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Natural gas — Quality designation

Gaz naturel — Désignation de la qualité

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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

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The committee responsible for this document is ISO/TC 193, *Natural gas*.

This second edition cancels and replaces the first edition (ISO 13686:1998), which has been technically revised.

Introduction

The need for an International Standard concerning the designation of natural gas quality was a basic reason for the establishment of ISO/TC 193 in 1989. Standardization of the designation of quality is specifically stated in the scope of ISO/TC 193. Natural gas, supplying 20 % of the world's primary energy, is likely to increase its market share greatly. Yet there is currently no generally accepted definition of natural gas quality.

To meet this need, it was decided that a general statement of the parameters (i.e. components and properties) recommended should be established and that the resulting International Standard would not specify values of, or limits for, these parameters.

Furthermore, it was decided that general-purpose natural gas transmitted to local distribution systems (LDS), referred to as "natural gas", should be the first consideration. Thus, this International Standard was developed. Informative annexes are attached as examples of actual natural gas quality specifications that already exist.

This International Standard does not impose any quality restrictions on raw gas transported via pipelines or gathering systems to processing or treating facilities.

It should be understood that this International Standard covers natural gas at the pipeline level prior to any treatment by LDS for peakshaving purposes. This covers the vast majority of the natural gas that is sold in international trade and transmitted for custody transfer to local distribution systems.

Natural gas — Quality designation

1 Scope

This International Standard specifies the parameters required to describe finally processed and, where required, blended natural gas. Such gas is referred to subsequently in this text simply as “natural gas”.

The main text of this International Standard contains a list of these parameters, their units and references to measurement standards. Informative annexes give examples of typical values for these parameters, with the main emphasis on health and safety.

In defining the parameters governing composition, physical properties and trace constituents, consideration has also been given to existing natural gases to ensure their continuing viability.

The question of interchangeability is dealt with in Annex A (see Clause A.2).

2 Normative references

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

ISO 6326-1, *Natural gas — Determination of sulfur compounds — Part 1: General introduction*

ISO 6326-3, *Natural gas — Determination of sulfur compounds — Part 3: Determination of hydrogen sulfide, mercaptan sulfur and carbonyl sulfide sulfur by potentiometry*

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

ISO 6327, *Gas analysis — Determination of the water dew point of natural gas — Cooled surface condensation hygrometers*

ISO 6570, *Natural gas — Determination of potential hydrocarbon liquid content — Gravimetric methods*

ISO 6974-1, *Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 1: General guidelines and calculation of composition*

ISO 6974-2, *Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 2: Uncertainty calculations*

ISO 6974-3, *Natural gas — Determination of composition with defined uncertainty by gas chromatography — Part 3: Determination of hydrogen, helium, oxygen, nitrogen, carbon dioxide and hydrocarbons up to C8 using two packed columns*

ISO 6974-4, *Natural gas — Determination of composition with defined uncertainty by gas chromatography — Part 4: Determination of nitrogen, carbon dioxide and C1 to C5 and C6+ hydrocarbons for a laboratory and on-line measuring system using two columns*

ISO 6974-5, *Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 5: Isothermal method for nitrogen, carbon dioxide, C1 to C5 hydrocarbons and C6+ hydrocarbons*

ISO 6974-6, *Natural gas — Determination of composition and associated uncertainty by gas chromatography — Part 6: Determination of helium, oxygen, nitrogen, carbon dioxide and C1 to C10 hydrocarbons using capaillary columns*

ISO 6975, *Natural gas — Extended analysis — Gas-chromatographic method*

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

ISO 6978-1, *Natural gas — Determination of mercury — Part 1: Sampling of mercury by chemisorption on iodine*

ISO 6978-2, *Natural gas — Determination of mercury — Part 2: Sampling of mercury by amalgamation on gold/platinum alloy*

ISO 10101-1, *Natural gas — Determination of water by the Karl Fischer method — Part 1: Introduction*

ISO 10101-2, *Natural gas — Determination of water by the Karl Fischer method — Part 2: Titration procedure*

ISO 10101-3, *Natural gas — Determination of water by the Karl Fischer method — Part 3: Coulometric procedure*

ISO 11541, *Natural gas — Determination of water content at high pressure*

ISO 13443, *Natural gas — Standard reference conditions*

ISO 14532, *Natural gas — Vocabulary*

ISO 15970:2008, *Natural gas — Measurement of properties — Volumetric properties: density, pressure, temperature and compression factor*

ISO 15971:2008, *Natural gas — Measurement of properties — Calorific value and Wobbe index*

ISO 18453, *Natural gas — Correlation between water content and water dew point*

ISO 19739, *Natural gas — Determination of sulfur compounds using gas chromatography*

ISO 23874, *Natural gas — Gas chromatographic requirements for hydrocarbon dewpoint calculation*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14532 and the following apply.

3.1
natural gas
gaseous fuel obtained from underground sources and consisting of a complex mixture of hydrocarbons, primarily methane, but generally also including ethane, propane and higher hydrocarbons in much smaller amounts

Note 1 to entry: It also includes some inert gases, such as nitrogen and carbon dioxide, plus minor amounts of trace constituents.

Note 2 to entry: Natural gas remains in the gaseous state under the temperature and pressure conditions normally found in service. It is produced by processing raw gas or from liquefied natural gas and, if required, blended to give a gas suitable for direct use. As pipeline quality natural gas, it can then be transmitted within a local distribution system, within a country, or across national borders. It is subject to contractual requirements between buyer and seller, and in some cases to national or state requirements as to quality (see Clause A.1).

3.2
liquefied natural gas
natural gas which, after processing, has been liquefied for storage or transportation purposes

Note 1 to entry: Liquefied natural gas is revaporized and introduced into pipelines for transmission and distribution as natural gas.

3.3
substitute natural gas
manufactured or blended gas with properties which make it interchangeable with natural gas

Note 1 to entry: Substitute natural gas is sometimes called synthetic natural gas.

Note 2 to entry: This also includes gases manufactured by thermal process from biomass.

3.4
raw gas

unprocessed gas taken from well heads through gathering lines to processing facilities

3.5
local distribution system

gas mains and services which supply natural gas directly to consumers

3.6
gas quality

attribute of natural gas by its composition (major components, minor components and trace components) and its physical properties (calorific value, Wobbe index, compression factor, relative density and dew points)

3.7
reference conditions

standard reference conditions of temperature, pressure and humidity (state of saturation) to be used for measurements and calculations carried out on natural gases, natural gas substitutes and similar fluids in the gaseous state

Note 1 to entry: Standard reference conditions are denoted by the subscript “s”: p_s = 101,325 kPa; T_s = 288,15 K.

Note 2 to entry: Adapted from ISO 13443.

3.8
calorific value

amount of heat which would be released by the complete combustion in air of a specified quantity of gas, in such a way that the pressure at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature as that of the reactants

Note 1 to entry: It is divided into two types: superior calorific value and inferior calorific value.

Note 2 to entry: Both superior and inferior calorific values, which differ by the heat of condensation of water formed by combustion, can be specified on a molar, mass or volumetric basis. For the volumetric basis the pressure and temperature shall be stated at standard reference conditions.

Note 3 to entry: Calorific values can also be stated as dry or wet, depending on the water vapour content of the gas prior to combustion.

Note 4 to entry: The effect of water vapour on the calorific values, either directly measured or calculated, is described in Annex F of ISO 6976:1995.

Note 5 to entry: Normally, the calorific value is expressed as the superior, dry value specified as a volumetric basis under standard reference conditions.

Note 6 to entry: Adapted from ISO 6976.

3.8.1
superior calorific value

amount of heat that would be released by the complete combustion with oxygen 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, which is condensed to the liquid state at t_1

Note 1 to entry: Adapted from ISO 6976.

3.8.2
inferior calorific value

amount of heat that would be released by the complete combustion with oxygen 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 to entry: Adapted from ISO 6976.

3.9
density

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

3.10
relative density

density of a gas divided by the density of dry air of standard composition at the same specified conditions of pressure and temperature

Note 1 to entry: The term “ideal relative density” applies when both gas and air are considered as fluids which obey the ideal gas law; the term “real relative density” applies when both gas and air are considered as real fluids. For the standard composition of dry air.

Note 2 to entry: Adapted from ISO 6976.

3.11
Wobbe index

volumetric-basis superior (inferior) calorific value, at specified reference conditions, divided by the square root of the relative density at the same specified metering reference conditions

Note 1 to entry: The heat input for different natural gas compositions is the same if they have the same Wobbe index and are used under the same gas pressure.

Note 2 to entry: Adapted from ISO 6976.

3.12
compression factor

compression factor Z is the quotient of the volume of an arbitrary mass of gas, at a specified pressure and temperature, and that of the same gas under the same conditions as calculated from the ideal gas law

Note 1 to entry: The terms “compressibility factor” and “Z-factor” are synonymous with compression factor.

Note 2 to entry: Adapted from ISO 12213-1.

3.13
water dew point

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

Note 1 to entry: For any pressure lower than the specified pressure there is no condensation at this temperature.

Note 2 to entry: Adapted from ISO 6327.

3.14
hydrocarbon dew point

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

Note 1 to entry: At a given dew point, there is a pressure range within which condensation occurs except at one point, the cricondentherm (see A.3.2).

3.15
gas composition

concentrations of the major and minor components and trace components in natural gas as analysed

3.16
molar composition

gas composition expressed as a molar (or mole) fraction, or molar (mole) percentage

Note 1 to entry: The mole fraction, x, of component i is the quotient of amount of substance of this component and amount of substance of the whole mixture. The unit of amount of substance is mole. The mass of one mole of any chemical species, in grams, is numerically equal to its relative molecular mass. A table of recommended values of molar masses is given in ISO 6976. For an ideal gas, the mole fraction is identical to the volume fraction, but this relationship cannot in general be assumed to apply to real gas behaviour.

3.17
gas analysis

use of test methods and other techniques for determining the gas composition, as stated in this International Standard

3.18
interchangeability

measure of the degree to which the combustion characteristics of one gas resemble those of another gas

Note 1 to entry: Two gases are said to be interchangeable when one gas may be substituted for the other without affecting the operation of gas burning appliances or equipment.

3.19
odorization

addition of odorants, in most cases intensively smelling organic sulfur compounds, to natural gas 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)

Note 1 to entry: Natural gas is normally odourless. It is necessary to add an odorant to the gas for safety reasons. It permits the detection of the gas by smell at very low concentrations.

Note 2 to entry: Odorants in use for gas odorization are specified in ISO 13734.

3.20
methane number

rating indicating the knocking characteristics of a fuel gas

Note 1 to entry: It is comparable to the octane number for petrol.

Note 2 to entry: The methane number expresses the volume 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.

4 Symbols, abbreviations and units

4.1 Symbols

Symbol	Meaning and units
d	Relative density
$\bar{H}$	Molar basis calorific value (kJ/mol)
$\hat{H}$	Mass basis calorific value (MJ/kg)
$\tilde{H}$	Volumetric basis calorific value (MJ/m^3)
M	Mass per mole (kg/kmol)
p	(Absolute) pressure (kPa)
t	Celsius temperature (°C)
T	Thermodynamic (absolute) temperature (K)
V	(Gas) volume (m^3)
W	Wobbe index (number) (MJ/m^3)
Z	Compression factor
D	Density (kg/m^3)

4.2 Abbreviations

Abbreviation	Meaning
LDS	Local distribution system
NG	Natural gas
SNG	Substitute (synthetic) natural gas

4.3 Subscripts

d	(Gas volume) dry
l	Inferior (calorific value)
s	(Gas volume) saturated
S	Superior (calorific value)
w	(Gas volume) wet

Superior calorific value is denoted by Hs; inferior calorific value is denoted by H_I. The calorific value shall be specified under the combustion conditions. The volumetric calorific value shall be specified under standard reference conditions. The calorific value is normally stated as “dry”.

EXAMPLE Superior calorific value, specified on a volumetric basis, at standard reference conditions and stated as wet. For simplicity, the combustion conditions are not specified.

$$\tilde{H}_{\mathrm{S,w}}(p_{\mathrm{s}},T_{\mathrm{s}})$$

The Wobbe index, denoted by W, is expressed on a volumetric basis and given in MJ/m3, where the volume is stated at standard reference conditions. The Wobbe index can be specified as superior or inferior, depending on the calorific value and as dry or wet, depending on the calorific value and the corresponding density.

EXAMPLE Wobbe index, superior, specified an a volumetric basis, at standard reference conditions and stated as “wet”.

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

5 Quality designation parameters

5.1 General

This clause deals with the various parameters which may be referred to in a designation of the quality of natural gas. The parameters actually selected will depend upon the purpose for which the designation is required and it is unlikely that all the parameters listed in this International Standard will be used.

5.2 Gas composition

5.2.1 General

Natural gas is composed primarily of methane with smaller amounts of higher hydrocarbons and of non combustible gases. Major and minor components and trace constituents may be determined as given in Tables 1, 2 and 3.

Limits are not given in this International Standard, but analysis to determine the natural-gas properties may be specified in contracts and state and federal codes in some countries (see informative annexes).

5.2.2 Major components

Table 1 — Major components of natural gas

Constituent	Units	Relevant standard
Methane	mol %	ISO 6974 (parts 1 to 6)
Ethane	mol %	ISO 6974 (parts 1 to 6)
Propane	mol %	ISO 6974 (parts 1 to 6)
Butanes	mol %	ISO 6974 (parts 1 to 6)
Pentanes	mol %	ISO 6974 (parts 1 to 6)
Hexanes plus	mol %	ISO 6974 (parts 1 to 6), ISO 6975
Nitrogen	mol %	ISO 6974 (parts 1 to 6)
Carbon dioxide	mol %	ISO 6974 (parts 1 to 6), ISO 6975

5.2.3 Minor components

Table 2 — Minor components of natural gas

Constituent	Units	Relevant standard
Hydrogen	mol %	ISO 6974-3 and ISO 6974–6, ISO 6975
Oxygen	mol %	ISO 6974-3 and ISO 6974–6, ISO 6975
Carbon monoxide	mol %	ISO 6974-3
Helium	mol %	ISO 6974-3 and ISO 6974–6, ISO 6975

5.2.4 Trace constituents

Table 3 — Trace constituents of natural gas

Constituent	Units	Relevant standard
Hydrogen sulfide	mg/m^3	ISO 6326-1and ISO 6326–3, ISO 19739
Mercaptan sulfur	mg/m^3	ISO 6326-3, ISO 19739
Dialkyl (di) sulfide	mg/m^3	ISO 19739
Carbonyl sulfide	mg/m^3	ISO 6326-3, ISO 19739
Total sulfur	mg/m^3	ISO 6326-5, ISO 19739
Mercury	µg/m^3	ISO 6978-1 and ISO 6978–2

5.3 Gas properties

5.3.1 General

Physical properties may be determined as specified in Table 4.

5.3.2 Physical properties

Table 4 — Physical properties of natural gas

Constituent	Units	Relevant standard
Molar calorific value, $\bar{H}$	MJ/mol	ISO 6976, ISO 15971
Mass-basis calorific value, $\hat{H}$	MJ/kg	ISO 6976, ISO 15971
Volumetric-basis calorific value $\tilde{H}$	MJ/m^3	ISO 6976, ISO 15971
Relative density, d	-	ISO 6976, ISO 15970
Wobbe index, W	MJ/m^3	ISO 6976, ISO 15971
Water dew point	°C (K)	ISO 6327, ISO 18453
Water content	mg/m^3	ISO 10101-1, ISO 18453 ISO 10101-2 ISO 10101-3 ISO 11541
Hydrocarbon dew point	°C (K)	ISO 23874
Hydrocarbon liquid content	mg/m^3	ISO 6570

5.3.3 Other parameters

Content of:

- water and hydrocarbons in liquid form;
- solid particulate substances;
- other gases.

NOTE Usually, the above substances are not present in the natural gas in an amount that could adversely affect the transportation, distribution or utilization of the gas.

6 Sampling

For the control of natural gas quality, sampling is necessary. Natural gas is generally sampled at agreed upon points, using routines representing established good practice, applying the relevant standards. See ISO 10715 for guidance on sampling.

Annex A
(informative)

Introduction to informative annexes

A.1 Quality specification

A.1.1 General

Gas quality specifications are originating from legislation, codes of practice and/or contractual agreement and are generally nationally based. Within the European Union all infrastructure operators publish the gas quality parameters to grant access to their systems. As examples, information on some national situations is given in the following.

A.1.2 German regulations

Code of Practice DVGW G 260:2008 (Relevant parts for natural gases, see Annex B)

NOTE Deutsche Vereinigung des Gas- und Wasserfaches (DVGW) is a scientific association whose prime task is the production of codes of practice for the entire gas and water industry. It is a member of DIN.

A.1.3 French regulations concerning gas quality

In France, gas quality is principally defined by two governmental regulatory texts (Arretes Ministeriels) the first of which specifies the superior calorific value and the second the water and sulfur contents. All other gas quality specifications shall be published by the infrastructure operators. The two governmental documents can be summed up as follows:

a) Arrête du 16 septembre 1977

Limits of variations of superior calorific value of natural gas. Reference conditions called normal conditions (n) are:

P: 1,013 bar T: 0 °C

The superior calorific value of natural gas must be between 10,7 and 12,8 kWh/m3 (n) in areas fed by high cal. gas (H Gas) and between 9,5 and 10,5 kWh/m3 (n) in areas fed by low cal. gas (B Gas). In the actual regulatory text calorific values are expressed in thermie (th)/m3 (n).

b) Arrête du 28 janvier 1981

Sulfur and sulfur components in natural gases:

The gas must not corrode the pipelines i.e. no component capable of reacting chemically with materials used in construction of the pipelines or which modifies physical characteristics of these material can be allowed in natural gas.

— Hydrogen sulfide

Instantaneous content of hydrogen sulfide must be less than 15 milligrams per cubic metre (n).

Hydrogen sulfide content must not exceed 12 milligrams per cubic meter (n) for more than 8 consecutive hours.

The average content of hydrogen sulfide for any period of 8 days must be less than 7 milligrams per cubic metre (n).

— Sulfur

Instantaneous total sulfur content must be less than 150 milligrams per cubic metre (n).

— Water

Water dew point must be less than - 5 °C at the maximum service pressure of the gas pipeline.

A.1.4 UK. Statutory Legislation with respect to gas quality

Within the UK there are certain statutory requirements with respect to gas quality. This legislation stipulates standards of purity and odourosity that must be met by any supplier of gas through pipes.

These standards are as follows:

— Purity

No person shall supply through pipes any gas which contains more than 5 mg of hydrogen sulphide per cubic metre.

— Odour

No person shall supply through pipes any gas which does not possess a distinctive odour.

A.2 Interchangeability

A.2.1 General

The interchangeability of natural gases in a given LDS is not only dependent on the relevant gas parameters, but is also strongly dependent on the characteristics of the appliances used in the LDS and on the end use pressure of the gas.

Interchangeability can be defined as the ability of a distributed natural gas to be substituted by another without the need for adjustment at the customer’s equipment. The appliances will continue to operate safely and satisfactorily.

The criteria to be considered for interchangeability are as follows:

— Thermal input: Flow of gas through an orifice at constant pressure, a function of Wobbe index.

— Flash back: The tendency for the flame to contract towards the port and for the combustion to take place inside the burner.

— Lifting: Burning surface expands to the point where burning ceases at the port and burns above it.

— Yellow tipping: Incomplete combustion where excess hydrocarbons could, but do not always, result in unacceptable levels of carbon monoxide. May result in soot deposition and a continuing deterioration of combustion.

The substituted gas may be deemed to be interchangeable when, without the need for adjustment of the appliances, it provides a thermal input comparable with that provided by the gas previously distributed, without the occurrence of flash back, lifting or yellow tipping.

For the examination of interchangeability there are two routes which can be followed, namely Wobbe index or gas composition-based prediction methods.

A.2.2 Wobbe index (see Annexes B, C)

Natural gases are included in the second gas family. Inside the second family different gas groups can be identified.

Each gas group is a collection of gases characterized by:

- a reference gas with which the appliances operate under nominal conditions, when supplied at the corresponding normal pressure;
- limit gases representative of the extreme variations in the characteristics of the usable gases;
- test pressures representative of the extreme variations in the appliance supply conditions.

Appliances adjusted on the reference gas, at the normal pressure, and judged to perform satisfactorily with the limit gases at the test pressures, are approved for use within this gas group. In this approach the Wobbe index is the primary gas parameter, whose range identifies the gas group.

A.2.3 AGA index method (see Annex D)

In this prediction method for interchangeability, the measured appliance characteristics in the LDS are translated to defined relevant gas parameters, based on gas composition. Wobbe index is basically a measure of heat input to the appliance. It is indicative of interchangeability, but not conclusive. When kept within the established limits as determined by appliance certification procedures, control of the Wobbe index provides a satisfactory measure.

However, where no such appliance certification regime exists, or for borderline cases of gas composition, alternative methods for determining interchangeability exist.

A.2.4 British Gas Hydrocarbon Equivalence method (see Annex E)

The British Gas method is a composition and Wobbe index-based prediction method for determining gas interchangeability within the UK.

A.2.5 Weaver index method (see Annex F)

The Weaver index method introduces the flame speed into the equations particularly for lifting and flash back.

A.2.6 French method for determining gas interchangeability (Delbourg method) (see Annex G)

The French method for determining gas interchangeability essentially continues to be the Delbourg method. The latter is based on the definition of interchangeability indices indicating the limits of gas combustion. In an appliance at reference conditions, the occurrence of a malfunction (incomplete combustion, flame lift, flashback, sooting, ignition at the injector) corresponds to a precise index value. The ranges deemed satisfactory for different indices were suggested to operators in 1963 after studying a sample of representative appliances available then.

The interchangeability diagram drawn then shows the range in a system of coordinates (corrected Wobbe number, combustion potential) within which all appliances will function satisfactorily. Any gas of a different composition is positioned on the basis of the 1963 reference values. The method of calculation and the interchangeability diagram are shown in Annex G.

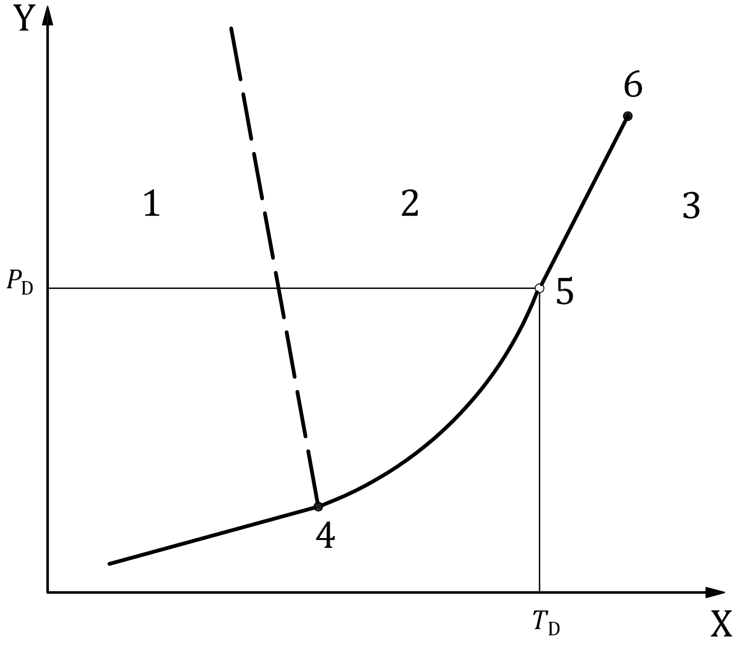
Whenever gas conversion becomes necessary, the likely scenario can be determined with the aid of the interchangeability indices. Deschamps defined in a general manner the indices for second-family gases. This new method was employed during the 1970s during the changeover from Groningen to Lacq gas.

NOTE Existing approaches to interchangeability are based essentially on experience and studies with atmospheric burner, natural draft appliances. The technology of gas appliances and equipment is changing rapidly. Many advanced efficiency units incorporate power burners with much less excess air allowance. Internal combustion engines used for cogeneration systems are growing in numbers. Natural gas vehicles, fuel cells, and other end-use applications are coming into use. Thus, interchangeability parameters and techniques must be constantly reviewed and updated as natural gas utilization becomes more complex and sophisticated with time.

The European test gas procedures, as embodied in EN 437, provide continuous interchangeability proof for equipment by means of appliance.

A.3 Condensation curves

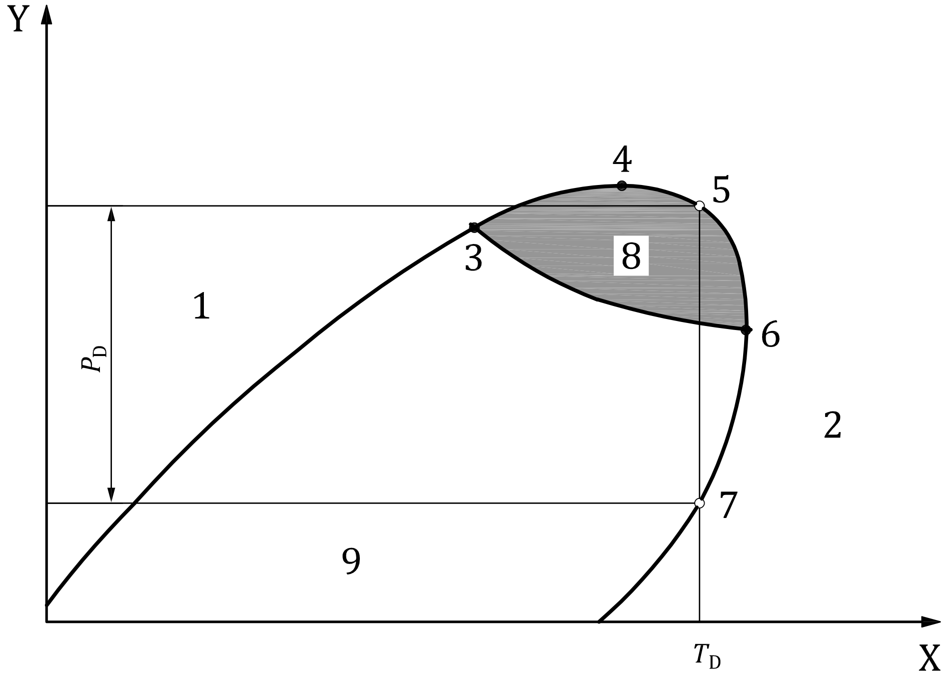
A.3.1 Water



Key

1	solid
2	liquid
3	vapour
4	triple point
5	D dew point
6	critical point

A.3.2 Hydrocarbons



Key

1	liquid
2	vapour
3	critical point
4	cricondenbar
5	dew point
6	cricondentherm
7	dew point
8	retrograde region
9	two phase area

A.4 Odorization

Distributed natural gas is always odorized to provide information about any possible leakage. The level of odorization is generally chosen so that the information is perceived before the gas concentration in air reaches 20 % (warning level). The following different categories of odorant blends are generally used to odorize natural gases.

a) Blends of mercaptans, consisting predominantly of Tertiary Butyl Mercaptan (TBM) with lower concentrations of Iso Propyl Mercaptan (IPM) and Normal Propyl Mercaptan (NPM).

b) Blends of mercaptans with alkyl sulfides, where Dimethyl Sulfide (DMS) and Methyl Ethyl Sulfide (MES) are the most commonly used alkyl sulfides.

c) Tetrahydrothiophene (THT): cyclic sulfide used in the gas industry as single component odorant.

d) Blends of THT with mercaptans.

e) Some countries introduced sulfur free or low sulfur odorants based on acrylates.

Odorant used for the odorization of natural gas have to meet the requirements mentioned in ISO 13734. Odorization guidelines are described in ISO/TS 16922.

A.5 Nominal range of natural gas components

A.5.1 European market

As relevant to the European market, 'Natural gas, dried' is determined by the components (all concentrations on a mass-to-mass basis) given in Table A.1.

Table A.1 — Natural gas components

Methane	70,0 % to 98,0 % (w/w)
Ethane	0,3 % to 18,0 % (w/w)
Propane	< 8,0 % (w/w)
Butane	< 2,0 % (w/w)
Pentane	< 0,2 % (w/w)
Nitrogen	< 30,0 % (w/w)
Carbon dioxide	< 15,0 % (w/w)

The content of each of all other components and constituents is less than 0,1 % (w/w).

NOTE Existing Substances Regulation No 793/93 /EEG of 23 March 1993, Natural gas, dried, EINECS no 270-085-9, CAS no 68410-63-9).

A.5.2 United States

A.5.2.1 National overview

Natural gas composition to end-use customers in the US is a complex issue, with no particularly 'correct' answer. There are certainly differences in the chemical constituents present in natural gas as well as in the key indices used to measure natural gas 'quality' and value: heating value, specific gravity, and Wobbe index. Existing gas industry practices acquired over the years provide a measure of self-regulating control and are complemented by contract terms for gas sales, regulatory oversight, desire for product quality, and the pragmatic need to account for gas volumes and their economic value. These and other factors tend to bring the key measures of natural gas to a common level.

The overwhelming majority of natural gas delivered in this country is non-descript; that is, there are no distinguishing features in these gases that would raise a concern. However, there are instances where gas utilities deliver a composition of natural gas that is different from the norm. This occurs most often for short periods at a select number of utilities (e.g. high demand points in the winter) or, in one instance, is characteristic of the daily deliveries by a gas utility. The key factor in these cases is whether such compositions represent a significant variation from the norm for a particular application. A concerted effort has been made to include in this database cities that represent the industry 'norm' as well as extremes. Twenty-six target cities in 19 states were identified for collection of data on gas composition. The cities represent the regions and states given in Table A.2.

Table A.2 — Regions and states

Region	States
Northeast	New York, New Jersey, Pennsylvania, Rhode Island, Massachusetts, Connecticut
Southeast	Maryland, Georgia, Virginia
North Central	Illinois, Ohio, Michigan, Wisconsin
South Central	Texas, Oklahoma, Louisiana
Mountain	Colorado
Pacific	California, Washington

Figure A.1 graphically shows the distribution of these target areas throughout the US.

A.5.2.2 Summary national statistics

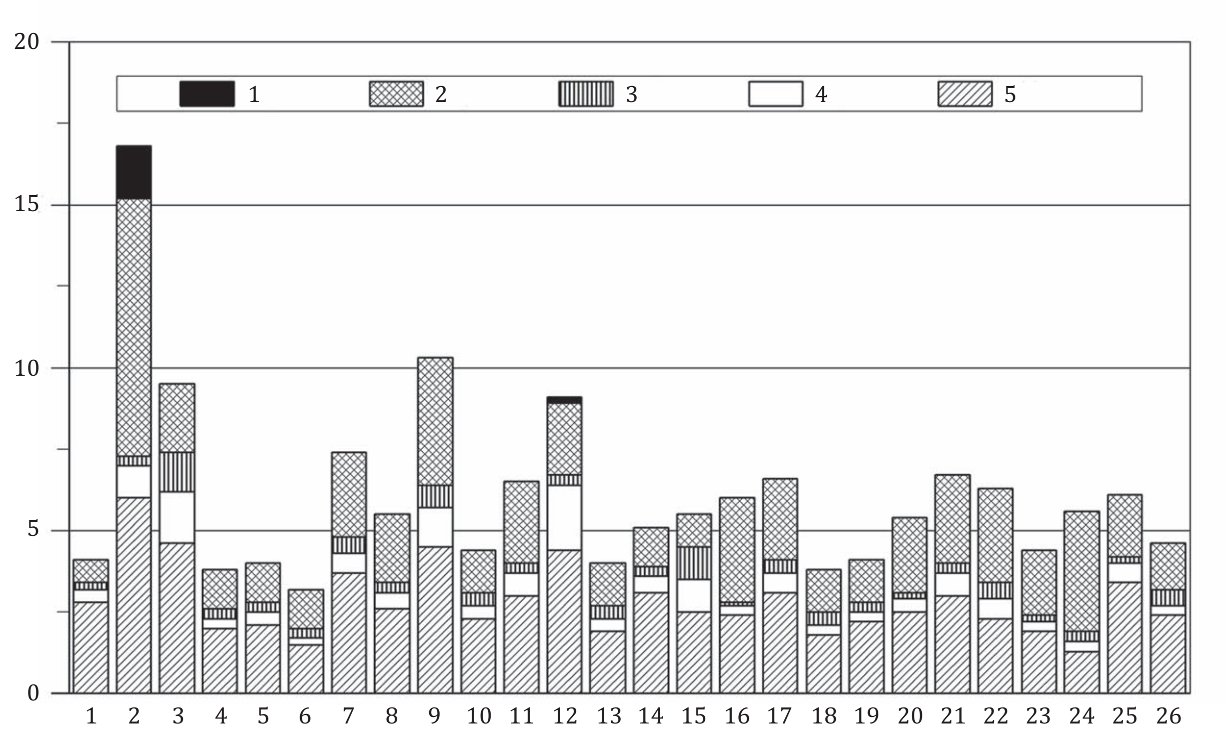
The methodology used to collect these data was described in the previous section, including the issue of weighting based an volumetric gas deliveries for statistics for all of the 26 cities. In total, these data constitute over 6 800 gas analyses. The mean column in Table A.3 shows typical composition and physical property data for end use delivered natural gas. The minimum and maximum columns illustrate the absolute extremes identified in the data, while the 10th and 90th percentile columns show relative extremes.

Table A.3 also indicates that the principal components of natural gas are methane, ethane, propane, and inert gases, with relatively trace levels of butane or heavier hydrocarbons. This fact is clearly illustrated in Figure A.2, showing average percent levels of non-methane constituents found in natural gas for each of the 26 cities (in mole percent or essentially equivalent volume percent). The values in Table A.3 also note several extreme values that were set by propane-air peak shaving gas (P/A) compositions. The consideration of peak shaving gases in three cities noticeably affects the maximum and minimum national values, as previously noted. The mean and percentile values, however, show little or no difference compared to when the propane-air peak shaving gases are not considered.

Table A.3 — Natural gas composition and physical properties

	Mean	Minimum with P/A	Minimum without P/A	Maximum with P/A	Maximum without P/A	10th %-ile	90th %-ile
Methane (mole %)	93,9	55,8	74,5	98,1	98,1	89,6	96,5
Ethane (mole %)	3,2	0,5	0,5	13,3	13,3	1,5	4,8
Propane (mole %)	0,7	0	0	23,7	2,6	0,2	1,2
C_4 + (mole %)	0,4	0	0	2,1	2,1	0	0,6
$CO_2 + N_2$ (mole %)	2,6	0	0	15,1	10,0	1,0	4,3
Heating value (MJ/m^3)	38,46	36,14	36,14	45,00	41,97	37,48	39,03
Heating value (BTU/scf)	1033	970	970	1208	1127	1006	1048
Specific gravity	0,598	0,563	0,563	0,883	0,698	0,576	0,623
Wobbe number (MJ/m^3)	49,79	44,76	44,76	52,85	52,85	49,59	50,55
Wobbe number (BTU/scf)	1336	1201	1201	1418	1418	1331	1357
Air/fuel ratio (mass)	16,4	12,7	13,7	17,1	17,1	15,9	16,8
Air/fuel ratio (volume)	9,7	9,1	9,1	11,4	10,6	9,4	9,9
Molecular weight	17,3	16,4	16,4	25,5	20,2	16,7	18,0
Critical compression ratio	13,8	9,7	12,5	14,2	14,2	13,4	14,0
Methane number	90,0	34,1	73,1	96,2	96,2	84,9	93,5
Lower flammability limit, %	5,00	4,30	4,56	5,25	5,25	4,84	5,07
Hydrogen:carbon ratio	3,92	3,24	3,68	3,97	3,97	3,82	3,95

Figure A.1 — Regional distribution of gas: Composition survey areas



Key

1 ethane

2 propane

3 butanes +

4 inerts

5 oxygen

Figure A.2 — Non-methane constituents in natural gas

Annex B
(informative)

German Regulation Code of Practice DVGW G 260:2008, Extract of the relevant parts for natural gases

B.1 Reference gases, conditioning gases, supplemental gases, substitute gases

Reference gases shall be the gases usually distributed in a service area.

Conditioning gases shall be gases or gas mixtures which are added to a reference gas to alter its technical combustion characteristics.

Supplemental gases shall be gas mixtures which differ substantially from a reference gas both in terms of composition and technical combustion characteristics. Such supplemental gases may be added to a reference gas in limited quantities to supplement gas supplies or allow gas locally available to be used, the amount of supplemental gas being determined by the requirement for similar combustion behaviours of the reference gas in question and the resulting gas mixture.

Substitute gases shall be gas mixtures which, while having different compositions and possibly different characteristics compared to a reference gas, exhibit a combustion behaviour for the same gas pressure and unchanged equipment settings that is similar to that of the reference gas to be substituted. Such a substitute gas is used instead of a reference gas.

B.2 Standard state

B.2.1 General

The state of a gas shall be deemed to be clearly characterized by its variables of state. Public utility gases fall into the group of real gases showing behaviour different to that of ideal gases.

B.2.2 Normal conditions according to ISO Standard 13443

The state at normal conditions shall be the reference state which is used for comparing gases at different flowing conditions. Such state at normal conditions shall be indicated by the subscript “n” and shall be defined as follows:

— pressure of gas at normal conditions: p_n = 1 013,25 hPa = 1,01325 bar and;

— temperature of gas at normal conditions: T_n = 273,15 K = 0 °C.

B.2.3 Standard conditions according to ISO standard 13443

The state at standard conditions according to ISO standard 13443 may also be used as a reference state. Such state at standard conditions shall be indicated by the subscript “s”:

p_S = 1,01325 bar

T_S = 288,15 K = 15 °C

B.3 Gas constituents

B.3.1 General

Gases shall be deemed to consist of main constituents and accompanying substances.

The main constituents of a gas or a gas mixture are the fuel gas and inert gas components whose volume, mole and mass fractions shall be indicated in percent (%).

The concentrations of the (gaseous, liquid or solid) accompanying substances contained in a gas shall be indicated in mg/m^3, cm^3/m^3 or mg/kg.

B.3.2 Wobbe index

The Wobbe index is a characteristic value for the interchangeability of gases in terms of heat load on gas-fired appliances. It is usually referred to normal conditions.

Fuel gases of different compositions but equal Wobbe indices produce almost the same heat load on a burner under the same pressure (low pressure) conditions.

The "upper" Wobbe index $W_{\mathrm{S,n}}$ is the quotient of the superior calorific value $H_{\mathrm{S,n}}$ and the square root of the relative density d. The "lower" Wobbe index $W_{\mathrm{I,n}}$ is the quotient of the inferior calorific value $H_{\mathrm{I,n}}$ and the square root of the relative density d.

$$W_{S,n} = \frac{H_{S,n}}{\sqrt{d}} \text{ or } W_{I,n} = \frac{H_{I,n}}{\sqrt{d}}$$

B.4 Methane number

The methane number is a measure of the knocking characteristics of a fuel gas. It is comparable to the octane number of petrol. The methane number indicates the volumetric content in percent of methane in a methane/hydrogen mixture which, in a test engine under standard conditions, exhibits the same knocking behaviour as the gaseous fuel to be examined.

B.5 Notes on gas constituents and accompanying substances

B.5.1 General

Main constituents of public utility gases are, for example, methane, hydrogen or liquefied petroleum gases. Public utility gases may also contain levels of gaseous, liquid or solid accompanying substances which either occur naturally in the gas or originate from a manufacturing process or may be added to the gas as a substance having a deliberate effect, but they may also be formed during gas transportation.

B.5.2 Hydrocarbons

The levels of saturated, unsaturated and aromatic higher hydrocarbons in gases shall be limited for reasons of distribution and combustion behaviour. The maximum concentration of said constituents in gas that is allowable to ensure trouble-free combustion depends on the type of hydrocarbons and on the concentration of hydrogen and oxygen in the gas. Unlike nitrogen, carbon dioxide also enhances the combustion of non-saturated and aromatic hydrocarbons particularly if diffusion burners are used.

The condensation of hydrocarbons is determined by the type and quantity of the condensable components contained in the gas as well as by the prevailing pressure and temperature. The limit is usually defined by determining the point of condensation, i.e. a temperature above which condensation of hydrocarbons at a defined pressure or in a defined pressure range is excluded.

B.5.3 Water

Gases subject to high or medium pressure should always be as dry as possible, i.e. the relative humidity should be below 60 % to prevent corrosion and the formation of gas hydrates.

As for hydrocarbons, limits shall be defined by specifying a dew point, i.e. a temperature above which, at a specific pressure, water condensation is excluded.

B.5.4 Oxygen

The oxygen contained in water vapour-carrying gases has a corrosive effect. For this reason, the maximum allowable oxygen content of a gas shall depend on its relative humidity.

The maximum oxygen concentration specified in Table B.1 may be exceeded if hydrocarbon/air mixtures are used as substitute or supplemental gases.

B.5.5 Carbon dioxide

Carbon dioxide may be present in gases either as a natural component or as a product of the gas manufacturing process. In wet gases, carbon dioxide will promote corrosion. For this reason, preventive action should be taken by drying the gas.

B.5.6 Mist and dust

The term "technically free" shall mean that condensates, mist and dust are removed from the gas to such an extent as to allow operation of gas appliances and gas equipment of a standard design or in conformity with applicable design requirements.

B.5.7 Sulfur compounds

Sulfur compounds contained in a gas may include hydrogen sulphide, carbonyl sulphide, carbon disulphide, other organic sulphides, disulphides, mercaptans and thiophenes.

The sulfur compound content of manufactured gas may vary depending on the feedstock and gas treatment process used. It may vary for natural gases depending on the field from where the gas originates and on the treatment process. The use of odorants can increase the sulfur content.

The sulfur content in a gas can have an adverse effect on the service lives of pipelines and gas appliances.

B.6 Characteristic combustion properties and limit values for components for gas quality

In terms of their characteristic combustion data and levels of gas components and accompanying substances, gases shall meet the values provided in Tables B.1.

All gases distributed through public utility systems to domestic users and/or customers to whom similar safety standards apply shall be odorised. The sulfur level of odorants is not included in the total sulfur content specified in Table B.1.

The total sulfur content of gases distributed in Germany including odorants is generally significantly lower than 30 mg/m^3.

Table B.1 — DVGW G260: 2008, Second gas family

Combustion characteristics				
Designation	**Symbol**	**Unit**	**Group L**	**Group H**
Wobbe index	$W_{S,n}$			
Total range		kWh/m^3	10,5 to 13,0	12,8 to 15,7
		MJ/m^3	37,8 to 46,8	46,1 to 56,5
Declared		kWh/m^3	12,4	15,0
		MJ/m^3	44,6	54,0
Allowable variation in service area		kWh/m^3	+ 0,6	+ 0,7
			- 1,4	- 1,4
Superior calorific value	$H_{S,n}$	kWh/m^3	8,4 to 13,1	
		MJ/m^3	30,2 to 47,2	
Relative density	d_n		0,55 to 0,75	
Gas supply pressure				
Total range	p_{sup}	mbar	18 to 25	
Declared		mbar	20	
(p_n = 1 013,25 hPa, T_n = 273,15 K)				
Accompanying substances	**Unit**	**Maximum orientation values**		
Hydrocarbon dewpoint	°C	ground temperature ground temperature at given pipeline pressure		
Water dewpoint	°C			
Mist, dust, liquid		Technically free		
Oxygen (by volume)	%			
in dry distribution grids		3		
in wet distribution grids		0,5		
Total sulphur	mg/m^3	30[a]		
Mercaptans	mg/m^3	6		
Short -term in exceptional circumstances	mg/m^3	16		
Hydrogen sulphide	mg/m^3	5		
Short-term in exceptional circumstances	mg/m^3	10		

[a] No odorant.

Annex C
(informative)

European Standard EN 437 “Test gases, test pressures and categories of appliances”

The scope of the European Standard EN 437 is restricted to test gases and is therefore not suitable to be used as a natural gas specification for the trading of natural gas. However the standard is still worthwhile to be mentioned in this International Standard, because it defines the expressions L-, H- and E-gas and also establishes a number of other parameters that characterize gases.

The European Standard EN 437 has been approved by most European countries and is often referred to as the document that is used to define gas compositions in different European nations. As stated before, EN 437 does not provide a complete characterization of natural gas for trading purposes but defines the composition and Wobbe index for gases that are to be used for performance testing of gas appliances.

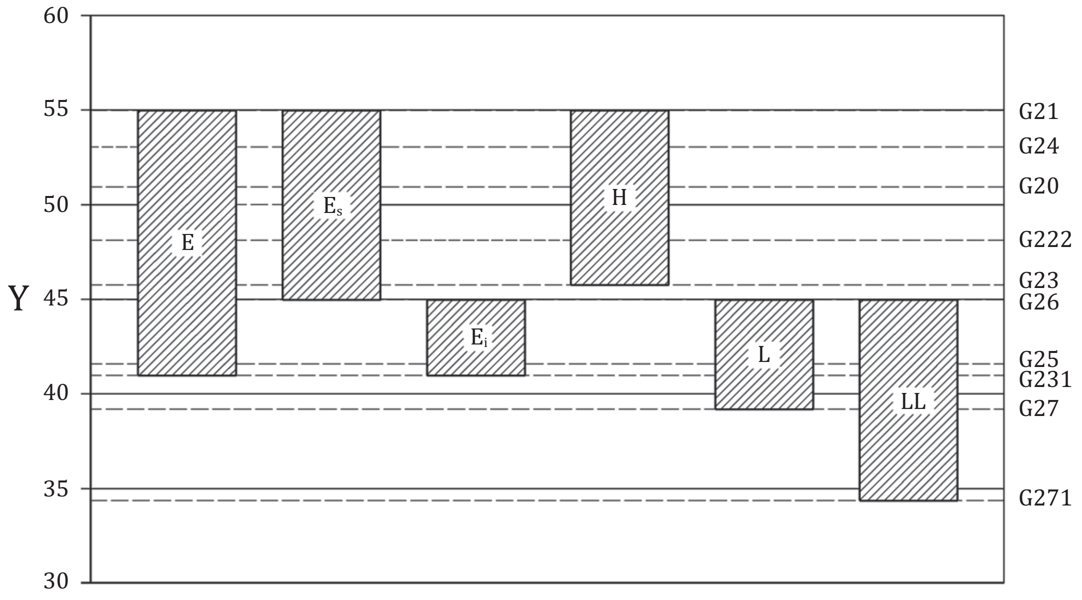
In EN 437, the second gas family is divided into three groups, as a function of the Wobbe index, according to the values given in Table C.1.

Table C.1 — Groups in the second gas family as a function of the Wobbe indices

Groups in second gas family	**Gross Wobbe index at 15 °C and 1013,25 mbar** MJ/m^3	
	Minimum	**Maximum**
Group H	45,7	54,7
Group L	39,1	44,8
Group E	40,9	54,7

Within the second gas family some special gas groups exists. The characteristics of these special gas groups correspond to gases distributed nationally or locally. These special gas groups are Group LL, E_i, and E_S.

A schematic overview of the various gas groups and their corresponding test gases is given in Figure C.1.



Key

Y Wobbe index (MJ/m^3)

Figure C.1 — Groups in the second gas family as a function of the Wobbe indices

The nature of the test gases defined in EN 437, their composition and their major properties are listed in Table C.2.

Table C.2 — Test gases for gas groups in the second family according to EN 437

Gas Group	Nature of gas	Designation	Composition by volume %	W_i MJ/m^3	H_i MJ/m^3	W_s MJ/m^3	H_s MJ/m^3	d MJ/m^3	Test pressures mbar
Group H	Reference	G20	CH_4 = 100	45,67	34,02	50,72	37,78	0,555	P_n = 20 P_{min} = 17 P_{max} = 25
	Incomplete combustion, sooting	G21	CH_4 = 87 C_3H_8 = 13	49,60	41,01	54,76	45,28	0,684	
	Light back limit	G222	CH_4 = 77 H_2 = 23	42,87	28,53	47,87	31,86	0,443	
	Lift limit	G23	CH_4 = 92,5 N_2 = 7,5	41,11	31,46	45,66	34,95	0,586	
Group L	Reference	G25	CH_4 = 86 N_2 = 14	37,38	29,25	41,52	32,49	0,612	P_n = 25 P_{min} = 20 P_{max} = 30
	Incomplete combustion, sooting	G26	CH_4 = 80 C_3H_8 = 7 N_2 = 13	40,52	33,36	44,83	36,91	0,678	
	Lift limit	G27	CH_4 = 82 N_2 = 18	35,17	27,89	39,06	30,98	0,629	

Table C.2 *(continued)*

Gas Group	**Nature of gas**	**Designation**	**Composition by volume** %	W_i MJ/m^3	H_i MJ/m^3	W_s MJ/m^3	H_s MJ/m^3	d MJ/m^3	**Test pressures** mbar
Group LL	Reference	G25	CH_4 = 86 N_2 = 14	37,38	29,25	41,52	32,49	0,612	P_n = 20 P_{min} = 18 P_{max} = 25
	Incomplete combustion, sooting	G26	CH_4 = 80 C_3H_8 = 7 N_2 = 13	40,52	33,36	44,83	36,91	0,678	
	Lift limit	G271	CH_4 = 74 N_2 = 26	30,94	25,17	34,36	27,96	0,662	
Group E	Reference	G20	CH_4 = 100	45,67	34,02	50,72	37,78	0,555	P_n = 20 P_{min} = 17 P_{max} = 25
	Incomplete combustion, sooting	G21	CH_4 = 87 C_3H_8 = 13	49,60	41,01	54,76	4,28	0,684	
	Light back limit	G222	CH_4 = 77 H_2 = 23	42,87	28,53	47,87	31,86	0,443	
	Lift limit	G231	CH_4 = 85 N_2 = 15	36,82	28,91	40,90	32,11	0,617	
Range E_s of Group E [a]	Reference	G20	CH_4 = 100	45,67	34,02	50,72	37,78	0,555	P_n = 20 P_{min} = 17 P_{max} = 25
	Incomplete combustion, sooting	G21	CH_4 = 87 N_2 = 13	49,60	41,01	54,76	45,28	0,684	
	Light back limit	G222	CH_4 = 77 H_2 = 23	42,87	28,53	47,87	31,86	0,443	
	Lift limit	G26	CH_4 = 80 C_3H_8 = 7 N_2 = 13	40,52	33,36	44,83	36,91	0,678	
Range E_i of Group E	Reference	G25	CH_4 = 86 N_2 = 14	37,38	29,25	41,52	32,49	0,612	P_n = 25 P_{min} = 20 P_{max} = 30
	Incomplete combustion, sooting	G26	CH_4 = 80 C_3H_8 = 7 N_2 = 13	40,52	33,36	44,83	36,91	0,678	
	Lift limit	G231	CH_4 = 85 N_2 = 15	36,82	28,91	40,90	32,11	0,617	

Annex D
(informative)

Interchangeability AGA index method

D.1 General

The AGA Interchangeability Program, Catalogue No. XH 8810, uses the index method based on AGA Research Bulletin 36 “Interchangeability of other fuel gases with natural gas” (1952, 2nd edition), the Weaver index method, and the Knoy Constant techniques to determine compatibility of gases. All methods involve an adjustment gas and a substitute gas. The AGA and Weaver index methods require a complete analysis of gas components, but the Knoy constant method uses only the superior, dry calorific value and relative density. Only the AGA index method is covered for this explanation.

Interchangeability in the AGA program is determined by calculating indexes for lifting, flashback, and yellow tipping (complete combustion), and by establishing preferable and objectional limits for each. The equations used for the individual indices were derived experimentally by the Bulletin 36 work. An exactly interchangeable gas, that is, if the adjustment gas and the substitute gas were of the same composition, would yield values of I_l, I_f and I_y equal to 1,0. The preferable limits are pegged at this value. The objectionable limits are values which just provide satisfactory performance. Such values are determined by testing a variety of appliances, by setting them up on the adjustment gas, and by changing gas mixtures until the three interchangeability criteria occur, namely, lifting, flashback and yellow tipping.

D.2 Example for a calculation

D.2.1 Natural gas of the second family

D.2.1.1 General

Group H compositions of Adjustment (Reference) and Limit gases, as stated in EN 437, are put into the AGA program. The compositions of these gases are given under the heading “test gases”. Extracts from the original program worksheets are attached and the limiting index values noted. See worksheets 1, 2 and 3.

Two tables result from each calculation of a given adjustment gas-limit gas set. Table D.1 presents the index values calculated for both the AGA and Weaver methods. Any violation of the index range that has been established will be printed out alongside the index in question. Note that the yellowtip index is cited as AGA 36 predicting problems. This note is not appropriate for the H gas calculation since its criteria were based on a different adjustment gas-limit gas regimen.

One of the features of the program is the ability to insert new limiting index values which would be the case here since G 21 is the yellow tip limit gas. Thus, the note would no longer show at an I_y of 0,762 (worksheet 1). Table D.2 prints out values for various properties pertaining to the adjustment and substitute gases. These include superior, dry calorific value, relative density, Wobbe index, and numerous other factors used in the interchangeability calculations. The equations used for the AGA calculations are not reproduced here, but are available through AGA if desired.

For ease of understanding, this concept is put into Interchangeability Limit Box format for H gas (graph 1). One constructs the Limit Box by treating the AGA Indices as coordinates, using the reciprocal of I_y as the abscissa. The preferred values form the inner box. The objectionable values form the limits. Gas compositions falling inside the limits are substitutable, those outside are not. Each gas has two plot points, namely, I_l versus $1/I_y$ and I_f versus $1/I_y$.

As a corollary to the Interchangeability Limit Box, it is also necessary to determine that the Wobbe index of the substitute gas is within limits. Wobbe index relates directly to the BTU/hr (MJ/h) input to gas appliances. The ratio of Wobbe indexes between adjustment and substitute gases yield the percent change (plus or minus) in input. Wobbe index is often thought of as a measure of interchangeability, but it is indicative rather than conclusive. However, it is a positive measure of the ability of the appliance to perform its function, and thus must remain within limits. The rule of thumb in the USA is a maximum plus or minus 10 % change. European limits are somewhat narrower as derived from the limit gas compositions. The Wobbe Index Limit Box is shown in graph 2 for H gas.

Table D.1 — Test gases used for the example to explain the AGA method

H Gas reference and limit gases					
Reference	G 20	Methane	100 %		
Yellow tipping	G 21	Methane	87 %	Propane	13 %
Flash back	G 222	Methane	77 %	Hydrogen	23 %
Lifting	G 23	Methane	92,5 %	Nitrogen	7,5 %

D.2.1.2 AGA Worksheet 1

Table D.2 — Yellow tipping: G 20 (reference gas), G 21 (substitute gas)

AGA BULLETIN 36: Lifting Index I_l	0,941		
Flashback Index l_f	1,034		
Yellow tip Index I_y	0,762	AGA 36	PREDICTS YELLOW TIPPING
$1/I_y$	1,312		PROBLEMS
WEAVER: Heat rate ratio	1,078	J_H	Limit Value
Primary air ratio	1,078	J_A	
Lifting	1,118	J_L	WEAVER JH OUT OF RANGE
Flashback	0,073	J_F	
Yellow tipping	0,314	J_Y	
Incomplete Combustion	0,116	J_I	
			WEAVER J_Y INDICATES YELLOW TIPPING WEAVER J_I INDICATES INCOMPLETE COMBUSTION

Table D.3 — Interchangeability indices

Gas values	ADJUST GAS	SUBSTITUTE GAS
Compressibility	0,99801	0,99678
Calorific value	1014,0	1212,2
Mol. weight	index	19,690
Relative density	0,5547	0,6817
Wobbe index	1361,4	1468,2 Limit values
Knoy factor	1126,5	1256,2
Primary air (ft^3)	9,52	11,38
H/C ratio	4,00	3,59
N (C per 100)		26
Flame speed, S	14,06	14,58
Lifting constant	0,670	0,834
Yellow tip const.	218	317
Lifting limit K	1,208	1,223
Prim. air f (#36)	0,7345	0,6811
Air per 100 Btu	0,9392	0,9389
Yellow tip limit Y	22,89	27,86

D.2.1.3 AGA Worksheet 2

FLASH BACK - G 20 (reference gas), G 222 (substitute gas).

Table D.4 — Interchangeability indices

AGA BULLETIN 36: Lifting Index I_I	0,868		
Flashback Ind. I_f	1,198		Limit Value
Yellow tip Ind. I_y	1,160		
1 /I_y	0,862		
WEAVER: Heat rate ratio	0,944	JH	WEAVER JH OUT OF RANGE
Primary air ratio	0,926	JA	
Lifting	1,423	JL	
Flashback	0,640	JF	WEAVER JF INDICATES
Yellow tipping	- 0,074	JY	FLASHBACK
Incomplete combustion	- 0,128	J I	

Table D.5 — Gas values

	GAS	**SUBSTITUTE GAS**
Compressibility	0,99801	0,99897
Calorific value	1014,0	854,8
Mol. weight	16,043	12,817
Relative density	0,5547	0,4428
Wobbe index	1361,4	1284,7 Limit value
Knoy factor	1126,5	1021,7
Primary air (ft^3)	9,52	7,88
H/C ratio	4,00	4,60
N (C per 100)		
Flame speed, S	14,06	21,61
Lifting constant	0,670	0,654
Yellow tip const.	218	168
Lifting limit K	1,208	1,477
Prim. air f (#36)	0,7345	0,7784
Air per 100 Btu	0,9392	0,9219
Yellow tip limit Y	22,89	21,30

D.2.1.4 AGA Worksheet 3

LIFTING - G 20 (reference gas), G 23 (substitute gas).

Table D.6 — Interchangeability indices

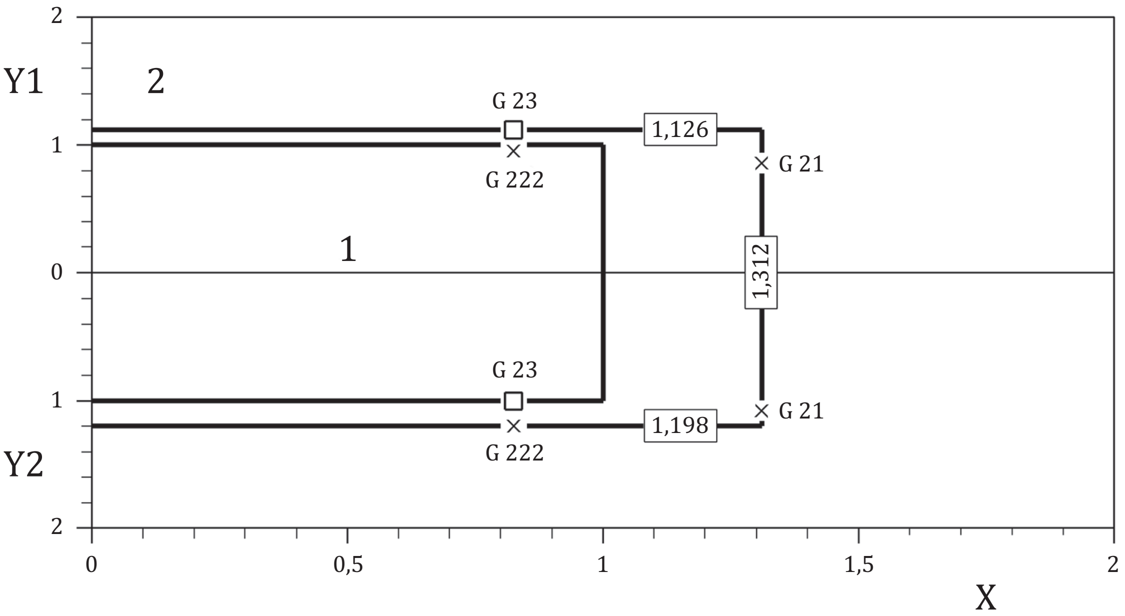
AGA BULLETIN 36: Lifting Index I_I	1,126	AGA 36	PREDICTS LIFT PROB LIMIT VALUE
Flashback Ind. I_f	1,021		Limit Value
Yellow tip Ind. I_y	1,177		
1 /Iy	0,850		
WEAVER: Heat rate ratio	0,900	JH	WEAVER JH OUT OF RANGE
Primary air ratio	0,900	JA	
Lifting	0,860	JL	
Flashback	0,095	JF	
Yellow tipping	- 0,100	JY	
Incomplete combustion	- 0,100	JI	

Table D.7 — Gas values

	ADJUST GAS	SUBSTITUTE GAS
Compressibility	0,99801	0,99817
Calorific value	1014,0	937,8
Mol. weight	16,043	16,941
Relative density	0,5547	0,5857
Wobbe index	1361,4	1225,4 Limit Value
Knoy factor	1126,5	996,4
Primary air (ft^3)	9,52	8,81
H/C ratio	4,00	4,00
N (C per 100)		
Flame speed, S	14,06	13,44
Lifting constant	0,670	0,671
Yellow tip const.	218	202
Lifting limit K	1,208	1,146
Prim. air f (#36)	0,7345	0,8161
Air per 100 Btu	0,9392	0,9394
Yellow tip limit Y	22,89	21,60

D.2.1.5 AGA Index Method Interchangeability Limit Box

Applied to the European test gases of the H group (Annex B).

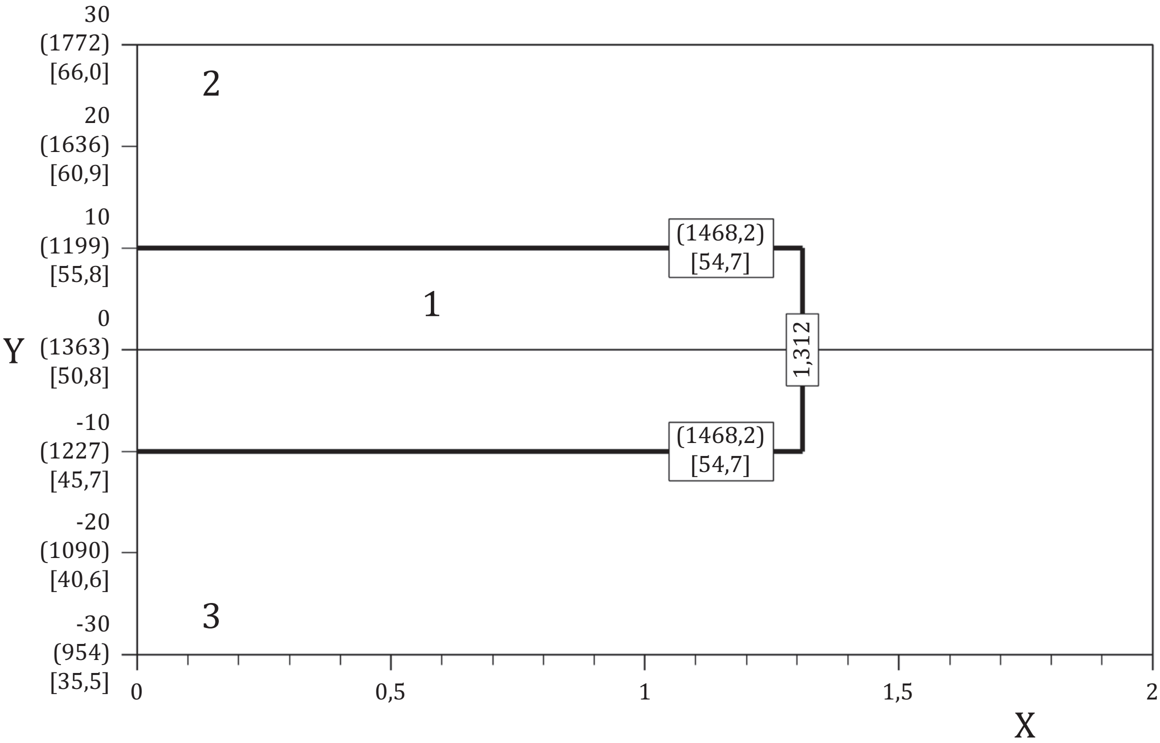


Key

X	adjustment gas = 100% methane
Y1	lifting index, I_l
Y2	flashback index, I_f
1	preferable
2	objectionable beyond limits

D.2.1.6 AGA Index Method: Wobbe Index Limit Box

Applied to the European test gases of the H group (Annex B)



Key

X adjustment gas = 100% methane

Y difference from adjust Wobbe number, %

1 yellowtip index, $1/I_y$

2 generally accepted US limits are +/- 10% European H Gas Standard Wobbe limits

3 ( ) - BTU/cf

[ ] - MJ/cm3

conversion factor used 1 MJ/m3 = 26 856 BTU/cf

Annex E
(informative)

British Gas Hydrocarbon Equivalence Method

E.1 Composition-based prediction

E.1.1 General

After extensive study within the United Kingdom it became clear that the occurrence of incomplete combustion and sooting with natural gas cannot be satisfactorily predicted on the basis of using Wobbe index and Weaver Flame Speed Factor as the only two variables. This problem can be overcome to a large extent by relating appliance malfunction, such as sooting, to the composition of the gas. A composition-based prediction system was developed in the 1980s by Dutton[8] at the Watson House Research Station of the then British Gas Corporation and was widely used to predict gas interchangeability within the UK.

The prediction system assumes that a gas can be regarded as a four-component "equivalent" mixture consisting of:

- methane;
- other hydrocarbons (i.e. the higher hydrocarbons ethane, propane, etc.);
- hydrogen;
- inerts (nitrogen and carbon dioxide).

The proportions of the individual components of the equivalent gas are selected to replicate the major properties as the original gas. The other hydrocarbons are expressed as an equivalent amount of propane and methane. The inerts are expressed as an equivalent amount of a standard inert, e.g. nitrogen.

Having expressed the gas as an equivalent mixture, in the original Dutton method employed by British Gas, the tendency of the equivalent mixture towards appliance malfunction is assessed by calculation of five parameters (Wobbe index, Incomplete Combustion Factor, Sooting Index, Lift Index and hydrogen content) and comparing their values with agreed limit values.

Following liberalisation of the UK gas industry, the UK government introduced in 1996 the Gas Safety (Management) Regulations, which contain an obligation on a gas transporter not to convey gas which does not comply with a schedule containing various gas quality criteria. Among those criteria were a set of interchangeability limit values, based on those of Dutton, but with some simplification.

To illustrate the basic features of the composition-based prediction system, an example gas composition, as shown in Table E.1, is examined.

Table E.1 — Composition of example natural gas

Component	Mole fraction
Methane	0,931700
Ethane	0,032600
Propane	0,006700
Butanes	0,002700
Pentanes	0,000800
Hexanes	0,000500
Heptanes	0,000300
Octanes	0,000100
Carbon dioxide	0,003400
Nitrogen	0,021200

E.1.2 Equivalent gas for the other hydrocarbons

The equivalent gas for the other hydrocarbons is the quantity of propane and methane which has the same ideal volume and the same average number of carbon atoms per molecule as the gas under consideration.

For example the equivalent for ethane is:

$$2C_2H_6 = C_3H_8 + CH_4$$

The equivalence factors for ethane in terms of propane and of methane are therefore 0,5 and 0,5 respectively.

Other hydrocarbons are expressed in equivalents in Table E.2. Please note that it is acceptable to use negative signs if appropriate.

Table E.2 — Equivalence factors for hydrocarbons

Hydrocarbon	Equivalent	
	Methane	Propane
Methane	1,0	0,0
Ethane	0,5	0,5
Propane	0,0	1,0
Butanes	- 0,5	1,5
Pentanes	- 1,0	2,0
Hexanes	- 1,5	2,5
Heptanes	−2,0	3,0
Octanes	−2,5	3,5

E.1.3 The inerts

The inert gases are expressed as an equivalent amount of nitrogen based on their relative effect on combustion properties. Then a further, small, adjustment to the N_2 component is needed so that the Wobbe index of the equivalent mixture matches that of the complete composition.

E.2 Prediction of interchangeability

In order to predict the interchangeability of the gas in Table E.1 we need to:

- calculate its Wobbe index;
- express the composition in terms of a four-component mixture;
- calculate the additional interchangeability parameters (Incomplete Combustion Factor, Sooting Index);
- assess its interchangeability by comparing the Wobbe index, Incomplete Combustion Factor, Sooting Index and hydrogen content with the limit values contained in the Gas Safety Management Regulations.

E.2.1 Calculation of Wobbe index

Wobbe index (W) is calculated according to ISO 6976 for the real gas at ISO reference conditions and expressed in units of MJ/m^3.

$$W = 49{,}98\ \text{MJ/m}^3$$

E.2.2 Express the composition in terms of a four-component mixture

Table E.3 shows the method used for the determination of the equivalent mixture for the gas of composition given in Table E.1.

Table E.3 — Equivalent four-component mixture for gas of composition given in Table E.1

	Mixture mole fraction	Equivalent methane	Equivalent propane	Equivalent mixture	
				Unnormalised	Normalised
Methane	0,931700	0,931700	0,000000	0,944250	0,943245
Ethane	0,032600	0,016300	0,016300		
Propane	0,006700	0,000000	0,006700	0,031150	0,031117
n-Butane	0,002700	−0,001350	0,004050		
n-Pentane	0,000800	−0,000800	0,001600		
n-Hexane	0,000500	−0,000750	0,001250		
n-Heptane	0,000300	−0,000600	0,000900		
n-Octane	0,000100	−0,000250	0,000350		
Carbon dioxide	0,003400				
Nitrogen	0,021200			0,025666	0,025638
Total	1,000000	0,944250	0,031150	1,001066	1,000000
Wobbe index (MJ/m^3)	49,97703			49,97703	49,97703

After calculating the unnormalized equivalent methane and equivalent propane content, the nitrogen content is adjusted to obtain the same Wobbe index of the original mixture and then normalized to a total mole fraction of 1.

E.2.3 Calculation of the additional interchangeability parameters

Incomplete Combustion Factor (ICF)

$$ICF = \frac{W - 50{,}73 + 3(C_3H_8 + N_2)}{1{,}56} - H_2 = \text{-}0{,}37353$$

NOTE 1 C_3H_8, N_2 and H_2 are expressed as mole fractions. Wobbe index is calculated for the real gas at ISO reference conditions and expressed in units of MJ/m^3.

Sooting Index (SI)

$$SI = 0{,}896\tan^{-1}\left(2{,}55C_3H_8 - 2{,}33N_2 - 0{,}91H_2 + 0{,}617\right) = 0{,}50795$$

NOTE 2 C_3H_8, N_2 and H_2 are expressed as mole fractions.

E.2.4 Assessment of interchangeability

The UK Gas Safety (Management) Regulations specify the following requirements under normal conditions:

a) Hydrogen mole fraction ≤ 0,001

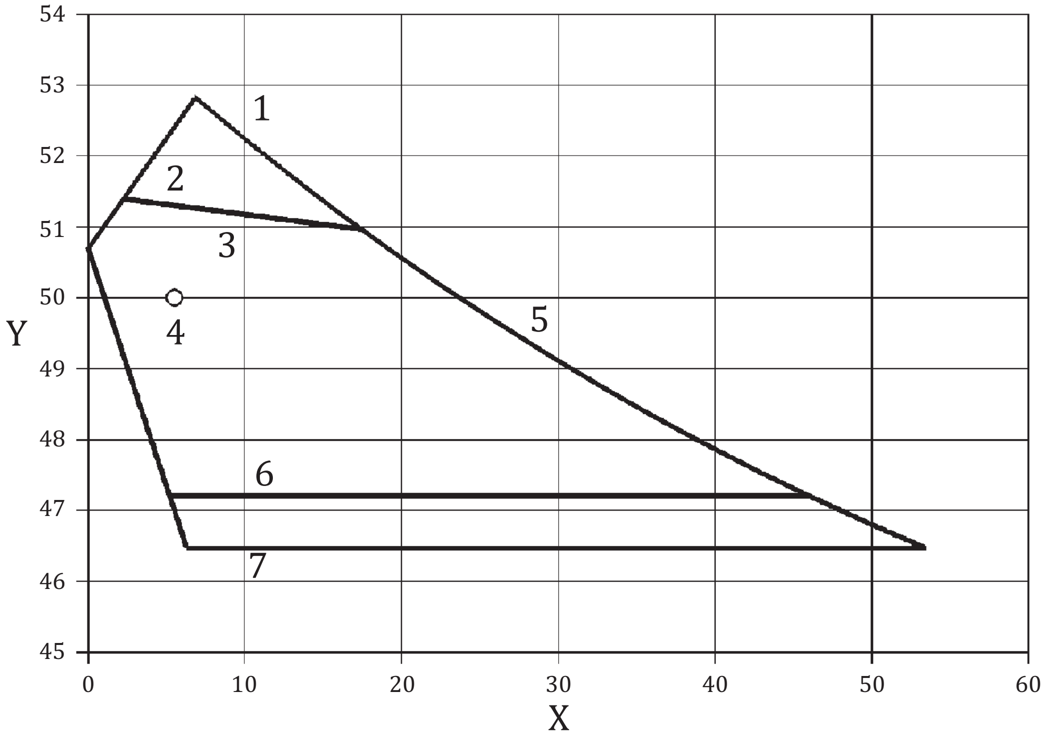
b) 47,2 ≤ Wobbe Index (MJ/m^3) ≤ 51,41

c) Incomplete Combustion Factor ≤ 0,48

d) Sooting Index ≤ 0,60

The mixture of composition in Table E.1 meets all of these requirements and is deemed to be interchangeable.

For mixtures meeting the hydrogen content requirement of the UK Gas Safety (Management) Regulations, interchangeability can be visually displayed on a plot of Wobbe index and the sum of the mole fractions of propane and nitrogen in the equivalent mixture. This is shown in Figure E.1. The example mixture lies within the area permitted for normal operation and is therefore interchangeable. In practice, compliance with requirements is assessed numerically using the limit criteria (a) to (d) above.



Key

X	equivalent $(C_3H_8 + N_2)$ mol%
Y	Wobbe index (MJ/m^3)
1	upper emergency limit
2	upper limit
3	normal limit
4	gas mixture
5	soot limit
6	lower normal limit
7	lower emergency limit

Figure E.1 — The UK Natural Gas Interchangeability Diagram

Annex F
(informative)

Weaver index method

Another index method for predicting interchangeability was developed by E.R. Weaver, circa 1951. A novel aspect of this work was the introduction of flame speed into the equations particularly for lifting and flash back. By assigning flame speed factors to the various components of adjustment and substitute gases a summation by volume percent of each component produces flame speed factors for each gas. The result is a series for six indices as follows:

Heat Rate Ratio, J_H - The ratio of Wobbe indexes for the substitute to the adjustment gases determines how the change in gas composition affects the heat rate input to the appliance.

Primary Air ratio, J_A - Determines the change in primary air requirement for complete combustion from the substitute to adjustment gases.

Lifting Index, J_L - Evaluates the tendency for lifting of flames from the burner ports. Linked to primary air ratio and flame speeds of the substitute to adjustment gases.

Flash back Index, J_F - Evaluates the tendency for flash back (lightback) to occur. Also linked to J_A and flame speeds of the substitute of adjustment gases.

Yellow Tipping Index, J_Y - Evaluates tendency to produce yellow flames and free carbon. Related to J_A and carbon content of fuel.

Incomplete Combustion Index, J_Z - Evaluates tendency to generate carbon monoxide. Related to J_A and the ratio of hydrogen to carbon atoms in the substitute to adjustment gases.

The equations used for the Weaver index calculations are not reproduced here, but are available through AGA if desired.

Weaver established limits for the various indices in his original work. These are used to indicate problems in the AGA Worksheets (see AGA Worksheets, 1, 2 and 3) as part of the AGA Interchangeability Program (Annex D). Note that many of the Group H limit gases show indications of problems with these criteria. Obviously, since appliances pass the test gas certification procedures required by EN 437, the Weaver limits are too restrictive for this protocol.

At least one utility in the US has done extensive work with the Weaver index method, and successfully applied it to a system which uses refinery/NG mixtures, refinery/landfill methane/ NG mixtures, propane-air peakshaving with NG, and revaporized LNG storage as peakshaving. Their experience resulted in a revised set of limit values. The calculations on the attached worksheets establish a set of Weaver index limits applicable to the group H situation. The various sets of criteria are listed in Table F.1.

Table F.1 — Weaver Index limits

INDEX	WEAVER	UTILITY	GROUP H
J_H	0,95 to 1,05	0,95 to 1,03	0,90 to 1,08
J_A	-	-	0,89 to 1,08
J_L	>0,64	>0,64	>0,86
J_F	<0,08	<0,26	<1,06
J_Y	<0,14	<0,05	<0,12
J_Z	<0	<0,05	<0,12

Two conclusions are drawn from these results:

1) The best assurance of interchangeability is a standard test gas routine applied to all appliances for certification, and keeping gas quality within the parameters of the test gases.

2) Otherwise, interchangeability requires extensive testing and knowledge of the appliances on a local distribution system. The appearance of new or altered gas compositions will always be a problem for the utility to prove acceptability.

Annex G

(informative)

French method for determining gas interchangeability (Delbourg method) (guide for determining the interchangeability of second family gases)

G.1 Calculation of interchangeability indices on the basis of chemical composition of the gas

G.1.1 Primary indices

G.1.1.1 General

To deal with traditional phenomena of incomplete combustion (production of CO), flame lift and lightback, the following are used simultaneously:

- corrected Wobbe index;
- combustion potential.

G.1.1.2 Corrected Wobbe index

$$W' = K_1 \times K_2 \frac{\mathrm{gcv}}{\sqrt{d}}$$

where

K_1 obtained from the curve in Figure G.1 as a function of the share of hydrocarbons (except methane) in the gross calorific value;

K_2 obtained from the curve in Figure G.2 as a function of the parameter:

$$1000 \times \frac{\mathrm{CO} + 4\mathrm{O}_2 - 0{,}5\mathrm{CO}_2}{\mathrm{gcv}}$$

where

gcv gross calorific value in kcal/m^3; 1 m^3 is measured in dry condition at 0°C and with 760 mm mercury column;

d relative density (air = 1).

G.1.1.3 Combustion potential

$$C = u \times \frac{\mathrm{H_2} + 0{,}7\,\mathrm{CO} + 0{,}3\,\mathrm{CH_4} + v \sum a\,\mathrm{C_nH_m}}{\sqrt{d}}$$

where

u	correction coefficient as a function of the oxygen content and the gcv (obtained from Figure G.3);
H_2, CO, CH_4, C_nH_m	content of each combustible constituent (in %) (C_nH_m: all hydrocarbons except CH_4);
v	correction coefficient depending on the value of the corrected Wobbe index expressed in kcal/m3(n) (obtained from Figure G.4);
a	specific coefficient of each hydrocarbon shown in the Table G.1.

G.1.2 Secondary indices

G.1.2.1 Yellow tip index

This index makes it possible to determine the occurrence of yellow tips in aerated flames and thus to avoid sooting.

$$I_j = \frac{\sum (j \times A)}{\sqrt{d}} \times \left(1 - 100 \times \frac{O_2}{GCV} \right)$$

where

A	hydrocarbon concentrations in the gas (CH_4 and C_nH_m) in %;
O_2	oxygen content of gas, in %;
j	specific coefficient of each hydrocarbon shown in the Table G.1;
d	relative density.

G.1.2.2 Index for indirect ignition at the injector

This index makes it possible to predict a particular form of ignition at the injector which takes place, on certain types of hot water appliances, through primary air entrained at the burner ports when the hot water valve is operated. This index has a value equal to the hydrogen content of the gas, expressed in %.

G.2 Interchangeability limits for second family gases for domestic appliances at 20 mbar (calculation of indices and diagram for appliances supplied with Lacq gas at 20 mbar)

G.2.1 Complete combustion and flame stability

The area common to all appliances is shown as continuous line in Figure G.5. However, to take account of both variations in supply pressure and fluctuations in appliance control, it is advisable to limit the interchangeability range to the hatched part in Figure G.5. If point K is located inside this zone, combustion will be complete and the flame stable.

G.2.2 Variations in heat input

The heat input is proportional to the semi-corrected Wobbe index ($K_1 x W$). This latter is equal to the corrected Wobbe index (W') in Figure G.5 if the gas does not contains oxygen and little CO or CO_2.In this case to limit the variations in heat input to 10 % on the basis of the nominal value obtained with the reference gas, the interchangeability range in Figure G.5 is limited to its upper section (hatched).

G.2.3 Yellow tip index

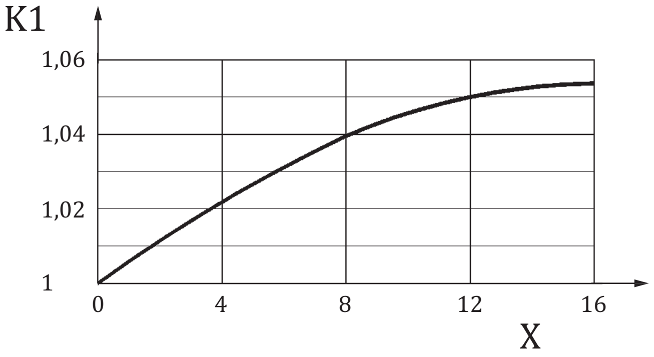
Index I_j should be lower than 230 and preferably below 210.

G.2.4 Index for indirect ignition at the injector

The hydrogen content in the mixture must be below 10 %.

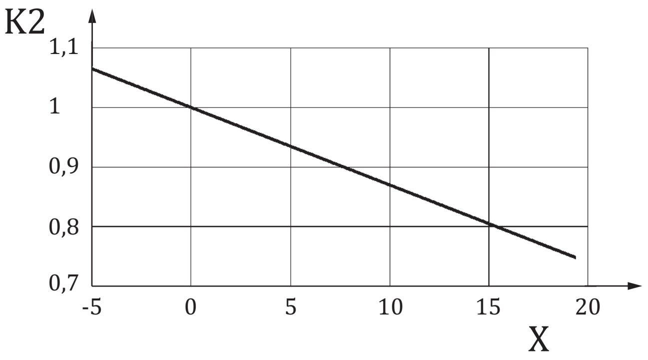
Table G.1 — Gas properties

		gcv **kcal/m^3**	***d*** **Density**	***a*** **Combustion potential**	***j*** **Yellow tip indices**
Carbon monoxide	CO	3 020	0,967	-	0
Hydrogen	H_2	3 050	0,070	-	0
Methane	CH_4	9 530	0,554	-	1
Ethane	C_2H_6	16 860	1,049	0,95	2,85
Propane	C_3H_8	24 350	1,562	0,95	4,80
n-Butane	n-C_4H_{10}	32 060	2,091	1,10	6,80
i-Butane	i-C_4H_{10}	31 570	2,064	1,10	6,80
Pentane	C_5H_{12}	40 600	2,675	1,15	8,80
Hexane	C_6H_{14}	45 600	2,97	1,15	12
Heptane	C_7H_{10}	52 900	3,45	1,15	15
Acetylene	C_2H_2	13 980	0,906	3	2,40
Ethylene	C_2H_4	15 180	0,975	1,75	2,65
Propylene	C_3H_6	22 430	1,481	1,25	4,80
n-Butene	n-C_4H_8	29 050	1,937	1,50	6,80
i-Butene	i-C_4H_8	28 880	1,937	1,50	6,80
Butadiene	C_4H_6	26 500	1,87	2,70	6,10
Benzene	C_6H_6	35 250	2,697	0,90	20
Toluene	C_7H_8	-	-	0,9	16
Nitrogen	N_2	0	0,967	0	0
Carbon dioxide	CO_2	0	1,529	0	0
Oxygen	O_2	0	1,105	0	0



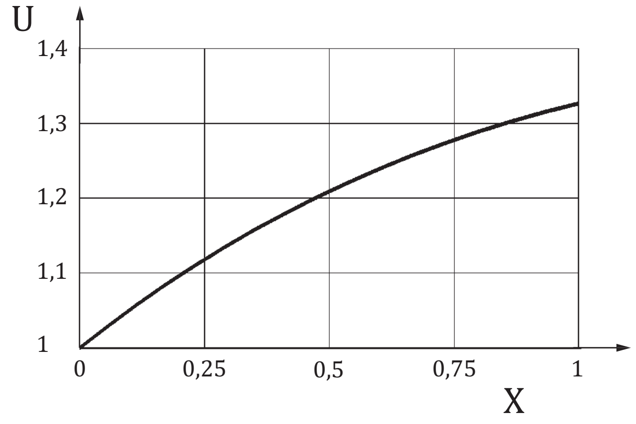
Share of hydrocarbons (except CH) in the gross calorific value [x 10’ kcal/m’ (n)]

FIGURE G.1 — Correction coefficient “K1” for Wobbe index (second family gases)



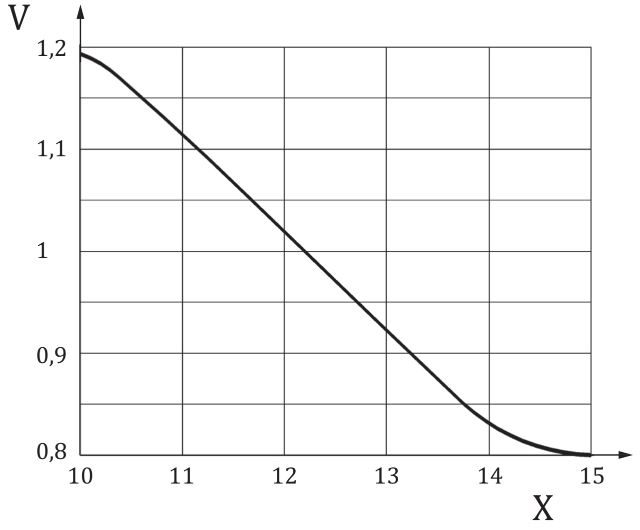
$1000\frac{CO+4\,O_2-0{,}5\,CO_2}{gcv}$ [CO, O2, CO2-content in%; gcv in kcal/m^3(n)]

FIGURE G.2 — Correction coefficient “K2” for Wobbe index (second family gases)



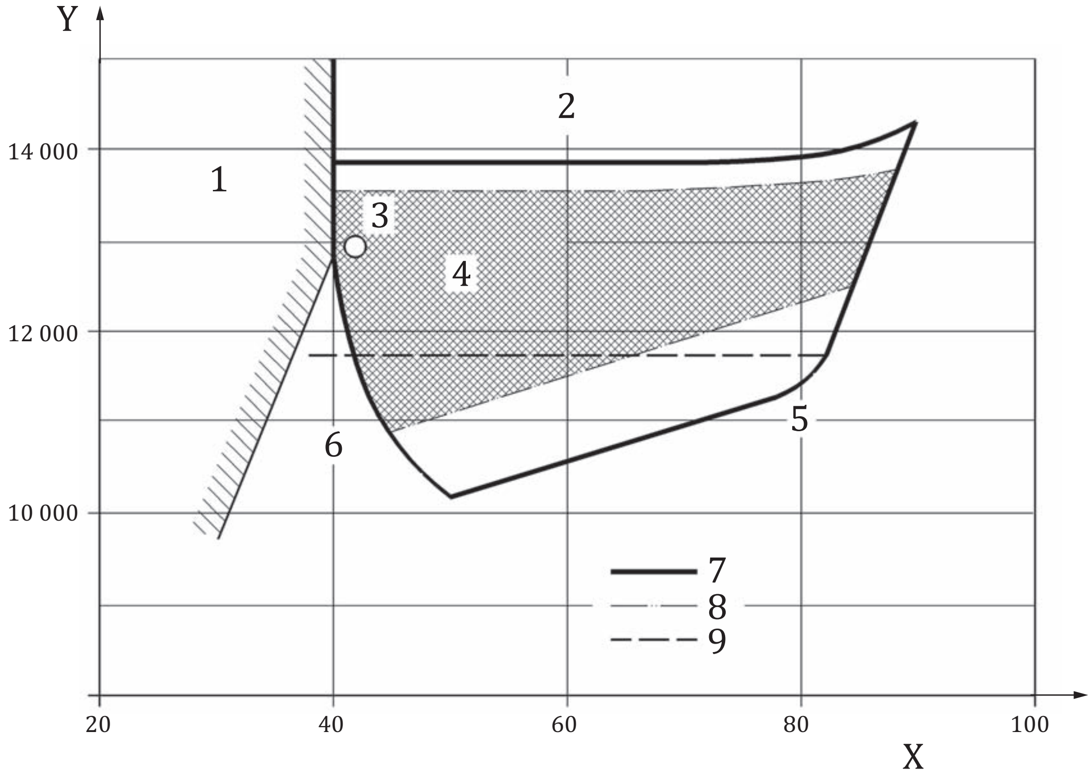
$1000\frac{O_2}{gcv}$ 02- content in % ; gcv in kcal/m’ (n)

FIGURE G.3 — Correction coefficient “U” for combustion potential (second family gases)



Corrected Wobbe index W’ (103 kcal/m^3)

FIGURE G.4 — Mean correction coefficient for hydrocarbons higher than methane (second family gases)



Key

X combustion potential

Y corrected Wobbe index W', in kcal/m^3 (n)

1 limit for possible gas mixtures

2 incomplete combustion (C0/C02 > 0,02)

3 reference natural gas

4 satisfactory functioning

5 flash back

6 flame lift

7 20 mbar gas supply

8 12 mbar to 22 mbar gas supply

9 limit for a 10% decrease in output against the reference natural gas; if the gas contains oxygen, the limit relates to K1 W and not W'

FIGURE G.5 — Gas interchangeability diagram (second family gases)

Annex H

(informative)

Spanish regulation code (Detail Protocol-01 — Measurement) — Extract of the relevant parts for natural gases

H.1 Gas quality

Natural gas which is introduced through the entry points of the gas system shall comply with the quality specifications of Table H.1.

The owner of the installation which allows the gas to enter into the gas system does not have the obligation of delivering the gas to the user at the exit points of natural gas, with exactly the same characteristics with which the user has introduced the gas via the entry points, as long as the agreed energy quantity is the same.

Table H.1 — Gas quality parameters as by Spanish regulation code

Property[a]	Unit	Minimum	Maximum
Wobbe index	kWh/m^3	13,368	16,016
PCS	kWh/m^3	10,23	13,23
d	m^3/m^3	0,555	0,700
Total S	mg/m^3	—	50
H_2S+COS (as S)	mg/m^3	—	15
RSH (as S)	mg/m^3	—	17
O_2	mol %	—	[0,01]
CO_2	mol %	—	2,5
H_2O (dew point)	°C at 70 bar (a)	—	+2
HC (dew point)	°C at 1 bar to 70 bar (a)	—	+5

[a] Table provided according the following reference conditions: [25 °C; V (0 °C: 1,01325 bar)]

Annex I
(informative)

Harmonization of gas property data for cross-border transportation

I.1 Common business practice

I.1.1 General

In 2002, the European Gas Regulation Forum (Madrid Forum), organized under the patronage of the European Commission, asked the European Association for the Streamlining of Energy Exchange - gas (EASEE-gas) to set up rules on gas quality at a European level in order to enhance the interoperability of networks. These rules have been defined in a common business practice (CBP) published in February 2005 and accepted in September that year by EASEE-gas members. The following text and table are directly copied from EASEE-gas CBP.

This Common Business Practice (CBP) recommends natural gas quality specifications to streamline interoperability at cross border points in Europe and describes the recommended gas quality parameters, parameter ranges and the implementation plan. The CBP is limited to cross border and EU entry points for high calorific gas without added odorants, including the exit of LNG import terminals and excluding areas of production and isolated systems where production, transportation and utilization are combined.

I.1.2 Gas parameters

The following parameters have been agreed for harmonization:

WI	Gross (superior) Wobbe index
d	relative density
S	Total sulfur
H_2S + COS	Hydrogen sulphide + Carbonyl sulphide
RSH	Mercaptans
O_2	Oxygen
CO_2	Carbon dioxide
H_2O DP	Water dew point
HC DP	Hydrocarbon dew point

For definition of the parameters, reference is made to ISO 14532.

I.1.3 Parameter units

For this CBP, the parameter units and reference conditions used are according to the EASEE-gas Common Business Practice 2003-001/01. This implies that the energy unit is kWh with a combustion reference temperature of 25 °C, and the volume unit is m^3 at a reference condition of 0°C and 1,01325 bar(a). For conversion to other reference conditions, reference is made to ISO 13443.

The ranges and values given in Table I.1 shall apply.

Table I.1 — EASEE-gas gas property data for cross-border transport of natural gas H in Europe

Parameter	Unit	Min.	Max.	Recommended implementation date
WI	kWh/m^3	[13,60]	15,81	1/10/2010
d	m^3/m^3	0,555	0,700	1/10/2010
Total S	mg/m^3	-	30	1/10/2006
H_2S + COS (as S)	mg/m^3	-	5	1/10/2006
RSH (as S)	mg/m^3	-	6	1/10/2006
O_2	mol %	-	0,001[a]	1/10/2010
CO_2	mol %	-	2,5	1/10/2006
H_2O DP	°C at 70 bar (a)	-	- 8	See note[b]
HC DP	°C at 1- 70 bar (a)	-	- 2	1/10/2006

[a] Limit is <0,001 mol%, daily average. However, cross border point daily average levels up to 0,01 mol% will be accepted if these are the result of the prudent operation of UGSs, existing in 2006, which use oxygen for desulphurisation purposes. (Based on the full CBP Wobbe range).

[b] At certain cross border points, less stringent values are used than defined in this CBP. For these cross border points, these values can be maintained and the relevant producers, shippers and transporters should examine together how the CBP value can be met in the long run. At all other cross border points, this value can be adopted by 1st October 2006.

I.2 Further information about the CBP

The implementation of EASEE-gas CBP as regards Wobbe index parameters has raised some concern about the safety of domestic users. Thus the European Commission has asked CEN with mandate M 400 to “draw up standards for gas quality parameters for H-gas, that are the broadest possible within reasonable costs”. The first phase of the work will be to study the impact of gas quality variations on appliances complying with the Directive 396/90/CEE. The second phase will be the development of a standard, considering the result of phase one and EASEE-gas work.

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