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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 8178-5:1997(E)

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.

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.

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

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 at site*

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

— *Part 4: Test cycles for different engine applications*

— *Part 5: Test fuels*

— *Part 6: Test report*

— *Part 7: Engine family determination*

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— *Part 8: Engine group determination*

— *Part 9: Test-bed measurement of exhaust gas smoke emissions from engines used in non-road mobile machinery*

Annex A forms an integral part of this part of ISO 8178. Annexes B, C and D are for information only.

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.

NOTE — 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.

This part of ISO 8178 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. on earth-moving machines, generating sets and for other applications.

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.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 8178. At the time of publication, the editions indicated where valid. All standards are subject to revision, and parties to agreements based on this part of ISO 8178 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2160:1985, *Petroleum products — Corrosiveness to copper — Copper strip test.*

ISO 2719:1988, *Petroleum products and lubricants— Determination of flash point — Pensky-Martens closed cup method.*

ISO 3007:1986, *Petroleum products — 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 operation instructions.*

ISO 3405:1988, *Petroleum products — Determination of distillation characteristics.*

ISO 3675:1993, *Crude petroleum and liquid petroleum products — Laboratory determination of density or relative density — Hydrometer method.*

ISO 3733:1976, *Petroleum products and bituminous materials — Determination of water — Distillation method.*

ISO 3735:1975, *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 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 4264:1995, *Petroleum products — Calculation of cetane index of middle-distillate fuels by the four-variable equation.*

ISO 5163:1990, *Motor and aviation-type fuels — Determination of knock characteristics — Motor method.*

ISO 5164:1990, *Motor fuels — Determination of knock characteristics — Research method.*

ISO 5165:1992, *Diesels fuels — Determination of ignition quality — Cetane method.*

ISO 6245:1993, *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 6974:1984, *Natural gas — Determination of hydrogen, inert gases and hydrocarbons up to C8 — Gas chromatographic method.*

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 8178-1:1996, *Reciprocating internal combustion engines — Exhaust emission measurement — Part 1: Test-bed measurement of gaseous and particulate exhaust emissions.*

ISO 8216-1:1996, *Petroleum products — Fuels (class F) — Classification — Part 1: Categories of marine fuels.*

ISO 8217:1996, *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 spectrometric method after ashing.*

ISO 8754:1992, *Petroleum products — Determination of sulfur content — Energy dispersive X-ray fluorescence method.*

ISO 8973:1997, *Liquefied petroleum gases — Determination of density and vapour pressure by calculation.*

ISO 10370:1993, *Petroleum products — Determination of carbon residue — Micro method.*

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

ASTM D 1319-95a, *Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption.*

ASTM D 3231-94, *Test Method for Phosphorus in Gazoline.*

ASTM D 3606-92, *Test Method for the Determination of Benzene and Toluene in Finished Motor and Aviation Gasoline by Gas Chromatography.*

ASTM D 4420-94, *Test Methods for Aromatics in Light Naphthas, and Aviation Gasolines by Gas Chromatography.*

ASTM D 5186-91, *Test Method for the Determination of Aromatic Content of Diesel Fuels by Supercritical Fluid Chromatography.*

DIN 51413 Teil 7, 1990, *Prüfung flüssiger Mineralöl-Kohlenwasserstoffe — Gaschromatographische Analyse — Teil 7: Bestimmung sauerstoffhaltiger organischer Verbindungen und des organisch gebundenen Sauerstoffs — Verfahren mittels eines sauerstoffspezifischen Detektors (O-FID).* [Testing of liquid mineral oil hydrocarbons; analysis by gas chromatography; determination of oxygenates and the oxygen content; procedure by oxygen-specific detector (O-FID)].

EN 116:1981, *Diesel and domestic heating fuels — Determination of cold filter plugging point.*

EN 238:1996, *Liquid petroleum products — Determination of benzene content-infrared spectrometric method.*

3 Definitions

For the purposes of this part of ISO 8178 the following definitions apply as well as any applicable definitions contained in the standards listed in the tables of annex B.

3.1 carbon residue: Residue formed by evaporation and thermal degradation of a carbon-containing material.

3.2 cetane index: Approximation of the ignition performance of distillate diesel fuel, which does not contain a cetane improver additive, calculated from the density and the distillation basis.

(See also 3.6, **diesel index**.)

3.3 cetane number: Number which characterizes the ignition performance of diesel fuel obtained by comparing it to reference fuels in a standardized test for engines.

(See also 5.5 and 5.6.)

3.4 crude oil: Naturally occurring hydrocarbon mixture, generally in a liquid state, which may also include compounds of sulphur, nitrogen, oxygen, metals and other elements.

3.5 diesel fuel: Any petroleum liquid suitable for the generation of power by combustion in compression ignition diesel engines.

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 normally gaseous hydrocarbons, predominantly propane or butane or both, that has been liquefied by compression or cooling or both, to facilitate storage, transport and handling.

3.8 octane number: For fuels used in spark ignition engines, a number which expresses resistance to knock obtained by comparison with reference fuels in a standardized engine.

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 8178-1:1996, clause 4 and including annex A. Those which are essential for this part of ISO 8178 are repeated below in order to facilitate comprehension.

Symbol		Definition	Unit
According to EEC-UNO regulations	SI[1]		
EAF	E	Excess air factor (in kilogrammes dry air per kilogramme of fuel)	kg/kg
F_{FD}	F_d	Fuel specific factor for exhaust flow calculation on dry basis	1
F_{FH}	F_h	Fuel specific factor used for calculating wet concentration from dry concentration	1
F_{FW}	F_w	Fuel specific factor for exhaust flow calculation on wet basis	1
F_{FCB}	F_{cb}	Fuel specific factor for the carbon balance calculation	1
V_{EXHD}	q_{Vxd}	Exhaust gas volume flow rate on dry basis[2]	m^3/h
V_{AIRD}	q_{Vad}	Intake air volume flow rate on dry basis[2]	m^3/h
V_{AIRW}	q_{Vaw}	Intake air volume flow rate on wet basis[2]	m^3/h
V_{EXHW}	q_{Vxwi}	Exhaust gas volume flow rate on wet basis[2]	m^3/h
G_{FUEL}	q_{mf}	Fuel mass flow rate	kg/h
ALF	w_{H2}	Mass fraction of hydrogen in the fuel	%
BET	w_C	Mass fraction of carbon in the fuel	%
GAM	w_S	Mass fraction of sulfur in the fuel	%
DEL	w_{N2}	Mass fraction of nitrogen in the fuel	%
EPS	w_{O2}	Mass fraction of oxygen in the fuel	%
Z	ζ	Fuel factor for calculation of ALF	1

1) According to ISO 31 on quantities and units.
2) At reference conditions (T = 273,15 K and p = 101,3 kPa).

5 Choice of fuel

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 1, Universal analytical data sheet — Natural gas

— table 2, Universal analytical data sheet — Liquefied petroleum gas

— table 6, Universal analytical data sheet — Motor gasolines

— table 11, Universal analytical data sheet — Diesel fuels

— table 13, Universal analytical data sheet — Distillate fuel oils

— table 14, Universal analytical data sheet — Residual fuel oils

— table 15, 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 8178-1:1996, annex A (see also annex A of this part of ISO 8178). Hydrogen and carbon mass fractions can be obtained by calculation or nomogram. The recommended methods are given in A.3.1, A.3.2 and A.3.3.

NOTE — For non-ISO test methods equivalent to those of ISO standards mentioned in this part of ISO 8178, see annex B.

5.1 Natural gas

Gaseous fuels are not referenced 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 1.

5.2 Liquefied petroleum gas

Liquefied petroleum gas is not referenced 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 2.

5.3 Motor gasolines

5.3.1 Referenced motor gasolines

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

a) CEC[1)] reference fuels: see table 3;

b) USA certification test fuel: see table 4;

c) Japanese certification test fuels: see table 5.

5.3.2 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 6 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.

5.4 Diesel fuels

5.4.1 Diesel reference fuels

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

a) CEC reference fuels: see table 7;

b) USA certification test fuels: see table 8;

c) Californian test fuel: see table 9;

d) Japanese certification test fuel: see table 10.

5.4.2 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 11 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.

5.5 Distillate fuel oils

As there are no existent reference fuels, it is recommended that the fuel used be in accordance with ISO 8216-1 and ISO 8217 (see table 12).

The fuel's properties, including the elemental analysis, shall be measured and reported with the results of the emission measurement. Table 13 represents a universal analytical data sheet giving the properties which shall be reported.

ISO 8216-1 and ISO 8217 do not specify ignition quality, as the CFR[2)] engine measurement procedure is not applicable for fuels containing residues.

The effect of the ignition quality on exhaust gas emissions 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 number 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.

1) Coordinating European Council for the Development of Performance Tests for Transportation Fuels, Lubricants and Other Fluids.

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

5.6 Residual fuel oils

No existent referenced fuels.

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

ISO 8216-1 and ISO 8217 do 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 recognised 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.

5.7 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 15 is given as a recommendation for a data sheet, of the properties to be reported.

5.8 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.

6 Requirements and additional information

For the determination of fuel properties ISO standards shall be used where they exist. Annex B lists standards, established by the standardization organizations, in use in parallel to ISO standards.

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

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

It should be noted that distillates and residual fuel oil typically have a high ash and sulfur content and this will normally result in high particulate levels. In the case of sulfur, this is due to the formation of sulfates and associated water during the dilution.

It should be noted that nitrogen content of the fuel increases the NO_x emission.

Related organisations capable of providing specifications for commercial fuels are given in annex C.

7 Calculation of the exhaust gas flow using fuel specific factors

NOTE — The calculation of the exhaust gas flow is derived from ISO 8178-1 for the following different cases.

7.1 Standard fuels

a) Known air volume flow and known fuel mass flow:

$V_{EXHD} = V_{AIRD} + F_{FD} \times G_{FUEL}$ (for dry emissions)

or

$V_{EXHW} = V_{AIRW} + F_{FW} \times G_{FUEL}$ (for wet emissions)

See ISO 8178-1:1996, 7.2.2.

b) Unknown air volume flow, known CO_2 in exhaust and known fuel mass flow: Use calculation specified in ISO 8178-1:1996, clause A.1.

7.2 Other fuels with known composition

a) Known air volume flow and known fuel mass flow: use the equations given in 7.1 a) with the appropriate factor (F_{FD} or F_{FW}), as specified in clause 8.

b) Unknown air volume flow, known CO_2 or O_2 in exhaust and known fuel mass flow: use derivation specified in ISO 8178-1:1996, clause A.2.

8 Calculation on the fuel specific factors

8.1 Fuel specific factors F_{FD} and F_{FW}

These factors are used for exhaust flow calculation (see clause 7).

The values of the fuel specific factors are calculated as follows, using the concentrations obtained by elementary analysis:

$$F_{FD} = -0{,}055\,64 \times \text{ALF} - 0{,}000\,11 \times \text{BET} - 0{,}000\,17 \times \text{GAM} + 0{,}008\,005\,5 \times \text{DEL} + 0{,}006\,998 \times \text{EPS}$$

$$F_{FW} = 0{,}055\,57 \times \text{ALF} - 0{,}000\,11 \times \text{BET} - 0{,}000\,17 \times \text{GAM} + 0{,}008\,005\,5 \times \text{DEL} + 0{,}006\,998 \times \text{EPS}$$

NOTE — The method used to derive these equations is described in ISO 8178-1:1996, A.2.7.

8.2 Fuel specific factors F_{FH} and F_{FCB}

The derivation of these factors is given in annex A which also contains an additional table with values for some different fuels.

Table 1 — Universal analytical data sheet — Natural gas

Property	Unit	Test method	Result of measurements
Molar fraction of each component	%	ISO 6974	
Mass concentration of sulphur	mg/m^3	ISO 6326-5	

Table 2 — 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 3 — Motor gasolines — CEC reference fuels

[Source: CEC, *Reference fuels manual*]

Property	Unit	Test method	RF-01-A-84 Premium leaded		RF-08-A-85 Premium unleaded	
			min.	max.	min.	max.
Research octane number (RON)	1	ASTM D 2699	98	—	95	—
Motor octane number (MON)	1	ASTM D 2700	—	—	85	—
Sensitivity (RON/MON)	1	ASTM D 2699 ASTM D 2700	—	—	—	—
Density at 15 °C	kg/l	ASTM D 1298	0,741	0,755	0,748	0,762
Reid vapour pressure	kPa	ASTM D 323	56	64	56	64
Distillation		ASTM D86				
Initial boiling point	°C		24	40	24	40
10 % Vol.	°C		42	58	42	58
50 % Vol.	°C		90	110	90	110
90 % Vol.	°C		150	170	155	180
Final boiling point	°C		185	205	190	215
Residue	%	—	—	2	—	2
Hydrocarbon analysis		ASTM D 1319				
Volume fraction of olefins	%		—	20	—	20
Volume fraction of aromatics	%	—	—	45	—	45
Volume fraction of benzene	%	—	—	—	—	5
Mass fraction of sulfur	%	ASTM D 1266 ASTM D 2622 ASTM D 2785	—	0,04	—	0,04
Mass concentration of lead	g/l	ASTM D 3341 ASTM D 3237	0,1 —	0,4 —	 —	— 0,005
Mass concentration of phosphorus	g/l	ASTM D 3231	—	—	—	0,001 3
Oxidation stability						
Induction period	min	ASTM D 525	480	—	480	—
Mass of existent gums per 100 ml	mg	ASTM D 381	—	4	—	4
Copper corrosion at 50 °C	—	ASTM D 130	—	—	—	class 1

Table 4 — Motor gasolines — USA certification test fuel

[Source: *Title 40, Code for Federal Regulations,* 86.113-94]

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		23.9	35.0
10 % Vol.	°C		48,9	57,2
50 % Vol.	°C		93,3	110,0
90 % Vol.	°C		148,9	162,8
Final boiling point	°C		—	212,8
Hydrocarbon analysis		ASTM D 1319		
Volume fraction of olefins	%		—	10
Volume fraction of aromatics	%		—	35
Mass fraction of sulfur	%	ASTM D 1266 ASTM D 2622 ASTM D 2785	—	0,1
Mass concentration of lead	g/l	ASTM D 3341 ASTM D3237	—	0,013
Mass concentration of phosphorus	g/l	ASTM D 3231	—	0,001 3
Oxidation stability	min	ASTM D 525	480	—
Mass of existent gums per 100 ml	mg	ASTM D 381	—	4

Table 5 — Motor gasolines — Japanese certification test fuels

[Source: standard JIS K 2202:1991]

Property	Unit	Test method	Gasoline No. 1		Gasoline No. 2	
			min.	max.	min.	max.
Research octane number (RON)	1	ASTM D 2699	96	—	89	—
Density at 15 °C	kg/l	ASTM D 1298	—	0,783	—	0,783
Reid vapour pressure	kPa	ASTM D 323	44	78	44	78
Distillation		ASTM D 86				
Initial boiling point	°C					
10 % Vol.	°C		—	70	—	70
50 % Vol.	°C		—	125	—	125
90 % Vol.	°C		—	180	—	180
Final boiling point	°C			220		220
Residue at 70 °C	%		—	2	—	2
Oxidation stability	min	ASTM D 525	240	—	240	—
Mass of existent gums per 100 ml	mg	ASTM D 381	—	5	—	5
Copper corrosion at 50 °C	—	ASTM D 130	—	class 1	—	class 1

Table 6 — 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	
Distillation		ISO 3405	
Initial boiling point	°C		
10 % Vol.	°C		
50 % Vol.	°C		
90 % Vol.	°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 4420 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		DIN 51413	
Elemental analysis[2)]			
Mass fraction of carbon	%		
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 7 — Diesels fuels — CEC reference fuels for European certification

[Source: CEC, *Reference fuels manual*]

Property	Unit	Test methods			RF-03-A-84		RF-73-A-93 (low sulfur)		RF-75-T-96	
					min.	max.	min.	max.	min.	max.
Cetane number	1	ISO 5165		ASTM D 613	49	53	49	53	47	50
Density at 15 °C	kg/l	ISO 3675		ASTM D 1298	0,835	0,845	0,835	0,845	0,835	0,845
Distillation		ISO 3405		ASTM D 86						
50 % Vol.	°C				245	—	245	—	—	—
90 % Vol.	°C				320	340	320	340	—	—
Final boiling point	°C				—	370	—	370	—	370
Flash point	°C	ISO 2719		ASTM D 93	55	—	55	—	55	—
Cold filter plulgging point	°C		EN 116		—	−5	—	−5	—	+5
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104		ASTM D 445	2,5	3,5	2,5	3,5	2,5	3,5
Mass fraction of sulfur	%	ISO 8754 ISO 4260	EN 4260	ASTM D 1266 ASTM D 2622 ASTM D 2785		0,3	0,03	0,05	0,1	0,2
Copper corrosion	—	ISO 2160		ASTM D 130	to be report-ed	class 1	—	class 1	—	class 1
Mass fraction of Conradson carbon residue (10 % DR)	%	ISO 10370		ASTM D 189		0,2	—	0,2	—	0,3
Mass fraction of ash	%			ASTM D 482		0,01	—	0,01	—	0,01
Mass fraction of water	%			ASTM D 95 ASTM D 1744		0,05	—	0,05	—	0,05
Neutralisation number	mgKOH/g			ASTM D 974	—	0,2	—	0,2	—	0,2
Oxidation stability	mg/100 ml			ASTM D 2274	—	2,5	—	2,5	—	2,5

Table 8 — Diesel fuels — USA certification tests fuels

[Source: *Title 40, Code for Federal Regulations*, 86.113-94]

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	ASTM D 1298	0,840	0,865
Distillation		ASTM D 86		
Initial boiling point	°C		171,1	204,4
10 % Vol.	°C		204,4	237,8
50 % Vol.	°C		243,3	282,2
90 % Vol.	°C		293,3	332,2
Final boiling point	°C		321,1	365,6
Flash point	°C	ASTM D 93	54,4	—
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 ASTM D 2785	0,03	0,05
Volume fraction of aromatics	%	ASTM D 1319	27	—

Table 9 — 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		171,1	204,4
10 % Vol.	°C		204,4	237,8
50 % Vol.	°C		243,3	282,2
90 % Vol.	°C		293,3	332,2
Final boiling point	°C		321,1	365,6
Flash point	°C	ASTM D 93	54,4	—
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 ASTM D 2785	0,03	0,05
Volume fraction of aromatics	%	ASTM D 1319	—	10

Table 10 — Diesel fuels — Japanese certification test fuel

[Source: standard JIS K 2204:1992]

Property	Unit	Test method	Grade 2 Fuel	
			min.	max.
Cetane index	1	ASTM D 976	45	—
Distillation 90 % Vol.	°C	ASTM D 86	—	350
Flash point	°C	ASTM D 93	50	—
Cold filter plugging point	°C	EN 116	—	−5,5
Pour point	°C	ASTM D 97	—	−7,5
Kinematic viscosity at 30 °C	mm²/s	ASTM D 445	2,5	—
Mass fraction of sulfur	%	ASTM D 1266 ASTM D 2622 ASTM D 2785	—	0,2
Mass fraction of carbon residue (10 % bottom)		ASTM D 189 ASTM D 4530	—	0,1

NOTE — This fuel is also used for Japanese certification tests.

Table 11 — 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 % Vol.	°C		
50 % Vol.	°C		
90 % Vol.	°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	
Neutralisation number	mgKOH/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	%		
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 12 — Distillate fuel oils — ISO class F test fuel oils

[Source: ISO 8217:1996]

Property	Unit	Test method	Fuel ISO-F-DMA		Fuel ISO-F-DMB	
			min.	max.	min.	max.
Cetane number[1]	1	ISO 5165	40	—	35	—
Density at 15 °C	kg/l	ISO 3675	—	0,890	—	0,900
Flash point	°C	ISO 2719	60		60	
Pour point		ISO 3016				
Winter grade	°C		—	– 6	—	0
Summer grade	°C		—	0	—	6
Kinematic viscosity at 40 °C	mm^2/s	ISO 3104	1,5	6,0	—	11
Mass fraction of sulfur	%	ISO 8754	—	1,5	—	2
Mass fraction of carbon residue, Ramsbottom on 10 % residue	%	ISO 4262	—	0,2	—	—
Mass fraction of carbon residue, Ramsbottom	%	ISO 4262	—	—	—	—
Mass fraction of ash	%	ISO 6245	—	0,01	—	0,01
Mass fraction of water	%	ISO 3733	—	—	—	0,3
Mass fraction of sediment	%	ISO 3735	—	—	—	0,07
Visual inspection	—	ISO 8217	2)		—	—

1) Not valid for fuels containing residues.
2) See ISO 8217:1996, subclause 6.2.

Table 13 — 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	%		
Mass fraction of nitrogen	%		
Mass fraction of oxygen	%		

1) Not valid for fuels containing residues.
2) See the ultimate paragraph of clause 5.

Table 14 — 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 100 °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	%		
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 15 — 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
(normative)

Calculation of the fuel specific factors

A.1 Derivation of the factors K_{Wr} and F_{FH}

These factors are used for the calculation of wet concentration from dry concentration according to clause 13.2 of ISO 8178-1:1996.

$$conc(wet) = K_{Wr} \times conc(dry)$$

NOTE — In the following derivation K_{Wr} is written, e.g. KWEXH. The reason is due to names of variables in the program mentioned in ISO 8178-1:1996, annex A which are used throughout this annex.

The derivation of F_{FH} considers dry intake air because equation (17) of ISO 8178-1:1996 deals with water in the intake air separately.

NOTE — Equation (17) mentioned above is considered that which allows the fuel specific factor F_{FH} to be determined. Defined in this way, F_{FH} is a value for the water content of the exhaust gases in relation to the fluel to air ratio.

Table A.1 contains a list of F_{FH} values for different fuels. It will be shown that F_{FH} is not only a fuel specific constant but also depends in a small magnitude, on the fuel to air ratio. A formula for calculating F_{FH} from the hydrogen content of the fuel and the fuel to air ratio will be given. No equation containing F_{FH} defines or calculates the value of F_{FH}.

Equation (17) of ISO 8178-1:1996 considers the water from the combustion and from the intake air to be independent of each other and to be complementary. Equation (A.45) in subclause A.27 of ISO 8178-1:1996 shows that the two water terms are not complementary. Equation (A.45) is correct but is of little use. Therefore the more practical equations (17) to (20) of ISO 8178-1:1996 should be used. They provide very good agreement when compared with equation (A.45) (with a deviation of $< 0{,}2$ % in most cases; see subclause A.2.6 of ISO 8178-1:1996).

$$\mathrm{KWEXH} = 1 - \mathrm{FFH} \times \frac{\mathrm{GFUEL}}{\mathrm{GAIRD}}$$

with $conc(wet) \times V_{EXHW} = conc(dry) \times V_{EXHD}$ (balance of the volumes),

$$\mathrm{KWEXH} = \frac{\mathrm{VEXHD}}{\mathrm{VEXHW}} = \frac{\mathrm{VEXHW} - \mathrm{VH2O}}{\mathrm{VEXHW}} =$$

$$1 - \frac{\mathrm{VH2O}}{\mathrm{VEXHW}} =$$

$$1 - \frac{\frac{\mathrm{GH2O}}{1\,000} \times \mathrm{EXHDENS}}{\frac{\mathrm{MWH2O}}{\mathrm{MVH2O}} \times \mathrm{GEXHW}}$$

and with $\mathrm{GH2O} = \frac{\mathrm{MWH2O}}{2 \times \mathrm{AWH}} \times \mathrm{GFUEL} \times \mathrm{ALF} \times 10$ and $\mathrm{GEXHW} = \mathrm{GAIRW} + \mathrm{GFUEL}$,

$$\mathrm{KEXHW} = 1 - \frac{\mathrm{GFUEL} \times \mathrm{ALF} \times \mathrm{EXHDENS} \times \mathrm{MVH2O}}{200 \times \mathrm{AWH} \times (\mathrm{GAIRW} + \mathrm{GFUEL})} =$$

$$1 - \frac{\mathrm{GFUEL} \times \mathrm{ALF} \times \mathrm{EXHDENS} \times \mathrm{MVH2O}}{\mathrm{GAIRW} \times 200 \times \mathrm{AWH} \times \left(1 + \frac{\mathrm{GFUEL}}{\mathrm{GAIRW}}\right)}$$

$$F_{FH} = FFH = \frac{ALF \times EXHDENS \times MVH20}{200 \times AWH \times \left(1 + \frac{GFUEL}{GAIRW}\right)}$$

This universal formula, applicable for all fuels (with known exhaust density) can be simplified for diesel fuels as follows:

$$F_{FH} = ALF \times 0,1448 \times \frac{1}{1 + \frac{GFUEL}{GAIRW}}$$

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

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

Fuel	Parameter									Density of exhaust gas
	BET %	ALF %	GAM %	EPS %	EAF kg/kg	F_{FH}	F_{FW}	F_{FD}	F_{FCB}	kg/m^3
Diesel	86,2	13,6	0,17	0	1 1,35 3,5	1,783 1,865 1,92	0,749	– 0,767	206,6	1,295 1,296 1,292
Rapeseed methyl ester	77,2	12	0	10,8	1 1,35 3,5	1,478 1,503 1,548	0,734	– 0,601	185	1,305 1,299 1,294
Methanol	37,5	12,6	0	50	1 1,35 3,5	1,605 1,653 1,755	1,045	– 0,354	89,8	1,254 1,263 1,282
Ethanol	52,1	13,1	0	34,7	1 1,35 3,5	1,706 1,748 1,84	0,967	– 0,492	125	1,267 1,273 1,285
Natural gas1)	60,6	19,3	0	1,9	1 1,35 3,5	2,513 2,57 2,68	1,079	– 1,067	145,2	1,242 1,252 1,272
Propane	81,7	18,3	0	0	1 1,35 3,5	2,423 2,471 2,574	1,007	– 1,025	195,8	1,268 1,274 1,286
Butane	82,7	17,3	0	0	1 1,35 3,5	2,304 2,348 2,444	0,955	– 0,972	198,1	1,273 1,278 1,287
Regular unleaded fuel	86,2	13,4	0	0,4	1 1,35 4,35	1,804 1,833 1,894	0,738	– 0,751	206,5	1,295 1,294 1,292
Premium unleaded fuel	86,5	12,9	0	0,6	1 1,35 4,35	1,74 1,767 1,824	0,712	– 0,722	207,3	1,298 1,296 1,293
	85,8	12,2	0	2	1 1,35 4,35	1,648 1,673 1,723	0,683	– 0,673	205,6	1,301 1,299 1,294
Premium leaded fuel	85,7	13,2	0	1,1	1 1,35 4,35	1,777 1,806 1,866	0,732	– 0,735	205,4	1,296 1,295 1,292

1) Volumetric composition: CO_2 1,10 %; N_2 12,1 %; CH_4 84,2 %; C_2H_6 3,42 %; C_3H_8 0,66 %; C_4H_{10} 0,22 %; C_5H_{12} 0,05 %; C_6H_{14} 0,05 %.

A.2 Derivation of the fuel specific factor F_{FCB}

This factor is used for the carbon balance equation of the particulate measurement method.

$$q_i = \frac{FFCB \times GFUEL}{GEXHW \times (CO2DIL - CO2AIR)}$$

and

$$GEDF = \frac{FFCB \times GFUEL}{CO2DIL - CO2AIR}$$

The variable GCO2DIL expresses the calculated equivalent mass flow rate of CO_2 (in grams per hour) in an equivalent full flow tunnel.

$$GCO2DIL = \frac{MWCO2 \times 10}{MVCO2 \times DILEXHDENS} \times (CO2DIL - CO2AIR) \times GEDF$$

$$GFUEL \times BET \times 10 = \frac{MWCO2 \times 10}{MVCO2 \times DILEXHDENS} \times (CO2DIL - CO2AIR) \times GEDF \times \frac{AWC}{MWCO2}$$

$$FFCB = \frac{GEDF \times (CO2DIL - CO2AIR)}{GFUEL} =$$

$$= \frac{BET \times MVCO2 \times DILEXHDENS}{AWC}$$

and, on condition that MVCO2 = 22,26, DILEXHDENS = 1,293 kg/m^3 and AWC = 12,011:

$$F_{FCB} = BET \times 2,396\,3$$

A.3 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.3.1, A.3.2 and A.3.3 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.3.1 Method 1

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

$$ALF = 26 - 15\rho$$

$$BET = 100 - ALF$$

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

A.3.2 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 sulphur content is known.

$$Z = \frac{(209{,}42 - 90{,}92 \times DFUEL)}{(107{,}606 - GAM) \times DFUEL - 17{,}546}$$

$$ALF = \frac{(100 - GAM) \times 1{,}00794 \times Z}{12{,}011 + 1{,}00794 \times Z}$$

$$BET = 100 - ALF - GAM$$

where DFUEL 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:

$$NHCV = 2{,}326 \times 10^{-3} \left[\left(11369{,}54 + \frac{6800{,}84}{DFUEL} - \frac{750{,}83}{DFUEL^2} \right) \times (1 - 0{,}01 \times GAM) + 43{,}7 \times GAM \right]$$

A.3.3 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.

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

$$BET = 100 - (ALF + GAM + DEL)$$

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

A.4 Ignition quality

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

A.4.1 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.4.2 Derivation of CII and CCAI

By use on the nomogram in figure A.2 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:

$$\mathrm{CII} = 270{,}795 + 0{,}1038T - 0{,}25456\rho + 23{,}708 \times \lg[\lg(\nu + 0{,}7)]$$

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

where

T is the temperature in degrees Kelvin;

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

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