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**Natural gas — Measurement of  
properties — Calorific value and Wobbe  
index**

*Gaz naturel — Mesurage des propriétés — Pouvoir calorifique et indice  
de Wobbe*

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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.

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

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

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

ISO 15971 was prepared by Technical Committee ISO/TC 193, *Natural gas*.

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## Introduction

The amount of energy delivered by a flowing natural gas is often determined as the product of the volume delivered and the calorific value per unit volume of the gas. It is, therefore, important to have available standardized methods of determining the calorific value. In many cases, it is possible to calculate the calorific value of natural gas, with sufficient accuracy, given the composition (see ISO 6976). However, it is also possible, and sometimes a preferred alternative, to measure calorific value using any one of several techniques that do not require a compositional analysis. The methods currently in use, and the many factors that it is necessary to address in the selection, evaluation, performance assessment, installation and operation of a suitable instrument, are detailed herein. The measurement of the Wobbe index, a property closely related to calorific value, is discussed briefly in an informative annex, but is not considered in detail in the normative parts of this International Standard.

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# Natural gas — Measurement of properties — Calorific value and Wobbe index

## 1 Scope

This International Standard concerns the measurement of calorific value of natural gas and natural gas substitutes by non-separative methods, i.e. methods that do not involve the determination of the gas composition nor calculation from it. It describes the principles of operation of a variety of instruments in use for this purpose, and provides guidelines for the selection, evaluation, performance assessment, installation and operation of these.

Calorific values can be expressed on a mass basis, a molar basis or, more commonly, a volume basis. The working range for superior calorific value of natural gas, on the volume basis, is usually between 30 MJ/m<sup>3</sup> and 45 MJ/m<sup>3</sup> at standard reference conditions (see ISO 13443). The corresponding range for the Wobbe index is usually between 40 MJ/m<sup>3</sup> and 60 MJ/m<sup>3</sup>.

This International Standard neither endorses nor disputes the claims of any commercial manufacturer for the performance of an instrument. Its central thesis is that fitness-for-purpose in any particular application (defined in terms of a set of specific operational requirements) can be assessed only by means of a well-designed programme of experimental tests. Guidelines are provided for the proper content of these tests.

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## 2 Normative references

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

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

ISO 14532: 2001, *Natural gas — Vocabulary*

## 3 Terms and definitions

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

### 3.1 Calorific value and Wobbe index

#### 3.1.1

##### superior calorific value

amount of heat that would be released by the complete combustion in air of a specified quantity of gas (on a molar, mass or volume basis), in such a way that the pressure,  $p$ , at which the reaction takes place remains constant and all the products of combustion are returned to the same specified temperature,  $T$ , as that of the reactants, all of these products being in the gaseous state, except for water formed by combustion, which is condensed to the liquid state at  $T$

See ISO 6976.

3.1.2

**inferior calorific value**

amount of heat that would be released by the complete combustion in air of a specified quantity of gas (on a molar, mass or volume basis), in such a way that the pressure,  $p$ , at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature,  $T$ , as that of the reactants, all of these products being in the gaseous state

See ISO 6976.

3.1.3

**Wobbe index**

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

See ISO 6976.

3.1.4

**standard reference conditions**

temperature,  $T = 288,15$  K, and (absolute) pressure,  $p = 101,325$  kPa, for the real dry gas

See ISO 13443.

NOTE Standard reference (or base) conditions of temperature, pressure and humidity (state of saturation) are defined for use only in natural gas and similar applications. For the calorific value on a volumetric basis, these conditions apply to both the metering and combustion of the gas. In the expression of physical quantities throughout this International Standard, these standard reference conditions as defined in ISO 13443 are taken to apply.

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3.2 Water content of gas

3.2.1

**saturated gas**

natural gas which, at the specified conditions of temperature and pressure, is at its water dew-point

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3.2.2

**dry gas**

natural gas which does not contain water vapour at a mole fraction greater than 0,000 05

See ISO 6976.

3.2.3

**partially saturated or wet gas**

natural gas which contains an amount of water vapour between that of the saturated gas and that of the dry gas, at the specified conditions of temperature and pressure

3.3 Performance classification

NOTE The following classification scheme is adopted in order to categorize the uncertainties associated with measurement of calorific value. The attached notes are explanatory, not parts of the definitions. The values given refer to an expanded uncertainty with a coverage factor of 2.

3.3.1

**class 0**

performance with which uncertainty limits of no greater than  $\pm 0,1$  % in calorific value may be associated

NOTE Performance of this quality can currently be achieved only by instruments in which all operations are carried out in strict accordance with the best metrological practices and in which all relevant physical measurements are directly traceable to primary metrological standards. Typically, such an instrument is custom-built and installed in a purpose-built, environmentally controlled specialist laboratory; a specially trained and identified operator is likely required. Instruments of this type are sometimes known as "reference calorimeters" and all, to date, make measurements discontinuously on discrete samples of gas.



### 3.3.2 class 1

performance with which uncertainty limits of no greater than  $\pm 0,1 \text{ MJ/m}^3$  on a volume-basis calorific value (approximately 0,25 %) may be associated

NOTE This is the lowest level of measurement uncertainty currently available for any form of commercial instrument used in routine field (i.e. non-laboratory) operation. Even for the few types of instrument that are intrinsically capable of this performance, it is unlikely to be achieved unless installation is in accordance with both the manufacturer's instructions and the principles described in this International Standard, and operation is in accordance with the calibration, verification, maintenance and quality control procedures described in this International Standard.

### 3.3.3 class 2

performance with which uncertainty limits of no greater than  $\pm 0,2 \text{ MJ/m}^3$  on a volume-basis calorific value (approximately 0,5 %) may be associated

### 3.3.4 class 3

performance with which uncertainty limits of no greater than  $\pm 0,5 \text{ MJ/m}^3$  on a volume-basis calorific value (approximately 1,0 %) may be associated

## 3.4 Terms from metrology

NOTE The following definitions, including the Notes attached to them (except the Note to 3.4.6), are all taken from ISO 14111, where additional explanatory details are given.

### 3.4.1 accuracy

closeness of agreement between a measurement result and the true value of the measurand

NOTE The term "accuracy" when applied to a set of measurement results, describes a combination of random components and a common systematic error or bias component.

### 3.4.2 trueness

closeness of agreement between the average value obtained from a large series of measurement results and the true value of the measurand

NOTE The measure of trueness is usually expressed in terms of bias.

### 3.4.3 bias

difference between the expectation of the measurement results and an accepted reference value

### 3.4.4 precision

closeness of agreement between independent measurement results obtained under prescribed conditions

NOTE Precision depends only on the distribution of random errors and does not relate to the true value.

### 3.4.5 repeatability

precision under conditions where independent measurement results are obtained with the same method on identical measuring objects in the same laboratory by the same operator within short intervals of time

NOTE Repeatability is expressed quantitatively based on the standard deviation of the results.

**3.4.6  
uncertainty**

estimate attached to a measurement result which characterizes the range of values within which the true value is asserted to lie

NOTE An alternative, but equivalent, definition taken from Reference [1] is as follows: parameter, associated with the result of a measurement, that characterizes the dispersion of the values that can reasonably be attributed to the measurand.

**3.4.7  
calibration**

set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards

**3.4.8  
verification**

confirmation by examination and provision of objective evidence that specified requirements have been fulfilled

## 4 Principles of measurement

### 4.1 Introduction

Instruments capable of class 0 performance (hereafter, for brevity, called class 0 calorimeters) have been established in a few specialist laboratories; but since they are, inevitably, labour-intensive, spot-test instruments, not commercially available and not suitable for field operation, details of their installation, operation and maintenance are beyond the scope of the main part of this International Standard.

Nevertheless, measurements made using calorimeters of this type can have an important part to play in the "everyday" determination of calorific value, mainly as one possible accredited means for the provision of certified calibration gases (certified gaseous reference materials) having traceability to international metrological standards (see 7.2). They may also be used for research purposes and the resolution of disputes.

The principles upon which typical class 0 calorimeters operate, together with details of many of the other relevant factors, are given in Annex C. All class 0 calorimeters so far devised have, as their primary determination, the mass-basis calorific value. To be useful for most routine applications, it is necessary to convert this by some secondary means to the volume-basis value. In order to achieve a volume-basis calorific value with an uncertainty of  $\pm 0,1$  %, it is usual to dedicate a density meter of sufficient accuracy for use with instruments of this type.

Instruments capable of class 1, class 2 or class 3 performance usually measure calorific value on the volume basis. They are normally designed for continuous, unattended operation in the field, producing an essentially continuous record of calorific value. Except for process gas chromatographs (which are not the subject of this International Standard), they are the only types of instrument that can sensibly be used for routine measurements of calorific value on natural gas passing through transmission and distribution systems.

The principle of operation may be either direct, indirect or inferential, within the meaning of these terms in accordance with ISO 14532. This International Standard is concerned mostly with the performance of these kinds of instruments. Some instruments have the additional facility of measuring relative density; in these cases, this capability is equivalent to making available the determination both of the calorific value on the mass basis and of the Wobbe index.

Depending upon the particular application, instruments can be required to record either the superior or the inferior calorific value. Although each particular type of instrument responds, in principle, to one or the other of these, most types can be set up so as to record, with little loss of accuracy for typical natural gases, the alternate value. To achieve this, the main requirement is that the instrument be set up using calibration gases that are correspondingly certified (see also 5.1.10.2).

## 4.2 Direct combustion calorimetry

Only those instruments that are true combustion calorimeters, in the sense that the energy released as heat by the combustion of gas is determined by means of thermometric measurements, fall into the “direct-measurement” category. All current commercial implementations determine the volume-basis calorific value.

In this type of instrument, the gas sample is metered volumetrically on a continuous basis, often through the use of a water-sealed “wet meter” (Reference [2], Chapter 4, and ISO 6145-1), before passing to a burner. The main measurement is of the quasi-stationary (equilibrium) rise in temperature of a continuously flowing (metered) heat-exchange medium with which the hot products of combustion do not mix.

The heat-exchange medium is usually air; water-flow calorimeters do exist in a wide variety of forms but all of these are now obsolete. The temperature rise is usually measured using resistance thermometry. Calibration is usually achieved by the use of gaseous reference materials (working standards) certified for calorific value.

Calorific values are usually measured by this method at ambient temperature and pressure. It is necessary, however, to refer the values recorded to specified reference conditions of temperature and pressure of both metering and of combustion. For this reason, prior information concerning the stability of the output with respect to variations of ambient temperature can be important (see 5.1.6).

It is also important to define the reference condition of water content for the gas, in particular if the instrument controls the water content of the gas (either by saturation or by drying) prior to or during the measurement process. At standard reference conditions, the difference between the superior calorific value of a dry gas and a saturated gas is approximately 1,7 %.

Instruments of this type are usually set up so as to record the superior calorific value. One of the main advantages of true combustion calorimeters is that there is no restriction on the composition of the sample gas for which they are expected to give the correct result.

Calorimeters based on this generic methodology (Reference [2], Chapter 10; Reference [6], Chapter 7; and References [3] to [5]) are often capable of class 1 performance, but typically have quite a sluggish response to changes in calorific value because of thermal inertia.

Typical examples of this kind of calorimeter are described in Annex D.

## 4.3 Indirect methods

### 4.3.1 General

Instruments that fall into the “indirect” category are those that measure some physicochemical property of the gas and use a known relationship, established by both practical observation and theoretical analysis, between calorific value and the property measured, in order to infer the calorific value, either superior or inferior, of the gas.

### 4.3.2 Stoichiometric combustion

Instruments of this type depend upon the principle that, for a gas mixture containing only alkane hydrocarbons and inert constituents, the volume-basis calorific value (either superior or inferior) is a linear function of the air-to-gas ratio required to achieve stoichiometric combustion.

There are at least two ways to implement this principle in a practical device. In one implementation, the stoichiometric point is determined by searching for the air-to-gas ratio at which the amount of oxygen in the products of complete combustion is zero. In an alternative implementation, the stoichiometric point is determined by searching for the air-to-gas ratio at which maximum flame temperature is achieved.

One disadvantage of instruments that operate on this principle is the requirement to confirm that the sample gas contains only alkane hydrocarbons and inert constituents. Any other constituent (for example, alkenes, hydrogen, carbon monoxide and, most severely, oxygen) can cause the instrument to give a false reading; in some cases, however, any errors can be accounted for by a correction procedure.

Instruments based on this principle [7] are readily capable of at least class 2 performance and typically exhibit rapid response to changes in calorific value.

Some practical details of these devices are given in Annex E.

#### 4.3.3 Catalytic combustion

Instruments of this type are based on the principle that a determination of the amount of heat released during the complete oxidation (combustion) of a gas at a catalytic surface is a proper representative measure of its calorific value.

In one implementation, a semi-continuous (i.e. on-off-on) metered flow of fuel gas undergoes oxidation at the surface of a catalyst-coated conductor; the heat released by this combustion process raises the temperature of the conductor and so influences its electrical resistance. The electrical resistance can readily be used to follow the rise in temperature over the "on" period of the gas flow, and the integrated temperature rise for this period may then be used as an indicator of inferior calorific value.

In another implementation, the oxidation process takes place within a bed of powdered catalytic material. The flowrate of fuel (at a constant flowrate of air) that is necessary to maintain the reaction chamber at a constant temperature is then measured and used as an indicator of inferior calorific value.

Catalytic combustion instruments of the types described in this subclause [8], [9] are at an advanced stage of development, but are not yet commercially available; their performance capabilities, therefore, cannot yet be assessed.

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#### 4.4 Inferential methods

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The dividing line between "indirect" and "inferential" methods is rather indistinct. It can logically be argued that all determinations of calorific value are, in some sense of the word, inferential. Here, inferential methods are taken to be those that depend upon an empirical (or possibly semi-empirical) correlation between calorific value and some other measured property or properties.

Examples of relevant properties that may be used in this way as predictors of calorific value include compression factor (which is related to calorific value by means of the SGERG-88 equation [10]) and speed of sound. Neither of these properties alone is sufficient to determine calorific value unambiguously (further information concerning the inert constituents is needed), and no commercial device has yet been produced to exploit such correlations. Nevertheless, the great precision with which speed of sound can readily be measured suggests a possible future role for a method based on this principle.

For the present, however, instruments that can best be classed as inferential are much less sophisticated, both in principle and in construction. In typical instruments of this kind, a supposedly constant proportion of the heat released by the combustion of a regulated flow of fuel gas is sensed (but not measured) by some particular device and related empirically to the calorific value.

In one long-established implementation of this principle (Reference [2], Chapter 10 and Reference [6], Chapter 6), the sensing device is the burner chimney itself, formed from two concentric metal tubes joined rigidly at the bottom; the two tubes expand differentially by an amount that depends on the heat transferred from the flue gases, and this may be used to give an indication of calorific value. In another implementation [4], the sensor is a single metal thermal-expansion tube located in the effluent gas stream; and in a slightly more modern implementation, it is a similarly located thermopile, the output of which is taken as an indication of calorific value. In none of these instruments is the water of combustion condensed; consequently all, in principle, respond to the inferior calorific value.

As a consequence of their acknowledged simplicity, instruments of this general type cannot usually be expected to achieve better than class 3 performance except in the most favourable of circumstances.

Very many other principles of operation have been described over the years, but it is not the intention here to describe ideas which no longer find, have never found, or are unlikely to find reasonably widespread application. There are countless “dead-end” patents.

## 5 Performance assessment and acceptance tests

The flowchart given as Figure 1 provides an overview of the procedures that it is typically necessary to carry out in order to satisfy performance assessment and acceptance testing requirements. Specific details are provided in 5.1 and 5.2.

### 5.1 Performance assessment for instrument selection

#### 5.1.1 General

For any application, it is necessary that an instrument for the measurement of calorific value meet some criteria of acceptability. Two common forms that these criteria may take for a commercially available instrument are

- a) a set of requirements that shall be met in order for the instrument to receive type-approval; in some cases, this can be issued by a statutory body responsible for the supervision of custody transfer or customer charging, and
- b) a technical specification for purchase contract purposes.

Annex B gives an example of a typical type-approval specification (Clause B.1) and of a typical technical specification forming part of the purchase documentation (Clause B.2).

5.1 relates to performance assessment tests that it is typically necessary to carry out on (usually) a single instrument as an exemplar of its type. In 5.1.2 to 5.1.13 are considered the factors that are those most often specified in a formal set of requirements, such as those referred to in this subclause. A purposeful test programme is likely to include the investigation of most, if not all, of these aspects of the instrumental performance.

The test programme shall include a specification for the calibration and other test gases that are required to carry out many aspects of the detailed testing and calibration, although some test gases might not require certification. Furthermore, any type-approval documentation issued as a result of the test programme shall include a specification for the gases for use on-site in the re-calibration and verification procedures, so as to ensure attainment and maintenance of the specified accuracy.

Instruments of all types considered in this International Standard generally perform optimally when left in continuous on-line operation; requirements calling for only intermittent or off-line operation demand special care and extra pre-testing (see 5.1.3).

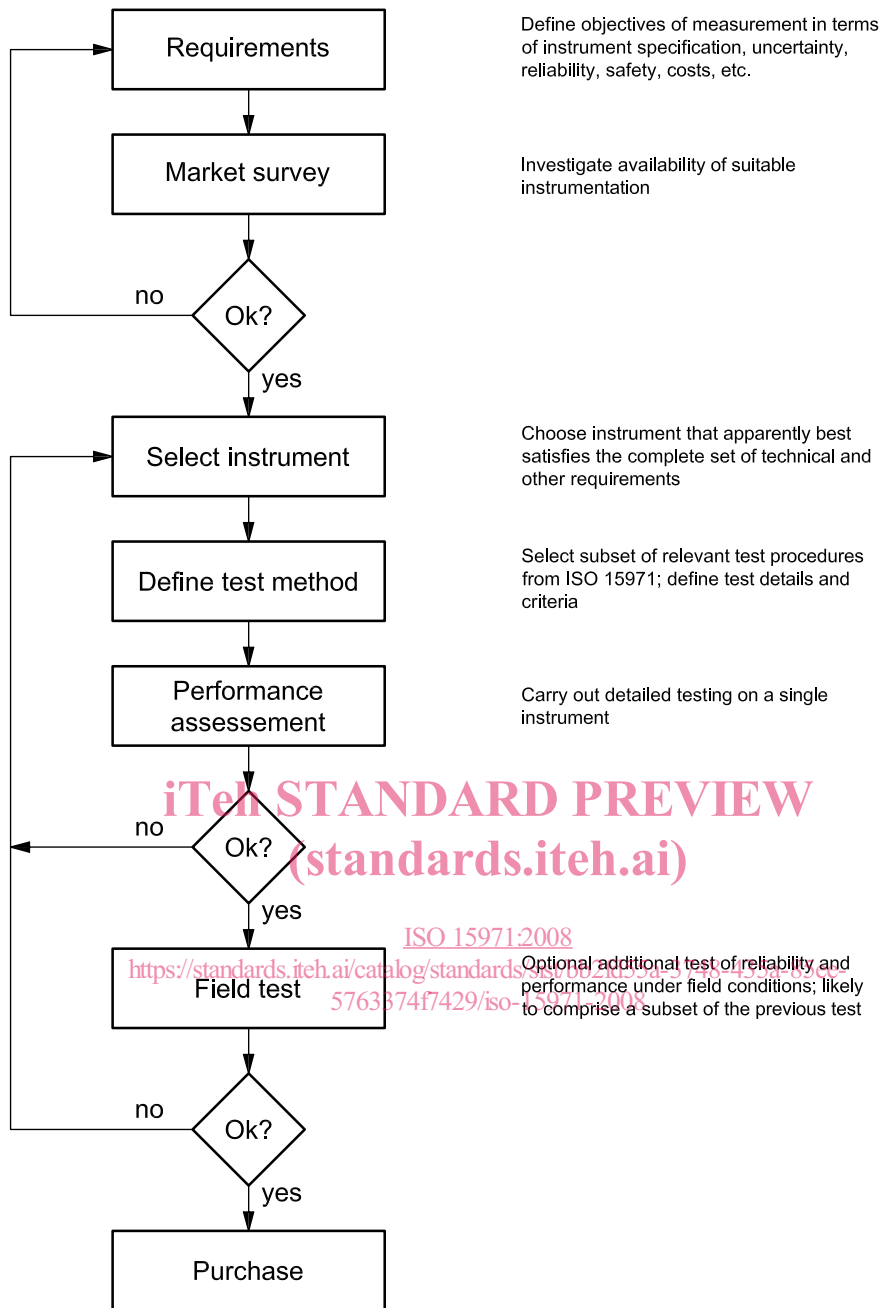


Figure 1 — Instrument evaluation, performance assessment and acceptance testing

Depending on the particular circumstances, performance assessment testing may be carried out by a regulatory authority, by an independent, accredited testing laboratory and/or by the purchaser. If carried out by a regulatory authority, the tests may lead to type-approval documentation. There is a clear trade-off between the length of time spent on a series of performance tests and the amount of detail that they yield about an instrument. Where a regulatory authority requires a thorough characterization of all aspects of performance, the test programme can easily extend over a period of one year or more.

A pro-forma checklist of the type given as Table 1 can be a useful means of keeping track of the progress of, and results from, a lengthy evaluation programme.

### 5.1.2 Continuity of operation

It is likely that an explicit requirement be for the instrument to be in-service and to operate correctly (and, for most applications, continuously) for a specified period of time. If the particular application requires intermittent operation only, then the trueness tests (see 5.1.3) should address this complicating factor as a priority before proceeding with other tests.

In the case of continuous operation, the instrument should be tested simply by letting it run without interruption or undue interference (such as unscheduled adjustments to settings) for a continuous period that exceeds the specified minimum required operating period by a specified percentage. Depending on the application, this may be anywhere from a few days to several months. It can, however, be possible to carry out other tests during this period, for example trueness and repeatability tests, without prejudice to the continuity (reliability) test.

Repeating the continuity (reliability) test, after routine maintenance in accordance with the manufacturer's instructions, at least once, is likely to be a worthwhile option. If the instrument cannot operate without breakdown or obvious malfunction for the specified period, then it fails this test.

The results from a completed test may be analysed in order to assess the period for which the specified instrument performance has been achieved. If this is less than the minimum for which correct operation is required, then the instrument has again failed. In this case, it can still be possible to use the instrument in applications where a shorter period of continuous satisfactory operation is acceptable.

If there is no explicit requirement for a minimum operating period, then it is possible to allow the frequency of maintenance operations to be determined by operational experience, i.e. the maintenance operations are performance-driven rather than requirement-driven.

Table 1 — Example of checklist for type-approval and acceptance testing

Property or test	Type approval testing			Factory acceptance test			On-site acceptance test		
	required	result	pass/fail	specified	result	pass/fail	specified	result	pass/fail
<b>1 Continuity of operation</b> continuous operation within maximum specified error of 0,25 MJ/m <sup>3</sup> test period	6 months	7 months	pass	1 month	1 month	pass	3 months	3 months	pass
<b>2 Trueness of calorific value</b> number of test gases range, MJ/m <sup>3</sup> linearity, MJ/m <sup>3</sup>	7 31<CV<46 < 0,10		pass	5 35<CV<42 < 0,10	0,05	pass	application gases  not tested		
<b>3 Repeatability</b> multiple readings type b) number of test readings spread, MJ/m <sup>3</sup>	40 < 0,10	0,08	pass	20 < 0,10	0,05	pass	20 < 0,10	0,06	pass
<b>4 Response to calorific value step-change</b> step, MJ/m <sup>3</sup> 95 % response time	38 to 42 < 4 min	2 min 35 s	pass	40 to 41 < 3 min	1 min 53 s	pass	40 to 41 < 3 min	1 min 42 s	pass