INTERNATIONAL STANDARD

ISO 8178-5

Third edition
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Reciprocating internal combustion engines — Exhaust emission measurement —

Part 5: Test fuels

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

Partie 5: Carburants d'essai

Reference number
ISO 8178-5:2015(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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

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

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

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

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

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

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

— *Part 4: Steady-state test cycles for different engine applications*[1)]

— *Part 5: Test fuels*

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

— *Part 7: Engine family determination*

— *Part 8: Engine group determination*

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

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

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

Introduction

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

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

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

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

Reciprocating internal combustion engines — Exhaust emission measurement —

Part 5:
Test fuels

1 Scope

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

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

2 Normative references

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

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

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

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

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

3 Terms and definitions

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

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

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

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

[SOURCE: ISO 1998-2:1998, 2.50.001]

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

Note 1 to entry: The formula used for calculation is reproduced from statistical analysis of a very large representative sample of world-wide diesel fuels, on which cetane number and distillation data are known, and thus is subject to change at 5 to10 year intervals. The current formula is given in ISO 4264. It is not applicable to fuels containing an ignition-improving additive.

[SOURCE: ISO 1998-2:1998, 2.30.111]

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

Note 1 to entry: It is expressed as the percentage by volume of hexadecane (cetane) in a reference mixture having the same ignition delay as the fuel for analysis. The higher the cetane number, the shorter the delay.

[SOURCE: ISO 1998-2:1998, 2.30.110]

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

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

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

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

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

[SOURCE: ISO 1998-1:1998, 1.20.131]

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

Note 1 to entry: No longer widely used for distillate fuels due to inaccuracy of this method, but applicable to some blended distillate residual fuel oils. See also 3.2, cetane index.

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

[SOURCE: ISO 1998-1:1998, 1.15.080]

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

Note 1 to entry: It is determined in test engines by comparison with reference fuels. There are several methods of test, consequently the octane number should be accompanied by reference to the method used.

[SOURCE: ISO 1998-2:1998, 2.30.100]

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

4 Symbols and abbreviated terms

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

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

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

5 Choice of fuel

5.1 General

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

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

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

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

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

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

— Table 13 (Universal analytical data sheet — Engine gasolines);

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

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

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

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

An elemental analysis of the fuel shall be carried out when the possibility of an exhaust mass flow measurement or combustion air flow measurement, in combination with the fuel consumption, is not possible.

In such cases, the exhaust mass flow can be calculated using the concentration measurement results of the exhaust emission, and using the calculation methods given in ISO 8178-1:2006, Annex A. In cases where the fuel analysis is not available, hydrogen and carbon mass fractions can be obtained by calculation. The recommended methods are given in A.2.1, A.2.2 and A.2.3.

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

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

5.2 Influence of fuel properties on emissions from compression ignition engines

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

5.2.1 Fuel sulfur

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

Consequently, fuel sulfur has a significant influence on the PM emission.

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

— fuel consumption of the engine (BSFC);

— fuel sulfur content (FSC);

— S ⇒ SO4 conversion rate (CR);

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

Fuel consumption and fuel sulfur content are measurable parameters, whereas the conversion rate can only be predicted, since it may vary from engine to engine. Typically, the conversion rate is approximately 2 % for engines without aftertreatment systems. The following formula has been applied for estimating the sulfur impact on PM, as presented in Formula (1):

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

where

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

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

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

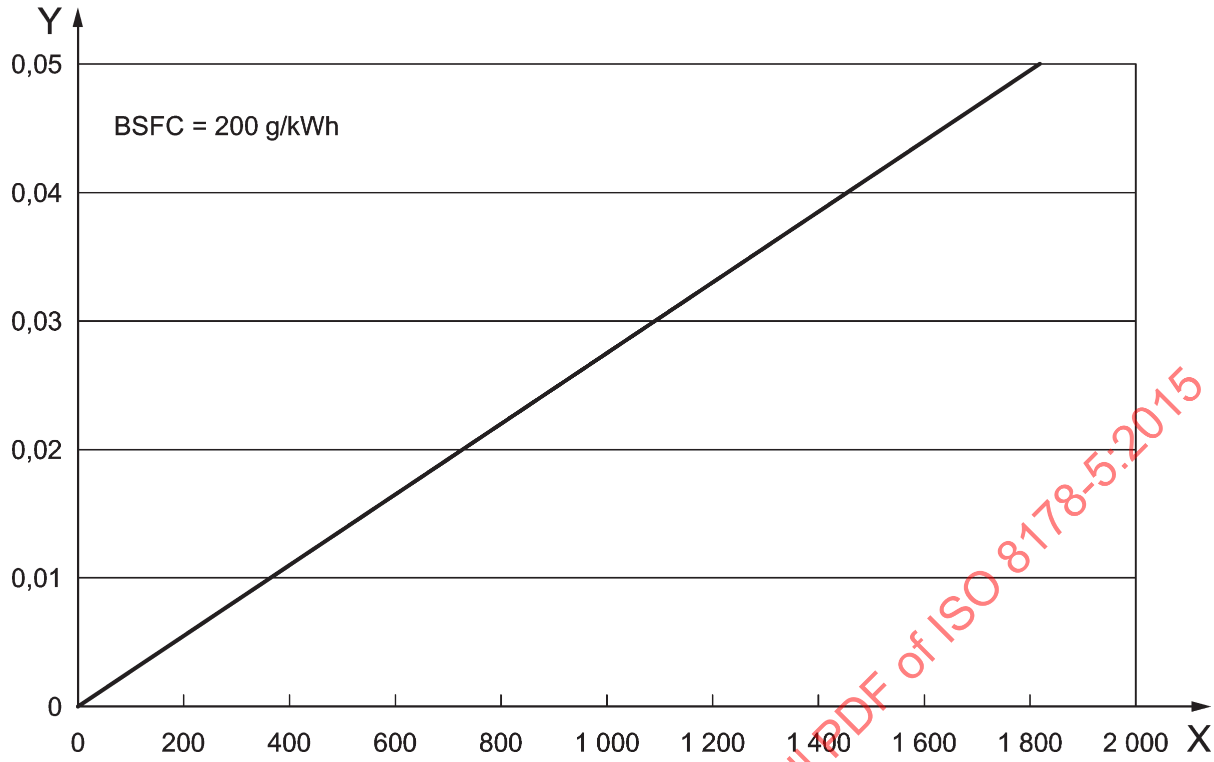
CR is the $S \Rightarrow SO_4$ conversion rate, expressed in percent %;

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

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

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

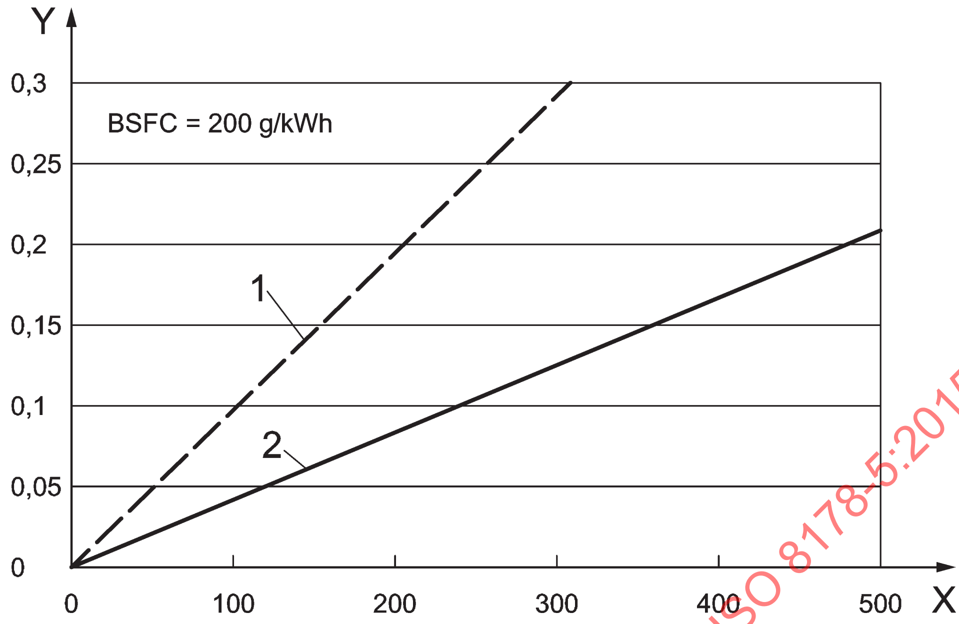


Key

X sulfur content, in mg/kg

Y sulfur PM, in g/kWh

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



Key

X sulfur content, in mg/kg

Y sulfur PM, in g/kWh

1 70 % conversion

2 30 % conversion

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

5.2.2 Specific considerations for marine fuels

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

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

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

5.2.3 Other fuel properties

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

For NO_x, total aromatics is the predominant parameter whereas the effect of poly-aromatics and density is less significant. This can be explained by an increase of the flame temperature with higher 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 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 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 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 O2 levels beyond that for which an open loop engine has been calibrated will typically increase NOx emissions and combustion temperatures which may 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;

b) USA certification test fuel: see Table 2;

c) Japanese certification test fuel: see Table 3.

6.1.2 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 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 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 9;

b) USA certification test fuel: see Table 10;

c) Japanese certification test fuels: see Table 12.

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 13 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.

6.4 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 14;

b) USA certification test fuels: see Table 15;

c) Californian test fuel: see Table 16;

d) Japanese certification test fuel: see Table 17.

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 18 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 19).

The fuel's properties, including the elemental analysis, shall be measured and reported with the results of the emission measurement. Table 20 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 21).

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 22 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 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 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. 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 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, 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.

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

Table 1 — Natural Gas — EU reference fuels

Property	Unit	Test method	G_{23}		G_R		G_{25}	
			min.	max.	min.	max.	min.	max.
Molar fraction of methane	mol %	ISO 6974	91,5	93,5	84	89	84	88
Molar fraction of ethane	mol %	ISO 6974	—	—	11	15	—	—
Molar fraction of C_{2+} components	mol %	ISO 6974	—	—	—	1	—	—
Molar fraction of inerts, (except N_2) + C_2 + C_{2+}	mol %	ISO 6974	—	1	—	—	—	1
Molar fraction of nitrogen	mol %	ISO 6974	6,5	8,5	—	—	12	16
Mass concentration of sulfur	mg/m^3	ISO 6326-5	—	10	—	10	—	10
Source: EU Regulation 582/2011.								

Table 2 — 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
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
Source: Title 40, Code of Federal Regulations, 1 065.715.						

Table 3 — Natural gas — Japanese certification test fuel

Property	Unit	Test method	Equivalent of 13A	
			min.	max.
Total calorific amount	kcal/m^3	JIS K2301	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 K2301	85,0	—
Molar fraction of ethane	mol %	JIS K2301	—	10,0
Molar fraction of propane	mol %	JIS K2301	—	6,0
Molar fraction of butane	mol %	JIS K2301	—	4,0
Molar fraction of C_3 + C_4 components	mol %	JIS K2301	—	8,0
Molar fraction of C_{5+} components	mol %	JIS K2301	—	0,1
Molar fraction of other gas (H_2 + O_2 + N_2 + CO + CO_2)	mol %	JIS K2301	—	14,0
Source: Details of Safety Regulations for Road Vehicles, Attachment 41and 42.				
[a] Wobbe index and Combustion speed index shall be calculated based on the gas composition.				

Table 3 *(continued)*

Property	Unit	Test method	Equivalent of 13A	
			min.	max.
Mass concentration of sulfur	mg/m^3	JIS K2301	—	10
Source: Details of Safety Regulations for Road Vehicles, Attachment 41and 42.				
[a] 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 MMmethane	%	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

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
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 Annex B	min. 89,0	min. 89,0
Source: EU Regulation 582/2011.				

Table 6 — 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
Source: Title 40, Code of Federal Regulations, 1065,720.				

Table 6 *(continued)*

Property	Unit	Test method		
			min.	max.
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 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	—
Source: Title 40, Code of Federal Regulations, 1065,720.				

Table 7 — 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 8 — Universal analytical data sheet — Liquefied petroleum gas

Property	Unit	Test methodText[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 9 — Engine gasolines — EU reference fuels

Property	Unit	Test method	Directive 2002/88/EC		Regulation 582/2011 (E10)	
			min.	max.	min.	max.
Research octane number (RON)	1	EN 25164	95	—	95	97
Engine octane number (MON)	1	EN 25163	85	—	84	86
Density at 15 °C	kg/m3	ISO 3675	748	762	743	756
Reid vapour pressure	kPa	EN 12	56	60	—	—
Vapour pressure (DVPE)	kPa	EN-ISO 13016-1	—	—	56	60
Water content	% V/V	ASTM E 1064				0,015
Distillation		EN-ISO 3405				
Initial boiling point	°C		24	40	24	44
Evaporated at 70°C	% V/V					
Evaporated at 100°C	% V/V		49	57	56	60
Evaporated at 150°C	% V/V		81	87	88	90
Final boiling point	°C		190	215	190	210
Residue	% V/V		—	2	—	2
Hydrocarbon analysis						
Volume fraction of olefins	% V/V	ASTM D 1319/ EN 14517	—	10	3	18
Volume fraction of aromatics	% V/V	ASTM D 1319/ EN 14517	28	40	25	35
Volume fraction of benzene	% V/V	EN 12177	—	1	0,4	1,0
Volume fraction of saturates	% V/V	ASTM D 1319		Balance		Report
Carbon/hydrogen ratio				Report		Report
Carbon/oxygen ratio						Report
Mass fraction of sulfur	mg/kg	EN-ISO 14596 EN-ISO 20846	—	100	—	10
Oxygen content	% m/m	EN 1601	—	2,3	—	3,7
Lead content	mg/l	EN 237		5	—	5
Phosphorus content	mg/l	ASTM D 3231	—	1,3	—	1,3
Oxidation stability						
Induction period	Min	EN-ISO 7536	480	—	480	—
Mass of existent gum	mg/ml	EN-ISO 6246	—	0,04	—	0,04
Copper corrosion at 50 °C	—	EN-ISO 2160	—	class 1	—	class 1
Ethanol	% V/V	EN 1601 EN 13132 EN 14517			9,5	10,0

Source: EU Directive 2002/88/EC.

Source: EU Regulation 582/2011.

Table 10 — Engine gasolines (no Ethanol) — USA certification test fuel for General Testing

Property	Unit	Test method	min.	max.
Sensitivity (RON/MON)	1	ASTM D 2699 ASTM D 2700	7,5	—
Dry vapour pressure equivalent	kPa	ASTM D 323	60,0	63,4[a,b]
Distillation range:		ASTM D 86		
Evaporated Initial boiling point	°C		24	35
10 % evaporated (by volume)	°C		49	57
50 % evaporated (by volume)	°C		93	110
90 % evaporated (by volume)	°C		149	163
Evaporated final boiling point	°C		—	213
Hydrocarbon analysis		ASTM D 1319		
Olefins	Vol %		—	10
Aromatics	Vol %		—	35
Saturates	Vol %		Remainder	
Mass fraction of sulfur	mg/kg		—	80
Mass concentration of lead	g/l	ASTM D3237	—	0,013
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,0013

Source: Title 40, Code of Federal Regulations, 1065,710.

Gasoline for testing must have octane values that represent commercially available fuels for the appropriate application.

a 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.

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

Table 11 — Engine gasolines (no Ethanol) — USA certification test fuel for Low Temperature Testing

Property	Unit	Test method	min.	max.
Dry vapour pressure equivalent	kPa	ASTM D 323	77,2	81,4
Distillation range:		ASTM D 86		
Evaporated Initial boiling point	°C		24	36
10 % evaporated (by volume)	°C		37	48
50 % evaporated (by volume)	°C		82	101
90 % evaporated (by volume)	°C		158	174
Evaporated fFinal boiling point	°C		—	212
Hydrocarbon analysis		ASTM D 1319		
Olefins	Vol %		—	17,5
Aromatics	Vol %		—	30,4
Saturates	Vol %		Remainder	
Mass fraction of sulfur	mg/kg		—	80

Source: Title 40, Code of Federal Regulations, 1065,710.

Gasoline for testing must have octane values that represent commercially available fuels for the appropriate application.

Table 11 *(continued)*

Property	Unit	Test method		
			min.	max.
Mass concentration of lead	g/l	ASTM D3237	—	0,013
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,005
Source: Title 40, Code of Federal Regulations, 1065,710.				
Gasoline for testing must have octane values that represent commercially available fuels for the appropriate application.				

Table 12 — 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/cm³	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[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
Source: Details of Safety Regulations for Road Vehicles, Attachment 41 and 42.						
[a] ND = not detectable.						

Table 13 — 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 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[b]			
Mass fraction of carbon	%		
Mass fraction of hydrogen	%	ASTM D 3343	
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

[a] Indicate the method used.

[b] See Clause 5.

Table 14 — Diesel fuels — EU reference fuels

Property	Unit	Test methods	Low Sulfur		Ultra low sulfur		B7 (Euro VI)	
			min.	max.	min.	max.	min.	max.
Cetane index		EN-ISO 4264					46	—
Cetane number	1	ISO 5165	52	54	—	54	52	56
Density at 15 °C	kg/m^3	ISO 3675	833	837	833	865	833	837
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	—	360
Flash point	°C	ISO 2719	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	3,0	6,0	3,0	6,0	2,0	4,0
Mass fraction of sulfur	mg/kg	EN-ISO 14596 EN-ISO 20846		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	%	EN-ISO 6245		0,01	—	0,01	—	0,01
Mass fraction of water	%	EN-ISO 12937		0,05	—	0,02	—	0,02
Total contamination	mg/kg	EN 12662					—	24
Lubricity (HFRR @ 60°C)	µm	EN ISO 12156			—	400	—	400
Neutralization number	mgKOH/g	ASTM D 974	—	0,02	—	0,02	—	0,10
Oxidation stability	mg/ml	EN-ISO 12205	—	0,025	—	0,025	—	0,025
Oxidation stability at 110°C	H	EN 15751					20,0	—
FAME	% V/V	EN 14078				prohib-ited	6,0	7,0
Source: EU Regulation 582/2011.								
Source: EU Directive 2004/26/EC.								

Table 15 — 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 D2622 or alternates as allowed under 40 CFR 80.580		
— ultra low			7	15
— low sulfur			300	500
— high sulfur			800	2500
Volume fraction of aromatics (Remainder shall be paraffins, naphthenes, and olefins)	g/kg	ASTM D 5186	(10)	—
Source: Title 40, Code of Federal Regulations, 1065,703.				

Table 16 — 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 K2280	53	57	53	60
Density at 15 °C	g/cm^3	JIS K2249	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[c]	—	25	—	25
Polycyclic aromatics	% by volume	JPI-5S-49-97[c]	—	5,0	—	5,0
Flash point	K (°C)	JIS K2265-3	331 (58)	—	331 (58)	—

Source: *Details of Safety Regulations for Road Vehicles, Attachment 41, 42 and 43.*

[a] Test fuel for on road vehicle specified in " Details of Safety Regulations for Road Vehicles, Attachment 41and 42".

[b] Test fuel for on road special vehicle specified in " Details of Safety Regulations for Road Vehicles, Attachment 43".

[c] Japan Petroleum Institute Standard.

[d] Ministry of Economy, Trade and Industry.

[e] ND = not detectable.

Table 16 *(continued)*

Property	Unit	Test method	Certification Fuel 1[a]		Certification Fuel 2[b]	
			min.	max.	min.	max.
Kinetic viscosity at 30 °C	mm^2/s	JIS K2283	3,0	4,5	3,0	4,5
Mass fraction of sulfur	mg/kg	JIS K2541-1,-2,-6,-7	—	10	—	10
Triglyceride		Measurement method specified by METI[d] bulletin		ND[e]		ND5)
Fatty acid methyl esters				ND[e]		ND5)

Source: *Details of Safety Regulations for Road Vehicles, Attachment 41, 42 and 43*.

a Test fuel for on road vehicle specified in " Details of Safety Regulations for Road Vehicles, Attachment 41 and 42".

b Test fuel for on road special vehicle specified in " Details of Safety Regulations for Road Vehicles, Attachment 43".

c Japan Petroleum Institute Standard.

d Ministry of Economy, Trade and Industry.

e ND = not detectable.

Table 17 — 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 4260	
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	

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 17 *(continued)*

Property	Unit	Test method[a]	Result of measurements
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 18 — Distillate fuel oils — ISO class F test fuel oils

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	2,00	6,00	2,00	11,0
Mass fraction of sulfur	%	ISO 8754	—	1,50	—	2,00
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	mg-KOH/g	ASTM D664	—	0,5	—	0,5
Cloud point	°C	ISO 3015	—	—	—	—
Lubricity, corrected wear scar diameter (wsd 1.4) at 60 °C2)	µm	ISO 12156-1	—	520	—	520
Visual inspection	—	ISO 8217	clear and bright		[a]	

Source: ISO 8217:2010.

[a] See ISO 8217:2010, 7.6.

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

Table 18 *(continued)*

Property	Unit	Test method	Fuel ISO-F-DMA		Fuel ISO-F-DMB	
			min.	max.	min.	max.
Property	Unit	Test Method	Fuel ISO-F-DMX min.	max.	Fuel ISO-F-DMZ min.	max.
Cetane index		ISO 4264	45	—	40	—
Density at 15 °C	kg/m³	ISO 3675	—	—	—	890,0
Flash point	°C	ISO 2719	43		60	
Cloud point	°C	ISO 3015	—	-16	—	—
Pour point		ISO 3016				
Winter quality	°C		—	—	—	-6
Summer quality	°C		—	—	—	0
Kinematic viscosity at 40 °C	mm²/s	ISO 3104	2,00	5,50	3,00	6,00
Mass fraction of sulfur	%	ISO 8754	—	1,00	—	1,50
Mass fraction of carbon residue, Ramsbottom on 10 % residue	%	ISO 10370	—	0,30	—	0,30
Mass fraction of carbon residue, Ramsbottom	%	ISO 10370	—	—	—	2,50
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	—	—	—	0,0
Mass fraction of hydrogen sulphide	mg/kg	IP 570	—	2,00	—	2,00
Acid number	mg-KOH/g	ASTM D664	—	0,5	—	0,5
Cloud point	°C	ISO 3015	-16	—	—	—
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	

Source: ISO 8217:2010.

a See ISO 8217:2010, 7.6.

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

Table 19 — 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	mm²/s	ISO 3104	
Mass fraction of Sulfur	%	ISO 8754	

a See Clause 5.

Table 19 *(continued)*

Property	Unit	Test method	Result of measurements
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	
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]	%		
Mass fraction of carbon	%		
Mass fraction of hydrogen	%	ASTM D 3343	
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

[a] See Clause 5.

Table 20 — 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/m³	ISO 3675	max.	920,0	960,0	975,0	991,0	991,0				1 010,0		
Kinematic viscosity at 50 °C	mm²/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	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 0,150		
Mass fraction of ash	%	ISO 6245	max.	0,040	0,070	0,070	0,070	0.100				0,50		
Volume fraction of water	%	ISO 3733	max.	0,30	0,50	0,50	0,50	0,50				0,10		
Mass fraction of sediment	%	ISO 10307-2	max.	0,10	0,10	0,10	0,10	0,10				0,10		

Source: ISO/8217:2010.

[a] See ISO 8217:2010, 6.3 a) and Annex F.

[b] See ISO 8217:2010, 7.2 and Annex C.

Table 20 *(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
Mass fraction of Aluminium + silicon	mg/kg	ISO 10478	max.	25	49	49	50	60				60		
Mass fraction of Vanadium	mg/kg	ISO 14597	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		
Acid number	mg KOH/g	ASTM D664	2,5	2,5	2,5	2,5	2,5	2,5				2,5		
Used lubricating oils (ULO): Calcium and zinc; or Calcium and phosphorus	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 > 30 and zinc > 15; or Calcium > 30 and phosphorus > 15									

Source: ISO/8217:2010.

a See ISO 8217:2010, 6.3 a) and Annex F.

b See ISO 8217:2010, 7.2 and Annex C.

Table 21 — 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 ISO 4260	
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]	%		
Mass fraction of carbon	%		
Mass fraction of hydrogen	%	ASTM D 3343	
Mass fraction of nitrogen	%		

a Indicate the method used.

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

c See Clause 5.

Table 21 *(continued)*

Mass fraction of oxygen	%		

[a] Indicate the method used.

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

[c] See Clause 5.

Table 22 — 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	
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 8178-1:2006, 14.3.

$$c_w = k_w \times c_d \quad \text{(A.1)}$$

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:

$$k_{wr} = \frac{c_{gasw}}{c_{gasd}} = \frac{q_{ved}}{q_{vew}} = 1 - \frac{q_{vH_2O}}{q_{vew}} \quad \text{(A.2)}$$

Base on the combustion equation, k_w results as follows:

$$k_{wr1} = \left(1 - \frac{1{,}244\,2 \times H_a + 111{,}19 \times w_{ALF} \times \frac{qmf}{q_{mad}} - 773{,}4 \times \frac{p_r}{p_b}}{773{,}4 + 1{,}244\,2 \times H_a + \frac{qmf}{q_{mad}} \times f_{fw} \times 1\,000} \right) \quad \text{(A.3)}$$

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

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

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

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

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 part of ISO 8178 and in ISO 8178-1:2006, 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		EAF independent fuel specific parameters		EAF	Values for dry intake air				
		% mass	Molar ratio				Exhaust density kg/m3 wet	Exhaust density kg/m3 dry	k_{wr}	M_{rew} g/mol	f_{fh}
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		EAF independent fuel specific parameters		EAF	Values for dry intake air				
							Exhaust density				
		% mass	Molar ratio				kg/m³ wet	kg/m³ dry	k_{wr}	M_{rew} g/mol	f_{fh}
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

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.

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

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

where

ρ 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.

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

$$w_{ALF} = \frac{(100 - w_{GAM}) \times 1,007\,94 \times Z}{12,011 + 1,007\,94 \times Z} \quad (A.9)$$

$$w_{BET} = 100 - w_{ALF} - w_{GAM} \quad (A.10)$$

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:

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

A.2.3 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 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.

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

$$w_{BET} = 100 - (w_{ALF} + w_{GAM} + w_{DEL}) \quad (A.13)$$

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 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 seak. These values allow ranking of its ignition performance. They can also be calculated as follows:

$$\text{CII} = \left(270,795 + 0,103\,8 \times T\right) - 0,25456 \times \rho + 23,708 \times \lg[\lg(v + 0,7)] \quad \text{(A.14)}$$

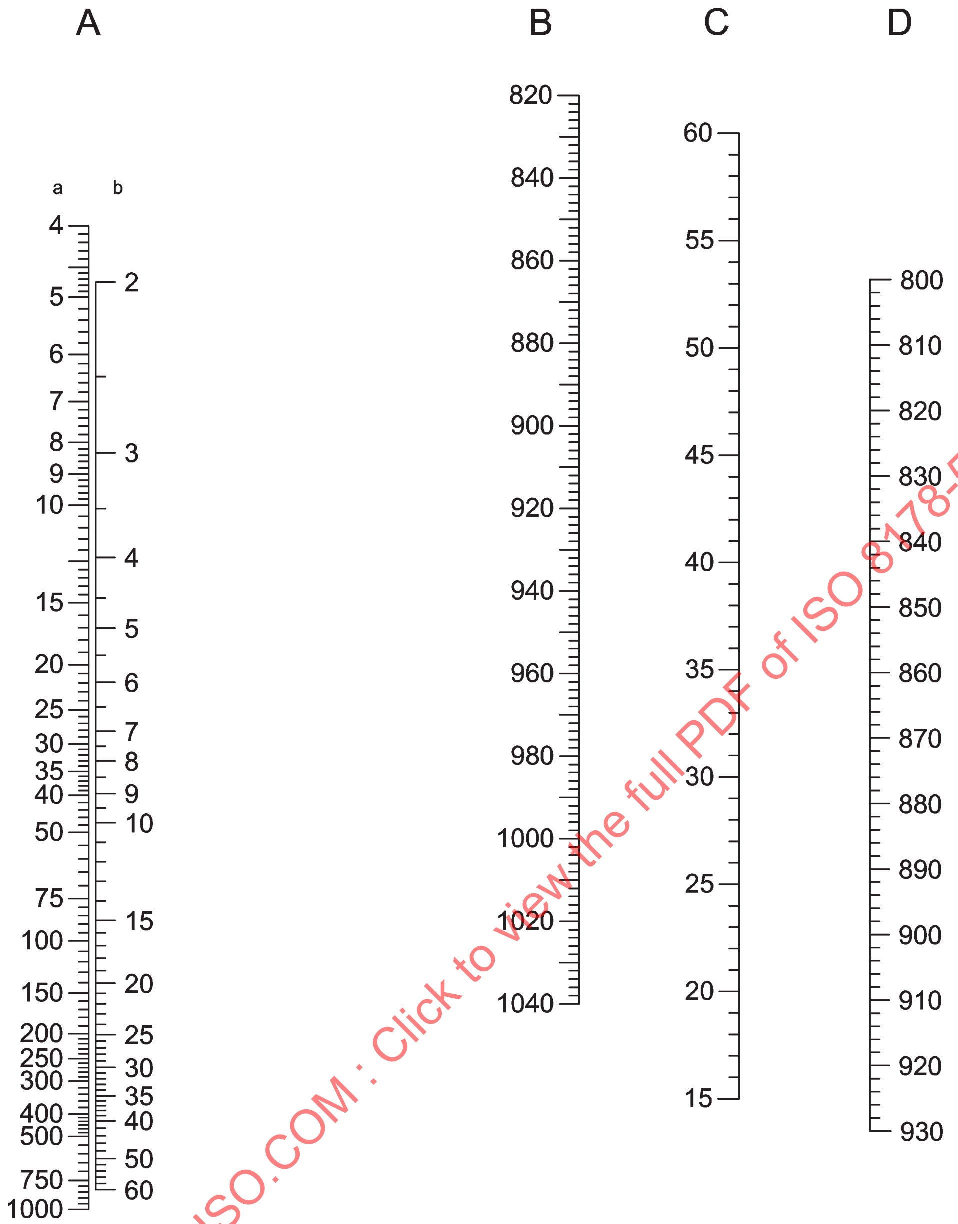
$$\text{CCAI} = \rho - 81 - 141 \times \lg\left[\lg(v + 0,85)\right] - 483 \times \lg\left(\frac{T + 273}{323}\right) \quad \text{(A.15)}$$

where

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 (CII) and the Calculated Carbon Aromaticity Index (CCAI)