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Edition 2.0 2022-12
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Fuel cell technologies –
Part 4-102: Fuel cell power systems for ~~industrial electric trucks~~ electrically powered industrial trucks – Performance test methods

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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FUEL CELL TECHNOLOGIES –

Part 4-102: Fuel cell power systems for ~~industrial electric trucks~~ electrically powered industrial trucks – Performance test methods

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 62282-4-102:2017. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 62282-4-102 has been prepared by IEC technical committee 105: Fuel cell technologies. It is an International Standard.

This second edition cancels and replaces the first edition published in 2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) alignment of the Scope with the second edition of IEC 62282-4-101:2022;
b) deletion of terms and definitions (previous entries 3.5, 3.10, and 3.15);
c) addition of new terms in Clause 3: "delivered power" (3.13) and "regenerated power" (3.14);
d) revision of symbols and their meanings in alignment with those of IEC 62282-3-201;
e) replacement of "reference conditions" with "standard conditions" as seen in Clause 5;
f) revision of the test method for the accessory load voltage spike test (13.3.2);
g) addition of clarifications in Clause 14 (Power stability under operation);
h) addition of a checklist for performance criteria dealt with in this document (Annex C).

The text of this International Standard is based on the following documents:

Draft	Report on voting
105/947/FDIS	105/954/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62282 series, published under the general title *Fuel cell technologies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 62282-4 provides consistent and repeatable test methods for the electric, thermal and environmental performance of fuel cell power systems for ~~industrial electric trucks~~ electrically powered industrial trucks.

The IEC 62282-4 series deals with categories such as safety, performance, and interchangeability of fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APUs). This document (IEC 62282-4-102) focuses on performance test methods for fuel cell power systems ~~for~~ used to drive industrial electric trucks, which are being manufactured and used increasingly worldwide. This is because such applications are urgently ~~demanded~~ needed in the world.

This part of IEC 62282-4 describes type tests and their test methods only. No routine tests are required or identified, and no performance targets are set in this document.

Fuel cell systems used in ~~industrial electric trucks~~ electrically powered industrial trucks, such as forklift trucks, ~~are hybrids~~ use both batteries and fuel cells, and so operate in several different modes. Similarly, forklift trucks operate in different modes. The purpose of this document is to evaluate the fuel cell system in the various combinations of fuel cell modes and forklift truck modes. This document breaks down these different modes and provides a framework for designing and evaluating a fuel cell system for use specifically in a forklift truck.

This part of IEC 62282-4 is intended to be used by either manufacturers of fuel cell power systems used for ~~industrial electric trucks and/~~ electrically powered industrial trucks or those who evaluate the performance of the systems used in them for certification purposes or both.

Users of this document ~~selectively execute test items that are suitable for their purposes from those described in this document~~ can select and perform the tests they need from those described. This document is not intended to exclude any other ~~methods~~ tests.

FUEL CELL TECHNOLOGIES –

Part 4-102: Fuel cell power systems for ~~industrial electric trucks~~ electrically powered industrial trucks – Performance test methods

1 Scope

This part of IEC 62282 specifies the performance test methods of fuel cell power systems for propulsion and auxiliary power units (APU). This document covers fuel cell power systems for propulsion other than those for road vehicles.

~~The scope of this document is limited to electrically powered industrial trucks. Hybrid trucks that include an internal combustion engine are not included in the scope. The scope of this standard will be applicable to material-handling equipment, e.g. forklifts.~~

This document covers the performance test methods of fuel cell power systems intended to be used for electrically powered industrial trucks as defined in ISO 5053-1, except for:

- rough-terrain trucks;
- non-stacking low-lift straddle carrier;
- stacking high-lift straddle carrier;
- rough-terrain variable-reach truck;
- slewing rough-terrain variable-reach truck;
- variable-reach container handler;
- pedestrian propelled trucks.

This document applies to gaseous hydrogen-fuelled fuel cell power systems and direct methanol fuel cell power systems for electrically powered industrial trucks. The following fuels are considered within the scope of this document:

- gaseous hydrogen, and
- methanol.

~~This document does not apply to reformer-equipped fuel cell power systems.~~

This document covers the fuel cell power system as defined in 3.7 and Figure 1.

This document applies to DC type fuel cell power systems, with a rated output voltage not exceeding DC 150 V for indoor and outdoor use.

This document covers fuel cell power systems whose fuel source container is permanently attached to either the industrial truck or the fuel cell power system. ~~A fuel source container of the detachable type is not permitted.~~

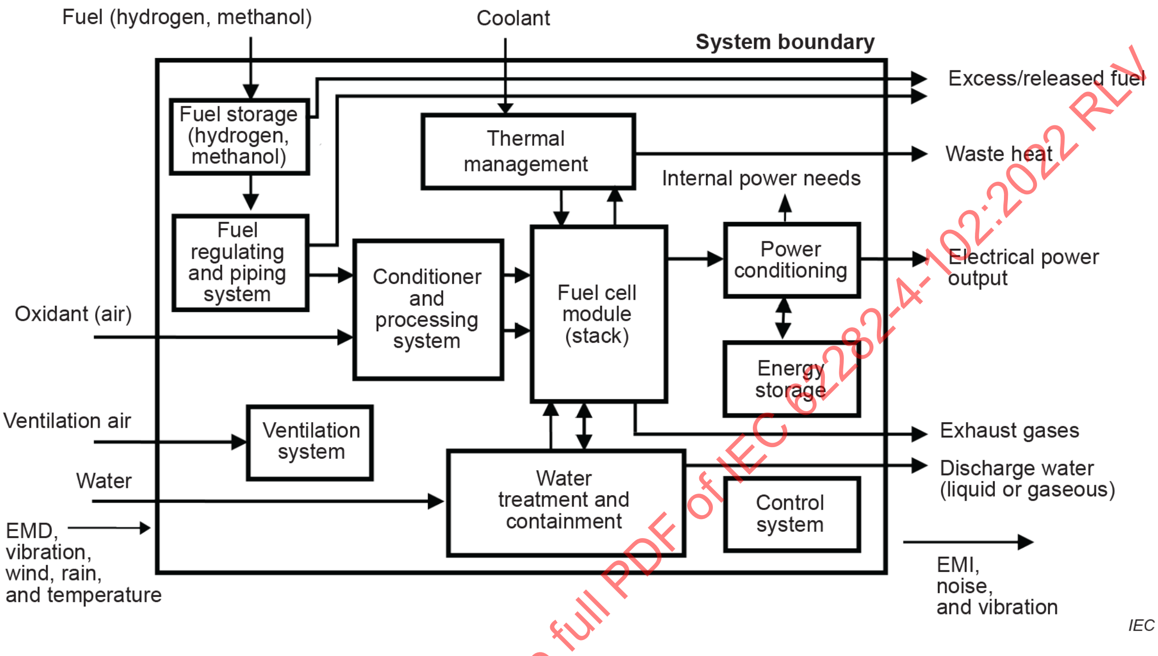
~~Fuel cell power systems intended for operation in potentially explosive atmospheres are excluded from the scope of this document.~~

~~This document does not cover the fuel storage systems using liquid hydrogen.~~

All systems with integrated energy storage systems are covered by this document. This includes systems such as batteries for internal recharges or recharged from an external source.

The following are not included in the scope of this document:

– detachable type fuel source containers;
– hybrid trucks that include an internal combustion engine;
– reformer-equipped fuel cell power systems;
– fuel cell power systems intended for operation in potentially explosive atmospheres;
– fuel storage systems using liquid hydrogen.



Key

EMD electromagnetic disturbance

EMI electromagnetic interference

NOTE A fuel cell power system can contain all or some of the above components.

Figure 1 – Fuel cell power systems for electrically powered industrial trucks

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

~~IEC 62282-3-201, *Fuel cell technologies – Part 3-201: Small stationary fuel cell power systems – Performance test methods for small fuel cell power systems*~~

IEC 62282-6-300:2012, *Fuel cell technologies – Part 6-300: Micro fuel cell power systems – Fuel cartridge interchangeability*

~~ISO 9000, *Quality management series of standards*~~

ISO 6798-1, *Reciprocating internal combustion engines – Measurement of sound power level using sound pressure – Part 1: Engineering method*

ISO 6798-2, *Reciprocating internal combustion engines – Measurement of sound power level using sound pressure – Part 2: Survey method*

ISO 14687, *Hydrogen fuel quality – Product specification*

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

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
noise level
sound pressure level produced by the fuel cell power system measured at a specified distance in all operation modes

Note 1 to entry: Noise level is expressed in decibels (dB) and measured as described in 15.2.

3.2
background noise level
sound pressure level of ambient noise at the measurement point

~~Note 1 to entry: This measurement is taken as described in 15.2 with the fuel cell power system in the cold state.~~

3.3
battery
electrochemical energy storage device that either provides energy input to support parasitic loads ~~and/~~or provides ~~electrical~~ energy output or both

Note 1 to entry: Back-up batteries for control software memory and similar applications are not included.

3.4
cold state
state of a fuel cell power system at ambient temperature with no power input or output

[SOURCE: ~~IEC/TS 62282-1:2013, 3.110.1~~ IEC 60050-485:2020, 485-21-01]

~~**3.5**~~
~~**discharge rate**~~
~~mass of discharged exhaust gas component per unit of time~~

3.5
discharge water
water discharged from the fuel cell power system including waste water and condensate

Note 1 to entry: Discharge water does not constitute part of a thermal recovery system.

~~[SOURCE: IEC/TS 62282-1:2013, 2.2, modified – Note 1 to entry added.]~~

3.6
fuel cell system electric~~al~~ efficiency
ratio of the average electric power output of a fuel cell power system ~~at~~ for a given duration to the average fuel power fed to the same fuel cell power system ~~at~~ for the same duration

3.7
fuel cell power system
generator system that uses one or more fuel cell modules to generate electric power and heat

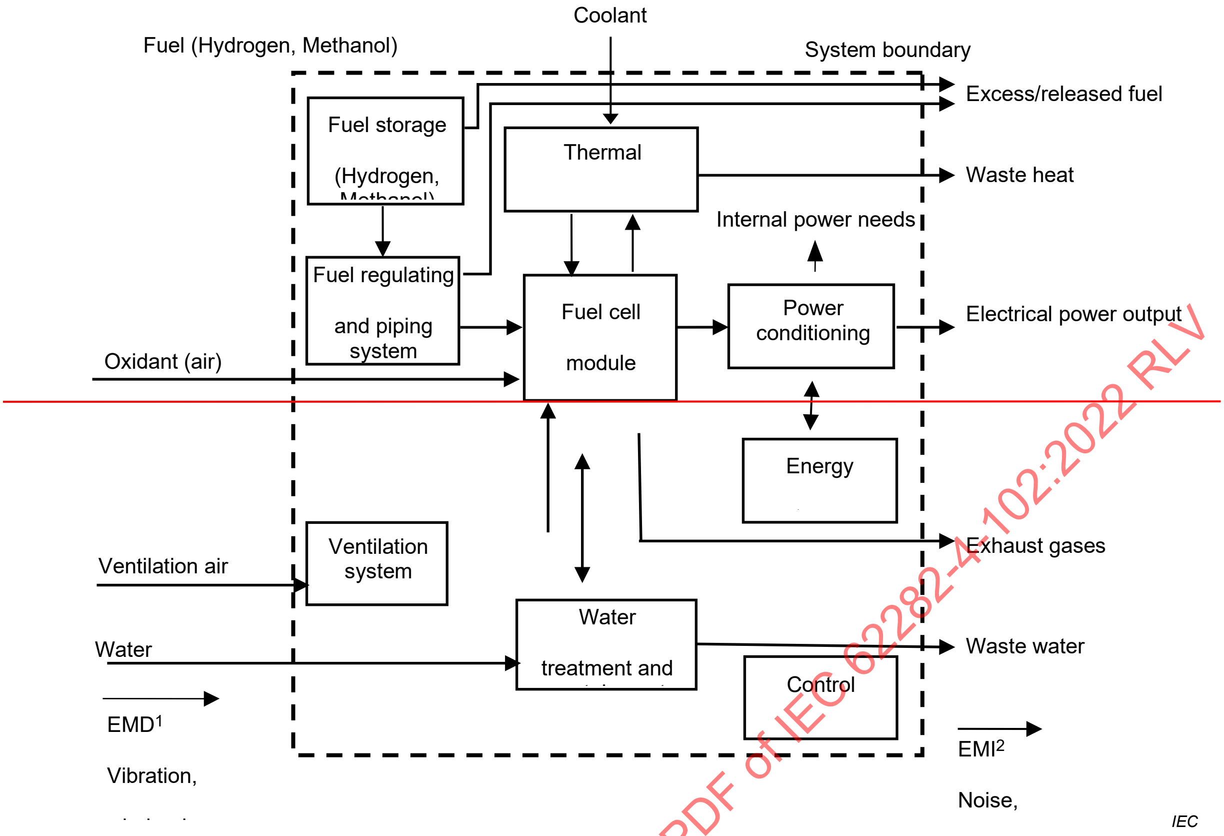
~~Note 1 to entry: See Figure 1 for a block diagram of a fuel cell power system.~~

~~Note 2 to entry: A fuel cell power system may contain all or some of the components shown in Figure 1. The fuel cell power system for use with industrial trucks will be in one of the forms as outlined in 3.9 and 3.10 of IEC 62282-4-101.~~

~~[SOURCE: IEC/TS 62282-1:2013, 3.49, modified – New Note 1 to entry has been added, and existing Note 1 to entry has become Note 2 to entry with the addition of the second sentence.]~~

Note 1 to entry: The fuel cell power system for use with industrial trucks will be in one of the forms as outlined in IEC 62282-4-101:2022, 3.9 and 3.10.

[SOURCE: IEC 60050-485:2020, 485-09-01, modified – Note 1 to entry has been added.]



~~**Key**~~

~~Fuel cell power system including subsystems. 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 configurations depend on the kind of fuel, type of fuel cell or system.~~

~~The interface points in the boundary to be measured for calculation data.~~

~~1 EMD electromagnetic disturbance~~

~~2 EMI electromagnetic interference~~

~~**Figure 1 – Fuel cell power systems for industrial electric trucks**~~

3.8
fuel input
amount of hydrogen or methanol supplied to the fuel cell power system

3.9
fuel consumption
volume or mass of fuel consumed by the fuel cell power system under specified operating conditions

~~**3.10**~~
~~**fuel power consumption**~~
~~amount of energy per time unit contained in the fuel consumed by the fuel cell power system~~

3.10
minimum electric power output
minimum power output, at which a fuel cell power system is able to operate continuously at a steady state

3.11
rated power
maximum continuous electric power output ~~power~~ that a fuel cell power system is designed to achieve under normal operating conditions specified by the manufacturer

[SOURCE: ~~IEC/TS 62282-1:2013, 3.85.4, modified – Note 1 to entry deleted~~ IEC 60050-485:2020, 485-14-04, modified – Note 1 to entry has been deleted.]

~~**3.14**~~
~~**auxiliary load**~~
~~power consumed by auxiliary machines and equipment such as balance of plant (BOP) necessary to operate a fuel cell power system~~

~~**3.15**~~
~~**storage state**~~
~~condition of a fuel cell power system that is non-operational and possibly requiring, under conditions specified by the manufacturer, the input of thermal or electric energy in order to prevent deterioration of the components and/or energize the control systems and other components, and is ready for start-up~~

~~[SOURCE: IEC/TS 62282-1:2013, 3.110.6, modified – Reference to an inert atmosphere has been deleted, "and/or energize control systems and other components, and is ready for start-up" has been added.]~~

3.12
test duration
time interval in which data points required for the computation of test results are recorded

3.13
delivered power
current and voltage delivery requirements of the industrial truck at various intervals as necessary in order to maintain acceptable truck performance

3.14
regenerated power
electro-dynamic power in which the energy produced by the motors is fed into the contact line or into energy storage on-board devices

Note 1 to entry: Examples of storage devices: batteries, flywheels.

[SOURCE: IEC 60050-811:2017, 811-06-25, modified – The term "regenerative braking" has been replaced with "regenerated power" and in the definition "braking" has been replaced with "power".]

4 Symbols

The symbols and their meanings used in this document are given in Table 1 for electric and thermal performance and in Table 2 for environmental performance, with the appropriate units.

Table 1 – Symbols and their meanings for electric and thermal performance

Symbol	Definition	Unit
M, m	**Molar mass, mass**	
~~M_{mf}~~ M_f	Molar mass of fuel	kg/mol
m_f	Fuel mass measured over the test duration	kg
p	**Pressure**	
~~p_0~~ p_s	~~Reference~~ Standard pressure (101,325 kPa (abs))	kPa (abs)
p_f	Average fuel pressure	kPa (abs)
P~~, dP~~	**Power~~, power change rate~~**	
P_n	Average net electric power output	kW
~~P_{inf}~~ P_{fin}	Average fuel power input	kJ/s
E	**Input energy**	
E_{mf}	Input energy of fuel per mass	kJ/kg
~~E_{fm}~~ E_{vf}	Input energy of fuel ~~(mass and volume)~~ per volume	kJ/~~kg~~l
~~E_{inf}~~ E_{fin}	Total fuel input energy	kJ
q_m	**Mass flow rate**	
q_{mf}	Average mass flow rate of fuel under the test conditions	kg/s
q_V	**Volumetric flow rate**	
q_{Vf}	Average volumetric flow rate of fuel under the test conditions	l/min
~~q_{Vf0}~~ q_{Vfs}	Average volumetric flow rate of fuel under ~~reference~~ standard conditions	l/min
H	**Heating value**	
~~H_{f0}~~ H_{fs}	Heating value of fuel on a molar basis under ~~reference~~ standard conditions	kJ/mol
H_{fl}	Heating value of liquid mass	kJ/kg
t	**Time**	
Δt	Test duration	s, min
T	**Temperature**	
~~T_0~~ T_s	~~Reference~~ Standard temperature (273,15 K)	K
T_f	Average fuel temperature	K
~~ΔT~~	~~Temperature difference between heat recovery fluid output and input~~	~~K~~
V, V_m	**Volume, molar volume**	
V_f	Total fuel volume measured over the test duration	l
~~V_{m0}~~ V_{ms}	~~Reference~~ Standard molar volume of ideal gas (22,414 l/mol) (at ~~reference~~ standard temperature T_0 = 273,15 K and pressure p_0 = 101,325 kPa)	~~m^3~~ l/mol
W	**Electric energy**	
W_{out}	Electric energy output	kW · h
η	**Efficiency**	
~~η_e~~ η_{el}	Electric efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%

Table 2 – Symbols and their meanings for environmental performance

Symbol	Definition	Unit
φ	**Volume fraction**	
$\varphi_{B,meas}$	measured volume fraction of ~~each~~ the component B	vol % or ml/m^3
$\varphi_{B,corr}$	corrected volume fraction of ~~each~~ the component B	vol % or ml/m^3
$\varphi_{at}(O_2)$	measured O_2 (oxygen) volume fraction in atmosphere at air inlet in dry state	vol %
$\varphi_{ex}(O_2)$	measured O_2 volume fraction in dry exhaust gas	vol %
~~$\varphi_{ex}(CO)_{corr}$~~ $\varphi_{ex,corr}(CO)$	corrected CO volume fraction in dry exhaust gas	ml/m^3
~~$\varphi_{ex}(THC)_{corr}$~~ $\varphi_{ex,corr}(THC)$	corrected total hydrocarbon (THC) volume fraction in dry exhaust gas (carbon equivalent)	ml/m^3 ~~C equivalent~~
γ	**Mass concentration**	
$\gamma_{ex}(CO)$	CO mass concentration in dry exhaust gas	mg/m^3
$\gamma_{ex}(THC)$	THC mass concentration in dry exhaust gas	mg/m^3
ε	**Emission**	
$\varepsilon(CO)$	mass of CO emission per ~~unit~~ energy of input fuel	mg/kW · h
$\varepsilon(THC)$	mass of THC emission per ~~unit~~ energy of fuel input	mg/kW · h
α	**Atom ratio**	
$\alpha(THC)$	hydrogen to carbon atom ratio of the THC in the exhaust gas	
~~H~~	~~**Heating value**~~	
ω	**Mass fraction**	
ω_B	mass fraction of methanol	

5 ~~Reference~~ Standard conditions

The ~~reference~~ standard conditions are specified as follows:

– ~~reference~~ standard temperature: ~~T_0~~ T_s = 273,15 K (0 °C);

– ~~reference~~ standard pressure: ~~p_0~~ p_s = 101,325 kPa (abs).

6 Heating value base

Except if otherwise specified, the given heating value of fuel shall be the low heating value (LHV) or similar.

NOTE The heating values of hydrogen and methanol (LHV and HHV) are given in Annex A.

In cases where the LHV is applied for the calculation of energy efficiency, it is not necessary to add the ~~initialism~~ LHV, as shown below:

$$\cancel{\eta_e}\,\eta_{el},\ \eta_{th},\ \text{or}\ \eta_{total} = \text{XX}\ \%$$

If the higher heating value (HHV) is applied, the ~~initialism~~ HHV shall be added to the value of energy efficiency as follows:

$~~\eta_e~~ \eta_{el}$, η_{th}, *or* η_{total} = XX % (HHV)

7 Test preparation

7.1 General

Clause 7 describes typical items that shall be considered prior to the implementation of a test. For each test, an effort shall be made to minimize uncertainty by selecting high-precision instruments and planning the tests with attention to detail. Detailed test plans shall be prepared by the parties to the test using this document as their basis. A written test plan shall be prepared.

The following items shall be considered for the test plan:

1) objective;
2) test specifications;
3) test personnel qualifications;
4) quality ~~assurance~~ management standards (ISO 9000, ISO 9001 and ISO 9004, collectively known as the ISO 9000 family, or other equivalent standards);
5) target uncertainty;
6) identification of measurement instruments (refer to Clause 9);
7) estimated range of test parameters;
8) data acquisition plan.

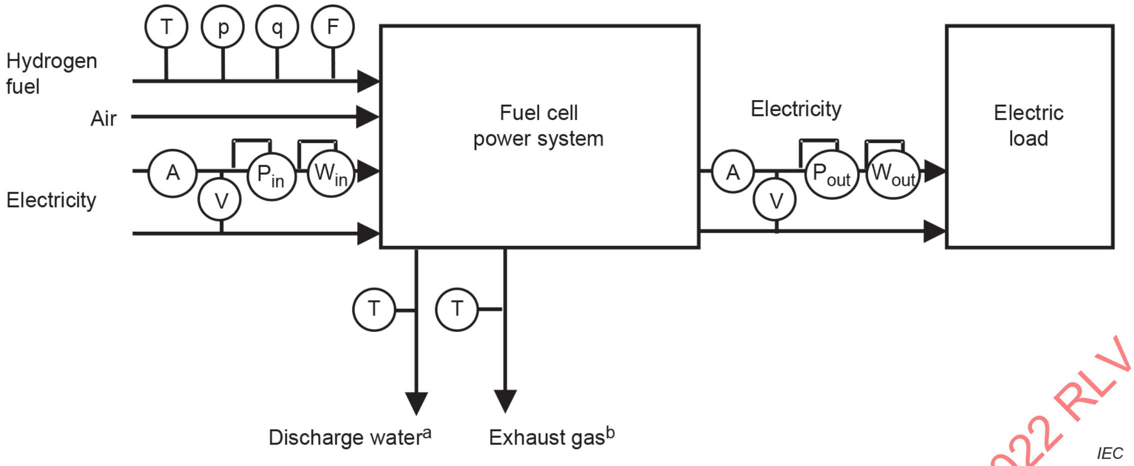
7.2 Data acquisition plan

In order to meet the target uncertainty, proper duration and frequency of readings shall be defined and data recording equipment shall be prepared before the performance test.

Automatic data acquisition using a personal computer or similar is preferable.

8 Test set-up

Figure 2 and Figure 3 illustrate examples of test set-ups that are required to conduct fuel cell power system testing with hydrogen fuel and methanol fuel, respectively, which are described in this document. An electric load is connected to a fuel cell power system.



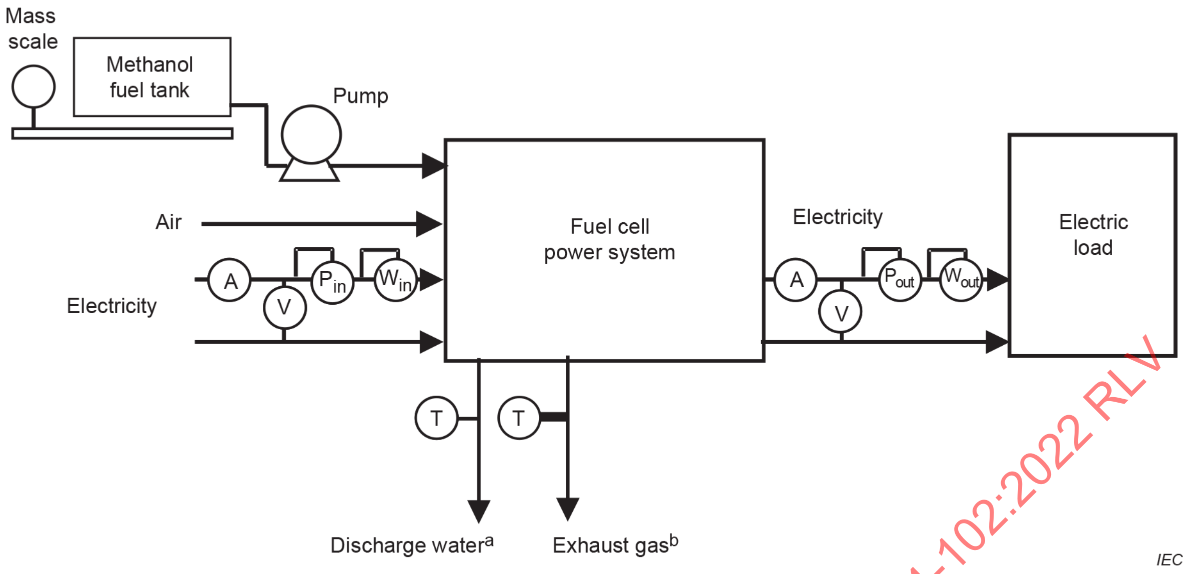
Key

A	ammeter
V	voltmeter
T	thermometer
p	pressure gauge
q	flowmeter
F	integrating flowmeter
P	electric power meter
W	integrating electric power meter (electric energy meter)

[a] To collecting device to measure volume (or weight), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD).

[b] To collecting device to analyse components.

Figure 2 – Example of a test set-up for hydrogen fuel



NOTE See explanations of the symbols in Figure 2.

[a] To collecting device to measure volume (or weight), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD).

[b] To collecting device to analyse components.

Figure 3 – Example of a test set-up for methanol fuel

9 Instruments and measurement methods

9.1 General

Measurement instruments and measurement methods shall conform to the relevant international standards. They shall be selected to meet the measurement range specified by the manufacturer and the required accuracy of measurements.

9.2 Measurement instruments

Measurement instruments are listed according to their intended use:

a) apparatus for measuring voltage spikes: oscilloscope, high-frequency analysers;

b) apparatus for measuring the electric power input and output, and electric energy input and output:

– electric power meters, electric energy meters, voltmeters, ammeters;

c) apparatus for measuring fuel input:

– flowmeters, integrating flowmeters, weight meters, pressure sensors, temperature sensors;

d) apparatus for measuring ambient conditions:

– barometers, hygrometers, and temperature sensors;

e) apparatus for measuring the noise level:

– sound level meters as specified in IEC 61672-1 or other measuring instruments of equivalent or better accuracy;

f) apparatus for measuring concentrations of the exhaust gas components:

– oxygen analyser (e.g. based on paramagnetic, electrochemical or zirconium oxide sensors);

– carbon dioxide analyser (e.g. GC-MS or based on infrared absorption sensor);

- carbon monoxide analyser (e.g. based on nondispersive infrared or electrochemical sensor);

g) apparatus for determining the discharge water:
   - graduated cylinder (for volume measurement), temperature sensor, pH meters, BOD probes.

~~NOTE 1 BOD means Biochemical Oxygen Demand, COD stands for Chemical Oxygen Demand, and THC is Total Hydrocarbon.~~

9.3 Measurement points

Measurement points for the different parameters are described below.

a) Hydrogen fuel flow rate:

   Place a flowmeter for fuel on the fuel supply line to the fuel cell power system to measure the fuel flow rate.

b) Hydrogen integrated fuel input:

   Place an integrating flowmeter for fuel on the fuel supply line to the fuel cell power system to measure the fuel input. The integrating flowmeter shall combine a flowmeter that measures the fuel flow rate.

c) Methanol fuel input weight:

   Place a weight meter under the fuel tank to measure the weight of fuel and tank together. Methanol fuel input weight is measured by subtracting the weight after the test from that before the test.

d) Fuel temperature:

   Connect a thermometer or a thermocouple immediately downstream of the fuel flowmeter.

e) Fuel pressure:

   Place a pressure meter immediately downstream of the fuel flowmeter to measure the gauge pressure of fuel.

f) Electric power output:

   Connect an electric~~al~~ power meter to the electric~~al~~ power output terminal of the fuel cell power system and close to the system boundary.

g) Electric energy output:

   Connect an electric~~al~~ energy meter to the electric~~al~~ power output terminal of the fuel cell power system and close to the system boundary. The electric~~al~~ energy meter shall incorporate an electric~~al~~ power meter that indicates electric~~al~~ power output.

h) Fuel composition:

   The fuel used for the tests shall be sampled and analysed for its composition for each test run.

i) Atmospheric pressure:

   Place an absolute pressure meter adjacent to the fuel cell power system where it will not be affected by ventilation, air intake or exhaust of the fuel cell power system.

j) Atmospheric temperature:

   Place a thermometer adjacent to the fuel cell power system where the thermometer will not be affected by ventilation, air intake or exhaust of the fuel cell power system.

k) Atmospheric humidity:

   Place a hygrometer adjacent to the fuel cell power system where the hygrometer will not be affected by ventilation, air intake or exhaust of the fuel cell power system.

l) Noise level:

   Refer to 15.2.

m) Exhaust gas:

Place one or more exhaust gas collecting probes combined with a temperature sensor in the exhaust stream at the exhaust gas outlet (refer to Figure 2 and Figure 3).

n) Discharge water:

Place a discharge water reservoir combined with a temperature sensor at the discharge water outlet.

9.4 Minimum required measurement systematic uncertainty

The test equipment should be chosen in a way that the systematic uncertainty of measurement is below 3 % for overall and thermal efficiencies, and below 2 % for electrical efficiency. In order to reach the desired efficiency uncertainties, the following systematic measurement uncertainties of the equipment are recommended. They are given in percentage of measured~~/~~ or calculated values or both, or as absolute values:

– electric power: ±1 %;

– electric energy: ±1 %;

– fuel gas flow rate: ±1 %;

– integrated gas flow: ±1 %;

– time: ±0,5 %;

– liquid fuel mass: ±1 % of the mass to be determined (not including the tare weight) as in IEC 62282-3-201;

– relative humidity: ±5 %;

– absolute pressure: ±1 %;

– fuel gas and discharge water temperature: ±1 K;

– exhaust gas temperature: ±4 K.

10 Test conditions

10.1 Laboratory conditions

Unless otherwise specified, performance shall be tested in the environment specified below:

– temperature: 20 °C ± 5 °C;

– humidity: 65 % ± 20 % relative humidity;

– pressure: between 91 kPa (abs) and 106 kPa (abs).

~~For each test run, The laboratory conditions shall be measured during the test. As air quality shall affect fuel cell system performance, laboratory air composition (CO_2, CO, SO_2 and so forth) shall be reported with the test result.~~

The laboratory conditions shall be measured and set for each test run. As air quality will affect fuel cell system performance, laboratory air composition including foreign substances and gases shall be reported with the test result.

10.2 Installation and operating conditions of the system

The fuel cell power system shall be assembled and operated in accordance with the manufacturer's installation instructions prior to the start of the tests.

10.3 Indication of battery condition

~~For the Systems with batteries, the battery SOC shall be constant at the beginning and at the end of the test duration.~~

Systems with batteries may be equipped with a means (for example, a display method or an output signal) to identify that the battery has reached a known nominal state of charge (including full charge state) that is determined by the manufacturer.

10.4 Determination of state of charge of the battery

The time when the battery is recharged to the known nominal state of charge can be determined by either one of the following two methods:

a) for a system equipped with a means (for example, a display method or an output signal) to identify that the battery has reached a known nominal state of charge, the charge-out time is determined by that means;

b) for a system equipped with no means to identify that the battery has reached a known nominal state of charge, the charge-out time to reach the nominal state of charge may be determined by measuring the time when the input fuel flow rate becomes stabilized within ±2 % of the rated fuel flow rate after the fuel flow increase for recharging the battery ceases. This measurement is not mandatory.

10.5 Quality of test fuel

10.5.1 Hydrogen

The hydrogen fuel used for the tests shall have the quality given in ~~Table 1 of ISO 14687-2~~ grade D of ISO 14687.

10.5.2 Methanol solution

The methanol used for preparing the methanol solution which is used for the tests shall be consistent with the specification given in IEC 62282-6-300:2012, 5.5.2.

The water mixed with methanol shall be ion-exchanged water with ~~electrical~~ an electric conductivity of less than 1 µS/cm.

The methanol concentration in the methanol solution shall be specified by the manufacturer.

11 Fuel consumption test

11.1 Hydrogen fuel consumption test

11.1.1 General

This test is for measuring the hydrogen fuel input at rated power output. If operation at partial loads of 50 %, of 75 % and at the minimum electric power output are specified by the manufacturer or if one of these operating points is selected , these operating points shall be measured as well.

This test shall be carried out concurrently with the electric~~al~~ power output test in Clause 12.

11.1.2 Test method

1) Operate the system at the rated power output ~~for more than~~ at least 30 min before starting the test.

   ~~NOTE Energy storage in the system reaches nominal state of charge after 30 min of operation.~~

2) For systems including electrochemical batteries, operate the system at the rated power output ~~for more than~~ at least 30 min and until a known nominal state of charge is reached, before starting the test.
3) Start the test while keeping the system operating at the ~~nominal electric~~ rated power output ~~power~~.
4) Measure the fuel temperature, fuel pressure, and integrated fuel input flow (in volume or in mass). Each measurement shall be taken for a minimum of 60 min.

11.1.3 Calculation of results

11.1.3.1 Calculation of average hydrogen fuel input rate

The average hydrogen fuel input rate shall be described either as the volumetric flow rate at ~~reference~~ standard conditions, $\cancel{q_{Vf0}}$ q_{Vfs} in l/min, or as the mass flow rate, q_{mf} in kg/s. It shall be calculated according to the following procedure.

1) Volumetric flow rate
   a) The average volumetric flow rate of fuel under the test conditions, q_{Vf} in l/min, shall be obtained by dividing the integrated ~~volumetric flow~~ fuel volume over the test duration by the test duration.

$$\cancel{q_{Vf} = q_{iv}/\Delta_t}$$

$$q_{Vf} = V_f / \Delta t \tag{1}$$

where

q_{Vf} is the average volumetric flow rate of fuel under the test conditions (l/min);

$\cancel{q_{iv}}$ V_f is the total ~~volumetric fuel flow~~ fuel volume over the test duration (l);

Δt is the test duration (min).

   b) The average volumetric flow rate of fuel under the ~~reference~~ standard conditions, $\cancel{q_{Vf0}}$ q_{Vfs} in l/min, shall be calculated with the following formula. The average values of fuel temperature and pressure obtained during the test duration shall be used.

$$\cancel{q_{Vf0} = q_{Vf} \times (T_0/T_f) \times (p_f/p_0)}$$

$$q_{Vfs} = q_{Vf} \times (T_s/T_f) \times (p_f/p_s) \tag{2}$$

where

$\cancel{q_{Vf0}}$ q_{Vfs} is the average volumetric flow rate of fuel under ~~reference~~ standard conditions (l/min);

q_{Vf} is the average volumetric flow rate of fuel under test conditions (l/min);

$\cancel{T_0}$ T_s is the ~~reference~~ standard temperature (273,15K);

$\cancel{p_0}$ p_s is the ~~reference~~ standard pressure (101,325 kPa (abs));

T_f is the average fuel temperature during the test duration (K);

p_f is the average fuel pressure during the test duration (kPa (abs)).

2) Mass flow rate

   The average mass flow rate of fuel under the test conditions, q_{mf} in kg/s, shall be obtained by dividing the integrated mass ~~flow~~ over the test duration by the test duration.

$$\cancel{q_{mf} = q_{imf} / \Delta_t}$$

$$q_{mf} = m_f / \Delta t \tag{3}$$

where

q_{mf} is the average mass flow rate of fuel under the test conditions (kg/s);

~~q_{imf}~~ m_f is the integrated mass ~~flow~~ over the test duration (kg);

Δt is the test duration (s).

11.1.3.2 Calculation of average hydrogen fuel power input

The average hydrogen fuel power input, ~~Q_{inf}~~ P_{fin} in kJ/s, shall be calculated either for volumetric flow rate or for mass flow rate according to the following procedure. The average values of fuel temperature and pressure obtained during the test duration shall be used.

1) Volumetric flow rate

a) The energy of fuel per ~~unit~~ volume at ~~reference~~ standard conditions, ~~E_{fv}~~ E_{vf} in kJ/l, shall be calculated with the following formula:

$$\cancel{E_{fv} = H_{f0} / M_0}$$

$$E_{vf} = H_{fs} / V_{ms} \tag{4}$$

where

~~E_{fv}~~ E_{vf} is the input energy of the fuel per ~~unit~~ volume (kJ/l);

~~H_{fo}~~ H_{fs} is the heating value of hydrogen fuel on a molar basis under ~~reference~~ standard conditions (~~241,72~~ 241,56 kJ/mol);

~~M_0~~ V_{ms} is the ~~reference~~ standard molar volume of ideal gas (22,4 l/mol) (at the ~~reference~~ standard temperature for this document, ~~t_0~~ t_s = 273,15 K).

NOTE 1 In general, fuel consumption energy and heating values are based on the low heating value (LHV).

b) The average fuel power input, ~~Q_{inf}~~ P_{fin} in kJ/s, shall be calculated with the following formula:

$$\cancel{Q_{inf} = q_{vf0} \times E_{fv} / 60}$$

$$P_{fin} = q_{Vfs} \times E_{vf} / 60 \tag{5}$$

where

~~Q_{inf}~~ P_{fin} is the average fuel power input (kJ/s);

~~q_{vf0}~~ q_{Vfs} is the average volumetric flow rate of fuel under ~~reference~~ standard conditions (l/min);

~~E_{fv}~~ E_{vf} is the energy input of the fuel per ~~unit~~ volume (kJ/l).

NOTE 2 The specific enthalpy and pressure energy of hydrogen fuel, which are considered in the calculation of fuel consumption energy in IEC 62282-3-~~201~~200, are ignored in the calculation of fuel consumption energy described above because they are negligible values in fuel cell power systems for forklift trucks that are operated at low temperature and at low pressure.

2) Mass flow rate

a) The input energy of fuel per ~~unit~~ mass, ~~E_{fm}~~ E_{mf} in kJ/kg, shall be calculated with the following formula:

$$\cancel{E_{fm} = H_{f0} / M_{mf}}$$

$$E_{mf} = H_{fs} / M_{f} \tag{6}$$

where

~~E_{fm}~~ E_{mf} is the input energy of fuel per ~~unit~~ mass (kJ/kg);

~~H_{f0}~~ H_{fs} is the heating value of fuel under ~~reference~~ standard conditions (kJ/mol);

~~M_{mf}~~ M_{f} is the molar mass of fuel (kg/mol).

b) The average fuel power input, ~~Q_{inf}~~ P_{fin} in kJ/s, shall be calculated with the following formula:

$$\cancel{Q_{inf} = q_{mf} \times E_{fm}}$$

$$P_{fin} = q_{mf} \times E_{mf} \tag{7}$$

where

~~Q_{inf}~~ P_{fin} is the average fuel power input (kJ/s);

~~E_{fm}~~ E_{mf} is the input energy of fuel per ~~unit~~ mass (kJ/kg);

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

11.2 Methanol fuel consumption test

11.2.1 General

This test is for measuring the methanol fuel input at rated power output. If operation at partial loads of 50 %~~,~~ of 75 % and~~/or~~ at the minimum electric~~al~~ power output are specified by the manufacturer ~~or~~ if one of these operating points is selected, these operating points shall be measured as well.

This test shall be carried out concurrently with the electric~~al~~ power output test in Clause 12.

11.2.2 Test method

1) Operate the system at the ~~nominal electrical power output for more than~~ rated power output at least 30 min before starting the test.

2) For systems including batteries, operate the system at the rated power output ~~for more than~~ at least 30 min and until a known nominal state of charge is reached, before starting the test.

3) Start the test while keeping the system operating at the ~~nominal electrical~~ rated power output. If such an operation is specified by the manufacturer, repeat the tests at partial load, 50 % and 75 % of nominal output, and~~/or~~ minimum output.

4) Measure the mass of the fuel tank or of the entire system, including the fuel tank, at the start.

5) Continue the test for a minimum of 3 h. If fuel is to be supplied intermittently, the total test duration shall be 20 times the duration of the fuel supply or 3 h, whichever is longer.

6) Measure the mass of the fuel tank or of the entire system, including the fuel tank, at the end of the test.

11.2.3 Calculation of average methanol fuel power input

Total methanol fuel input energy over the test duration, ~~E_{inf}~~ E_{fin} in kJ, shall be calculated by the following formula:

$$\cancel{E_{inf} = (A - B) \times H_{fl} \times W_B}$$

$$E_{fin} = (A - B) \times H_{fl} \times \omega_B \tag{8}$$

where

~~E_{inf}~~ E_{fin} is the total fuel input energy (kJ);

A is the mass at the start of the test (kg);

B is the mass at the end of the test (kg);

H_{fl} is the heating value of methanol (kJ/kg);

~~W_B~~ ω_B is the mass fraction of methanol.

The average fuel power input, ~~Q_{inf}~~ P_{fin} in kJ/s, shall be calculated as follows:

$$\cancel{Q_{inf} = \frac{E_{inf}}{\Delta_t}}$$

$$P_{fin} = E_{fin} / \Delta t \tag{9}$$

where

~~Q_{inf}~~ P_{fin} is the average fuel power input (kJ/s);

~~E_{inf}~~ E_{fin} is the total fuel input energy (kJ);

Δt is the test duration (s).

NOTE In general, fuel input energy and heat values are based on the low heating value (LHV).

12 Electric~~al~~ power output test

12.1 General

This test is for measuring the average ~~electrical~~ net electric output at the rated power output. If operation at partial loads of 50 %, of 75 % and~~/or~~ at the minimum electric~~al~~ power output are specified by the manufacturer or if one of these operating points is selected, these operating points shall be measured as well.

This test shall be carried out concurrently with the fuel consumption test in Clause 11.

12.2 Test method

1) Operate the system at the ~~nominal electrical power output for more than~~ rated power output at least 30 min before starting the test.
2) For systems including batteries, operate the system at the rated power output ~~for more than~~ at least 30 min and until a known nominal state of charge is reached before starting the test.
3) Start the test while keeping the system operating at the ~~nominal electrical~~ rated power output. If such an operation is specified by the manufacturer, repeat the test at partial loads of 50 % and of 75 % of the nominal output, and~~/or~~ the minimum output.
4) Measure the electric~~al~~ energy output during the test period. The test shall be conducted for at least 3 h. If fuel is to be supplied intermittently, the total test duration shall be 20 times the duration of the fuel supply or 3 h, whichever is longer.

12.3 Calculation of average electric~~al~~ power output

The average electric~~al~~ power output shall be calculated with the following formula:

$$P_n = \frac{W_{out}}{\Delta t} \times 3600 \qquad (10)$$

where

P_n is the average electric~~al~~ power output (kW);

W_{out} is the electric~~al~~ energy output during the test period (kWh);

Δt is the test duration(s).

12.4 Computation of electric~~al~~ efficiency

Electric~~al~~ efficiency is computed on the basis of calculated values given in Clauses 11 and 12.

Electric~~al~~ efficiency, $\cancel{\eta_e}$ η_{el} in %, shall be calculated with the following formula:

$$\cancel{\eta_e = \frac{P_n}{Q_{inf}} \times 100}$$

$$\eta_{el} = \frac{P_n}{P_{fin}} \times 100 \qquad (11)$$

where

$\cancel{\eta_e}$ η_{el} is the electric~~al~~ efficiency (%);

P_n is the average electric power output (kW) (refer to 12.3);

$\cancel{Q_{inf}}$ P_{fin} is the average fuel power input (kJ/s) (refer to 11.1.3.2 and 11.2.3).

13 Type tests on operational performance

13.1 ~~Cold start~~ Maximum power output test

13.1.1 General

The purpose of this test is to determine the fuel cell's ability to maintain the maximum electric~~al~~ power load immediately after start-up. One scenario will be tested on the fuel cell after it has been in a pre-generation state for a period of time. Another scenario will be tested after running at nominal load for a period of time, powering down the fuel cell, then powering up the fuel cell with the maximum continuous load connected.

13.1.2 Test method

1) To condition the system prior to the test, operate the system at the ~~nominal electrical power output for more than~~ rated power output at least 30 min before starting the test.
2) The fuel cell system shall be powered down and cooled down to the ambient temperature. Connect the maximum ~~rated~~ electric~~al~~ load, specified by the manufacturer, to the fuel cell system. Power on the fuel cell system ~~as per~~ in accordance with the manufacturer's recommendations.
3) Operate the system at the maximum electric~~al~~ power output for the manufacturer's specified time or for 1 h (whichever is shorter). Power down the fuel cell system completely ~~as per~~ in accordance with the manufacturer's specifications. Connect the maximum ~~rated~~ electric~~al~~ load to the fuel cell system specified by the manufacturer. Within 2 min, power up the fuel cell system ~~as per~~ in accordance with the manufacturer's recommendations.

13.1.3 Processing of data

When powering up the fuel cell system with loads, if the system disconnects power to the load, the time duration that the load is without power shall be recorded. If any warning lights on the system, such as a low-battery indicator, illuminate, these shall also be recorded in the report.

13.2 Power cycling electric~~al~~ load test

13.2.1 General

The purpose of this test is to stress the fuel cell system by cycling an electric~~al~~ load connected to the system in a similar manner to how the load in an electric industrial truck shall vary.

13.2.2 Test method

1) Operate the system at the ~~nominal electrical power output for more than~~ rated power output at least 30 min before starting the test.
2) Operate the system at the ~~nominal electrical~~ rated power output for 15 min, then operate the system at the maximum electrical power specified by the manufacturer for 15 min. Repeat this cycle for 8 h. If the fuel cell system disconnects power ~~to the load during this cycling and when the system reconnects to the load~~ from the load and then reconnects, the times of disconnection and reconnection shall be recorded in the report.

13.2.3 Processing of data

When the fuel cell system is being cycled, if the system disconnects power to the load, or if any warning lights on the system, such as a low-battery indicator, illuminate, these shall be recorded in the report. The time of the event shall be recorded, as well as the duration of the event.

13.3 Accessory load voltage spike test

13.3.1 General

The purpose of this test is to determine if the fuel cell system clamps inductive spikes caused by using a contactor to power external loads.

13.3.2 Test method

1) Connect the inductive load to a fuel cell system (such as a fan).
2) Spikes shall be measured at the electrical power output where the customer's cable connects to the system output.
3) ~~Power up The fuel cell system as per the manufacturer's recommendation. Record the fuel cell's system electrical voltage. Voltage spikes greater than + 5 % of the fuel cell's power~~

~~system's nominal voltage are unacceptable. Voltage spikes greater than 2 V below 0 V are unacceptable. The duration of the spikes shall also be recorded in the report.~~

The fuel cell power system shall be started in accordance with the manufacturer's instructions. The amplitude and duration of the voltage spikes generated shall be recorded in the report.

13.3.3 Processing of data

1) The inductive load used shall be recorded in the report. The load shall be lower than the manufacturer's specifications.
2) When powering up the fuel cell system with a load, voltage spikes greater than 2 V above the fuel cell's nominal voltage or spikes greater than 2 V below 0 V shall be recorded in the report. The voltage spike magnitude and the duration shall also be recorded in the report.

14 Power stability under operation

14.1 General

The purpose of this test is to determine the stability of the power output of the fuel cell power system when driving the truck in a real-life situation. The energy flow between the fuel cell power system and the rotating electric load are shown in Figure 4.

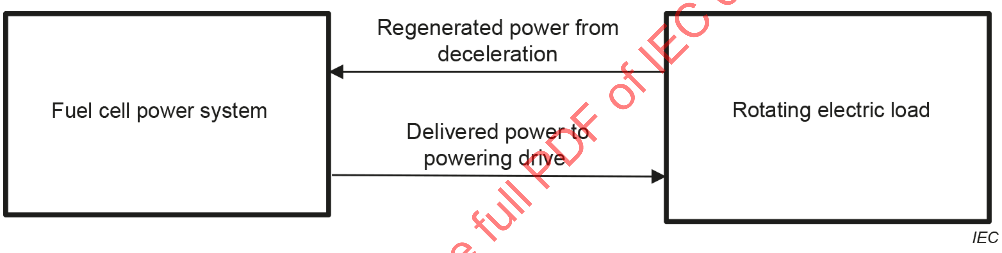


Figure 4 – Energy flow for regenerated power and delivered power

14.2 Delivered power

~~The truck manufacturer shall specify the current and voltage delivery requirements of the industrial truck at various intervals as necessary in order to maintain acceptable truck performance.~~

The delivered power required for the truck operation as stated by the manufacturer shall be measured and recorded.

The fuel cell power system shall be operated at rated power output for 30 min for warming-up, and the battery shall be checked to have reached the target SOC ~~state~~ before starting the test.

~~The truck shall be operating at the intervals TD$_1$, TD$_2$, TD$_3$ with the times given in column ID$_{min}$ and with no-load (zero current) conditions.~~ The fuel cell power system shall be operated with the discharge times given in Table 3 and with no extra load (zero current) conditions. Additional ~~intervals shall~~ discharge times can be added by the manufacturer. These are not a definition of the truck's application requirements; they define the requirements of the truck's control system.

The values requested in Table 3 shall be recorded during the operation of the truck.

Table 3 – Delivered power measurements

~~Intervals~~	~~ID_{min} (A)~~	~~VD_{max} (V)~~	~~VD_{min} (V)~~
~~TD_1~~	~~Rated current at 5 s stated by the fuel cell manufacturer~~		
~~TD_2~~	~~Rated current at 30 s stated by the fuel cell manufacturer~~		
~~TD_3~~	~~Rated current at 1 h stated by the fuel cell manufacturer~~		
~~TD_0~~	~~0~~		

Discharge time	Current A	Average current A	Maximum voltage V	Minimum voltage V
0 s	0			
5 s	I_1			
30 s	I_2			
1 h	I_3			
NOTE Currents I_1, I_2, and I_3 are given by the truck manufacturer.				

14.3 ~~Power absorbed~~ Regenerated power

The truck manufacturer shall specify the ~~current and voltage absorption~~ regenerated power requirements of the industrial truck ~~at~~ in various ~~time durations~~ operating modes, as necessary, in order to maintain acceptable truck performance.

Warm-up of the fuel cell power system shall be made prior to the test. The test shall be started at the target SOC on the electrical storage device.

~~The truck shall be operating at the intervals TA_1, and TA_2 with the times given in column IA_{min}.~~ The truck shall be operating with the discharge times given in Table 4. Additional ~~intervals shall~~ discharge times can be added by the truck manufacturer. These are not a definition of the truck’s application requirements; they define the requirements of the truck's control system.

The values requested in Table 4 shall be recorded during the operation of the truck.

Table 4 – ~~Power absorbed~~ Regenerated power measurements

~~Intervals~~	~~IA_{min}~~ ~~(A)~~	~~VA_{max}~~ ~~(V)~~	~~VA_{min}~~ ~~(V)~~
~~TA_1~~	~~Rated current at 5 s stated by the truck manufacturer~~		
~~TA_2~~	~~Rated current at 30 s stated by the truck manufacturer~~		

Discharge time	Current A	Average current A	Maximum voltage V	Minimum voltage V
5 s	I_1			
30 s	I_2			
NOTE Currents I_1 and I_2 are given by the truck manufacturer.				

The battery condition (state of charge and temperature upon measurement) shall be recorded.

15 Type tests on environmental performance

15.1 General

The type tests on environmental performance include:

– noise test (15.2); and

– exhaust gas test (15.3).

15.2 Noise test

15.2.1 General

This test is conducted to measure the level of noise generated from the system with the measuring apparatus listed in 9.2 e) at each operation phase from start-up, the rated power output, the minimum electrical power output (if such operation is specified by the manufacturer and desired by the user), up until shutdown. The rated power output is specified by the manufacturer.

15.2.2 Test conditions

15.2.2.1 Reference planes

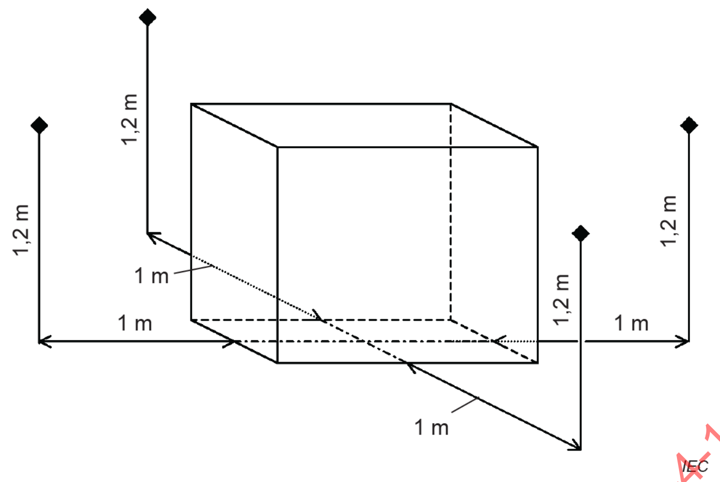
The reference planes shall be set at 1 m away from the four sides (front, back, left, and right) of the fuel cell power system. If this is not feasible, they shall be set at 50 cm away, and the test report shall expressly state this.

Any protrusions or projections on the fuel cell power system surfaces shall be ignored if they are deemed to have no significant effects on the surface noise, and the power system surfaces are conceptually simplified in accordance with ISO 6798-1 and ISO 6798-2.

15.2.2.2 Measurement points

Measurements shall be taken at four points, namely in two directions on the front-back centre line, and two directions on the right-left centre line of the fuel cell power system. The measurement points shall be located on the reference plane at a height of 1,2 m from the bottom of the power system (see Figure 5).

The sound level meter microphone shall be perpendicularly oriented with respect to the reference planes.



Key

◆ Measurement point

Figure 5 – Noise measurement points for fuel cell power systems

15.2.2.3 Effect of background noise

It is desirable to have a difference of 10 dB or more in the noise meter readings between when there is noise to be measured and when there is no noise. If the difference in readings is 3 dB or more but less than 10 dB, the readings can be adjusted according to Table 5 to estimate the noise level when the fuel cell power system is the only noise source.

Table 5 – ~~Compensation of readings against~~ Correction values corresponding to the effect of background noise

Difference in readings with and without the subject noise dB	3	4	5	6	7	8	9
Correction value dB	−3	−2		−1			

15.2.2.4 Effect of sound reflection

When there is a large reflecting body near the microphones or the sound source, measurement errors will occur as sounds reflected from the reflecting body add to the sound from the source. Before taking measurements, it is desirable to remove, to the greatest extent possible, any objects that reflect sounds. If that is not possible under the measurement conditions, state this in the test report.

15.2.3 Test method

1) Measure the background noise level with the system to be measured in the cold state.
2) Start up the system from its cold state ~~or storage state~~.
3) Raise the output to the rated power output, and wait until at least 30 min passes after reaching rated power output. Continue to operate the system at the rated power output for another 1 h or more.
4) If a minimum electrical power output operation is specified by the manufacturer and measurement is desired by the user, set the system to minimum electrical power output and

wait until at least 30 min afterwards. Continue to operate the system at the ~~rated~~ minimum electrical power output for another 1 h or more.

5) Shut down the system.
6) Measure the noise level from start-up to shutdown. The frequency of measurement shall be 1 s intervals. Readings shall be rounded off to the nearest whole number (e.g. 45,7 becomes 46).
7) Measure the background noise level after shutdown is complete and verify that ~~they do not deviate from each other~~ there is no difference of reading from the background noise level measured in 1).

15.2.4 Processing of data

1) The effect of background noise shall be corrected as explained in 15.2.2.3.
2) The following shall be reported as representative noise level values:
   – the maximum noise level throughout all operation phases and the operation phase in which the maximum value was generated;
   – the mean value of noise levels for 1 h of operation at rated power.

15.3 Exhaust gas test

15.3.1 General

The exhaust gas test applies only to direct methanol fuel cells. This test is for measuring the volume fraction of each component in the exhaust gas from the direct methanol fuel cell power system. It is used to calculate the following values during start-up time, the rated ~~electrical~~ power output ~~power~~ phase and shutdown time:

– the mass concentrations of CO and THC (mg/m^3) (15.3.4.3);
– the masses of CO and THC per ~~unit~~ energy of fuel input (mg/kWh) (15.3.4.4).

15.3.2 Components to be measured

The components and values to be measured shall be as follows:

– carbon monoxide (CO);
– total hydrocarbons (THC);
– oxygen (O_2).

15.3.3 Test method

a) ~~Use care~~ When putting the sampling probe(s) entirely into the exhaust stream, ensure that the sampling probe(s) do not block the exhaust duct. The probe(s) shall be placed close to the exhaust gas outlet of the fuel cell power system, either inside of the exhaust gas evacuation duct for closed exhaust ventilation systems, or directly at the outlet of the exhaust gas for open exhaust ventilation systems. If the exhaust ducting is large in size, take readings at the centre of the exhaust duct and at representative points in a grid across the exhaust duct and average the readings.
b) For open exhaust gas ventilation systems, ~~use care to place~~ the probe(s) shall be placed in a way that prevents the mixing of the sample gas with ambient air.
c) During measurements, ensure that condensation on the temperature sensor is avoided. Condensation on the sensor will invalidate the readings.
d) Start up the system from its cold state ~~or storage state~~ and wait until the rated ~~electrical~~ power output ~~power~~ is reached. Wait until at least another 30 min passes after reaching the rated ~~electrical~~ power output ~~power~~.
e) Continue to operate the system at the rated ~~electrical~~ power output ~~power~~ for another 3 h or more, then shut down the system.

f) Measure the volume fraction of each component in the exhaust gas (in vol % or ml/m^3), fuel flow (in volume or mass flow), fuel pressure and temperature, room temperature and humidity from start-up to shutdown. The frequency of data collection shall be 15 s or less.

15.3.4 Processing of data

15.3.4.1 General

The corrected volume fraction at dry and air-free conditions (15.3.4.2) shall be used in the following calculations:

– the mass concentrations of CO and THC (mg/m^3) (15.3.4.3);

– the masses of CO and THC per ~~unit~~ energy of input fuel (mg/kW · h) (15.3.4.4).

The calculated values which shall be reported are indicated in 15.3.4.5 and 15.3.4.6.

15.3.4.2 Correction to volume fraction at dry and air-free conditions

The measured volume fraction of each component (in ml/m^3) in the exhaust gas shall be corrected to the volume fraction at dry and air-free conditions with the following equation using the measured O_2 volume fraction in dry exhaust gas:

$$\varphi_{B,corr} = \varphi_{B,meas} \times \frac{\varphi_{at}(O_2)}{\varphi_{at}(O_2) - \varphi_{ex}(O_2)} \qquad (12)$$

where

$\varphi_{B,corr}$ is the corrected volume fraction of each component (vol % or ml/m^3);

$\varphi_{B,meas}$ is the measured volume fraction of each component (vol % or ml/m^3);

$\varphi_{at}(O_2)$ is the measured O_2 volume fraction in atmosphere at the air inlet in dry state (vol %, in case of fresh air, $\varphi_{at}(O_2) \approx 21$ %);

$\varphi_{ex}(O_2)$ is the measured O_2 volume fraction in dry exhaust gas (vol %).

15.3.4.3 Mass concentration of each component

15.3.4.3.1 CO mass concentration

The CO mass concentration shall be calculated with the following equation:

$$\cancel{\gamma_{ex,CO} = \varphi_{ex,(CO),corr} \times 1252}$$

$$\gamma_{ex}(CO) = \varphi_{ex,corr}(CO) \times 1{,}250 \qquad (13)$$

where

$\gamma_{ex}(CO)$ is the CO mass concentration in dry exhaust gas (mg/m^3);

$\cancel{\varphi_{ex(CO),corr}}$ $\varphi_{ex,corr}(CO)$ is the corrected CO volume fraction in dry exhaust gas (ml/m^3);

~~1,252~~ 1,250 is the value for the CO density under standard conditions (kg/m^3).

15.3.4.3.2 THC mass concentration

The THC mass concentration shall be calculated with the following equation:

$$\cancel{\gamma_{\text{ex(THC)}} = \varphi_{\text{ex(THC),corr}} \times \left(0{,}537 + \alpha_{\text{THC}} \times 0{,}045\right)}$$

$$\gamma_{\text{ex}}(\text{THC}) = \varphi_{\text{ex,corr}}(\text{THC}) \times \left(0{,}537 + \alpha(\text{THC}) \times 0{,}045\right) \tag{14}$$

where

γ_{ex}(THC) is the THC mass concentration in dry exhaust gas (mg/m^3);

~~$\varphi_{\text{ex(THC),corr}}$~~ $\varphi_{\text{ex,corr}}$(THC) is the corrected THC volume fraction in dry exhaust gas (ml/m^3, C equivalent);

α(THC) is the hydrogen to carbon atom ratio of the THC in the exhaust gas;

0,537 is the C atomic weight divided by molar volume at standard conditions (kg/m^3);

0,045 is the H atomic weight divided by molar volume at standard conditions (kg/m^3).

NOTE The standard conditions are 0 °C and 101,325 kPa (1 atm).

15.3.4.4 Mass of each component per ~~unit~~ energy of input fuel

15.3.4.4.1 Mass of CO per ~~unit~~ energy of input fuel

The mass of CO emission per ~~unit~~ energy of input fuel (mg/kW · h) shall be calculated with the following equation:

$$\cancel{\varepsilon_{\text{CO}} = \varphi_{\text{ex(CO),corr}} \times \left(\frac{22{,}4 \times 10^{-3}}{H_{\text{f0}}}\right) \times 1{,}252 \times 3\,600}$$

$$\varepsilon(\text{CO}) = \varphi_{\text{ex,corr}}(\text{CO}) \times \left[\frac{22{,}4 \times 10^{-3}}{H_{\text{fs}}}\right] \times 1{,}250 \times 3600 \tag{15}$$

where

~~ε_{co}~~ ε(CO) is the mass of CO emission per ~~unit~~ energy of input fuel (mg/kW · h);

~~$\varphi_{\text{ex(CO),corr}}$~~ $\varphi_{\text{ex,corr}}$(CO) is the corrected CO volume fraction in dry exhaust gas (ml/m^3);

~~H_{f0}~~ H_{fs} is the molar heating value of methanol under standard conditions (kJ/mol);

$22{,}4 \times 10^{-3}$ is the theoretical dry exhaust gas volume (CO_2) per 1 mol of methanol input according to the following reaction (m^3/mol);

$$CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$$

~~1,252~~ 1,250 is the value for the CO density under standard conditions (kg/m^3);

3 600 is the conversion factor of kJ into kW · h.

15.3.4.4.2 Mass of THC per ~~unit~~ energy of input fuel

The mass of THC emissions per ~~unit~~ energy of input fuel (mg/kW · h) shall be calculated with the following equation:

$$\cancel{\varepsilon_{\text{THC}} = \varphi_{\text{ex,THC,corr}} \times \left(\frac{22{,}4 \times 10^{-3}}{H_{\text{f0}}}\right) \times (0{,}537 + \alpha_{\text{THC}} \times 0{,}045) \times 3\,600}$$

$$\varepsilon(\text{THC}) = \varphi_{\text{ex,corr}}(\text{THC}) \times \left[\frac{22{,}4 \times 10^{-3}}{H_{\text{fs}}}\right] \times \left(0{,}537 + \alpha(\text{THC}) \times 0{,}045\right) \times 3600 \qquad (16)$$

where

~~ε_{THC}~~ $\varepsilon(\text{THC})$	is the mass of THC per ~~unit~~ energy of fuel input (mg/kW · h);
~~$\varphi_{\text{ex(THC),corr}}$~~ $\varphi_{\text{ex,corr}}(\text{THC})$	is the corrected THC volume fraction in dry exhaust gas (ml/m^3);
~~H_{f0}~~ H_{fs}	is the molar heating value of methanol under standard conditions (kJ/mol);
$\alpha(\text{THC})$	is the hydrogen to carbon atom ratio of the THC in the exhaust gas.

15.3.4.5 Averaging the data

The mean mass concentration and the mean mass per ~~unit~~ input fuel energy for each measured harmful component during the rated power output operation (for 1 h starting from 30 min after the rated power output is reached) shall be calculated by averaging the mass concentration and the mass per ~~unit~~ input fuel energy respectively.

The mean mass concentration and the mean mass per ~~unit of~~ input fuel energy shall be recorded with annex notes that include average electrical power output, average room temperature, and average humidity.

15.3.4.6 Averaging the temperature of exhaust gas

The average exhaust gas temperature measured at the rated power output shall be recorded.

15.4 Discharge water test

15.4.1 General

~~This test is for measuring~~ When applicable, the quality of discharged water from the fuel cell power system shall be measured throughout all phases of operation from start-up, rated power output to shutdown. The rated power output is specified by the manufacturer.

15.4.2 Test method

1) After installing a device for collecting the discharge water, start the fuel cell power system.
2) The discharge water shall be collected and pooled together from start-up to shutdown through the rated power output for 3,5 h, or one hydrogen tank content, whichever comes first.
3) Measure the following items:
   - total amount of discharge water (time duration of operation shall be recorded);
   - temperature of discharge water;
   - pH;
   - biochemical oxygen demand (BOD) when necessary;
   - chemical oxygen demand (COD) when necessary.

It is recommended to refer to ISO 10523 for pH measurement, ISO 5815 (all parts) for BOD measurement, and ISO 6060 for COD measurement.

16 Test reports

16.1 General

Test reports shall accurately, clearly, and objectively present sufficient information to demonstrate that all the objectives of the tests have been attained. The minimum requirements for the test report shall be a title page, a table of contents and a summary report. For fuel cell systems tested in compliance with this document, the summary report shall be made available to interested parties.

More information obtained under Clauses 11 and 12 can be provided with either a detailed report ~~and/~~or a full report for internal purposes. Guidelines for the contents of the detailed report and the full report are given in Annex B.

16.2 Title page

The title page shall present the following information:

a) report identification number~~ (optional)~~;

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

c) authors of the report;

d) entity conducting the tests;

e) date of report;

f) location of the tests;

g) titles of the tests;

h) date and time of the tests;

i) fuel cell power system identification code and the manufacturer’s name.

16.3 Table of contents

The table of contents shall present the titles of chapters, clauses, subclauses, etc. in the report with the page numbers in an orderly sequence.

16.4 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) confidence for each test result;

5) conclusions as appropriate;

6) discussion of the tests and their results (i.e. comments and observations);

7) results of fuel analyses.

16.5 Checklist for performance parameters

The performance criteria dealt with in this document are given in Annex C.

Annex A
(informative)

Heating values for hydrogen and methanol at ~~reference~~ standard conditions

The heating values for hydrogen and methanol are given in Table A.1.

Table A.1 – Heating values for hydrogen and methanol at ~~reference~~ standard conditions

	Component	Lower heating value on a molar basis kJ/mol	Higher heating value on a molar basis kJ/mol	Lower heating value on a mass basis MJ/kg	Higher heating value on a mass basis MJ/kg
1	Hydrogen	~~241,72~~ 241,56	~~286,15~~ 286,63	~~119,91~~ 119,83	~~141,95~~ 142,19
2	Methanol	~~676,22~~ 676,44	~~765,09~~ 766,59	~~21,1~~ 21,11	~~23,88~~ 23,92
NOTE These values were extracted from ISO 6976.					

Annex B
(informative)

Guidelines for the contents of detailed and full reports

B.1 General

It is recommended that the detailed report ~~and/~~or the full report be created to record sufficient information to demonstrate that all the objectives of the tests have been attained.

Each type of report shall include the title page and the table of contents, and the title page shall contain the same information as that described in 16.2.

B.2 Detailed report

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

1) type, specifications, 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) calibration results of instruments;
4) reference to the calculation method;
5) tabular and graphical presentation of the results.

NOTE The detailed discussion of uncertainty analysis can be found in IEC 62282-3-200:2015, Annex A.

B.3 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;~~

~~2)~~ • copies of original data sheets that shall include the following information in addition to the measurement data:
  – date and time of the test run;
  – model and serial number and measurement accuracy of instruments used for the test;
  – ambient test conditions;
  – name and qualifications of person(s) conducting the test;
  – full and detailed uncertainty analysis.

Annex C
(informative)

Checklist for performance criteria dealt with in this document

Parameters		Relevance ☒yes / ☐no?
1	Principles of parameter integration	☒
2	Fuel quality	
2.1	Types of fuel (e.g., propane, natural gas, methanol)	☒
2.2	Fuel composition (e.g., hydrogen content)	☒
2.3	Fuel impurities (e.g., Sulphur, NOx, CO)	☒
2.4	Particles	☐
3	Air quality (if applicable)	
3.1	Chemical active ingredients	☒
3.2	Humidity	☒
4	Media input	
4.1	Minimum requirements	☒
4.2	Air temperature	☒
4.3	Air pressure	☐
4.4	Air flow rate	☐
4.5	Fuel temperature	☒
4.6	Fuel flow rate	☒
4.7	Fuel pressure	☒
4.8	Air excess/Air fuel ratio	☐
4.9	Flow rate[1)]	☒
4.10	Maximum temperature[1)]	☐
4.11	Normal operating temperature[1)]	☒
4.12	Minimum temperature[1)]	☐
4.13	Maximum pressure[1)]	☐
4.14	Normal operating pressure[1)]	☒
4.15	Minimum pressure[1)]	☐
5	Energy/power input	
5.1	Electrical	☐
	• Voltage external power supply	☐
5.2	Mechanical	☐
5.3	Heat	☐
5.4	Fuel	☒

Parameters		Relevance ☒yes / ☐no?
5.5	**Maximum load[2)]**	☒
5.6	**Normal operating load[2)]**	☐
5.7	**Minimum load[2)]**	☐
5.8	**Standby energy[2)]**	☐
5.9	**Start-up energy[2)]**	☐
6	**Media output (Minimum requirements)**	
6.1	**Exhaust gas temperature**	☐
6.2	**Exhaust gas flow rate**	☐
6.3	**Oxygen content [Vol %]**	☐
6.4	**Content of harmful or restricted components**	☐
6.5	**Flow rate[1)]**	☒
6.6	**Maximum temperature[1)]**	☐
6.7	**Normal operating temperature[1)]**	☐
6.8	**Minimum temperature[1)]**	☐
6.9	**Maximum pressure[1)]**	☐
6.10	**Normal operating pressure[1)]**	☐
6.11	**Minimum pressure[1)]**	☐
7	**Energy/power output**	
7.1	**Electric**	
	• Maximum voltage	☒
	• Minimum voltage	☒
	• Maximum current	☒
	• Frequency	☐
	• Overload capability	☒
	• Power stability under the operation	☒
7.2	**General performance measured**	
	• Electric efficiency	☒
	• Heat recovery efficiency	☐
	• Rated power output	☒
	• Ramp up rate	☐
	• Start-up energy	☐
	• Shutdown energy	☐
	• Pre-generation	☒
	• Maximum power output	☒
	• Environmental performance	☐
7.3	**Recovered heat**	☐
7.4	**Maximum load [2)]**	☐

Parameters		Relevance ☒yes / ☐no?
7.5	Normal operating load (rated[3])[2])	☐
7.6	Minimum load[2])	☐
8	**Efficiency**	
8.1	Electrical efficiency at rated load[3])	☒
8.2	Electrical efficiency at minimum load	☐
8.3	Heat recovery efficiency at rated load[3])	☐
8.4	Heat recovery efficiency at minimum load	☐
8.5	Overall energy efficiency at rated load[3])	☐
8.6	Overall energy efficiency at minimum load	☐
9	**Dynamic operation[4])**	
9.1	Start-up	☐
9.2	Load change	☐
9.3	Shutdown	☐
10	**Environmental performance**	
10.	Exhaust gas temperature and composition (e.g., O_2, CO_2, CO, NOx, SO_2, Total Hydrocarbon (THC) concentrations)	☒
10.2	Discharged water properties (e.g., flow rate, temperature, pH-Value, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD))	☒
10.3	Noise level	☒
10.4	Vibration level	☐
10.5	Electromagnetic Compatibility (EMC) behaviour	☐
10.6	Ambient temperature operation	☐
10.7	Ambient temperature standby and start-up	☐
10.8	Relative humidity	☒
11	**Control and communications**	
11.1	Communication interface	☐

Remarks

1) Applicable per each used process medium. Media are all substances that are supplied or removed from the fuel cell power system. Examples are also cooling substances or water needed for heating.

2) Applicable per subsystem/component.

3) See definition of "rated power" in IEV 485-14-04: maximum continuous electric power output that a fuel cell power system is designed to achieve under normal operating conditions specified by the manufacturer.

4) Dynamic operation should be defined by the manufacturer to avoid unacceptable conditions (thermal stresses, increased degradation, etc.)

Bibliography

IEC 60050-811, *International Electrotechnical Vocabulary (IEV) – Part 811: Electric traction,* available at http://www.electropedia.org

IEC 60050-485, *International Electrotechnical Vocabulary (IEV) – Part 485: Fuel cell technologies,* available at http://www.electropedia.org

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

~~IEC/TS 62282-1, *Fuel cell technologies – Part 1: Terminology*~~

IEC 62282-3-200:2015, *Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*

IEC 62282-3-201, *Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*

IEC 62282-4-101:2022, *Fuel cell technologies – Part 4-101: Fuel cell power systems for ~~propulsion other than road vehicles and auxiliary power units (APU)~~ electrically powered industrial trucks – Safety ~~of electrically powered industrial trucks~~*

ISO 5053-1, *Industrial trucks – Vocabulary – Part 1: Types of industrial trucks*

ISO 5815 (all parts), *Water quality – Determination of biochemical oxygen demand after n days (BODn)*

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

~~ISO 6798, *Reciprocating internal combustion engines – Measurement of emitted airborne noise – Engineering method and survey method*~~

ISO 6976, *Natural gas – Calculation of calorific values, density, relative density and Wobbe ~~index~~ indices from composition*

ISO 9000, *Quality management systems – Fundamentals and vocabulary*

ISO 9001, *Quality management systems – Requirements*

ISO 9004, *Quality management – Quality of an organization – Guidance to achieve sustained success*

ISO 10523, *Water quality – Determination of pH*

~~ASTMD-1152/97, *Specification for methanol*~~

IEC 62282-4-102

Edition 2.0 2022-12

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Fuel cell technologies –
Part 4-102: Fuel cell power systems for electrically powered industrial trucks – Performance test methods

Technologies des piles à combustible –
Partie 4-102: Systèmes à piles à combustible pour chariots de manutention électriques – Méthodes d'essai des performances

IEC 62282-4-102:2022-12(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

FUEL CELL TECHNOLOGIES –

Part 4-102: Fuel cell power systems for electrically powered industrial trucks – Performance test methods

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 62282-4-102 has been prepared by IEC technical committee 105: Fuel cell technologies. It is an International Standard.

This second edition cancels and replaces the first edition published in 2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) alignment of the Scope with the second edition of IEC 62282-4-101:2022;
b) deletion of terms and definitions (previous entries 3.5, 3.10, and 3.15);
c) addition of new terms in Clause 3: "delivered power" (3.13) and "regenerated power" (3.14);
d) revision of symbols and their meanings in alignment with those of IEC 62282-3-201;
e) replacement of "reference conditions" with "standard conditions" as seen in Clause 5;
f) revision of the test method for the accessory load voltage spike test (13.3.2);

g) addition of clarifications in Clause 14 (Power stability under operation);

h) addition of a checklist for performance criteria dealt with in this document (Annex C).

The text of this International Standard is based on the following documents:

Draft	Report on voting
105/947/FDIS	105/954/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62282 series, published under the general title *Fuel cell technologies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This part of IEC 62282-4 provides consistent and repeatable test methods for the electric, thermal and environmental performance of fuel cell power systems for electrically powered industrial trucks.

The IEC 62282-4 series deals with categories such as safety, performance, and interchangeability of fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APUs). This document (IEC 62282-4-102) focuses on performance test methods for fuel cell power systems used to drive industrial electric trucks, which are being manufactured and used increasingly worldwide. This is because such applications are urgently needed in the world.

This part of IEC 62282-4 describes type tests and their test methods only. No routine tests are required or identified, and no performance targets are set in this document.

Fuel cell systems used in electrically powered industrial trucks, such as forklift trucks, use both batteries and fuel cells, and so operate in several different modes. Similarly, forklift trucks operate in different modes. The purpose of this document is to evaluate the fuel cell system in the various combinations of fuel cell modes and forklift truck modes. This document breaks down these different modes and provides a framework for designing and evaluating a fuel cell system for use specifically in a forklift truck.

This part of IEC 62282-4 is intended to be used by either manufacturers of fuel cell power systems used for electrically powered industrial trucks or those who evaluate the performance of the systems used in them for certification purposes or both.

Users of this document can select and perform the tests they need from those described. This document is not intended to exclude any other tests.

FUEL CELL TECHNOLOGIES –

Part 4-102: Fuel cell power systems for electrically powered industrial trucks – Performance test methods

1 Scope

This part of IEC 62282 specifies the performance test methods of fuel cell power systems for propulsion and auxiliary power units (APU). This document covers fuel cell power systems for propulsion other than those for road vehicles.

This document covers the performance test methods of fuel cell power systems intended to be used for electrically powered industrial trucks as defined in ISO 5053-1, except for:

– rough-terrain trucks;
– non-stacking low-lift straddle carrier;
– stacking high-lift straddle carrier;
– rough-terrain variable-reach truck;
– slewing rough-terrain variable-reach truck;
– variable-reach container handler;
– pedestrian propelled trucks.

This document applies to gaseous hydrogen-fuelled fuel cell power systems and direct methanol fuel cell power systems for electrically powered industrial trucks. The following fuels are considered within the scope of this document:

– gaseous hydrogen, and
– methanol.

This document covers the fuel cell power system as defined in 3.7 and Figure 1.

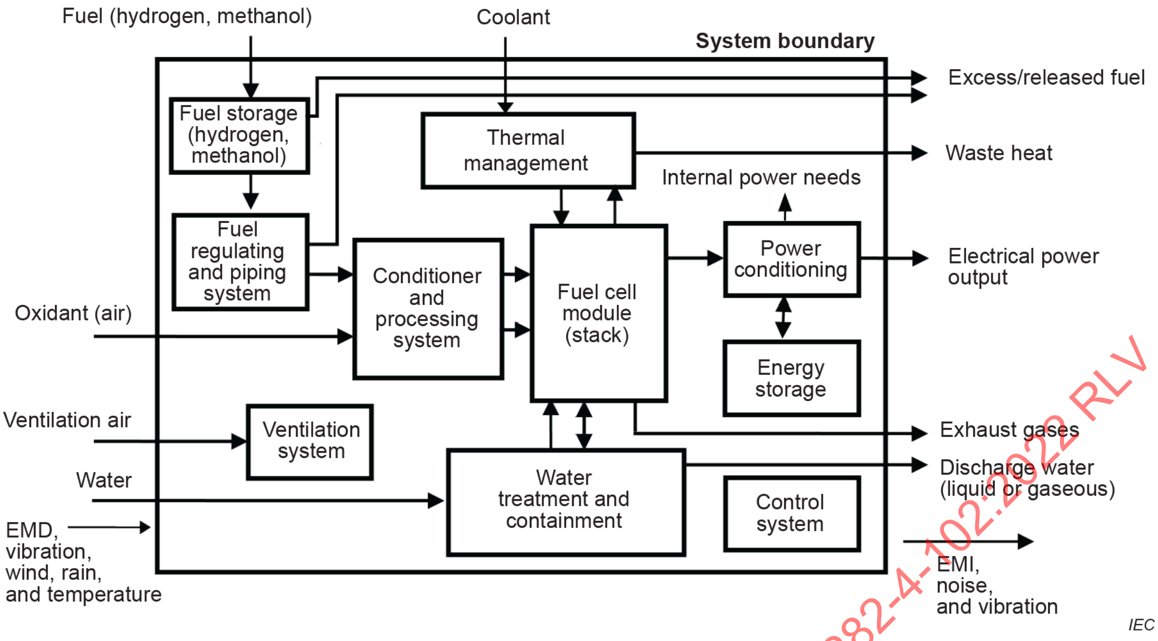
This document applies to DC type fuel cell power systems, with a rated output voltage not exceeding DC 150 V for indoor and outdoor use.

This document covers fuel cell power systems whose fuel source container is permanently attached to either the industrial truck or the fuel cell power system.

All systems with integrated energy storage systems are covered by this document. This includes systems such as batteries for internal recharges or recharged from an external source.

The following are not included in the scope of this document:

– detachable type fuel source containers;
– hybrid trucks that include an internal combustion engine;
– reformer-equipped fuel cell power systems;
– fuel cell power systems intended for operation in potentially explosive atmospheres;
– fuel storage systems using liquid hydrogen.



Key

EMD electromagnetic disturbance

EMI electromagnetic interference

NOTE A fuel cell power system can contain all or some of the above components.

Figure 1 – Fuel cell power systems for electrically powered industrial trucks

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62282-6-300:2012, *Fuel cell technologies – Part 6-300: Micro fuel cell power systems – Fuel cartridge interchangeability*

ISO 6798-1, *Reciprocating internal combustion engines – Measurement of sound power level using sound pressure – Part 1: Engineering method*

ISO 6798-2, *Reciprocating internal combustion engines – Measurement of sound power level using sound pressure – Part 2: Survey method*

ISO 14687, *Hydrogen fuel quality – Product specification*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
noise level
sound pressure level produced by the fuel cell power system measured at a specified distance in all operation modes

Note 1 to entry: Noise level is expressed in decibels (dB) and measured as described in 15.2.

3.2
background noise level
sound pressure level of ambient noise at the measurement point

3.3
battery
electrochemical energy storage device that either provides energy input to support parasitic loads or provides electric energy output or both

Note 1 to entry: Back-up batteries for control software memory and similar applications are not included.

3.4
cold state
state of a fuel cell power system at ambient temperature with no power input or output

[SOURCE: IEC 60050-485:2020, 485-21-01]

3.5
discharge water
water discharged from the fuel cell power system including waste water and condensate

Note 1 to entry: Discharge water does not constitute part of a thermal recovery system.

3.6
fuel cell system electric efficiency
ratio of the average electric power output of a fuel cell power system for a given duration to the average fuel power fed to the same fuel cell power system for the same duration

3.7
fuel cell power system
generator system that uses one or more fuel cell modules to generate electric power and heat

Note 1 to entry: The fuel cell power system for use with industrial trucks will be in one of the forms as outlined in IEC 62282-4-101:2022, 3.9 and 3.10.

[SOURCE: IEC 60050-485:2020, 485-09-01, modified – Note 1 to entry has been added.]

3.8
fuel input
amount of hydrogen or methanol supplied to the fuel cell power system

3.9
fuel consumption
volume or mass of fuel consumed by the fuel cell power system under specified operating conditions

3.10
minimum electric power output
minimum power output, at which a fuel cell power system is able to operate continuously at a steady state

3.11
rated power
maximum continuous electric power output that a fuel cell power system is designed to achieve under normal operating conditions specified by the manufacturer

[SOURCE: IEC 60050-485:2020, 485-14-04, modified – Note 1 to entry has been deleted.]

3.12
test duration
time interval in which data points required for the computation of test results are recorded

3.13
delivered power
current and voltage delivery requirements of the industrial truck at various intervals as necessary in order to maintain acceptable truck performance

3.14
regenerated power
electro-dynamic power in which the energy produced by the motors is fed into the contact line or into energy storage on-board devices

Note 1 to entry: Examples of storage devices: batteries, flywheels.

[SOURCE: IEC 60050-811:2017, 811-06-25, modified – The term "regenerative braking" has been replaced with "regenerated power" and in the definition "braking" has been replaced with "power".]

4 Symbols

The symbols and their meanings used in this document are given in Table 1 for electric and thermal performance and in Table 2 for environmental performance, with the appropriate units.

Table 1 – Symbols and their meanings for electric and thermal performance

Symbol	Definition	Unit
M, m	**Molar mass, mass**	
M_f	Molar mass of fuel	kg/mol
m_f	Fuel mass measured over the test duration	kg
$\boldsymbol{p}$	**Pressure**	
p_s	Standard pressure (101,325 kPa (abs))	kPa (abs)
p_f	Average fuel pressure	kPa (abs)
$\boldsymbol{P}$	**Power**	
P_n	Average net electric power output	kW
P_{fin}	Average fuel power input	kJ/s
$\boldsymbol{E}$	**Input energy**	
E_{mf}	Input energy of fuel per mass	kJ/kg
E_{vf}	Input energy of fuel per volume	kJ/l
E_{fin}	Total fuel input energy	kJ
$\boldsymbol{q_m}$	**Mass flow rate**	
q_{mf}	Average mass flow rate of fuel under the test conditions	kg/s

Symbol	Definition	Unit
q_V	**Volumetric flow rate**	
q_{Vf}	Average volumetric flow rate of fuel under the test conditions	l/min
q_{Vfs}	Average volumetric flow rate of fuel under standard conditions	l/min
H	**Heating value**	
H_{fs}	Heating value of fuel on a molar basis under standard conditions	kJ/mol
H_{fl}	Heating value of liquid mass	kJ/kg
t	**Time**	
Δt	Test duration	s, min
T	**Temperature**	
T_s	Standard temperature (273,15 K)	K
T_f	Average fuel temperature	K
V, V_m	**Volume, molar volume**	
V_f	Total fuel volume measured over the test duration	l
V_{ms}	Standard molar volume of ideal gas (22,414 l/mol) (at standard temperature T_0 = 273,15 K and pressure p_0 = 101,325 kPa)	l/mol
W	**Electric energy**	
W_{out}	Electric energy output	kW · h
η	**Efficiency**	
η_{el}	Electric efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%

Table 2 – Symbols and their meanings for environmental performance

Symbol	Definition	Unit
φ	**Volume fraction**	
$\varphi_{B,meas}$	measured volume fraction of the component B	vol % or ml/m^3
$\varphi_{B,corr}$	corrected volume fraction of the component B	vol % or ml/m^3
$\varphi_{at}(O_2)$	measured O_2 (oxygen) volume fraction in atmosphere at air inlet in dry state	vol %
$\varphi_{ex}(O_2)$	measured O_2 volume fraction in dry exhaust gas	vol %
$\varphi_{ex,corr}$(CO)	corrected CO volume fraction in dry exhaust gas	ml/m^3
$\varphi_{ex,corr}$(THC)	corrected total hydrocarbon (THC) volume fraction in dry exhaust gas (carbon equivalent)	ml/m^3
γ	**Mass concentration**	
γ_{ex}(CO)	CO mass concentration in dry exhaust gas	mg/m^3
γ_{ex}(THC)	THC mass concentration in dry exhaust gas	mg/m^3
ε	**Emission**	
ε(CO)	mass of CO emission per energy of input fuel	mg/kW · h
ε(THC)	mass of THC emission per energy of fuel input	mg/kW · h
α	**Atom ratio**	

Symbol	Definition	Unit
α(THC)	hydrogen to carbon atom ratio of the THC in the exhaust gas	
ω	**Mass fraction**	
ω_B	mass fraction of methanol	

5 Standard conditions

The standard conditions are specified as follows:

– standard temperature: T_s = 273,15 K (0 °C);

– standard pressure: p_s = 101,325 kPa (abs).

6 Heating value base

Except if otherwise specified, the given heating value of fuel shall be the low heating value (LHV) or similar.

NOTE The heating values of hydrogen and methanol (LHV and HHV) are given in Annex A.

In cases where the LHV is applied for the calculation of energy efficiency, it is not necessary to add the LHV, as shown below:

$$\eta_{el}, \eta_{th}, \text{ or } \eta_{total} = \text{XX } \%$$

If the higher heating value (HHV) is applied, the HHV shall be added to the value of energy efficiency as follows:

$$\eta_{el}, \eta_{th}, \text{ or } \eta_{total} = \text{XX } \% \text{ (HHV)}$$

7 Test preparation

7.1 General

Clause 7 describes typical items that shall be considered prior to the implementation of a test. For each test, an effort shall be made to minimize uncertainty by selecting high-precision instruments and planning the tests with attention to detail. Detailed test plans shall be prepared by the parties to the test using this document as their basis. A written test plan shall be prepared.

The following items shall be considered for the test plan:

1) objective;
2) test specifications;
3) test personnel qualifications;
4) quality management standards (ISO 9000, ISO 9001 and ISO 9004, collectively known as the ISO 9000 family, or other equivalent standards);
5) target uncertainty;
6) identification of measurement instruments (refer to Clause 9);
7) estimated range of test parameters;
8) data acquisition plan.

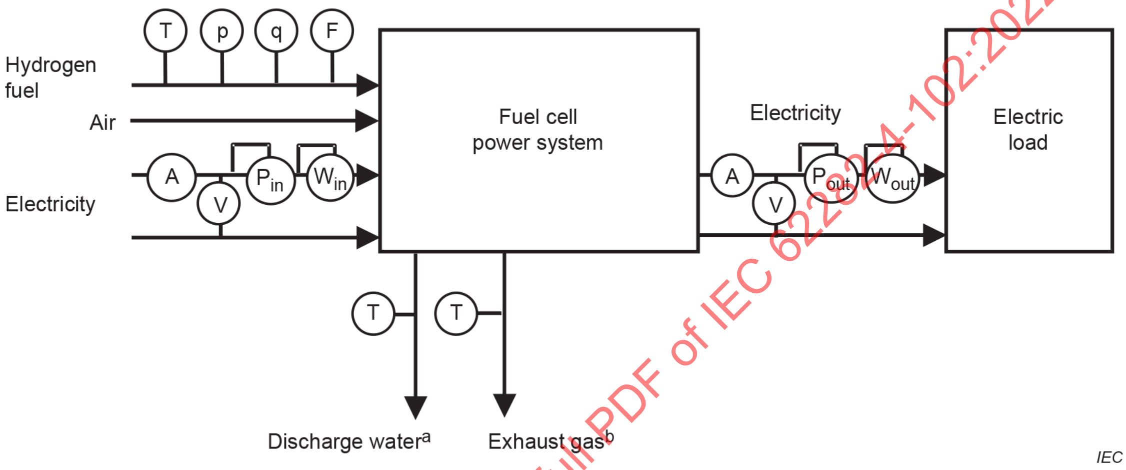
7.2 Data acquisition plan

In order to meet the target uncertainty, proper duration and frequency of readings shall be defined and data recording equipment shall be prepared before the performance test.

Automatic data acquisition using a personal computer or similar is preferable.

8 Test set-up

Figure 2 and Figure 3 illustrate examples of test set-ups that are required to conduct fuel cell power system testing with hydrogen fuel and methanol fuel, respectively, which are described in this document. An electric load is connected to a fuel cell power system.



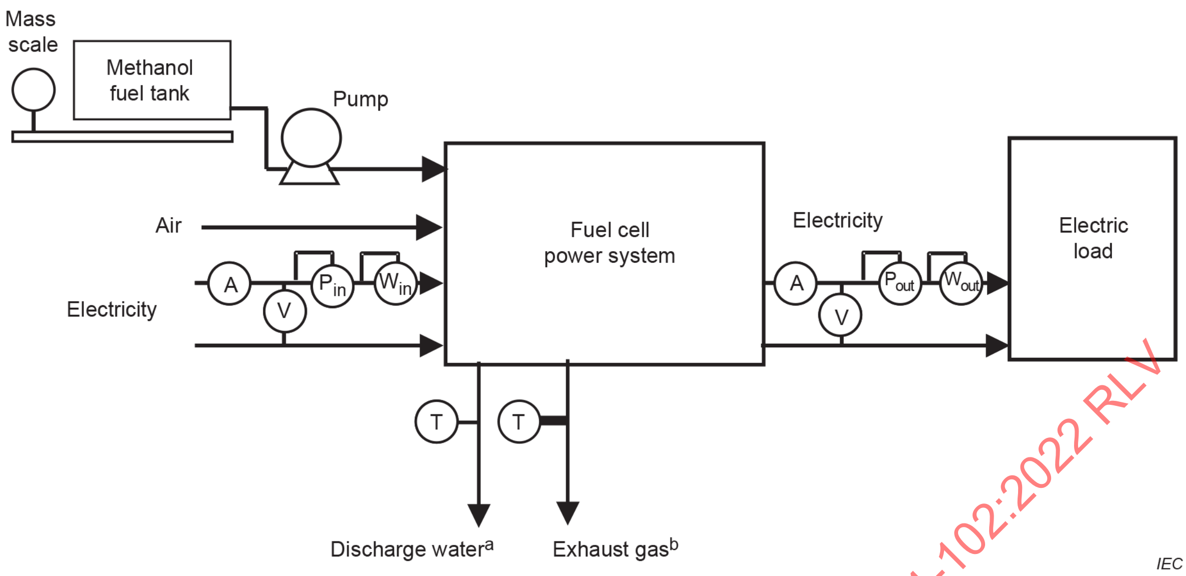
Key

A	ammeter
V	voltmeter
T	thermometer
p	pressure gauge
q	flowmeter
F	integrating flowmeter
P	electric power meter
W	integrating electric power meter (electric energy meter)

[a] To collecting device to measure volume (or weight), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD).

[b] To collecting device to analyse components.

Figure 2 – Example of a test set-up for hydrogen fuel



NOTE See explanations of the symbols in Figure 2.

[a] To collecting device to measure volume (or weight), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD).

[b] To collecting device to analyse components.

Figure 3 – Example of a test set-up for methanol fuel

9 Instruments and measurement methods

9.1 General

Measurement instruments and measurement methods shall conform to the relevant international standards. They shall be selected to meet the measurement range specified by the manufacturer and the required accuracy of measurements.

9.2 Measurement instruments

Measurement instruments are listed according to their intended use:

a) apparatus for measuring voltage spikes: oscilloscope, high-frequency analysers;

b) apparatus for measuring the electric power input and output, and electric energy input and output:
   – electric power meters, electric energy meters, voltmeters, ammeters;

c) apparatus for measuring fuel input:
   – flowmeters, integrating flowmeters, weight meters, pressure sensors, temperature sensors;

d) apparatus for measuring ambient conditions:
   – barometers, hygrometers, and temperature sensors;

e) apparatus for measuring the noise level:
   – sound level meters as specified in IEC 61672-1 or other measuring instruments of equivalent or better accuracy;

f) apparatus for measuring concentrations of the exhaust gas components:
   – oxygen analyser (e.g. based on paramagnetic, electrochemical or zirconium oxide sensors);
   – carbon dioxide analyser (e.g. GC-MS or based on infrared absorption sensor);

– carbon monoxide analyser (e.g. based on nondispersive infrared or electrochemical sensor);

g) apparatus for determining the discharge water:

– graduated cylinder (for volume measurement), temperature sensor, pH meters, BOD probes.

9.3 Measurement points

Measurement points for the different parameters are described below.

a) Hydrogen fuel flow rate:

Place a flowmeter for fuel on the fuel supply line to the fuel cell power system to measure the fuel flow rate.

b) Hydrogen integrated fuel input:

Place an integrating flowmeter for fuel on the fuel supply line to the fuel cell power system to measure the fuel input. The integrating flowmeter shall combine a flowmeter that measures the fuel flow rate.

c) Methanol fuel input weight:

Place a weight meter under the fuel tank to measure the weight of fuel and tank together. Methanol fuel input weight is measured by subtracting the weight after the test from that before the test.

d) Fuel temperature:

Connect a thermometer or a thermocouple immediately downstream of the fuel flowmeter.

e) Fuel pressure:

Place a pressure meter immediately downstream of the fuel flowmeter to measure the gauge pressure of fuel.

f) Electric power output:

Connect an electric power meter to the electric power output terminal of the fuel cell power system and close to the system boundary.

g) Electric energy output:

Connect an electric energy meter to the electric power output terminal of the fuel cell power system and close to the system boundary. The electric energy meter shall incorporate an electric power meter that indicates electric power output.

h) Fuel composition:

The fuel used for the tests shall be sampled and analysed for its composition for each test run.

i) Atmospheric pressure:

Place an absolute pressure meter adjacent to the fuel cell power system where it will not be affected by ventilation, air intake or exhaust of the fuel cell power system.

j) Atmospheric temperature:

Place a thermometer adjacent to the fuel cell power system where the thermometer will not be affected by ventilation, air intake or exhaust of the fuel cell power system.

k) Atmospheric humidity:

Place a hygrometer adjacent to the fuel cell power system where the hygrometer will not be affected by ventilation, air intake or exhaust of the fuel cell power system.

l) Noise level:

Refer to 15.2.

m) Exhaust gas:

Place one or more exhaust gas collecting probes combined with a temperature sensor in the exhaust stream at the exhaust gas outlet (refer to Figure 2 and Figure 3).

n) Discharge water:

Place a discharge water reservoir combined with a temperature sensor at the discharge water outlet.

9.4 Minimum required measurement systematic uncertainty

The test equipment should be chosen in a way that the systematic uncertainty of measurement is below 3 % for overall and thermal efficiencies, and below 2 % for electrical efficiency. In order to reach the desired efficiency uncertainties, the following systematic measurement uncertainties of the equipment are recommended. They are given in percentage of measured or calculated values or both, or as absolute values:

- electric power: ±1 %;
- electric energy: ±1 %;
- fuel gas flow rate: ±1 %;
- integrated gas flow: ±1 %;
- time: ±0,5 %;
- liquid fuel mass: ±1 % of the mass to be determined (not including the tare weight) as in IEC 62282-3-201;
- relative humidity: ±5 %;
- absolute pressure: ±1 %;
- fuel gas and discharge water temperature: ±1 K;
- exhaust gas temperature: ±4 K.

10 Test conditions

10.1 Laboratory conditions

Unless otherwise specified, performance shall be tested in the environment specified below:

- temperature: 20 °C ± 5 °C;
- humidity: 65 % ± 20 % relative humidity;
- pressure: between 91 kPa (abs) and 106 kPa (abs).

The laboratory conditions shall be measured and set for each test run. As air quality will affect fuel cell system performance, laboratory air composition including foreign substances and gases shall be reported with the test result.

10.2 Installation and operating conditions of the system

The fuel cell power system shall be assembled and operated in accordance with the manufacturer's installation instructions prior to the start of the tests.

10.3 Indication of battery condition

Systems with batteries may be equipped with a means (for example, a display method or an output signal) to identify that the battery has reached a known nominal state of charge (including full charge state) that is determined by the manufacturer.

10.4 Determination of state of charge of the battery

The time when the battery is recharged to the known nominal state of charge can be determined by either one of the following two methods:

a) for a system equipped with a means (for example, a display method or an output signal) to identify that the battery has reached a known nominal state of charge, the charge-out time is determined by that means;

b) for a system equipped with no means to identify that the battery has reached a known nominal state of charge, the charge-out time to reach the nominal state of charge may be determined by measuring the time when the input fuel flow rate becomes stabilized within ±2 % of the rated fuel flow rate after the fuel flow increase for recharging the battery ceases. This measurement is not mandatory.

10.5 Quality of test fuel

10.5.1 Hydrogen

The hydrogen fuel used for the tests shall have the quality given in grade D of ISO 14687.

10.5.2 Methanol solution

The methanol used for preparing the methanol solution which is used for the tests shall be consistent with the specification given in IEC 62282-6-300:2012, 5.5.2.

The water mixed with methanol shall be ion-exchanged water with an electric conductivity of less than 1 μS/cm.

The methanol concentration in the methanol solution shall be specified by the manufacturer.

11 Fuel consumption test

11.1 Hydrogen fuel consumption test

11.1.1 General

This test is for measuring the hydrogen fuel input at rated power output. If operation at partial loads of 50 %, of 75 %, and at the minimum electric power output are specified by the manufacturer or if one of these operating points is selected , these operating points shall be measured as well.

This test shall be carried out concurrently with the electric power output test in Clause 12.

11.1.2 Test method

1) Operate the system at the rated power output at least 30 min before starting the test.

2) For systems including electrochemical batteries, operate the system at the rated power output at least 30 min and until a known nominal state of charge is reached, before starting the test.

3) Start the test while keeping the system operating at the rated power output.

4) Measure the fuel temperature, fuel pressure, and integrated fuel input flow (in volume or in mass). Each measurement shall be taken for a minimum of 60 min.

11.1.3 Calculation of results

11.1.3.1 Calculation of average hydrogen fuel input rate

The average hydrogen fuel input rate shall be described either as the volumetric flow rate at standard conditions, q_{Vfs} in l/min, or as the mass flow rate, q_{mf} in kg/s. It shall be calculated according to the following procedure.

1) Volumetric flow rate

   a) The average volumetric flow rate of fuel under the test conditions, q_{Vf} in l/min, shall be obtained by dividing the integrated fuel volume over the test duration by the test duration.

$$q_{\mathrm{Vf}} = V_{\mathrm{f}} / \Delta t \tag{1}$$

   where

   q_{Vf} is the average volumetric flow rate of fuel under the test conditions (l/min);

   V_{f} is the total fuel volume over the test duration (l);

   Δt is the test duration (min).

   b) The average volumetric flow rate of fuel under the standard conditions, q_{Vfs} in l/min, shall be calculated with the following formula. The average values of fuel temperature and pressure obtained during the test duration shall be used.

$$q_{\mathrm{Vfs}} = q_{\mathrm{Vf}} \times (T_{\mathrm{s}}/T_{\mathrm{f}}) \times (p_{\mathrm{f}}/p_{\mathrm{s}}) \tag{2}$$

   where

   q_{Vfs} is the average volumetric flow rate of fuel under standard conditions (l/min);

   q_{Vf} is the average volumetric flow rate of fuel under test conditions (l/min);

   T_{s} is the standard temperature (273,15K);

   p_{s} is the standard pressure (101,325 kPa (abs));

   T_{f} is the average fuel temperature during the test duration (K);

   p_{f} is the average fuel pressure during the test duration (kPa (abs)).

2) Mass flow rate

   The average mass flow rate of fuel under the test conditions, q_{mf} in kg/s, shall be obtained by dividing the integrated mass over the test duration by the test duration.

$$q_{\mathrm{mf}} = m_{\mathrm{f}}/\Delta t \tag{3}$$

   where

   q_{mf} is the average mass flow rate of fuel under the test conditions (kg/s);

   m_{f} is the integrated mass over the test duration (kg);

   Δt is the test duration (s).

11.1.3.2 Calculation of average hydrogen fuel power input

The average hydrogen fuel power input, P_{fin} in kJ/s, shall be calculated either for volumetric flow rate or for mass flow rate according to the following procedure. The average values of fuel temperature and pressure obtained during the test duration shall be used.

1) Volumetric flow rate

a) The energy of fuel per volume at standard conditions, E_{vf} in kJ/l, shall be calculated with the following formula:

$$E_{vf} = H_{fs}/V_{ms} \tag{4}$$

where

E_{vf} is the input energy of the fuel per volume (kJ/l);

H_{fs} is the heating value of hydrogen fuel on a molar basis under standard conditions (241,56 kJ/mol);

V_{ms} is the standard molar volume of ideal gas (22,4 l/mol) (at the standard temperature for this document, t_s = 273,15 K).

NOTE 1 In general, fuel consumption energy and heating values are based on the low heating value (LHV).

b) The average fuel power input, P_{fin} in kJ/s, shall be calculated with the following formula:

$$P_{fin} = q_{Vfs} \times E_{vf} / 60 \tag{5}$$

where

P_{fin} is the average fuel power input (kJ/s);

q_{Vfs} is the average volumetric flow rate of fuel under standard conditions (l/min);

E_{vf} is the energy input of the fuel per volume (kJ/l).

NOTE 2 The specific enthalpy and pressure energy of hydrogen fuel, which are considered in the calculation of fuel consumption energy in IEC 62282-3-200, are ignored in the calculation of fuel consumption energy described above because they are negligible values in fuel cell power systems for forklift trucks that are operated at low temperature and at low pressure.

2) Mass flow rate

a) The input energy of fuel per mass, E_{mf} in kJ/kg, shall be calculated with the following formula:

$$E_{mf} = H_{fs} / M_f \tag{6}$$

where

E_{mf} is the input energy of fuel per mass (kJ/kg);

H_{fs} is the heating value of fuel under standard conditions (kJ/mol);

M_f is the molar mass of fuel (kg/mol).

b) The average fuel power input, P_{fin} in kJ/s, shall be calculated with the following formula:

$$P_{fin} = q_{mf} \times E_{mf} \tag{7}$$

where

P_{fin} is the average fuel power input (kJ/s);

E_{mf} is the input energy of fuel per mass (kJ/kg);

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

11.2 Methanol fuel consumption test

11.2.1 General

This test is for measuring the methanol fuel input at rated power output. If operation at partial loads of 50 %, of 75 % and at the minimum electric power output are specified by the manufacturer or if one of these operating points is selected, these operating points shall be measured as well.

This test shall be carried out concurrently with the electric power output test in Clause 12.

11.2.2 Test method

1) Operate the system at the rated power output at least 30 min before starting the test.
2) For systems including batteries, operate the system at the rated power output at least 30 min and until a known nominal state of charge is reached, before starting the test.
3) Start the test while keeping the system operating at the rated power output. If such an operation is specified by the manufacturer, repeat the tests at partial load, 50 % and 75 % of nominal output, and minimum output.
4) Measure the mass of the fuel tank or of the entire system, including the fuel tank, at the start.
5) Continue the test for a minimum of 3 h. If fuel is to be supplied intermittently, the total test duration shall be 20 times the duration of the fuel supply or 3 h, whichever is longer.
6) Measure the mass of the fuel tank or of the entire system, including the fuel tank, at the end of the test.

11.2.3 Calculation of average methanol fuel power input

Total methanol fuel input energy over the test duration, E_{fin} in kJ, shall be calculated by the following formula:

$$E_{fin} = (A - B) \times H_{fl} \times \omega_B \tag{8}$$

where

E_{fin} is the total fuel input energy (kJ);

A is the mass at the start of the test (kg);

B is the mass at the end of the test (kg);

H_{fl} is the heating value of methanol (kJ/kg);

ω_B is the mass fraction of methanol.

The average fuel power input, P_{fin} in kJ/s, shall be calculated as follows:

$$P_{fin} = E_{fin} / \Delta t \tag{9}$$

where

P_{fin} is the average fuel power input (kJ/s);

E_{fin} is the total fuel input energy (kJ);

Δt is the test duration (s).

NOTE In general, fuel input energy and heat values are based on the low heating value (LHV).

12 Electric power output test

12.1 General

This test is for measuring the average net electric output at the rated power output. If operation at partial loads of 50 %, of 75 % and at the minimum electric power output are specified by the manufacturer or if one of these operating points is selected, these operating points shall be measured as well.

This test shall be carried out concurrently with the fuel consumption test in Clause 11.

12.2 Test method

1) Operate the system at the rated power output at least 30 min before starting the test.
2) For systems including batteries, operate the system at the rated power output at least 30 min and until a known nominal state of charge is reached before starting the test.
3) Start the test while keeping the system operating at the rated power output. If such an operation is specified by the manufacturer, repeat the test at partial loads of 50 % and of 75 % of the nominal output, and the minimum output.
4) Measure the electric energy output during the test period. The test shall be conducted for at least 3 h. If fuel is to be supplied intermittently, the total test duration shall be 20 times the duration of the fuel supply or 3 h, whichever is longer.

12.3 Calculation of average electric power output

The average electric power output shall be calculated with the following formula:

$$P_n = \frac{W_{out}}{\Delta t} \times 3600 \tag{10}$$

where

P_n is the average electric power output (kW);

W_{out} is the electric energy output during the test period (kWh);

Δt is the test duration(s).

12.4 Computation of electric efficiency

Electric efficiency is computed on the basis of calculated values given in Clauses 11 and 12.

Electric efficiency, η_{el} in %, shall be calculated with the following formula:

$$\eta_{el} = \frac{P_n}{P_{fin}} \times 100 \tag{11}$$

where

η_{el} is the electric efficiency (%);

P_n is the average electric power output (kW) (refer to 12.3);

P_{fin} is the average fuel power input (kJ/s) (refer to 11.1.3.2 and 11.2.3).

13 Type tests on operational performance

13.1 Maximum power output test

13.1.1 General

The purpose of this test is to determine the fuel cell's ability to maintain the maximum electric power load immediately after start-up. One scenario will be tested on the fuel cell after it has been in a pre-generation state for a period of time. Another scenario will be tested after running at nominal load for a period of time, powering down the fuel cell, then powering up the fuel cell with the maximum continuous load connected.

13.1.2 Test method

1) To condition the system prior to the test, operate the system at the rated power output at least 30 min before starting the test.
2) The fuel cell system shall be powered down and cooled down to the ambient temperature. Connect the maximum electric load, specified by the manufacturer, to the fuel cell system. Power on the fuel cell system in accordance with the manufacturer’s recommendations.
3) Operate the system at the maximum electric power output for the manufacturer's specified time or for 1 h (whichever is shorter). Power down the fuel cell system completely in accordance with the manufacturer's specifications. Connect the maximum electric load to the fuel cell system specified by the manufacturer. Within 2 min, power up the fuel cell system in accordance with the manufacturer’s recommendations.

13.1.3 Processing of data

When powering up the fuel cell system with loads, if the system disconnects power to the load, the time duration that the load is without power shall be recorded. If any warning lights on the system, such as a low-battery indicator, illuminate, these shall also be recorded in the report.

13.2 Power cycling electric load test

13.2.1 General

The purpose of this test is to stress the fuel cell system by cycling an electric load connected to the system in a similar manner to how the load in an electric industrial truck shall vary.

13.2.2 Test method

1) Operate the system at the rated power output at least 30 min before starting the test.
2) Operate the system at the rated power output for 15 min, then operate the system at the maximum electrical power specified by the manufacturer for 15 min. Repeat this cycle for 8 h. If the fuel cell system disconnects power from the load and then reconnects, the times of disconnection and reconnection shall be recorded in the report.

13.2.3 Processing of data

When the fuel cell system is being cycled, if the system disconnects power to the load, or if any warning lights on the system, such as a low-battery indicator, illuminate, these shall be recorded in the report. The time of the event shall be recorded, as well as the duration of the event.

13.3 Accessory load voltage spike test

13.3.1 General

The purpose of this test is to determine if the fuel cell system clamps inductive spikes caused by using a contactor to power external loads.

13.3.2 Test method

1) Connect the inductive load to a fuel cell system (such as a fan).
2) Spikes shall be measured at the electrical power output where the customer's cable connects to the system output.
3) The fuel cell power system shall be started in accordance with the manufacturer's instructions. The amplitude and duration of the voltage spikes generated shall be recorded in the report.

13.3.3 Processing of data

1) The inductive load used shall be recorded in the report. The load shall be lower than the manufacturer's specifications.
2) When powering up the fuel cell system with a load, voltage spikes greater than 2 V above the fuel cell's nominal voltage or spikes greater than 2 V below 0 V shall be recorded in the report. The voltage spike magnitude and the duration shall also be recorded in the report.

14 Power stability under operation

14.1 General

The purpose of this test is to determine the stability of the power output of the fuel cell power system when driving the truck in a real-life situation. The energy flow between the fuel cell power system and the rotating electric load are shown in Figure 4.

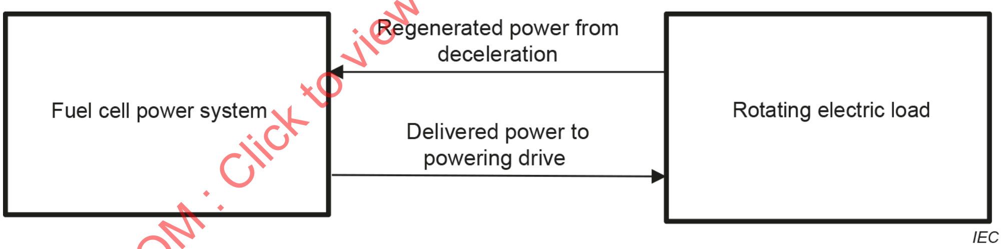


Figure 4 – Energy flow for regenerated power and delivered power

14.2 Delivered power

The delivered power required for the truck operation as stated by the manufacturer shall be measured and recorded.

The fuel cell power system shall be operated at rated power output for 30 min for warming-up, and the battery shall be checked to have reached the target SOC before starting the test.

The fuel cell power system shall be operated with the discharge times given in Table 3 and with no extra load (zero current) conditions. Additional discharge times can be added by the manufacturer. These are not a definition of the truck's application requirements; they define the requirements of the truck's control system.

The values requested in Table 3 shall be recorded during the operation of the truck.

Table 3 – Delivered power measurements

Discharge time	Current A	Average current A	Maximum voltage V	Minimum voltage V
0 s	0			
5 s	I_1			
30 s	I_2			
1 h	I_3			
NOTE Currents I_1, I_2, and I_3 are given by the truck manufacturer.				

14.3 Regenerated power

The truck manufacturer shall specify the regenerated power requirements of the industrial truck in various operating modes, as necessary, in order to maintain acceptable truck performance.

Warm-up of the fuel cell power system shall be made prior to the test. The test shall be started at the target SOC on the electrical storage device.

The truck shall be operating with the discharge times given in Table 4. Additional discharge times can be added by the truck manufacturer. These are not a definition of the truck's application requirements; they define the requirements of the truck's control system.

The values requested in Table 4 shall be recorded during the operation of the truck.

Table 4 – Regenerated power measurements

Discharge time	Current A	Average current A	Maximum voltage V	Minimum voltage V
5 s	I_1			
30 s	I_2			
NOTE Currents I_1 and I_2 are given by the truck manufacturer.				

The battery condition (state of charge and temperature upon measurement) shall be recorded.

15 Type tests on environmental performance

15.1 General

The type tests on environmental performance include:

– noise test (15.2); and
– exhaust gas test (15.3).

15.2 Noise test

15.2.1 General

This test is conducted to measure the level of noise generated from the system with the measuring apparatus listed in 9.2 e) at each operation phase from start-up, the rated power output, the minimum electrical power output (if such operation is specified by the manufacturer and desired by the user), up until shutdown. The rated power output is specified by the manufacturer.

15.2.2 Test conditions

15.2.2.1 Reference planes

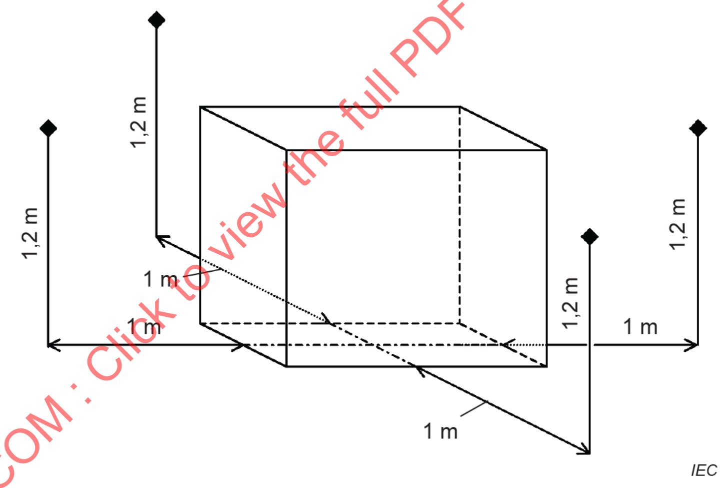
The reference planes shall be set at 1 m away from the four sides (front, back, left, and right) of the fuel cell power system. If this is not feasible, they shall be set at 50 cm away, and the test report shall expressly state this.

Any protrusions or projections on the fuel cell power system surfaces shall be ignored if they are deemed to have no significant effects on the surface noise, and the power system surfaces are conceptually simplified in accordance with ISO 6798-1 and ISO 6798-2.

15.2.2.2 Measurement points

Measurements shall be taken at four points, namely in two directions on the front-back centre line, and two directions on the right-left centre line of the fuel cell power system. The measurement points shall be located on the reference plane at a height of 1,2 m from the bottom of the power system (see Figure 5).

The sound level meter microphone shall be perpendicularly oriented with respect to the reference planes.



Key

◆ Measurement point

Figure 5 – Noise measurement points for fuel cell power systems

15.2.2.3 Effect of background noise

It is desirable to have a difference of 10 dB or more in the noise meter readings between when there is noise to be measured and when there is no noise. If the difference in readings is 3 dB or more but less than 10 dB, the readings can be adjusted according to Table 5 to estimate the noise level when the fuel cell power system is the only noise source.

Table 5 – Correction values corresponding to the effect of background noise

Difference in readings with and without the subject noise dB	3	4	5	6	7	8	9
Correction value dB	−3	−2		−1			

15.2.2.4 Effect of sound reflection

When there is a large reflecting body near the microphones or the sound source, measurement errors will occur as sounds reflected from the reflecting body add to the sound from the source. Before taking measurements, it is desirable to remove, to the greatest extent possible, any objects that reflect sounds. If that is not possible under the measurement conditions, state this in the test report.

15.2.3 Test method

1) Measure the background noise level with the system to be measured in the cold state.
2) Start up the system from its cold state.
3) Raise the output to the rated power output, and wait until at least 30 min passes after reaching rated power output. Continue to operate the system at the rated power output for another 1 h or more.
4) If a minimum electrical power output operation is specified by the manufacturer and measurement is desired by the user, set the system to minimum electrical power output and wait until at least 30 min afterwards. Continue to operate the system at the minimum electrical power output for another 1 h or more.
5) Shut down the system.
6) Measure the noise level from start-up to shutdown. The frequency of measurement shall be 1 s intervals. Readings shall be rounded off to the nearest whole number (e.g. 45,7 becomes 46).
7) Measure the background noise level after shutdown is complete and verify that there is no difference of reading from the background noise level measured in 1).

15.2.4 Processing of data

1) The effect of background noise shall be corrected as explained in 15.2.2.3.
2) The following shall be reported as representative noise level values:
   – the maximum noise level throughout all operation phases and the operation phase in which the maximum value was generated;
   – the mean value of noise levels for 1 h of operation at rated power.

15.3 Exhaust gas test

15.3.1 General

The exhaust gas test applies only to direct methanol fuel cells. This test is for measuring the volume fraction of each component in the exhaust gas from the direct methanol fuel cell power system. It is used to calculate the following values during start-up time, the rated power output phase and shutdown time:

– the mass concentrations of CO and THC (mg/m^3) (15.3.4.3);
– the masses of CO and THC per energy of fuel input (mg/kWh) (15.3.4.4).

15.3.2 Components to be measured

The components and values to be measured shall be as follows:

– carbon monoxide (CO);
– total hydrocarbons (THC);
– oxygen (O_2).

15.3.3 Test method

a) When putting the sampling probe(s) entirely into the exhaust stream, ensure that the sampling probe(s) do not block the exhaust duct. The probe(s) shall be placed close to the exhaust gas outlet of the fuel cell power system, either inside of the exhaust gas evacuation duct for closed exhaust ventilation systems, or directly at the outlet of the exhaust gas for open exhaust ventilation systems. If the exhaust ducting is large in size, take readings at the centre of the exhaust duct and at representative points in a grid across the exhaust duct and average the readings.

b) For open exhaust gas ventilation systems, the probe(s) shall be placed in a way that prevents the mixing of the sample gas with ambient air.

c) During measurements, ensure that condensation on the temperature sensor is avoided. Condensation on the sensor will invalidate the readings.

d) Start up the system from its cold state and wait until the rated power output is reached. Wait until at least another 30 min passes after reaching the rated power output.

e) Continue to operate the system at the rated power output for another 3 h or more, then shut down the system.

f) Measure the volume fraction of each component in the exhaust gas (in vol % or ml/m^3), fuel flow (in volume or mass flow), fuel pressure and temperature, room temperature and humidity from start-up to shutdown. The frequency of data collection shall be 15 s or less.

15.3.4 Processing of data

15.3.4.1 General

The corrected volume fraction at dry and air-free conditions (15.3.4.2) shall be used in the following calculations:

– the mass concentrations of CO and THC (mg/m^3) (15.3.4.3);
– the masses of CO and THC per energy of input fuel (mg/kW · h) (15.3.4.4).

The calculated values which shall be reported are indicated in 15.3.4.5 and 15.3.4.6.

15.3.4.2 Correction to volume fraction at dry and air-free conditions

The measured volume fraction of each component (in ml/m^3) in the exhaust gas shall be corrected to the volume fraction at dry and air-free conditions with the following equation using the measured O_2 volume fraction in dry exhaust gas:

$$\varphi_{\text{B,corr}} = \varphi_{\text{B,meas}} \times \frac{\varphi_{\text{at}}(\text{O}_2)}{\varphi_{\text{at}}(\text{O}_2) - \varphi_{\text{ex}}(\text{O}_2)} \qquad (12)$$

where

$\varphi_{\text{B,corr}}$ is the corrected volume fraction of each component (vol % or ml/m^3);

$\varphi_{\text{B,meas}}$ is the measured volume fraction of each component (vol % or ml/m^3);

$\varphi_{\text{at}}(\text{O}_2)$ is the measured O_2 volume fraction in atmosphere at the air inlet in dry state (vol %, in case of fresh air, $\varphi_{\text{at}}(\text{O}_2) \approx 21$ %);

$\varphi_{\text{ex}}(\text{O}_2)$ is the measured O_2 volume fraction in dry exhaust gas (vol %).

15.3.4.3 Mass concentration of each component

15.3.4.3.1 CO mass concentration

The CO mass concentration shall be calculated with the following equation:

$$\gamma_{ex}(CO) = \varphi_{ex,corr}(CO) \times 1{,}250 \tag{13}$$

where

$\gamma_{ex}(CO)$ is the CO mass concentration in dry exhaust gas (mg/m^3);

$\varphi_{ex,corr}(CO)$ is the corrected CO volume fraction in dry exhaust gas (ml/m^3);

1,250 is the value for the CO density under standard conditions (kg/m^3).

15.3.4.3.2 THC mass concentration

The THC mass concentration shall be calculated with the following equation:

$$\gamma_{ex}(THC) = \varphi_{ex,corr}(THC) \times \left(0{,}537 + \alpha(THC) \times 0{,}045\right) \tag{14}$$

where

$\gamma_{ex}(THC)$ is the THC mass concentration in dry exhaust gas (mg/m^3);

$\varphi_{ex,corr}(THC)$ is the corrected THC volume fraction in dry exhaust gas (ml/m^3, C equivalent);

$\alpha(THC)$ is the hydrogen to carbon atom ratio of the THC in the exhaust gas;

0,537 is the C atomic weight divided by molar volume at standard conditions (kg/m^3);

0,045 is the H atomic weight divided by molar volume at standard conditions (kg/m^3).

NOTE The standard conditions are 0 °C and 101,325 kPa (1 atm).

15.3.4.4 Mass of each component per energy of input fuel

15.3.4.4.1 Mass of CO per energy of input fuel

The mass of CO emission per energy of input fuel (mg/kW · h) shall be calculated with the following equation:

$$\varepsilon(CO) = \varphi_{ex,corr}(CO) \times \left[\frac{22{,}4 \times 10^{-3}}{H_{fs}}\right] \times 1{,}250 \times 3600 \tag{15}$$

where

$\varepsilon(CO)$ is the mass of CO emission per energy of input fuel (mg/kW · h);

$\varphi_{ex,corr}(CO)$ is the corrected CO volume fraction in dry exhaust gas (ml/m^3);

H_{fs} is the molar heating value of methanol under standard conditions (kJ/mol);

$22{,}4 \times 10^{-3}$ is the theoretical dry exhaust gas volume (CO_2) per 1 mol of methanol input according to the following reaction (m^3/mol);

$$CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$$

1,250	is the value for the CO density under standard conditions (kg/m^3);
3 600	is the conversion factor of kJ into kW · h.

15.3.4.4.2 Mass of THC per energy of input fuel

The mass of THC emissions per energy of input fuel (mg/kW · h) shall be calculated with the following equation:

$$\varepsilon(\text{THC}) = \varphi_{\text{ex,corr}}(\text{THC}) \times \left[\frac{22{,}4 \times 10^{-3}}{H_{\text{fs}}}\right] \times \left(0{,}537 + \alpha(\text{THC}) \times 0{,}045\right) \times 3600 \tag{16}$$

where

ε(THC)	is the mass of THC per energy of fuel input (mg/kW · h);
$\varphi_{\text{ex,corr}}$(THC)	is the corrected THC volume fraction in dry exhaust gas (ml/m^3);
H_{fs}	is the molar heating value of methanol under standard conditions (kJ/mol);
α(THC)	is the hydrogen to carbon atom ratio of the THC in the exhaust gas.

15.3.4.5 Averaging the data

The mean mass concentration and the mean mass per input fuel energy for each measured harmful component during the rated power output operation (for 1 h starting from 30 min after the rated power output is reached) shall be calculated by averaging the mass concentration and the mass per input fuel energy respectively.

The mean mass concentration and the mean mass per input fuel energy shall be recorded with annex notes that include average electrical power output, average room temperature, and average humidity.

15.3.4.6 Averaging the temperature of exhaust gas

The average exhaust gas temperature measured at the rated power output shall be recorded.

15.4 Discharge water test

15.4.1 General

When applicable, the quality of discharged water from the fuel cell power system shall be measured throughout all phases of operation from start-up, rated power output to shutdown. The rated power output is specified by the manufacturer.

15.4.2 Test method

1) After installing a device for collecting the discharge water, start the fuel cell power system.
2) The discharge water shall be collected and pooled together from start-up to shutdown through the rated power output for 3,5 h, or one hydrogen tank content, whichever comes first.
3) Measure the following items:
   – total amount of discharge water (time duration of operation shall be recorded);
   – temperature of discharge water;
   – pH;
   – biochemical oxygen demand (BOD) when necessary;
   – chemical oxygen demand (COD) when necessary.

It is recommended to refer to ISO 10523 for pH measurement, ISO 5815 (all parts) for BOD measurement, and ISO 6060 for COD measurement.

16 Test reports

16.1 General

Test reports shall accurately, clearly, and objectively present sufficient information to demonstrate that all the objectives of the tests have been attained. The minimum requirements for the test report shall be a title page, a table of contents and a summary report. For fuel cell systems tested in compliance with this document, the summary report shall be made available to interested parties.

More information obtained under Clauses 11 and 12 can be provided with either a detailed report or a full report for internal purposes. Guidelines for the contents of the detailed report and the full report are given in Annex B.

16.2 Title page

The title page shall present the following information:

a) report identification number;
b) type of report (summary, detailed, or full);
c) authors of the report;
d) entity conducting the tests;
e) date of report;
f) location of the tests;
g) titles of the tests;
h) date and time of the tests;
i) fuel cell power system identification code and the manufacturer's name.

16.3 Table of contents

The table of contents shall present the titles of chapters, clauses, subclauses, etc. in the report with the page numbers in an orderly sequence.

16.4 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) confidence for each test result;
5) conclusions as appropriate;
6) discussion of the tests and their results (i.e. comments and observations);
7) results of fuel analyses.

16.5 Checklist for performance parameters

The performance criteria dealt with in this document are given in Annex C.

Annex A
(informative)

Heating values for hydrogen and methanol at standard conditions

The heating values for hydrogen and methanol are given in Table A.1.

Table A.1 – Heating values for hydrogen and methanol at standard conditions

	Component	Lower heating value on a molar basis kJ/mol	Higher heating value on a molar basis kJ/mol	Lower heating value on a mass basis MJ/kg	Higher heating value on a mass basis MJ/kg
1	Hydrogen	241,56	286,63	119,83	142,19
2	Methanol	676,44	766,59	21,11	23,92
NOTE These values were extracted from ISO 6976.					

Annex B
(informative)

Guidelines for the contents of detailed and full reports

B.1 General

It is recommended that the detailed report or the full report be created to record sufficient information to demonstrate that all the objectives of the tests have been attained.

Each type of report shall include the title page and the table of contents, and the title page shall contain the same information as that described in 16.2.

B.2 Detailed report

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

1) type, specifications, 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) calibration results of instruments;
4) reference to the calculation method;
5) tabular and graphical presentation of the results.

NOTE The detailed discussion of uncertainty analysis can be found in IEC 62282-3-200:2015, Annex A.

B.3 Full report

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

- copies of original data sheets that shall include the following information in addition to the measurement data:
  - date and time of the test run;
  - model and serial number and measurement accuracy of instruments used for the test;
  - ambient test conditions;
  - name and qualifications of person(s) conducting the test;
  - full and detailed uncertainty analysis.

Annex C
(informative)

Checklist for performance criteria dealt with in this document

	Parameters	Relevance ☒yes / ☐no?
1	**Principles of parameter integration**	☒
2	**Fuel quality**	
2.1	**Types of fuel (e.g., propane, natural gas, methanol)**	☒
2.2	**Fuel composition (e.g., hydrogen content)**	☒
2.3	**Fuel impurities (e.g., Sulphur, NOx, CO)**	☒
2.4	**Particles**	☐
3	**Air quality (if applicable)**	
3.1	**Chemical active ingredients**	☒
3.2	**Humidity**	☒
4	**Media input**	
4.1	**Minimum requirements**	☒
4.2	**Air temperature**	☒
4.3	**Air pressure**	☐
4.4	**Air flow rate**	☐
4.5	**Fuel temperature**	☒
4.6	**Fuel flow rate**	☒
4.7	**Fuel pressure**	☒
4.8	**Air excess/Air fuel ratio**	☐
4.9	**Flow rate**[1)]	☒
4.10	**Maximum temperature**[1)]	☐
4.11	**Normal operating temperature**[1)]	☒
4.12	**Minimum temperature**[1)]	☐
4.13	**Maximum pressure**[1)]	☐
4.14	**Normal operating pressure**[1)]	☒
4.15	**Minimum pressure**[1)]	☐
5	**Energy/power input**	
5.1	**Electrical**	☐
	• Voltage external power supply	☐
5.2	**Mechanical**	☐
5.3	**Heat**	☐
5.4	**Fuel**	☒

Parameters	Relevance ☒yes / ☐no?
5.5 Maximum load [2]	☒
5.6 Normal operating load [2]	☐
5.7 Minimum load [2]	☐
5.8 Standby energy [2]	☐
5.9 Start-up energy [2]	☐
6 Media output (Minimum requirements)	
6.1 Exhaust gas temperature	☐
6.2 Exhaust gas flow rate	☐
6.3 Oxygen content [Vol %]	☐
6.4 Content of harmful or restricted components	☐
6.5 Flow rate [1]	☒
6.6 Maximum temperature [1]	☐
6.7 Normal operating temperature [1]	☐
6.8 Minimum temperature [1]	☐
6.9 Maximum pressure [1]	☐
6.10 Normal operating pressure [1]	☐
6.11 Minimum pressure [1]	☐
7 Energy/power output	
7.1 Electric	
• Maximum voltage	☒
• Minimum voltage	☒
• Maximum current	☒
• Frequency	☐
• Overload capability	☒
• Power stability under the operation	☒
7.2 General performance measured	
• Electric efficiency	☒
• Heat recovery efficiency	☐
• Rated power output	☒
• Ramp up rate	☐
• Start-up energy	☐
• Shutdown energy	☐
• Pre-generation	☒
• Maximum power output	☒
• Environmental performance	☐
7.3 Recovered heat	☐
7.4 Maximum load [2]	☐

Parameters		Relevance ☒yes / ☐no?
7.5	Normal operating load (rated[3])[2]	☐
7.6	Minimum load[2]	☐
8	Efficiency	
8.1	Electrical efficiency at rated load[3]	☒
8.2	Electrical efficiency at minimum load	☐
8.3	Heat recovery efficiency at rated load[3]	☐
8.4	Heat recovery efficiency at minimum load	☐
8.5	Overall energy efficiency at rated load[3]	☐
8.6	Overall energy efficiency at minimum load	☐
9	Dynamic operation[4]	
9.1	Start-up	☐
9.2	Load change	☐
9.3	Shutdown	☐
10	Environmental performance	
10.	Exhaust gas temperature and composition (e.g., O_2, CO_2, CO, NOx, SO_2, Total Hydrocarbon (THC) concentrations)	☒
10.2	Discharged water properties (e.g., flow rate, temperature, pH-Value, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD))	☒
10.3	Noise level	☒
10.4	Vibration level	☐
10.5	Electromagnetic Compatibility (EMC) behaviour	☐
10.6	Ambient temperature operation	☐
10.7	Ambient temperature standby and start-up	☐
10.8	Relative humidity	☒
11	Control and communications	
11.1	Communication interface	☐

Remarks

1) Applicable per each used process medium. Media are all substances that are supplied or removed from the fuel cell power system. Examples are also cooling substances or water needed for heating.

2) Applicable per subsystem/component.

3) See definition of "rated power" in IEV 485-14-04: maximum continuous electric power output that a fuel cell power system is designed to achieve under normal operating conditions specified by the manufacturer.

4) Dynamic operation should be defined by the manufacturer to avoid unacceptable conditions (thermal stresses, increased degradation, etc.)

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

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ISO 9004*, Quality management – Quality of an organization – Guidance to achieve sustained success*

ISO 10523, *Water quality – Determination of pH*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

TECHNOLOGIES DES PILES À COMBUSTIBLE –

Partie 4-102: Systèmes à piles à combustible pour chariots de manutention électriques – Méthodes d'essai des performances

AVANT-PROPOS

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L'IEC 62282-4-102 a été établie par le comité d'études 105 de l'IEC: Technologies des piles à combustible. Il s'agit d'une Norme internationale.

Cette deuxième édition annule et remplace la première édition parue en 2017. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) alignement du domaine d'application sur la deuxième édition de l'IEC 62282-4-101:2022;
b) suppression de termes et de définitions (les entrées 3.5, 3.10 et 3.15 qui existaient précédemment);

c) ajout de nouveaux termes à l'Article 3: "puissance fournie" (3.13) et "puissance régénérée" (3.14);

d) révision de symboles et de leurs significations en vue d'un alignement sur ceux de l'IEC 62282-3-201;

e) remplacement de "conditions de référence" par "conditions normales" comme vu à l'Article 5;

f) révision de la méthode d'essai pour l'essai de pointe de tension des charges accessoires (13.3.2);

g) ajout de clarifications à l'Article 14 (Stabilité de la puissance en fonctionnement);

h) ajout d'une liste de contrôle pour les critères de performance traités dans le présent document (Annexe C).

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
105/947/FDIS	105/954/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications.

Une liste de toutes les parties de la série IEC 62282, publiées sous le titre général *Technologies des piles à combustible*, se trouve sur le site web de l'IEC.

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- reconduit,
- supprimé,
- remplacé par une édition révisée, ou
- amendé.

INTRODUCTION

La présente partie de l'IEC 62282-4 fournit des méthodes d'essai cohérentes et reproductibles pour les performances électriques, thermiques et environnementales des systèmes à piles à combustible pour chariots de manutention électriques.

La série IEC 62282-4 traite d'aspects tels que la sécurité, les performances et l'interchangeabilité des systèmes à piles à combustible utilisés pour la propulsion autres que ceux destinés aux véhicules routiers et aux groupes auxiliaires de puissance (GAP). Le présent document (IEC 62282-4-102) porte essentiellement sur les méthodes d'essai des performances des systèmes à piles à combustible servant à entraîner les chariots de manutention, dont la fabrication et l'utilisation connaissent un développement important au niveau mondial. Cela est dû à un besoin urgent de disposer de ces applications partout dans le monde.

La présente partie de l'IEC 62282-4 ne décrit que les essais de type et leurs méthodes d'essai. Le présent document ne spécifie aucune exigence pour les essais individuels de série et n'établit aucun objectif de performance.

Les systèmes à piles à combustible utilisés sur les chariots de manutention électriques tels que les chariots élévateurs à fourche utilisent à la fois des batteries et des piles à combustible, et fonctionnent par conséquent dans différents modes. De même, les chariots élévateurs à fourche fonctionnent dans différents modes. Le présent document a pour objet d'évaluer le système à piles à combustible dans les différentes combinaisons de modes de fonctionnement des piles à combustible et des chariots élévateurs à fourche. Le présent document décompose ces différents modes et propose un cadre de conception et d'évaluation d'un système à pile à combustible destiné spécifiquement aux chariots élévateurs à fourche.

La présente partie de l'IEC 62282-4 est prévue pour être utilisée soit par les fabricants de systèmes à piles à combustible pour chariots de manutention électriques, soit par les responsables chargés de l'évaluation des performances des systèmes utilisés dans ceux-ci à des fins de certification, soit les deux.

Les utilisateurs du présent document peuvent choisir et réaliser les essais dont ils ont besoin parmi ceux décrits. Le présent document n'a pas pour objet d'exclure tout autre essai.

TECHNOLOGIES DES PILES À COMBUSTIBLE –

Partie 4-102: Systèmes à piles à combustible pour chariots de manutention électriques – Méthodes d'essai des performances

1 Domaine d'application

La présente partie de l'IEC 62282 spécifie les méthodes d'essai des performances des systèmes à piles à combustible pour la propulsion et les groupes auxiliaires de puissance (GAP). Le présent document couvre les systèmes à piles à combustible destinés à la propulsion, autres que ceux destinés aux véhicules routiers.

Le présent document concerne les méthodes d'essai des performances des systèmes à piles à combustible destinés à être utilisés sur des chariots de manutention électriques définis dans l'ISO 5053-1, à l'exception:

– des chariots tout-terrain;
– des chariots cavaliers élévateurs non gerbeurs;
– des chariots cavaliers élévateurs gerbeurs;
– des chariots tout-terrain à portée variable;
– des chariots tout-terrain rotatifs à portée variable;
– des chariots porte-conteneurs à portée variable;
– des chariots manuels.

Le présent document s'applique aux systèmes à piles à combustible utilisant de l'hydrogène gazeux et à ceux utilisant du méthanol direct pour les chariots de manutention électriques. Les combustibles suivants relèvent du domaine d'application du présent document:

– hydrogène gazeux; et
– méthanol.

Le présent document traite du système à pile à combustible défini en 3.7 et à la Figure 1.

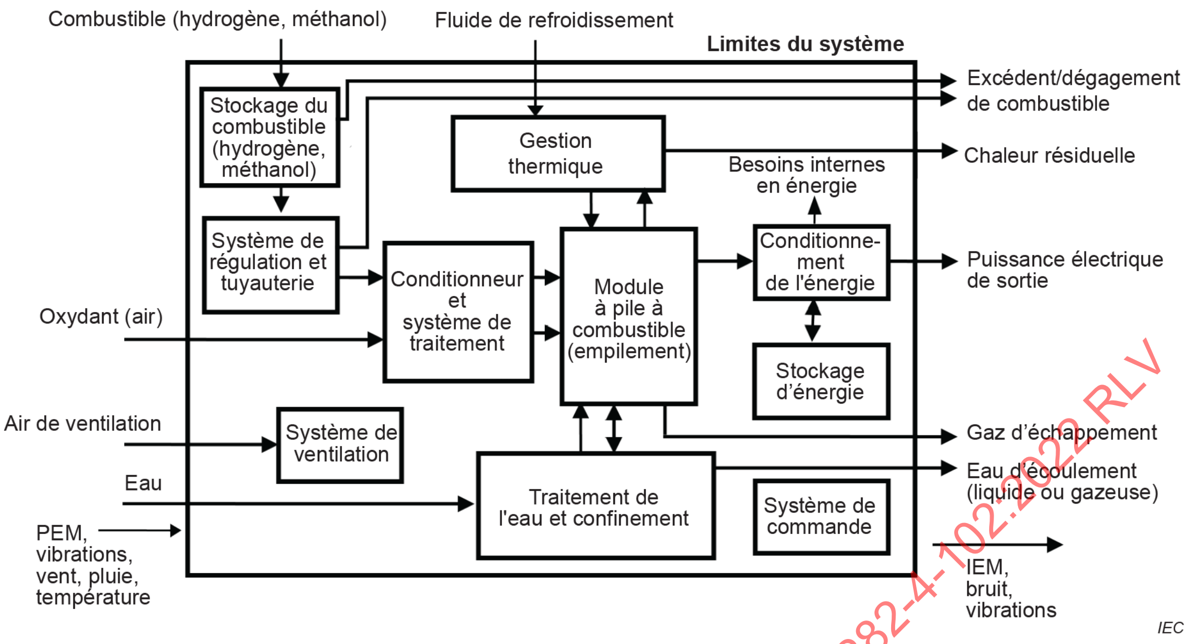
Le présent document s'applique aux systèmes à piles à combustible de type à courant continu, d'une tension de sortie assignée maximale de 150 V en courant continu pour utilisation à l'intérieur et à l'extérieur.

Le présent document concerne les systèmes à piles à combustible dont le conteneur de source de combustible est fixé à demeure, soit au chariot de manutention, soit au système à pile à combustible.

Le présent document s'applique à tous les systèmes équipés de systèmes de stockage d'énergie intégrés. Ces derniers comprennent des systèmes tels que des batteries pour recharge interne ou rechargées par une source externe.

Les éléments suivants ne relèvent pas du domaine d'application du présent document:

– conteneurs de source de combustible de type amovible;
– chariots hybrides qui contiennent un moteur à combustion interne;
– systèmes à piles à combustible équipés d'un reformeur;
– systèmes à piles à combustible conçus pour fonctionner dans des atmosphères potentiellement explosives;
– systèmes de stockage de combustible utilisant de l'hydrogène liquide.



Légende

PEM perturbations électromagnétiques

IEM interférences électromagnétiques

NOTE Un système à pile à combustible peut comporter tous les composants représentés ci-dessus ou seulement certains d'entre eux.

Figure 1 – Systèmes à piles à combustible pour chariots de manutention électriques

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 62282-6-300:2012, *Technologies des piles à combustible – Partie 6-300: Systèmes à micro-piles à combustible – Interchangeabilité de la cartouche de combustible*

ISO 6798-1, *Moteurs alternatifs à combustion interne – Mesurage du niveau de puissance acoustique à partir de la pression acoustique – Partie 1: Méthode d'expertise*

ISO 6798-2, *Moteurs alternatifs à combustion interne – Mesurage du niveau de puissance acoustique à partir de la pression acoustique – Partie 2: Méthode de contrôle*

ISO 14687, *Qualité du carburant hydrogène – Spécification de produit*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse https://www.electropedia.org/;
- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp.

3.1
niveau de bruit
niveau de pression acoustique produit par le système à pile à combustible mesuré à une distance spécifiée et dans tous les modes de fonctionnement

Note 1 à l'article: Le niveau de bruit est exprimé en décibels (dB) et est mesuré comme décrit en 15.2.

3.2
niveau de bruit de fond
niveau de pression acoustique d'un bruit ambiant au point de mesure

3.3
batterie
dispositif électrochimique de stockage de l'énergie qui fournit soit l'énergie d'entrée nécessaire pour traiter des charges parasites, soit l'énergie électrique de sortie, soit les deux

Note 1 à l'article: Les batteries de sauvegarde pour la mémoire des logiciels de contrôle et des applications similaires ne sont pas incluses.

3.4
état froid
état d'un système à pile à combustible, à la température ambiante, lorsqu'il ne reçoit pas d'énergie ou qu'il n'en produit pas

[SOURCE: IEC 60050-485:2020, 485-21-01]

3.5
eau d'écoulement
eau qui s'écoule du système à pile à combustible, y compris l'eau résiduelle et le condensat

Note 1 à l'article: L'eau d'écoulement ne fait pas partie du système de récupération de la chaleur.

3.6
rendement électrique du système à pile à combustible
rapport de la puissance électrique de sortie moyenne d'un système à pile à combustible sur une durée donnée et de la puissance moyenne du combustible fournie au même système à pile à combustible sur la même durée

3.7
système à pile à combustible
système générateur qui utilise un ou plusieurs modules à piles à combustible pour produire de l'énergie électrique et de la chaleur

Note 1 à l'article: Le système à pile à combustible destiné à être utilisé avec des chariots de manutention est représenté sous l'une des formes indiquées dans l'IEC 62282-4-101:2022, 3.9 et 3.10.

[SOURCE: IEC 60050-485:2020, 485-09-01, modifié – La Note 1 à l'article a été ajoutée.]

3.8
entrée de combustible
quantité d'hydrogène ou de méthanol fournie au système à pile à combustible

3.9
consommation de combustible
volume ou masse de combustible consommé par le système à pile à combustible dans des conditions de fonctionnement spécifiées

3.10
puissance électrique minimale en sortie
puissance électrique minimale, à laquelle le système à pile à combustible est capable de fonctionner de façon continue et stable

3.11
puissance assignée
puissance de sortie électrique continue maximale, dans les conditions normales de fonctionnement spécifiées par le fabricant, pour laquelle un système à pile à combustible est conçu

[SOURCE: IEC 60050-485:2020, 485-14-04, modifié – La Note 1 à l'article a été supprimée.]

3.12
durée d'essai
laps de temps au cours duquel les points de données exigés pour le calcul des résultats d'essai sont enregistrés

3.13
puissance fournie
exigences de fourniture de courant et de tension du chariot de manutention à différents intervalles de temps, nécessaires au maintien des performances acceptables du chariot

3.14
puissance régénérée
puissance électrodynamique dans laquelle les moteurs de traction fournissent de l'énergie à la ligne de contact ou à des dispositifs d'accumulation d'énergie

Note 1 à l'article: Exemples de dispositifs de stockage: batteries, volants d'inertie.

[SOURCE: IEC 60050-811:2017, 811-06-25, modifié – Le terme "freinage par récupération" a été remplacé par "puissance régénérée" et dans la définition, "freinage" a été remplacé par "puissance".]

4 Symboles

Les symboles et leurs significations utilisés dans le présent document sont donnés dans le Tableau 1 pour les performances électriques et thermiques et dans le Tableau 2 pour les performances environnementales, avec les unités appropriées.

Tableau 1 – Symboles et signification correspondante pour les performances électriques et thermiques

Symbole	Définition	Unité
$\boldsymbol{M, m}$	**Masse molaire, masse**	
M_f	Masse molaire du combustible	kg/mol
m_f	Masse de combustible mesurée au cours de la durée d'essai	kg
$\boldsymbol{p}$	**Pression**	
p_s	Pression normale (101,325 kPa (abs))	kPa (abs)
p_f	Pression moyenne du combustible	kPa (abs)
$\boldsymbol{P}$	**Puissance**	
P_n	Puissance électrique nette moyenne de sortie	kW
P_{fin}	Puissance moyenne du combustible en entrée	kJ/s
$\boldsymbol{E}$	**Énergie d'entrée**	
E_{mf}	Énergie d'entrée du combustible par masse	kJ/kg
E_{vf}	Énergie d'entrée du combustible par volume	kJ/l
E_{fin}	Énergie d'entrée totale du combustible	kJ
$\boldsymbol{q_m}$	**Débit massique**	
q_{mf}	Débit massique moyen de combustible dans les conditions d'essai	kg/s
$\boldsymbol{q_V}$	**Débit volumétrique**	
q_{Vf}	Débit volumétrique moyen de combustible dans les conditions d'essai	l/min
q_{Vfs}	Débit volumétrique moyen de combustible dans les conditions normales	l/min
$\boldsymbol{H}$	**Valeur calorifique**	
H_{fs}	Valeur calorifique du combustible sur une base molaire dans les conditions normales	kJ/mol
H_{fl}	Valeur calorifique de la masse de liquide	kJ/kg
t	**Temps**	
Δt	Durée d'essai	s, min
$\boldsymbol{T}$	**Température**	
T_s	Température normale (273,15 K)	K
T_f	Température moyenne du combustible	K
$\boldsymbol{V, V_m}$	**Volume, volume molaire**	
V_f	Volume de combustible total mesuré au cours de la durée d'essai	l
V_{ms}	Volume molaire de référence de gaz idéal (22,414 l/mol) (à la température normale T_0 = 273,15 K et à la pression normale p_0 = 101,325 kPa)	l/mol
$\boldsymbol{W}$	**Énergie électrique**	
W_{out}	Énergie électrique de sortie	kW · h
$\boldsymbol{\eta}$	**Rendement**	
η_{el}	Rendement électrique	%
η_{th}	Rendement de l'énergie thermique récupérable	%
η_{total}	Rendement énergétique global	%

Tableau 2 – Symboles et signification correspondante pour les performances environnementales

Symbole	Définition	Unité
φ	**Fraction volumique**	
$\varphi_{B,meas}$	Fraction volumique mesurée du constituant B	vol % ou ml/m^3
$\varphi_{B,corr}$	Fraction volumique corrigée du constituant B	vol % ou ml/m^3
$\varphi_{at}(O_2)$	Fraction volumique en O_2 (oxygène) mesurée dans l'atmosphère à l'entrée d'air sec	vol %
$\varphi_{ex}(O_2)$	Fraction volumique en O_2 mesurée dans un gaz d'échappement sec	vol %
$\varphi_{ex,corr}(CO)$	Fraction volumique en CO (monoxyde de carbone) corrigée dans un gaz d'échappement sec	ml/m^3
$\varphi_{ex,corr}(THC)$	Fraction volumique en hydrocarbures totaux (THC) corrigée dans un gaz d'échappement sec (équivalent carbone)	ml/m^3
γ	**Concentration massique**	
$\gamma_{ex}(CO)$	Concentration massique en CO dans un gaz d'échappement sec	mg/m^3
$\gamma_{ex}(THC)$	Concentration massique en THC dans un gaz d'échappement sec	mg/m^3
ε	**Émission**	
$\varepsilon(CO)$	Masse d'émission de CO par énergie de combustible d'entrée	mg/kW · h
$\varepsilon(THC)$	Masse d'émission de THC par énergie de combustible d'entrée	mg/kW · h
α	**Rapport atomique**	
$\alpha(THC)$	Rapport atomique entre l'hydrogène et le carbone du THC dans le gaz d'échappement	
ω	**Fraction massique**	
ω_B	Fraction massique du méthanol	

5 Conditions normales

Les conditions normales sont spécifiées comme suit:

– température normale: T_s = 273,15 K (0 °C);

– pression normale: p_s = 101,325 kPa (abs).

6 Base de la valeur calorifique

Sauf spécification contraire, la valeur calorifique du combustible doit être la valeur calorifique inférieure (VCI) ou une valeur calorifique similaire.

NOTE Les valeurs calorifiques de l'hydrogène et du méthanol (VCI et VCS) sont données à l'Annexe A.

Lorsque la valeur calorifique inférieure (VCI) est appliquée pour le calcul du rendement énergétique, il n'est pas nécessaire d'ajouter "VCI", comme indiqué ci-dessous:

$$\eta_{el},\ \eta_{th},\ \text{ou}\ \eta_{total} = \text{XX}\ \%$$

Si la valeur calorifique supérieure (VCS) est appliquée, "VCS" doit être ajouté à la valeur du rendement énergétique comme suit:

$$\eta_{\text{el}},\ \eta_{\text{th}},\ ou\ \eta_{\text{total}} = \text{XX \% (VCS)}$$

7 Préparation aux essais

7.1 Généralités

L'Article 7 décrit les éléments types qui doivent être pris en compte avant de réaliser un essai. Pour chaque essai, l'incertitude doit, dans toute la mesure du possible, être réduite le plus possible en choisissant des appareils à haute précision et en planifiant minutieusement les essais. Les parties concernées par l'essai doivent préparer des plans d'essai détaillés en se fondant sur le présent document. Un plan d'essai écrit doit être établi.

Les éléments suivants doivent être pris en compte pour le plan d'essai:

1) objectif;
2) spécifications d'essai;
3) qualifications du personnel d'essai;
4) normes de management de la qualité (ISO 9000, ISO 9001 et ISO 9004, appelées collectivement famille ISO 9000, ou d'autres normes équivalentes);
5) incertitude cible;
6) identification des appareils de mesure (voir l'Article 9);
7) plage estimée de paramètres d'essai;
8) plan d'acquisition des données.

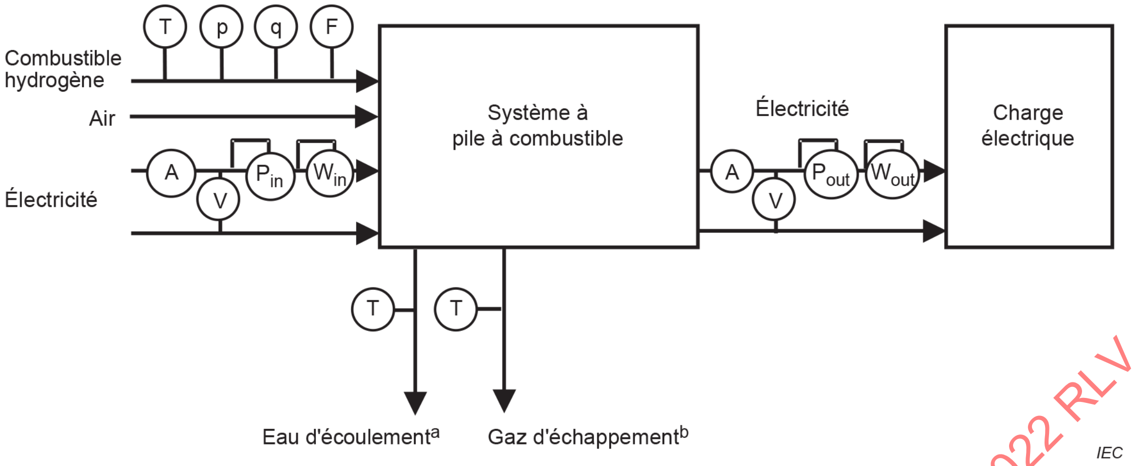
7.2 Plan d'acquisition des données

Pour déterminer de manière satisfaisante l'incertitude cible, la durée et la fréquence appropriées des valeurs lues doivent être définies et des enregistreurs de données doivent être préparés avant l'essai de performance.

L'acquisition automatique des données à l'aide d'un ordinateur personnel ou d'un appareil similaire est préférable.

8 Montage d'essai

La Figure 2 et la Figure 3 donnent des exemples de montages d'essai qui sont exigés pour soumettre le système à pile à combustible à l'essai avec le combustible hydrogène et le combustible méthanol, respectivement, qui sont décrits dans le présent document. Une charge électrique est connectée à un système à pile à combustible.



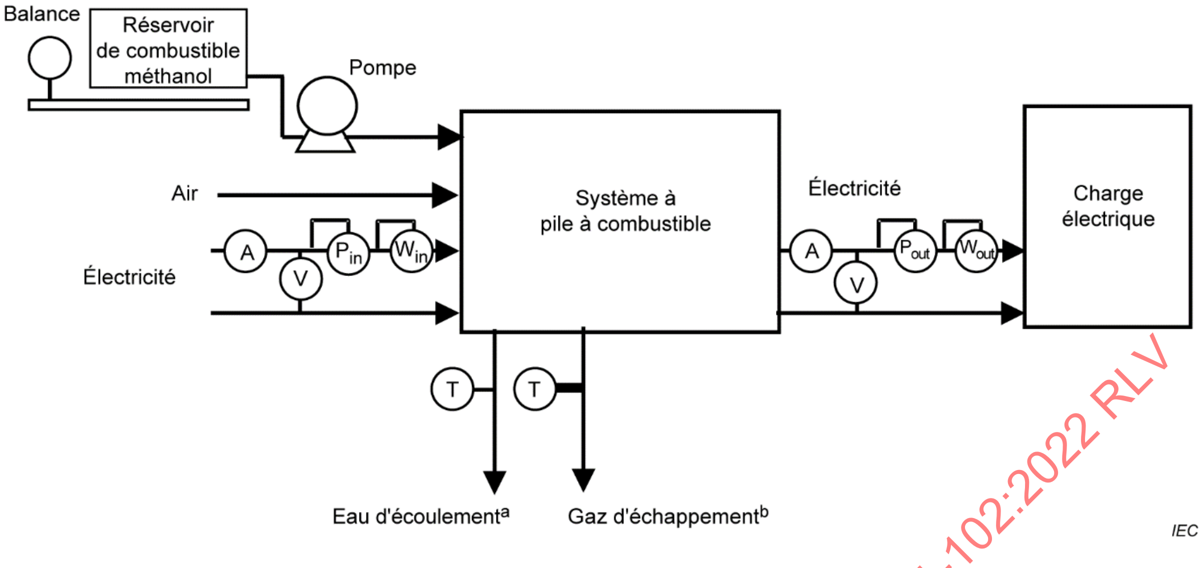
Légende

A	ampèremètre
V	voltmètre
T	thermomètre
p	manomètre
q	débitmètre
F	compteur totalisateur
P	wattmètre
W	wattmètre totaliseur (compteur d'énergie électrique)

[a] vers le dispositif de collecte pour la mesure du volume (ou du poids), du pH, de la demande biochimique en oxygène (BOD), de la demande chimique en oxygène (COD).

[b] vers le dispositif de collecte pour l'analyse des constituants.

Figure 2 – Exemple de montage d'essai pour combustible hydrogène



NOTE Voir les explications des symboles à la Figure 2.

[a] vers le dispositif de collecte pour la mesure du volume (ou du poids), du pH, de la demande biochimique en oxygène (BOD), de la demande chimique en oxygène (COD).

[b] vers le dispositif de collecte pour l'analyse des constituants.

Figure 3 – Exemple de montage d'essai pour combustible méthanol

9 Appareils de mesure et méthodes de mesure

9.1 Généralités

Les appareils de mesure et les méthodes de mesure doivent être conformes aux Normes internationales applicables. Ils doivent être choisis pour satisfaire à la plage de mesure spécifiée par le fabricant et à l'exactitude de mesure exigée.

9.2 Appareils de mesure

Les appareils de mesure sont indiqués en fonction de leur utilisation prévue:

a) appareils de mesure des pointes de tension: oscilloscope, analyseurs haute fréquence;

b) appareils de mesure de la puissance électrique en entrée et en sortie, et de l'énergie électrique en entrée et en sortie:

   – wattmètres, compteurs d'énergie électrique, voltmètres, ampèremètres;

c) appareils de mesure de l'entrée de combustible:

   – débitmètres, compteurs totaliseurs, balances, capteurs de pression, capteurs de température;

d) appareils de mesure des conditions ambiantes:

   – baromètres, hygromètres et capteurs de température;

e) appareils de mesure du niveau de bruit:

   – sonomètres tels que spécifiés dans l'IEC 61672-1 ou autres appareils de mesure d'exactitude équivalente ou meilleure;

f) appareils de mesure des concentrations des composants des gaz d'échappement:

   – analyseur d'oxygène (par exemple, basé sur des capteurs paramagnétiques, électrochimiques ou d'oxyde de zirconium);

   – analyseur de dioxyde de carbone (par exemple, CG-SM ou basé sur des capteurs d'absorption infrarouge);

– analyseur de monoxyde de carbone (par exemple, basé sur des capteurs infrarouges non dispersifs ou électrochimiques);

g) appareils de détermination de l'eau d'écoulement:

– éprouvette graduée (pour le mesurage du volume), capteur de température, appareils de mesure du pH, sondes de DBO.

9.3 Points de mesure

Les points de mesure pour les différents paramètres sont indiqués ci-dessous.

a) Débit du combustible hydrogène:

Placer un débitmètre de combustible sur la conduite d'alimentation en combustible du système à pile à combustible pour mesurer le débit de combustible.

b) Entrée de combustible hydrogène intégré:

Placer un compteur totaliseur de combustible sur la conduite d'alimentation en combustible du système à pile à combustible pour mesurer l'entrée de combustible. Le compteur totaliseur doit comporter un débitmètre qui mesure le débit de combustible.

c) Poids de l'entrée de combustible méthanol:

Placer une balance sous le réservoir de combustible pour mesurer le poids total du combustible et du réservoir. Le poids de l'entrée de combustible méthanol est mesuré en soustrayant le poids obtenu après l'essai de celui obtenu avant l'essai.

d) Température du combustible:

Connecter un thermomètre ou un thermocouple juste en aval du débitmètre de combustible.

e) Pression du combustible:

Placer un appareil de mesure de la pression juste en aval du débitmètre de combustible pour mesurer la pression relative du combustible.

f) Puissance électrique de sortie:

Connecter un wattmètre à la borne de sortie de la puissance électrique du système à pile à combustible et à proximité des limites du système.

g) Énergie électrique de sortie:

Connecter un compteur d'énergie électrique à la borne de sortie de la puissance électrique du système à pile à combustible et à proximité des limites du système. Le compteur d'énergie électrique doit comporter un wattmètre qui indique la puissance électrique de sortie.

h) Composition du combustible:

La composition du combustible utilisé pour les essais doit être échantillonnée et analysée pour chaque session d'essai.

i) Pression atmosphérique:

Placer un appareil de mesure de la pression absolue à côté du système à pile à combustible et de manière à ce qu'il ne soit pas affecté par la ventilation, la prise ou l'évacuation d'air du système à piles à combustible.

j) Température de l'air:

Placer un thermomètre à côté du système à pile à combustible et de manière à ce qu'il ne soit pas affecté par la ventilation, la prise ou l'évacuation d'air du système à piles à combustible.

k) Humidité de l'air:

Placer un hygromètre à côté du système à pile à combustible et de manière à ce qu'il ne soit pas affecté par la ventilation, la prise ou l'évacuation d'air du système à pile à combustible.

l) Niveau de bruit:

Voir 15.2.