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Introductory note

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IEC TC 105 Fuel Cell Technologies

Test Methods
for
Performance of Fuel Cell Power Systems

Project Number IEC 62282-3-2

Part 3: Stationary Fuel Cell System / Part 3.2 Performance Tests

WG No. 4

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Contents

Introduction

This standard describes how to measure the performance of stationary fuel cell power systems for residential, commercial and industrial applications. The following fuel cell types have been considered: Alkaline fuel cells (AFC), Phosphoric acid fuel cells (PAFC), Polymer electrolyte fuel cells (PEFC), Molten carbonate fuel cells (MCFC) and Solid oxide fuel cells (SOFC).

1. Scope

1.1 This standard covers operational and environmental aspects of the fuel cell power systems performance. Safety related tests are covered by IEC 62282-3 (IEC TC105 Working Group 3).

1.2 Scope of tests

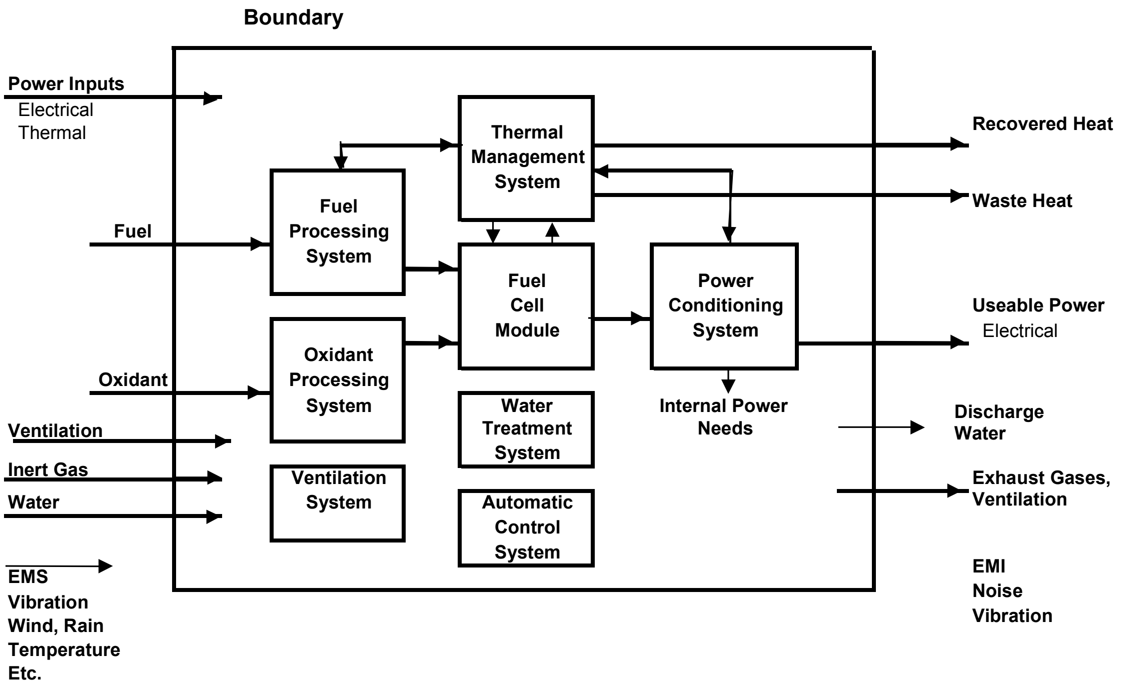
- power output under specified operating conditions
- electrical and thermal efficiency under specified operating conditions
- environmental characteristic; e.g., gas emissions, noise, etc. under specified operating conditions
- EMC is not being provided in this International standard and is being referred to TC 105 for further direction.

1.3 Fuel cell power systems may have different sub-systems depending upon types of fuel cell and applications, and they have different streams of material and energy into and out of them. However, a common system diagram and boundary has been defined for evaluation of the fuel cell power system (see Figure 1).

1.4 The following conditions are considered in order to determine the test boundary of the fuel cell power system:

- All energy recovery systems are included within the system boundary.
- Calculation of the heating value of the input fuel (such as natural gas, propane gas, and pure hydrogen gas, etc.) is based on the conditions of the fuel at the boundary of the fuel cell power system.

1.5 This standard does not take into account mechanical (shaft) power or mechanical energy inputs or outputs. Mechanical systems required for fuel cell operation (i.e. ventilation or micro-turbines 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 fuel cell power system operation. If mechanical (shaft) power and energy cross the test boundary, additional measurements and calculations are necessary.



Notes

: **Fuel Cell Power System** including subsystems, and the interface is defined as a conceptual or functional one instead of hardware such as a power package

: **Subsystems**; Fuel Cell Module, Fuel Processor etc. These subsystem configuration depend on a kind of fuel, type of fuel cell or system.

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

Figure 1 Fuel Cell Power System Diagram

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard.

IEC 60050-2 *International Electrotechnical Vocabulary (IEV)*

IEC 62282-1 *Terminology & Definitions for Fuel Cell Technologies*

IEC 60050-300 2001-07 *International Electrotechnical Vocabulary: Electrical and electronic measurements and measuring instruments*
Part 311: General terms relating to measurements
Part 312: General terms relating to electrical measurements
Part 313: Types of electrical measuring instruments
Part 314: Specific terms according to the type of instrument

IEC 60051:1984 *Direct acting indicating analogue electrical measuring instruments and their accessories*

IEC 60359:1987 *Expression of the performance of electrical and electronic equipment*

IEC 60687:1992 *Alternating current static watt-hour meters for active energy (classes 0,2S and 0,5S)*

IEC 60688:1992 *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*

IEC 61000-4-7 *Testing and measurement techniques –General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-4-13 *Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity test.*

IEC 61028:1991 *Electrical measuring instruments X-Y recorders*

IEC 61036:1990 *Alternating current static watt-hour meters for active energy (classes 1 and 2)*

IEC 61143:1992 *Electrical measuring instruments X-t recorders*

IEC 60651 *Sound level meters*

ISO 6568 *Natural gas − Simple analysis by gas chromatography*

ISO 6974 *Natural gas−Determination of composition with define*

ISO 6975 *Natural gas−Extended –Gas-Chromatographic method*

ISO 6326 *Natural gas−Determination of sulfur compounds*

ISO 10101	*Natural gas−Determination of water by Karl Fisher Method*
ISO 11541	*Natural gas -- Determination of water content at high pressure*
ISO 7934	*Stationary source emissions—Methods for determination of sulfur oxides in flue gas*
ISO 11564	*Stationary source emissions—Methods for determination of mass concentration nitrogen oxides in flue gases*
ISO 14687	*Hydrogen fuel –product specification*
ISO 5167	*Measurement of fluid flow by means of pressure differential devices*
ISO 3648	*Estimation of net specific energy*
ISO 8217	*Petroleum products -Fuel (class F)-Specifications of marine fuels*
ISO 10780	*Stationary source emissions -- Measurement of velocity and volume flow rate of gas streams in ducts*
ISO 9096	*Stationary source emissions -- Determination of concentration and mass flow rate of particulate material in gas-carrying ducts -- Manual gravimetric method*
ISO 11042-1,-2	*Gas turbines—Exhaust gas emission—Part1:, Part2:*
ISO 7935	*Stationary source emissions -- Determination of the mass concentration of sulfur dioxide -- Performance characteristics of automated measuring methods*
ISO 10396	*Stationary source emissions -- Sampling for the automated determination of gas concentrations*
ISO 11564	*Stationary source emissions – Method for determination of mass concentration nitrogen oxides in flue gases*
ISO 10523	*Water quality – Determination of Ph*
ISO 10849	*Stationary source emissions – Determination of the mass concentration of nitrogen oxides – Performance characteristics of automated measuring methods*
ISO 10707	*Water quality -- Evaluation in an aqueous medium of the "ultimate" aerobicbiodegradability of organic compounds –*
ISO 6060	*Water quality -- Determination of the chemical oxygen demand Method by analysis of biochemical oxygen demand (closed bottle test)*
ISO 3744	*Acoustic – Determination of sound power levels of noise source using sound pressure – Engineering method in an essentially free field over a reflecting place*

ISO 5348	*Mechanical vibration and shock – Mechanical mounting of accelerometers*
ISO 4677-1	*Atmospheres for Conditioning and Testing – Determination of Relative Humidity – Part 1 Aspirated Psychrometer Method*
ISO 4677-2	*Atmospheres for Conditioning and Testing – Determination of Relative Humidity – Part 2 Whirling Psychrometer Method*
ISO 16622	*Meteorology – Sonic Anemometer / Thermometers – Acceptance Test Methods for Mean Wind Measurements*
ISO/TAG 1995	*Guide to the Expression of Uncertainty in Measurement*
ASTM D4809-00	*Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method).*
ASME PTC50	*Performance Test Code 50 on Fuel Cell Power Systems Performance*

3 Definitions, Reference conditions, and Symbols

3.1 Definitions

The following definitions are applied for this International Standard.

3.1.1 fuel cell power system : system which electrochemically converts chemical energy to electric energy (direct current or alternating current electricity) and thermal energy

Note: The system is composed of all or some of the following subsystems: one or more fuel cell modules, a fuel processing system, a power conditioning system, a thermal management system, other subsystems needed and a balance of plant (BOP). A generic fuel cell power system is shown in Figure 1.

3.1.2 interface point : measurement point at the boundary of a fuel cell power system at which material and/or energy either enters or leaves.

Note: This boundary is intentionally selected to accurately measure the performance of the system. If necessary, the boundary or the interface points of the fuel cell power system (Figure-1) to be assessed shall be determined by agreement of the parties.

3.1.3 parasitic load : power required for auxiliary machines and equipment necessary to operate a fuel cell power system

Note: Auxiliary machines include balance of plant (BOP) equipment such as blowers, pumps, heaters, sensors, etc.

3.1.4 electrical efficiency : ratio of the electrical energy output to the energy input of the fuel cell power system

Note: Where electric power is supplied from an external source for a parasitic load, this energy is deducted from the electrical energy output of the generator.

3.1.5 recovered heat : recuperated thermal energy from the fuel cell power system

Note: Measured by determining the temperatures and flow rates of fluid media (water, steam, air or oil etc.), entering and leaving the thermal energy recovery subsystem at the boundary of the fuel cell power system

3.1.6 heat recovery efficiency : ratio of the recuperated thermal energy to the energy input of the fuel cell power system.

3.1.7 overall energy efficiency : sum of the electrical efficiency η_e and heat recovery efficiency η_{th}.

Note: Refer to Definition 3.1.4 and 3.1.6.

3.1.8 transient response time of power output : time period between initiating a power output change and attaining the specified power

Note: Time is expressed in seconds.

3.1.9 Cold state : fuel cell power system at ambient temperature with no power input or output

3.1.10 storage state : non-operating condition where fuel cell power system may require some thermal or electrical energy input in order to prevent deterioration of the components

Note: The manufacturer shall specify the conditions for this state so that the system is stable for long periods.

3.1.11 standby state : fuel cell power system maintained at elevated temperature ready to output power

Note: The manufacturer shall specify the conditions for this state so that the system is stable for long periods.

3.1.12 start-up time: period required for transitioning from Storage State to net electrical output

3.1.13 start-up energy : amount of electrical or thermal input required to reach the net power from the Storage State.

3.1.14 response time : period required for transitioning from the Standby State to net power output.

3.1.15 time to rated power : period required for transitioning from Standby State to 100% of rated power specified by the manufacturer.

3.1.16 shut-down time : period for transitioning from generating electric power at 100% of nominal rated load to completion of inert gas purge (if necessary) or when the power consumption of auxiliaries goes down the minimum value

Note: The shutdown operation is classified into types: Normal shutdown and Emergency Shutdown.

3.1.17 emission characteristics : concentrations of total sulfur oxides (SO_x), total nitrogen oxides (NO_x), carbon dioxide (CO2), carbon monoxide (CO), total hydrocarbon compounds and particulates in the exhaust gas

Note: Measured at the point of discharge to the environment as described in this standard.

3.1.18 noise level : sound level produced by the fuel cell power system

Note: Expressed as decibels (dBA) and measured as described in this Standard.

3.1.19 background noise : level of ambient noise at the measurement point.

Note: This measurement is taken as described in this Standard with the fuel cell power system shut down.

3.1.20 vibration level : maximum measurement value of mechanical oscillations produced by the fuel cell power system during operation

Note: This is a value expressed as decibels (dB) as described in this Standard.

3.1.21 background vibration : mechanical oscillations caused by the environment that affect vibration level readings

Note: Background vibration is measured with the fuel cell power system not operating.

3.1.22 discharge water : water that is removed from the fuel cell power system

Note: Discharge water does not constitute part of a thermal recovery system.

3.1.23 water consumption : water supplied (from outside the system boundary) to the power system on a steady state basis.

3.1.24 oxidant consumption : amount of oxygen consumed inside the fuel cell power system

3.1.25 waste heat :. thermal energy released and not recovered

3.1.26 test run : time period during which data are recorded

Note: Reported results are computed based on these data points

3.1.27 response time constant : time period between initiating a power output change and attaining the specified power within 10% of the specified value

Note: Time is expressed in seconds.

3.2 Reference conditions

3.2.1 Temperature and pressure

This clause provides the reference conditions to be referred to compute test results to be applied for open technical data.

The reference conditions are specified as follows:

Reference temperature : t_0 = 288.15 K(15°C)

Reference pressure : p_0 = 101.325 kPa

3.2.2 Heating value base

Heating value of fuel is based on LHV in principle.

$$\eta_e = XX\%$$

In case of LHV, it is not necessary to add the symbol "LHV".

If HHV is applied, the abbreviation "HHV" shall be added to the value of energy efficiency as follows;

$$\eta_e = XX\% \text{ (HHV)}$$

Note - LHV: Lower heating value, HHV: Higher heating value

3.3 Symbols

The symbols and their meanings used in this International Standard are given in Table 1, with unit.

Table 1-Symbols

Symbol	Definition	Unit
q_v	**Volumetric flow rate**	
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/s
q_{vf0}	Volumetric flow rate of fuel at the reference conditions	m^3/s
q_{ve}	Volumetric flow rate of exhaust gas	m^3/s
q_{va}	Volumetric flow rate of air at temperature t_a and pressure p_a	m^3/s
q_{va0}	Volumetric flow rate of air at the reference conditions	m^3/s
q_{vw}	Volumetric flow rate of water	m^3/s
q_m	**Mass flow rate**	
q_{mf}	Mass flow rate of fuel	kg/s
q_{ma}	Mass flow rate of air	kg/s
q_{mHR1}	Mass flow rate of heat recovery fluid at the interface point of fluid output	kg/s
q_{mHR2}	Mass flow rate of heat recovery fluid at the interface point of fluid input(Return stream to the fuel cell power system)	kg/s
q_{me}	Mass flow rate of emission	kg/s
P	**Electric power**	
P_{out}	Active power of electric power output (incl. Direct current)	W, kW
P_{in}	Active power of electric power input for external power source (incl. Direct current)	W, kW
p	**Pressure**	
p_0	Reference pressure	kPa
p_f	Pressure of fuel	kPa
p_a	Pressure of oxidant (air)	kPa
p_{HR1}	Pressure of heat recovery fluid output	kPa
p_{HR2}	Pressure of heat recovery fluid input	KPa
t	**Temperature**	
t_0	Reference temperature	K
t_f	Temperature of fuel	K
t_a	Temperature of oxidant (air)	K
t_{HR1}	Temperature of heat recovery fluid output	K
t_{HR2}	Temperature of heat recovery fluid input	K
ρ	**Density**	
ρ_{f0}	Density of fuel at the reference conditions	kg/m^3
ρ_f	Density of liquid fuel at temperature t_f	kg/m^3
ρ_{a0}	Density of oxidant (air) at the reference conditions	kg/m^3
ρ_ε	Mass concentration of emission	kg/m^3
x_j	Molar ratio of component j	--

Table 1-Symbols (concluded)

Symbol	Definition	Unit
Q	**Heating value**	
Q_{HR}	Value of recovered thermal energy	kJ/s
Q_{fo}	Heating value of fuel at the reference conditions	kJ/mol
Q_{fl}	Heating value of fuel at liquid phase	kJ/kg
Q_{f0j}	Heating value of component j	kJ/mol
Q_{WH}	Waste heat	kJ/s
H,h	**Enthalpy, Specific enthalpy**	
H_{HR1}	Enthalpy of heat recovery fluid output	kJ
H_{HR2}	Enthalpy of heat recovery fluid input	kJ
h_{HR1}	Specific enthalpy of heat recovery fluid at temperature t_{HR1} and at pressure p_{HR1}	kJ/kg
h_{HR2}	Specific enthalpy of heat recovery fluid at temperature t_{HR2} and at pressure p_{HR2}	kJ/kg
h_f	Specific enthalpy of fuel at temperature t_f	kJ/mol
h_{fo}	Specific enthalpy of fuel at the reference temperature	kJ/mol
h_a	Specific enthalpy of oxidant (air) at temperature t_f	kJ/mol
h_{ao}	Specific enthalpy of oxidant (air) at the reference temperature	kJ/mol
E	**Input Energy**	
E_{fv}	Input energy of the fuel	kJ/m^3
E_{pf}	Pressure energy of the fuel	kJ/mol
E_{av}	Input energy of the oxidant (air)	kJ/m^3
E_{pa}	Pressure energy of the oxidant (air)	kJ/mol
η	**Efficiency**	
η_e	Electrical efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%
V	**Voltage**	
V_{out}	Voltage of electrical power output	V, kV
V_{in}	Voltage of electrical power input	V, kV
I	**Current**	
I_{out}	Current of electrical power output	A
I_{in}	Current of electrical power input	A
λ	**Power factor**	
λ_{out}	Power factor of electrical power output	--
λ_{in}	Power factor of electrical power input	--

Note ; Main symbols in the fuel cell power system corresponded to Figure 2-Symbol Diagram

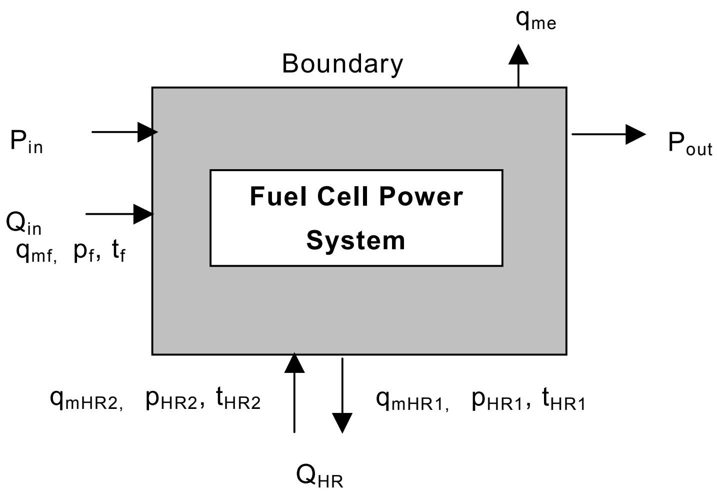


Figure 2-Symbol Diagram

4 Performance and classes of tests

4.1 Performance tests

The performance assessment of the fuel cell power systems is to be considered from these points of view:

Operation : to test the performance of the system during normal operation

Environmental aspects : to test how the system affects the environment

Table 2 indicates the test items for the operating performance tests and the environmental performance tests. The test items in Table 2 shall be applied to the fuel cell power system considered as a whole.

Unless otherwise specified, all tests are required for all fuel cell types. Differences in system design and differences in technology may result in some portions of the tests being omitted (e.g. systems without heat recovery will not require measurement of heat recovered).

4.2 Classes of tests

There are three categories of tests depending on the scope of application defined by the IEV. However additional explanations are provided as follows, to provide clarification.

(a) **Type test :** A test of one or more devices made to a certain design to show that the design meets certain specifications (IEC 60050-2/ IEV 151-04-15 and 811-10-04)

Note - Type tests are mandatory. They shall be performed on a representative number of fuel cell power systems each one considered as a whole. The purpose is to verify the compliance of the design with the selected requirements

(b) **Routine test :** A test to which each individual device is subjected during or after manufacture to ascertain whether it complies with certain criteria (IEC 60050-2/IEV 151-04-16 and 811-10-05).

Note - No routine performance tests are required or necessary or identified in this standard.

(c) **Acceptance test :** A contractual test to prove to the customer that the device meets certain conditions of its specification (IEC 60050-2/ IEV 151-04-20 and 811-10-01).

Note - Acceptance tests, agreed between the manufacturer and the user and according to the specifications of the user, may be selected from the items listed in Table 2. When such tests are selected they shall be performed according to this standard.

Note 1 - Type Tests and Routine Tests are generally performed in the same way and by using the same procedure. Differences between Type Tests and Routine Tests may be necessary, in the event that Routine Tests are done (e.g. the most strict stability requirements may not be necessary or the number of measurements taken may be less for Routine Tests). These differences will be explained in the description of the test method.

Note 2 - This standard describes test methods only, no performance targets are set.

Table 2 - Test item and test classification

Item	Test	Type Test	Routine Test
	Operation		
1	Electric power output	x	
2	Power quality [1]	x	
3	Fuel consumption	x	
4	Electrical efficiency	x	
5	Heat recovery efficiency	x	
6	Overall energy efficiency	x	
7	Transient response of power output	x	
8	Start-up/Shutdown characteristics	x	
9	Purge gas consumption	x	
10	Water consumption	x	
11	Oxidant consumption	x	
12	Waste heat	x	
	Environmental aspects		
1	Particulate emission	x	
2	SOx , Nox emission	x	
3	CO_2, CO emission	x	
4	Total hydrocarbon emission	x	
5	Noise	x	
6	Vibration	x	
7	Discharge water quality	x	

Note 1: Power quality is defined as Harmonics in this International Standard

5 Test preparation

5.1 General

This section describes typical items that shall be considered prior to the implementation of a test. For each test an effort must be made to minimise uncertainty by selecting high precision instruments and planning the tests carefully with attention to detail. Detailed test plans shall be prepared by the parties to the test using this standard as the basis. A written test plan shall be prepared. Relevant test items are listed in Table 3.

The following items shall be considered for the test plan.

a) Objective

b) Test Specifications

c) Target Uncertainty (refer to 5.3 and Annex B)

d) Identification of measurement Instruments (refer to 6)

e) Estimated Range of Test Parameters

f) Data Acquisition Plan (refer to 5.3.2)

5.2 Uncertainty analysis

5.2.1 Uncertainty analysis items

An uncertainty analysis shall be performed to indicate the reliability of the test results and to comply with customer requests. The following test results shall be analyzed to determine the absolute and relative uncertainty. A test shall be planned so that the reliability of the results can be evaluated. (See Annex-B).

- Electrical Power Output
- Electrical Efficiency
- Heat Recovery Efficiency
- Overall Efficiency

5.2.2 Data acquisition plan

Data acquisition system (i.e. duration and frequency of readings) in order to meet the target uncertainty (See B.2 in Annex-B) and data recording equipment that is suitable for the required frequency of readings and reading speed, shall be prepared in advance to performance test.

6 Instruments and measurement methods

6.1 General

This section describes the measuring instruments used for testing the fuel cell power system, their method of usage and precautions. The types of instruments for measuring and measurement methods shall be conformed to the relevant International Standards and shall be selected to meet the measurement uncertainty targets specified by manufacturer. If necessary, external equipment with required values shall be added.

The following instruments and equipment are typically used to measure the performance of fuel cell power systems.

6.2 Instruments

(1) Instruments for measuring the electric power output and power input

-voltage, current, power meters and other accessories;

(2) Apparatus for measuring fuel consumption

-fuel flow meters, pressure sensors, temperature sensors

(3) Apparatus for determining the heating value of the fuel

-gas chromatography or alternate means with comparable accuracy.

-calorimeter or alternate means with comparable accuracy.

(4) Instruments for measuring the recovered heat

-fluid flow meters, temperature sensors, and pressure sensors

(5) Apparatus for determining the composition of exhaust gas and discharge water quality

-exhaust gas analyser; e.g., particulates, SOx, NOx, CO_2, CO and Total hydrocarbon

- water quality analyser; e.g., pH meter, electrochemical probe meter

(6) Instruments for measuring noise

-noise level meter, microphones

(7) Instruments for measuring vibration

-vibration level meters, accelerometers, pick-up sensors

(8) Instruments for measuring ambient conditions

-barometers, hygrometers and temperature sensors

6.3 Measurement methods

6.3.1 Electric power

Electric power measurement shall include electric power output from the fuel cell power system, and electric power inputs to handle parasitic loads. The measurement items are as follows:

a) Power

b) Voltage

c) Current

d) Power factor

They shall be measured in accordance with IEC 60051:1984, IEC 60359:1987, IEC 60687:1992, IEC 60688:1992, IEC 61028:1991, IEC 61036:1990 and IEC 61143:1992

(1) Preparation for measurement

Electric power meters, voltage meters, current meters and power factor meters must be appropriate in terms of accuracy before starting measurement.

(2) Location of electric power meters

In order to measure electric power output, an electric power meter, voltage meter, current meter and power factor meter shall be located at the electric output interface point.

In order to measure electric power input for parasitic loads from an external power source, an electric power meter, voltage meter, current meter and power factor meter shall be located at the electric input interface point.

Power factor measurements shall be conducted with the fuel cell power system connected to an external load or connected to the local electrical power grid.

6.3.2 Fuel consumption

Either gaseous or liquid fuels may be used depending on the specifications of fuel cell power systems tested. Fuel heating values must be consistent throughout the test period (see table 4).

6.3.2.1 Gaseous fuel

Gaseous fuel characteristics shall include the determination of

a) heating value;

b) temperature;

c) pressure.

Heating value will be calculated in accordance with 7.3.3.1.

6.3.2.2 Fuel composition

1)Sampling

Fuel gas shall be sampled during operation of the fuel cell power system on a frequency and with an appropriate number of samples to meet the requirements of the uncertainty analysis.

Pre-analysed bottled gas may be substituted for gas sampling, provided that the uncertainty of the analysed gas is consistent with the uncertainty required.

2)Fuel gas composition measurement

Natural gas mainly comprises methane and small quantities of higher hydrocarbons, as well as some non-combustible gases.

All major components shall be measured according to methods detailed in norms ISO 6568, ISO 6974 and ISO 6975:

-Methane
-Ethane
-Propane
-Butane
-Pentane
-Hexane plus
-Nitrogen
-Carbon dioxide

The following minor components shall be measured according to methods detailed in ISO 6974 and ISO 6975:

-Hydrogen
-Oxygen
-Carbon monoxide.

The sulphur compounds (including odourant) shall be measured according to methods detailed in ISO 6326.

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

When hydrogen is used as a fuel, sampling and the determination of the gas composition shall be performed in accordance with ISO 14687:1999/Cor. 2001.

6.3.2.3 Fuel flow

Fuel flow is essential to the measurement of fuel cell power system efficiency. Gas fuel consumption may be determined by means of either 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 is recommended and they shall be applied in accordance with ISO 5167. Fuel flow meters shall be compatible with the pressure of gas used and their uncertainty shall be consistent with the uncertainty required.

Precautions for location of the flow meter and flow measurement are described in the following;

a) Location of flow meters

Flow meters shall be located near the system boundary.

b) Measurement conditions

Temperature and pressure of fuel shall be measured near the flow meter installed at the system boundary.

6.3.2.4 Fuel temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer

b) resistance thermometer with transducer

Temperature sensors shall be appropriate in terms of accuracy before starting measurement.

Temperature sensors shall be located just upstream of the flow measurement device.

6.3.2.5 Fuel pressure

Calibrated manometers, dead-weight gauges, Bourdon Tubes or other elastic type gauges may be used. Alternatives include calibrated pressure transducers. Fuel pressure instrumentation must be suitable for the pressures during the test and uncertainty must be consistent with the uncertainty analysis.

Connecting piping shall be checked to be leak-free under working conditions in advance of the performance test.

If pressure fluctuations occur, a suitable means of damping shall be used in an effective position.

Fuel pressure measured shall be static pressure and effects of velocity shall be considered and eliminated.

6.3.3 Liquid fuel measurements

An appropriate sampling method shall be used to determine the fuel characteristics. This includes:

a) density (mass per unit volume);

b) heating value;

c) viscosity where applicable;

d) temperature

These characteristics shall be determined in accordance with the relevant ISO standards (i.e. ISO 3648 and ISO 8217 and ASTM 4809 - 00) or by using a laboratory familiar with these International Standard methods.

6.3.3.1 Liquid fuel flow

The accurate measurement of fuel flow to the fuel cell power system is essential to determine a heat rate of the fuel cell power system. The use of flow nozzles, orifices, and venturi meters is recommended. Instrumentation shall be applied in accordance with ISO 5167. Alternatives include displacement meters, mass flow meters, volumetric meters, turbine type flow meters, calibrated liquid meters and direct weighing means. In any case, the uncertainty of fuel flow measuring devices used shall be known and shall be consistent with the uncertainty calculation.

No fuel spill or leakage after the point of measurement shall be allowed.

6.3.3.2 Liquid fuel temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer

b) resistance thermometer with transducer,

Temperature sensors shall be appropriate in terms of accuracy before starting measurement, and shall be located just upstream of the fuel flow meter.

6.3.4 Recovered heat

Thermal media may be hot water, hot air or coolant such as oil etc. A combination of these media may be used depending on the specifications of fuel cell power systems tested.

The temperature and pressure of heat transfer fluids shall be measured concurrently.

6.3.4.1 Fluid flow

Appropriate equipment for each thermal media shall be applied. The accurate measurement of thermal media flow to and from the thermal energy utilisation / storage is necessary to determine a thermal efficiency of the fuel cell power system. The use of flow nozzles, orifices, or venturi meters is recommended and they shall be applied in accordance with ISO 5167. Mass flow meters and turbine type flow meters may also be used.

Flow meters shall be appropriate in terms of scale and accuracy before starting measurement.

Flow measuring devices shall be located near the boundary of the fuel cell power system.

6.3.4.2 Fluid temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer

b) resistance thermometer with transducer,

c) fluid temperature measurement devices shall be appropriate in terms of scale and accuracy before starting measurement.

d) fluid temperature measuring devices shall be located near the boundary of the fuel cell power system.

e) temperature measurement devices shall be located just upstream of the associated flow meter. Ensure that the temperature sensors do not touch the pipe.

6.3.4.3 Fluid pressure

This measurement method is for gas phase fluid including steam.

(1) preparation for measurement

Pressure gages shall be appropriate in terms of accuracy before starting measurement.

(2) location of pressure gages

Pressure gage sensors shall be located just upstream of the associated flow meter near the interface points (fluid output and input points) in a fluid flow line. Adequate thermal insulation around pipes shall be required.

(3) appropriate compensation for condensation shall be applied.

6.3.5 Purge gas flow

Purge Gas consumption shall be determined by means indicated in 6.3.7.

6.3.6 Oxidant (Air) characteristics

Oxidant characteristics shall include the determination of

a) temperature

b) pressure

c) composition (Oxidant characteristics can affect fuel cell performance. The composition of the oxidant shall be stated in the test report.)

d) density

6.3.6.1 Oxidant (Air) flow

Oxidant (Air) flow rate may be determined by means of either 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 is recommended and they shall be applied in accordance with ISO 5167. Flow meters shall be compatible with the pressure of gas used and uncertainty shall be consistent with the uncertainty analysis.

Precautions for location of the flow meter and measurement are described in the following;

a) location of flow meters

b) flow meters shall be located near the system boundary.

6.3.6.2 Oxidant (Air) temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer

b) resistance thermometer with transducer

Temperature sensors shall be appropriate in terms of accuracy before starting measurement.

Temperature sensors shall be located just upstream of the flow measurement device.

6.3.6.3 Oxidant (Air) pressure

Calibrated manometers, dead-weight gages, Bourdon tubes or other elastic type gages may be used. Alternatives include calibrated pressure transducers. Oxidant (Air) pressure instrumentation must be suitable for the pressures during the test and uncertainty must be consistent with the uncertainty analysis.

Connecting piping shall be checked to be leak-free under working conditions in advance of the performance test.

If pressure fluctuations occur, a suitable means of damping shall be used in an effective position.

Oxidant (air) pressure measured shall be static pressure and effects of velocity shall be considered and eliminated.

6.3.6.4 Oxidant (Air) composition

Oxidant composition shall be measured using gas chromatography or other suitable means. If air is used as the oxidant, composition shall be considered to be ordinary atmospheric air unless otherwise indicated.

6.3.7 Other fluid flow

If necessary, the measurement of coolant water and drain water flows shall be accomplished by one of the following methods

a) standard nozzle or orifice

b) displacement meter

c) other specified methods such as direct weighing or volumetric tanks, mass flow meters, etc.

6.3.8 Exhaust gas emission measurement

6.3.8.1 Exhaust gas temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer

b) resistance thermometer with transducer

Exhaust gas temperature is used to quantify emissions and to correct the emissions rate for temperature.

Exhaust gas temperature instrumentation shall be installed just upstream of the exhaust gas flow meter and just upstream of the exhaust gas analyser.

6.3.8.2 Exhaust gas pressure

Calibrated manometers, dead-weight gauges, or other elastic type gauges may be used. Alternatives include calibrated pressure transducers. Exhaust gas pressure instrumentation must be suitable for the pressures and temperatures during the test and instrumentation uncertainty must be consistent with the uncertainty analysis.

Connecting piping shall be checked to be leak-free under working conditions in advance of the performance test.

If pressure fluctuations occur, a suitable means of damping shall be used in an effective position.

Exhaust gas pressure is used to quantify emissions and to correct emissions rate for pressure.

Exhaust gas pressure instrumentation shall be installed just upstream of the exhaust gas flow meter and just upstream of the exhaust gas composition analyser.

6.3.8.3 Exhaust gas flow

Refer to ISO 10780.

In case ISO 10780 is not applicable, measurement of exhaust gas flow may be accomplished by mass flow meter, volumetric meter, or turbine type flow meter. Flow measurement by nozzles, orifices, or venturi meters may be applicable. If nozzles, orifices, or venturi meters are used they shall be applied in accordance with ISO 5167. Flow meters shall be compatible with the pressure of gas used and uncertainty shall be consistent with the uncertainty analysis.

6.3.8.4 Particulate concentration

Refer to ISO 9096 and ISO 11042 –1, ISO 11042-2.

6.3.8.5 SOx and NOx concentration

SOx concentration:

Refer to ISO 7934, ISO 7935, and ISO 11042-1 and ISO 11042-2, and ISO 10396. Other methods suitable for the service may be used providing they are consistent with the uncertainty analysis.

NOx concentration:

Refer to ISO 11564, ISO 10849, ISO 11042-1, ISO 11042-2, and ISO 10396. Other methods suitable for the service may be used providing they are consistent with the uncertainty analysis.

6.3.8.6 CO_2 and CO concentration

CO2: Refer to ISO 11042-1, ISO 11042-2, ISO 10396.

CO2 may be calculated based on carbon content of the fuel.

CO: Refer to ISO 11042-1, ISO 11042-2, ISO 10396.

6.3.8.7 Total hydrocarbon concentration

Refer to ISO 11042-1 and ISO 11042-2.

6.3.8.8 Oxygen concentration

Refer to ISO 11042-1 and ISO 11042-2.

6.3.9 Discharge water quality measurement

Discharge water quality measurements for water discharged from a fuel cell power system shall include the determination of:

a) volume of discharge water

b) temperature of discharged water

c) pH

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

e) emission levels of other substances, which are restricted to the domestic law and might be exhausted from fuel cell power system.

6.3.9.1 Volume of discharge water

Refer to 6.3.7.

6.3.9.2 Temperature of discharge water

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer

b) resistance thermometer with transducer

6.3.10 pH

Refer to ISO 10523.

6.3.11 COD (Chemical Oxygen Demand)

Refer to ISO 6060.

6.3.12 BOD (Biochemical Oxygen Demand)

Refer to ISO 10707.

6.3.13 Noise

Noise produced by the fuel cell power system shall be measured using a sound level meter defined in IEC 60651. The test shall be conducted in accordance with ISO 3744.

The following parameters will be determined in accordance with ISO 3744:

1) measuring surface; (at distance from the body of fuel cell power system)
2) number of measuring points;
3) influence of background noise;

6.3.14 Vibration

Vibration shall be measured with the fuel cell power system installed and operated in accordance with the manufacturer's installation instructions.

Vibration emitted by the fuel cell power system shall be measured at the mounting points as described below.

Mounting hardware supplied by the manufacturer shall be used to mount the unit as required above. The mounting point is the transmission point, transmitting vibration from the unit to the ground, floor, walls, ceiling, or other support structure according to the manufacturer's design. If multiple mounting configurations are designed, all configurations shall be measured.

1) Measuring positions – Measurements shall be taken at the mounting points that significantly respond to the dynamic forces and characterise the overall vibration of the system. For systems without fixed mounting points, dynamic analysis or preliminary testing is required to determine the significant measurement points.
2) To define the vibration behavior at each measuring position, it is necessary to take measurements in three mutually perpendicular directions.
3) Mounting of accelerometers; refer to ISO 5348.

6.3.15 Total harmonic distortion

Total harmonic distortion shall be measured and reported for fuel cell power systems that produce alternating current. Refer to IEC 61000-4-7 and IEC 61000-4-13 for measurement guidance.

6.3.16 Ambient conditions

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

Refer to ISO 4677-1 and ISO 4677-2 for ambient humidity measurement.

Refer to ISO 1662 for ambient wind measurement.

Recommended instruments for measuring ambient temperature directly are:

a) thermocouples with transducer
b) resistance thermometer with transducer

Temperature sensors shall be appropriate in terms of accuracy before starting measurement.

Recommended instruments for measuring ambient pressure directly are:

a) mercury barometer

b) alcohol barometer

Pressure sensors shall be appropriate in terms of accuracy before starting measurement.

7 Test method and computation of results

7.1 Test plan

The test items in Table 2 must be carried out under different operating conditions depending upon the purpose of the test. The different conditions are:

a) Steady State at rated power

b) Steady State at partial load near the mid-point between rated power and minimum power level

c) Steady State at standby conditions at minimum power (0%)

d) Steady State where maximum values are found

e) Transient conditions

Table 3 shows this information for all the test items.

7.1.1 Ambient conditions

For each test run, the ambient conditions shall be measured

a) ambient Temperature

b) barometric Pressure

c) relative Humidity

d) wind

Table 3 - Test item and system status

Item	Test	Steady state conditions			Maxi-mising measured values	Transient State (3)
		Rated power	Partial load	Standby		
	Operation					
1	Electric power output	X	X			
2	Power quality (1)	X	X			
3	Fuel consumption	X	X	X		
4	Electrical efficiency (2)	X	X			
5	Heat recovery efficiency (2)	X	X			
6	Overall energy efficiency	X	X			
7	Transient response of power output					X
8	Start-up/Shutdown characteristics					X
9	Purge gas consumption					X
10	Water consumption	X	X	X	X	
11	Oxidant consumption	X	X	X		
12	Waste heat	X	X	X		
	Environmental aspects					
1	Particulate emission				X	
2	SOx , NOx emission				X	
3	CO_2, CO emission				X	
4	Total hydrocarbon emission				X	
5	Noise	X	X	X	X	X
6	Vibration	X	X	X	X	X
7	Discharge water quality	X	X	X		

(1) To be performed as the harmonic distortion

(2) Tests to be performed concurrently

(3) Transient testing includes shutdown testing

7.1.2 Maximum permissible variation in steady state operating conditions

The maximum permissible variations are given in Table 4.

Table 4- Maximum Permissible Variations in Test Operating Conditions

Parameter	Allowable Variation During a Test Run
System Stabilisation Parameter As Specified by the Manufacturer and Agreed to by all Parties	As Specified
Real Power Output, kW	+/- 2%
Total Power, kVA	+/- 2%
Barometric Pressure at Site	+/- 0.5%
Inlet Air Temperature	+/- 3 K
Heat Value – Fuel Per Unit Volume	+/- 1%
Gaseous Fuel Pressure as delivered to system	+/- 1%
Absolute Exhaust Pressure	+/- 0.5%
Absolute inlet air pressure to system	+/- 0.5%
Heat Rejection Rate to External Cooling rate	+/- 2%
Fuel Flow	+/- 2%
Fuel Temperature	+/- 2 K
Secondary Thermal Energy Input Temperature	+/- 3 K
Secondary Thermal Energy Input Delivery Rate	+/- 2%
Inlet Air / Oxidant Flow Rate	not specified
Thermal Energy Output Delivery Rate	+/-2%
Total Harmonic Distortion : THD(see Note 2 below)	+/- 2%

Note 1: Reference; ASME-PTC50. Instruments and measurement methods

Note 2 for THD only: For THD with a mean value of 5%, THD values between 3% and 7% is acceptable.

7.1.3 Test operating procedure

The following tests must be done concurrently:

- electric power output and heat recovery efficiency
- fuel consumption and oxidant consumption

Note: Overall energy efficiency and Waste heat in Table 3 are calculated based on measured values given in the tests mentioned above.

Other tests as follows shall be executed efficiently during testing the test items mentioned above

-water consumption, dynamic transient response of power output, start-up/shut-down and purge gas consumption

7.2 Duration of test and frequency of readings

The appropriate duration and frequency of readings are determined according to the type of fuel cell power system tested. A sufficient number of measurements and number of measurement sets shall be established based on requirements for data fluctuations, stability of average values, and “Uncertainty Analysis”. See B.5 in Annex B.

The evaluation of electrical power output, electrical efficiency and heat recovery efficiency (if applicable) shall be carried out three times consecutively, the duration of each test run being not less than 10 minutes. These conditions shall be determined by results of the uncertainty analysis.

Note:In computing results of tests, the determination may be made with averaged values of observations made during a single test run. See B2 in Annex-B

.

7.3 Computation of results

7.3.1 Electrical power

Electric power output and input shall be measured during a single test run in accordance with 6.3.1 at three different loads as defined in 7.1.

(1) Electric power output

When the voltage, current, and power factor of electric power output are measured, electrical power output, P_{out} (W) is calculated as follows:

a) Three phase system

$$P_{out} = \sqrt{3} \times V_{out} \times I_{out} \times \lambda_{out}$$

where,

V_{out} is the voltage of electric power output (line to line) (V)
I_{out} is the current of electric power output (A)
λ_{out} is the power factor of electric power output

b) Single phase system

$$P_{out} = V_{out} \times I_{out} \times \lambda_{out}$$

where,

V_{out} is the voltage of electric power output (line to neutral) (V)
I_{out} is the current of electric power output (A)
λ_{out} is the power factor of electric power output

c) Direct current

$$P_{out} = V_{out} \times I_{out}$$

where,

V_{out} is the voltage of electric power output (V)
I_{out} is the current of electric power output (A)

(2) Electric power input from external power source

The power input shall be measured as the same time as the power output is measured at each load.

When the voltage, current, and power factor of electric power input are measured, respectively expressed as V_{in}, I_{in}, and λ_{in}, electric power input, P_{in}, is calculated using the same equations as above.

7.3.2 Fuel consumption

This clause provides the computation method to obtain the fuel consumption and fuel energy corresponding to the fuel consumption.

Fuel consumption shall be measured during the electrical power input and output testing in 7.3.1. Fuel consumption is calculated in accordance with 6.3.2 and by means of the following equation:

7.3.2.1 Gaseous fuel

$$q_{vf0} = q_{vf} \times (t_0 / t_f) \times (p_f / p_0)$$

$$q_{mf} = q_{vf0} \times \rho_{f0}$$

where,

- q_{vf0} is the volumetric flow rate of fuel at the reference conditions; (m^3/s)
- q_{vf} is the volumetric flow rate of the fuel at temperature t_f and pressure p_f; (m^3/s)
- q_{mf} is the mass flow rate of fuel; (kg/s)
- ρ_{f0} is the density of raw fuel at the reference conditions; (kg/m^3)
- t_0 is the reference temperature (288.15 K)
- p_0 is the reference pressure (101.325 kPa)
- t_f is the temperature of fuel at test conditions; (K)
- p_f is the pressure of the fuel at test conditions; (kPa)

7.3.2.2 Liquid fuel

$$q_{mf} = q_{vf0} \times \rho_{f0}$$

where,

- q_{mf} is the mass flow rate of fuel; (kg/s)
- q_{vf0} is the volumetric flow rate of the fuel at the reference condition; (m^3/s)
- ρ_{f0} is the density of raw fuel at the reference conditions; (kg/m^3)

7.3.3 Calculation of fuel energy

7.3.3.1 Gaseous fuel

The energy of fuel at a temperature t_f, a pressure p_f of a mixture of known composition is calculated from the following equation

$$E_{fv} = (Q_{f0} + h_f - h_{f0} + E_{pf}) / M_o$$

where,

- E_{fv} is the input energy of the fuel per unit of volume; (kJ/m^3)
- Q_{f0} is the heating value of the fuel at reference conditions; (kJ/mol)
- h_f is the specific enthalpy of the fuel at temperature t_f; (kJ/mol)
- h_{f0} is the specific enthalpy of the fuel at the reference temperature t_0; (kJ/mol)
- E_{pf} is the pressure energy of the fuel.; (kJ/mol)
- Mo is the reference molar volume of ideal gas; (2.3645×10^{-2} m^3/mol) (at the reference temperature for this standard, t_0 = 288.15 K)

The heating value of fuel is calculated from the following equation

$$Q_{f0} = \sum_{j=1}^{N} x_j Q_{f0j}$$

where,

- Q_{f0j} is the heating value of component $_j$; (kJ/mol)
- x_j is the molar ratio of component j .

Note: Numerical values of Q_{f0j} are given in Table C1 of Annex-C

The specific enthalpy of fuel is calculated from the equation

$$h_f = \sum_{j=1}^{N} x_j h_{fj}$$

where,

- h_{fj} is the specific enthalpy of component j at temperature t_f ; (kJ/mol)

$$h_{fj} = (A_{fj} \times t_f + (B_{fj}/2000) \times t_f^2 + (C_{fj}/3 \times 10^6) \times t_f^3) \times 10^{-3}$$

where,

- A_j, B_j and C_j are the constants of component j. and given in Worksheet-1 of Annex-C.
- h_{f0} is the specific enthalpy of the fuel at the reference temperature
- h_{f0} is calculated by the same equation of h_f.

The pressure energy of fuel is calculated from the following equation

$$E_{pf} = R \times t_o \times \ln(p_f / p_0)$$

where,

- R is the universal gas constant (8.314 J/mol K)
- t_0 is the reference temperature (288.15 K)
- p_0 is the reference pressure (101.325 kPa)
- p_f is the pressure of fuel (kPa)

7.3.3.2 Liquid fuel

The energy of fuel at a temperature t_f is calculated from the following equation

$$E_{fv} = \rho_f \times Q_{fl}$$

where,

- ρ_f is the density of fuel at temperature t_f; (kg/m^3), and shall be measured according to the relevant international standard corresponded to liquid fuel applied to testing.
- Q_{fl} is the measured heating value of the fuel;(kJ/kg), and shall be measured according to the methods detailed in ASTM 4809 - 00 at temperature t_f

7.3.4 Electrical efficiency

Electrical efficiency is calculated as follows, based on the measurement values of the electric power output and input given in 7.3.1 and input energy supplied by the fuel given in 7.3.3 and the oxidant (air) in 7.3.12.

The electrical efficiency η_e ;

$$\eta_e = \frac{(P_{out} - P_{in})}{(q_{vf0} \times E_{fv} + q_{va0} \times E_{av})} \times 100$$

where,

- P_{out} is the active power of electric power output (kW)
- P_{in} is the active power of electric power input for parasitic load etc., (kW)
- E_{fv} is the input energy of the fuel per unit volume (kJ/m^3)
- E_{av} is the input energy of the air per unit volume (kJ/m^3)
- q_{vf0} is the volumetric flow rate of the fuel at reference conditions (m^3/sec)
- q_{va0} is the volumetric flow rate of the air at reference conditions p_a (m^3/sec)

7.3.5 Heat recovery efficiency

The recovered heat shall be measured in accordance with 6.3.4, during the electrical power input and electrical power output performance tests in 7.3.1. The recovered heat is calculated by the formula given in 7.3.5.1.

Heat recovery efficiency is calculated by the formula in 7.3.5.2. based on the measurement values of the recovered heat given in 7.3.5.1 and the input energy supplied by the fuel given in 7.3.3 and the oxidant (air) in 7.3.12.

7.3.5.1 Calculation of recovered heat

The recovered thermal energy, Q_{HR} is calculated by means of the following equation:

$$Q_{HR} = h_{HR1} \times q_{mHR1} - h_{HR2} \times q_{mHR2}$$

where,

- Q_{HR} is the recovered thermal energy (kJ/s)
- h_{HR1} is the specific enthalpy (kJ/kg) of heat recovery fluid at temperature t_{HR1} and at pressure p_{HR1}
- h_{HR2} is the specific enthalpy (kJ/kg) of heat recovery fluid at temperature t_{HR2} and at pressure p_{HR2}
- q_{mHR1} is the mass flow rate of heat recovery fluid at the interface of fluid output (kg/s)
- q_{mHR2} is the mass flow rate of heat recovery fluid at the interface of fluid input (kg/s)

7.3.5.2 Heat recovery efficiency calculation

The heat recovery efficiency η_{th}

$$\eta_{th} = \frac{Q_{HR}}{(q_{vf} \times E_{fv} + q_{va} \times E_{av})} \times 100$$

where,

- Q_{HR} is the recovered thermal energy (kJ/s)
- E_{fv} is the input energy (kJ/m^3) of the fuel per unit volume
- E_{av} is the input energy (kJ/m^3) of the oxidant (air) per unit volume
- q_{vf} is the volumetric flow rate (m^3/s) of the fuel at temperature t_f and pressure p_f,
- q_{va} is the volumetric flow rate (m^3/s) of the air at temperature t_a and pressure p_a

7.3.6 Overall energy efficiency

The overall energy efficiency, η_{total}, is calculated as follows, based on the value of the electrical efficiency; η_e given in 7.3.4 and the heat recovery efficiency; η_{th} given in7.3.5.2.

$$\eta_{total} = \eta_e + \eta_{th}$$

where,

- η_e is the electrical efficiency; (%)
- η_{th} is the heat recovery efficiency; (%)

7.3.7 Transient response characteristics

7.3.7.1 Maximum acceptable instantaneous electrical power output transient for grid-independent systems

For fuel cell power systems designed for stand alone operations (i.e. independent from the electrical grid), this test procedure is designed to determine the maximum electric power transient that a fuel cell power system can accept without undergoing emergency shut-down. The test shall be conducted feeding a resistive load.

The net electrical power output, measured in accordance with 6.3.1, is monitored continuously during this test.

An electrical power transient is deemed acceptable to the fuel cell power system if the change in net electrical power output between an initial steady state value (see 7.1 and Table 4) and a new value of net electrical power output can occur within 20 ms[1]. Only net electrical power output is monitored; any instability or subsequent variation of other parameters listed in Table 4, as well as system stabilisation parameters (as specified by the manufacturer) and total harmonic distortions (THD), is disregarded in this test.

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1 i.e. one period of a 50 Hz signal. This criterion is also applicable to fuel cell power systems that provide 60 Hz alternating current, and to those that provide continuous current. For systems where this time limit is inappropriate by design, the manufacturer may specify a different time limit and take specific exception to this in the report.

The manufacturer shall specify a target transient level. For example, a manufacturer may specify a target transient level (e.g. 57%) as their maximum transient capability. Testing is started at the target value. If the test is successful, an additional test may be performed at a higher power level as specified by the manufacturer to verify a higher capability. If the initial test fails, other testing shall be conducted using a smaller transient power level change, as specified by the manufacturer. At least one test must be successful for a result to be reported.

An up-transient is obtained with an initial steady state of net electrical power output value equal to 0% rated power output.

A down-transient is obtained with an initial steady state of net electrical power value equal to 100% rated power.

7.3.7.2 Transient response time

7.3.7.2.1 Grid independent net electrical power output transient

For fuel cell power systems designed for grid independent operation, the transient response time defined in 3.1.8 for net electrical power output shall be observed between two steady state operating conditions with respect to Total Harmonic Current Distortion (THD)[2] and Total Harmonic Voltage Distortion (THD) when the maximum acceptable instantaneous electrical power output transient defined in 7.3.7.1 is required from the fuel cell power system feeding a resistive load.

The transient response time of net electrical power output shall be calculated by means of the following equation:

$$T = T_{attain} - T_{ini.}$$

Where,

T_{ini} is the time when the electrical load change signal is sent

T_{attain} is the time when the variation of THD values have reached the value of Table 4, thereby defining a new steady state operating condition.

1) Down-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at rated electrical power output.
b) The request signal for an electrical power-down with a step equal to that determined in 7.3.7.1 is sent to the controllers of the fuel cell power system.
c) The fuel cell power system decreases in electrical power output according to this control signal.
d) The transient response time from initiation of the electrical power demand signal until the variation of the THD values have reached the value of Table 4, thereby defining a new steady state operating condition with respect to THD, shall be observed and recorded.

2) Up-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at minimum electrical power output.
b) The request signal for an electrical power-up with a step equal to that determined in 7.3.7.1 is sent to the controllers of the fuel cell power system.
c) The fuel cell power system increases in electrical power output according to this control signal.

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2 THD = square root of the sum of squares of the amplitudes of harmonic currents or voltages (up to the 50^{th} harmonic) divided by the magnitude of the fundamental waveform.

d) The transient response time from initiation of the electrical power demand signal until the variation of the THD values have reached the value of Table 4, thereby defining a new steady state operating condition with respect to THD, shall be observed and recorded.

7.3.7.2.2 Grid connected net electrical power output transient

This section covers fuel cell power systems intended for grid connected operation.

The response time as defined in 3.1.8 will be measured. The electrical power output shall be measured continuously during the test in accordance with 6.3.1.

The ramp rate of the transient response of electrical power output shall be calculated with reference to Figure A2 in Annex A by means of the following equation:

(1) Down-Transient response of electrical power output

$$PR_{ramp} = (P_{rated} - P_{mini})/(T_{attain} - T_{ini}) = (P_{rated} - P_{mini})/ T_{down}$$

(2) Up-transient response of electrical power output

$$PR_{ramp} = (P_{rated} - P_{mini})/(T_{attain} - T_{ini}) = (P_{rated} - P_{mini})/ T_{up}$$

Where,

PR_{ramp} is the ramp rate (W/s, kW/s)
P_{rated} is the electrical power output at rated electrical power output (W, kW)
P_{mini} is the electrical power output at minimum electrical power output (W, kW)
T_{ini} is the time at starting the load change
T_{attain} is the time at attaining steady state rated electrical power output or steady state minimum electrical power output (within ±2% in accordance with Table 4).
T_{down} is the period from T_{ini} to T_{attain} (s)
T_{up} is the period from T_{ini} to T_{attain} (s)

1) Down-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at rated electrical load.
b) The electrical power-down signal to minimum electrical load is sent to the controllers of the fuel cell power system.
c) The fuel cell power system decreases in electrical power output according to this control signal.
d) The transient response time from initiation of the electrical power demand signal until attaining steady state minimum electrical power output (within ±2% in accordance with Table 4) shall be observed and reported.

2) Up-transient response of electrical power output

The fuel cell power system shall be confirmed to be in a steady state operating condition at minimum electrical power output.

The electrical power-up signal to rated electrical load is sent to the controllers of the fuel cell power system.

The power system increases in electrical power output according to this control signal.

The transient response time from initiation of the electrical power demand signal until attaining steady state rated electrical power output (within ±2% in accordance with Table 4) shall be observed and reported.

7.3.7.2.3 Thermal power output transient

For systems that are controlled according to the recovered heat, as defined in 3.1.5, the transient response time defined in 3.1.8 for thermal power output shall be observed by continuously measuring the recovered heat in accordance with 6.3.4.

The ramp rate of the transient response of thermal power output shall be calculated with reference to Figure A2 in Annex A by means of the following equation:

(1) Down-Transient response of thermal power output

$$QR_{ramp} = (Q_{rated} - Q_{mini})/(T_{attain} - T_{ini}) = (Q_{rated} - Q_{mini})/ T_{down}$$

(2) Up-transient response of thermal power output

$$QR_{ramp} = (Q_{rated} - Q_{mini})/(T_{attain} - T_{ini}) = (Q_{rated} - Q_{mini})/ T_{up}$$

Where,

QR_{ramp} is the ramp rate (kJ/s/s, or W/s, kW/s)

Q_{rated} is the thermal power output at rated thermal power output (recovered heat :Q_{HR}) (kJ/s, or W, kW)

Q_{mini} is the thermal power output at minimum thermal power output (recovered heat: Q_{HR}) (kJ/s, W, kW)

T_{ini} is the time at starting the thermal power output change

T_{attain} is the time at attaining steady state rated thermal power output or steady state minimum thermal power output (within ±2% in accordance with Table 4).

T_{down} is the period from T_{ini} to T_{attain} (s)

T_{up} is the period from T_{ini} to T_{attain} (s)

1) Down-transient response of thermal power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at rated thermal power output.
b) The thermal power-down signal to minimum thermal load is sent to the controllers of the fuel cell power system.
c) The fuel cell power system decreases in thermal power output according to this control signal.
d) The transient response time from initiation of the thermal power demand signal until attaining steady state minimum thermal power output (within ±2% in accordance with Table 4) shall be observed and reported

2) Up-transient response of thermal power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at minimum thermal power output.
b) The thermal power-up signal to rated thermal power output is sent to the controllers of the fuel cell power system.
c) The power system increases in thermal power output according to this control signal.
d) The transient response time from initiation of the thermal power demand signal until attaining steady state rated thermal power output (within ±2% in accordance with Table 4) shall be observed and reported

7.3.7.3 Response time constant

7.3.7.3.1 Grid independent net electrical power output transient

For fuel cell power systems designed for grid independent operation, the response time constant defined in 3.1.27 for net electrical power output shall be observed when the maximum acceptable instantaneous electrical power output transient defined in 7.3.7.1 is required from the fuel cell power system feeding a resistive load.

The response time constant of net electrical power output shall be calculated by means of the following equation:

$$T = T_{attain90} - T_{ini}$$

Where,

$T_{attain90}$ is the time when the electrical power output has reached 90% of the transient defined in 7.3.7.1 (within 10% of the specified value).

T_{ini} is the time when the electrical load change signal is sent

1) Down-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at rated electrical power output.
b) The request signal for an electrical power-down with a step equal to that determined in 7.3.7.1 is sent to the controllers of the fuel cell power system.
c) The fuel cell power system decreases in electrical power output according to this control signal.
d) The response time constant shall be observed and recorded from initiation of the electrical power demand signal until the electrical power output has reached 90% of the transient defined in 7.3.7.1 (within 10% of the specified value).

2) Up-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at minimum electrical power output.
b) The request signal for an electrical power-up with a step equal to that determined in 7.3.7.1 is sent to the controllers of the fuel cell power system.
c) The fuel cell power system increases in electrical power output according to this control signal.
d) The response time constant shall be observed and recorded from initiation of the electrical power demand signal until the electrical power output has reached 90% of the transient defined in 7.3.7.1 (within 10% of the specified value).

7.3.7.3.2 Grid connected net electrical power output transient

This section covers fuel cell power systems intended for grid connected operation.

The response time constant as defined in 3.1.27 will be measured. The electrical power output shall be measured continuously during the test in accordance with 6.3.1.

The time constant ramp rate of the transient response of electrical power output shall be calculated with reference to Figure A2 in Annex A by means of the following equation:

(1) Down-Transient response of electrical power output

$$PR_{ramp} = (P_{rated} - P_{mini})/(T_{attain10} - T_{ini}) = (P_{rated} - P_{mini})/ T_{down}$$

(2) Up-transient response of electrical power output

$$PR_{ramp} = (P_{rated} - P_{mini})/(T_{attain90} - T_{ini}) = (P_{rated} - P_{mini})/ T_{up}$$

Where,

PR_{ramp} is the time constant ramp rate (W/s, kW/s)
P_{rated} is the electrical power output at rated electrical power output (W, kW)
P_{mini} is the electrical power output at minimum electrical power output (W, kW)
T_{ini} is the time at starting the electrical power output change
$T_{attain10}$ is the time at attaining the electric power output within 10% of the minimum electrical power output.
$T_{attain90}$ is the time at attaining the electric power output within 90% of the rated electrical power output.
T_{down} is the period from T_{ini} to $T_{attain10}$ (s)
T_{up} is the period from T_{ini} to $T_{attain90}$ (s)

1) Down-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at rated electrical power output.
b) The electrical power-down signal to minimum electrical power output is sent to the controllers of the fuel cell power system.
c) The fuel cell power system decreases in electrical power output according to this control signal.
d) The response time constant from initiation of the electrical power output demand signal until attaining within 10% of minimum electrical power output shall be observed and recorded.

2) Up-transient response of electrical power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at minimum electrical power output.
b) The electrical power-up signal to rated electrical power output is sent to the controllers of the fuel cell power system.
c) The power system increases in electrical power output according to this control signal.
d) The transient response time from initiation of the electrical power output demand signal until attaining within 90% of rated electrical power output shall be observed and recorded.

7.3.7.3.3 Thermal power output transient

For systems that are controlled according to the recovered heat, as defined in 3.1.5, the response time constant defined in 3.1.27 for thermal power output shall be observed by continuously measuring the recovered heat in accordance with 6.3.4.

The time constant ramp rate of the transient response of thermal power output shall be calculated with reference to Figure A2 in Annex A by means of the following equation:

(1) Down-Transient response of thermal power output

$$QR_{ramp} = (Q_{rated} - Q_{mini})/(T_{attain10} - T_{ini}) = (Q_{rated} - Q_{mini})/ T_{down}$$

(2) Up-transient response of thermal power output

$$QR_{ramp} = (Q_{rated} - Q_{mini})/(T_{attain90} - T_{ini}) = (Q_{rated} - Q_{mini})/ T_{up}$$

Where,

QR_{ramp} is the time constant ramp rate (kJ/s/s, or W/s, kW/s)
Q_{rated} is the thermal power output at rated thermal power output (recovered heat:Q_{HR}) (kJ/s, W, kW)

Q_{mini} is the thermal power output at minimum thermal power output (recovered heat: Q_{HR}) (kJ/s, W, kW)
T_{ini} is the time at starting the thermal power output change
$T_{attain10}$ is the time at attaining within 10% of minimum thermal power output
$T_{attain90}$ is the time at attaining within 90% of rated thermal power output
T_{down} is the period from T_{ini} to $T_{attain10}$ (s)
T_{up} is the period from T_{ini} to $T_{attain90}$ (s)

1) Down-transient response of thermal power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at rated thermal power output.
b) The thermal power-down signal to minimum thermal power output is sent to the controllers of the fuel cell power system.
c) The fuel cell power system decreases in thermal power output according to this control signal.
d) The transient response time from initiation of the thermal power output demand signal until attaining within 10% of minimum thermal power output shall be observed and recorded.

2) Up-transient response of thermal power output

a) The fuel cell power system shall be confirmed to be in a steady state operating condition at minimum thermal power output.
b) The thermal power-up signal to rated thermal power output is sent to the controllers of the fuel cell power system.
c) The power system increases in thermal power output according to this control signal.
d) The transient response time from initiation of the thermal power output demand signal until attaining within 90% of rated thermal power output shall be observed and recorded.

7.3.8 Start-up and Shut-down characteristics

The test item includes the measurement of:

a) start-up time (see 3.1.12)

b) shutdown time (see 3.1.16)

c) start-up energy (see 3.1.13).

The manufacturer shall specify the conditions for the storage state and the stand-by state, as defined in 3.1.10 and 3.1.11 respectively. See Figure A1 in Annex A for additional information.

The test for a) and b) listed above consists of measuring the time between the initiation of the command for the start up or shutdown until the requested status is attained.

For c) listed above, the energy during the start up is measured. Electrical power output and thermal power output shall be measured concurrently during the start up energy test in accordance with 6.3.1 and 6.3.4 respectively.

7.3.9 Purge gas consumption

Measure purge gas flow rate according to 6.3.7.

(1) Separately carry out the measurement of purge gas consumption at the following conditions:

a) cold state,

b) start-up,

c) normal shutdown,

d) emergency shutdown, and

e) storage state.

(2) In the measurement of purge gas consumption during start-up, measure the amount of purge gas used from the instant when the start-up process is initiated to the instant when the start-up is completed.

(3) In the measurement of purge gas consumption during a normal shutdown, measure the amount of purge gas used from the instant when the normal shutdown process is initiated to the instant when the shutdown is completed.

(4) In the measurement of purge gas consumption during an emergency shutdown, measure the amount of purge gas used from the instant when the emergency shutdown process is initiated to the instant when the emergency shutdown is completed.

(5) In the measurement of purge gas consumption during the storage state, measure the amount of purge gas used per hour after completion of normal shutdown or emergency shutdown process.

7.3.10 Water consumption

Water consumption; q_{vw} (m^3/s) shall be measured in accordance with 6.3.7 at the conditions specified in Table 3.

The power level shall be measured and recorded during the tests.

The duration of each test run shall be measured and recorded.

The total amount of water used during each test run shall be measured and recorded.

7.3.11 Oxidant (Air) consumption

Measure oxidant (air) consumption in accordance with 6.3.6.1 during testing as shown in Table 4.

When the measured flow rate of the oxidant (air) is provided in volume, the mass flow rate shall be calculated by means of the following equation:

$$q_{va0} = q_{va} \times (t_0 / t_a) \times (p_a / p_0)$$

$$q_{ma} = q_{va0} \times \rho_{a0}$$

where,

q_{va0} is the volumetric flow rate of the oxidant (air) at the reference conditions; (m^3/s)

q_{va} is the volumetric flow rate of the oxidant (air) at temperature t_a and pressure p_a; (m^3/s)

q_{ma} is the mass flow rate of the oxidant (air) ; (kg/s)

ρ_{a0} is the density of the oxidant (air) at the reference conditions; (kg/m^3)

t_0 is the reference temperature (288.15 K)
p_0 is the reference pressure (101.325 kPa)
t_a is the temperature of the oxidant at test conditions; (K)
p_a is the pressure of the oxidant at test conditions; (kPa)

Note: These values shall be provided as average value during the test period.

7.3.12 Calculation of oxidant (air) energy

When hot or pressurised oxidant (air) is directly supplied to the fuel cell power system, the energy of the oxidant (air) shall be calculated based on the conditions of the oxidant (air) at the interface point of the fuel cell power system.

The energy of air at a temperature t_a and a pressure p_a is calculated from the equation

$$E_{av}= (h_a - h_{a0} + E_{pa})/M_0$$

where

E_{av} is the input energy of the oxidant (air) per unit of volume; (kJ/m^3)
h_a is the specific enthalpy of the oxidant (air) at temperature t_a; (kJ/mol)
h_{a0} is the specific enthalpy of the oxidant (air) at reference temperature t_0; (kJ/mol)
E_{pa} is the pressure energy of the oxidant (air); (kJ/mol)
M_o is the reference molar volume of ideal gas; (2.3645×10^{-2} m^3/mol) (at the reference temperature for this standard, t_0 = 288.15 K)

The specific enthalpy of air is calculated from the equation

$$h_a=(A_a \times t_a+(B_a/2000) \times t_a^2+(C_a/3 \times 10^6) \times t_a^3) \times 10^{-3}$$

where,

A_a, B_a, and C_a are the constants of oxidant (air), and the numerical values of A_a, B_a, and C_a, (for air) are given in Worksheet-2 of Annex-C.
h_a is calculated by the same equation of $h_{f.}$ for air. Other oxidants must have the enthalpy calculated separately.
t_a is the temperature of oxidant [K]

The pressure energy of oxidant (air) is calculated by the equation

$$E_{pa}=R \times t_o \times \ln(p_a/p_0)$$

where,

R is the universal gas constant (8.314 J/mol K)
t_0 is the reference temperature (288.15 K)
p_0 is the reference pressure (101.325 kPa)
p_a is the pressure of oxidant (kPa)

7.3.13 Waste heat

The waste heat is calculated by the equation:

$$Q_{WH}=q_{vf0} \times E_{fv}+q_{va0} \times E_{av}-P_{out}-P_{in}-Q_{HR}$$

where,

Q_{WH} is the waste heat(kJ/s)

q_{vf0} is the volumetric flow rate of the fuel at reference conditions(m^3/s)
E_{fv} is the input energy of fuel per unit volume(kJ/m^3)
q_{va0} is the volumetric flow rate of the oxidant (air) at reference conditions (m^3/s)
E_{av} is the input energy of air per unit volume (kJ/m^3)
P_{out} is the active power of electric power output (kW)
P_{in} is the active power of electric power input from external power source (kW)
Q_{HR} is the energy of recovered heat (kJ/s)

7.3.14 Exhaust gas emission

This test procedure is confirmation of emission characteristics exhausted from a fuel cell power system operated under the following conditions;

a) Measure the peak concentration of each constituent as described in 6.3.8 during a start-up.

b) Measure the peak concentration of each constituent as described in 6.3.8 during a shutdown.

c) Measure the amount of each constituent as described in 6.3.8 during operation at partial power output specified in 7.1

d) Measure the amount of each constituent as described in 6.3.8 during operation at rated power output.

Emission of particulate, SOx, NOx, CO_2, CO, and total hydrocarbon shall be continuously measured according to 6.3.8 and Table 4. The exhaust gas temperature, pressure, and flow rate shall be measured according to6.3.8.1, 6.3.8.2 and 6.3.8.3, respectively.

7.3.15 Calculation of emission production

The quantity of a specified gas emission shall be calculated as follows:

$$q_{me} = q_{ve} \times \rho_e$$

where,

q_{me} is the mass flow rate of gas emission component (kg/s)
q_{ve} is the measured volumetric flow rate of exhaust gas (m^3/s)
ρ_e is the mass concentration of a specified gas component (kg/m^3)

These ρ_e values must be corrected using ISO 7934 for actual temperature, actual pressure, and wet/dry conditions.

Exhaust gas oxygen concentration must be measured and reported.

7.3.16 Noise

Noise produced by a fuel cell power system shall be measured through the operating process; (start-up to shutdown) in accordance with 6.3.13 and Table 3 in order to get the maximum value.

Corrections for background noise shall be made in accordance with ISO 3744, Section 8.

The maximum corrected noise level, and the corresponding operating conditions and output power level shall be reported.

7.3.17 Vibration

Vibration produced by a fuel cell power system shall be measured through the operating condition mentioned below in accordance with 6.3.14. The background vibration level shall be measured when the fuel cell power system is not in operation.

The vibration level shall be monitored during a start-up transient starting from the cold state. Vibration levels shall be measured through increasing power levels up to rated load. The vibration level shall be measured at steady state rated load. The vibration shall also be monitored during a shutdown transient starting from rated load. Vibration levels shall also be measured during the shutdown transient until the fuel cell power system reaches the standby state or the cold state to find the maximum vibration level.

The maximum operating vibration level shall be reported. The background vibration level with the fuel cell power system not operating shall also be reported.

Corrections for the background vibration level shall be made for the maximum vibration level in accordance with the following procedure.

The difference between the reported maximum vibration level and the background vibration level shall be calculated in dB.

Calculate the correction to the reported maximum vibration level using Table 5.

If the difference is at more than 9 dB (maximum vibration level is higher than background by more than 9 dB) no correction is necessary.

If the difference is less than 3 dB, the background is too high for reliable measuring and must be reduced.

For very low vibration systems, the maximum vibration level may be very low. The maximum vibration level may be below 10 dB. For these very low vibration systems, below 10 dB measured maximum vibration, no correction for background is necessary.

If the difference between the maximum operating vibration level and the non-operating background is between 3 and 10 dB, use the following Table 5 to compute the correction to the reported maximum vibration level.

Table 5 – Vibration Correction Factors

Difference of indicated value in dB	3	4	5	6	7	8	9
Correction Value	-3	-2	-2	-1	-1	-1	-1

Note 1: A difference of 10 dB or more indicates no significant influence of background vibration, and the correction is not necessary.

Note 2. A difference less than 3 dB implies that the background vibration is too large for reliable measurement.

7.3.18 Discharge water quality

Measure discharge water quality in accordance with 6.3.9 and Table 3.

8 Test reports

Test reports shall accurately, clearly and objectively present sufficient information to demonstrate that all the objectives of the tests have been attained. The reports shall contain all information developed in 7. Three types of reports are required, summary, detailed, and full. Each type of report shall contain the same title page and a table of contents. For fuel cell systems tested in compliance with this standard, the summary report will be made available to interested parties.

8.1 Title page

The title page shall present the following information:

1) Report identification number; (optional)
2) Type of reporting; (summary, detailed or full)
3) Author of report;
4) Entity conducting the test;
5) Date of report;
6) Location of test;
7) Title of the test;
8) Date of test;
9) Fuel cell power system identification and manufacturer's name;
10) Type of fuel used for the test with reference to appropriate gas reference table (Annex D).

8.2 Table of contents

For each type of report, a Table of Contents shall be provided.

8.3 Summary report

The summary report shall include the following information:

1) Objective of the test
2) Description of the test, equipment and instruments.
3) All test results
4) Uncertainty level attached to each test result
5) Confidence level attached to each test result.
6) For determination of recovered heat, pressure and temperature of the heat recovery fluid.
7) Conclusions as appropriate.

8.4 Detailed report

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

1) The type and operating configuration of the fuel cell power system and the process flow diagram showing the test boundary.
2) Description of the arrangements, location and operating conditions of the equipment and instruments.
3) Reference to the calculation method;
4) Tabular and graphical presentation of the results;
5) Discussion of the test and its results (i.e. comments and observations).

8.5 Full report

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

1) Copies of original data sheets

Original data sheets shall include the following information in addition to measurement data;

a) Date of the test run.
b) Model number and measurement accuracy of instruments used for the test.
c) Ambient test conditions
d) Name of person(s) conducting the test
e) Full and detailed uncertainty analysis.
f) Results of fuel analysis

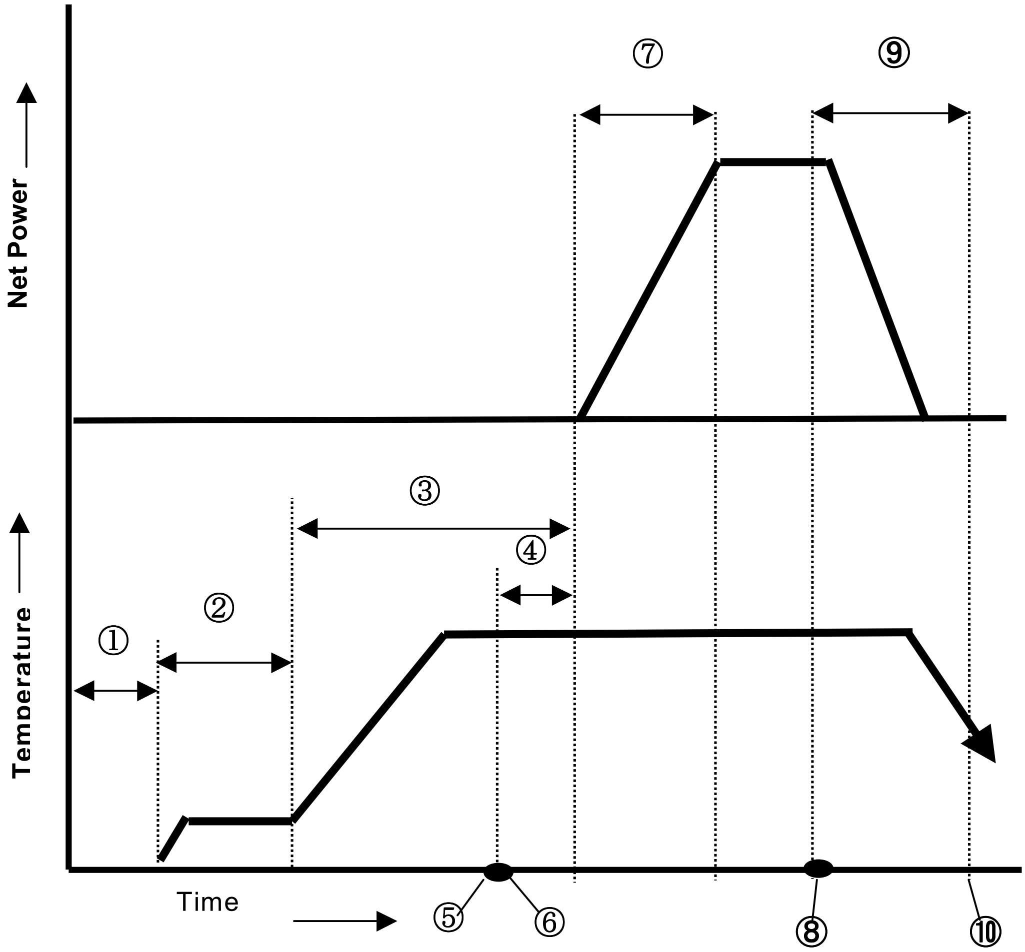
Annex A

Definition of Operating Process /Fuel Cell Power System

A.1 General

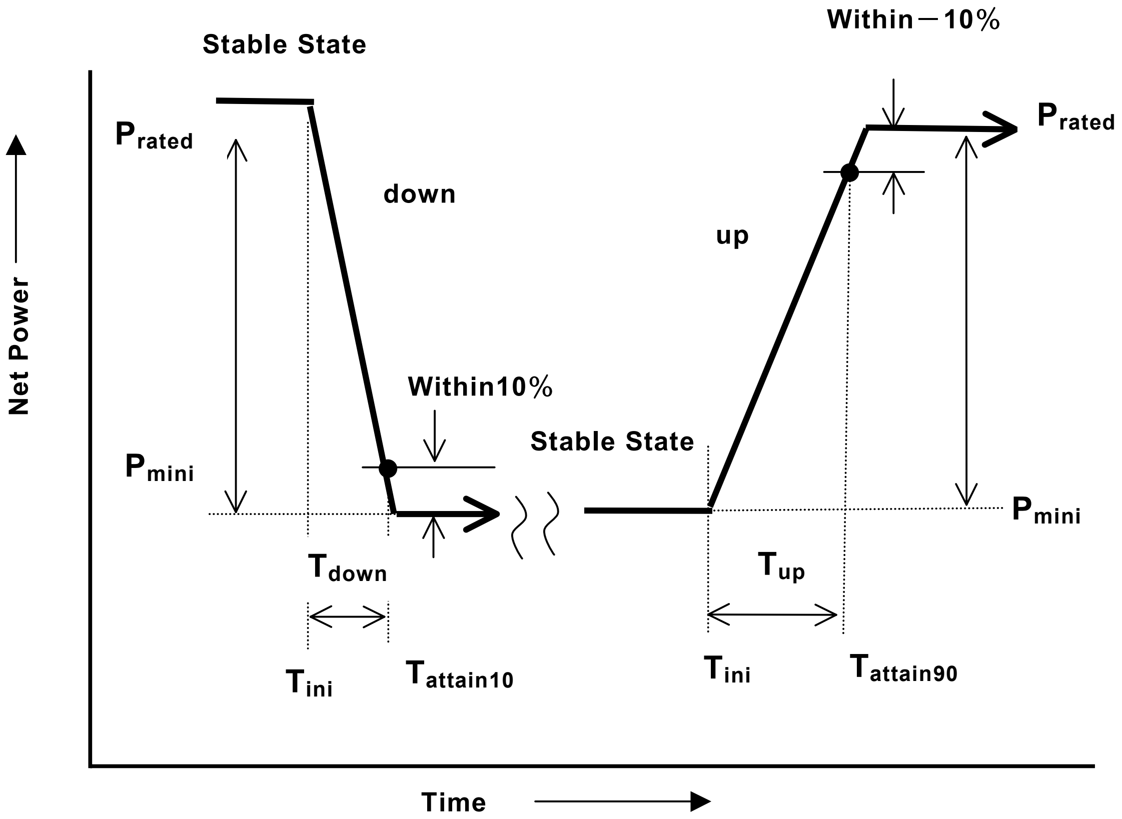
Figure A.1 provides more information for the definitions from **3.1.9** to **3.1.16**.

Figure A.2 provides more information for the definitions from **3.1.8** and **3.1.27**.



1 Shutdown (Cold state) Ambient temperature, Zero power input
2 Storage state
3 Start-up time
4 Response time to net power output (refer to Figure A2)
5 Stand-by state
6 Power up action initiated
7 Response time to rated power
8 Shutdown action initiated
9 Shutdown time
10 Shutdown condition specified

Figure A1- Operating Process Chart of Fuel Cell Power System



P_{rated}	Rated Power Output
P_{mini}	Minimum Power Output
T_{ini}	Time at starting the power output change
$T_{attain90}$	Time at attaining within 10% of rated power output
$T_{attain10}$	Time at attaining within 10% of minimum power output
T_{down},	Period from T_{ini} to $T_{attain10}$
T_{up}	Period from T_{ini} to $T_{attain90}$

Figure A2- Response Time Constant Characteristics

Annex B

Guidance Uncertainty Analysis

B.1 General

When reporting the result of a measurement of a physical quantity, it is obligatory that some quantitative indication of the quality of the result be given so that those who use it can asses its reliability (G.E.U.M.) Therefore, uncertainty analysis is indispensable for a fuel cell power system 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 fuel cell power system performance. Uncertainty shall be indicated with a performance value (i.e. electric efficiency, heat recovery efficiency and so on).

This Annex serves as a guide for pre-test and post-test uncertainty calculations and shows an example of uncertainty analysis for electrical efficiency, it is only provided for informative purposes, not as an explicit test result. The user of this standard must read, understand, and follow the ISO/IEC Guide for Expression of Uncertainty in Measurement – 1995 in order to accomplish a proper uncertainty analysis.

The Uncertainty Analysis for this standard must be performed in accordance with the ISO/IEC Guide for Expression of Uncertainty in Measurement – 1995. This Annex gives examples but please refer to the ISO/IEC G.E.U.M. for explicit guidance.

B.2 Preparations

Uncertainty of fuel cell power system performance (i.e. electric efficiency and so on) can be computed by the uncertainties of the various parameters, as well as fuel cell power system 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 minimise the uncertainty of fuel cell power system performance, systematic uncertainties and random uncertainties of the parameters shall be minimised.

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

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

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

Fluctuations of measurements (both short term and long term variations), and steady state test conditions must be confirmed by preliminary test, before conducting the performance test. Steady state is defined in 7.1. Test run duration must be decided according to the fluctuations of long-term parameter measurements. Test run duration must include at least one cycle of long-term fluctuations.

During test run duration, at least 30 independent data sets of every parameter shall be measured to obtain a standard deviation of the data. Each data set shall 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 the IEC/ISO Guide to Expresseion of Uncetainty in Measurement – 1995. The guidance herein is simplified for use with fuel cell systems, using assumptions consistent with their design as well as good testing practice dictated by this standard.

Basic assumptions include:

All systematic uncertainty sources are assumed normally distributed and are estimated as 2σ for 95% coverage. In this standard, systematic uncertainty is defined as the calibration error or accuracy of an instrument, B.

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 the G.E.U.M. .

All random uncertainty sources are assumed normally distributed and estimated as $2S_{\bar{x}}$ of measurements, which is 95% confidence coverage.

Total uncertainty, U_{95} is obtained by combining systematic uncertainty, B and random uncertainties of a measurement, $S_{\bar{x}}$ with following equation.

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

Which is equivalent to

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

B.4 General approach

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

(1) Define the Measurement Process

a) Review test objectives and test duration

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

b) List all independent measurement parameters and their nominal levels

c) List all calibrations and instrument settings that will affect each parameter. Be sure to check for uncertainties in measurement system components that affect two or more measurements simultaneously (correlated uncertainties).

d) Define the functional relationship between the independent measurement parameters and the test result. (Define the equations for calculating fuel cell power system performance as given in the text.)

(2) List elemental error sources

a) Make a complete and exhaustive list of all possible test uncertainty sources for all parameters.

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

a) Absolute systematic uncertainty (B_i) is calculated by multiplying calibration accuracy by the nominal value of every parameter

b) Absolute random uncertainty ($2S_{xi}$) is two times as much as the standard deviation of parameter.

(4) Propagate the systematic and random uncertainty for each parameter.

a) The systematic and random uncertainty of the independent parameters is propagated separately all the way to the final result with following equation.

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

$$B_R = \left[\sum (\theta_i B_{\overline{P}i})^2\right]^{1/2}$$

$$2S_R = \left[\sum (\theta_i 2S_{\overline{P}i})^2\right]^{1/2}$$

B_R is the systematic uncertainty component of a result.

$2S_R$ is the random uncertainty component of a result.

(5) Calculate the Total Uncertainty

Calculation of uncertainty is done in accordance with following equation, combining the systematic and random uncertainties to get the total uncertainty.

$$U_{R95} = \left[(B_R)^2 + (2S_R)^2\right]^{1/2}$$

(6) Prepare the report in accordance with 8,Test Report.

B.5 Example calculations

B.5.1 Uncertainty calculation for electrical efficiency

B.5.1.1 Definition of the measurement process

This example will focus on the calculation of electrical efficiency. The system is a 1kW PEFC fuel cell system, with 0.1kW electrical inputs from grid for parasitic load and fuel input. The system uses city gas fuel and provides 1.1kW electric power output at the terminals. Net electrical power output is 1kW. City gas fuel is provided at the temperature of 298.15K and pressure of 110kPa. Oxidant (air) is provided at ambient temperature and pressure.

The fuel flow is measured with a precision mass flow meter and online sampling is used to compute the lower heating value of the fuel. Electrical output and electrical input are measured using a power kWh meter.

Test run duration was decided taking into account the long term fluctuations of parameter measurements. Test run duration included 5 cycles of long term fluctuation. During test run duration, 60 sets of 30 measurements of every parameter were obtained. Interval of every set of measurements was 1 minute. Every value of parameter for calculating performance is the total mean of 60 sets of 30 measurements.

All independent measurement parameters and their nominal levels of the total means of 60 sets of 30 measurements are listed on Table B1.

The electrical efficiency, η_e is defined as follows according to 7.3.4. In this example, the term of energy carried by air is omitted as follows.

$$\eta_e = \frac{(P_{out} - P_{in})}{q_{vo} \times E_{fv}} \times 100$$

where,

P_{out} is the electric power output

P_{in} is the electric power input for parasitic load etc.

q_{v0} is the volumetric flow rate of fuel at the reference conditions,m^3/sec

E_{fv} is the input energy of the fuel per unit of volume; kJ/m^3

When fuel is a gas, the mass flow rate of the fuel "q_{vf0}" is calculated as follows:

$$q_{vf0} = q_{vf} \times (288.15/t_f) \times (p_f / 1.013 \times 10^2)$$

where,

t_f is the temperature of fuel

p_f is the pressure of fuel

q_{vf0} is the volumetric flow rate of fuel at the reference conditions,m^3/s.

q_{vf} is the volumetric flow rate of the fuel at temperature tf and pressure pf; m^3/s.

When fuel is a gas, the input energy of the fuel "E_{fv}" is calculated as follows:

$$E_{fv} = (Q_{f0} + h_f - h_{f0} + E_{pf}) / M_0$$

where

E_{fv} is the input energy of the fuel per unit of volume; kJ/m^3
Q_{f0} is the heating value of the fuel at reference conditions;kJ/mol
h_f is the specific enthalpy of the fuel at temperature t_f;kJ/mol
h_{f0} is the specific enthalpy of the fuel at the reference temperature. t_0; kJ/mol
E_{pf} is the pressure energy of the fuel.;kJ/mol
M_o is the reference molar volume of ideal gas; 2.3645x10^{-2} m^3/mol (at the reference temperature for this standard, 288.15 K)

The heating value of fuel is calculated from the following equation

$$Q_{f0} = \sum_{j=1}^{N} x_j \times Q_{f0j}$$

where,

Q_{f0j} is the heating value of component j; (kJ/mol)
x_j is the molar ratio of component j

Note; Numerical values of Q_{f0j} are given in Table C1 of ANNEX-C

The specific enthalpy of fuel is calculated from the following equation

$$h_f = \sum_{j=1}^{N} x_j \times h_{fj}$$

where,

h_{fj} is the specific enthalpy of component j at temperature t_f ; kJ/mol

h_{fj} is calculated as follows;

$$h_{fj}=A_j \cdot t_f+B_j \cdot t_f^2+C_j \cdot t_f^3$$

where,

A_j, B_j and C_j are the constants of component j.

Note: Numerical values of A_j, B_j, and C_j, are given in Table C2 of ANNEX-C.

The specific enthalpy of the fuel at the reference temperature; h_{f0} It is calculated by the same equation of h_f.

The pressure energy of fuel is calculated from the following equation

$$E_{pf}=R \cdot t_o \cdot \ln(p_f/101.325)$$

where,

R is the universal gas constant (8.314 J/mol K)

Table B1-Summary of measurement parameters and their nominal values.

Parameter (Pi)	Description	Units	Nominal Value
q_v	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/h	0.2367
t_f	Temperature of fuel	K	298.15
p_f	Pressure of fuel	kPa	110
Fuel Composition (13A)	Methane	%	88
Fuel Composition (13A)	Ethane	%	6
Fuel Composition (13A)	Propane	%	5
Fuel Composition (13A)	Butane	%	2
P_{out}	Electric power output	kW	1.10
P_{in}	Electric power input for parasitic load etc.	kW	0.10

Table B2-Nominal values of the calculation results

Calculated Results	Description	Units	Nominal Value
q_{v0}	Volumetric flow rate of fuel at the reference conditions	m^3/h	0.2484
Qf0	Heating value of fuel at the reference conditions (LHV)	kJ/mol	926.4
hf	Specific enthalpy of fuel at temperature tf	kJ/mol	7.969
hf0	Specific enthalpy of fuel at the reference temperature	kJ/mol	7.583
Epf	Pressue energy of the fuel	kJ/mol	0.2036
Efv	Input energy of the fuel	kJ/m^3	39203.2
η e	Electrical efficiency	%	37.0

B.5.1.2 List Elemental Error Sources

Elemental error sources can be estimated based on judgement, calculated using pre-test data, or developed using calibration laboratory calculations. Elemental error sources for the various parameters in the example procedure are given on Table 4.

Table B3 - Elemental error sources for the various parameters

Parameter (Pi)	Description	Units	Nominal Value	Elemental Error Sources
$q_{v\,f}$	Volumetric flow rate of fuel at temperature tf and	m3/h	0.2367	Meter calibration errors, random errors
t_f	Temperature of fuel	K	298.15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors
Fuel Composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,
Fuel Composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,
Fuel Composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,
Fuel Composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,
P_{out}	Active power of electric power output	kW	1.10	Revenue meter calibration errors, loop calibration errors, random errors
P_{in}	Active power of electric power input for parasitic load etc.	kW	0.10	Revenue meter calibration errors, loop calibration errors, random errors

B.5.1.3 Calculate or Assign the Systematic and Random Uncertainty for Each Parameter.

Systematic Uncertainty; Calibration errors will account for the majority of the systematic uncertainty and so they are used with judgment as the absolute systematic uncertainty for those instruments where the calibration uncertainty is known. For instruments or instrument loops where calibration is ± 1% of full scale, the absolute uncertainty is calculated by multiplying 0.01 by the full-scale reading of the instrument. For instruments where the calibration uncertainty is ± 1% of reading, the absolute uncertainty is calculated by multiplying 0.01 by the nominal reading. Different calibration uncertainties will require different numerical inputs.

Absolute systematic uncertainty (Bi) is calculated by multiplying calibration accuracy by the nominal value of every parameter on Table B4.

Random Uncertainty; Random uncertainty is estimated as two times as much as standard deviation of parameters measurements.

Standard deviation (Sxi) of a parameter was calculated with the total mean of 60 sets of 30 measurements for a parameter during test run duration.

Absolute random uncertainty (2Sxi) is two times as much as the standard deviation on Table B4. σ is standard deviation in percentage.

For post-test analysis, the actual standard deviation must be used. If the random uncertainty is too high, additional test duration and additional data points shall lower the standard deviation.

Table B4 — Absolute Systematic Uncertainty (Bi) and Absolute random uncertainty (2Sxi)

Parameter (Pi)	Description	Units	Nominal Value	Elemental Error Sources	Cal	Absolute Systematic Uncertainty (Bi)	σ (Sxi)	Absolute Random Uncertainty (2Sxi)
$q_{v\,f}$	Volumetric flow rate of fuel at temperature tf and	m3/h	0.2367	Meter calibration errors, random errors	0.010	2.37.E-03	0.010	4.73.E-03
t_f	Temperature of fuel	K	298.15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	-	1.00.E+00	0.015	2.00.E+00
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	0.005	5.50.E-01	0.001	2.20.E-01
Fuel Composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,	0.005	4.40.E-01	0.001	1.76.E-01
Fuel Composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,	0.005	2.90.E-02	0.001	1.16.E-02
Fuel Composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,	0.005	2.25.E-02	0.001	9.00.E-03
Fuel Composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors,	0.005	8.50.E-03	0.001	3.40.E-03
P_{out}	Active power of electric power output	kW	1.10	Revenue meter calibration errors, loop calibration errors, random errors	0.005	5.50.E-03	0.001	2.20.E-03
P_{in}	Active power of electric power input for parasitic load etc.	kW	0.10	Revenue meter calibration errors, loop calibration errors, random errors	0.005	5.00.E-04	0.001	0.0002

B.5.1.4 Propagate the Systematic and Random Uncertainty for Each Parameter

The systematic and random uncertainty of the independent parameters are propagated separately all the way to the final result. In order to propagate the various uncertainties properly, the various sensitivities θ_i of each parameter Pi must be calculated. The sensitivity of a particular parameter is calculated with either taking the partial differential of the parameter with respect to the result (the efficiency in this case) or carrying out a computer perturbation of the data fields using small changes in each parameter independently to ascertain the change in the result for a small change in the parameter. In this example, the latter way was introduced. The change in parameters was 0.0001%. The systematic uncertainty and random uncertainty for each parameter must be multiplied by the proper sensitivity in accordance with the following equations.

$$B_R = \left[\sum (\theta_i B_{\bar{P}i})^2\right]^{1/2}$$

$$2S_R = \left[\sum (\theta_i 2S_{\bar{P}i})^2\right]^{1/2}$$

where,

B_{PI} is absolute systematic uncertainty for the parameter Pi
S_{PI} is absolute standard deviation of the mean for parameter Pi
B_R is the systematic uncertainty component of a result.
$2S_R$ is the random uncertainty component of a result.
θ_i is sensitivity coefficient for the parameter Pi

$(\theta_i B^-{}_{,Pi})^2$ is absolute systematic uncertainty contribution for the parameter Pi

$(\theta_i 2S^-{}_{,Pi})^2$ is random systematic uncertainty contribution for the parameter Pi

The sensitivity coefficients for the parameters Pi are listed on Table B5.

Propagated systematic uncertainty $\mathbf{B_R}$ and random uncertainty $\mathbf{2S_R}$ are listed on Table B6.

Table B 5— Sensitivity coefficients for the parameter Pi

Delta X% 0.0001

Parameter for Sensitivity		qv f	tf	pf	Methane	Ethane	Propane	Butane	Pout	Pin
Parameter (Pi)	Base	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta
qv f	0.0000E+00	2.3672E-07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
tf	0.0000E+00	0.0000E+00	2.9815E-04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
pf	0.0000E+00	0.0000E+00	0.0000E+00	1.1000E-04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Methane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	8.8000E-05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Ethane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.8000E-06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Propane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.5000E-06	0.0000E+00	0.0000E+00	0.0000E+00
Butane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.7000E-06	0.0000E+00	0.0000E+00
Pout	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.1000E-06	0.0000E+00
Pin	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E-07
Calculated Results	η e Nom	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta
q_{v0}	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484
Qf0	926.4	926.4	926.4	926.4	926.4	926.4	926.4	926.4	926.4	926.4
hf	7.969	7.969	7.969	7.969	7.969	7.969	7.969	7.969	7.969	7.969
hf0	7.583	7.583	7.583	7.583	7.583	7.583	7.583	7.583	7.583	7.583
Epf	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036
Efv	39203.2	39203.2	39203.2	39203.3	39203.2	39203.2	39203.2	39203.2	39203.2	39203.2
η_e	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
Absolute Sensitivity (θ i)	–	3.1031E+02	-3.3154E-04	7.9858E-02	3.8214E-01	5.7447E+00	7.8138E+00	2.1744E+01	7.0568E+01	3.3268E+02

Table B6 — Propagated systematic uncertainty B_R and random uncertainty $2S_R$

Parameter (Pi)	Description	Units	Nominal Value	Elemental Error Sources	Cal	Absolute Systematic Uncertainty (Bi)	σ (Sxi)	Absolute Random Uncertainty (2Sxi)	Absolute Sensitivity (θ i)	Absolute Systematic Uncertainty Contribution $(\theta i \cdot Bi)^2$	Absolute Random Uncertainty Contribution $(\theta i \cdot 2Sxi)^2$
q_{vf}	Volumetric flow rate of fuel at temperature tf and pressure pf	m3/h	0.2367	Meter calibration errors, random errors	0.010	2.37.E-03	0.010	4.73.E-03	3.1031E+02	5.3959E-01	2.1584E+00
t_f	Temperature of fuel	K	298.15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	-	1.00.E+00	0.015	2.00.E+00	-3.3154E-04	1.0992E-07	4.3966E-07
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	0.005	5.50.E-01	0.001	2.20.E-01	7.9858E-02	1.9291E-03	3.0866E-04
Fuel Composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	4.40.E-01	0.001	1.76.E-01	3.8214E-01	2.8271E-02	4.5234E-03
Fuel Composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	2.90.E-02	0.001	1.16.E-02	5.7447E+00	2.7755E-02	4.4407E-03
Fuel Composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	2.25.E-02	0.001	9.00.E-03	7.8138E+00	3.0909E-02	4.9454E-03
Fuel Composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	8.50.E-03	0.001	3.40.E-03	2.1744E+01	3.4159E-02	5.4654E-03
P_{out}	Active power of electric power output	kW	1.10	Revenue meter calibration errors, loop calibration errors, random errors	0.005	5.50.E-03	0.001	2.20.E-03	7.0568E+01	1.5064E-01	2.4102E-02
P_{in}	Active power of electric power input for parasitic load etc.	kW	0.10	Revenue meter calibration errors, loop calibration errors, random errors	0.005	5.00.E-04	0.001	0.0002	3.6964E+01	3.4159E-04	5.4654E-05
Calculated Results	**Description**	**Units**	**Nominal Value**						Σ (θ i· Bi)2 (L) Σ (θ i· 2Sxi)2 (R)	8.1359E-01	2.2022E+00
q_{v0}	Volumetric flow rate of fuel at the standard conditions	m3/h	0.2484						B_R(L), $2S_R$(R)	9.0199E-01	1.4840E+00
Qf0	Heating value of fuel at the standard conditions (LHV)	kJ/mole	926.4								
hf	Specific enthalpy of fuel at temperature tf	kJ/mole	7.969								
hf0	Specific enthalpy of fuel at the standard temperature	kJ/mole	7.583								
Epf	Pressue energy of the fuel	kJ/mole	0.2036								
Efv	Input energy of the fuel	kJ/m3	39203.2								
η_e	Electrical efficiency	%	37.0								

B.5.1.5 Calculate the Total Uncertainty

The Total Absolute Uncertainty of the Result is computed by combining the absolute systematic uncertainty with the absolute random uncertainty in the following manner.

Total Absolute Uncertainty of the Result, $U_{R95} = \sqrt{B_R^2 + (2S_R)^2}$

Where,

B_R is the propagation of systematic uncertainty components as a result.
$2S_R$ is the propagation of random uncertainty components as a result.

Percent Uncertainty of U_{R95} of electric efficiency is obtained by dividing total absolute uncertainty with nominal value of electric efficiency.

Total Absolute Uncertainty of the Result U_{R95} and Percent Uncertainty of U_{R95} of electric efficiency are shown in Table B7.

B.5.1.6 Prepare the Report in accordance with 8.Test Report.

The result of uncertainty analysis is expressed as follow, for example .

Electrical efficiency : 37.0%±1.7%

Total uncertainty of electrical efficiency: 4.7%.

Table B7 — Total Absolute Uncertainty of the Result U_{R95} and Percent Uncertainty of U_{R95} of electric efficiency

Uncertainty Analysis for Electric Efficiency

Electrical efficiency: 37.0 ± 1.7 %   Total Uncertainty ± 4.7%

Parameter (Pi)	Description	Units	Nominal Value	Elemental Error Sources	Cal	Absolute Systematic Uncertainty (Bi)	σ (Sxi)	Absolute Random Uncertainty (2Sxi)	Absolute Sensitivity (θi)	Absolute Systematic Uncertainty Contribution $(\theta i\cdot Bi)^2$	Absolute Random Uncertainty Contribution $(\theta i\cdot 2Sxi)^2$
q_{vf}	Volumetric flow rate of fuel at temperature tf and pressure pf	m3/h	0.2367	Meter calibration errors, random errors	0.010	2.37.E-03	0.010	4.73.E-03	3.1031E+02	5.3959E-01	2.1584E+00
t_f	Temperature of fuel	K	298.15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	-	1.00.E+00	0.015	2.00.E+00	-3.3154E-04	1.0992E-07	4.3966E-07
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	0.005	5.50.E-01	0.001	2.20.E-01	7.9858E-02	1.9291E-03	3.0866E-04
Fuel Composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	4.40.E-01	0.001	1.76.E-01	3.8214E-01	2.8271E-02	4.5234E-03
Fuel Composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	2.90.E-02	0.001	1.16.E-02	5.7447E+00	2.7755E-02	4.4407E-03
Fuel Composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	2.25.E-02	0.001	9.00.E-03	7.8138E+00	3.0909E-02	4.9454E-03
Fuel Composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0.005	8.50.E-03	0.001	3.40.E-03	2.1744E+01	3.4159E-02	5.4654E-03
P_{out}	Active power of electric power output	kW	1.10	Revenue meter calibration errors, loop calibration errors, random errors	0.005	5.50.E-03	0.001	2.20.E-03	7.0568E+01	1.5064E-01	2.4102E-02
P_{in}	Active power of electric power input for parasitic load etc.	kW	0.10	Revenue meter calibration errors, loop calibration errors, random errors	0.005	5.00.E-04	0.001	0.0002	3.6964E+01	3.4159E-04	5.4654E-05
									Σ(θi·Bi)2 (L) Σ(θi·2Sxi)2 (R)	8.1359E-01	2.2022E+00
									B_R(L), $2S_R$(R)	9.0199E-01	1.4840E+00

Total Absolute Uncertainty (UR_{95})	Percent Uncertainty (UR_{95})
1.7	4.7%

Calculated Results	Description	Units	Nominal Value
q_{v0}	Volumetric flow rate of fuel at the standard conditions	m3/h	0.2484
Qf0	Heating value of fuel at the standard conditions (LHV)	kJ/mole	926.4
hf	Specific enthalpy of fuel at temperature tf	kJ/mole	7.969
hf0	Specific enthalpy of fuel at the standard temperature	kJ/mole	7.583
Epf	Pressue energy of the fuel	kJ/mole	0.2036
Efv	Input energy of the fuel	kJ/m3	39203.2
η_e	Electrical efficiency	%	37.0

Delta X% 0.0001

Parameter for Sensitivity		qvf	tf	pf	Methane	Ethane	Propane	Butane	Pout	Pin
Parameter (Pi)	Base	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta	0.0001% Delta
qvf	0.0000E+00	2.3672E-07	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
tf	0.0000E+00	0.0000E+00	2.9815E-04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
pf	0.0000E+00	0.0000E+00	0.0000E+00	1.1000E-04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Methane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	8.8000E-05	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Ethane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	5.8000E-06	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Propane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	4.5000E-06	0.0000E+00	0.0000E+00	0.0000E+00
Butane	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.7000E-06	0.0000E+00	0.0000E+00
Pout	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.1000E-06	0.0000E+00
Pin	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E-07
Calculated Results	η e Nom	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta	η e + Delta
q_{v0}	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484	0.2484
Qf0	926.4	926.4	926.4	926.4	926.4	926.4	926.4	926.4	926.4	926.4
hf	7.969	7.969	7.969	7.969	7.969	7.969	7.969	7.969	7.969	7.969
hf0	7.583	7.583	7.583	7.583	7.583	7.583	7.583	7.583	7.583	7.583
Epf	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036	0.2036
Efv	39203.2	39203.2	39203.2	39203.3	39203.2	39203.2	39203.2	39203.2	39203.2	39203.2
η_e	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
Absolute Sensitivity (θi)	–	3.1031E+02	−3.3154E−04	7.9858E−02	3.8214E−01	5.7447E+00	7.8138E+00	2.1744E+01	7.0568E+01	3.3268E+02

Annex C

Calculation of Fuel Heating Value

Table C1-Heating Values for components of Natural gases at various combustion reference condition for ideal gas

	Component	Heating Value on a molar basis(kJ/mol)	Heating Value on a mass basis(MJ/kg)
1	Methane	802.69	50.035
2	Ethane	1428.84	47.52
3	Propane	2043.37	46.34
4	n-Butane	2657.60	45.72
5	2-Methylpropane	2648.42	45.57
6	n-Pentane	3272.00	45.35
7	2-Metylbutane	3265.08	45.25
8	2.2-Dimethylpropane	3250.83	45.06
9	n-Hexane	3887.21	45.11
10	2-Methylpetane	3879.59	45.02
11	3-Methylpetane	3882.19	45.05
12	2.2-Dimethylbutane	3869.80	44.91
13	2.3-Dimethylbutane	3877.57	45.00
14	n-Hepetane	4501.72	44.93
15	n-Octane	5116.11	44.79
16	n-Nonane	5731.49	44.69
17	n-Decane	6346.14	44.60
18	Ethylene	1324.24	47.17
19	Propylene	1926.13	45.77
20	1-Butene	2540.97	45.29
21	cis-2-Butene	2534.2	45.17
22	trans-2-Butene	2530.5	45.10
23	2-Methylpropene	2524.3	44.99
24	1-Pentene	3155.59	44.99
25	Propadiene	1855.09	46.30
26	1.2-Butadiene	2461.82	45.51
27	1.3-Butadiene	2408.80	44.53
28	Acetylene	1256.94	48.27
29	Cyclopentane	3100.03	44.20
30	Methylcyclopentane	3705.86	44.03
31	Ethylcyclopentane	4320.92	44.01
32	Cyclohexane	3689.42	43.84
33	Methylcyclohexane	4293.06	43.72
34	Ethylcyclohexane	4911.49	43.77
35	Benzene	3169.56	40.58
36	Toluene	3772.08	40.94
37	Ethylbenzene	4387.37	41.33
38	o-Xylene	4376.48	41.22
39	Methanol	676.22	21.10
40	Methanethiol	1151.41	23.93
41	Hydrogen	241.72	119.91
42	Water	0	0
43	Hydrogen sulfide	517.95	15.20
44	Ammonia	316.86	18.61
45	Hydrogen cyanide	649.5	24.03
46	Carbon monoxide	282.91	10.10
47	Carbonyl sulfide	548.15	9.12
48	Carbon disulfide	1104.32	14.50

*Temperature t_0 = 288.15K

*Reference: Table3 and Table4 in ISO6976

Worksheet 1 - CALCULATION WORKSHEET FOR ENERGY OF FUEL GASE

Temperature of fuel(t_f) __________ K···①
Pressure of fuel(p_f) __________ kPa···②

Component	Fuel Composition (mol%)···③	Heating Value of Gas Component (KJ/mol) ···④ (*1)	Heating Value of Fuel Component (Q_{f0})(kJ/mol)	Constant A of Gas Component (*2)	Constant B of Gas Component	Constant C of Gas Component	Specific Enthalpy of fuel Component at the reference temperature (kJ/mol)···⑥	Specific Enthalpy of fuel Component at the reference temperature (h_{f0})(kJ/mol)	Specific Enthalpy of fuel Component at temperature t_f (kJ/mol)···⑧	Specific Enthalpy of fuel Component at the reference temperature t_f (h_f)(kJ/mol)
			③×④×10^{-2}				Eq1 (*3)	③×⑥×10^{-2}	Eq2 (*4)	③×⑧×10^{-2}
Nitrogen				27.016	5.812	-0.289				
Oxygen				25.594	13.251	-4.205				
Carbon Monoxide				26.537	7.6831	-1.1719				
Methane				14.146	75.496	-17.991				
Ethane				9.401	159.833	-46.229				
Propane				10.083	239.304	-73.358				
Butane				18.631	302.378	-92.943				
Hydrogen				29.062	-0.820	1.9903				
Water				30.204	9.933	1.117				
Total			⑤					⑦		⑨

*1:reference ISO6976
*2:reference JANAF Thermochemical Tables D.R.Stull,H.Prophet published by NSRDS-NBS 37 (1965,1971)
*3:Eq1=(A×288.15+B/2×10^{-3}×288.15^2+C/3×10^{-6}×288.15^3)×10^{-3}
*4:Eq2= (A×①+B/2×10^{-3}×$①^2$+C/3×10^{-6}×$①^3$)×10^{-3}

Heating Value(Q_{f0}) __________ KJ/mol(from ⑤)···⑩
Specific Enthalpy of fuel Component at temperature (h_f) __________ KJ/mol(from ⑨)···⑪
Specific Enthalpy of fuel Component at the reference temperature (h_{f0}) KJ/mol(from ⑦)···⑫
Pressue Enegry of the fuel(E_{pf})=8.314×10^{-3}×①×ln(②/101.325) KJ/mol···⑬

ToalEergy of the fuel(Efv)=Qf0+hf-hf0+Epf=⑩+⑪-⑫+⑬= __________ kJ/mol

Worksheet 2 - CALCULATION WORKSHEET FOR ENERGY OF AIR

Temperature of Air(ta)____________ K･･･①
Pressure of Air(pa)____________ kPa･･･②

Component	Constant A of Air (＊1)	Constant B of Air	Constant C of Air	Specific Enthalpy of Air at the reference temperature(h_{a0}) (kJ /mol)･･･③	Specific Enthalpy of fuel Component at temperature t_a(h_a) (kJ /mol)･･･④
				Ea1 (＊2)	Ea2 (＊3)
Air	27.434	6.180	−0.8987		

*1:reference
*3:Ea1=(A× 288.15+B /2× 10^{-3}× 288.15^2+C/3× 10^{-6}× 288.15^3) × 10^{-3}
*4:Ea2=(A× ①+B /2× 10^{-3}× $①^2$+C/3× 10^{-6}× $①^3$) × 10^{-3}

Specific Enthalpy of Air at temperature ta (h_a) ____________ KJ /mol(from ④)･･･⑤
Specific Enthalpy of Air at the reference temperature (h_{a0})____________ KJ /mol(from ③)･･･⑥
Pressue Enegry of the fuel(E_{pa})=8.314× 10^{-3}× ①× ln (②/ 101.325) ____________ KJ /mol･･･⑦

Toal Eergy of the Air (Eav)=ha−ha_0+Ea_f=⑤−⑥+⑦= ____________ kJ /mol

Annex D

Reference gas

D.1 General

The reference gas tables here are provided to allow a customer to compare the performances measured by himself, obtained with his 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 shall be able to find the adjustment factor in order to correct the advertised performances to his particular gas composition by referring to the closest reference gas.

D.2 Reference gases for Natural gas and Propane gas

a) A set of 14 reference gases for Natural gas is provided in Table D1, and a set of 17 reference gases for Propane in Table D2.

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

c) Natural gas distribution systems generally include various sulphur compounds as odourants:

Major sulphur compounds; Tetrahydrothiophene, Hydrogen sulphide (H_2S), Diethylsulphide (DES), Methylethylsulphide (MES), Dimethylsulphide (DMS), methylmercaptan (MM), iso-propylmercaptan (IPM), tertio-butylmercaptan (TBM), iso-butylmercaptan (IBM), 2-butylmercaptan (SBM), etc.

Table D1 - Reference gas for Natural gas

	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
CH4	66,2	67,2	63,0	82,4	65,1	74,9	75,6	97,2	88,9	71,7	92,0	85,7	83,4	72,0
C2H6	5,0	1,7	11,7	0,0	8,3	3,3	11,7	0,0	10,0	15,0	1,7	13,3	6,7	13,3
C3H8	0,7	3,3	2,0	0,0	4,0	3,3	0,7	1,3	0,0	2,7	6,0	0,7	4,7	5,3
C4H10	0,2	0,0	0,0	1,0	0,7	1,0	0,5	0,2	0,0	0,3	0,2	0,2	1,5	1,3
C5H12	0,1	0,0	0,0	0,7	0,6	0,4	0,3	0,1	0,0	0,2	0,1	0,1	1,0	0,9
C6+	0,1	0,0	0,0	0,3	0,3	0,3	0,2	0,1	0,0	0,1	0,1	0,1	0,5	0,4
CO2	7,8	10,0	5,6	2,2	5,6	1,1	8,9	1,1	1,1	3,3	0,0	0,0	0,0	2,2
N2	20,0	17,8	17,8	13,3	15,6	15,6	2,2	0,0	0,0	6,7	0,0	0,0	2,2	4,4
LHV (kWh/m3)	7,84	7,86	8,89	9,01	9,66	9,58	10,21	10,19	10,65	10,77	11,19	11,26	11,92	11,96
LHV (MJ/m3)	28,21	28,30	32,01	32,43	34,77	34,48	36,76	36,68	38,34	38,77	40,30	40,55	42,93	43,07
HHV (kWh/m3)	8,69	8,71	9,84	9,99	10,67	10,59	11,30	11,31	11,81	11,90	12,39	12,47	13,17	13,20
HHV (MJ/m3)	31,27	31,36	35,41	35,96	38,40	38,14	40,67	40,72	42,51	42,85	44,62	44,90	47,42	47,50

Table D2 - Reference gas for Propane gas

	1A	1B	1C	1D	1E	2A	2B	2C	2D	3A	3B	3C	3D	3E	3F	3G	3H
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
C2H6	0	5	0	5	0	5	0	5	0	5	0	5	5	0	0	5	0
C3H8	100	90	90	80	80	70	70	60	60	50	50	40	40	20	20	0	0
C4H10	0	5	10	15	20	25	30	35	40	45	50	55	60	75	80	95	100
LHV (kWh/m3)	28.22	28,25	29.14	29.14	30.06	30.09	30.98	31	31.9	31.92	32.82	32.84	33.73	34.68	35.57	36.52	37.41
LHV (MJ/m3)	101.6	101.7	104.9	105	108.2	108.3	111.5	111.6	114.8	114.9	118.1	118.2	121.4	124.9	127.1	131.5	134.7
HHV (kWh/m3)	28.94	25.96	26.8	26.82	27.65	10,59	28.51	28.53	29.39	29.38	30.22	30.24	31.07	31.95	32.78	33.66	34.49
HHV (MJ/m3)	93.38	93.47	96.46	96.55	99.54	99.63	102.6	102.7	105.7	105.8	108.8	108.9	111.9	115	118	121.2	124.2