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Natural gas — Calculation of compression factor —

Part 1:
Introduction and guidelines

Gaz naturel — Calcul du facteur de compression —

Partie 1: Introduction et directives

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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 12213-1 was prepared by Technical Committee ISO/TC 193, *Natural gas*, Subcommittee SC 1, *Analysis of natural gas.*

ISO 12213 consists of the following parts, under the general title *Natural gas — Calculation of compression factor*:

— *Part 1: Introduction and guidelines*

— *Part 2: Calculation using molar-composition analysis*

— *Part 3: Calculation using physical properties*

Annex A forms an integral part of this part of ISO 12213. Annexes B and C are for information only.

Natural gas — Calculation of compression factor

Part 1:
Introduction and guidelines

1 Scope

This International Standard specifies methods for the calculation of compression factors of natural gases, natural gases containing a synthetic admixture and similar mixtures at conditions under which the mixture can exist only as a gas.

The standard is in three parts: part 1 gives an introduction and provides guidelines for the methods of calculation described in parts 2 and 3.

Part 2 gives a method for use where the detailed molar composition of the gas is known. Part 3 gives a method for use where a less detailed analysis, comprising superior calorific value (volumetric basis), relative density, carbon dioxide content and (if non-zero) hydrogen content, is available.

Both methods are applicable to dry gases of pipeline quality within the range of conditions under which transmission and distribution, including metering for custody transfer or other accounting purposes, are normally carried out. In general, such operations take place at temperatures between about 263 K and 338 K (approximately – 10 °C to 65 °C) and pressures not exceeding 12 MPa (120 bar). Within this range, the uncertainty of prediction of both methods is about ± 0,1 % provided that the input data, including the relevant pressure and temperature, have no uncertainty.

NOTE — Pipeline quality gas is used in this International Standard as a concise term for gas which has been processed so as to be suitable for use as industrial, commercial or domestic fuel. Although there is no formal international agreement upon the composition and properties of a gas which complies with this concept, some quantitative guidance is provided in 5.1.1. A detailed gas quality specification is usually a matter for contractual arrangements between buyer and seller.

The method given in part 2 is also applicable (with increased uncertainty) to broader categories of natural gas, including wet or sour gases, within a wider range of temperatures and to higher pressures, for example at reservoir or underground storage conditions or for vehicular (NGV) applications.

The method given in part 3 is applicable to gases with a higher content of nitrogen, carbon dioxide or ethane than normally found in pipeline quality gas. The method may also be applied over wider ranges of temperature and pressure but with increased uncertainty.

For the calculation methods described to be valid, the gas must be above its water and hydrocarbon dewpoints at the prescribed conditions.

The standard gives all of the equations and numerical values needed to implement both methods. Verified computer programmes are available (see annex B).

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 12213. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 12213 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

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

ISO 13443:1996, *Natural gas — Standard reference conditions*.

3 Definitions

For the purposes of the various parts of this International Standard, the following definitions apply.

3.1 compression factor, Z: The ratio of the volume of an arbitrary mass of gas, at a specified pressure and temperature, to the volume of the same mass of gas under the same conditions as calculated from the ideal-gas law, as follows:

$$Z = V_\mathrm{m}(\mathrm{real})/\,V_\mathrm{m}(\mathrm{ideal}) \quad \text{. . . (1)}$$

where $$V_\mathrm{m}(\mathrm{ideal}) = RT/p \quad \text{. . . (2)}$$

Thus, $$Z(p, T, y) = pV_\mathrm{m}(p, T, y)/(RT) \quad \text{. . . (3)}$$

where

p is the absolute pressure;

T is the thermodynamic temperature;

y is a set of parameters which uniquely characterizes the gas (in principle, the latter may be the complete molar composition or a distinctive set of dependent physico-chemical properties, or a mixture of both);

V_m is the molar volume of the gas;

R is the molar gas constant in coherent units.

The compression factor is a dimensionless quantity usually close to unity.

NOTE — The terms “compressibility factor” and “Z-factor” are synonymous with compression factor.

3.2 density, ρ: The mass of a given quantity of gas divided by its volume at specified conditions of pressure and temperature.

3.3 molar composition: The term used when the proportion of each component in a homogeneous mixture is expressed as a mole (or molar) fraction, or mole (molar) percentage, of the whole.

Thus the mole fraction x_i of component i is the ratio of the number of moles of component i in a given volume of a mixture to the total number of moles of all the components in the same volume of the mixture. One mole of any chemical species is the amount of substance which contains the relative molecular mass in grams. A table of recommended values of relative molecular masses is given in ISO 6976.

For an ideal gas, the mole fraction (or percentage) is identical to the volume fraction (or percentage), but this is not in general a sufficiently accurate approximation to real-gas behaviour for the purposes of this International Standard.

3.4 molar calorific value, H**:** The amount of heat which would be released by the complete combustion in air of the hydrocarbons in one mole of natural 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, all of these products being in the gaseous state except for water formed by combustion, which is condensed to the liquid state at the specified temperature.

Note that the molar calorific value only includes the hydrocarbons in the natural gas, i.e. inert components (primarily nitrogen, carbon dioxide and helium) and other combustible components (such as hydrogen and carbon monoxide) are excluded.

The specified temperature is 298,15 K (25 °C) and the reference pressure is 101,325 kPa.

The term “molar heating value” is synonymous with “molar calorific value”.

3.5 superior calorific value, H_S (volumetric basis)**:** The amount of heat which would be released by the complete combustion in air of all the combustible components in unit volume of natural 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, all of these products being in the gaseous state except for water formed by combustion, which is condensed to the liquid state at the specified temperature.

Note that the superior calorific value includes all the combustible components in the natural gas.

The reference temperature at which the volume is measured is 273,15 K (0 °C) and the specified temperature at which combustion takes place is 298,15 K (25 °C). The reference pressure is 101,325 kPa.

NOTE — Annex D of part 3 of this International Standard gives conversion factors which enable superior calorific values and relative densities determined at other reference or specified temperatures, and other reference pressures, including the ISO standard reference conditions (see ISO 13443), to be used as input data for the calculation method described.

The terms “gross”, “higher”, “upper” and “total calorific value” and “heating value” are synonymous with “superior calorific value”.

3.6 relative density, d**:** The ratio of the mass of a given volume of natural gas to the mass of dry air of standard composition which would be contained in the same volume at the same reference conditions of pressure and temperature.

The relative density includes all the components of the natural gas.

NOTE — The standard composition of dry air is given in ISO 6976.

In this International Standard, the reference temperature is 273,15 K (0 °C) and the reference pressure is 101,325 kPa (see note in 3.5).

The term “specific gravity” is synonymous with “relative density”.

3.7 uncertainty of a predicted compression factor, $\pm \Delta Z$**:** The range of values $Z - \Delta Z$ to $Z + \Delta Z$ within which the (unknown) true value is expected to lie with a confidence level of 95 %. This uncertainty may be expressed either as an absolute value or as a percentage.

Estimates of the 95 % confidence limits are, to the extent that this is practicable, established by comparison of test data of low uncertainty with calculated values of Z.

4 General principles

The methods recommended use equations which are based on the concept that any natural gas may be uniquely characterized for calculation of its volumetric properties either by component analysis or by an appropriate and distinctive set of measurable physical properties. These characteristics, together with the pressure and temperature, are used as input data for the methods.

In the sense that the volumetric behaviour of a gas mixture derives directly from the numbers and types of molecular interactions (collisions) which take place, a method which explicitly recognizes each molecular constituent of the mixture, and its proportion of the whole, is to some degree more fundamental than alternatives.

The method given in part 2 of this International Standard uses a detailed molar-composition analysis in which all constituents present in amounts exceeding a mole fraction of 0,000 05 should be represented. The sum of the mole fractions used should be unity to within 0,000 1. For a typical distributed (pipeline quality) gas, this includes all alkane hydrocarbons up to about C_7 or C_8 together with nitrogen, carbon dioxide and helium. For gases containing a synthetic admixture, hydrogen, carbon monoxide and ethylene are also likely to be significant components. For broader categories of gas, other components such as water vapour and hydrogen sulfide need to be taken into consideration.

The equation recommended is known as the AGA8 detailed characterization equation, and will be referred to hereafter as the AGA8-92DC equation [1] (see annex C). It is a revision of the equation described in AGA Report No. 8 [2].

The method given in part 3 of this International Standard uses two distinct physical properties, namely superior calorific value and relative density, together with the carbon dioxide content.

NOTE — In principle, any three from superior calorific value, relative density, carbon dioxide content and nitrogen content may be used, the calculation methods being essentially equivalent. However, the set comprising the first three is preferred for this International Standard. The reader interested in the use of alternative input variables is referred to the GERG TM5 documentation [3].

This method is particularly useful in the common situation where a complete molar composition is not available, but may also be preferred for its relative simplicity. For gases containing a synthetic admixture, the amount of hydrogen needs to be known.

The equation recommended is known as the SGERG-88 equation [3]. This equation is derived from the MGERG-88 equation [4], which uses a detailed molar analysis to characterize the gas.

The evaluation of both the AGA8-92DC and the SGERG-88 equations has been carried out using a large databank of high-accuracy (± 0,1 %) compression factor measurements (most of which are traceable to the relevant international metrological standards), compiled for the purpose by the Groupe Européen de Recherches Gazières [5] and the Gas Research Institute [6] [7]. Within the transmission and distribution pressure and temperature ranges, the equations are of essentially identical performance.

5 Guidelines

5.1 Pipeline quality natural gases

5.1.1 Pipeline quality gas

To make a definitive quantitative specification of what does or does not represent pipeline quality natural gas is, for several reasons, an elusive and contentious objective. Nevertheless, most transmission and distribution engineers are familiar with the general concept and will normally know whether any particular natural gas falls within the scope of this term. The following is therefore intended simply to provide summary guidance for any other users, rather than to formalize criteria for pipeline quality gas.

Pipeline quality gas is taken to consist predominantly (mole fraction greater than 0,70) of methane and to have a superior calorific value normally within the range 30 MJ·m^{-3} to 45 MJ·m^{-3} (see table 1). Nitrogen and carbon dioxide are the main diluents (each up to a mole fraction of about 0,20).

Ethane (up to a mole fraction of about 0,10), propane, butanes, pentanes and higher alkanes will usually be present in steadily decreasing amounts. Minor amounts of helium, benzene and toluene may be present at mole fractions of less than 0,001. For natural gases with a synthetic admixture, hydrogen and carbon monoxide may be present in mole fractions of up to about 0,10 and 0,03, respectively, and there may be small amounts of ethylene. No other component, such as those found in wet and sour gases (for example water vapour, hydrogen sulfide or oxygen), is normally present in greater than trace amounts, and there should be no aerosol, liquid or particulate matter present. Minor and trace components should be treated as specified in part 2 of this International Standard.

This way of defining pipeline quality gas is not intended to exclude natural gases of other compositions from being transported through pipelines.

The limits allowable for the purpose of this International Standard are given in table 1.

Table 1 — Allowable limits for mole fractions of components

Component	Mole fraction
Main components	
Methane	$\geqslant 0,70$
Nitrogen	$\leqslant 0,20$
Carbon dioxide	$\leqslant 0,20$
Ethane	$\leqslant 0,10$
Propane	$\leqslant 0,035$
Butanes	$\leqslant 0,015$
Pentanes	$\leqslant 0,005$
Hexanes	$\leqslant 0,001$
Heptanes	$\leqslant 0,000\,5$
Octanes and above	$\leqslant 0,000\,5$
Hydrogen	$\leqslant 0,10$
Carbon monoxide	$\leqslant 0,03$
Helium	$\leqslant 0,005$
Water	$\leqslant 0,000\,15$
Minor and trace components	
Ethylene	$\leqslant 0,001$
Benzene	$\leqslant 0,000\,5$
Toluene	$\leqslant 0,000\,2$
Argon	$\leqslant 0,000\,2$
Hydrogen sulfide	$\leqslant 0,000\,2$
Oxygen	$\leqslant 0,000\,2$
Total unspecified components	$\leqslant 0,000\,1$

5.1.2 Transmission and distribution metering

The main use of this International Standard is expected to be for the calculation of compression factors in applications concerned with transmission and distribution of pipeline quality gases. The range of conditions encountered in such applications varies from country to country, but almost all will be covered by the limits

$$263\ \mathrm{K} \leqslant T \leqslant 338\ \mathrm{K}$$

$$0\ \mathrm{MPa} < p \leqslant 12\ \mathrm{MPa}$$

The methods given in parts 2 and 3 apply with equal validity for all conditions within these limits.

5.1.3 Calculation using a molar-composition analysis

The AGA8-92DC equation may be used for any pipeline quality gas for which a detailed molar-composition analysis is available. The components which the analysis should include are: methane, nitrogen, carbon dioxide, carbon monoxide, hydrogen, helium, ethane, propane, butanes, pentanes, hexanes, and (if present at mole fractions greater than 0,000 05) higher hydrocarbons up to C_{10}. The amount of each minor or trace component specified in the lower part of table 1 should be demonstratably within the relevant limit. Any non-negligible amount of a minor or trace component should be treated in the manner specified in part 2 of this International Standard.

Within the ranges quoted in 5.1.2, the calculated compression factor values have the same status (i.e. equal validity) as those calculated from superior calorific value, relative density and carbon dioxide content.