INTERNATIONAL
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15403-1

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Natural gas — Natural gas for use as a compressed fuel for vehicles —

Part 1:
Designation of the quality

Gaz naturel — Gaz naturel pour usage comme carburant comprimé pour véhicules —

Partie 1: Désignation de la qualité

Reference number
ISO 15403-1:2006(E)

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Contents

Page

Foreword

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

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

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

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

ISO 15403-1 was prepared by Technical Committee ISO/TC 193, *Natural gas.*

This first edition of ISO 15403-1 cancels and replaces ISO 15403:2000, of which it constitutes a minor revision including the following changes:

- correction of the title to reflect that ISO 15403 is now formed of two parts;
- reformat the document in accordance with the ISO/IEC Directives, Part 2, Fifth edition, 2004;
- reformat the references cited in Clause 2 and in the Bibliography, in accordance with the ISO/IEC Directives, Part 2, Fifth edition, 2004.

ISO 15403 consists of the following parts, under the general title *Natural gas — Natural gas for use as a compressed fuel for vehicles*:

- *Part 1: Designation of the quality*
- *Part 2: Specification of the quality* (Technical Report)

Introduction

Natural gas has been used to some extent as a fuel for internal combustion engines in compressor stations, co-generation systems, and vehicles of various types for many years now. However, the prerequisites for growth, i.e. economic viability and fuel availability, were generally not satisfied. Now, with the natural gas industry well established, supplying 20 % of the world's primary energy, and the need for alternative, low-emission fuels, the situation has improved considerably. During the past decade, natural gas vehicles have become a viable option with some five millions units now in use around the world. Growth is continuing as many governments actively promote this clean-burning fuel with its environmental benefits. Many fleet operators are converting their vehicles, and vehicle manufacturers are developing and marketing dedicated natural gas equipment.

In the context of this International Standard, natural gas vehicles (NGVs) utilize compressed natural gas stored “on-board”. The pressure of the gas stored in multiple containers is up to a maximum 25 000 kPa. Although the pressure has to be reduced before combustion, compression and storage gives NGVs an adequate range. While NGVs were initially equipped with converted gasoline or diesel engines, high-performance, dedicated natural gas engines are now being extensively developed and produced. Liquefied natural gas (LNG) may also be stored in the fuel tanks of natural gas vehicles. This, however, will be the subject of a separate International Standard.

This part of ISO 15403 for the quality designation of compressed natural gas is designed to stipulate the international requirements placed on the natural gas used as a motor fuel. Engine and vehicle manufacturers must know these requirements so they can develop high-performance equipment which runs on compressed natural gas.

A technical report giving detailed data on the gas compositions used in this part of ISO 15403 is being published as ISO/TR 15403-2.

INTERNATIONAL STANDARD **ISO 15403-1:2006(E)**

Natural gas — Natural gas for use as a compressed fuel for vehicles —

Part 1:
Designation of the quality

1 Scope

The aim of this part of ISO 15403 is to provide manufacturers, vehicle operators, fuelling station operators and others involved in the compressed-natural-gas vehicle industry with information on the fuel quality for natural gas vehicles (NGVs) required to develop and operate compressed-natural-gas vehicle equipment successfully.

Fuel meeting the requirements of this part of ISO 15403 should

a) provide for the safe operation of the vehicle and associated equipment needed for its fuelling and maintenance;

b) protect the fuel system from the detrimental effects of corrosion, poisoning, and liquid or solid deposition;

c) provide satisfactory vehicle performance under any and all conditions of climate and driving demands.

Some aspects of this part of ISO 15403 may also be applicable for the use of natural gas in stationary combustion engines.

2 Normative references

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

ISO 6976:1995, *Natural gas — Calculation of calorific values, density, relative density and Wobbe index from composition*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. Definitions were taken from ISO 14532 whenever possible.

3.1
natural gas
complex mixture of hydrocarbons, primarily methane, but generally also including ethane, propane and higher hydrocarbons in much smaller amounts and some non-combustible gases, such as nitrogen and carbon dioxide

NOTE 1 Natural gas generally also includes minor amounts of trace constituents.

NOTE 2 Natural gas is produced and processed from the raw gas or liquefied natural gas and, if required, blended to the extent suitable for direct use (for example as gaseous fuel).

NOTE 3 Natural gas remains in the gaseous state under the temperature and pressure conditions normally found in service.

NOTE 4 Natural gas consists predominantly of methane (mole fraction greater than 0,70), and has a superior calorific value normally within the range 30 MJ/m^3 to 45 MJ/m^3. It contains also ethane (typically up to 0,10 mole fraction), propane, butanes and higher alkanes in steadily decreasing amounts. Nitrogen and carbon dioxide are the principal non-combustible components, each present at levels which typically vary from less than 0,01 mole fraction to 0,20 mole fraction.

Natural gas is processed from the raw gas so as to be suitable for use as industrial, commercial, residential fuel or as a chemical feedstock. The processing is intended to reduce the contents of potentially corrosive components, such as hydrogen sulfide and carbon dioxide, and of other components, such as water and higher hydrocarbons, potentially condensable in the transmission and distribution of the gas. Hydrogen sulfide, organic sulfur compounds and water are then reduced to trace amounts, and high carbon dioxide contents are likely to be reduced to below 0,05 mole fraction.

Natural gas is normally technically free from aerosol, liquid and particulate matter.

In some circumstances natural gas may be blended with town gas or coke oven gas, in which case hydrogen and carbon monoxide will be present in amounts up to 0,10 mole fraction and 0,03 mole fraction respectively. In this case, small amounts of ethylene may also be present.

Natural gas may also be blended with LPG1)/air mixtures, in which case oxygen will be present, and the levels of propane and butanes will be considerably enhanced.

NOTE 5 Pipeline quality natural gas is one which has been processed so as to be suitable for direct use as industrial, commercial, residential fuel or as a chemical feed stock.

The processing is intended to reduce the corrosive and toxicity effects of certain components, and to avoid condensation of water or hydrocarbons in the transmission and distribution of the gas.

Hydrogen sulfide and water should only be present in trace amounts, and high carbon dioxide content is likely to be reduced.

[ISO 14532:2001, 2.1.1.1]

3.2
substitute natural gas

manufactured or blended gas which is interchangeable in its properties with natural gas

[ISO 14532:2001, 2.1.1.3]

NOTE Manufactured gas is sometimes called synthetic natural gas.

3.3
compressed natural gas

natural gas used as a fuel for vehicles, typically compressed up to 20 000 kPa in the gaseous state

[ISO 14532:2001, 2.1.1.12]

NOTE The maximum pressure for natural gas stored in a container is 25 000 kPa.

3.4
gas quality

attribute of natural gas dependent on its composition and its physical properties

[ISO 14532:2001, 2.1.1.14]

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1) LPG = liquefied petroleum gas.

3.5
normal reference conditions

reference conditions of pressure, temperature and humidity (state of saturation) equal to: 101,325 kPa and 273,15 K for a real, dry gas

3.6
standard reference conditions

reference conditions of pressure, temperature and humidity (state of saturation) equal to: 101,325 kPa and 288,15 K for a real, dry gas

NOTE 1 Good practice requires that the reference conditions are incorporated as part of the symbol, and not of the unit, for the physical quantity represented.

EXAMPLE

$$\tilde{H}_{\mathrm{S}}\left[p_{\mathrm{crc}},T_{\mathrm{crc}},V\left(p_{\mathrm{mrc}},T_{\mathrm{mrc}}\right)\right]$$

where

$\tilde{H}_{\mathrm{S}}$	superior calorific value on volumetric basis;
T_{crc}	temperature of the combustion reference conditions;
p_{crc}	pressure of the combustion reference conditions;
$V(p_{\mathrm{mrc}}, T_{\mathrm{mrc}})$	volume at temperature and pressure of the metering reference conditions.

NOTE 2 Standard reference conditions are also referred to as metric standard conditions.

NOTE 3 The abbreviation s.t.p. (standard temperature and pressure) replaces the abbreviation N.T.P. (Normal Temperature and Pressure), as formerly used, and is defined as the condition of pressure and temperature equal to: 101,325 kPa and 288,15 K. No restriction is given on the state of saturation.

[ISO 14532:2001, 2.6.1.4]

3.7
superior calorific value

energy released as heat by the complete combustion in air of a specified quantity of gas, in such a way that the pressure p_1 at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature T_1 as that of the reactants, all of these products being in the gaseous state except for water formed by combustion, which is condensed to the liquid state at T_1

NOTE 1 Where the quantity of gas is specified on a molar basis, the calorific value, expressed in MJ/mol, is designated as:

$$\bar{H}_{\mathrm{S}}\left(p_1,T_1\right)$$

On a mass basis the calorific value, expressed in MJ/kg, is designated as:

$$\hat{H}_{\mathrm{S}}\left(p_1,T_1\right)$$

Where the quantity of gas is specified on a volumetric basis, the calorific value, expressed in MJ/m^3, is designated as:

$$\tilde{H}_{\mathrm{S}}\left[p_1,T_1,V\left(p_2,T_2\right)\right]$$

where p_2 and T_2 are the gas volume (metering) reference conditions.

The volumetric based calorific value should be specified to normal or standard reference conditions.

NOTE 2 The terms gross, higher, upper and total calorific value, or heating value, are synonymous with superior calorific value.

NOTE 3 The calorific value should be specified to the combustion conditions.

NOTE 4 The calorific value is normally stated as dry.

EXAMPLE $\tilde{H}_{\mathrm{S,w}}\left(p_{\mathrm{src}},T_{\mathrm{src}}\right)$ designates the superior calorific value, specified on a volumetric basis, at standard reference conditions and stated as wet. For simplicity, the combustion conditions are not specified.

NOTE Adapted from ISO 14532:2001, 2.6.4.2.

3.8
inferior calorific value

energy released as heat by the complete combustion in air of a specified quantity of gas, in such a way that the pressure p_1 at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature T_1 as that of the reactants, all of these products being in the gaseous state

NOTE 1 Superior calorific value differs from inferior calorific value by the heat of condensation of water formed by combustion.

NOTE 2 Where the quantity of gas is specified on a molar basis, the calorific value, expressed in MJ/mol, is designated as:

$$\bar{H}_{\mathrm{I}}\left(p_1,T_1\right)$$

On a mass basis the calorific value, expressed in MJ/kg, is designated as:

$$\hat{H}_{\mathrm{I}}\left(p_1,T_1\right)$$

Where the quantity of gas is specified on a volumetric basis, the calorific value, expressed in MJ/m3, is designated as:

$$\tilde{H}_{\mathrm{I}}\left[p_1,T_1,V\left(p_2,T_2\right)\right]$$

where p_2 and T_2 are the gas volume (metering) reference conditions.

NOTE 3 The terms net and lower calorific value, or heating value, are synonymous with inferior calorific value.

NOTE 4 Superior and inferior calorific values can also be stated as dry or wet (denoted by the subscript “w”) depending on the water vapour content of the gas prior to combustion.

The effects of water vapour on the calorific values, either directly measured or calculated, are described in Annex F of ISO 6976:1995.

NOTE 5 Normally the calorific value is expressed as the superior, dry value specified on volumetric basis under normal or standard reference conditions.

[ISO 14532:2001, 2.6.4.2]

3.9
density

mass of gas divided by its volume at specified conditions of pressure and temperature

NOTE In a mathematical representation the density is given by:

$$\rho\left(p,T\right)=\frac{m}{V\left(p,T\right)}$$

[ISO 14532:2001, 2.6.3.1]

3.10
relative density

quotient of the mass of a gas, contained within an arbitrary volume, and the mass of dry air of standard composition (defined in ISO 6976:1995) which would be contained in the same volume at the same reference conditions

NOTE 1 An equivalent definition is given by the ratio of the density of the gas ρ_g to the density of dry air of standard composition ρ_a at the same reference conditions.

$$d=\frac{\rho_\mathrm{g}\left(p_\mathrm{src},T_\mathrm{src}\right)}{\rho_\mathrm{a}\left(p_\mathrm{src},T_\mathrm{src}\right)}$$

where

p_src is the pressure at standard reference conditions;

T_src is the temperature at standard reference conditions;

$\rho(p_\mathrm{src}, T_\mathrm{src})$ is the mass volume at the standard-temperature and standard-pressure conditions

NOTE 2 Density can be expressed in terms of the real gas law:

$$\rho=\frac{M\cdot p}{Z\cdot R\cdot T}$$

With this relation the relative density, when both gas and air are considered as real fluids, becomes:

$$d=\frac{\dfrac{M_\mathrm{g}\cdot p_\mathrm{src}}{Z_\mathrm{g}\left(p_\mathrm{src},T_\mathrm{src}\right)\cdot R\cdot T_\mathrm{src}}}{\dfrac{M_\mathrm{a}\cdot p_\mathrm{src}}{Z_\mathrm{a}\left(p_\mathrm{src},T_\mathrm{src}\right)\cdot R\cdot T_\mathrm{src}}}=\frac{M_\mathrm{g}\cdot Z_\mathrm{a}\left(p_\mathrm{src},T_\mathrm{src}\right)}{M_\mathrm{a}\cdot Z_\mathrm{g}\left(p_\mathrm{src},T_\mathrm{src}\right)}$$

For ideal gas behaviour of the gases, when both gas and air are considered as fluids which obey the ideal gas law, the relative density becomes:

$$d=\frac{M_\mathrm{g}}{M_\mathrm{a}}$$

NOTE 3 In former times, the above ratio $M_\mathrm{g}/M_\mathrm{a}$ was called specific gravity of a gas, which has the same value as the relative density if ideal behaviour of the gases is assumed. The term relative density should now replace the term specific gravity.

[ISO 14532:2001, 2.6.3.2]

3.11
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

NOTE 1 The volume is stated at normal or standard reference conditions.

NOTE 2 The Wobbe index is specified as superior (denoted the subscript “S”) or inferior (denoted the subscript “I”), depending on the calorific value, and as dry or wet (denoted by the subscript “w”) depending on the calorific value and the corresponding density.

EXAMPLE

Wobbe index, superior, specified on a volumetric basis, at standard reference conditions and stated as wet (denoted by the supscript “w”)

$$W_{\mathrm{S}}\left(p_{\mathrm{src}},T_{\mathrm{src}}\right)=\frac{\tilde{H}_{\mathrm{S,w}}\left(p_{\mathrm{src}},T_{\mathrm{src}}\right)}{\sqrt{d_{\mathrm{w}}\left(p_{\mathrm{src}},T_{\mathrm{src}}\right)}}$$

NOTE 3 The Wobbe index is a measure of heat input to gas appliances derived from the orifice flow equation. Heat input for different natural gas compositions is the same if they have the same Wobbe index, and operate under the same gas pressure (see ISO 6976).

NOTE Adapted from ISO 14532:2001, 2.6.4.4.

3.12
compression factor

quotient of the actual (real) volume of an arbitrary mass of gas, at a specified pressure and temperature, and the volume of the same gas, under the same conditions, as calculated from the ideal gas law

NOTE 1 The terms «compressibility factor» and «Z-factor» are synonymous with compression factor.

NOTE 2 The formula for the compression factor is as follows:

$$Z=\frac{V_{\mathrm{m}}(\mathrm{real})}{V_{\mathrm{m}}(\mathrm{ideal})}$$

where

$$V_{\mathrm{m}}(\mathrm{ideal})=\frac{R\cdot T}{p}$$

Thus

$$Z(p,T,y)=\frac{p\cdot V_{\mathrm{m}}(y)}{R\cdot T}$$

where

p absolute pressure;

T thermodynamic temperature;

y set of parameters which uniquely characterizes the gas;

V_{m} molar volume;

R molar gas constant in coherent units;

Z compression factor.

In principle, y may be the complete molar composition (see ISO 12213-2 [1]) or a distinctive set of dependent physico-chemical properties (see ISO 12213-3 [2]).

NOTE 3 Compression factor is a dimensionless quantity usually close to unity near standard or normal reference conditions. Within the range of pressures and temperatures encountered in gas transmission, compression factor can significantly differ from unity.

NOTE 4 The supercompressibility factor is defined as the square root of the ratio of the compression factor at reference conditions to the compression factor of the same gas at the conditions of interest:

$$f = \sqrt{\frac{Z_\mathrm{b}}{Z(p,T,y)}}$$

where

Z_b is the compression factor at base conditions of pressure and temperature.

Base conditions are temperature and pressure conditions at which natural gas volumes are determined for purpose of custody transfer. In natural gas measurements the properties of interest are temperature, pressure and composition. Assuming ideal gas properties, for simplicity, tables of pure compounds can be prepared for use in calculating gas properties for any composition at “base conditions”. These “base conditions” are chosen near ambient.

In the IGU Dictionary of the Gas Industry the supercompressibility factor is defined as:

$$f = \frac{1}{\sqrt{Z(p,T,y)}}$$

The supercompressibility factor is used with measurements made by flow instruments. The volume obtained with a flow meter must be multiplied by “f” to obtain the corrected volume.

The compression factor is used with measurements made by displacement methods. In this case the volume must be multiplied by “$1/Z$” to obtain the correct volume.

[ISO 14532:2001, 2.6.2.2]

3.13
water dew point

temperature above which no condensation of water occurs at a specified pressure

NOTE For any pressure lower than the specified pressure there is no condensation at this dew-point temperature.

[ISO 14532:2001, 2.6.5.1.1]

3.14
hydrocarbon dew point

temperature above which no condensation of hydrocarbons occurs at a specified pressure

NOTE 1 At a given dew point temperature there is a pressure range within which condensation occurs because of retrograde behaviour. The cricondentherm defines the maximum temperature at which condensation can occur.

NOTE 2 The dew point line is the locus of pressure and temperature points which separate the single phase gas from the gas-hydrocarbon liquid region.

[ISO 14532:2001, 2.6.5.2.1]

3.15
molar composition

proportion of each component expressed as a molar (or mole) fraction, or molar (mole) percentage, of the whole

NOTE 1 Thus the mole fraction, x_i, of component i is the quotient of the number of moles of component i and the number of moles of the whole mixture present in the same arbitrary volume. One mole of any chemical species is the amount of sub-stance which has the relative molecular mass in grams. A table of recommended values of relative molecular masses is given in ISO 6976:1995.

NOTE 2 For an ideal gas, the mole fraction (or percentage) is identical to the volume fraction (percentage), but this relationship cannot in general be assumed to apply to real gas behaviour.

3.16
gas composition

fractions or percentages of the main components, associated components, trace components and other components determined from natural gas analysis

NOTE Adapted from ISO 14532:2001, 2.6.6.1.

3.17
odorization

addition of odorants, normally intensively smelling organic sulfur compounds, to natural gas (normally odourless) to allow the recognition of gas leaks by smell at very low concentration (before a build up to a dangerous gas in air concentration can occur) [ISO 14532]

3.18
methane number

rating indicating the knocking characteristics of a fuel gas

NOTE It is comparable to the octane number for petrol. The methane number expresses the mole fraction expressed as a percentage of methane in a methane/hydrogen mixture which, in a test engine under standard conditions, has the same tendency to knock as the fuel gas to be examined.

NOTE Adapted from ISO 14532:2001, 2.6.6.1.

4 Symbols and abbreviations

Quantity	**Symbol**	**Units**
Relative density	d	
Calorific value	H	
Calorific value, molar basis	$\bar{H}$	megajoules per mole (MJ/mol)
Calorific value, mass basis	$\hat{H}$	megajoules per kilogram (MJ/kg)
Calorific value, volumetric basis	$\tilde{H}$	megajoules per cubic metre (MJ/m^3)
Inferior calorific value	H_I	
Superior calorific value	H_S	
Gas pressure	p	kilopascals (kPa)
Gas temperature	T	kelvins (K)
Gas volume	V	cubic metres (m^3)
Wobbe index, volumetric basis	W	megajoules per cubic metre (MJ/m^3)
Gas compression factor, (Compressibility factor)	Z	
Density	ρ	kilograms per cubic metre (kg/m^3)

Subscript

m	quantity per mole
n	relates to “normal reference conditions”
crc	relates to “combustion reference conditions”
mrc	relates to “metering reference conditions”
src	relates to “standard reference conditions”
w	states the parameter as “wet”
S	superior
I	inferior

5 Gas composition requirements

5.1 Water

The single most important safety requirement of compressed natural gas (CNG) fuel is a very low water dew-point temperature to preclude the formation of liquid water at any time. Liquid water is a precursor to the formation of corrosive compounds through combination with components in natural gas, namely carbon dioxide and hydrogen sulfide. The combination of corrosive agents, and the pressure cycling, caused by fuel consumption and subsequent refilling of the fuel storage container, can result in crack growth in metals and ultimately damage and failure. Also, liquid water itself can be detrimental as it can cause blockages, both liquid and solid, in the fuel system.

Thus, the water dew-point of the fuel gas at the fuelling station outlet shall be sufficiently below the lowest ambient temperature in which fuelling stations and vehicles will operate.

5.2 Hydrocarbons

While hydrocarbon components contained in natural gas normally remain in the gaseous state in local distribution systems, the pressures and temperatures experienced by CNG may cause condensation. Changes in fuel composition due to revaporization of this liquid condensate at reduced tank pressures may affect the vehicle performance unless a self-adaptive system is applied.

In cases where the natural gas contains significant quantities of propane and butane, for example caused by peak-shaving operations, a liquid phase can be formed at elevated pressures and low temperatures because of their relatively low vapour pressure (see Annex A).

Thus, to minimize such occurrences, the composition of compressed natural gas shall be such, that at any pressure, less than 1 % of a liquid condensate is formed at the lowest ambient temperatures and under the worst gas storage pressure conditions (see ISO 6570-1). Maximum condensation occurs at pressures between 2 500 kPa to 4 500 kPa.

5.3 Potential corrosive components

5.3.1 Sulfur-containing components

Some sulfur components are corrosive; the total sulfur content may have an adverse impact on exhaust gas cleaning devices and should be taken into consideration.

5.3.2 Hydrogen sulfide

Given that the corrosive environment is controlled by the lack of liquid water in accordance with 5.1, no extraordinary limitations are required on the concentration of hydrogen sulfide. Hydrogen sulfide in combination with oxygen may cause powdering, especially on copper, which can have detrimental effects on the system.

5.3.3 Carbon dioxide

Given that the corrosive environment is controlled by the lack of liquid water in accordance with 5.1, no extraordinary limitations are required on the concentration of carbon dioxide.

5.3.4 Oxygen

Given that the corrosive environment is controlled by the lack of liquid water in accordance with 5.1, no extraordinary limitations are required on the concentration of oxygen.

5.3.5 Methanol

Methanol can cause corrosion of natural gas containers and deterioration of fuel system components. Methanol is not needed if the water dew-point temperature is maintained in accordance with 5.1. No methanol shall be added to natural gas at the CNG fuelling station.

5.4 Particulate material

The CNG fuel delivered shall be technically free from dust. The possible oil content of natural gas shall have no adverse effect on the safe operation of the vehicle. For this purpose, filters and separators may be used if necessary.

NOTE A small amount of oil may be helpful for the protection of containers and lubrication of injectors.

5.5 Odour

Natural gas delivered to any natural gas vehicles should be odorized similar to a level found in the local distribution system (see ISO 13734).

6 Gas properties

6.1 Wobbe index

A change in Wobbe index may affect the power output and performance of the engine. Most present natural gas engine metering systems utilize orifices, and therefore variations in the Wobbe index will produce similar variations in the air-fuel ratio. Variations of this parameter most significantly affect engines that are not equipped with closed-loop (self-adaptive) control (see Annex B).

6.2 Knock rating

6.2.1 General

The ability of a fuel to resist auto-ignition, also known as detonation or combustion knock (see Annex C), is a basic fuel characteristic. Long used to rate gasoline by standard test procedures, there have been numerous studies to identify, correlate, and describe natural gas knock ratings. To date, however, no generally accepted standard test procedure has emerged. Briefly, the work can be summarized as follows.

6.2.2 Methane number

Knock resistance of natural gas changes with composition. Methane is the major component of natural gas, and has a high knock resistance. Increasing amounts of heavier hydrocarbons like ethane and propane lower the fuel knock resistance. This has given rise to a criterion known as methane number, which can be calculated from the gas composition analysis (see Annex D).

6.2.3 Octane number

The octane number methodology (see Annex D) is used to compare liquid fuels as to their knocking tendency. It determines the knocking intensity between the test fuel and a reference fuel of known octane number. Reference fuels for the octane scale are octane (2,3,4-trimethylpentane) rated at 100, and *n*-heptane rated at 0. Mixtures of these fuels are used to create other octane number fuels to be compared with the test fuel.

The octane scale is not as appropriate for use with high octane natural gas (in excess of 100) as with lower octane number liquid fuels. Thus, there is a need for a standard test method for determining an equivalent octane number of natural gas. The work done to date puts this equivalent octane number of natural gas in the range of 115 to 135. The octane number of pure methane is in the order of 140+.

7 Driveability

Any transportation fuel shall have the attributes of providing satisfactory performance of the vehicle under any and all conditions of climate, road surface, and driving demands. Natural gas is ideally suited to provide such performance provided it is kept free of liquid and/or particulate matter. The requirement of this part of ISO 15403 to preclude any condensation of water vapour in the fuel system is expected to adequately eliminate such operational problems. If water vapour is permitted to enter the vehicle fuel system, even in small amounts, liquid water may be created and interfere with consistently smooth natural gas flow and result in driveability problems such as clogging or freezing of gas lines, fittings, valves, regulators, fuel injectors and similar items.

8 Test methods

8.1 General considerations

Having given requirements for gas composition (Clause 5) and gas properties (Clause 6), it is necessary to provide guidance as to how these requirements can be measured. Fuelling station operators, regulatory agencies, and equipment manufacturers will have vital interests in the measurement of NGV gas quality. It should be understood that some requirements are not yet included in International Standards. The Bibliography references are used to provide the status of development of such situations.

8.2 Gas composition measurement

8.2.1 Water

All the International Standards listed in the Bibliography for water determination can be used. These are, namely, ISO 6327, ISO 10101-1, ISO 10101-2, ISO 10101-3 and ISO 11541. In addition, any commercially suitable instruments which can be proven to provide results comparable to the above International Standards may be used.

Since measurements are to be taken at temperature and pressure conditions different from those cited in the International Standards, it is most essential that a satisfactory method be used to calculate dew point at maximum operating pressure of the container, and lowest ambient temperature of the fuelling station. See Annex E for methodology and examples. The frequency of testing should assure that no liquid water will be formed in the system.

8.2.2 Hydrocarbons

Since butane and propane are the hydrocarbons of concern, they can be monitored in accordance with appropriate part(s) of ISO 6974. Again, it will be necessary to calculate values from measurement conditions to the lowest ambient temperature and worst gas storage pressure conditions. Annex A should be used as a guide to the maximum allowable mole fractions of propane and butane expressed as a percentage. ISO 6570-1 can be used for determination of the potential hydrocarbon liquid content in natural gas.

8.2.3 Potential corrosive components

No limits are set on the concentrations of hydrogen sulfide, carbon dioxide, oxygen, and methanol other than values normally found in natural gas. Thus, testing for these components is not normally required. If for any reason it is deemed necessary to test for these components, ISO 6326-1, ISO 6326-3, ISO 6326-4 or ISO 6326-5 can be used for sulfur compounds, and the appropriate part(s) of ISO 6974 for the others.

8.2.4 Oil and particulate matter

No standardized test methods are available for these items at present.

8.2.5 Odour

Tests for odour, when required, should be the same as those currently performed on the local distribution system servicing the refuelling station.

There are no tests described in International Standards for odour.

NOTE Attention is drawn to national standards or other regulations in this regard.

8.3 Gas property determination

8.3.1 Wobbe index

Use ISO 6976 to determine the Wobbe index.

8.3.2 Knock rating

No International Standards exist for the determination of the knock rating of CNG at present. ISO 5163 and ISO 5164 are available for determination of the motor octane number (MON) and research octane number (RON). These International Standards apply to liquid fuels. However, EN 589 contains a method for calculation of the motor octane number from the compositional analysis of LPG and is presented in Clause D.4.

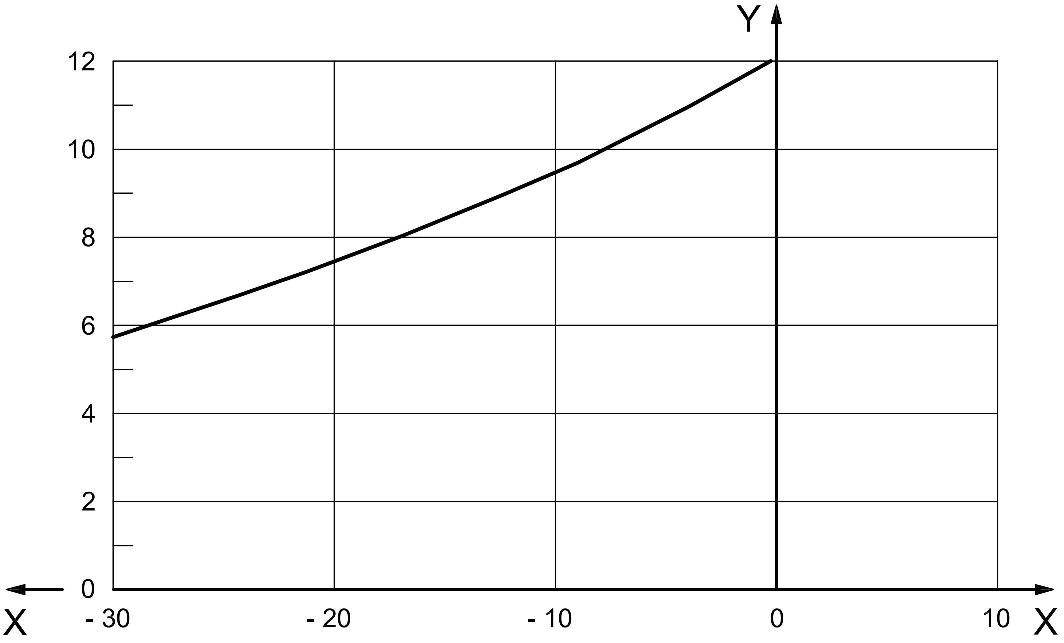
9 Sampling

Compressed natural gas for on-board vehicle storage shall be sampled at agreed points and routines based on established good practice shall be used for the purpose of applying the test methods required.

Annex A
(informative)

Propane and butane content

Figures A.1 and A.2 show the maximum allowable mole fractions of propane (see SAE J 1616) and butane expressed as a percentage that corresponds to 1 % of the original gaseous volume as liquid condensation volume for various low ambient temperatures and worst-case gas storage pressure conditions. The amount of propane and butane should be compatible with the climatic conditions under which the vehicle will operate.

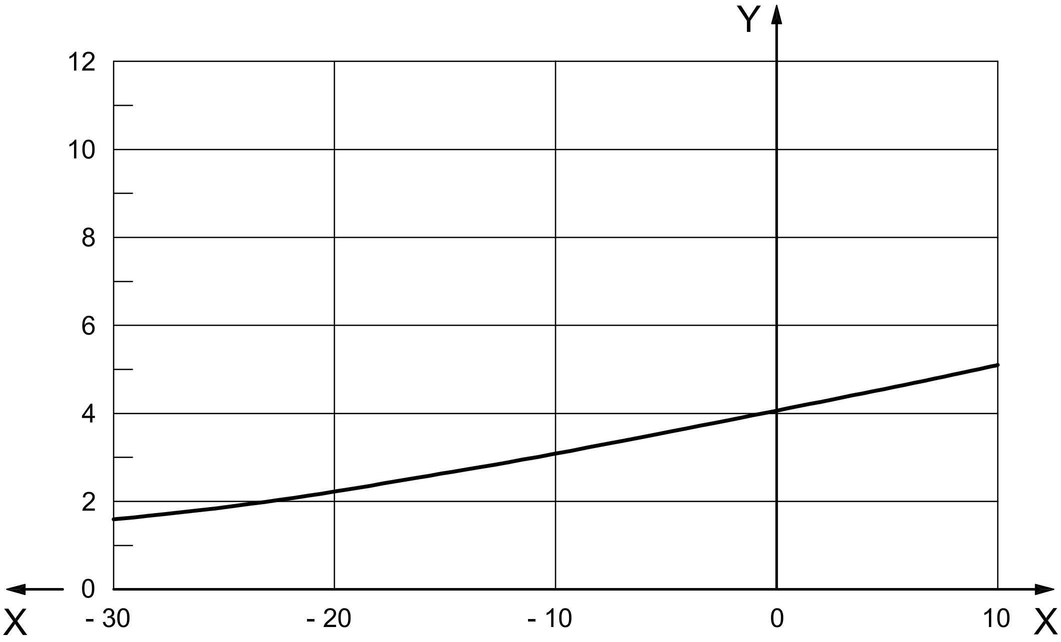


Key

X temperature, °C

Y molar fraction, %

Figure A.1 — Maximum propane content (pressure range: 6 MPa to 10 MPa)



Key

X temperature, °C

Y molar fraction, %

Figure A.2 — Maximum butane content (pressure range: 6 MPa to 10 MPa)

Annex B
(informative)

Wobbe index range

Some countries, notably in Europe, operate within well defined ranges of Wobbe index on their local distribution systems. These stem from appliance certification standards and are as follows:

a) the Wobbe index ranges given in Table B.1 are taken from the German Code of Practice DVGW G 260/I;

Table B.1 — Wobbe index range [a] taken from German Code of Practice DVGW G 260/I

Designation	Abb.	Unit	Group L	Group H
Relative density	d		0,55 to 0,70	
Gross calorific value	$H_{S,n}$	kWh/m^3 MJ/m^3	8,4 to 13,1 30,2 to 47,2	
Wobbe index	$W_{S,n}$			
Total range		kWh/m^3 MJ/m^3	10,5 to 13,0 37,8 to 46,8	12,8 to 15,7 46,1 to 56,5
Rated value		kWh/m^3 MJ/m^3	12,4 44,6	15,0 54,0
Fluctuation range in local supply area		kWh/m^3	+ 0,6 − 1,2	+ 0,7 − 1,4

[a] Conditions: T_n = 273,15 K; p_n = 101,325 kPa

b) Wobbe index ranges given in Table B.2 are taken from the EN 437:1993 certification standard for appliances;

Table B.2 — Wobbe index range [a] taken from EN 437:1993 certification standard for appliances

Second family — Natural gas	
Group	**Wobbe index range** W_S MJ/m^3
L	39,1 to 44,8
LL	34,4 to 44,8
E_I	40,9 to 44,8
E	40,9 to 54,7
E_S	44,8 to 54,7
H	45,6 to 54,7

[a] Conditions: T_{src} = 288,15 K; p_{src} = 101,325 kPa

c) in North America, there are no such standards, although individual local distribution systems seek to maintain a more or less uniform Wobbe index on their systems; the predominant range is between 48,5 MJ/m^3 and 52,2 MJ/m^3, but significant volumes exist in the range of 44,7 MJ/m^3 to 46,6 MJ/m^3.

Other areas of the world may have other ranges of Wobbe index with local production often being well above or below the predominant range.

Annex C
(informative)

Engine knock

C.1 General

The thermal efficiency of a standard spark ignition engine increases with compression ratio. There is, however, an upper limit to the compression ratio which is due, primarily, to the fact that the fluid compressed in the cylinders is a mixture of fuel vapour and air. The temperature of the combustible mixture increases on compression, and if the compression ratio is too high, it is possible for the phenomenon of detonation to occur. This condition is more commonly known as “engine knock” and can lead to a serious loss in power and damage to the engine. To meet more demanding vehicle and emission regulations, optimized engines tend to operate close to the knock limited power, and changes in fuel composition resulting in changes to the knock resistance of the fuel, can cause operational problems.

Several phenomena are involved and the nature of the problem is complex. In simple terms, engine knock or detonation can be explained as follows.

Under normal conditions, combustion begins near the spark plug, after a short delay following the formation of the spark, and the flame spreads through the mixture with a rapid, but finite, velocity. The energy released by the spark is small and it sets off a relatively slow flameless reaction.

Further energy is released at an accelerating rate by the reaction until a proper flame front develops.

Combustion knock occurs when the pressure rise becomes uncontrolled and propagates near the speed of sound. This usually occurs towards the end of the combustion process when the unburnt part of the air-fuel mixture, known as the “end gas”, is already highly compressed and at a high temperature. Knock causes high pressure peaks, compared to normal combustion, which can damage pistons, seals and the cylinder head.

The customary practice of retarding ignition, in order to eliminate combustion knock, can cause problems with high exhaust gas temperatures. It is therefore necessary to reliably detect and avoid knock.

The danger of combustion knock in a petrol-fuelled engine is more usually reduced by fuel additives, or by using fuel with improved knock resistance.

Some petrol fuels permit the use of higher compression ratios than others, depending on the additives to suppress the tendency to knock.

C.2 Knock rating

To measure the detonating or knock tendency of a fuel, one method is to compare the performance of the fuel with that of a heptane-octane mixture in a special variable compression ratio engine. *n*-Heptane is liable to knock at low compression ratios, whilst *iso*-octane knocks at much higher ratios; different mixtures of the two provide a continuous “octane number” scale, from 0 to 100.

To test a particular fuel, the compression ratio of the special engine is raised until the fuel under test knocks, and the highest percentage of octane in a heptane-octane mixture that produces knock at the same compression ratio is called the octane number or knock rating of the fuel. Two different procedures are used internationally: the research method produces the research octane number (RON) ISO 5164 and the motor method which provides the motor octane number (MON) ISO 5163. MON values are lower than RON numbers.

Annex D
(informative)

Methane number and octane number

D.1 Methane number scale

The composition of natural gas varies with both geographic location and time. The levels of methane and heavier hydrocarbons in natural gas are of particular importance because they have an effect on the performance of a natural-gas-fuelled spark ignition engine, in particular the knock resistance.

Methane, the main constituent of natural gas, has a very high knock resistance. Natural gas, however, also contains amounts of heavier hydrocarbons, such as ethane, propane and butane, which have a lower knock resistance. Natural gas may also contain inerts, which increase the knock resistance.

Knock resistance of liquid fuels is commonly measured by the octane scale, as discussed in Annex C, and is used to rate fuels such as petrol. The octane scale can be extended beyond 100 by adding increasing amounts of tetraethyl lead to the calibration fuels to give mixtures with an octane rating of about 120. The octane scale is not suitable for rating natural gas, which typically has an equivalent octane number greater than 120.

To overcome this problem, a methane number scale has been developed. The scale uses pure methane as the knock-resistant reference fuel, and hydrogen as the knock-sensitive reference fuel. This provides a scale suitable for natural gas fuels since any other hydrocarbon additions to methane will result in a lower methane number.

D.2 GRI method

D.2.1 General

The Gas Research Institute (GRI) sponsored research undertaken at South West Research Institute (SWRI) has applied the ASTM octane rating method to various natural gas fuels to measure MON. This data is documented in a GRI report (see Reference [3]) and associated SAE paper (see Reference [4]). The work shows that pure methane has a MON of about 140. Most natural gases have MONs in the range of 115-113, while peak-shaving gases high in propane (17 % to 25 %) have MON ratings of 100 to 105. Pure propane has a MON rating of 96 to 97.

Two mathematical relations that can be used to estimate the MON rating of a natural gas fuel were developed and cover most conventional fuels. Both equations provided excellent fits to the experimental data points.

D.2.2 Linear coefficient relation

$$\text{MON} = (137{,}78x_{\text{methane}}) + (29{,}948x_{\text{ethane}}) + (-\ 18{,}193x_{\text{propane}}) + (-\ 167{,}062x_{\text{butane}}) + (181{,}233x_{\text{CO}_2}) + (26{,}994x_{\text{N}_2})$$

where

x is the mole fraction of the corresponding components methane, ethane, propane, butane, CO_2 and N_2.

D.2.3 Hydrogen/carbon ratio relation

$$\mathrm{MON} = -406{,}14 + (508{,}04 \times f_{\mathrm{H/C}}) - [173{,}55 \times (f_{\mathrm{H/C}})^2] + [20{,}17 \times (f_{\mathrm{H/C}})^3]$$

where

$f_{\mathrm{H/C}}$ is the ratio of hydrogen atoms to carbon atoms.

D.2.4 Correlation between MON and MN

A third equation was also developed from measured data, and provides a reasonable correlation between MON and methane number (MN).

NOTE The correlation is not quite linear, and as a result the equations are not exact inverses of each other.

$$\mathrm{MON} = 0{,}679 \times (\mathrm{MN}) + 72{,}3$$

and $\mathrm{MN} = 1{,}445 \times (\mathrm{MON}) - 103{,}42$

D.3 Reference method AVL

In the reference method of Anstalt für Verbrennungsmotoren Prof. Dr. List (AVL) for the determination of the methane number, the same engine, the committee for fuel research (CFR) engine, was used as described in ASTM D 2699-97.

Binary and ternary mixtures were investigated and the calculation model is explained in Reference [5] of the Bibliography.

Four examples are given in Table D.1

Table D.1 — Methane number

Values in mole fraction (%)

Components	Natural gas			
	A	B	C	D
% N_2	0,63	3,62	11,13	0,81
% CO_2	0,00	1,59	1,28	0,08
% C_1	88,58	87,48	82,90	98,31
% C_2	8,37	5,40	3,68	0,05
% C_3	1,73	1,31	0,67	0,19
% C_4+	0,69	0,60	0,34	0,56
Methane number	73,18	76,20	86,18	95,00

D.4 EN 589 method for determining the motor octane number

Annex B of EN 589:1999 describes a method for the calculation of the motor octane number from a compositional analysis of LPG using gas chromatography. The motor octane number of the sample is calculated from the partial motor octane factors of the constituents and their concentrations determined from the analyses.

The mole fraction of each constituent present in excess of 0,1 mole fraction (%) in the gas sample is determined using the method described in ISO 7941:1988.

The partial motor octane number for each component in the mixture is calculated as follows:

Partial octane number = $M \times C$

where

M is the motor octane number factor of a specific component (see Table D.2);

C is the mole fraction of the component in the mixture.

The sum, rounded to the nearest 0,1, of all partial motor octane numbers determined for the components present in the sample is then reported as the LPG motor octane number of the sample.

Table D.2 — Empirical values of motor octane number factors

Component	Motor octane number factor M
Propane (+ C_2)	95,4
Propene	83,9
Butane (+ C_5)	89,0
2-Methylpropane (*iso*-butane)	97,2
Butenes	75,8

NOTE The above motor octane number factors are empirical values applicable only to calculation procedures of the method described in Annex B of EN 589:1999.

Annex E
(informative)

Water content of natural gas

The concentration of water vapour, absolute humidity, in a gas mixture is mainly a function of the vapour pressure of water, which in turn is a function of the temperature of the mixture. In addition, the water vapour concentration is further influenced to some extent by:

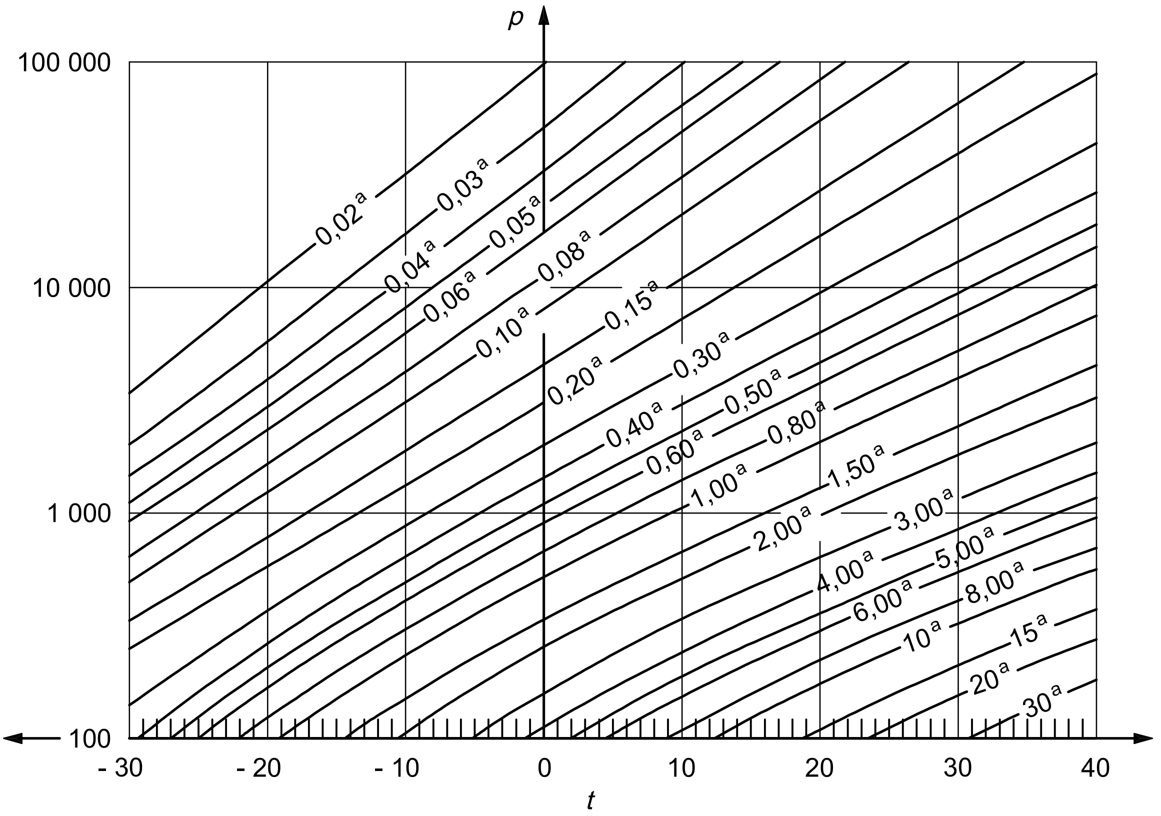
a) the pointing effect: the effect of system pressure on water vapour pressure;

b) the solubility effect: the effect of intermolecular energy exchange;

c) composition: this has little effect in practice and is generally disregarded.

The effects referred to in a) and b) are difficult to represent in a simple formula.

Figure E.1 gives the water content of natural gases saturated by water for various values of temperature and pressure (see Reference [23] in the Bibliography).



Key

t	temperature, °C
p	absolute pressure, kPa
a	Water content of natural gases in g/m^3 (0 °C, 101,325 kPa, dry)

NOTE The graph shows the water dew-point temperature for a given water content line at a specified pressure. At a lower temperature, condensation of water will occur under the same conditions. For instance, with a water content in natural gas of less than 0,03 g/m^3 no problems are expected if natural gas is compressed up to 25 000 kPa and the temperature is not below − 13 °C.

EXAMPLE Water content 0,8 g/m^3, t = 10 °C, p = 1 400 kPa

Figure E.1 — Water content of natural gases as a function of absolute pressure p and temperature t

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