{1{,}2442 \times H_{\mathrm{a}} + 111{,}19 \times w_{\mathrm{ALF}} \times \frac{qmf}{q_{mad}} - 773{,}4 \times \frac{p_{\mathrm{r}}}{p_{\mathrm{b}}}}{773{,}4 + 1{,}2442 \times H_{\mathrm{a}} + \frac{qmf}{q_{mad}} \times f_{fw} \times 1\,000} \right) \tag{A.3}$$

The fuel specific constants f_{fw} [m^3 volume change from combustion air to dry exhaust/kg fuel] is calculated, as follows:

$$f_{fw} = 0{,}055\,594 \times w_{\mathrm{ALF}} + 0{,}008\,0021 \times w_{\mathrm{DEL}} + 0{,}007\,0046 \times w_{\mathrm{EPS}} \tag{A.4}$$

The fuel specific constants f_{fd} [m^3 volume change from combustion air to dry exhaust/kg fuel] is calculated, as follows:

$$f_{fd} = -0{,}055\,593 \times w_{\mathrm{ALF}} + 0{,}008\,002 \times w_{\mathrm{DEL}} + 0{,}007\,0046 \times w_{\mathrm{EPS}} \tag{A.5}$$

Table A.1 shows fuel specific factors for some selected fuels.

Table A.1 also contains a list of F_{fh} values for different fuels. In this document and in ISO 8178-4, it is not used any longer, since it is not only a fuel specific constant but also depends to a small degree on the fuel to air ratio.

Table A.1 — Values of fuel specific factors for some selected fuels

Fuel		Composition		λ independent fuel specific parameters		λ	Values for dry intake air				
		% mass	Molar ratio				Exhaust density		k_{wr}	M_{rew} g/mol	f_{fh}
							kg/m^3 wet	kg/m^3 dry			
Diesel	H	13,50	1,860 0	A/F$_{st}$	14,550 7	1,00	1,295 5	1,365 7	0,882 5	29,023	1,818 4
	C	86,49	1,000 0	f_{fw}	0,750 5	1,35	1,294 8	1,345 9	0,913 5	29,009	1,848 3
	S	0,001	0,000 0	f_{fd}	−0,750 4	2,00	1,294 3	1,328 1	0,943 2	28,996	1,877 0
	N	0,00	0,000 0	k_f	208,691 7	3,00	1,293 8	1,316 1	0,964 3	28,987	1,897 4
	O	0,00	0,000 0	M_{rf}	13,887 2	4,00	1,293 6	1,310 3	0,975 1	28,982	1,907 8
						5,00	1,293 5	1,306 8	0,981 6	28,979	1,914 1
FAME	H	12,00	1,852 3	A/F$_{st}$	12,504 8	1,00	1,296 8	1,369 2	0,879 3	29,053	1,601 1
	C	77,20	1,000 0	f_{fw}	0,742 8	1,35	1,295 9	1,348 5	0,910 9	29,032	1,631 3
	S	0,00	0,000 0	f_{fd}	−0,591 4	2,00	1,295 0	1,329 9	0,941 3	29,012	1,660 4
	N	0,00	0,000 0	k_f	186,275 9	3,00	1,294 3	1,317 4	0,963 0	28,997	1,681 1
	O	10,80	1,105 0	M_{rf}	15,558 3	4,00	1,294 0	1,311 2	0,974 0	28,990	1,691 6
						5,00	1,293 8	1,307 5	0,980 7	28,985	1,698 0
Methanol	H	12,50	3,972 1	A/F$_{st}$	6,427 3	1,00	1,234 6	1,364 0	0,775 6	27,661	1,483 9
	C	37,50	1,000 0	f_{fw}	1,045 2	1,35	1,247 7	1,344 6	0,827 7	27,954	1,553 9
	S	0,00	0,000 0	f_{fd}	−0,344 6	2,00	1,261 0	1,327 2	0,880 7	28,252	1,625 1
	N	0,00	0,000 0	k_f	90,483 8	3,00	1,271 0	1,315 5	0,920 4	28,475	1,678 3
	O	50,00	1,001 0	M_{rf}	32,029 3	4,00	1,276 2	1,309 8	0,941 2	28,592	1,706 3
						5,00	1,279 4	1,306 4	0,954 0	28,664	1,723 5
Ethanol	H	13,10	2,993 4	A/F$_{st}$	8,972 2	1,00	1,260 6	1,363 7	0,822 9	28,243	1,651 0
	C	52,15	1,000 0	f_{fw}	0,971 7	1,35	1,268 2	1,344 3	0,866 4	28,413	1,705 3
	S	0,00	0,000 0	f_{fd}	−0,484 8	2,00	1,275 7	1,327 1	0,909 4	28,581	1,759 0
	N	0,00	0,000 0	k_f	125,832 7	3,00	1,281 2	1,315 4	0,940 8	28,704	1,798 2
	O	34,75	0,500 2	M_{rf}	23,031 6	4,00	1,284 1	1,309 7	0,957 0	28,768	1,818 5
						5,00	1,285 8	1,306 3	0,966 9	28,806	1,830 9
Natural Gas	H	19,30	3,795 2	A/F$_{st}$	13,479 5	1,00	1,242 1	1,341 0	0,823 1	27,829	2,479 9
	C	60,60	1,000 0	f_{fw}	1,231 9	1,35	1,254 3	1,327 7	0,867 1	28,100	2,549 8
	S	0,003	0,000 0	f_{fd}	−0,913 9	2,00	1,266 1	1,315 9	0,910 4	28,366	2,618 2
	N	18,20	0,257 5	k_f	146,221 7	3,00	1,274 8	1,308 0	0,941 7	28,559	2,667 9
	O	1,90	0,023 5	M_{rf}	19,820 1	4,00	1,279 2	1,304 2	0,957 8	28,658	2,693 4
						5,00	1,281 9	1,301 9	0,967 6	28,718	2,708 9
Propane	H	18,30	2,669 2	A/F$_{st}$	15,642 3	1,00	1,268 9	1,354 4	0,852 2	28,429	2,425 3
	C	81,70	1,000 0	f_{fw}	1,017 4	1,35	1,274 8	1,337 4	0,890 2	28,560	2,475 1
	S	0,00	0,000 0	f_{fd}	−1,017 2	2,00	1,280 5	1,322 3	0,927 0	28,687	2,523 2
	N	0,00	0,000 0	k_f	197,133 9	3,00	1,284 5	1,312 3	0,953 2	28,778	2,557 6
	O	0,00	0,000 0	M_{rf}	14,701 3	4,00	1,286 6	1,307 4	0,966 6	28,824	2,575 1
						5,00	1,287 9	1,304 4	0,974 8	28,852	2,585 8

Table A.1 *(continued)*

Fuel		Composition		λ independent fuel specific parameters		λ	Values for dry intake air				
							Exhaust density		k_{wr}	M_{rew} g/mol	f_{fh}
		% mass	Molar ratio				kg/m^3 wet	kg/m^3 dry			
Butane	H	17,30	2,492 8	A/F$_{st}$	15,415 0	1,00	1,274 1	1,356 6	0,858 1	28,545	2,300 0
	C	82,70	1,000 0	f_{fw}	0,961 8	1,35	1,278 7	1,339 1	0,894 8	28,648	2,345 4
	S	0,00	0,000 0	f_{fd}	−0,961 6	2,00	1,283 2	1,323 5	0,930 1	28,748	2,389 2
	N	0,00	0,000 0	k_f	199,546 8	3,00	1,286 4	1,313 0	0,955 4	28,819	2,420 5
	O	0,00	0,000 0	M_{rf}	14,523 6	4,00	1,288 0	1,307 9	0,968 3	28,855	2,436 5
						5,00	1,289 0	1,304 9	0,976 1	28,877	2,446 1
Gasoline	H	12,20	1,694 4	A/F$_{st}$	13,940 1	1,00	1,302 1	1,369 0	0,889 3	29,173	1,647 1
	C	85,80	1,000 0	f_{fw}	0,692 3	1,35	1,299 9	1,348 3	0,918 7	29,122	1,673 3
	S	0,001	0,000 0	f_{fd}	−0,664 1	2,00	1,297 7	1,329 8	0,946 8	29,073	1,698 3
	N	0,00	0,000 0	k_f	207,026 8	3,00	1,296 2	1,317 3	0,966 8	29,038	1,716 1
	O	2,00	0,017 5	M_{rf}	13,998 8	4,00	1,295 4	1,311 1	0,976 9	29,021	1,725 2
						5,00	1,294 9	1,307 4	0,983 0	29,010	1,730 6
Hydrogen	H	100,00		A/F$_{st}$	34,209 8	1,00	1,099 7	1,257 1	0,659 3	24,639	11,872 8
	C	0,00		f_{fw}	5,559 4	1,35	1,143 1	1,268 2	0,737 6	25,610	12,432 5
	S	0,00		f_{fd}	−5,558 6	2,00	1,187 2	1,277 2	0,817 1	26,598	13,001 6
	N	0,00		k_f	0,000 0	3,00	1,220 1	1,282 8	0,876 6	27,336	13,427 1
	O	0,00		M_{rf}	2,015 9	4,00	1,237 4	1,285 5	0,907 8	27,723	13,650 5
						5,00	1,248 1	1,287 1	0,927 0	27,962	13,788 2

A.2 Estimation of the fuel composition without elemental analysis

A.2.1 General

In cases where it is not possible to measure the contents of the fuels because of time and/or facility constraints, the methods specified in A.2.2, A.2.3 and A.2.4 can provide reasonably accurate results. These methods are recommended for certification purposes, but in some cases can be helpful in calculating the hydrogen to carbon ratio on the basis of the density of the fuel and on the knowledge of the sulfur and the nitrogen content.

A.2.2 Method 1

This method is a simple formula for diesel fuels only when the sulfur and nitrogen content is not known.

$$w_{ALF} = 26 - 15 \times \rho_f \tag{A.6}$$

$$w_{BET} = 100 - w_{ALF} \tag{A.7}$$

Where ρ_f is the density of the fuel at 288 K (15 °C) in grams per cubic centimetre.

A.2.3 Method 2

The method has been published in the “Book of ASTM Standards” (June 1968) with the original title: *Proposed method for estimation of net and gross heat of combustion of burner and diesel fuels.*

In this formula, the sulfur content is known.

$$Z = \frac{\left(209{,}42 - 90{,}92 \times \rho_f\right)}{\left(107{,}606 - w_{\mathrm{GAM}}\right) \times \rho_f - 17{,}546} \tag{A.8}$$

$$w_{\mathrm{ALF}} = \frac{\left(100 - w_{\mathrm{GAM}}\right) \times 1{,}00794 \times Z}{12{,}011 + 1{,}00794 \times Z} \tag{A.9}$$

$$w_{\mathrm{BET}} = 100 - w_{\mathrm{ALF}} - w_{\mathrm{GAM}} \tag{A.10}$$

Where ρ_{f} is the density of the fuel at 15 °C, in grams per cubic centimetre.

It is also possible to estimate the net heat of combustion value, NHCV in megajoules per kilogram:

$$H_{\mathrm{NHCV}} = 2{,}326 \times 10^{-3} \left[\left(11\,369{,}54 + \frac{6800{,}84}{\rho_f} - \frac{750{,}83}{\rho_f^{\,2}}\right) \times \left(1 - 0{,}01 \times w_{\mathrm{GAM}}\right) + 43{,}7 \times w_{\mathrm{GAM}}\right] \tag{A.11}$$

A.2.4 Method 3

The following formulae are modified versions of those published by the American National Bureau of Standards. They are more directly applicable. The errors to be expected are -0,3 % to +0,6 % for the carbon content and -0,3 % to +0,3 % for the hydrogen content. The range of application for petroleum fuels for these errors has been proven to be within a density range of 0,77 g/cm^3 to 0,98 g/cm^3. An error of 1 % of the carbon content of the fuel gives an error of about 1 % of the calculated exhaust gas volume based on the measurement of the CO$_2$ percentage in the exhaust gas.

$$w_{\mathrm{ALF}} = (26 - 15 \times \rho) \times \left[1 - 0{,}01 \times \left(w_{\mathrm{GAM}} + w_{\mathrm{DEL}}\right)\right] \tag{A.12}$$

$$w_{\mathrm{BET}} = 100 - \left(w_{\mathrm{ALF}} + w_{\mathrm{GAM}} + w_{\mathrm{DEL}}\right) \tag{A.13}$$

where ρ is the density at 288 K (15 °C), in grams per cubic centimetre.

A.3 Ignition quality

A.3.1 Application

Ignition performance requirements of residual fuel oils in marine diesel engines are primarily determined by the engine type and, more significantly, engine operating conditions. Fuel factors influence ignition characteristics to a much lesser extent. For this reason, no general limits for ignition quality can be applied since a value which is problematical to one engine under adverse conditions can perform quite satisfactorily in many other instances. If required, further guidance on acceptable ignition quality values should be obtained from the engine manufacturer.

A.3.2 Derivation of CII and CCAI

By use on the nomogram in Figure A.1 it is possible to determine either the calculated ignition index (I_{CII}) or the calculated carbon aromaticity index (I_{CCAI}) of a fuel oil by extending a straight line connecting to viscosity and the density and reading the values thus obtained on the I_{CII} and I_{CCAI} scale. These values allow ranking of its ignition performance. They can also be calculated as follows:

$$I_{\mathrm{CII}} = (270{,}795 + 0{,}1038 \times T) - 0{,}25456 \times \rho + 23{,}708 \times \lg[\lg(v + 0{,}7)] \tag{A.14}$$

$$I_{\mathrm{CCAI}} = \rho - 81 - 141 \times lg\left[\lg\left(v + 0{,}85\right)\right] - 483 \times lg\left(\frac{T + 273}{323}\right) \tag{A.15}$$

where

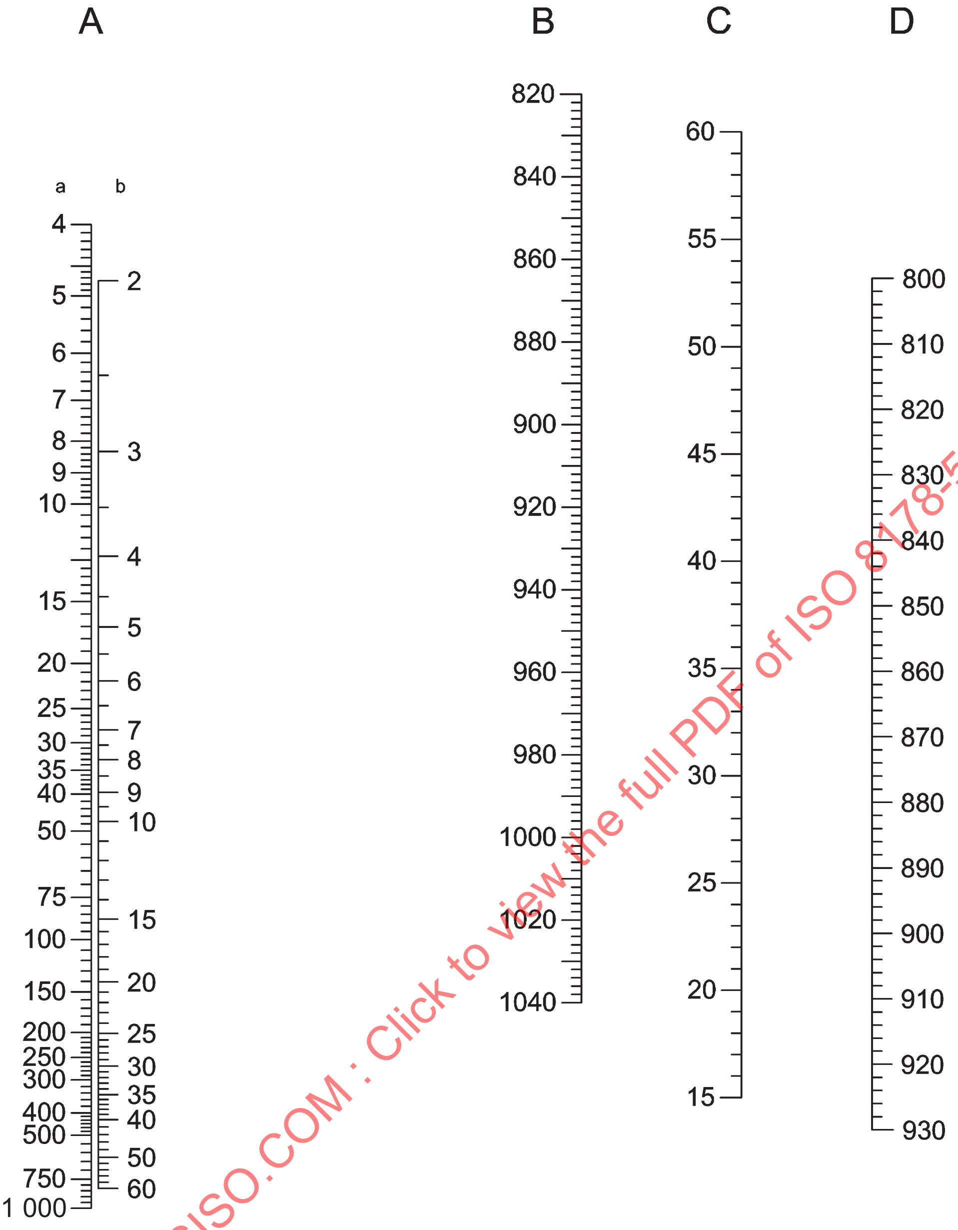
I_{CII} is the calculated ignition index

$I_{\mathrm{CCAI}}$is the calculated carbon aromaticity index

T is the temperature in degrees Kelvin;

v is the kinematic viscosity, in square millimetres per second at temperature T;

ρ is the density at 15 °C in kilograms per cubic metre.



Key

A	kinematic viscosity, square millimetres per second
B	density at 15 °C, in kilograms per cubic metre
C	CII
D	CCAI
a	At 50 °C.
b	At 100 °C.

Figure A.1 — Nomogram for deriving the calculated ignition index (I_{CII}) and the calculated carbon aromaticity index (I_{CCAI})

Annex B
(informative)

Equivalent non-ISO test methods

The International Standards given in this Annex are not completely equivalent but should be considered comparable. See Tables B.1 to B.6.

Table B.1 — Liquefied petroleum gases

Property	ISO test method	ASTM test method	JIS test method
Composition	ISO 7941	ASTM D 2163	JIS K 2240
Mass fraction of sulfur	ISO 8754	ASTM D 2784	JIS K 2240
Vapour pressure at 40 °C	ISO 4256 ISO 8973	ASTM D 1267 ASTM D 2598	JIS K 2240
Density at 15 °C	ISO 3993 ISO 8973	ASTM D 1657 ASTM D 2598	JIS K 2240

Table B.2 — Engine gasolines

Property	ISO test method	ASTM test method	CEN test method	JIS test method
Research octane number (RON)	ISO 5164	ASTM D 2699	—	JIS K 2280
Engine octane number (MON)	ISO 5163	ASTM D 2700	—	JIS K 2280
Sensitivity (RON/MON)	ISO 5163 ISO 5164	ASTM D 2699 ASTM D 2700	—	JIS K 2280 JIS K 2280
Density at 15 °C	ISO 3675	ASTM D 1298	—	JIS K 2249
Reid vapour pressure	ISO 3007	ASTM D 323	—	JIS K 2258
Distillation	ISO 3405	ASTM D 86	—	JIS K 2254
Hydrocarbon analysis	ISO 3837	ASTM D 1319	—	JIS K 2536
Mass fraction of sulfur	ISO 8754	ASTM D 1266 ASTM D 2622	EN 24260	JIS K 2541
Mass fraction of lead	ISO 3830	ASTM D 3341 ASTM D 3237	EN 237	JIS K 2255
Oxidation stability Induction period	ISO 7536	ASTM D 525	—	JIS K 2287
Mass of existent gums per 100 ml	ISO 6246	ASTM D 381	—	JIS K 2261
Copper corrosion at à 50 °C	ISO 2160	ASTM D 130	—	

Table B.3 — Distillate products and residual fuel oils

Property	ISO test method	ASTM test method	CEN test method	JIS test method
Cetane number	ISO 5165	ASTM D 613	—	JIS K 2280

[a] See Table B.5.

[b] See Table B.4.

Table B.3 *(continued)*

Property	ISO test method	ASTM test method	CEN test method	JIS test method
Cetane index[a]				
Density at 15 °C	ISO 3675	ASTM D 1298	—	JIS K 2249
Distillation	ISO 3405	ASTM D 86	—	JIS K 2254
Flash point (PM)	ISO 2719	ASTM D 93	—	JIS K 2265
Cloud point	ISO 3015	ASTM D 2500	—	JIS K 2269
Pour point	ISO 3016	ASTM D 97	—	JIS K 2283
Viscosity	ISO 3104	ASTM D 445	—	JIS K 2283
	ISO 3105			
Mass fraction of sulfur	ISO 4260	ASTM D 1266	EN 41	JIS K 2541
	ISO 8754	ASTM D 2622	—	
Copper corrosion	ISO 2160	ASTM D 130	—	JIS K 2513
Mass fraction of carbon residue[b]				
Mass fraction of ash	ISO 6245	ASTM D 482	ISO 6245	JIS K 2272
Mass fraction of water				
Distillation	ISO 3733	ASTM D 95	—	JIS K 2275
Karl Fischer method	ISO 6296	ASTM D 1744	—	JIS K 2275

[a] See Table B.5.

[b] See Table B.4.

Table B.4 — Carbon residue determination

Method	ISO	ASTM	JIS
Micro residue	ISO 10370	ASTM D 4530	JIS K 2270
Ramsbottom	ISO 4262	—	—
Conradson carbon	ISO 6615	ASTM D 189	JIS K 2270

Table B.5 — Methods for the determination of ignition quality (calculated cetane index)

Number of variables	ISO method	ASTM method	IP[a] method	JIS method
4	ISO 4264	ASTM D 4737	IP 380	JIS K 2280
2	—	ASTM D 976	IP 364	—

[a] Institute of Petroleum, UK.

Table B.6 — Statistical methods

ISO method	ASTM method	JIS method
ISO 4259	ASTM D 3244	—

Annex C

(informative)

Supplementary requirements for conducting emission testing using gaseous reference fuels comprising pipeline gas with admixture of other gases

C.1 Method of gas analysis and gas flow measurement

For the purpose of this annex, where required the composition of the gas shall be determined by analysis of the gas using gas chromatography according to ISO 6974 (all parts), or by an alternative technique that achieves at least a similar level of accuracy and repeatability.

For the purpose of this annex, where required the measurement of gas flow shall be performed using a mass-based flowmeter.

C.2 Analysis and flowrate of incoming utility gas supply

a) The composition of the utility gas supply shall be analysed prior to the admixture blending system.

b) The flowrate of the utility gas entering the admixture blending system shall be measured.

C.3 Analysis and flowrate of admixture

a) When an applicable certificate of analysis is available for an admixture (for example issued by the gas supplier) this may be used as the source of that admixture composition. In this case the on-site analysis of that admixture composition shall be permitted but shall not be required.

b) Where an applicable certificate of analysis is not available for an admixture the composition of that admixture shall be analysed.

c) The flowrate of each admixture entering the admixture blending system shall be measured.

C.4 Analysis of blended gas

The analysis of the composition of the gas supplied to the engine after leaving the admixture blending system shall be permitted in addition to, or as an alternative to the analysis required by C.2 a) and C.3 a), but shall not be required.

C.5 Calculation of S_λ and MN of the blended gas

The results of the gas analysis according to C.2 a), C.3 a) or C.3 b) and, where applicable, C.4, combined with the mass flowrate of gas measured according to C.2 b) and C.3 c), shall be used to calculate the MN according to EN 16726. The same set of data shall be used to calculate S_λ according to the procedure set out in C.2.

C.6 Control and verification of gas blend during the test

C.6.1 General

The control and verification of the gas blend during the test shall be performed using either an open loop or closed loop control system.

C.6.2 Open loop blend control system

In this case the gas analysis, flow measurements and calculations set out in E.1, E.2, E.3 and E.4 shall be performed prior to the emission test.

The proportion of utility gas and admixture(s) shall be set to ensure that the S_λ is within the permitted range for the relevant reference fuel in Table 1.1.

When the relative proportions have been set they shall be maintained throughout the emission test. Adjustments to individual flow rates to maintain the relative proportions shall be permitted.

When the emission test has been completed the analysis of gas composition, flow measurements and calculations set out in E.2, E.3, E.4 and E.5 shall be repeated. In order for the test to be considered valid the value of S_λ shall remain within the specified range for the respective reference fuel given in Table 1.1.

C.6.3 Closed loop blend control system

In this case the analysis of gas composition, flow measurements and calculations set out in E.2, E.3, E.4 and E.5 shall be performed at intervals during the emission test. The intervals shall be chosen taking into consideration the frequency capability of the gas chromatograph and corresponding calculation system.

The results from the periodic measurements and calculations shall be used to adjust the relative proportions of utility gas and admixture in order to maintain the value of S_λ within the range specified in Table 1.1 for the respective reference fuel. The frequency of adjustment shall not exceed the frequency of measurement.

In order for the test to be considered valid the value of S_λ shall be within the range specified in Table 1.1 for the respective reference fuel for at least 90 % of the measurement points.

Annex D
(normative)

Calculation of λ-Shift factor (S_λ)

D.1 Calculation

The λ-shift factor (S_λ) shall be calculated by means of Formula (D.1):

$$S_\lambda = \frac{2}{\left(1 - \frac{c_{\mathrm{inert}}\ \%}{100}\right) \times \left(n + \frac{m}{4}\right) - \frac{c_{\mathrm{O}_2^*}}{100}} \tag{D.1}$$

Where:

S_λ is the λ-shift factor;

$c_{\mathrm{inert}}\ \%$ is the percentage by volume of inert gases in the fuel (i.e. N_2, CO_2, He, etc.);

$c_{\mathrm{O}_2^*}$ is the percentage by volume of original oxygen in the fuel;

n and m refer to average CnHm representing the fuel hydrocarbons, i.e

$$n = \frac{1 \times \left[\frac{CH_4\ \%}{100}\right] + 2 \times \left[\frac{C_2\ \%}{100}\right] + 3 \times \left[\frac{C_3\ \%}{100}\right] + 4 \times \left[\frac{C_4\ \%}{100}\right] + \ldots]]}{\frac{1 - c_{\mathrm{diluent}}\ \%}{100}} \tag{D.2}$$

$$m = \frac{4 \times \left[\frac{CH_4\ \%}{100}\right] + 4 \times \left[\frac{C_2H_4\ \%}{100}\right] + 6 \times \left[\frac{C_2H_6\ \%}{100}\right] + \ldots 8 \times \left[\frac{C_3H_8\ \%}{100}\right] + \ldots}{\frac{1 - c_{\mathrm{diluent}}\ \%}{100}} \tag{D.3}$$

Where:

CH_4 is the percentage by volume of methane in the fuel;

C_2 is the percentage by volume of all C_2 hydrocarbons (e.g.: C_2H_6, C_2H_4, etc.) in the fuel;

C_3 is the percentage by volume of all C_3 hydrocarbons (e.g.: C_3H_8, C_3H_6, etc.) in the fuel;

C_4 is the percentage by volume of all C_4 hydrocarbons (e.g.: C_4H_{10}, C_4H_8, etc.) in the fuel;

C_5 is the percentage by volume of all C_5 hydrocarbons (e.g.: C_5H_{12}, C_5H_{10}, etc.) in the fuel;

c_{diluent} is the percentage by volume of dilution gases in the fuel (i.e.: O_2*, N_2, CO_2, He, etc.).

D.2 Examples for the calculation of the λ-shift factor S_λ:

Example 1 G_{25}: CH_4 = 86 %, N_2 = 14 % (by volume)

$$n=\frac{1\times\left[\frac{CH_4\,\%}{100}\right]+2\times\left[\frac{C_2\,\%}{100}\right]+\ldots}{\frac{1-c_{\text{diluent}}\,\%}{100}}=\frac{1\times0{,}86}{1-\frac{14}{100}}=\frac{0{,}86}{0{,}86}=1$$

$$m=\frac{4\times\left[\frac{CH_4\,\%}{100}\right]+4\times\left[\frac{C_2H_4\,\%}{100}\right]+\ldots}{\frac{1-c_{\text{diluent}}\,\%}{100}}=\frac{4\times0{,}86}{0{,}86}=4$$

$$S_\lambda=\frac{2}{\left(1-\frac{\text{inert}\,\%}{100}\right)\times\left(n+\frac{m}{4}\right)-\frac{\text{O}_2^*}{100}}=\frac{2}{\left(1-\frac{14}{100}\right)\times\left(1+\frac{4}{4}\right)}=16$$

Example 2 G$_R$: CH_4 = 87 %, C_2H_6 = 13 % (by vol)

$$n=\frac{1\times\left[\frac{CH_4\,\%}{100}\right]+2\times\left[\frac{C_2\,\%}{100}\right]+\ldots}{\frac{1-c_{\text{diluent}}\,\%}{100}}=\frac{1\times0{,}87+2\times0{,}13}{1-\frac{0}{100}}=\frac{1{,}13}{1}=1{,}13$$

$$m=\frac{4\times\left[\frac{CH_4\,\%}{100}\right]+4\times\left[\frac{C_2H_4\,\%}{100}\right]+\ldots}{\frac{1-c_{\text{diluent}}\,\%}{100}}=\frac{4\times0{,}87+6\times0{,}13}{1}=4{,}26$$

$$S_\lambda=\frac{2}{\left(1-\frac{inert\,\%}{100}\right)\times\left(n+\frac{m}{4}\right)-\frac{O_2^*}{100}}=\frac{2}{\left(1-\frac{0}{100}\right)\times\left(1{,}13+\frac{4{,}26}{4}\right)}=0{,}911$$

Example 3 USA: CH_4 = 89 %, C_2H_6 = 4,5 %, C_3H_8 = 2,3 %, C_6H_{14} = 0,2 %, O_2 = 0,6 %, N_2 = 4 %

$$n=\frac{1\times\left[\frac{CH_4\,\%}{100}\right]+2\times\left[\frac{C_2\,\%}{100}\right]+\ldots}{\frac{1-c_{\text{diluent}}\,\%}{100}}=\frac{1\times0{,}89+2\times0{,}045+3\times0{,}023+4\times0{,}002}{1-\frac{0{,}64+4}{100}}=1{,}11$$

$$m=\frac{4\times\left[\frac{CH_4\,\%}{100}\right]+4\times\left[\frac{C_2H_4\,\%}{100}\right]+6\times\left[\frac{C_2H_6\,\%}{100}\right]+\ldots8\times\left[\frac{C_3H_8\,\%}{100}\right]}{\frac{1-c_{\text{diluent}}\,\%}{100}}=\frac{4\times0{,}89+4\times0{,}045+8\times0{,}023+14\times0{,}002}{1-\frac{0{,}64+4}{100}}=4{,}24$$

$$S_\lambda=\frac{2}{\left(1-\frac{inert\,\%}{100}\right)\times\left(n+\frac{m}{4}\right)-\frac{O_2^*}{100}}=\frac{2}{\left(1-\frac{4}{100}\right)\times\left(1{,}11+\frac{4{,}24}{4}\right)-\frac{0{,}6}{100}}=0{,}96$$

As an alternative to the above formulae, S_λ may be calculated from the ratio of the stoichiometric air demand of pure methane to the stoichiometric air demand of the fuel blend supplied to the engine, as specified below.

Lambda-shift factor (S_λ) expresses the oxygen demand of any fuel blend in relation to oxygen demand of pure methane. Oxygen demand means the amount of oxygen to oxidise methane in a stoichiometric composition of reaction partners to products of complete combustion (i.e. carbon-dioxide and water).

For the combustion of pure methane, the reaction is the following:

$$1*CH_4+2*O_2\rightarrow 1*CO_2+2*H_2O$$

In this case the ratio of molecules in stoichiometric composition of reaction partners is exactly 2:

$$\frac{n_{\mathrm{O_2}}}{n_{\mathrm{CH_4}}}=2 \qquad \text{(D.4)}$$

Where:

n_{O2}	is the number of molecules [mol] of oxygen;
n_{CH4}	is the number of molecules [mol] of methane.

The oxygen demand for pure methane is therefore:

$n_{\mathrm{O2}}=2*n_{\mathrm{CH4}}$ with a reference value of $[n_{CH4}]$ = 1 kmol

The value of S_λ may be determined from the ratio of the stoichiometric composition of oxygen and methane to the ratio of the stoichiometric composition of oxygen and the fuel blend supplied to the engine, as set out in Formula (D.5):

$$S_\lambda=\frac{\left(\dfrac{n_{\mathrm{O2}}}{n_{\mathrm{CH4}}}\right)}{\left(\dfrac{n_{\mathrm{O2}}}{n_{\mathrm{blend}}}\right)}=\frac{2}{\left(n_{\mathrm{O2}}\right)_{\mathrm{blend}}} \qquad \text{(D.5)}$$

Where:

n_{blend}	is the number of molecules [mol] of the fuel blend;
n_{CH4}	is the number of molecules [mol] in the stoichiometric composition of oxygen and the fuel blend supplied to the engine.

Because air contains 21 mol.% oxygen the stoichiometric air demand L_{st} of any fuel shall be calculated by means of Formula (D.6):

$$L_{\mathrm{st,fuel}}=\frac{n_{\mathrm{O2,\,fuel}}}{0{,}21} \qquad \text{(D.6)}$$

Where:

$L_{\mathrm{st,\,fuel}}$	is the the stoichiometric air demand for the fuel on volumetric or molecular basis;
$n_{\mathrm{O2,\,fuel}}$	is the the stoichiometric oxygen demand for the fuel in [mol].

Consequently, the value of S_λ may also be determined from the ratio of the stoichiometric composition of air and methane to the ratio of the stoichiometric composition of air and the fuel blend supplied to