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Natural gas — Standard reference conditions

Gaz naturel — Conditions de référence standard

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Annexes

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Foreword

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

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

International Standard ISO 13443 was prepared by Technical Committee ISO/TC 193, *Natural gas*.

Annexes A and C form an integral part of this International Standard. Annexes B, D, E and F are for information only.

Introduction

The multiplicity of so-called "standard reference conditions" of temperature, pressure and humidity (state of saturation) used in the measurement of natural-gas quality and quantity can cause much confusion. Failure to take unrecognized differences of reference conditions into account can have serious consequences in, for example, custody transfer applications. Often enough, even an experienced gas engineer may not recognize the potential for error, as the units of measurement usually employ identical terminology, irrespective of differences in the reference conditions. All of the ambiguity and its undesirable consequences may easily be removed by the adoption of a single standardized set of reference conditions. The set chosen in this International Standard will be known as the ISO standard reference conditions.

Natural gas — Standard reference conditions

1 Scope

This International Standard specifies the standard reference conditions of temperature, pressure and humidity to be used for measurements and calculations carried out on natural gases, natural-gas substitutes and similar fluids.

The primary application is expected to be in international custody transfer, where the reduction to a common basis of those physical attributes of a gas which describe both its quality and quantity will simplify the practice of world trade and commerce.

2 Normative reference

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

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

3 Standard reference conditions

The standard reference (or base) 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 are 288,15 K and 101,325 kPa for the real dry gas.

The physical properties to which these ISO standard reference conditions apply include volume, density, relative density, compression factor, superior calorific value, inferior calorific value and Wobbe index. Full definitions of these quantities are given in ISO 6976:1995. In the cases of calorific value and Wobbe index, both the volume of gas burned and the energy released by combustion shall relate to the ISO standard reference conditions.

It is recognized, however, that in certain circumstances it may be impracticable or even unallowable to use the ISO standard reference conditions. For example, national legislation or contractual obligations may demand the use of alternative reference conditions. For this reason, annex A provides factors for conversion between several sets of metric reference conditions which are known to be in regular use, and annex B gives equations which enable values of properties (relating to any other known reference conditions) to be converted to values for the ISO standard reference conditions. Annex D gives some example calculations. Annex E gives the metric reference conditions which, at present time, are believed to be those in most common usage in the countries listed.

NOTES

1 Among other considerations, the ISO standard reference conditions have been chosen to conform with those standardized in ISO 5024[1] for use in the measurement of petroleum liquids and gases.

2 288,15 K = 15 °C = 59 °F
101,325 kPa = 1,013 25 bar = 14,695 9 psia = 1 standard atmosphere (atm)

3 In ISO 6976:1995, a dry gas is defined as one for which the mole fraction of water vapour is less than 0,000 05, but this criterion is unnecessarily restrictive in the context of this International Standard, where a mole fraction of up to 0,001 may be allowable.

4 The conditions 273,15 K, 101,325 kPa and 288,15 K, 101,325 kPa are commonly referred to as "normal" and "(metric) standard" conditions, respectively, in gas-measurement practice (see IGU/G-64[4], IGU/G-73[5] and IGU/G-76[6]). This usage should not be confused with "NTP" (normal temperature and pressure) and "STP" (standard temperature and pressure), both of which conventionally refer to the former conditions. The definitions of "normal" and "standard" given in ISO 7504[2] conflict with the usage given above, and are incorrect.

5 Good practice requires that the relevant reference conditions are incorporated as part of the symbol (and *not* the unit) for the physical quantity represented wherever ambiguity is possible. For example:

— use $Z(273{,}15\ \text{K}, 101{,}325\ \text{kPa})$ or $Z(t/°\text{C} = 0, p/\text{atm} = 1)$, not Z_n, for compression factor at "normal" conditions;

— use $V(273{,}15\ \text{K}, 101{,}325\ \text{kPa})\ \text{m}^3$ for the volume of gas in cubic metres at "normal" conditions, not m_n^3, $\text{m}^3(\text{n})$, nm^3 or Nm^3, and certainly not simply m^3;

— use $V(t/°\text{C} = 15, p/\text{kPa}= 101{,}325)\ \text{m}^3$ for the volume of gas in cubic metres at "standard" conditions, not $\text{m}^3(\text{st})$, sm^3 or m_s^3.

Abbreviated versions such as $Z(0)$, $V(0)/\text{m}^3$ and $V(15)/\text{m}^3$, respectively, are acceptable when no misinterpretation is possible. In the latter case, $V(\text{ISO})/\text{m}^3$ is probably the best designation.

Annex A
(normative)

Factors for conversion between reference conditions

To obtain the value of a property at the reference condition given in row [b] of table A.1 from a known value in the same units at the reference condition in row [a], multiply by the factor indicated. To carry out the reverse conversion, divide by the factor indicated.

Conversions for properties of the ideal gas are expected to be accurate to within – 0,01 % for all natural gases. For the real-gas volumetric properties (volume per unit amount, density, relative density, compression factor), the expected accuracy is – 0,02 %, and for the real-gas combustion properties (calorific values, Wobbe index) – 0,05 %.

Conversion factors for non-metric (e.g. Imperial) reference conditions are not provided, as the continued use of these — particularly in international trade — is discouraged. Most non-metric reference conditions use a temperature base of 60 °F, but several distinct pressure bases have been invoked. Annex B provides equations which will allow the conversion of property values from reference conditions not shown in table A.1 to equivalent values for the ISO standard reference conditions.

In table A.1, the pressure base for both combustion and volumetric metering is always 101,325 kPa and the gas is taken to be dry.

Table A.1 — Factors for conversion between reference conditions

		Metering t_2/°C			Combustion t_1/°C					
	[a] ﬁ [b] ﬁ	20 to **15**	20 to 00	**15** to 00	25 to 20	25 to **15**	25 to 00	20 to **15**	20 to 00	**15** to 00
1	Ideal volume	0,982 9	0,931 8	0,947 9						
2	Ideal density	1,017 4	1,073 2	1,054 9						
3	Ideal relative density	1,000 0	1,000 0	1,000 0						
4	Compression factor	0,999 9	0,999 5	0,999 6						
5	Real volume	0,982 8	0,931 3	0,947 6						
6	Real density	1,017 5	1,073 8	1,055 3						
7	Real relative density	1,000 1	1,000 3	1,000 2						
8	Molar-basis ideal superior calorific value				1,000 5	1,001 0	1,002 6	1,000 5	1,002 1	1,001 6
9	Molar-basis ideal inferior calorific value				1,000 1	1,000 1	1,000 3	1,000 0	1,000 2	1,000 2
10	Mass-basis ideal superior calorific value				1,000 5	1,001 0	1,002 6	1,000 5	1,002 1	1,001 6
11	Mass-basis ideal inferior calorific value				1,000 1	1,000 1	1,000 3	1,000 0	1,000 2	1,000 2
12	Molar-basis real superior calorific value				1,000 5	1,001 0	1,002 6	1,000 5	1,002 1	1,001 6
13	Molar-basis real inferior calorific value				1,000 1	1,000 1	1,000 3	1,000 0	1,000 2	1,000 2
14	Mass-basis real superior calorific value				1,000 5	1,001 0	1,002 6	1,000 5	1,002 1	1,001 6
15	Mass-basis real inferior calorific value				1,000 1	1,000 1	1,000 3	1,000 0	1,000 2	1,000 2

		Combustion t_1/°C : Metering t_2/°C					
	[a] ﬁ [b] ﬁ	25:20 to 25:00	25:20 to **15:15**	25:20 to 00:00	25:00 to **15:15**	25:00 to 00:00	**15:15** to 00:00
16	Volume-basis ideal superior calorific value	1,073 2	1,018 4	1,076 0	0,948 9	1,002 6	1,056 6
17	Volume-basis ideal inferior calorific value	1,073 2	1,017 5	1,073 5	0,948 1	1,000 3	1,055 1
18	Ideal Wobbe index	1,073 2	1,018 4	1,076 0	0,948 9	1,002 6	1,056 6
19	Volume-basis real superior calorific value	1,073 8	1,018 5	1,076 6	0,948 6	1,002 6	1,057 0
20	Volume-basis real inferior calorific value	1,073 8	1,017 6	1,074 1	0,947 7	1,000 3	1,055 5
21	Real Wobbe index	1,073 6	1,018 5	1,076 4	0,948 7	1,002 6	1,056 9

Annex B
(informative)

Equations for conversion between reference conditions

Equations B.1 to B.21 allow the conversion of values of the properties listed from reference conditions T_1/K, T_2/K, p_1/kPa and p_2/kPa to the equivalent values in the same units of measurement at the ISO standard reference conditions. The equations given are valid for the ranges: $270 < T/\mathrm{K} < 300$ and $95 < p/\mathrm{kPa} < 105$.

The equations given use simple linear functions of temperature and pressure. These have been derived by approximating $(\partial Z/\partial p)_T$, $(\partial Z/\partial T)_p$, $(\partial Z_\mathrm{air}/\partial T)_p$, $1/\overline{H}_\mathrm{S}^\circ(\partial\overline{H}_\mathrm{S}^\circ/\partial T)$ and $1/\overline{H}_\mathrm{I}^\circ(\partial\overline{H}_\mathrm{I}^\circ/\partial T)$ as constants, the respective values being determined by trial calculations for a wide range of natural gases. The values used are

$$(\partial Z/\partial p)_T = -0{,}000\,020/\mathrm{kPa}$$

$$(\partial Z/\partial T)_p = +0{,}000\,025/\mathrm{K}$$

$$(\partial Z_\mathrm{air}/\partial T)_p = +0{,}000\,011/\mathrm{K}$$

$$1/\overline{H}_\mathrm{S}^\circ(\partial\overline{H}_\mathrm{S}^\circ/\partial T) = -0{,}000\,10/\mathrm{K}$$

$$1/\overline{H}_\mathrm{I}^\circ(\partial\overline{H}_\mathrm{I}^\circ/\partial T) = -0{,}000\,01/\mathrm{K}$$

The values of $\partial\overline{H}_\mathrm{S}^\circ/\partial p$ and $\partial\overline{H}_\mathrm{I}^\circ/\partial p$ are taken to be zero.

Despite the simplicity of these approximations, it is expected that the accuracy of conversion will usually still be within the limits quoted in annex A. The equations may *not* be used to increase the number of digits given in the conversion factors given in annex A.

Note that if the reference conditions for the source data are not given in K and kPa (for example in °C or °F, and in atm, mbar, psia or psig, respectively) then these must be converted appropriately before the equations may be applied (see BS 350:Part 1:1974[3]).

Ideal volume V°

$$V^\circ(\mathrm{ISO}) = V^\circ(T_2, p_2) \times 288{,}15\, p_2/101{,}325\, T_2 \quad \ldots \text{(B.1)}$$

Ideal density ρ°

$$\rho^\circ(\mathrm{ISO}) = \rho^\circ\,(T_2, p_2) \times 101{,}325\, T_2/288{,}15\, p_2 \quad \ldots \text{(B.2)}$$

Ideal relative density d°

$$d^\circ(\mathrm{ISO}) = d^\circ(T_2, p_2) \quad \ldots \text{(B.3)}$$

Compression factor Z

$$Z(\mathrm{ISO}) = Z(T_2, p_2) \times [1 + 0{,}000\,020\,(p_2 - 101{,}325)]/[1 + 0{,}000\,025\,(T_2 - 288{,}15)] \quad \ldots \text{(B.4)}$$

Real volume V

$$V(\mathrm{ISO}) = V(T_2, p_2) \times [288{,}15\, p_2/101{,}325\, T_2] \times [1 + 0{,}000\,020\,(p_2 - 101{,}325)]/[1 + 0{,}000\,025\,(T_2 - 288{,}15)] \quad \ldots \text{(B.5)}$$

Real density ρ

$$\rho(\mathrm{ISO}) = \rho(T_2, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,025(T_2 - 288{,}15)]/[1 + 0{,}000\,020(p_2 - 101{,}325)] \qquad \ldots\ (\mathrm{B.6})$$

Real relative density d

$$d(\mathrm{ISO}) = d(T_2, p_2) \times [1 + 0{,}000\,014\,(T_2 - 288{,}15)]/[1 + 0{,}000\,020\,(p_2 - 101{,}325)] \qquad \ldots\ (\mathrm{B.7})$$

Molar-basis ideal superior calorific value $\overline{H}{}_\mathrm{S}^\mathrm{o}$

$$\overline{H}{}_\mathrm{S}^\mathrm{o}(\mathrm{ISO}) = \overline{H}{}_\mathrm{S}^\mathrm{o}(T_1, p_1) \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.8})$$

Molar-basis ideal inferior calorific value $\overline{H}{}_\mathrm{I}^\mathrm{o}$

$$\overline{H}{}_\mathrm{I}^\mathrm{o}(\mathrm{ISO}) = \overline{H}{}_\mathrm{I}^\mathrm{o}(T_1, p_1) \times [1 + 0{,}000\,01\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.9})$$

Mass-basis ideal superior calorific value $\hat{H}{}_\mathrm{S}^\mathrm{o}$

$$\hat{H}{}_\mathrm{S}^\mathrm{o}(\mathrm{ISO}) = \hat{H}{}_\mathrm{S}^\mathrm{o}(T_1, p_1) \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.10})$$

Mass-basis ideal inferior calorific value $\hat{H}{}_\mathrm{I}^\mathrm{o}$

$$\hat{H}{}_\mathrm{I}^\mathrm{o}(\mathrm{ISO}) = \hat{H}{}_\mathrm{I}^\mathrm{o}(T_1, p_1) \times [1 + 0{,}000\,01\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.11})$$

Molar-basis real superior calorific value $\overline{H}_\mathrm{S}$

$$\overline{H}_\mathrm{S}(\mathrm{ISO}) = \overline{H}_\mathrm{S}(T_1, p_1) \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.12})$$

Molar-basis real inferior calorific value $\overline{H}_\mathrm{I}$

$$\overline{H}_\mathrm{I}(\mathrm{ISO}) = \overline{H}_\mathrm{I}(T_1, p_1) \times [1 + 0{,}000\,01\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.13})$$

Mass-basis real superior calorific value $\hat{H}_\mathrm{S}$

$$\hat{H}_\mathrm{S}(\mathrm{ISO}) = \hat{H}_\mathrm{S}(T_1, p_1) \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.14})$$

Mass-basis real inferior calorific value $\hat{H}_\mathrm{I}$

$$\hat{H}_\mathrm{I}(\mathrm{ISO}) = \hat{H}_\mathrm{I}(T_1, p_1) \times [1 + 000\,01\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.15})$$

Volume-basis ideal superior calorific value $\tilde{H}{}_\mathrm{S}^\mathrm{o}$

$$\tilde{H}{}_\mathrm{S}^\mathrm{o}(\mathrm{ISO}) = \tilde{H}{}_\mathrm{S}^\mathrm{o}(T_1, T_2, p_1, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.16})$$

Volume-basis ideal inferior calorific value $\tilde{H}{}_\mathrm{I}^\mathrm{o}$

$$\tilde{H}{}_\mathrm{I}^\mathrm{o}(\mathrm{ISO}) = \tilde{H}{}_\mathrm{I}^\mathrm{o}(T_1, T_2, p_1, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,01\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.17})$$

Ideal Wobbe index W^o

$$W^\mathrm{o}(\mathrm{ISO}) = W^\mathrm{o}(T_1, T_2, p_1, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \qquad \ldots\ (\mathrm{B.18})$$

Volume-basis real superior calorific value $\tilde{H}_\mathrm{S}$

$$\begin{aligned}\tilde{H}_\mathrm{S}(\mathrm{ISO}) = {} & \tilde{H}_\mathrm{S}(T_1, T_2, p_1, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \times \\ & [1 + 0{,}000\,025\,(T_2 - 288{,}15)]/[1 + 0{,}000\,020\,(p_2 - 101{,}325)] \qquad \ldots\ (\mathrm{B.19})\end{aligned}$$

Volume-basis real inferior calorific value $\tilde{H}_\mathrm{I}$

$$\begin{aligned}\tilde{H}_\mathrm{I}(\mathrm{ISO}) = {} & \tilde{H}_\mathrm{I}(T_1, T_2, p_1, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,01\,(T_1 - 288{,}15)] \times \\ & [1 + 0{,}000\,025\,(T_2 - 288{,}15)]/[1 + 0{,}000\,020\,(p_2 - 101{,}325)] \qquad \ldots\ (\mathrm{B.20})\end{aligned}$$

Real Wobbe index W

$$\begin{aligned}W(\mathrm{ISO}) = {} & W(T_1, T_2, p_1, p_2) \times [101{,}325\, T_2/288{,}15\, p_2] \times [1 + 0{,}000\,10\,(T_1 - 288{,}15)] \times \\ & \{[1 + 0{,}000\,020\,(p_2 - 101{,}325)]/[1 + 0{,}000\,036\,(T_2 - 288{,}15)]\}^{-1/2} \qquad \ldots\ (\mathrm{B.21})\end{aligned}$$

Annex C
(normative)

Symbols

Symbol	Meaning	SI unit (or multiple)
d	relative density	—
$\bar{H}_\mathrm{I}$	molar-basis inferior calorific value	kJ mol^{-1}
$\hat{H}_\mathrm{I}$	mass-basis inferior calorific value	MJ kg^{-1}
$\tilde{H}_\mathrm{I}$	volume-basis inferior calorific value	MJ m^{-3}
$\bar{H}_\mathrm{S}$	molar-basis superior calorific value	kJ mol^{-1}
$\hat{H}_\mathrm{S}$	mass-basis superior calorific value	MJ kg^{-1}
$\tilde{H}_\mathrm{S}$	volume-basis superior calorific value	MJ m^{-3}
p	(absolute) pressure	kPa
T	(absolute) temperature	K
t	Celsius temperature = T − 273,15	°C
V	volume	m^3
W	Wobbe index	MJ m^{-3}
Z	compression factor	—
ρ	density	kg m^{-3}

Subscripts

1	for the combustion reference condition
2	for the volumetric or metering reference condition

Superscript

o	for the ideal-gas state (no superscript indicates the real-gas state)

Annex D
(informative)

Example calculations

The examples given below are all for real dry natural gases consisting preponderantly (greater than about 70 % molar) of methane.

EXAMPLE 1

What is the compression factor at ISO standard reference conditions of a natural gas which has a compression factor of 0,997 1 at a temperature of 273,15 K and a pressure of 101,325 kPa?

From table A.1, line 4, column 3 (used inversely):

$$Z(\text{ISO}) = 0{,}997\,1 \times (1/0{,}999\,6) = 0{,}997\,5$$

The same value (to four significant digits) is obtained from equation (B.4).

EXAMPLE 2

What is the volume occupied at ISO standard reference conditions of a natural gas which occupies 1 000 m^3 at normal conditions?

The term "normal conditions" is taken to mean 273,15 K (0 °C) at 101,325 kPa.

From table A.1, line 5, column 3 (used inversely):

$$V(\text{ISO}) = 1\,000 \times (1/0{,}947\,6) = 1\,055{,}3\ \text{m}^3$$

The same value (to five significant digits) is obtained from equation (B.5).

EXAMPLE 3

What is the mass-basis superior calorific value at ISO standard reference conditions of a natural gas determined as having a calorific value of 54,21 MJ·kg^{-1} at 25 °C and a pressure of 100 kPa?

Molar-basis and mass-basis calorific values are taken to be independent of pressure p_1 within the pressure range given in annex B (which covers the range of normal atmospheric variation); the pressure assignment is therefore irrelevant in this case.

From table A.1, line 14, column 2:

$$\hat{H}_S\,(\text{ISO}) = 54{,}21 \times 1{,}001\,0 = 54{,}26\ \text{MJ}\cdot\text{kg}^{-1}$$

The same value (exactly) is obtained from equation (B.14).