INTERNATIONAL STANDARD

ISO 8178-5

Second edition
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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 5: **Test fuels**

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

Partie 5: Carburants d'essai

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 8178-5 was prepared by Technical Committee ISO/TC 70, *Internal combustion engines*, Subcommittee SC 8, *Exhaust gas emission measurement*.

This second edition cancels and replaces the first edition (ISO 8178-5:1997), which has been technically revised.

ISO 8178 consists of the following parts, under the general title *Reciprocating internal combustion engines — Exhaust emission measurement*:

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

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

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

— *Part 4: Steady-state test cycles for different engine applications*

— *Part 5: Test fuels*

— *Part 6: Report of measuring results and test*

— *Part 7: Engine family determination*

— *Part 8: Engine group determination*

— *Part 9: Test cycles and test procedures for test bed measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

— *Part 10: Test cycles and test procedures for field measurement of exhaust gas smoke emissions from compression ignition engines operating under transient conditions*

— *Part 11: Test-bed measurement of gaseous and particulate exhaust emissions from engines used in nonroad mobile machinery under transient test conditions*

Introduction

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

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

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

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

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 5: Test fuels

1 Scope

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

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

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3 Terms and definitions

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

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

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

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

[ISO 1998-2:1998, 2.50.001]

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

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

[ISO 1998-2:1998, 2.30.111]

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

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

[ISO 1998-2:1998, 2.30.110]

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

[ISO 1998-1:1998, 1.05.005]

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

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

NOTE It is often referred to as "automotive diesel fuel".

[ISO 1998-1:1998, 1.20.131]

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

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

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

[ISO 1998-1:1998, 1.15.080]

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

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

[ISO 1998-2:1998, 2.30.100]

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

4 Symbols and abbreviations

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

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

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

5 Choice of fuel

5.1 General

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

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

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

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

- Table 4 (Universal analytical data sheet — Natural gas);
- Table 8 (Universal analytical data sheet — Liquefied petroleum gas);
- Table 12 (Universal analytical data sheet — Motor gasolines);
- Table 17 (Universal analytical data sheet — Diesel fuels);
- Table 19 (Universal analytical data sheet — Distillate fuel oils);
- Table 21 (Universal analytical data sheet — Residual fuel oils);
- Table 22 (Universal analytical data sheet — Crude oil).

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

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

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

5.2 Influence of fuel properties on emissions from compression ignition engines

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

5.2.1 Fuel sulfur

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

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

— the fuel consumption of the engine (BSFC);

— the fuel sulfur content (FSC);

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

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

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

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

where

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

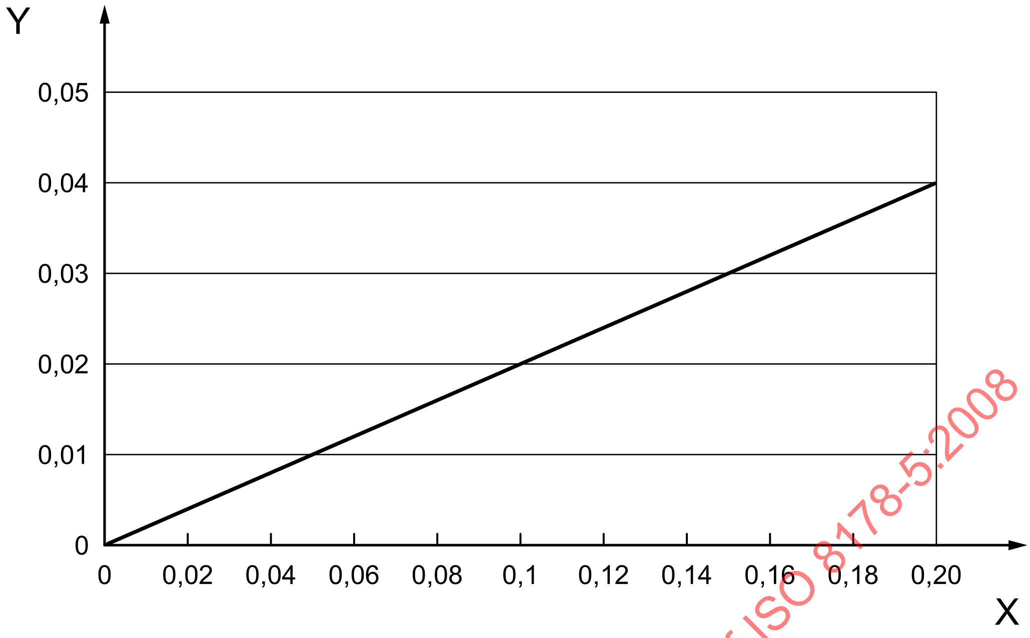
FSC is the fuel sulfur content, expressed in milligrams per kilogram (mg/kg);

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

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

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

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

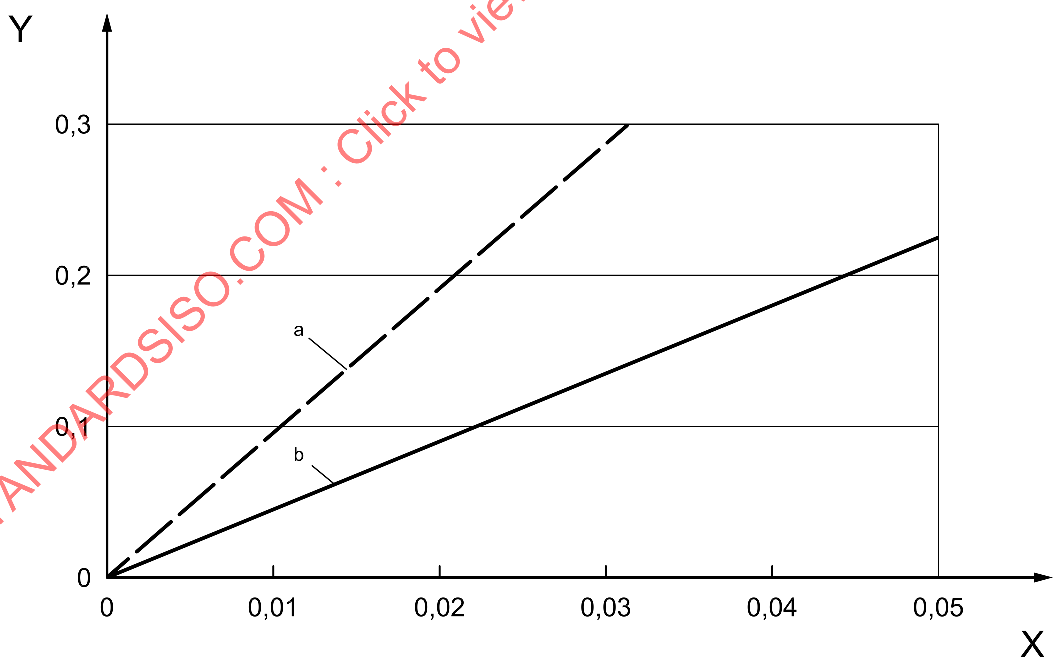


Key

X sulfur content, in mg/kg

Y sulfur PM, in g/kW·h

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



Key

X sulfur content, in mg/kg

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

a 70 % conversion.

b 30 % conversion.

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

5.2.2 Specific considerations for marine fuels

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

Typically, the sulfur content is higher than for onroad or nonroad diesel fuels by a factor of approximately 10, as shown in Table 20. Even without any aftertreatment system, the PM sulfur level will be approximately 0,4 g/kW·h for a 2 % sulfur fuel. In addition, the high ash, vanadium and sediment fractions will significantly contribute to the total PM emission. As a consequence, the inherent engine PM emission, which is mainly soot, is only a very small fraction of the total PM emission. In the application of aftertreatment systems, 5.2.1 should be carefully considered.

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

5.2.3 Other fuel properties

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

For NO_x, total aromatics is the predominant parameter whereas the effect of poly-aromatics and density is less significant. This can be explained by an increase of the flame temperature with higher aromatics content during combustion, which results in 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 cetane number (CN) will improve engine cold start and therefore white smoke emission. It has also a favorable 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 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. When a customer uses gasoline with an octane level lower than that required, knocking may result which could lead to severe engine damage. Engines equipped with knock sensors can handle lower octane 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, potentially causing misfire which leads to increased emissions, increased fuel consumption and poor engine performance. They also accumulate on and partly plug the catalyst causing an increased fuel consumption in addition to reduced emission control.

Oxygenated organic compounds, such as MTBE and 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.

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 Referenced natural gas

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

a) EU reference fuels: see Table 1;

b) USA certification test fuel: see Table 2;

c) Japanese certification test fuel: see Table 3.

6.1.2 Non-referenced natural gas

Often, 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 4.

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 5;

b) USA certification test fuel: see Table 6;

c) Japanese certification test fuel: see Table 7.

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 8.

6.3 Motor gasolines

6.3.1 Referenced motor gasolines

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

a) EU reference fuels: see Table 9;

b) USA certification test fuel: see Table 10;

c) Japanese certification test fuels: see Table 11.

6.3.2 Non-referenced motor gasolines

If it is necessary to use non-referenced motor gasolines, the properties of the individual fuel shall be reported with the results of the test. Table 12 represents a universal analytical data sheet giving the properties which shall be reported.

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

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 13;

b) USA certification test fuels: see Table 14;

c) Californian test fuel: see Table 15;

d) Japanese certification test fuel: see Table 16.

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 17 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 18.

The fuel's properties, including the elemental analysis, shall be measured and reported with the results of the emission measurement. Table 19 represents a universal analytical data sheet giving the properties which shall be reported.

ISO 8217 does not specify ignition quality for fuel ISO-F-DMC, which contains residues, as the CFR[1] engine measurement procedure is not applicable for fuels containing residues.

1) An engine standardized by the Co-operative Fuel Research Committee.

6.6 Residual fuel oils

As there are no existent reference fuels, it is recommended that the fuel used be in accordance with ISO 8217. See Table 20.

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 21 represents a universal analytical data sheet giving the properties which shall be reported.

ISO 8217 does not specify ignition quality, as the CFR engine measurement procedure is not applicable for fuels containing residues.

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. It is too early to specify a supplementary maximum ignition quality level in the fuel specification during exhaust emission acceptance tests. Clause A.4 gives equations for CCAI and CII.

Another method, which is currently under investigation, is the fuel ignition analyzer (FIA). The ignition quality of a fuel is determined as an ignition delay and time delay for start of 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.

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 22 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, ISO International Standards shall be used where they exist. Annex B lists standards, established by the standardization organizations, in use in parallel to ISO International Standards. It should be noted that non-ISO standards are not always identical in all details to the parallel ISO 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.

Related organizations capable of providing specifications for commercial fuels are given in Annex C.

Table 1 — Natural gas — EU reference fuels

[Source: EU Directive 2005/78/EC]

Property	Unit	Test method	G_{23}		G_R		G_{25}	
			min.	max.	min.	max.	min.	max.
Methane	mol %	ISO 6974	91,5	93,5	84	89	84	88
Ethane	mol %	ISO 6974	—	—	11	15	—	—
Inerts + C_{2+}	mol %	ISO 6974	—	—	—	1	—	—
Inerts (except N_2) + C_2 + C_{2+}	mol %	ISO 6974	—	1	—	—	—	1
Nitrogen	mol %	ISO 6974	6,5	8,5	—	—	12	16
Sulfur content	mg/m^3	ISO 6326-5	—	10	—	10	—	10

Table 2 — Natural gas — USA certification test fuel

[Source: Title 40, Code of Federal Regulations, § 1065.715]

Property	Unit	Test method	Prior to 2008		as of 2008	
			min.	max.	min.	max.
Methane	mol %	ASTM D 1945	89	—	87	—
Ethane	mol %	ASTM D 1945	—	4,5	—	5,5
C_3 and higher	mol %	ASTM D 1945	—	2,3	—	1,7
C_6 and higher	mol %	ASTM D 1945	—	0,2	—	0,1
Inert gases, Σ CO_2 and N_2	mol %	ASTM D 1945	—	4,0	—	5,1

Table 3 — Natural gas — Japanese certification test fuel

[Source: Details of Safety Regulations for Road Vehicles, Attachments 41 and 42]

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	1)	13 260	13 730
Combustion speed index	MCP	1)	36,8	37,5
Methane	mol %	JIS K 2301	85,0	—
Ethane	mol %	JIS K 2301	—	10,0
Propane	mol %	JIS K 2301	—	6,0
Butene	mol %	JIS K 2301	—	4,0
C_3 + C_4	mol %	JIS K 2301	—	8,0
C_5 and higher	mol %	JIS K 2301	—	0,1
Other gas (H_2 + O_2 + N_2 + CO + CO_2)	mol %	JIS K 2301	—	14,0
Sulfur	mg/m^3	JIS K 2301	—	10
1) Wobbe index and combustion speed index shall be calculated based on the gas composition.				

Table 4 — Universal analytical data sheet — Natural gas

Property	Unit	Test method	Result of measurements
Molar fraction of methane	%	ISO 6974	
Molar fraction of C_2 components	%	ISO 6974	
Molar fraction of C_{2+} components	%	ISO 6974	
Molar fraction of C_{6+} components	%	ISO 6974	
Molar fraction of inerts, Σ CO_2 and N_2	%	ISO 6974	
Mass concentration of sulfur	mg/m^3	ISO 6326-5	

Table 5 — Liquefied petroleum gas — EU reference fuel

[Source: EU Directive 2005/78/EC]

Property	Unit	Test method	Fuel A	Fuel B
C_3 content	% by volume	ISO 7941	50 ± 2	85 ± 2
C_4 content	% by volume	ISO 7941	Balance	Balance
$< C_3, > C_4$	% by volume	ISO 7941	max. 2,0	max. 2,0
Olefins	% by volume	ISO 7941	max.12	max.14
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. 50/10	max. 50/10
Hydrogen sulfide		ISO 8819	none	none
Copper strip corrosion	rating	ISO 6251	Class 1	Class 1
Odour			characteristic	characteristic
Motor octane number		EN 589 Annex B	min. 92,5	min. 92,5

Table 6 — Liquefied petroleum gas — USA certification test fuel

[Source: Title 40, Code of Federal Regulations, § 1065.720]

Property	Unit	Test method	min.	max.
Propane	% by volume	ASTM D 2163	85	—
Butane	% by volume	ASTM D 2163	—	5
Butenes	% by volume	ASTM D 2163	—	2
Pentenes and heavier	% by volume	ASTM D 2163	—	0,5
Propene	%	ASTM D 2163	—	10
Vapour pressure at 38 °C	kPa	ASTM D 1267	—	1 400
Volatility residue	°C	ASTM D 1837	—	−38
Residual matter	ml	ASTM D 2158	—	0,05
Copper strip corrosion	rating	ASTM D 1838	—	Class 1
Sulfur	mg/kg	ASTM D 2784	—	80
Moisture content	rating	ASTM D 2713	Pass	—

Table 7 — Liquefied petroleum gas — Japanese reference fuel

Property	Unit	Test method	min.	max.
Propane and propylene	mol %	JIS K 2240	20	30
Butane and butylene	mol %	JIS K 2240	70	80
Density at 15 °C	g/cm^3	JIS K 2240	0,500	0,620
Vapour pressure at 40 °C	MPa	JIS K 2240	—	1,55
Sulfur	% by mass	JIS K 2240	—	0,02

Table 8 — Universal analytical data sheet — Liquefied petroleum gas

Property	Unit	Test method [1)]	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	

1) Indicate the method used.

Table 9 — Motor gasolines — EU reference fuels

[Source: CEC, *Reference fuels manual*]

[Source: EU Directive 2002/80/EC]

[Source: EU Directive 2004/26/EC]

[Source: ECE *Regulation* 83]

Property	Unit	Test method	RF-02-99 Unleaded		RF-02-03 Unleaded	
			min.	max.	min.	max.
Research octane number (RON)	1	ISO 5164	95	—	95	—
Motor octane number (MON)	1	ISO 5163	85	—	85	—
Density at 15 °C	kg/m^3	ISO 3675	748	762	740	754
Reid vapour pressure	kPa	ISO 3007	56	60	—	—
Vapour pressure (DVPE)	kPa	EN 13016-1	—	—	56	60
Distillation		ISO 3405				
Initial boiling point	°C		24	40	24	40
Evaporated at 100 °C	% by volume		49	57	50	58
Evaporated at 150 °C	% by volume		81	87	83	89
Final boiling point	°C		190	215	190	210
Residue	%		—	2	—	2

Table 9 (*continued*)

Property	Unit	Test method	RF-02-99 Unleaded		RF-02-03 Unleaded	
			min.	max.	min.	max.
Hydrocarbon analysis						
Volume fraction of olefins	%	ASTM D 1319	—	10	—	10
Volume fraction of aromatics	%	ASTM D 1319	28	40	29	35
Volume fraction of benzene	%	EN 12177	—	1	—	1
Volume fraction of saturates	%	ASTM D 1319		balance		balance
Mass fraction of sulfur	mg/kg	ISO 14596	—	100	—	10
Oxygen content	% (by mass)	EN 1601	—	2,3	—	1,0
Lead content	mg/l	EN 237		5	—	5
Phosphorus content	mg/l	ASTM D 3231	—	1,3	—	1,3
Oxidation stability						
Induction period	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

Table 10 — Motor gasolines — USA certification test fuel

[Source: *Code of Federal Regulations*, Title 40, 86.1313-2004]

[Source: *Code of Federal Regulations*, Title 40, 1065.710]

Property	Unit	Test method	min.	max.
Research octane number (RON)	1	ASTM D 2699	93	—
Sensitivity (RON/MON)	1	ASTM D 2699 ASTM D 2700	7,5	—
Reid vapour pressure	kPa	ASTM D 323	60,0	63,4
Distillation		ASTM D 86		
Initial boiling point	°C		24	35
10 % (by volume)	°C		49	57
50 % (by volume)	°C		93	110
90 % (by volume)	°C		149	163
Final boiling point	°C		—	213
Hydrocarbon analysis		ASTM D 1319		
Volume fraction of olefins	%		—	10
Volume fraction of aromatics	%		—	35
Volume fraction of saturates	%		Remainder	
Mass fraction of sulfur	mg/kg		—	80
Mass concentration of lead	g/l	ASTM D 3237	—	0,013
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,0013

Table 11 — Motor gasolines — Japanese certification test fuels

[Source: Details of Safety Regulations for Road Vehicles, Attachments 41 and 42]

Property	Unit	Test method	Regular Grade		Premium Grade	
			min.	max.	min.	max.
Research octane number (RON)	1	JIS K 2280	90	92	99	101
Motor 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				
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 [1)]	—	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

1) ND = not detectable.

Table 12 — Universal analytical data sheet — Motor gasolines

Property	Unit	Test method 1)	Result of measurements
Research octane number (RON)	1	ISO 5164	
Motor 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 4260 ISO 8754	
Mass concentration of phosphorus	g/l	ASTM D 3231	
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 2)			
Mass fraction of carbon	%	ASTM D 3343	
Mass fraction of hydrogen	%		
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

1) Indicate the method used.

2) See the ultimate paragraph of Clause 5.

Table 13 — Diesel fuels — EU reference fuels

[Source: CEC, *Reference fuels manual*]

[Source: EU Directive 2005/78/EC]

[Source: EU Directive 2004/26/EC]

Property	Unit	Test methods	RF-06-99		RF-06-03		RF-75-T-96	
			min.	max.	min.	max.	min.	max.
Cetane number	1	ISO 5165	52	54	52	54	45	50
Density at 15 °C	kg/m³	ISO 3675	833	837	833	837	835	845
Distillation		ISO 3405						
50 % (by volume)	°C		245	—	245	—	—	—
95 % (by volume)	°C		345	350	345	350	—	—
Final boiling point	°C		—	370	—	370	—	370
Flash point	°C	ISO 2719	55	—	55	—	55	—
Cold filter plugging point	°C	EN 116	—	−5	—	−5	—	+5
Kinematic viscosity at 40 °C	mm²/s	ISO 3104	2,5	3,5	2,5	3,3	2,5	3,5
Polycyclic aromatic hydrocarbons	% (by mass)	EN 12916	3,0	6,0	2,0	6,0		
Mass fraction of sulfur	mg/kg	ISO 14596		300 (50)	—	10	1 000	2000
Copper corrosion	—	ISO 2160		class 1	—	class 1	—	class 1
Mass fraction of Conradson carbon residue (10 % DR)	%	ISO 10370	to be reported	0,2	—	0,2	—	0,3
Mass fraction of ash	%	ISO 6245		0,01	—	0,01	—	0,01
Mass fraction of water	%	ISO 12937		0,05	—	0,02	—	0,05
Lubricity (HFRR at 60 °C)	µm	CEC F-06-A-96			—	400		
Neutralization number	mg KOH/g		—	0,02	—	0,02	—	0,02
Oxidation stability	mg/ml	ISO 12205	—	0,025	—	0,025	—	0,025

Table 14 — Diesel fuels — USA certification test fuels

[Source: *Code for Federal Regulations*, Title 40, 86.1313-98]

[Source: *Code for Federal Regulations*, Title 40, 86.1313-2007]

[Source: *Code of Federal Regulations*, Title 40, § 1065.703]

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
Density at 15 °C	kg/l	ASTM D 1298	0,840	0,865
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	mm²/s	ASTM D 445	2	3,2
Mass fraction of sulfur	%	ASTM D 1266	0,03	0,05
	ppm	ASTM D 2622	7	15
Volume fraction of aromatics	%	ASTM D 1319	27 (10)	—

Table 15 — Diesel fuels — California certification test fuel

[Source: *California Code of Regulations*, Title 13, Division 3]

Property	Unit	Test method	Fuel 2-D	
			min.	max.
Cetane number	1	ASTM D 613	42	50
Cetane index	1	ASTM D 976	42	50
Density at 15 °C	kg/l		0,840	0,865
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	%	ASTM D 1266 ASTM D 2622	0,03	0,05
Volume fraction of aromatics	%	ASTM D 1319	—	10

Table 16 — Diesel fuels — Japanese certification test fuel

[Source: *Details of Safety Regulations for Road Vehicles, Attachments 41, 42 and 43*]

Property	Unit	Test method	Certification Fuel 1 [1]		Certification Fuel 2 [2]	
			min.	max.	min.	max.
Cetane index	—	JIS K 2280	53	57	53	60
Density at 15 °C	g/cm^3	JIS K 2249	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-49-97 [3]	—	25	—	25
Polycyclic aromatics	% by volume	JPI-5S-49-97 [3]	—	5,0	—	5,0
Flash point	K (°C)	JIS K 2265-3	331 (58)	—	331 (58)	—
Kinetic 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 [4] bulletin		ND [5]		ND [5]
Fatty acid methyl esters				ND [5]		ND [5]

1) Test fuel for on road vehicle specified in “Details of Safety Regulations for Road Vehicles”, Attachments 41 and 42.

2) Test fuel for on road special vehicle specified in “Details of Safety Regulations for Road Vehicles”, Attachment 43.

3) Japan Petroleum Institute Standard.

4) Ministry of Economy, Trade and Industry.

5) ND = not detectable.

Table 17 — Universal analytical data sheet — Diesel fuels

Property	Unit	Test method [1)]	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 4260	
Volume fraction of aromatics	%	ASTM D 1319 [2)] 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 existant gum per 100 ml	mg	ASTM D 381	
Elemental analysis [3)]			
Mass fraction of carbon	%		
Mass fraction of hydrogen	%	ASTM D 3343	
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

1) Indicate the method used.

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

3) See the ultimate paragraph of Clause 5.

Table 18 — Distillate fuel oils — ISO class F test fuel oils

[Source: ISO 8217:2005]

Property	Unit	Test method	Fuel ISO-F-DMA		Fuel ISO-F-DMB	
			min.	max.	min.	max.
Cetane index		ISO 4264	40	—	35	—
Density at 15 °C	kg/m³	ISO 3675	—	890,0	—	900,0
Flash point	°C	ISO 2719	60		60	
Pour point		ISO 3016				
Winter quality	°C		—	− 6	—	0
Summer quality	°C		—	0	—	6
Kinematic viscosity at 40 °C	mm²/s	ISO 3104	1,50	6,00	—	11,0
Mass fraction of sulfur	%	ISO 8754	—	1,50	—	2,00
Mass fraction of carbon residue, Ramsbottom on 10 % residue	%	ISO 4262	—	0,30	—	—
Mass fraction of carbon residue, Ramsbottom	%	ISO 4262	—	—	—	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
Visual inspection	—	ISO 8217	clear and bright		1)	
Property	**Unit**	**Test method**	**Fuel ISO-F-DMX**		**Fuel ISO-F-DMC**	
			min.	max.	min.	max.
Cetane index		ISO 4264	45	—	—	—
Density at 15 °C	kg/m³	ISO 3675	—	—	—	920,0
Flash point	°C	ISO 2719	43		60	
Cloud point	°C	ISO 3015	—	− 16	—	—
Pour point		ISO 3016				
Winter quality	°C		—	—	—	0
Summer quality	°C		—	—	—	6
Kinematic viscosity at 40 °C	mm²/s	ISO 3104	1,40	5,50	—	14,0
Mass fraction of sulfur	%	ISO 8754	—	1,00	—	2,00
Mass fraction of carbon residue, Ramsbottom on 10 % residue	%	ISO 4262	—	0,30	—	—
Mass fraction of carbon residue, Ramsbottom	%	ISO 4262	—	—	—	2,50
Mass fraction of ash	%	ISO 6245	—	0,01	—	0,05
Volume fraction of water	%	ISO 3733	—	—	—	0,3
Mass fraction of sediment	%	ISO 10307-1	—	—	—	0,10
Vanadium	mg/kg	ISO 14597	—	—	—	100
Aluminium + silicon	mg/kg	ISO 10478	—	—	—	25
Visual inspection	—	ISO 8217	clear and bright		—	—

1) See ISO 8217:2005, 7.4.

Table 19 — Universal analytical data sheet — Distillate fuel oils

Property	Unit	Test method	Result of measurements
Cetane number 1)	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, Ramsbottom on 10 % residue	%	ISO 4262	
Mass fraction of carbon residue, Ramsbottom	%	ISO 4262	
Mass fraction of ash	%	ISO 6245	
Mass fraction of water	%	ISO 3733	
Mass fraction of sediment	%	ISO 3735	
Visual inspection	—	ISO 8217	
Elemental analysis 2)	%		
Mass fraction of carbon	%		
Mass fraction of hydrogen	%	ASTM D 3343	
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

1) Not valid for fuels containing residues.

2) See the ultimate paragraph of Clause 5.

Table 20 — Residual fuel oils — ISO class F test fuel oils

[Source: ISO 8217:2005]

Property	Unit	Test method	Limit	RMA 30	RMB 30	RMD 80	RME 180	RMF 180	RMG 380	RMH 380	RMK 380	RMH 700	RMK 700
Density at 15 °C	kg/m^3	ISO 3675	max.	960,0	975,0	980,0	991,0	991,0	991,0	991,0	991,0	991,0	1010,0
Kinematic viscosity at 50 °C	mm^2/s	ISO 3104	max.	30,0	30,0	80,0	180,0	180,0	380,0	380,0	380,0	700,0	700,0
Flash point	°C	ISO 2719	min.	60	60	60	60	60	60	60	60	60	60
Pour point (upper)	°C	ISO 3016											
Winter quality			max.	0	24	30	30	30	30	30	30	30	30
Summer quality			max.	6	24	30	30	30	30	30	30	30	30
Mass fraction of sulfur	%	ISO 8754	max.	3,50	3,50	4,00	4,50	4,50	4,50	4,50	4,50	4,50	4,50
Mass fraction of carbon residue	%	ISO 10370	max.	10	10	14	15	20	18	22	22	22	22
Mass fraction of ash	%	ISO 6245	max.	0,10	0,10	0,10	0,10	0,15	0,15	0,15	0,15	0,15	0,15
Volume fraction of water	%	ISO 3733	max.	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Mass fraction of sediment	%	ISO 10307-2	max.	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
Aluminium + silicon	mg/kg	ISO 10478	max.	80	80	80	80	80	80	80	80	80	80
Vanadium	mg/kg	ISO 14597	max.	150	150	350	200	500	300	600	600	600	600

Table 21 — Universal analytical data sheet — Residual fuel oils

Property	Unit	Test method [1)]	Result of measurements
CCAI [2)]	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 ISO 4260	
Mass fraction of carbon residue (10 % DR)	%	ISO 6615 ISO 10370	
Mass fraction of ash	%	ISO 6245	
Mass fraction of water	%	ISO 3733	
Mass fraction of sediment	%	ISO 3735	
Mass fraction of aluminium and silicon	mg/kg	ISO 10478	
Mass fraction of vanadium	mg/kg	ISO 8691	
Elemental analysis [3)]	%		
Mass fraction of carbon	%		
Mass fraction of hydrogen	%	ASTM D 3343	
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

1) Indicate the method used.

2) CCAI = calculated carbon aromaticity index (see Clause A.4).

3) See the ultimate paragraph of Clause 5.

Table 22 — Universal analytical data sheet — Crude oil

Property	Unit	Test method [1)]	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	
Pour point	°C	ISO 3016	
Reid vapour pressure	bar	ISO 3007	
Mass fraction of water	%	ISO 3733	

1) 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 of wet concentration from dry concentration according to ISO 8178-1:2006, 14.3.

$$c_{\mathrm{w}} = k_{\mathrm{w}} \times c_{\mathrm{d}}$$

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:

$$k_{\mathrm{wr}} = \frac{c_{\mathrm{gasw}}}{c_{\mathrm{gasd}}} = \frac{q_{v\mathrm{ed}}}{q_{v\mathrm{ew}}} = 1 - \frac{q_{v\mathrm{H2O}}}{q_{v\mathrm{ew}}}$$

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

$$k_{\mathrm{wr1}} = \left(1 - \frac{1{,}244\,2 \times H_{\mathrm{a}} + 111{,}19 \times w_{\mathrm{ALF}} \times \frac{q_{m\mathrm{f}}}{q_{m\mathrm{ad}}} - 773{,}4 \times \frac{p_{\mathrm{r}}}{p_{\mathrm{b}}}}{773{,}4 + 1{,}244\,2 \times H_{\mathrm{a}} + \frac{q_{m\mathrm{f}}}{q_{m\mathrm{ad}}} \times f_{\mathrm{fw}} \times 1\,000} \right)$$

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

$$f_{\mathrm{fw}} = 0{,}055\,594 \times w_{\mathrm{ALF}} + 0{,}008\,002\,1 \times w_{\mathrm{DEL}} + 0{,}007\,004\,6 \times w_{\mathrm{EPS}}$$

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

$$f_{\mathrm{fd}} = -0{,}055\,593 \times w_{\mathrm{ALF}} + 0{,}008\,002 \times w_{\mathrm{DEL}} + 0{,}007\,004\,6 \times w_{\mathrm{EPS}}$$

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 part of ISO 8178 and in ISO 8178-1:2006, this factor 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 % (by mass)	Composition Molar ratio	EAF Independent fuel specific parameters		EAF	Values for dry intake air: Exhaust density kg/m³ wet	Exhaust density kg/m³ dry	k_{wr}	M_{rew} g/mol	f_{fh}
Diesel	H	13,45	1,8529	A/F_{st}	14,5364	1,00	1,2968	1,3672	0,8864	29,030	1,8134
	C	86,50	1,0000	f_{fw}	0,7382	1,35	1,2958	1,3469	0,9175	29,014	1,8428
	S	0,05	0,0002	f_{fd}	-0,7578	2,00	1,2950	1,3288	0,9472	28,999	1,8710
	N	0,00	0,0000	k_f	207,2800	3,00	1,2943	1,3166	0,9683	28,989	1,8911
	O	0,00	0,0000	M_{rf}	13,8855	4,00	1,2940	1,3106	0,9790	28,983	1,9012
						5,00	1,2938	1,3070	0,9855	28,980	1,9074
RME	H	12,00	1,8523	A/F_{st}	12,5048	1,00	1,2979	1,3706	0,8829	29,053	1,6025
	C	77,20	1,0000	f_{fw}	0,7342	1,35	1,2967	1,3495	0,9146	29,032	1,6323
	S	0,00	0,0000	f_{fd}	-0,6005	2,00	1,2955	1,3306	0,9451	29,012	1,6611
	N	0,00	0,0000	k_f	184,9944	3,00	1,2947	1,3178	0,9668	28,997	1,6816
	O	10,80	0,1050	M_{rf}	15,5583	4,00	1,2943	1,3115	0,9779	28,990	1,6920
						5,00	1,2940	1,3077	0,9846	28,985	1,6983
Methanol	H	12,50	3,9721	A/F_{st}	6,4273	1,00	1,2355	1,3655	0,7788	27,661	1,4851
	C	37,50	1,0000	f_{fw}	1,0406	1,35	1,2484	1,3457	0,8311	27,954	1,5548
	S	0,00	0,0000	f_{fd}	-0,3497	2,00	1,2615	1,3279	0,8843	28,252	1,6258
	N	0,00	0,0000	k_f	89,8613	3,00	1,2713	1,3160	0,9241	28,475	1,6788
	O	50,00	1,0010	M_{rf}	32,0293	4,00	1,2765	1,3102	0,9449	28,592	1,7066
						5,00	1,2796	1,3067	0,9578	28,664	1,7238
Ethanol	H	13,10	2,9934	A/F_{st}	8,9722	1,00	1,2615	1,3651	0,8263	28,243	1,6522
	C	52,15	1,0000	f_{fw}	0,9657	1,35	1,2689	1,3454	0,8699	28,413	1,7063
	S	0,00	0,0000	f_{fd}	-0,4914	2,00	1,2762	1,3277	0,9131	28,581	1,7597
	N	0,00	0,0000	k_f	124,9670	3,00	1,2816	1,3159	0,9446	28,704	1,7987
	O	34,75	0,5002	M_{rf}	23,0316	4,00	1,2843	1,3100	0,9608	28,768	1,8189
						5,00	1,2860	1,3066	0,9708	28,806	1,8312
Natural gas	H	19,30	3,7952	A/F_{st}	13,4795	1,00	1,2429	1,3421	0,8266	27,829	2,4814
	C	60,60	1,0000	f_{fw}	1,2250	1,35	1,2548	1,3285	0,8708	28,100	2,5509
	S	0,00	0,0000	f_{fd}	-0,9218	2,00	1,2665	1,3164	0,9141	28,366	2,6191
	N	18,20	0,2575	k_f	145,2158	3,00	1,2750	1,3084	0,9455	28,559	2,6684
	O	1,90	0,0235	M_{rf}	19,8201	4,00	1,2794	1,3045	0,9616	28,658	2,6938
						5,00	1,2820	1,3021	0,9714	28,718	2,7093
Propane	H	18,30	2,6692	A/F_{st}	15,6423	1,00	1,2698	1,3556	0,8558	28,429	2,4270
	C	81,70	1,0000	f_{fw}	1,0083	1,35	1,2755	1,3383	0,8939	28,560	2,4764
	S	0,00	0,0000	f_{fd}	-1,0272	2,00	1,2809	1,3229	0,9308	28,687	2,5241
	N	0,00	0,0000	k_f	195,7777	3,00	1,2848	1,3126	0,9571	28,778	2,5582
	O	0,00	0,0000	M_{rf}	14,7013	4,00	1,2868	1,3076	0,9705	28,824	2,5756
						5,00	1,2881	1,3046	0,9786	28,852	2,5862
Butane	H	17,30	2,4928	A/F_{st}	15,4150	1,00	1,2750	1,3579	0,8617	28,545	2,3017
	C	82,70	1,0000	f_{fw}	0,9526	1,35	1,2794	1,3400	0,8985	28,648	2,3467
	S	0,00	0,0000	f_{fd}	-0,9716	2,00	1,2836	1,3241	0,9339	28,748	2,3901
	N	0,00	0,0000	k_f	198,1740	3,00	1,2867	1,3134	0,9592	28,819	2,4211
	O	0,00	0,0000	M_{rf}	14,5236	4,00	1,2882	1,3082	0,9722	28,855	2,4369
						5,00	1,2892	1,3051	0,9800	28,877	2,4465
Gasolline	H	12,20	1,6944	A/F_{st}	13,9401	1,00	1,3032	1,3703	0,8929	29,173	1,6484
	C	85,80	1,0000	f_{fw}	0,6828	1,35	1,3007	1,3493	0,9224	29,122	1,6743
	S	0,00	0,0000	f_{fd}	-0,6742	2,00	1,2983	1,3304	0,9506	29,073	1,6990
	N	0,00	0,0000	k_f	205,6025	3,00	1,2965	1,3177	0,9706	29,038	1,7166
	O	2,00	0,0175	M_{rf}	13,9988	4,00	1,2957	1,3114	0,9808	29,021	1,7255
						5,00	1,2951	1,3077	0,9869	29,010	1,7309
Hydrogen	H	100,00		A/F_{st}	34,2098	1,00	1,0997	1,2575	0,6628	24,639	11,873
	C	0,00		f_{fw}	5,5584	1,35	1,1431	1,2684	0,7411	25,610	12,433
	S	0,00		f_{fd}	-5,5646	2,00	1,1872	1,2773	0,8207	26,598	13,002
	N	0,00		k_f	0,0000	3,00	1,2201	1,2829	0,8803	27,336	13,427
	O	0,00		M_{rf}	2,0159	4,00	1,2374	1,2856	0,9116	27,723	13,651
						5,00	1,2481	1,2871	0,9308	27,962	13,788

A.2 Estimation of the fuel composition without elemental analysis

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.2.1, A.2.2 and A.2.3 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.2.1 Method 1

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

$$w_{\mathrm{ALF}} = 26 - 15 \times \rho_{\mathrm{f}}$$

$$w_{\mathrm{BET}} = 100 - w_{\mathrm{ALF}}$$

where ρ_{f} is the density at 288 K (15 °C) in grams per cubic centimetre.

A.2.2 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.

$$z = \frac{(209{,}42 - 90{,}92 \times \rho_{\mathrm{f}})}{(107{,}606 - w_{\mathrm{GAM}}) \times \rho_{\mathrm{f}} - 17{,}546}$$

$$w_{\mathrm{ALF}} = \frac{(100 - w_{\mathrm{GAM}}) \times 1{,}007\,94 \times z}{12{,}011 + 1{,}007\,94 \times z}$$

$$w_{\mathrm{BET}} = 100 - w_{\mathrm{ALF}} - w_{\mathrm{GAM}}$$

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:

$$\mathrm{NHCV} = 2{,}326 \times 10^{-3} \left[\left(11\,369{,}54 + \frac{6\,800{,}84}{\rho_{\mathrm{f}}} - \frac{750{,}83}{\rho_{\mathrm{f}}^{2}} \right) \times (1 - 0{,}01 \times w_{\mathrm{GAM}}) + 43{,}7 \times w_{\mathrm{GAM}} \right]$$

A.2.3 Method 3

The following equations 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 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.

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

$$w_{\mathrm{BET}} = 100 - (w_{\mathrm{ALF}} + w_{\mathrm{GAM}} + w_{\mathrm{DEL}})$$

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

A.3 Ignition quality

The following is a rewritten working draft and is given for information only.

A.3.1 Application

Ignition performance requirements of residual fuel oils in marine diesel engines are primarily determined by 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 may be problematical to one engine under adverse conditions may 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 (CII) or the calculated carbon aromaticity index (CCAI) of a fuel oil by extending a straight line connecting to viscosity and the density and reading the values thus obtained on the CII and CCAI scales. These values allow ranking of its ignition performance. They can also be calculated as follows:

$$\text{CII} = (270{,}795 + 0{,}103\,8 \times T) - 0{,}254\,56 \times \rho + 23{,}708 \times \lg\left[\lg(\nu + 0{,}7)\right]$$

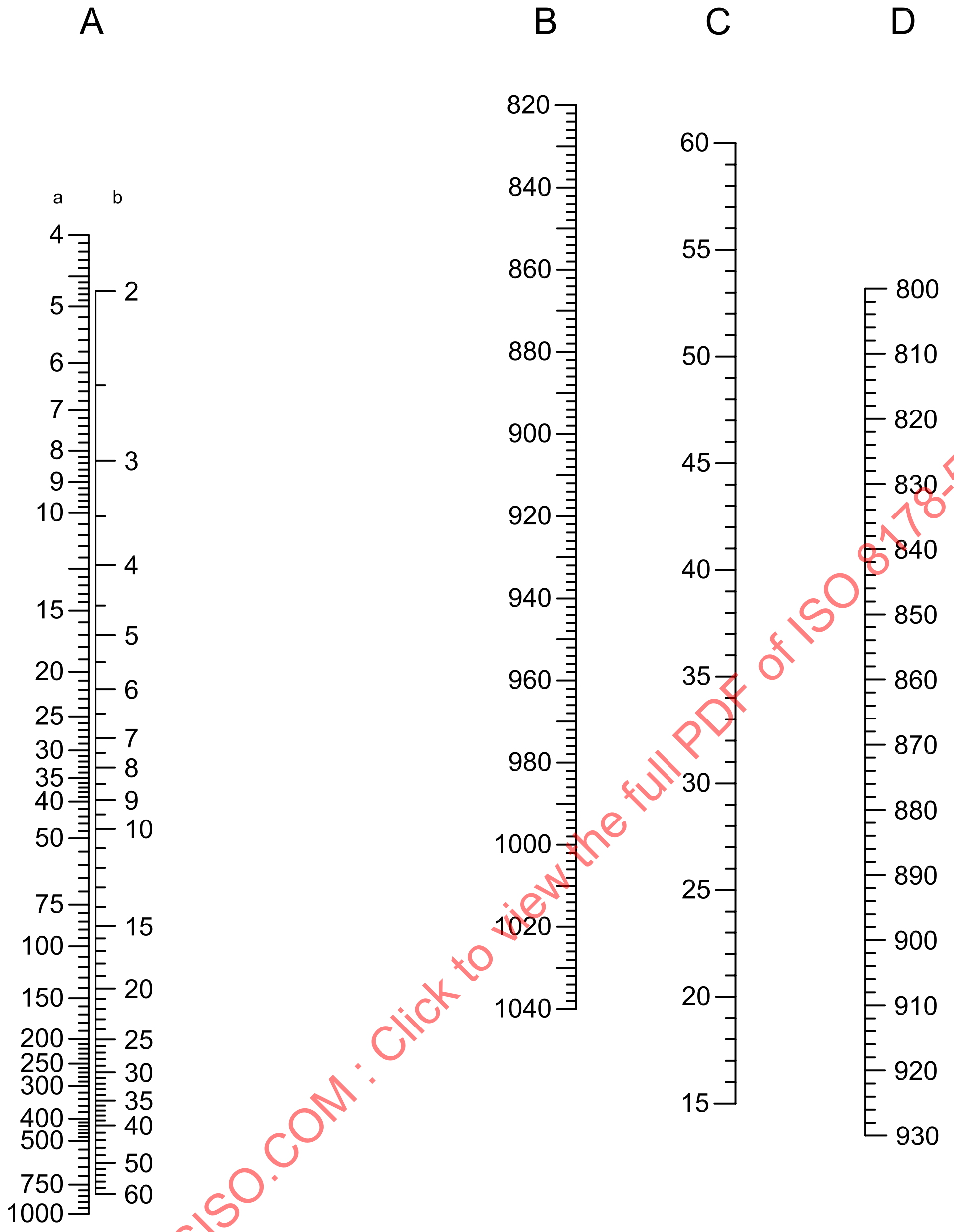
$$\text{CCAI} = \rho - 81 - 141 \times \lg\left[\lg(\nu + 0{,}85)\right] - 483 \times \lg\left(\frac{T + 273}{323}\right)$$

where

T is the temperature, in degrees Celsius;

ν 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 (CII) and the calculated carbon aromaticity index (CCAI)

Annex B
(informative)

Equivalent non-ISO test methods

The standards given in this annex are not completely equivalent but should be considered comparable.

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 4260	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 — Motor 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
Motor 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 4260 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 50 °C	ISO 2160	ASTM D 130	—	