INTERNATIONAL STANDARD

ISO 23306

First edition
2020-10

Specification of liquefied natural gas as a fuel for marine applications

Spécification du gaz naturel liquéfié comme carburant pour les applications maritimes

Reference number
ISO 23306:2020(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Foreword

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

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 4, *Classifications and specifications,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 408, *Natural gas and biomethane for use in transport and biomethane for injection in the natural gas grid,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Due to numerous economic and environmental factors, the use of liquefied natural gas (LNG) as fuel for marine applications has increased. The 0,10 % sulfur limit, in the sulfur emission controlled areas in Europe and the US, which entered into force on 1 January 2015 has been one of the major driving forces for using LNG as fuel for marine applications. The decision for the 0,50 % global sulfur limit from 1 January 2020 by the International Maritime Organization (IMO) might further increase the interest in LNG. The International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) was a response to the need of guidance in this emerging market. Since LNG-fueled vessels are likely to bunker LNG in different parts of the world, a common specification is needed for ship owners, ship operators and LNG suppliers. It would help engine manufacturers and ship designers and it is beneficial for the development of this new alternative marine fuel market.

In 2018, IMO adopted an initial strategy on reduction of greenhouse gas (GHG) emissions from ships. The strategy includes the objective to peak GHG emissions from international shipping as soon as possible, whilst pursuing efforts towards decarbonizing the sector as soon as possible in this century. It also includes the objectives to reduce the CO_2 emissions per transport work and total annual GHG emissions from international shipping by 2050, with an interim target in 2030. Thus, LNG produced from renewable sources as biomethane that can reduce CO_2 emissions when used as marine fuel is also addressed in this document.

LNG is produced in different locations in the world in liquefaction plants. Large scale production facilities are often dedicated to specific markets such as natural gas grids and large power plants that use their own standards. This document takes into consideration this major constraint for any adaptation to marine applications specificities/requirements.

Specification of liquefied natural gas as a fuel for marine applications

1 Scope

This document specifies the quality requirements for Liquefied Natural Gas (LNG) used as a fuel for marine applications. It defines the relevant parameters to measure as well as the required values and the test reference methods for all those parameters.

This document applies to LNG from any source, e.g. gas from conventional reservoirs, shale gas, coalbed methane, biomethane, synthetic methane. LNG described in this document can come from synthesis process out of fossil fuels or renewable sources.

This document identifies the required specifications for fuels delivered at the time and place of custody transfer (at the delivery point).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6578, *Refrigerated hydrocarbon liquids — Static measurement — Calculation procedure*

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

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

ISO 8943, *Refrigerated light hydrocarbon fluids — Sampling of liquefied natural gas — Continuous and intermittent methods*

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

3 Terms and definitions

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

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

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
biomethane
methane rich gas derived from biogas or from gasification of biomass by upgrading with the properties similar to natural gas

[SOURCE: ISO 14532:2014, 2.1.1.15]

3.2
liquefied natural gas
LNG
natural gas that has been liquefied after processing

[SOURCE: ISO 14532:2014, 2.1.1.12, modified — Definition has been shortened, note to entry has been deleted.]

3.3
methane number
MN
rating indicating the knocking characteristics of a fuel gas

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

[SOURCE: ISO 14532:2014, 2.6.6.1]

3.4
natural gas
complex gaseous mixture of hydrocarbons, primarily methane, but generally includes ethane, propane and higher hydrocarbons, and some non-combustible gases such as nitrogen and carbon dioxide

Note 1 to entry: Natural gas can also contain components or contaminants such as sulfur compounds and/or other chemical species.

[SOURCE: ISO 14532:2014, 2.1.1.1]

3.5
Wobbe index
calorific value on a volumetric basis at specified reference conditions, divided by the square root of the relative density at the same specified metering reference conditions

[SOURCE: ISO 14532:2014, 2.6.4.3, modified — Note to entry has been deleted.]

4 General requirements

4.1 The LNG at the delivery point shall conform with the characteristics and limits given in Table 1 when tested in accordance with the specified methods.

The components listed in Table 1 and Table 2 shall be measured to enable the calculation of the physical properties of the LNG at the delivery point.

4.2 The LNG delivered shall be free from any material at a concentration that causes the LNG to be unacceptable for use, i.e. material not at a concentration that is harmful to personnel, jeopardizes the safety of the ship, or adversely affects the performance of the machinery.

4.3 Physicochemical characteristics not requiring measurement are listed in Table 3.

It is not practical to require detailed chemical analysis for each delivery of fuels beyond the requirements listed in Table 1 or Table 2. Instead, a liquefaction plant, LNG terminal or any other supply facility, including supply barges and truck deliveries, shall have in place adequate quality assurance and management of change procedures to ensure that the resultant LNG is in conformance with the requirements of this document.

Examples of LNG compositions are given in Annex B.

Information on ageing of LNG can be found in Annex D and information on particles can be found in Annex E.

4.4 The reference conditions shall be 288,15 K, 101,325 kPa (see ISO 13443:1996, Clause 3) in the gaseous phase.

5 Sampling

Samples for quality verification are not mandatory but can be taken at various locations as agreed among the parties concerned. Samples, if any, can also be taken at multiple moments in time, as LNG has distinct different ageing characteristics than traditional hydrocarbon maritime fuels (with regards to ageing reference is made to Annex D). In order to ensure a representative sample, proper sampling procedures should be followed.

When sampling of LNG for analysis is carried out, it shall be in accordance with the procedures provided in ISO 8943 or an equivalent national standard agreed between the parties concerned. Where specific sampling requirements are documented, the relevant parties should agree on the reference test methods. The LNG collected in liquid state shall be instantly conditioned to gaseous state without any partial vaporization or loss of molecular components to ensure a representative sample.

There are two methods for sampling LNG as defined in ISO 8943, continuous and intermittent. Both methods obtain LNG from the LNG cargo/bunker line and then it is gasified in a vaporizer. The continuous method collects the gasified LNG in a sample holder at a constant flow rate for offline analysis. The intermittent method collects gasified LNG and directs it to an on-line analyzer at predetermined intervals. Please refer to ISO 8943 for more details on these methods.

The requirements for sampling LNG for marine applications can vary throughout the industry, depending on availability and equipment. Load port samples can be used for quality determination if the sampling equipment is not available and if it is agreed between the parties.

6 Requirements, limit values and related test methods

The components and physicochemical characteristics that shall be measured or calculated using the related test methods are given in Table 1 and Table 2.

NOTE Information can be found in ISO 6975[1].

Information on MN and Wobbe index can be found in Annex C.

Table 1 — Physicochemical characteristics requiring measurement/calculation with limit values

Characteristic	Unit	Limit	Value	Test method
Net Calorific Value (NCV)	MJ/m^3 (s)	Min	33,6[a]	ISO 6976
Nitrogen	% (mol)	Max	1,0	ISO 6974 (all parts)
Methane Number (MN)	no unit	Min	[b]	Annex A (Propane knock index) or EN 16726

[a] Calculated for a theoretical mixture of 99 % (mol) methane and 1 % (mol) nitrogen in liquid phase. The Gross Calorific Value can be calculated from the Net Calorific Value (see ISO 13443:1996).

[b] Both the method used for determining the MN and the minimum value shall be agreed between supplier and user.

The fuel supplier shall calculate the actual MN at the delivery point and provide this information to the user (see Clause 5 for sampling location). This information shall be given as MN $_{\text{(PKI)}}$ or MN $_{\text{(EN 16726)}}$. For guidance on the MN applicability to a specific application, Original Equipment Manufacturer (OEM) specifications should be considered.

Table 2 — Physicochemical characteristics requiring measurement without limit values

Characteristic	Unit	Test method	Value
Density[a]	kg/m^3	ISO 6578	Report
Methane (CH_4)	% (mol)	ISO 6974 (all parts)	Report
Ethane (C_2H_6)	% (mol)	ISO 6974 (all parts)	Report
Propane (C_3H_8)	% (mol)	ISO 6974 (all parts)	Report
n-Butane (C_4H_{10}) i-Butane	% (mol)	ISO 6974 (all parts)	Report
Pentane(C_5H_{12})	% (mol)	ISO 6974 (all parts)	Report

[a] Density at temperature of the liquid phase.

7 Main compounds removed by liquefaction process

Natural gas is liquid at around −160 °C under atmospheric pressure and becomes Liquefied Natural Gas (LNG). To avoid freezing and plugging in the liquefaction plant's cryogenic heat exchangers, usual impurities or compounds that are present in the natural gas from various sources are removed upstream from the liquefaction process below their solubility level. Some LNG components (e.g. ethane, propane, butane and pentane) are possibly removed for commercial reasons or to achieve a targeted calorific value range.

LNG composition is therefore within more narrow limits compared to natural gas. The compounds that can be considered as harmful for marine applications are removed or reduced to very low levels (trace) so that they are no more a concern. They shall comply with 4.2. The main compounds removed by liquefaction are listed in Table 3 and below for information and reference. The measurement of these species is not required. However, if the parties concerned agree to measure them, they should be measured according to the referenced methods listed in Table 3.

The melting and boiling points for a range of compounds, including those possibly present in biomethane, are available in Table F.1.

Table 3 — Main compounds removed by liquefaction and not requiring measurement

Characteristic	Unit	Test method	Solubility limit in LNG (around −160 °C, atm. Pressure)	Typical value out of LNG plant	Remarks
Hexane and higher hydrocarbons	% (mol)	ISO 6974 (all parts)	n.a.	n.a.	n.a.
Total sulfur	mg(S)/m^3	ISO 19739[5] ISO 20729[6]	(n.a.)	Max 30 mg(S)/m^3 (gas)	Depends on LNG contracts. Actual value very often much lower.
Hydrogen sulfide	mg/m^3	ISO 19739	n.a.	4,29 mg/m^3 (N)	Removed in Acid Gas Removal Unit (AGRU) in liquefaction plant for safety purposes.
Mercaptan	mg/m^3	ISO 19739	Depends on size of molecule	n.a.	Removed in AGRU or in heavy hydrocarbon removal unit in liquefaction plant.
Carbon dioxide	% (mol)	ISO 6974 (all parts)	Around 0,02 % (mol)	0,005 % (mol)	Removed in AGRU in liquefaction plant.
Oxygen	% (mol)	ISO 6974 (all parts)	n.a.	n.a.	Removed in liquefaction plant
Water	mg/m^3	ISO 10101[3]	Below 0,74 mg/m^3	0,74 mg/m^3 or below	Removed in dehydration unit in liquefaction plant
Mercury	µg/m^3	ISO 6978-2[2]	n.a.	0,01 µg/m^3	Removed in liquefaction plant

NOTE See Annex F for components in low concentration or absent, e.g. siloxanes.

n.a. Not available.

Annex A
(normative)

Propane knock index: Methane number calculation method

The MN of a gaseous fuel can be calculated from its composition according to several different methods, all of which can give different results. The methodology described in this Annex shall be employed to calculate MN $_{(PKI)}$.

For components listed in Table 3, the mole fraction can be taken as equal to "0".

DNV GL®[1] developed a MN method ("PKI MN") that characterizes gases for their knock resistance based on the combustion properties of the fuel mixtures themselves. The PKI MN method is based on a methane-propane scale (PKI, Propane Knock Index)[8] where the knock resistance of gas composition is compared to the knock resistance of a methane-propane gas mixture under identical engine conditions.

To calculate the PKI values a polynomial, Formula (A.1) is used:

$$PKI = \sum \alpha_{i^n} X_i^n + \sum \beta_{i^n * j^m} X_i^n X_j^m \qquad \text{(A.1)}$$

where

X is the (normalized) mole fraction,

i = CH_4, C_2H_6, C_3H_8, i-C_4H_{10}, n-C_4H_{10}, n-C_5H_{12}, i-C_5H_{12}, neo-C_5H_{12}, CO_2, CO, H_2 and N_2;

j = C_2H_6, C_3H_8, i-C_4H_{10}, n-C_4H_{10}, n-C_5H_{12}, i-C_5H_{12}, neo-C_5H_{12}, CO_2, CO, H_2 and N_2;

n = 1 to 4;

m = 1, 2;

α and β values are given in Table A.2.

The calculation is valid for PKI values ≤20 (or $MN_{(PKI)}$≥ 53, see below) and the gas composition range in Table A.1.

Table A.1 — Gas composition range

Species	Min, mol %	Max, mol %
CH_4	65	100
C_2H_6	0	20
C_3H_8	0	20
i-C_4H_{10}	0	5
n-C_4H_{10}	0	5
n-C_5H_{12}	0	2
i-C_5H_{12}	0	2
neo-C_5H_{12}	0	2
C_6+	0	1,5
H_2	0	20

---

[1] DNV GL is a trademark of DNV GL AS. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO.

Table A.1 *(continued)*

Species	Min, mol %	Max, mol %
CO	0	10
CO_2	0	20
N_2	0	20
H_2S	0	0,5

To account for the presence of C_6+ and H_2S in the gas mixture scaling factors are derived based on autoignition measurements in a rapid compression machine at DNV GL®1). These scaling factors are used in the algorithm to translate the effect of C_6+ and H_2S on the knock resistance of a gas mixture to an equivalent fraction of n-C_5H_{12}. The factors are used to correct the methane and n-pentane mole fractions as in Formulae (A.2) and (A.3).

$$X_{CH4,new} = X_{CH4\,in\,gasmixture} - 0{,}3 \times X_{C6+} \tag{A.2}$$

$$X_{nC5H12,new} = X_{nC5H12\,in\,gasmixture} + X_{H2S} + 1{,}3 \times X_{C6+} \tag{A.3}$$

Where X denotes the mole fraction. Here we note that the results of the algorithm are only valid if the total mole percentages of the gas mixture is 100 %.

Table A.2 — α and β coefficients in Formula (A.1)

Coefficient	Value	Description
α_{CH4}	569,285 536 016 002 0	CH_4
$\alpha_{(\mathrm{CH4})}{}^{2}$	−650,854 339 490 7	CH_4^2
$\alpha_{(\mathrm{CH4})}{}^{3}$	64,359 575 257 386 2	CH_4^3
$\alpha_{(\mathrm{CH4})}{}^{4}$	17,214 959 222 053 6	CH_4^4
α_{C2H6}	−645,099 966 662 855 0	C_2H_6
$\alpha_{(\mathrm{C2H6})}{}^{2}$	694,229 376 857 102 0	C_2H_6^2
$\alpha_{(\mathrm{C2H6})}{}^{3}$	−675,381 075 231 165 0	C_2H_6^3
$\alpha_{(\mathrm{C2H6})}{}^{4}$	1 474,790 791 373 33	C_2H_6^4
α_{C3H8}	499,398 492 651 52	C_3H_8
$\alpha_{(\mathrm{C3H8})}{}^{2}$	−576,665 945 472 394 0	C_3H_8^2
$\alpha_{(\mathrm{C3H8})}{}^{3}$	252,193 674 060 28	C_3H_8^3
$\alpha_{(\mathrm{C3H8})}{}^{4}$	593,958 975 466 507 0	C_3H_8^4
$\alpha_{\mathrm{n\text{-}C4H10}}$	934,466 273 223 240 0	N_C_4
$\alpha_{(\mathrm{n\text{-}C4H10})}{}^{2}$	−86,872 357 077 023 8	N_C_4^2
$\alpha_{(\mathrm{n\text{-}C4H10})}{}^{3}$	−20 418,906 767 397 9	N_C_4^3
$\alpha_{(\mathrm{n\text{-}C4H10})}{}^{4}$	633 286,561 358 521 0	N_C_4^4
$\alpha_{\mathrm{iso\text{-}C4H10}}$	735,223 884 113 728 0	I_C_4
$\alpha_{(\mathrm{iso\text{-}C4H10})}{}^{2}$	−3 182,614 393 379 67	I_C_4^2
$\alpha_{(\mathrm{iso\text{-}C4H10})}{}^{3}$	20 945,186 725 021 9	I_C_4^3
$\alpha_{(\mathrm{iso\text{-}C4H10})}{}^{4}$	159 067,868 032 595 0	I_C_4^4
$\alpha_{\mathrm{n\text{-}C5H12}}$	2 571,930 793 605 35	N_C_5
$\alpha_{(\mathrm{n\text{-}C5H12})}{}^{2}$	10 516,494 109 227 50	N_C_5^2
$\alpha_{(\mathrm{n\text{-}C5H12})}{}^{3}$	−770 539,377 197 693	N_C_5^3
$\alpha_{(\mathrm{n\text{-}C5H12})}{}^{4}$	28 633 475,586 565 4	N_C_5^4
$\alpha_{\mathrm{iso\text{-}C5H12}}$	−3 582,967 844 353 79	I_C_5
$\alpha_{(\mathrm{iso\text{-}C5H12})}{}^{2}$	0	I_C_5^2

Table A.2 *(continued)*

Coefficient	Value	Description
$\alpha_{(\text{iso-C5H12})}{}^3$	403 155,950 864 334	I_C$_5$^3
$\alpha_{(\text{iso-C5H12})}{}^4$	−11 917 333,837 932 9	I_C$_5$^4
$\alpha_{\text{neo-C5H12}}$	1 123,396 367 098 65	NEC$_5$
$\alpha_{(\text{neo-C5H12})}{}^2$	1 679,728 075 248 10	NEC$_5$^2
$\alpha_{(\text{neo-C5H12})}{}^3$	−172 182,649 067 176	NEC$_5$^3
$\alpha_{(\text{neo-C5H12})}{}^4$	3 467 918,607 466 990	NEC$_5$^4
α_{N2}	−469,428 097 827 742	N$_2$
$\alpha_{(\text{N2})}{}^2$	352,688 107 288 763	N$_2$^2
$\alpha_{(\text{N2})}{}^3$	−220,491 687 402 358	N$_2$^3
$\alpha_{(\text{N2})}{}^4$	1 419,680 053 962 420	N$_2$^4
α_{CO2}	−953,460 328 339 263	CO$_2$
$\alpha_{(\text{CO2})}{}^2$	1 148,487 258 682 280	CO$_2$^2
$\alpha_{(\text{CO2})}{}^3$	−601,339 855 375 907	CO$_2$^3
$\alpha_{(\text{CO2})}{}^4$	448,125 565 457 084	CO$_2$^4
α_{CO}	−5 813,759 963 900 21	CO
$\alpha_{(\text{CO})}{}^2$	5 511,721 025 828 67	CO^2
$\alpha_{(\text{CO})}{}^3$	1 647,043 065 843 26	CO^3
$\alpha_{(\text{CO})}{}^4$	−3 471,241 525 554 25	CO^4
α_{H2}	−906,859 878 136 883	H$_2$
$\alpha_{(\text{H2})}{}^2$	1 059,747 810 140 28	H$_2$^2
$\alpha_{(\text{H2})}{}^3$	−1 302,861 581 498 63	H$_2$^3
$\alpha_{(\text{H2})}{}^4$	3 639,859 493 045 20	H$_2$^4
$\beta_{\text{CH4}\times\text{C2H6}}$	201,788 909 592 169	CH$_4$*C$_2$H$_6$
$\beta_{\text{CH4}\bullet\text{C3H8}}$	−865,856 657 223 225	CH$_4$*C$_3$H$_8$
$\beta_{\text{CH4}\bullet\text{n-C4H10}}$	−1 210,227 541 932 4	CH$_4$*N_C$_4$
$\beta_{(\text{CH4}\bullet\text{n-C4H10})}{}^2$	1 331,555 523 696 450	(CH$_4$*N_C$_4$)^2
$\beta_{\text{CH4}\bullet\text{iso-C4H10}}$	−1 023,278 147 470 3	CH$_4$*I_C$_4$
$\beta_{(\text{CH4}\times\text{iso-C4H10})}{}^2$	1 550,095 184 612 58	(CH4*I_C4)^2
$\beta_{\text{CH4}\times\text{n-C5H12}}$	−2 811,677 404 325 23	CH4*N_C5
$\beta_{\text{CH4}\times\text{iso-C5H12}}$	3 363,981 505 063 56	CH4*I_C5
$\beta_{\text{CH4}\times\text{neo-C5H12}}$	−1 534,525 674 887 23	CH4*NEC5
$\beta_{\text{CH4}\times\text{N2}}$	−1,053 973 329 306 09	CH4*N2
$\beta_{\text{CH4}\times\text{CO2}}$	473,574 764 109 71	CH4*CO2
$\beta_{(\text{CH4}\times\text{CO2})}{}^2$	−308,259 010 229 21	(CH4*CO2)^2
$\beta_{\text{CH4}\times\text{CO}}$	5 356,433 570 549 5	CH4*CO
$\beta_{\text{CH4}\times\text{H2}}$	118,685 621 913 274	CH4*H2
$\beta_{\text{CH4}\times(\text{H2})^2}$	252,885 168 496 247	CH4*(H2^2)
$\beta_{(\text{CH4})^2\times\text{H2}}$	325,305 174 695 724	(CH4^2)*H2
$\beta_{\text{C2H6}\times\text{C3H8}}$	0	C2H6*C3H8
$\beta_{\text{C2H6}\times\text{n-C4H10}}$	−437,695 363 730 406	C2H6*N_C4
$\beta_{\text{C2H6}\times\text{iso-C4H10}}$	−109,983 789 902 769	C2H6*I_C4
$\beta_{\text{C2H6}\times\text{n-C5H12}}$	−1 870,347 465 005 63	C2H6*N_C5
$\beta_{\text{C2H6}\times\text{iso-C5H12}}$	3 909,509 060 762 45	C2H6*I_C5
$\beta_{\text{C2H6}\times\text{neo-C5H12}}$	−886,578 525 827 322	C2H6*NEC5

Table A.2 *(continued)*

Coefficient	Value	Description
$\beta_{\mathrm{C2H6} \times \mathrm{N2}}$	968,887 620 927 515	C2H6*N2
$\beta_{(\mathrm{C2H6})^2 \times \mathrm{N2}}$	267,472 766 191 96	(C2H6^2)*N2
$\beta_{\mathrm{C2H6} \times (\mathrm{N2})^2}$	337,464 863 958 288	C2H6*(N2^2)
$\beta_{\mathrm{C2H6} \times \mathrm{CO2}}$	1 431,950 116 993 15	C2H6*CO2
$\beta_{\mathrm{C2H6} \times \mathrm{CO}}$	6 463,144 442 956 27	C2H6*CO
$\beta_{\mathrm{C2H6} \times \mathrm{H2}}$	1 865,090 903 843 57	C2H6*H2
$\beta_{\mathrm{C3H8} \times \mathrm{n\text{-}C4H10}}$	−118,490 180 710 956	C3H8*N_C4
$\beta_{\mathrm{C3H8} \times \mathrm{iso\text{-}C4H10}}$	0	C3H8*I_C4
$\beta_{\mathrm{C3H8} \times \mathrm{n\text{-}C5H12}}$	−1 734,805 682 394 27	C3H8*N_C5
$\beta_{\mathrm{C3H8} \times (\mathrm{n\text{-}C5H12})^2}$	127 551,642 193 201	C3H8*(N_C5^2)
$\beta_{(\mathrm{C3H8})^2 \times \mathrm{n\text{-}C5H12}}$	11 318,418 395 072 2	(C3H8^2)*N_C5
$\beta_{\mathrm{C3H8} \times \mathrm{iso\text{-}C5H12}}$	3 318,968 208 193 38	C3H8*I_C5
$\beta_{\mathrm{C3H8} \times \mathrm{neo\text{-}C5H12}}$	0	C3H8*NEC5
$\beta_{\mathrm{C3H8} \times \mathrm{N2}}$	13,345 337 812 469	C3H8*N2
$\beta_{\mathrm{C3H8} \times \mathrm{CO2}}$	292,275 289 330 565	C3H8*CO2
$\beta_{\mathrm{C3H8} \times \mathrm{CO}}$	5 403,502 607 948 29	C3H8*CO
$\beta_{(\mathrm{C3H8})^2 \times \mathrm{CO}}$	2 333,823 463 429 21	(C3H8^2)*CO
$\beta_{\mathrm{C3H8} \times \mathrm{H2}}$	957,887 281 487 301	C3H8*H2
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{iso\text{-}C4H10}}$	3 500,702 828 522 74	N_C4*I_C4
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{n\text{-}C5H12}}$	−4 737,328 494 949 99	N_C4*N_C5
$\beta_{\mathrm{n\text{-}C4H10} \times (\mathrm{n\text{-}C5H12})^2}$	525 591,310 711 326	NC4*(NC5^2)
$\beta_{(\mathrm{n\text{-}C4H10})^2 \times \mathrm{n\text{-}C5H12}}$	297 556,039 242 685	(NC4^2)*NC5
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{iso\text{-}C5H12}}$	6 095,059 988 750 87	N_C4*I_C5
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{neo\text{-}C5H12}}$	−953,002 183 779 388	N_C4*NEC5
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{N2}}$	0	N_C4*N2
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{CO2}}$	−103,571 484 346 062	N_C4*CO2
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{CO}}$	5 869,190 506 527 74	N_C4*CO
$\beta_{\mathrm{n\text{-}C4H10} \times \mathrm{H2}}$	1 267,619 534 835 89	N_C4*H2
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{n\text{-}C5H12}}$	5 056,603 091 637 61	I_C4*N_C5
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{iso\text{-}C5H12}}$	6 619,278 776 370 44	I_C4*I_C5
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{neo\text{-}C5H12}}$	−1 363,961 016 448 41	I_C4*NEC5
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{N2}}$	14,803 895 799 972 4	I_C4*N2
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{CO2}}$	211,752 602 673 394	I_C4*CO2
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{CO}}$	5 786,325 257 174 88	I_C4*CO
$\beta_{\mathrm{iso\text{-}C4H10} \times \mathrm{H2}}$	1 458,460 720 431 54	I_C4*H2
$\beta_{\mathrm{n\text{-}C5H12} \times \mathrm{iso\text{-}C5H12}}$	12 268,283 772 748	N_C5*I_C5
$\beta_{\mathrm{n\text{-}C5H12} \times \mathrm{neo\text{-}C5H12}}$	0	N_C5*NEC5
$\beta_{\mathrm{n\text{-}C5H12} \times \mathrm{N2}}$	−1 573,688 937 706 25	N_C5*N2
$\beta_{\mathrm{n\text{-}C5H12} \times \mathrm{CO2}}$	−898,466 856 535 774	N_C5*CO2
$\beta_{(\mathrm{n\text{-}C5H12})^2 \times \mathrm{CO2}}$	−42 401,411 139 182 4	(N_C5^2)*CO2
$\beta_{\mathrm{n\text{-}C5H12} \times \mathrm{CO}}$	3 985,110 420 511 03	N_C5*CO
$\beta_{(\mathrm{n\text{-}C5H12})^2 \times \mathrm{CO}}$	48 265,319 103 373 7	(N_C5^2)*CO
$\beta_{\mathrm{n\text{-}C5H12} \times \mathrm{H2}}$	−1 112,443 527 705 6	N_C5*H2
$\beta_{(\mathrm{n\text{-}C5H12})^2 \times \mathrm{H2}}$	99 558,333 341 943 2	(N_C5^2)*H2

Table A.2 *(continued)*

Coefficient	Value	Description
$\beta_{\text{iso-C5H12} \times \text{neo-C5H12}}$	3 773,449 267 853 97	I_C5*NEC5
$\beta_{\text{iso-C5H12} \times \text{N2}}$	4 490,678 300 326 75	I_C5*N2
$\beta_{\text{iso-C5H12} \times \text{CO2}}$	5 122,009 935 455 09	I_C5*CO2
$\beta_{(\text{iso-C5H12})^2 \times \text{CO2}}$	−28 087,848 186 432 6	(I_C5^2)*CO2
$\beta_{\text{iso-C5H12} \times \text{CO}}$	10 248,340 825 423 2	I_C5*CO
$\beta_{\text{iso-C5H12} \times \text{H2}}$	5 464,934 669 232 21	I_C5*H2
$\beta_{\text{neo-C5H12} \times \text{H2}}$	−642,170 828 416 611	NEC5*N2
$\beta_{\text{neo-C5H12} \times \text{CO2}}$	0	NEC5*CO2
$\beta_{(\text{neo-C5H12})^2 \times \text{CO2}}$	−11 320,112 689 948 1	(NEC5^2)*CO2
$\beta_{\text{neo-C5H12} \times \text{CO}}$	4 772,677 301 186 82	NEC5*CO
$\beta_{\text{neo-C5H12} \times \text{H2}}$	0	NEC5*H2
$\beta_{\text{N2} \times \text{CO2}}$	1 156,200 327 160 21	N2*CO2
$\beta_{(\text{N2})^2 \times \text{CO2}}$	359,342 203 118 816	(N2^2)*CO2
$\beta_{\text{N2} \times \text{CO}}$	6 076,818 092 916 31	N2*CO
$\beta_{(\text{N2})^2 \times \text{CO}}$	389,853 153 629 781	(N2^2)*CO
$\beta_{\text{N2} \times (\text{CO})^2}$	367,319 351 280 689	N2*(CO^2)
$\beta_{\text{N2} \times \text{H2}}$	1 506,655 641 914 57	N2*H2
$\beta_{\text{CO2} \times \text{CO}}$	6 557,376 349 418 7	CO2*CO
$\beta_{(\text{CO2} \times \text{CO})^2}$	1 824,585 879 374 03	(CO2*CO)^2
$\beta_{\text{CO2} \times \text{H2}}$	1 924,917 595 080 54	CO2*H2
$\beta_{(\text{CO2} \times \text{H2})^2}$	−1 656,219 745 263 47	(CO2*H2)^2
$\beta_{\text{CO} \times \text{H2}}$	6 896,458 388 070 18	CO*H2
$\beta_{(\text{CO} \times \text{H2})^2}$	911,791 848 875 967	(CO*H2)^2

To put the method on a scale analogous to the currently used methane number methods, the propane-based scale (PKI) has been converted to a 0 - 100 scale, referred to as MN $_{\text{(PKI)}}$in Formula (A.4):

$$MN_{\text{(PKI)}} = a_1\, PKI + a_2\, PKI\text{\^{}}2 + a_3\, PKI\text{\^{}}3 + a_4\, PKI\text{\^{}}4 + a_5\, PKI\text{\^{}}5 + a_6\, PKI\text{\^{}}6 + b \qquad \text{(A.4)}$$

By using Formula (A.4) and the coefficients presented in Table A.3, the PKI values calculated by using Formula (A.1) are converted to a MN $_{\text{(PKI)}}$.

Table A.3 — coefficients in Formula (A.4) for conversion of PKI into MN $_{\text{(PKI)}}$

Coefficients	Values
a_1	−9,757 977
a_2	1,484 961
a_3	−0,139 533
a_4	0,007 031 306
a_5	−0,000 177 002 9
a_6	0,000 001 751 212
b	100

EXAMPLE

In general, α values are for the individual components and β values are for the interaction between individual components.

For example, if we consider a mixture of 90 % CH_4 and 10 % C_2H_6 then the PKI can be calculated using Formula (A.1) in the document.

$X_{\mathrm{CH4}} = 0{,}9$

$X_{\mathrm{C2H6}} = 0{,}1$

PKI = X_{CH4}*α_{CH4} + $(X_{\mathrm{CH4}})^{2*}(\alpha_{\mathrm{CH4}})^2$ +$(X_{\mathrm{CH4}})^{3*}(\alpha_{\mathrm{CH4}})^3$ +$(X_{\mathrm{CH4}})^{4*}(\alpha_{\mathrm{CH4}})^4$ + X_{C2H6}*α_{C2H6} + $(X_{\mathrm{C2H6}})^{2*}(\alpha_{\mathrm{C2H6}})^2$ + $(X_{\mathrm{C2H6}})^{3*}(\alpha_{\mathrm{C2H6}})^3$ + $(X_{\mathrm{C2H6}})^{4*}(\alpha_{\mathrm{C2H6}})^4$ + X_{CH4}*X_{C2H6}*$\beta_{\mathrm{CH4xC2H6}}$ =

(see also values in Table A.2)

0,9*569,285 536 016 002 0 + (0,9*0,9)* −650,854 339 490 7 + (0,9*0,9*0,9)* 64,359 575 257 386 2 + (0,9*0,9*0,9*0,9)* 17,214 959 222 053 6+ 0,1*−645,099 966 662 855 0 + (0,1*0,1)* 694,229 376 857 102 0 + (0,1*0,1*0,1)* −675,381 075 231 165 0 + (0,1*0,1*0,1*0,1)* 1 474,790 791 373 33 +

0,1*0,9*201,788 909 592 169 = 3,4

Thus, a PKI value of 3,4 is calculated for this mixture.

Next, using Formula (A.4), we can calculate the MN $_{\mathrm{(PKI)}}$ using the values from Table A.3:

MN $_{\mathrm{(PKI)}}$=a_1 PKI+a_2 PKI^2+a_3 PKI^3+a_4 PKI^4+a_5 PKI^5+a_6 PKI^6+b

=−9,757 977*3,4 + 1,484 961*(3,4*3,4) + −0,139 533*(3,4*3,4*3,4)+ 0,007 031 306*(3,4*3,4*3,4*3,4) + −0,000 177 002 9*(3,4*3,4*3,4*3,4*3,4) + 0,000 001 751 212*(3,4*3,4*3,4*3,4*3,4*3,4) + 100 = 79

Please note that 0,9*0,9 is mathematically equal to $(0{,}9)^2$. In Formula (A.1), this is shown as (for example in this case with $X_{\mathrm{CH4}} = 0{,}9$) X_{CH4}^2 or $(X_{\mathrm{CH4}})^2$.

Annex B
(informative)

Examples of LNG composition

The examples given in Table B.1 of LNG composition are given by GIIGNL (International Group of LNG Importers) in its annual report[9]. They are only coming from fossil sources. The data have last been updated in 2012. The average composition is chosen as being representative among compositions reported by the different receiving terminals. Additional information on the energy quantity of LNG can be found in the GIIGNL LNG Custody Transfer Handbook[8].

Columns have been added for Methane Number, Net Calorific Value, Gross Calorific Value and Wobbe index in the ISO reference conditions. The column on the expansion ratio was removed.

Table B.1 — Examples of LNG composition

Origin	Nitrogen N2 %	Methane C1 %	Ethane C2 %	Propane C3 %	C4+ %	LNG Density[a] kg/m^3	Gas Density[b] kg/m^3(n)	Gas GCV[b] MJ/m^3(n)	Gas GCV[c] MJ/m^3(s)	Gas NCV (MJ/kg)	Wobbe index[b] MJ/m^3(n)	Wobbe index[c] MJ/m^3(s)	Methane number[d]	Methane number[e]
Australia - NWS	0,04	87,33	8,33	3,33	0,97	467,35	0,83	45,32	42,88	49,2	56,53	53,49	68	69
Australia - Darwin	0,10	87,64	9,97	1,96	0,33	461,05	0,81	44,39	42,00	49,3	56,01	53,00	71	73
Algeria - Skikda	0,63	91,40	7,35	0,57	0,05	446,65	0,78	42,30	40,02	49,1	54,62	51,69	79	80
Algeria - Bethioua	0,64	89,55	8,20	1,30	0,31	454,50	0,80	43,22	40,89	49,0	55,12	52,16	75	76
Algeria - Arzew	0,71	88,93	8,42	1,59	0,37	457,10	0,80	43,48	41,14	48,9	55,23	52,26	74	74
Brunei	0,04	90,12	5,34	3,02	1,48	461,63	0,82	44,68	42,27	49,3	56,18	53,16	69	68
Egypt - Idku	0,02	95,31	3,58	0,74	0,34	437,38	0,76	41,76	39,51	49,6	54,61	51,68	83	83
Egypt - Damietta	0,02	97,25	2,49	0,12	0,12	429,35	0,74	40,87	38,67	49,8	54,12	51,21	90	91
Equatorial Guinea	0,00	93,41	6,52	0,07	0,00	439,64	0,76	41,95	39,69	49,7	54,73	51,79	85	84
Indonesia - Arun	0,08	91,86	5,66	1,60	0,79	450,96	0,79	43,29	40,96	49,4	55,42	52,44	75	74
Indonesia - Badak	0,01	90,14	5,46	2,98	1,40	461,07	0,82	44,63	42,23	49,3	56,17	53,15	69	69
Indonesia - Tangguh	0,13	96,91	2,37	0,44	0,15	431,22	0,74	41,00	38,79	49,7	54,14	51,23	88	89
Malaysia - Bintulu	0,14	91,69	4,64	2,60	0,93	454,19	0,80	43,67	41,32	49,3	55,59	52,60	73	72

[a] Calculated according to ISO 6578 [T = −160 °C].

[b] Calculated according to ISO 6976 [0 ºC / 0 °C, 1,013 25 bar].

[c] Calculated at 15 °C / 15 °C, 1,013 25 bar.

[d] Calculated by method in EN 16726.

[e] Calculated by PKI method in Annex A.

Table B.1 *(continued)*

Origin	Nitrogen N2 %	Methane C1 %	Ethane C2 %	Propane C3 %	C4+ %	LNG Density[a] kg/m^3	Gas Density[b] kg/m^3(n)	Gas GCV[b] MJ/m^3(n)	Gas GCV[c] MJ/m^3(s)	Gas NCV (MJ/kg)	Wobbe index[b] MJ/m^3(n)	Wobbe index[c] MJ/m^3(s)	Methane number[d]	Methane number[e]
Nigeria	0,03	91,70	5,52	2,17	0,58	451,66	0,79	43,41	41,07	49,5	55,50	52,52	75	74
Norway	0,46	92,03	5,75	1,31	0,45	448,39	0,78	42,69	40,39	49,2	54,91	51,96	77	77
Oman	0,20	90,68	5,75	2,12	1,24	457,27	0,81	43,99	41,62	49,2	55,73	52,74	72	71
Peru	0,57	89,07	10,26	0,10	0,01	451,80	0,79	42,90	40,59	49,1	55,00	52,04	77	78
Qatar	0,27	90,91	6,43	1,66	0,74	453,46	0,79	43,43	41,09	49,3	55,40	52,42	74	74
Russia - Sakhalin	0,07	92,53	4,47	1,97	0,95	450,67	0,79	43,30	40,97	49,4	55,43	52,45	75	74
Trinidad	0,01	96,78	2,78	0,37	0,06	431,03	0,74	41,05	38,84	49,8	54,23	51,32	88	89
USA - Alaska	0,17	99,71	0,09	0,03	0,01	421,39	0,72	39,91	37,76	49,8	53,51	50,63	99	99
Yemen	0,02	93,17	5,93	0,77	0,12	442,42	0,77	42,29	40,01	49,6	54,91	51,96	80	81

[a] Calculated according to ISO 6578 [T = −160 °C].

[b] Calculated according to ISO 6976 [0 ºC / 0 °C, 1,013 25 bar].

[c] Calculated at 15 °C / 15 °C, 1,013 25 bar.

[d] Calculated by method in EN 16726.

[e] Calculated by PKI method in Annex A.

Annex C
(informative)

Methane number (knock resistance) and Wobbe index (thermal input through a restriction)

C.1 Methane number

The ability of a fuel to resist engine knock for given conditions in the cylinder of an engine is referred to as its knock resistance. The knock resistance for a gaseous fuel is usually characterized using a methane number. The knock resistance of the fuel is an important parameter for engine operation; the maximum non-knocking power output of many marine engine types can depend on the methane number.

Originally, the methane number was derived in analogy with the octane number for gasoline; it is a measure for the specific knock intensity in a reference engine. The knock intensity for a given fuel is compared to a mixture of reference fuels. For the methane number, pure methane was assigned the value of "100", while pure hydrogen was assigned the value of "0".

There are several calculation tools for determining the methane number, which often give different methane numbers for the same fuel composition. The same method can for some gas compositions overestimate the methane number and for other gas compositions underestimate it. The differences between the tools reflect different engine conditions for which the tools are intended (e.g., stoichiometric vs. lean-burn) and differences in how the methane numbers are derived from experimental, empirical and theoretical data. This results in different approaches for how the effects of higher hydrocarbons and their isomers, as well as the impact of inert gases, are incorporated in the tools.

NOTE In EN 16726:2015, the MWM method has been used to calculate the Methane Number.

C.2 Wobbe index

While the net calorific value (NCV) is important for characterizing LNG for reciprocating engines, natural gas for other end-use equipment (e.g. boiler) is characterized by the Wobbe index. At constant pressure drop, the heat input to such end-use equipment is proportional to the Wobbe index.

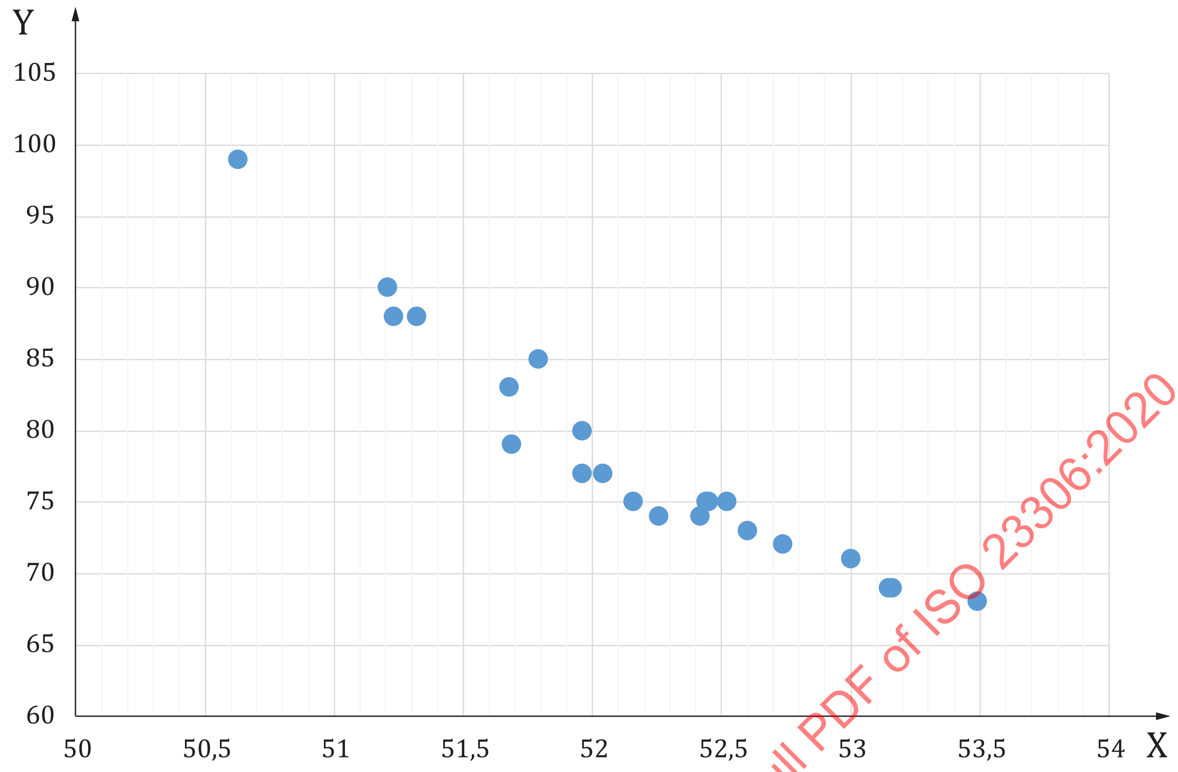
The gross Wobbe index is the gross calorific value (*GCV*) divided by the square root of the relative density (*d*) of the fuel as shown in Formula (C.1):

$$grossWI = GCV / \sqrt{d} \tag{C.1}$$

While the methane number decreases, and the Wobbe index increases, with an increasing fraction of higher hydrocarbons (ethane, propane, butanes, etc.), the methane number, which depends upon the detailed composition of the fuel, is not reliably predicted by the Wobbe index. For LNG compositions, the methane number can vary by 5-10 points for fuels having similar Wobbe index, as illustrated in Figure C.1, below, showing the methane number for the 2018 GIIGNL list as a function of Wobbe index.

NOTE The different methods to calculate the methane number show similar results when plotted vs. Wobbe index; the results shown reflect the MWM method.

Since specifications for MN are given to whole numbers, using a correlation with Wobbe index does not possess enough predictive power for this purpose.



Key

X Wobbe index [MJ/m^3] (15 °C/15 °C)

Y methane number [-] (EN 16726)

The data come from Table B.1.

Figure C.1 — Methane number plotted vs. Wobbe index