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Hydrogen generators using fuel processing technologies —

Part 2: Test methods for performance

Générateurs d'hydrogène faisant appel aux technologies du traitement du carburant —

Partie 2: Méthodes d'essai de rendement

Reference number
ISO 16110-2:2010(E)

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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 16110-2 was prepared by Technical Committee ISO/TC 197, *Hydrogen technologies.*

ISO 16110 consists of the following parts, under the general title *Hydrogen generators using fuel processing technologies*:

- *Part 1: Safety*
- *Part 2: Test methods for performance*

Introduction

This part of ISO 16110 describes how to measure and document the performance of stationary hydrogen generators for residential, commercial and industrial applications.

The following hydrogen generation types have been considered:

- hydrogen generators using fuel processing technologies.

INTERNATIONAL STANDARD **ISO 16110-2:2010(E)**

Hydrogen generators using fuel processing technologies —

Part 2:
Test methods for performance

1 Scope

This part of ISO 16110 provides test procedures for determining the performance of packaged, self-contained or factory matched hydrogen generation systems with a capacity less than 400 m^3/h at 0 °C and 101,325 kPa, herein referred to as hydrogen generators, that convert a fuel to a hydrogen-rich stream of composition and conditions suitable for the type of device using the hydrogen (e.g. a fuel cell power system, or a hydrogen compression, storage and delivery system).

2 Normative references

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

ISO 3744, *Acoustics — Determination of sound power levels of noise sources using sound pressure — Engineering method in an essentially free field over a reflecting plane*

ISO 4677 (all parts), *Atmospheres for conditioning and testing — Determination of relative humidity*

ISO 5167 (all parts), *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*

ISO 6060, *Water quality — Determination of the chemical oxygen demand*

ISO 6326 (all parts), *Natural gas — Determination of sulfur compounds*

ISO 6974 (all parts), *Natural gas — Determination of composition with defined uncertainty by gas chromatography*

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

ISO 7934, *Stationary source emissions — Determination of the mass concentration of sulfur dioxide — Hydrogen peroxide/barium perchlorate/Thorin method*

ISO 9096, *Stationary source emissions — Manual determination of mass concentration of particulate matter*

ISO 10101 (all parts), *Natural gas — Determination of water by the Karl Fischer method*

ISO 10523, *Water quality — Determination of pH*

ISO 10707, *Water quality — Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds — Method by analysis of biochemical oxygen demand (closed bottle test)*

ISO 11042 (all parts), *Gas turbines — Exhaust gas emission*

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

ISO 11564, *Stationary source emissions — Determination of the mass concentration of nitrogen oxides — Naphthylethylenediamine photometric method*

ISO 14687-1, *Hydrogen fuel — Product specification — Part 1: All applications except proton exchange membrane (PEM) fuel cell for road vehicles*

ISO 14687-2, *Hydrogen fuel — Product specification — Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles*

ISO 16622, *Meteorology — Sonic anemometers/thermometers — Acceptance test methods for mean wind measurements*

IEC 61010-1, *Safety requirements for electrical equipment for measurement, control, and laboratory use — Part 1: General requirements*

IEC 61672-1, *Electroacoustics — Sound level meters — Part 1: Specifications*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
audible noise level
sound pressure level produced by the hydrogen generator measured at a specified distance

NOTE Audible noise level is expressed as decibels (dBA) and measured as described in this part of ISO 16110.

3.1.2
background noise level
sound pressure level of ambient noise at the measurement point

3.1.3
cold state
condition of a hydrogen generator at ambient temperature with no substantial fuel or power input

3.1.4
discharge water
water that is released by the hydrogen generator

NOTE Discharge water does not constitute part of a thermal recovery system. It is comprised of the water treatment waste and the process condensate shown in Figure 1.

3.1.5
hydrogen generator
system that converts a fuel to a hydrogen-rich stream

NOTE The hydrogen generator is composed of all or some of the following subsystems: a fuel processing system, a fluid management system, a thermal management system, and other subsystems as described in more detail in ISO 16110-1.

3.1.6
interface point
measurement point of a hydrogen generator at which material and/or energy either enters or leaves

3.1.7
return gas
tail gas
unused reformed hydrogen-rich gas, which returns to the hydrogen generator and is used as a fuel

NOTE Return gas generally includes hydrogen, carbon dioxide, water vapour and slipped hydrocarbon.

3.1.8
standby state
state in which the hydrogen generator is at operating temperature and is in an operational mode from which it can be promptly switched to an operational mode with net hydrogen output

See Figure 2, item 2.

3.1.9
start-up time
time from cold start to supply of hydrogen gas at the rated hydrogen pressure

See Figure 2, item 1-3.

3.1.10
waste heat
thermal energy released and not recovered

3.2 Symbols

The symbols and their meanings are described in Annex A.

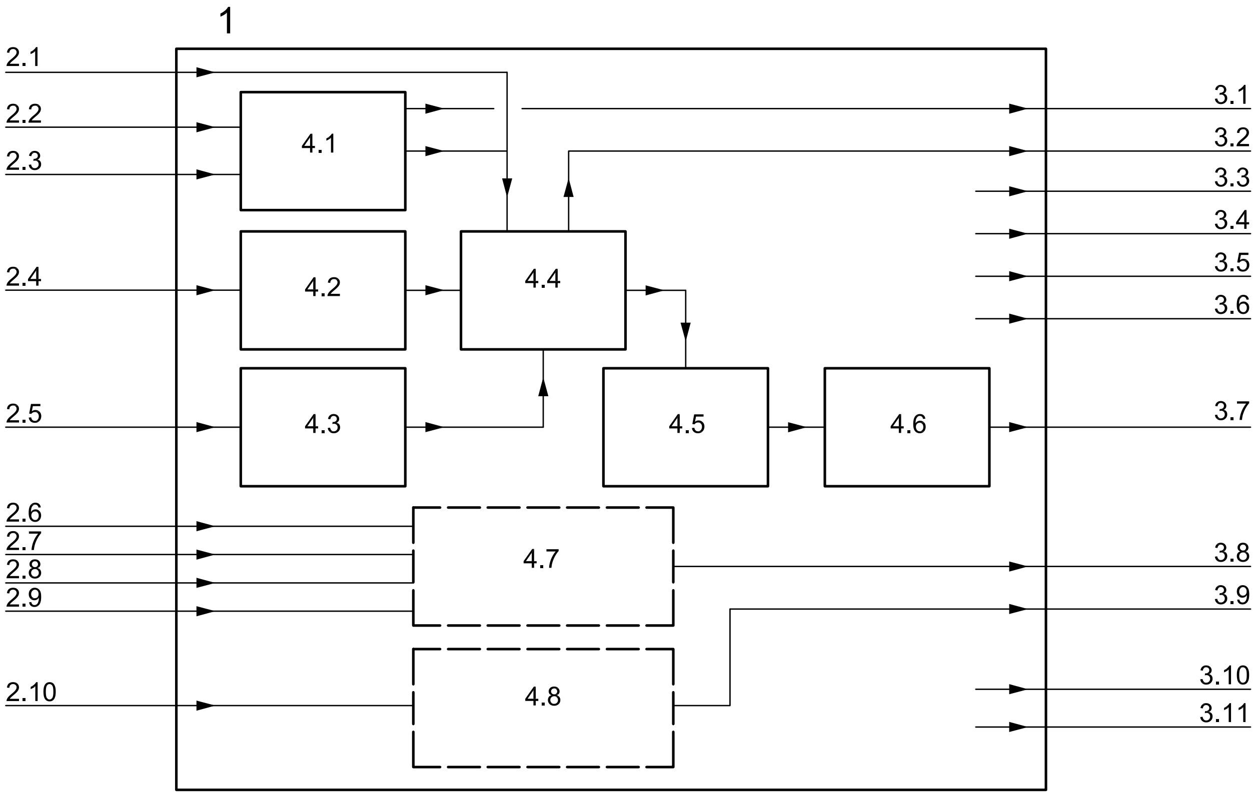
4 Test conditions/Test boundary

Hydrogen generators may have different subsystems depending on types of primary conversion processes and applications, and they have different streams of material and energy in and out of them. However, a common system diagram and boundary has been defined for evaluation of the hydrogen generator (see Figure 1).

The following conditions shall be considered in order to determine the test boundary of the hydrogen generator:

- All energy recovery systems shall be included within the system boundary.
- Calculation of the heating value of the input fuel (such as natural gas, propane gas, etc.) shall be based on the conditions of the input fuel at the boundary of the hydrogen generator.
- Calculation of the heating value of the output hydrogen containing gas stream shall be based on the conditions of the gas stream at the boundary of the hydrogen generator.
- Mechanical systems required for hydrogen generator operation (i.e. ventilation or micro-turbines, expanders or compressors) shall be included inside the test boundary. The direct measurement of these mechanical systems inside the test boundary is not required; however, their effects shall be included in the hydrogen generator operation. If mechanical (shaft) power and energy cross the test boundary, additional measurements and calculations may be necessary.

  NOTE This part of ISO 16110 does not take into account mechanical (shaft) power or mechanical energy inputs or outputs.



1 **system boundary of the hydrogen generator** including subsystems and the interface is defined as a conceptual or functional one

2 **inputs**
2.1 steam (if imported)
2.2 water
2.3 treatment chemicals
2.4 air/oxidant
2.5 fuel
2.6 purge gas
2.7 cooling fluid
2.8 instrument gas
2.9 electrical power input
2.10 atmospheric air

3 **outputs**
3.1 water treatment waste
3.2 exhaust gas
3.3 process vents
3.4 recovered heat
3.5 process condensate
3.6 solid waste
3.7 hydrogen
3.8 cooling fluid
3.9 ventilation exhaust
3.10 noise
3.11 waste heat

4 **subsystems** (the configurations depend on the kind of fuel, type of fuel cell or system)
4.1 water treatment and steam generation
4.2 air/oxidant processing system
4.3 feedstock compression and processing
4.4 fuel processing system
4.5 hydrogen purification (optional)
4.6 hydrogen metering and analysis
4.7 process utilities (cooling fluid, purge gas, instrument gas, electrical, etc.)
4.8 ventilation system

→: **The interface points** in the boundary to be measured for calculation data.

NOTE The fuel input can also consist of return gas.

Figure 1 — Typical hydrogen generator diagram

5 Measurement technique

5.1 General

The types of measuring instruments and measurement methods shall conform to the relevant International Standards and shall be selected to meet the measurement uncertainty targets in line with the uncertainty analysis of 6.4. If necessary, external equipment with required specification shall be added.

5.2 Operational parameters

5.2.1 Electrical power input

The electrical power input to the hydrogen generator, the voltage, the current and the power factor shall be determined and measured in accordance with IEC 61010-1.

5.2.2 Input and output fluid characteristics

5.2.2.1 General

The composition, the heating value (only for fuels), the temperature, the pressure and the flow rate of the input and output fluids shall be determined as per 5.2.2.2 to 5.2.2.6.

If there is fluctuation greater than ± 2 % in any measured value, the amplitude and the frequency of the fluctuation shall be measured and reported as part of the test results.

5.2.2.2 Composition of fluids

The composition of each input and output fluid shall be measured. The measurement technique shall be appropriate to the chemical composition of the fluid in question. If the fluid is not critical to operability or utility consumption, direct measurement of the fluid composition shall not be required for conformance with this part of ISO 16110.

If the only chemical oxidant employed is atmospheric air, only the moisture content shall be measured. The moisture content value may be calculated from other direct measurements (e.g. wet bulb and dry bulb temperatures) and reported as relative humidity.

The composition of natural gas shall be measured in accordance with methods detailed in ISO 6974 and ISO 6975.

The sulfur compounds (including odorant) of natural gas shall be measured according to methods detailed in ISO 6326.

The water vapour content of natural gas shall be measured according to methods detailed in ISO 10101 and ISO 11541.

The hydrogen composition shall be determined using the test methods specified in ISO 14687-1 or ISO 14687-2, as applicable.

The composition of other fluids shall be measured in accordance with the standard(s) appropriate to the fluids.

5.2.2.3 Heating value

The heating value of the input and output fluids shall only be measured for combustible fluids. The heating value shall be determined through either calorimetric methods, or via calculation based on the fluid composition as specified in Clause 8. The accuracy and detection limits of the composition measurement technique shall be determined, and its effect on the uncertainty analysis of 6.4 shall be explicitly considered. Pre-analysed bottled fuel gas may be substituted for gas sampling, provided that the uncertainty of the analysed gas is consistent with the uncertainty required by the uncertainty analysis of 6.4.

In principle, the lower heating value (LHV) shall be used for all the calculations defined in this part of ISO 16110. Should the higher heating value (HHV) be applied instead of LHV, the abbreviation “HHV” shall be added to all the results that derive from the use of the HHV, such as the heating value of gaseous fuel calculated as per Equation (15), the energy of gaseous fuel calculated as per Equation (16), the input energy of gaseous fuel calculated as per Equation (15) and the efficiency calculated as per Annex D.

EXAMPLE If the value of efficiency is based on the HHV, it should be expressed as follows:

$\eta_h = XX\%$ (HHV)

NOTE In case of LHV, it is not necessary to add the abbreviation “LHV”.

5.2.2.4 Temperature

The temperature of each fluid shall be measured at the boundary of the hydrogen generator.

5.2.2.5 Pressure

The static pressure of each fluid shall be measured at the boundary of the hydrogen generator.

The height above grade shall be measured and recorded for input and output liquids.

The potential effects of condensable fractions shall be considered in the uncertainty analysis of 6.4 and in the location of the pressure measurement means.

If the discharge of a particular fluid is to the atmosphere, its pressure need not be measured.

5.2.2.6 Flow rate

The flow rate of each fluid shall be measured at the boundary of the hydrogen generator.

Flow rates may be determined by means of a volumetric meter, mass flow meter or turbine type flow meter. If such a method is not practicable, flow measurement by nozzles, orifices or venturi meters should be used and they shall be applied in accordance with ISO 5167.

If a particular fluid is not chemically modified in the hydrogen generator, such as cooling fluid, instrument air or purge gas, only the input or output flow rate shall be measured.

The effects of the flow measurement on the operability of the hydrogen generator shall be considered.

5.2.3 Solid output characteristics

Any solid outputs from the hydrogen generator, which is generated on a continuous basis, and which have to be removed or disposed of continuously or in a repetitive batch operation, shall be characterized. The following properties shall be measured:

a) composition;

b) mass generation rate;

c) frequency of removal, if a batch operation is necessary.

5.3 Environmental aspects

5.3.1 Particulate emission

Particulate emission in the exhaust gases shall be measured in accordance with ISO 9096.

5.3.2 SOx and NOx emission

5.3.2.1 SOx emission

SOx emission in the exhaust gases shall be measured in accordance with ISO 7934. Other methods suitable for the service may be used providing they are consistent with the uncertainty analysis of 6.4.

5.3.2.2 NOx emission

NOx emission in the exhaust gases shall be measured in accordance with ISO 11564. Other methods suitable for the service may be used providing they are consistent with the uncertainty analysis of 6.4.

5.3.3 CO_2 and CO emission

CO_2 emission in the exhaust gases shall be measured in accordance with ISO 11042-1 and ISO 11042-2. CO_2 may be calculated based on carbon content of the fuel.

CO emission in the exhaust gases shall be measured in accordance with ISO 11042-1 and ISO 11042-2.

5.3.4 Total hydrocarbon emission

Total hydrocarbon emission in the exhaust gases shall be measured in accordance with ISO 11042-1 and ISO 11042-2.

5.3.5 Discharge water quality measurement

5.3.5.1 General

Quality measurements for water discharged from a hydrogen generator shall include the determination of:

a) volume of discharge water;

b) temperature of discharge water;

c) pH;

d) chemical oxygen demand (COD) or, if necessary, biochemical oxygen demand (BOD).

5.3.5.2 pH

The pH shall be measured in accordance with ISO 10523.

5.3.5.3 Chemical oxygen demand (COD)

The COD shall be measured in accordance with ISO 6060.

5.3.5.4 Biochemical oxygen demand (BOD)

When applicable, the BOD shall be measured in accordance with ISO 10707.

5.3.6 Audible noise level

The audible noise level produced by the hydrogen generator shall be measured using a sound level meter that complies with IEC 61672-1. The test shall be conducted in accordance with ISO 3744 and shall record the following parameters:

a) measuring surface (at distance from the body of hydrogen generator);

b) number of measuring points;

c) the background noise level, which shall be measured with the hydrogen generator in the cold state.

5.4 Ambient conditions

Ambient humidity, wind, pressure and temperature shall be measured.

Ambient humidity measurement shall be performed as per ISO 4677-1 and ISO 4677-2.

Ambient wind measurement shall be performed as per ISO 16622.

6 Test plan

6.1 General

A detailed test plan shall be prepared taking into consideration the following:

a) the test operating modes specified in 6.2;

b) the measurements, the test frequency and duration specified in 6.3;

c) the uncertainty analysis of 6.4.

6.2 Test operating modes

The hydrogen generator shall be tested in the operation modes listed below and shown in Figure 2:

a) start-up from cold state to the minimum hydrogen rated output;

b) steady-state operation at the minimum hydrogen rated output;

c) ramp-up from minimum hydrogen rated output to maximum hydrogen rated output;

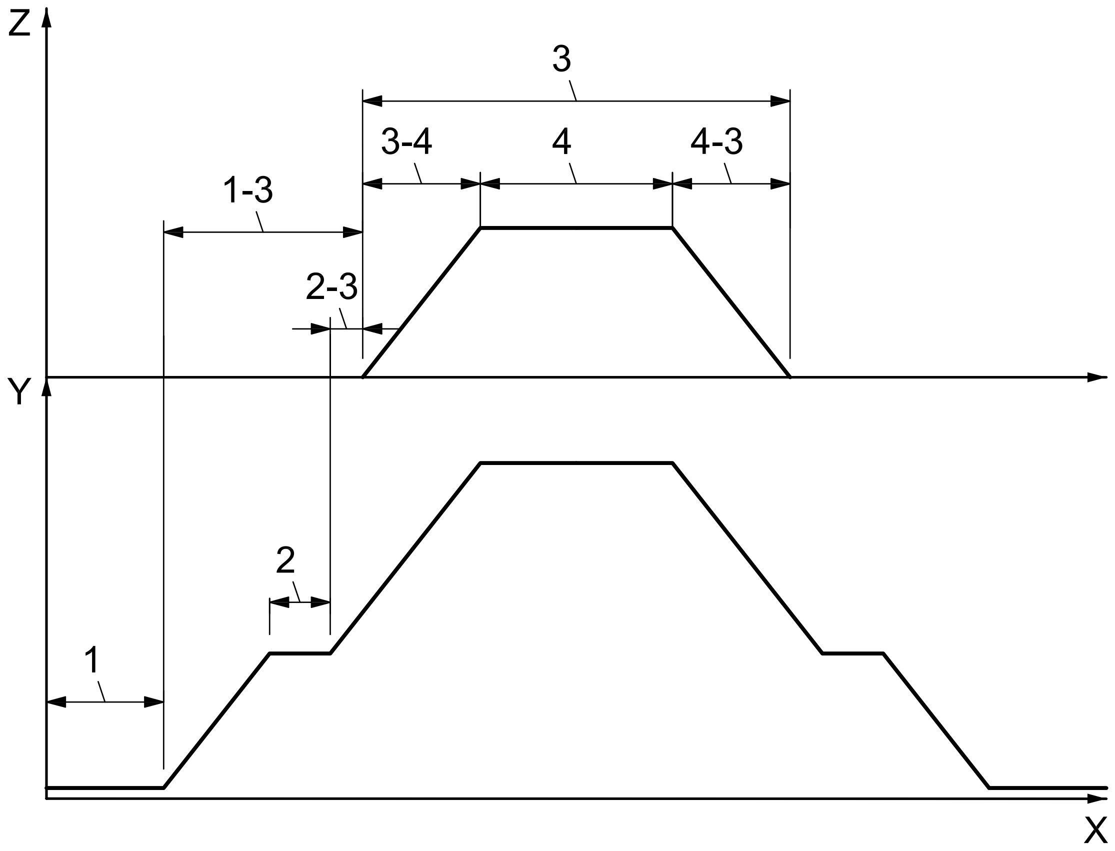
d) steady-state operation at the maximum hydrogen rated output;

e) ramp-down from maximum hydrogen rated output to minimum hydrogen rated output;

f) shutdown to cold state;

g) standby state.

NOTE The hydrogen generator operating modes listed above do not prevent documentation of additional process states in accordance with the methods of this part of ISO 16110, nor do they prevent inclusion of additional test data in the data reports defined in this part of ISO 16110.



Key

X time

Y utility inputs

Z hydrogen product

Operating states

1 cold state

2 standby state (optional)

3 operational state (hydrogen product available)

4 maximum hydrogen rated output

Transitional states

1-3 cold state to operational state

2-3 standby state to operational state

3-4 ramp-up from minimum hydrogen rated output to maximum hydrogen rated output

4-3 ramp-down from maximum hydrogen rated output to minimum hydrogen rated output

Figure 2 — Hydrogen generator operating modes

For steady-state operational testing, the criteria in Table 1 shall be used to define the permissible deviations allowed during testing for each parameter. For all transient testing, the parameters not directly affected by the transient test shall be in accordance with Table 1.

Table 1 — Maximum permissible variations in test operating conditions during a steady-state period

Parameter	Average variation rate per hour
Power input, kW	± 2 %
Barometric pressure at site, kPa	± 0,5 %
Heating value, kJ/mol	± 2 %
Gaseous fuel pressure as delivered to system, kPa	± 1 %
Gaseous output hydrogen pressure, kPa	± 1 %
Fuel input and hydrogen output flow, m^3/s	± 2 %

During transients measured during ramp-up and ramp-down, impurity levels in the hydrogen product shall be within the manufacturer's specifications.

6.3 Measurement, test frequency and duration

Measurements shall be taken during each phase of the test operating sequence as shown in Table 2.

NOTE For hydrogen generators not equipped with one or more of the operating modes, no measurements are required and no results need to be included in the test report. If relevant, other steady-state outputs between minimum and maximum hydrogen rated output may be selected.

Table 2 — Test item and system status

Item	Test	Steady-state conditions		Standby	Start-up and shutdown	Ramp-up and ramp-down
		Maximum hydrogen rated output	Minimum hydrogen rated output			
Operational aspects						
1	Electrical power input as per 5.2.1	×	×	×	×	
2	Input fluid characteristics as per 5.2.2	×	×	×	×	×
3	Output fluid characteristics as per 5.2.2	×	×	×	×	×
4	Solid output characteristics as per 5.2.3	×	×	×	×	
Environmental aspects						
1	Particulate emissions as per 5.3.1	×	×	×		
2	SOx and NOx emissions as per 5.3.2	×	×	×		
3	CO_2 and CO emissions as per 5.3.3	×	×	×		
4	Total hydrocarbon emissions as per 5.3.4	×	×	×		
5	Discharge water quality as per 5.3.5	×	×	×		
6	Audible noise level as per 5.3.6	×	×	×	×	×

The duration and frequency of measurements shall be determined according to the type of hydrogen generator tested. A sufficient number of measurements and number of measurement sets shall be established based on requirements for measured value fluctuations, stability of average values, and the uncertainty analysis of 6.4. The required frequency of measurement shall be chosen based on the expected duration of the transient measurements required under this part of ISO 16110. The test results shall be analysed to determine the absolute and relative uncertainty.

If discrete measurement is used, the interval between measurements shall not be less than 10 minutes. The frequency of discrete measurements, if employed, shall be expressly considered in the uncertainty analysis of 6.4.

For continuous monitoring of the readings, at least one hour of steady-state operation shall be required.

NOTE In computing results of tests, the determination can be made with averaged values of observations made during a single test.

6.4 Uncertainty analysis

6.4.1 General

An uncertainty analysis shall be performed on all tests. The test results shall be analysed to determine the absolute and relative uncertainty.

NOTE Guidance on how to carry out an uncertainty analysis is provided in Annex B.

6.4.2 Uncertainty of test instruments

The uncertainty of the measurements to be taken shall be established based on the instrument calibration documents prior to initiating the testing process. The uncertainty shall be expressed as a +/– value expressed in the units of the variable. For measured values requiring multiple inputs, such as flow rate, care shall be taken to account for the total uncertainty for all instruments.

7 Test procedure

7.1 Safe operation of the hydrogen generator and test equipment

The hydrogen generator shall be operated in accordance with the manufacturer's written operating instructions at all times during the execution of the test plan.

NOTE All hazards associated with each gas and testing equipment need to be taken into consideration. Guidance can be found in the manufacturer-related safety information located in the respective manufacturer instruction manuals and the Material Safety Data Sheets (MSDS) for gases and solids associated with the system.

7.2 Execution of the test plan

7.2.1 Operational data

The test plan specified in Clause 6 shall be executed as planned.

At a minimum, the following operational data shall be included in the overall summary of the testing process:

a) start-up time;

b) minimum operational hydrogen rated output, including the following data:

    1) capacity,

    2) hydrogen pressure and temperature fluctuations and frequency,

    3) hydrogen flow fluctuations and frequency,

    4) hydrogen purity variations and frequency (if above purity specifications);

c) ramp-up rate from minimum to maximum hydrogen rated output, including the following data:

    1) capacity,

    2) hydrogen flow fluctuations and frequency,

    3) hydrogen pressure and temperature fluctuations and frequency,

    4) hydrogen purity variations and frequency (if above purity specifications);

d) maximum hydrogen rated output, including the following data:

    1) capacity,

    2) hydrogen pressure and temperature fluctuations and frequency,

    3) hydrogen flow fluctuations and frequency,

    4) hydrogen purity variations and frequency (if above purity specifications);

e) ramp-down rate from maximum to minimum hydrogen rated output, including the following data:

    1) capacity,

    2) hydrogen flow fluctuations and frequency,

    3) hydrogen pressure and temperature fluctuations and frequency,

    4) hydrogen purity variations and frequency (if above purity specifications);

f) shut-down time.

7.2.2 Data acquisition plan

The data acquisition system (i.e. duration and frequency of readings) shall be taken into account in the uncertainty (see B.2) and the data recording equipment that is suitable for the required frequency of readings and reading speed shall be prepared in advance of the tests.

8 Calculations

8.1 Electrical power input

When the voltage, current, and power factor of electrical power input are measured, electrical power input (P_{in}) shall be calculated as follows:

a) three phase system

$$P_{\text{in}} = \sqrt{3} \times V_{\text{in}} \times I_{\text{in}} \times \lambda_{\text{in}} \quad (1)$$

where

P_{in} is the electrical power input (W);

V_{in} is the voltage of electrical power input (line to line) (V);

I_{in} is the current of electrical power input (A);

λ_{in} is the power factor of electrical power input.

b) single phase system

$$P_{\mathrm{in}} = V_{\mathrm{in}} \times I_{\mathrm{in}} \times \lambda_{\mathrm{in}} \quad (2)$$

where

P_{in} is the electrical power input (W);

V_{in} is the voltage of electrical power input (line to neutral) (V);

I_{in} is the current of electrical power input (A);

λ_{in} is the power factor of electrical power input.

c) direct current

$$P_{\mathrm{in}} = V_{\mathrm{in}} \times I_{\mathrm{in}} \quad (3)$$

where

P_{in} is the electrical power input (W);

V_{in} is the voltage of electrical power input (V);

I_{in} is the current of electrical power input (A).

8.2 Calculation of flow rates

Fuel, return gas, steam input rates and hydrogen output flow rate shall be calculated by means of the following equations.

8.2.1 Gaseous fuel

$$q_{\mathrm{mf}} = q_{\mathrm{vf0}} \times \rho_{\mathrm{f0}} \quad (4)$$

where

q_{mf} is the mass flow rate of gaseous fuel (kg/s);

q_{vf0} is the volumetric flow rate of gaseous fuel at reference conditions calculated as per Equation (5) ($\mathrm{m^3/s}$);

ρ_{f0} is the density of gaseous fuel at reference conditions ($\mathrm{kg/m^3}$);

$$q_{\mathrm{vf0}} = q_{\mathrm{vf}} \times (t_0 / t_{\mathrm{f}}) \times (p_{\mathrm{f}} / p_0) \quad (5)$$

where

q_{vf} is the volumetric flow rate of the fuel at temperature t_{f} and pressure p_{f} ($\mathrm{m^3/s}$);

t_0 is the reference temperature (288,15 K);

t_{f} is the temperature of gaseous fuel at test conditions (K);

p_{f} is the pressure of gaseous fuel at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.2.2 Liquid fuel

$$q_{\mathrm{ml}} = q_{\mathrm{vl0}} \times \rho_{\mathrm{l0}} \tag{6}$$

where

q_{ml} is the mass flow rate of liquid fuel (kg/s);

q_{vl0} is the volumetric flow rate of liquid fuel at reference conditions (m^3/s);

ρ_0 is the density of liquid fuel at reference conditions (kg/m^3).

8.2.3 Return gas

$$q_{\mathrm{mrh}} = q_{\mathrm{vrh0}} \times \rho_{\mathrm{h0}} \tag{7}$$

where

q_{mrh} is the mass flow rate of hydrogen in return gas (kg/s);

q_{vrh0} is the volumetric flow rate of hydrogen in return gas at reference conditions, calculated as per Equation (8) (m^3/s);

ρ_{h0} is the density of hydrogen at reference conditions (kg/m^3).

$$q_{\mathrm{vrh0}} = q_{\mathrm{vr0}} \times x_{\mathrm{rh}} \tag{8}$$

where

q_{vr0} is the volumetric flow rate of return gas at reference conditions (m^3/s) calculated as per Equation (9);

x_{rh} is the molar ratio of hydrogen in return gas.

$$q_{\mathrm{vr0}} = q_{\mathrm{vr}} \times \left(t_0/t_{\mathrm{r}}\right) \times \left(p_{\mathrm{r}}/p_0\right) \tag{9}$$

where

q_{vr} is the volumetric flow rate of return gas at temperature t_{r} and pressure p_{r} (m^3/s);

t_0 is the reference temperature (288,15 K);

t_{r} is the temperature of return gas at test conditions (K);

p_{r} is the pressure of return gas at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.2.4 Steam input

$$q_{\mathrm{ms}} = q_{\mathrm{vs0}} \times \rho_{\mathrm{s0}} \tag{10}$$

where

q_{ms} is the mass flow rate of steam (kg/s);

q_{vs0} is the volumetric flow rate of steam at reference conditions calculated as per Equation (11) (m^3/s);

ρ_{s0} is the density of steam at reference conditions (kg/m^3).

$$q_{\mathrm{vs0}} = q_{\mathrm{vs}} \times (t_0/t_{\mathrm{s}}) \times (p_{\mathrm{s}}/p_0) \tag{11}$$

where

q_{vs} is the volumetric flow rate of steam at temperature t_{s} and pressure p_{s} (m^3/s);

t_0 is the reference temperature (288,15 K);

t_{s} is the temperature of steam at test conditions (K);

p_{s} is the pressure of steam at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.2.5 Gaseous hydrogen output

$$q_{\mathrm{mh}} = q_{\mathrm{vh0}} \times \rho_{\mathrm{h0}} \tag{12}$$

where

q_{mh} is the mass flow rate of the hydrogen in hydrogen-rich gas (kg/s);

q_{vh0} is the volumetric flow rate of hydrogen in hydrogen-rich gas at reference conditions calculated as per Equation (13) (m^3/s);

ρ_{h0} is the density of the hydrogen at reference conditions ($\mathrm{kg/m}^3$).

$$q_{\mathrm{vh0}} = q_{\mathrm{vhr0}} \times x_{\mathrm{h}} \tag{13}$$

where

q_{vhr0} is the volumetric flow rate of hydrogen-rich gas at reference conditions calculated as per Equation (14) (m^3/s);

x_{h} is the molar ratio of hydrogen in hydrogen-rich gas.

$$q_{\mathrm{vhr0}} = q_{\mathrm{vhr}} \times (t_0/t_{\mathrm{h}}) \times (p_h/p_0) \tag{14}$$

where

q_{vhr} is the volumetric flow rate of hydrogen-rich gas at temperature t_{h} and pressure p_{h} (m^3/s);

t_0 is the reference temperature (288,15 K);

t_{h} is the temperature of hydrogen-rich gas at test conditions (K);

p_{h} is the pressure of hydrogen-rich gas at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.3 Calculation of fuel, steam and hydrogen energy

8.3.1 General

Input and output energies shall be calculated by means of the following equations.

In the equations below, the heating value determined through calorimetric methods (see 5.2.2.3) may be used instead of that calculated based on the fluid composition.

8.3.2 Input energy of gaseous fuel

The input energy of gaseous fuel per unit of time (Q_{inf}) shall be calculated from the following equation:

$$Q_{\mathrm{inf}} = \left(E_{\mathrm{fv}} / M_{\mathrm{o}}\right) \times q_{\mathrm{vf0}} \tag{15}$$

where

Q_{inf} is the input energy of gaseous fuel per unit of time (kJ/s);

E_{fv} is the energy of gaseous fuel calculated as per Equation (16) (kJ/mol);

M_{o} is the reference molar volume of ideal gas (2,3645x10^{-2}m^3/mol) at the reference temperature, $t_0 = 288{,}15$ K;

q_{vf0} is the volumetric flow rate of gaseous fuel at reference conditions calculated as per Equation (5) (m^3/s).

The energy of gaseous fuel per unit of volume (E_{fv}) at a temperature t_{f} and a pressure p_{f} of a mixture of known composition shall be calculated from the following equation:

$$E_{\mathrm{fv}} = Q_{\mathrm{f0}} + h_{\mathrm{f}} - h_{\mathrm{f0}} + E_{\mathrm{pf}} \tag{16}$$

where

Q_{f0} is the heating value of gaseous fuel at reference conditions calculated as per Equation (17) (kJ/mol);

h_{f} is the specific enthalpy of gaseous fuel at temperature t_{f} calculated as per Equation (18) (kJ/mol);

h_{f0} is the specific enthalpy of gaseous fuel at the reference temperature t_0 (kJ/mol);

E_{pf} is the pressure energy of gaseous fuel calculated as per Equation (20) (kJ/mol).

The heating value of gaseous fuel (Q_{f0}) at reference conditions shall be calculated from the following equation:

$$Q_{\mathrm{f0}} = \sum_{j=1}^{N} x_j \, Q_{\mathrm{f0}j} \tag{17}$$

where

$Q_{\mathrm{f0}j}$ is the heating value of gaseous fuel component j at reference conditions (kJ/mol);

x_j is the molar ratio of gaseous fuel component j.

NOTE Numerical values of $Q_{\mathrm{f0}j}$ are given in Table C.1.

The specific enthalpy of gaseous fuel at temperature t_{f} (h_{f}) shall be calculated from the following equation:

$$h_{\mathrm{f}} = \sum_{j=1}^{N} x_j \, h_{\mathrm{f}j} \tag{18}$$

where

x_j is the molar ratio of gaseous fuel component j;

$h_{\mathrm{f}j}$ is the specific enthalpy of gaseous fuel component j at temperature t_{f} calculated as per Equation (19) (kJ/mol).

The specific enthalpy of gaseous fuel component j at temperature t_f (h_{fj}) shall be calculated as follows:

$$h_{fj} = \left[\left(A_{fj} \times t_f \right) + \left(\frac{B_{fj} \times t_r^{\,2}}{2\,000} \right) + \left(\frac{C_{fj} \times t_f^{\,3}}{3 \times 10^6} \right) \right] \times 10^{-3} \qquad (19)$$

where

A_{fj}, B_{fj} and C_{fj} are the constants of gaseous fuel component j and given in Worksheet 1 of Annex C;

t_f is the temperature of gaseous fuel at test conditions (K).

The specific enthalpy of gaseous fuel at the reference temperature t_0 (h_{f0}) shall be calculated from Equation (18), except that the temperature shall be changed to the reference temperature t_0.

The pressure energy of gaseous fuel (E_{pf}) shall be calculated from the following equation:

$$E_{pf} = R \times t_0 \times \ln \left(p_f / p_0 \right) \qquad 20$$

where

R is the universal gas constant (8,314 x 10^{-3} kJ/mol K);

t_0 is the reference temperature (288,15 K);

p_f is the pressure of gaseous fuel at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.3.3 Input energy of liquid fuel

The input energy of liquid fuel per unit of time (Q_{inl}) shall be calculated from the following equation:

$$Q_{inl} = E_{lv} \times q_{vl0} \qquad (21)$$

where

Q_{inl} is the input energy of liquid fuel per unit of time (kJ/s);

E_{lv} is the energy of liquid fuel per unit of volume at a temperature t_l calculated as per Equation (22) (kJ/m^3);

q_{vl0} is the volumetric flow rate of liquid fuel at reference conditions (m^3/s).

The energy of liquid fuel per unit of volume at a temperature t_l (E_{lv}) shall be calculated from the following equation:

$$E_{lv} = \rho_l \times Q_{ll} \qquad (22)$$

where

ρ_l is the density of liquid fuel at temperature t_l (kg/m^3);

Q_{ll} is the measured heating value of liquid fuel at temperature t_l (kJ/kg).

8.3.4 Input energy of hydrogen in return gas

The input energy of hydrogen in return gas per unit of time Q_{ret} (kJ/s) shall be calculated from the following equation:

$$Q_{\mathrm{ret}} = \left(E_{\mathrm{rv}}/M_{\mathrm{o}}\right) \times q_{\mathrm{vr0}} \tag{23}$$

where

Q_{ret} is the input energy of hydrogen in return gas per unit of time (kJ/s);

E_{rv} is the energy of hydrogen in return gas calculated as per Equation (24) (kJ/mol);

M_{o} is the reference molar volume of ideal gas (2,3645x10^{-2} m^3/mol) at the reference temperature, $t_0 = 288{,}15$ K;

q_{vr0} is the volumetric flow rate of return gas at reference conditions calculated as per Equation (9) (m^3/s).

The energy of hydrogen in return gas per unit of volume at a temperature t_{r} and a pressure p_{r} (E_{rv}) of a mixture of known composition shall be calculated from the following equation:

$$E_{\mathrm{rv}} = x_{\mathrm{rh}} \left(Q_{\mathrm{h0}} + h_{\mathrm{r}} - h_0 + E_{\mathrm{pr}}\right) \tag{24}$$

where

x_{rh} is the molar ratio of hydrogen in return gas;

Q_{h0} is the heating value of hydrogen at reference conditions (kJ/mol);

h_{r} is the specific enthalpy of hydrogen at temperature t_{r} calculated as per Equation (25) (kJ/mol);

h_0 is the specific enthalpy of hydrogen at the reference temperature t_0 (kJ/mol);

E_{pr} is the pressure energy of hydrogen in return gas calculated as per Equation (26) (kJ/mol).

NOTE Numerical values of Q_{h0} are given in Table C.1.

The specific enthalpy of hydrogen at temperature t_{r} (h_{r}) shall be calculated from the following equation:

$$h_{\mathrm{r}} = \left[\left(A_{\mathrm{h}} \times t_{\mathrm{r}}\right) + \left(\frac{B_{\mathrm{h}} \times {t_{\mathrm{r}}}^2}{2\,000}\right) + \left(\frac{C_{\mathrm{h}} \times {t_{\mathrm{r}}}^3}{3 \times 10^6}\right)\right] \times 10^{-3} \tag{25}$$

where

A_{h}, B_{h} and C_{h} are the constants given in Worksheet 1 of Annex C;

t_{r} is the temperature of return gas at test conditions (K).

The specific enthalpy of hydrogen at reference temperature t_0 (h_0) shall be calculated from Equation (25), except that the temperature shall be changed to the reference temperature $t_{0.}$

The pressure energy of hydrogen in return gas (E_{pr}) shall be calculated from the following equation:

$$E_{\text{pr}} = R \times t_0 \times \ln\left(p_{\text{pr}}/p_0\right) \tag{26}$$

where

R is the universal gas constant ($8{,}314 \times 10^{-3}$ kJ/mol K);

t_0 is the reference temperature (288,15 K);

p_{pr} is the partial pressure of hydrogen in return gas at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.3.5 Input energy of steam

The input energy of steam per unit of time (Q_{st}) shall be calculated from the following equation:

$$Q_{\text{st}} = E_{\text{sv}} \times q_{\text{vs0}} \tag{27}$$

where

Q_{st} is the input energy of steam per unit of time (kJ/s);

E_{sv} is the energy of steam per unit of volume at a temperature t_{s} and a pressure p_{s} calculated based on IAPWS-IF97 (kJ/m^3);

q_{vs0} is the volumetric flow rate of steam at reference conditions calculated as per Equation (11) (m^3/s).

8.3.6 Output energy of hydrogen in hydrogen-rich gas

The output energy of hydrogen in hydrogen-rich gas per unit of time Q_{out} (kJ/s) shall be calculated from the following equation:

$$Q_{\text{out}} = \left(E_{\text{hv}}/M_{\text{o}}\right) \times q_{\text{vhr0}} \tag{28}$$

where

Q_{out} is the output energy of hydrogen in hydrogen-rich gas per unit of time (kJ/s);

E_{hv} is the energy of hydrogen in hydrogen-rich gas calculated as per Equation (29) (kJ/mol);

M_{o} is the reference molar volume of ideal gas ($2{,}3645 \times 10^{-2}\text{m}^3$/mol) at reference temperature, $t_0 = 288{,}15$ K;

q_{vhr0} is the volumetric flow rate of hydrogen-rich gas at reference conditions calculated as per Equation (14) (m^3/s).

The energy of hydrogen in hydrogen-rich gas per unit of volume at a temperature t_h and a pressure ρ_h (E_{hv}) of a mixture of known composition shall be calculated from the following equation:

$$E_{hv} = x_h \left(Q_{h0} + h_h - h_0 + E_{ph} \right) \tag{29}$$

where

x_h is the molar ratio of hydrogen in hydrogen-rich gas;

Q_{h0} is the heating value of the hydrogen at reference conditions (kJ/mol);

h_h is the specific enthalpy of hydrogen at temperature t_h calculated as per Equation (30) (kJ/mol);

h_0 is the specific enthalpy of hydrogen at reference temperature t_0 (kJ/mol);

E_{ph} is the pressure energy of hydrogen in hydrogen-rich gas calculated as per Equation (31) (kJ/mol).

NOTE Numerical values of Q_{h0} are given in Table C.1.

The specific enthalpy of the hydrogen at temperature t_h (h_h) shall be calculated from the following equation:

$$h_h = \left[\left(A_h \times t_h \right) + \left(\frac{B_h \times {t_h}^2}{2\,000} \right) + \left(\frac{C_h \times {t_h}^3}{3 \times 10^6} \right) \right] \times 10^{-3} \tag{30}$$

where

A_h, B_h and C_h are the constants given in Worksheet 1 of Annex C;

t_h is the temperature of hydrogen-rich gas (K).

The specific enthalpy of hydrogen at reference temperature t_0 (h_0) shall be calculated from Equation (30), except that the temperature shall be changed to reference temperature $t_{0.}$

The pressure energy of hydrogen in hydrogen-rich gas (E_{ph}) shall be calculated from the following equation:

$$E_{ph} = R \times t_0 \times \ln \left(p_{ph} / p_0 \right) \tag{31}$$

where

R is the universal gas constant (8,314 x 10^{-3} kJ/mol K);

t_0 is the reference temperature (288,15 K);

p_{ph} is the partial pressure of hydrogen in hydrogen-rich gas at test conditions (kPa);

p_0 is the reference pressure (101,325 kPa).

8.4 Calculation of efficiency

There are several different definitional equations of efficiencies used by different parties from different standpoints. Two representative definitional equations are given in Annex D.

Different definitional equations of efficiency from those listed in Annex D may also be used by the manufacturer, with the agreement of the user.

9 Test reports

9.1 General

Test reports shall accurately, clearly and objectively present sufficient information to demonstrate that all the objectives of the tests have been attained. Three types of reports are defined: summary (see 9.2), detailed (see 9.3) and full (see 9.4). Each type of report shall contain the same title page and a table of contents.

The title page shall present the following information:

a) report identification number (optional);

b) type of reporting (summary, detailed or full);

c) author of report;

d) entity conducting the test;

e) date of report;

f) location of test;

g) title of the test;

h) date of test;

i) hydrogen generator identification and manufacturer's name;

j) type of fuel used for the test with reference to appropriate gas reference table (Annex E), if appropriate;

k) test procedures according to this part of ISO 16110.

9.2 Summary report

The summary report shall contain, at a minimum, the nameplate information for the hydrogen generator tested. Proprietary information should not be included in the summary report. The summary report shall include the following information:

a) objective of the test;

b) description of the test, equipment and instruments;

c) general test data:

  - system inputs at maximum and minimum hydrogen rated output, including the tolerance;
  - system outputs at maximum and minimum hydrogen rated output, including the tolerance;
  - ramp rate of system (specify up and down if different);
  - average pressure at maximum and minimum hydrogen rated output;

d) confidence and uncertainty attached to each test result;

e) conclusions as appropriate.

9.3 Detailed report

The detailed report shall include the following information in addition to the information contained in the summary report:

a) all test results;

b) the type and operating configuration of the hydrogen generator and the process flow diagram showing the test boundary;

c) description of the arrangements, location and operating conditions of the equipment and instruments;

d) reference to the calculation method;

e) tabular and graphical presentation of the results;

f) discussion of the test and its results (i.e. comments and observations);

g) description of test methods other than those described in this part of ISO 16110.

9.4 Full report

The full report shall include copies of original data sheets in addition to the information contained in the detailed report. Original data sheets shall include the following information in addition to measurement data:

a) date and time of the test;

b) model number and measurement accuracy of instruments used for the test;

c) ambient test conditions;

d) name and qualifications of person(s) conducting the test;

e) full and detailed uncertainty analysis as per 6.4;

f) results of fuel analysis.

Annex A
(normative)

Symbols and abbreviated terms

The symbols and their meanings used in this part of ISO 16110 are given in Table A.1. This table also provides the unit used in the equations in this document.

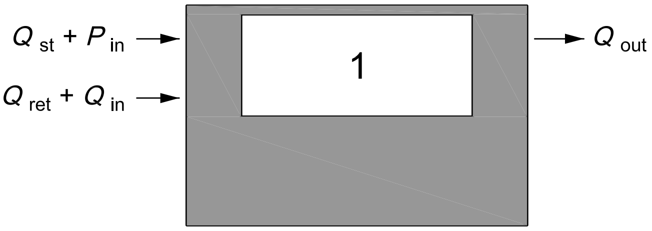
Table A.1 — Symbols

Symbol	Definition	Unit
Current		
I_{in}	Current of electrical power input	A
Density		
ρ_{f0}	Density of gaseous fuel at reference conditions	kg/m^3
ρ_{l0}	Density of liquid fuel at reference conditions	kg/m^3
ρ_{l}	Density of liquid fuel at temperature t_{l}	kg/m^3
ρ_{h0}	Density of hydrogen at reference conditions	kg/m^3
ρ_{s0}	Density of steam at reference conditions	kg/m^3
Electrical power		
P_{in}	Active power of electrical power input for external power source (incl. direct current)	W
Energy		
E_{fv}	Energy of gaseous fuel	kJ/ mol
E_{lv}	Energy of liquid fuel per unit of volume at temperature t_{l}	kJ/m^3
E_{pf}	Pressure energy of gaseous fuel	kJ/mol
E_{rv}	Energy of hydrogen in return gas	kJ/ mol
E_{pr}	Pressure energy of hydrogen in return gas	kJ/mol
E_{sv}	Energy of steam per unit of volume at temperature t_{s} and pressure p_{s}	kJ/m^3
E_{hv}	Energy of hydrogen in hydrogen-rich gas	kJ/ mol
E_{ph}	Pressure energy of hydrogen in hydrogen-rich gas	kJ/mol
Q_{in}	Input energy of fuel per unit of time	kJ/s
Q_{inf}	Input energy of gaseous fuel per unit of time	kJ/s
Q_{inl}	Input energy of liquid fuel per unit of time	kJ/s
Q_{ret}	Input energy of hydrogen in return gas per unit of time	kJ/s
Q_{st}	Input energy of steam per unit of time	kJ/s
Q_{out}	Output energy of hydrogen in hydrogen-rich gas per unit of time	kJ/s
Heating value		
Q_{f0}	Heating value of gaseous fuel at reference conditions	kJ/mol
Q_{h0}	Heating value of hydrogen at reference conditions	kJ/mol
$Q_{\text{f0}j}$	Heating value of gaseous fuel component j at reference conditions	kJ/mol
Mass flow rate		
q_{mf}	Mass flow rate of gaseous fuel	kg/s
q_{ml}	Mass flow rate of liquid fuel	kg/s
q_{ms}	Mass flow rate of steam	kg/s
q_{mh}	Mass flow rate of hydrogen in hydrogen-rich gas	kg/s
q_{mrh}	Mass flow rate of hydrogen in return gas	kg/s

Table A.1 (*continued*)

Symbol	Definition	Unit
Molar ratio		
x_{rh}	Molar ratio of hydrogen in return gas	—
x_{h}	Molar ratio of hydrogen in hydrogen-rich gas	—
x_j	Molar ratio of gaseous fuel component j	—
Power factor		
η	Efficiency	—
η_{h}	Efficiency	—
Pressure		
p_0	Reference pressure	kPa
p_{f}	Pressure of gaseous fuel	kPa
p_{r}	Pressure of return gas at test conditions	kPa
p_{s}	Pressure of steam at test conditions	kPa
p_{h}	Pressure of hydrogen-rich gas at test conditions	kPa
p_{pr}	Partial pressure of hydrogen in return gas at test conditions	kPa
p_{ph}	Partial pressure of hydrogen in hydrogen-rich gas at test conditions	kPa
Specific enthalpy		
h_{r}	Specific enthalpy of hydrogen at temperature t_{r}	kJ/mol
h_{f}	Specific enthalpy of gaseous fuel at temperature t_{f}	kJ/mol
$h_{\mathrm{f}j}$	Specific enthalpy of gaseous fuel component j at temperature t_{f}	kJ/mol
h_{f0}	Specific enthalpy of gaseous fuel at reference temperature t_0	kJ/mol
h_{h}	Specific enthalpy of hydrogen at temperature t_{h}	kJ/mol
h_0	Specific enthalpy of hydrogen at reference temperature t_0	kJ/mol
Temperature		
t_0	Reference temperature	K
t_{r}	Temperature of return gas at test conditions	K
t_{s}	Temperature of steam at test conditions	K
t_{f}	Temperature of gaseous fuel at test conditions	K
t_{l}	Temperature of liquid fuel at test conditions	K
t_{h}	Temperature of hydrogen-rich gas at test conditions	K
Voltage		
V_{in}	Voltage of electrical power input	V, kV
Volumetric flow rate		
q_{vf}	Volumetric flow rate of gaseous fuel at temperature t_{f} and pressure p_{f}	m^3/s
q_{vf0}	Volumetric flow rate of gaseous fuel at reference conditions	m^3/s
q_{vl0}	Volumetric flow rate of liquid fuel at reference conditions	m^3/s
q_{vr}	Volumetric flow rate of return gas at temperature t_{f} and pressure p_{f}	m^3/s
q_{vr0}	Volumetric flow rate of return gas at reference conditions	m^3/s
q_{vrh0}	Volumetric flow rate of hydrogen in return gas at reference conditions	m^3/s
q_{vs}	Volumetric flow rate of steam at temperature t_{s} and pressure p_{s}	m^3/s
q_{vs0}	Volumetric flow rate of steam at reference conditions	m^3/s
q_{vh0}	Volumetric flow rate of hydrogen in hydrogen-rich gas at reference conditions	m^3/s
q_{vhr}	Volumetric flow rate of hydrogen-rich gas at temperature t_{h} and pressure p_{h}	m^3/s
q_{vhr0}	Volumetric flow rate of hydrogen-rich gas at reference conditions	m^3/s

The energy input/output in the hydrogen generator corresponds to Figure A.1.



Key

1 hydrogen generator system

Figure A.1 — Energy input/output

Annex B
(informative)

Guidance for uncertainty analysis

B.1 General

When reporting the result of a measurement of a physical quantity, some quantitative indication of the quality of the result should be given so that those who use it can assess its reliability. Therefore, uncertainty analysis is indispensable for a hydrogen generator performance test. The uncertainty can be analysed at pre-test and/or post-test.

A pre-test uncertainty analysis is recommended. The pre-test uncertainty analysis allows corrective action to be taken prior to the test, which will either decrease the uncertainty to an appropriate level consistent with the overall objective of the test or will reduce the cost of the test while still attaining the test uncertainty.

A post-test uncertainty analysis is mandatory. The uncertainty analysis will make use of empirical data to determine uncertainty of hydrogen generator performance. Uncertainty should be indicated with a performance value.

This annex serves as a guide for pre-test and post-test uncertainty calculations and shows an example of uncertainty analysis for hydrogen production parameters. It is only provided for informative purposes, not as an explicit test result. The user of this part of ISO 16110 should read, understand, and follow the ISO/IEC Guide 98-3 in order to accomplish a proper uncertainty analysis.

B.2 Preparations

Uncertainty analysis of hydrogen generator performance measurements (i.e. hydrogen production efficiency) can be computed by the uncertainties of the various parameters, as well as hydrogen generator performance.

Every measurement of the parameters is the combination of a true value plus a total measurement error. The total measurement error consists of systematic error and random error.

The total uncertainty of a parameter is the combination of uncertainty due to systematic error and random error.

In order to minimize the uncertainty of the hydrogen generator performance measurement, systematic uncertainties and random uncertainties of the parameters should be minimized.

In order to minimize systematic uncertainty, higher accuracy instrumentation is recommended, because the accuracy of the instrument (calibration uncertainty) is treated as systematic uncertainty. Careful selection of instrumentation is necessary.

In order to minimize random uncertainty, test procedures, test conditions and data collection methods should be investigated. Random uncertainty is estimated as two times as much as standard deviation (2σ for 95 % coverage). Careful test planning is necessary before conducting the performance test.

Parameter measurements should be as simultaneous as possible. Data recording using automated equipment will help to ensure simultaneous data sets. Test conditions should be steady-state for the performance tests.

Fluctuations of measurements (both short-term and long-term variations) and steady-state test conditions should be confirmed by preliminary test, before conducting the performance test. Steady-state is defined in 6.2. Test duration should be decided according to the fluctuations of long-term parameter measurements. Test duration should include at least one cycle of long-term fluctuations.

During test duration, at least 30 independent data points of every parameter should be measured to obtain a standard deviation of the data. Each data set should be an average of measurements taken (i.e. for measurement of voltage) or an accumulation divided by measurement time (i.e. for flow rate of fuel).

In order to maintain independence of the data points, a minimum of one minute between data sets is also required.

B.3 Basic assumptions

The guidance in this annex is based on ISO/IEC Guide 98-3. The guidance herein is simplified for use with hydrogen generators, using assumptions consistent with their design as well as good testing practice dictated by this part of ISO 16110.

Basic assumptions include the following.

- All systematic uncertainty sources are assumed to be normally distributed and estimated as 2σ for 95 % coverage. Systematic uncertainty is defined as the estimate of errors that remain constant during the test process. The systematic uncertainty estimate (B) should consider calibration error, instrument installation effects (e.g. temperature probe radiation), and input data (e.g. gas properties measured as part of test protocol but not measured continuously during entire test process).
- At least 30 independent data points are taken for all parameters. If fewer than 30 independent data points are taken for one or more parameters, additional calculations are required. Please consult ISO/IEC Guide 98-3.
- All random uncertainty sources are assumed to be normally distributed and estimated as $2S_{\bar{x}}$ of measurements, which is 95 % confidence coverage.

Total uncertainty (U_{95}) should be obtained by combining systematic uncertainty (B) and random uncertainties $(S_{\bar{x}})$ of a measurement using the following equation:

$$U_{95} = \left[B^2 + \left(2S_{\bar{x}} \right)^2 \right]^{1/2}$$

which is equivalent to

$$U_{95} = 2\left[\left(B/2 \right)^2 + \left(S_{\bar{x}} \right)^2 \right]^{1/2}$$

B.4 General approach

The following gives a step-by-step calculation procedure.

a) Define the measurement process:

   1) Review test objectives and test duration.

      A preliminary test should be carried out to decide test duration, if necessary.

   2) List all independent measurement parameters and their nominal levels.

   3) List all calibrations and instrument settings that will affect each parameter.

      The uncertainties in measurement system components that affect two or more measurements simultaneously should be checked (correlated uncertainties).

4) Define the functional relationship between the independent measurement parameters and the test result using the equations for calculating hydrogen generator performance as given in this part of ISO 16110.

b) List elemental error sources by making a complete and exhaustive list of all possible test uncertainty sources for all parameters.

c) Calculate or assign the absolute systematic and random uncertainty for each parameter.

1) The absolute systematic uncertainty (B_i) is to be calculated by multiplying calibration accuracy by the nominal value of every parameter.

2) The absolute random uncertainty ($2S_{x\mathrm{i}}$) is two times as much as the standard deviation of parameter.

d) Propagate the systematic and random uncertainty for each parameter.

1) The systematic and random uncertainty of the independent parameters should be propagated separately all the way to the final result using the following equation:

$$B_\mathrm{R} = \left[\Sigma \left(\theta_\mathrm{i} \, B_{\overline{\mathrm{R}}\mathrm{i}} \right)^2 \right]^{1/2}$$

$$2S_\mathrm{R} = \left[\Sigma \left(\theta_\mathrm{i} \, 2S_{\overline{\mathrm{R}}\mathrm{i}} \right)^2 \right]^{1/2}$$

where

B_R is the systematic uncertainty of a result;

$2S_\mathrm{R}$ is the random uncertainty of a result.

2) This requires a calculation of the sensitivity factors, θ_i, either by differentiation or by computer perturbation with the functional relationship defined in d) 1) above.

e) Calculate the total uncertainty using the following equation, combining the systematic and random uncertainties to get the total uncertainty.

$$U_\mathrm{R95} = \left[\left(B_\mathrm{R} \right)^2 + \left(2S_\mathrm{R} \right)^2 \right]^{1/2}$$

f) Prepare the report in accordance with Clause 9 of this part of ISO 16110.

Annex C
(normative)

Calculation of fuel heating value

Table C.1 — Heating values for components of natural gases at various combustion reference conditions for ideal gas

	Component	Lower heating value on a molar basis (kJ/mol)	Higher heating value on a molar basis (kJ/mol)	Lower heating value on a mass basis (MJ/kg)	Higher heating value on a mass basis (MJ/kg)
1	Methane	802,69	891,56	50,035	55,574
2	Ethane	1 428,84	1 562,14	47,52	51,95
3	Propane	2 043,37	2 221,1	46,34	50,37
4	*n*-Butane	2 657,6	2 879,76	45,72	49,55
5	2-Methylpropane	2 648,42	2 870,58	45,57	49,39
6	*n*-Pentane	3 272.00	3 538,6	45,35	49,04
7	2-Methylbutane	3 265,08	3 531,68	45,25	48,95
8	2,2-Dimethylpropane	3 250,83	3 517,43	45,06	48,75
9	*n*-Hexane	3 887,21	4 198,24	45,11	48,72
10	2-Methylpetane	3 879,59	4 190,62	45,02	48,43
11	3-Methylpetane	3 882,19	4 193,22	45,05	48,66
12	2,2-Dimethylbutane	3 869,8	4 180,83	44,91	48,51
13	2,3-Dimethylbutane	3 877,57	4 188,6	45.00	48,6
14	*n*-Heptane	4 501,72	4 857,18	44,93	48,47
15	*n*-Octane	5 116,11	5 516,01	44,79	48,29
16	*n*-Nonane	5 731,49	6 175,82	44,69	48,15
17	*n*-Decane	6 346,14	6 834,9	44,6	48,04
18	Ethylene	1 323,24	1 412,11	47,17	50,34
19	Propylene	1 926,13	2 059,43	45,77	48,94
20	1-Butene	2 540,97	2 718,7	45,29	48,46
21	*cis*-2-Butene	2 534,2	2 711,9	45,17	48,33
22	*trans*-2-Butane	2 530,5	2 708,3	45,1	48,27
23	2-Methylpropene	2 524,3	2 702.00	44,99	48,16
24	1-Pentene	3 155,59	3 377,75	44,99	48,16
25	Propadiene	1 855,09	1 943,96	46,3	48,52
26	1,2-Butadiene	2 461,82	2 595,12	45,51	47,98
27	1,3-Butadiene	2 408,8	2 542,1	44,53	47,00
28	Acetylene	1 256,94	1 301,37	48,27	49,98
29	Cyclopentane	3 100,03	3 322,19	44,2	47,37

Table C.1 (*continued*)

	Component	Lower heating value on a molar basis (kJ/mol)	Higher heating value on a molar basis (kJ/mol)	Lower heating value on a mass basis (MJ/kg)	Higher heating value on a mass basis (MJ/kg)
30	Methylcyclopentane	3 705,86	3 912,46	44,03	47,2
31	Ethylcyclopentane	4 320,92	4 631,95	44,01	47,17
32	Cyclohexane	3 689,42	3 956,02	43,84	47,01
33	Methylcyclohexane	4 293,06	4 604,09	43,72	46,89
34	Ethylcyclohexane	4 911,49	5 266,95	43,77	46,94
35	Benzene	3 169,56	3 302,86	40,58	42,28
36	Toluene	3 772,08	3 949,81	40,94	42,87
37	Ethylbenzene	4 387,37	4 609,53	41,33	43,42
38	*o*-Xylene	4 376,48	4 598,64	41,22	43,31
39	Methanol	676,22	765,09	21,1	23,88
40	Methanethiol	1 151,41	1240,28	23,93	25,78
41	Hydrogen	241,72	286,15	119,91	141,95
42	Water	0	44,433	0	2,47
43	Hydrogen sulfide	517,95	562,38	15,2	16,5
44	Ammonia	316,86	383,51	18,61	22,52
45	Hydrogen cyanide	649,5	671,7	24,03	24,85
46	Carbon monoxide	282,91	282,91	10,1	10,1
47	Carbonyl sulfide	548,15	548,15	9,12	9,12
48	Carbon disulfide	1 104,32	1 104,32	14,5	14,5

NOTE These values were extracted from Table 3 and Table 4 of ISO 6976:1995.

Worksheet 1 — Calculation worksheet for energy of gaseous fuel

Temperature of gaseous fuel (t_f) 293 K

Pressure of gaseous fuel (p_f) 103,325 kPa

Component	Molar ratio of components j	Heating value of gaseous fuel components [a]	Heating value of fuel	Constant A of gas component [b]	Constant B of gas component	Constant C of gas component	Specific enthalpy of component at reference temperature	Specific enthalpy of gaseous fuel component at the reference temperature	Specific enthalpy of fuel component at temperature t_f
	(x_j)	(Q_{f0j}) (kJ/mol)	(Q_{f0}) (kJ/mol)				(h_{fj}) (kJ/mol)	(h_{f0}) (kJ/mol)	(h_f) (kJ/mol)
			Equation (17)				Equation (19)	Equation (18)	Equation (19)
Nitrogen	0,00	0,00	0,00	27,016	5,812	−0,289	8,023 6	0,00	8,16
Oxygen	0,00	0,00	0,00	25,594	13,251	−4,205	7,891 5	0,00	8,03
Carbon monoxide	0,00	282,91	0,00	26,537	7,683 1	−1,171 9	7,956 1	0,00	8,10
Methane	0,88	802,69	706,37	14,146	75,496	−17,991	7,066 9	6,22	7,23
Ethane	0,058	1 428,84	82,87	9,401	159,833	−46,229	8,975 7	0,52	9,23
Propane	0,045	2 043,37	91,95	10,083	239,304	−73,358	12,255 1	0,55	12,61
Butane	0,017	2 657,60	45,18	18,631	302,378	−92,943	17,180 6	0,29	17,66
Hydrogen	0,00	241,72	0,00	29,062	−0,820	1,990 3	8,356 0	0,00	8,50
Water	0,00	0,00	0,00	30,204	9,933	1,117	9,124 6	0,00	9,29
Total			926,37					7,58	7,77

[a] Reference ISO 6976:1995, Table 3.

[b] Reference *JANAF Thermochemical Tables*, ed. D.R. Stull and H. Prophet, published by NSRDS-NBS 37 (1965, 1971).

Heating value (Q_{f0}) calculated as per Equation (17).	926,37	kJ/mol
Specific enthalpy of gaseous fuel at temperature (h_f) calculated as per Equation (19).	7,77	kJ/mol
Specific enthalpy of gaseous fuel component at the reference temperature (h_{f0}) calculated as per Equation (19).	7,58	kJ/mol
Pressure energy of gaseous fuel (E_{pf}) calculated as per Equation (20).	0,05	kJ/mol
Energy of gaseous fuel (E_{fv}) calculated as per Equation (16).	926,61	kJ/mol

Worksheet 2 — Calculation worksheet for energy of air

Temperature of air (t_a) 300 K

Pressure of air (p_a) 103,325 kPa

Component	Constant A of air [a]	Constant B of air	Constant C of air	Specific enthalpy of fuel component at the reference temperature (h_{a0}) (kJ/mol)	Specific enthalpy of fuel component at temperature t_a (h_a) (kJ/mol)
				Equation (19)	Equation (19)
Air	27,434	6,180	–0,898 7	8,154 5	8,500 2

[a] Reference *JANAF Thermochemical Tables*, ed. D.R. Stull and H. Prophet, published by NSRDS-NBS 37 (1965, 1971).

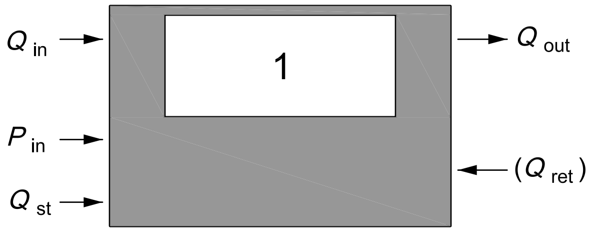
Specific enthalpy of air at temperature t_a (h_a) calculated as per Equation (19).	8,50	kJ/mol
Specific enthalpy of air at the reference temperature (h_{a0}) calculated as per Equation (19).	8,15	kJ/mol
Pressure energy of the fuel (E_{pa}) calculated as per Equation (20).	0,05	kJ/mol
Energy of the air (E_{av}) calculated as per Equation (16).	0,40	kJ/mol

Annex D
(informative)

Definition of hydrogen generator efficiency

D.1 General

Figure D.1 shows energies in and out of hydrogen generator systems. The definitions of the symbols are given in Table A.1, and the calculations of the numerical value of the symbols are given in Clause 8.



Key

1 hydrogen generator system

Figure D.1 — Influx and efflux of energy

The efficiency of the hydrogen generator systems is calculated from the energy in and out of the hydrogen generator systems.

There are several different equations of efficiencies from different standpoints. Two representative definitional equations are shown in D.2 and D.3.

D.2 Energy efficiency

Energy efficiency of hydrogen generator system η_{he} is defined by the following equation:

$$\eta_{\mathrm{he}} = \frac{Q_{\mathrm{out}}}{Q_{\mathrm{in}} + Q_{\mathrm{st}} + P_{\mathrm{in}}}$$

The denominator is the total input energy fed to the hydrogen generator system, and the numerator is the output energy of hydrogen produced from the hydrogen generator system.

D.3 Fuel efficiency

Fuel efficiency of hydrogen generator system η_{hf} is defined by the following equation:

$$\eta_{\mathrm{hf}} = \frac{Q_{\mathrm{out}}}{Q_{\mathrm{in}}}$$

The denominator is the input fuel energy fed to the hydrogen generator system, and the numerator is the output energy of hydrogen produced from the hydrogen generator system.

In case the hydrogen generator system utilizes some of the hydrogen it produces, its hydrogen energy Q_{ret} is not added to the denominator but deducted from the numerator. The representative case is the hydrogen generator system combined with the fuel cell, which utilizes unreacted hydrogen exhausted from the fuel cell as a fuel for the burner of a fuel processing system.

NOTE Other equations of efficiency different from those described above, which may be defined by the manufacturer, can be also used, with the agreement of the user.

Annex E
(informative)

Reference gas

E.1 General

Tables E.1 and E.2 are provided to allow customers to compare their measured performances, obtained with their own natural gas, with the performances advertised by the manufacturer, obtained with the manufacturer's natural gas. When a manufacturer and more and more customers test the same equipment with different natural gases (and publish their test results), a database of adjustment factors can be progressively established to distinguish between natural gases. Eventually, a new customer should be able to find the adjustment factor in order to correct the advertised performances to its particular gas composition by referring to the closest reference gas.

E.2 Reference gases for natural gas and propane gas

A set of 14 reference gases for natural gas is provided in Table E.1 and a set of 17 reference gases for propane is provided in Table E.2.

When a test gas is used, the reference gas, which is closest to the test gas, should be mentioned in the report.

Natural gas distribution systems generally include various sulfur compounds as odorants such as major sulfur compounds: tetrahydrothiophene, hydrogen sulfide (H_2S), diethylsulfide (DES), methylethylsulfide (MES), dimethylsulfide (DMS), methylmercaptan (MM), iso-propylmercaptan (IPM), tertio-butylmercaptan (TBM), iso-butylmercaptan (IBM), 2-butylmercaptan (SBM), etc.

Table E.1 — Reference gas for natural gas

	A1	A2	G25	B1	B2	G20	C1	C2	D1	D2	E1	E2	F1	F2	N1	N2	N4	N5	K4	J1	J2	J3	J4	G1	G2
CH_4	66,2	67,2	86,0	63,0	82,4	100,0	65,1	74,9	75,6	97,2	88,9	71,7	92,0	85,70	90,65	90,50	90,35	89,57	90,00	89,6	88,9	87,50	89,2	83,4	72,0
C_2H_6	5,0	1,7	0,0	11,7	0,0	0,0	8,3	3,3	11,7	0,0	10,0	15,0	1,7	13,30	4,0	4,0	4,0	5,0	6,0	5,6	6,8	5,9	4,6	6,7	13,3
C_3H_8	0,7	3,3	0,0	2,0	0,0	0,0	4,0	3,3	0,7	1,3	0,0	2,7	6,0	0,7	1,0	1,0	1,0	1,0	1,0	3,4	3,1	5,3	2,7	4,7	5,3
C_4H_{10}	0,2	0,0	0,0	0,0	1,0	0,0	0,7	1,0	0,5	0,2	0,0	0.3	0,2	0,2	n-0,3	n-0,3	n-0,15	n-0,3	n-0,2	1,4	1,2	1,2	3,4	1,5	1,3
															i-0,3	i-0,3	i-0,3	i-0,3	i-0,2						
C_5H_{12}	0,1	0,0	0,0	0,0	0,7	0,0	0,6	0,4	0,3	0,1	0,0	0.2	0,1	0,1	neo-0,0	neo-0,0	neo-0,15	neo-0,1	neo-0,0	0,0	0,0	0,0	0,0	1,0	0,9
															n-0,1 i-0,1	n-0,15 i-0,15	n-0,15 i-0,15	n-0,1 i-0,1	n-0,2 i-0,2						
C_{6+}	0,1	0,0	0,0	0,0	0,3	0,0	0,3	0,3	0,2	0,1	0,0	0,1	0,1	0,1	0,05	0,1	0,1	0,03	0,2	0,0	0,0	0,0	0,0	0,5	0,4
CO_2	7,8	10,0	0,0	5,6	2,2	0,0	5,6	1,1	8,9	1,1	1,1	3,3	0,0	0,0	1,0	1,0	1,0	1,0	0,8	0,0	0,0	0,0	0,0	0,0	2,2
N_2	20,0	17,8	14,0	17,8	13,3	0,0	15,6	15,6	2,2	0,0	0,0	6,7	0,0	0,0	2,5	2,5	2,5	2,5	1,2	0,0	0,0	0,1	0,1	2,2	4,4
LHV (kWh^3)	7,84	7,86	8,13	8,89	9,01	9,45	9,66	9,58	10,19	10,21	10,65	10,77	11,19	11,26	—	—	—	—	—	11,29	11,29	11,56	11,58	11,92	11,96
LHV (MJ/m^3)	28,21	28,30	29,25	32,01	32,43	34,02	34,77	34,48	36,76	36,68	38,34	38,77	40,30	40,55	—	—	—	—	—	40,64	40,66	41,63	41,69	42,93	43,07
LHV (kWh^3)	8,69	8,71	9,03	9,84	9,99	10,49	10,67	10,59	11,30	11,31	11,81	11,90	12,39	12,47	—	—	—	—	—	12,51	12,51	12,80	12,82	13,17	13,20
LHV (MJ/m^3)	31,27	31,36	32,49	35,41	35,96	37,78	38,40	38,14	40,67	40,72	42,51	42,85	44,90	44,90	—	—	—	—	—	45,02	45,03	46,07	46,15	47,42	47,50

Table E.2 — Reference gas for propane gas

	JP1	1A	1B	1C	1D	1E	2A	2B	2C	2D	3A	3B	3C	3D	3E	3F	3G	3H	G30
C_2H_6	0,8	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	0,0
C_3H_8	98,0	100,0	90,0	90,0	80,0	80,0	70,0	70,0	60,0	60,0	50,0	50,0	40,0	40,0	20,0	20,0	0,0	0,0	0,0
C_4H_{10}	1,2	0,0	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0	45,0	50,0	55,0	60,0	75,0	80,0	95,0	100,0	n-50 i-50
LHV (kWh/m^3)	25,37	25,94	25,96	26,80	26,82	27,65	27,68	28,51	28,53	29,36	29,38	30,22	30,24	31,07	31,95	32,78	33,66	34,49	32,25
LHV (MJ/m^3)	91,35	93,38	93,47	96,46	96,55	99,54	99,63	102,62	102,71	105,70	105,78	108,77	108,86	111,85	115,02	118,01	121,17	124,16	116,09
HHV (kWh/m^3)	27,56	28,22	28,25	29,14	29,14	30,06	30,09	30,98	31,00	31,90	31,92	32,82	32,84	33,73	34,68	35,57	36,52	37,41	34,94
HHV (MJ/m^3)	99,22	101,58	101,69	104,90	105,00	108,21	108,31	111,52	111,62	114,83	114,92	118,13	118,23	121,44	124,85	127,06	131,47	134,68	125,81

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