# IEC/TS 62282-7-1

Edition 1.0 2010-06

# TECHNICAL SPECIFICATION

## Fuel cell technologies –
## Part 7-1: Single cell test methods for polymer electrolyte fuel cell (PEFC)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

## About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub

The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, withdrawn and replaced publications.

- IEC Just Published: www.iec.ch/online_news/justpub

Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.

- Electropedia: www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.

- Customer Service Centre: www.iec.ch/webstore/custserv

If you wish to give us your feedback on this publication or need further assistance, please visit the Customer Service Centre FAQ or contact us:

Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00

# IEC/TS 62282-7-1

Edition 1.0 2010-06

# TECHNICAL SPECIFICATION

## Fuel cell technologies –
## Part 7-1: Single cell test methods for polymer electrolyte fuel cell (PEFC)

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE X

ICS 27.070

ISBN 978-2-88910-984-5

# CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

___________

# FUEL CELL TECHNOLOGIES –

## Part 7-1: Single cell test methods for polymer electrolyte fuel cell (PEFC)

## 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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62282-7-1, which is a technical specification, has been prepared by IEC technical committee 105: Fuel cell technologies.

The text of this technical specification is based on the following documents:

| Enquiry draft | Report on voting |
|---|---|
| 105/241/DTS | 105/253A/RVC |

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

# INTRODUCTION

This Technical Specification describes standard single-cell test methods for polymer electrolyte fuel cells (PEFCs); it provides consistent and repeatable methods to test the performance of single cells. This Technical Specification is to be used by component manufacturers or stack manufacturers who assemble components in order to evaluate the performance of cell components, including membrane-electrode assemblies (MEAs) and flow plates. This Technical Specification is also available for fuel suppliers to determine the maximum allowable impurities in fuels.

Users of this Technical Specification may selectively execute test items suitable for their purposes from those described in this technical specification. This document is not intended to exclude any other methods.

# FUEL CELL TECHNOLOGIES –

## Part 7-1: Single cell test methods for polymer electrolyte fuel cell (PEFC)

## 1 Scope

This part of IEC 62282 covers cell assemblies, test apparatus, measuring instruments and measuring methods, performance test methods, and test reports for PEFC single cells.

This Technical Specification is used for evaluating:

a) the performance of membrane electrode assemblies (MEAs) for PEFCs,

b) materials or structures of other components of PEFCs, or

c) the influence of impurities in fuel and/or in air on the fuel cell performance.

## 2 Normative references

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

IEC/TS 62282-1:2010, *Fuel cell technologies – Part 1: Terminology*

ISO/TS 14687-2:2008, *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:

**3.1**
**anode**
the electrode at which fuel oxidation takes place by the removal of electrons from the fuel to the external electric load, concurrent with the release of protons ($H^+$) to the polymer electrolyte

**3.2**
**catalyst**
substance that accelerates (increases the rate of) a reaction without being consumed itself

The catalyst lowers the activation energy of the reaction, allowing for an increase in the reaction rate. This is also referred to as an electrocatalyst, as defined in IEC/TS 62282-1.

**3.3**
**catalyst-coated membrane**
**CCM**
term used to describe a membrane (in a PEFC) whose surfaces are coated with a layer of catalyst to form the reaction zone of the electrode

**3.4**
**cathode**
the electrode at which oxidant reduction takes place, facilitated by the donation of electrons from the external circuit and protons ($H^+$) from the polymer electrolyte, followed by the release of reduced oxidant products (water)

**3.5**
**clamping plate (or pressure plate)**
frame used to compress the cell components together to maintain electrical conductivity and sealing

**3.6**
**current collector**
conductive material, which can consist of metals, graphite or composite materials, that collects electrons from an anode or disburses electrons to a cathode

**3.7**
**electrode**
catalytic layer that facilitates either an oxidation or reduction reaction, and has both electronic and ionic conduction.

**3.8**
**flow plate**
conductive plate made of metals, a material such as graphite, or a conductive polymer that may be a carbon-filled composite, which is incorporated with flow channels for fuel or oxidant gas feed and has electrical contact with an electrode

**3.9**
**fuel**
hydrogen or hydrogen-containing gas that reacts at the anode

**3.10**
**fuel cell**
electrochemical device that converts the chemical energy of a fuel and an oxidant to electrical energy (DC power), heat and reaction products

The fuel and oxidant are typically stored outside of the fuel cell and transferred into the fuel cell as the reactants are consumed.

**3.11**
**gas diffusion electrode**
**GDE**
component on the anode or cathode side comprising all electronic conductive elements of the electrode, i.e. gas diffusion layer and catalyst layer

**3.12**
**gas diffusion layer**
**GDL**
porous conductive component placed between an electrode and a flow plate, to serve as electric contact and allow access of reactants to the electrode and the removal of reaction products

**3.13**
**gasket**
sealing component which prevents the reaction gas from leaking out of a cell

**3.14**
**limiting current density**
the current density where the cell voltage sharply decreases to near zero

**3.15**
**maximum current density**
the highest current density specified by the manufacturer allowed for a short time

**3.16**
**membrane electrode assembly**
**MEA**
component of a fuel cell (3.10) consisting of an electrolyte membrane with gas diffusion electrodes (3.11) on either side

**3.17**
**minimum cell voltage**
the lowest cell voltage specified by the manufacturer

**3.18**
**open circuit voltage**
**OCV**
the cell voltage at zero current density with the cell under operating conditions

**3.19**
**oxidant**
oxygen or oxygen-containing gas (e.g., air) that reacts at the cathode

**3.20**
**polymer electrolyte**
polymer resin membrane having proton exchange capability in which current is carried by the movement of such ions from an anode to a cathode

**3.21**
**polymer electrolyte fuel cell**
**PEFC**
fuel cell that employs a polymer electrolyte membrane as an electrolyte, which is also called a proton exchange membrane fuel cell (PEMFC)

**3.22**
**power**
measure calculated from the voltage multiplied by the current at a steady state ($P = V \times I$)

**3.23**
**power density**
measure calculated by dividing the power by the geometric, electrode area

**3.24**
**rated current density**
maximum current density specified by the manufacturer of the MEA or single cell for continuous operation

**3.25**
**rated power density**
maximum power density specified by the manufacturer of the MEA or single cell for continuous operation

### 3.26

**rated voltage**

minimum cell voltage specified by the manufacturer of the MEA or single cell for continuous operation

### 3.27

**single cell**

cell typically consisting of an anode flow plate, MEA, cathode flow plate and sealing gaskets (see Annex B for additional information)

### 3.28

**single cell test**

test of the fuel cell performance based on a single cell

### 3.29

**stoichiometry**

molar ratio of the fuel (or oxidant) gases supplied to the cell to that required by the chemical reaction, as calculated from the current

## 4 General safety considerations

An operating fuel cell uses oxidizing and reducing gases. Typically, these gases are stored in high-pressure containers. The fuel cell itself may or may not be operated at pressures greater than atmospheric pressure.

Those who carry out single cell testing shall be trained and experienced in the operation of single cell test systems and specifically in safety procedures involving electrical equipment and reactive, compressed gases. Safely operating a single cell test station requires appropriate technical training and experience as well as safe facilities and equipment, all of which are outside the scope of this technical specification.

## 5 Cell components

### 5.1 General

A single cell of a PEFC shall be composed of all or some of the following components:

a) an MEA,

b) gaskets,

c) an anode-side flow plate and a cathode-side flow plate,

d) an anode-side current collector and a cathode-side current collector,

e) an anode-side clamping plate and a cathode-side clamping plate,

f) electrically insulating sheets,

g) clamping or axial load hardware which may include bolts, washers, springs, etc.,

h) temperature-control devices,

i) other miscellaneous parts.

### 5.2 Sizing the membrane electrode assembly (MEA)

The electrode area shall be as large as needed to measure desired parameters. A suggested electrode size should be approximately 25 cm$^2$, though larger cells having larger electrodes may give more relevant data for practical applications. The active electrode area shall be reported and shall be the smaller of the two electrode active areas. The approximate uncertainty in the area measurement shall be reported also.

### 5.3 Gas diffusion layer (GDL)

A gas diffusion layer shall be made of highly gas-diffusible, electrically conductive and corrosion-resistant materials.

### 5.4 Gasket

The gasket material shall be compatible with fuel cell reactants, components and reaction products, and cell operating temperature. It shall prevent gas leakage.

### 5.5 Flow plate

Flow plates shall be made of materials that have negligible gas permeability, but high electric conductivity. Resin-impregnated, high-density, synthetic graphite, polymer/carbon composites, or corrosion-resistant metal, such as titanium or stainless steel, is recommended. If metal is used, the plate surface may be coated/plated (e.g., with gold) in order to reduce contact resistance. The flow plate should be corrosion-resistant and should provide a suitable seal.

A serpentine flow channel is suggested. Further information about a suggest design is given in Annex A. The flow field configuration shall be documented in the test report.

The flow plates for testing shall allow the accurate measurement of cell operating temperature. For example, flow plates may have a small hole on an edgewise face in order to accommodate a temperature sensor. In this case, the hole shall reach the centre of the flow plate.

NOTE If the objective of testing is to evaluate the design of a particular flow channel, it is not necessary to use the suggested flow plate design.

### 5.6 Current collector

Current collectors shall be made of materials that have high electric conductivity, such as metal. Metal collectors may be plated with contact-resistance-reducing materials, such as gold or silver; however care must be taken in choosing the coating material. It must be compatible with the cell components and reactants and products.

They should be thick enough to minimize voltage drop over their surface area. They should provide an output terminal for wire connection.

If metal flow plates act as current collectors, independent current collectors are not required.

### 5.7 Clamping plate (or pressure plates)

Clamping plates (or pressure plates) shall be flat and smooth-surfaced, with their mechanical properties strong enough to withstand the bending force being applied when clamped with bolts.

If the clamping plates are conductive, they shall be insulated from the current collectors in order to prevent short-circuiting.

### 5.8 Clamping hardware

Clamping hardware shall have high mechanical strength in order to withstand the stresses generated during installation and operation. Washers and springs may be used to maintain constant, uniform pressure on the single cell. A torque wrench or other measuring device shall be used to set exact pressure on the cell.

It is recommended to electrically insulate the clamping hardware.

### 5.9 Temperature-control device

The single cell shall be provided with a temperature-control device (for heating/cooling) in order to maintain it at a constant temperature and with a uniform temperature profile along the flow plate and across the cell. The temperature-control device may be programmable to follow a fixed temperature profile. The temperature-control device shall have means to prevent over-temperature.

There are multiple ways of achieving this requirement.

One simple way is to convectively cool and electrically heat the clamping (pressure) plates. The heating can be achieved by attaching a skin resistance heater to the external surface of the plate. An alternate method is to insert a cartridge heater into a hole in the plate.

In either case, care is required to maintain isolation for electrical safety.

## 6 Cell assembly

### 6.1 Assembly procedure

Cell assembly procedures have large impact on the repeatability of fuel cell data. Specific procedures shall be documented for the following assembly operations:

a) membrane alignment, including identification of anode and cathode sides,
b) diffusion media (i.e., GDL) alignment, including identification of anode and cathode parts, as well as the sides to be placed facing the membrane and flowfield,
c) gasket/seal placement,
d) alignment fixtures or jigs to be used, if any,
e) compression procedures and specifications, such as diffusion media compression values, bolt tightening order, compression springs, and final torque specifications.

NOTE Pressure may be checked by pressure-sensitive paper/film.

Typical alignment of cell component is shown in Annex B.

After assembling, the isolation between the clamping plates and current collectors shall be checked.

### 6.2 Cell orientation and gas connections

A cell shall be operated in an orientation which facilitates product water removal. The cell orientation shall be documented.

Many flow patterns can be used; the flow pattern shall be documented. Examples are given in Annex A.

### 6.3 Leak check

The differential pressure on the membrane is the most critical. The maximum differential pressure specified by the manufacturer should not be exceeded.

The cell must have minimal external and internal leakage. Examples leak-check procedures are given in Annex C. In principle, the leak-check procedure consists of injecting an inert or test gas into both the anode and cathode sides. By using a suitable pressure difference, the nature and direction of the leak can be ascertained. The maximum pressures, the nature of the test gas and leakage rates shall be documented. If a leak is detected, other tests, such as bubble test, may be performed to further delineate type and nature of leak.

# 7 Test station setup

## 7.1 Minimum equipment requirement

A fuel cell test station is required to conduct the testing of the single cell. The minimum test equipment functionality in order to meet the intention of the single cell test procedure includes the following test parameters:

a) reactant gas flow rate control – to meter the flow rate of fuel and oxidant gases to the fuel cell at the desired stoichiometric ratio;

b) reactant gas humidification control – to humidify the reactant gases to a specified dew point prior to delivery to the fuel cell. The recommended water resistivity is at least 1 MΩ·cm (or at most a conductivity of $10^{-4}$ S $m^{-1}$).

NOTE The gas transfer lines between the humidifiers and the cell should be heated, at minimum, 5 °C to 10 °C above the dew point temperature to minimize condensation. The lines should be insulated to minimize heat loss.

c) reactant gas pressure control – to regulate the reactant gas pressure within the fuel cell;

d) load control – load bank to draw a specified current from the cell. It should be capable of operating in either constant current or constant voltage mode;

e) cell heating/cooling control – to heat or cool the single cell to the desired operating temperature;

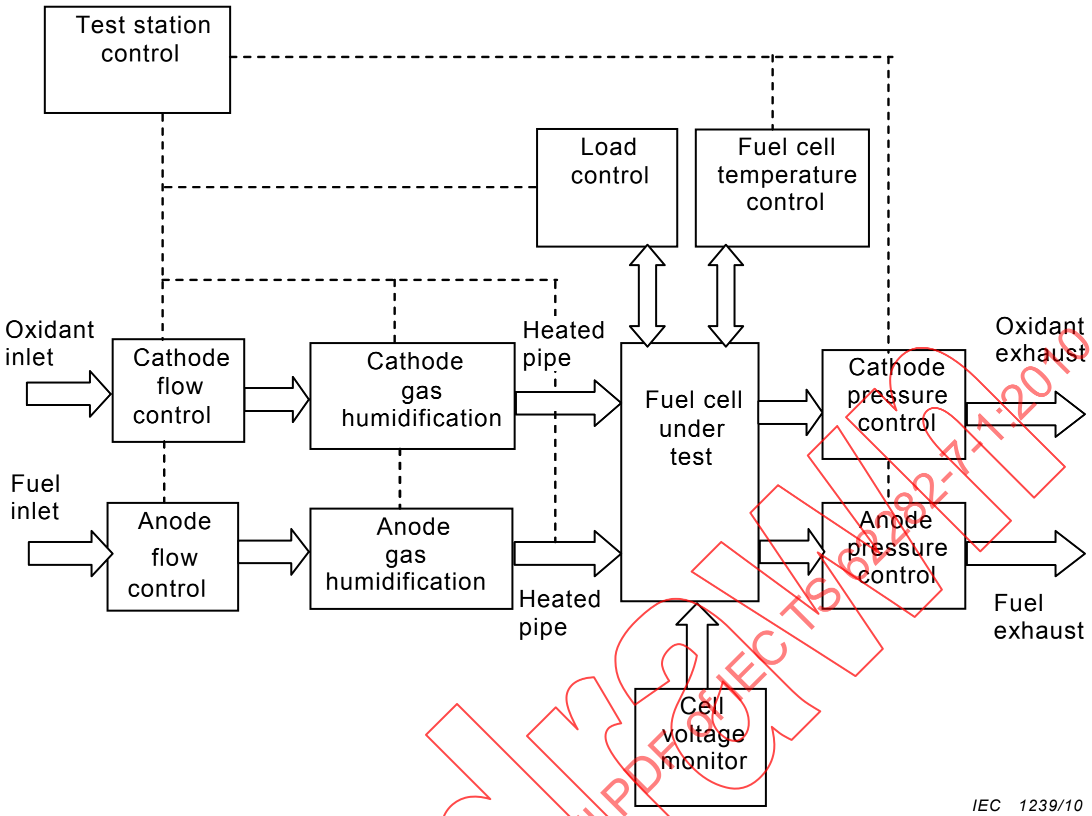
f) cell voltage monitoring and data acquisition – instrumentation to measure and record the cell voltage throughout the test;

g) test station control – test station must be capable of controlling the above parameters;

h) safety systems – a safety system is needed that is capable of automatically (or manually with audible alarms) shutting down the test in the event of a failure. A nitrogen purge capability is recommended for the anode and cathode circuits. Interlocks triggered by high/low cell voltage, pressure and temperature and gas leaks are also recommended. Adequate ventilation should also be provided.

## 7.2 Schematic diagram

Figure 1 is a schematic block representation of the major sub-systems required in a test station to conduct fuel cell testing.



IEC 1239/10

**Figure 1 – Test station schematic diagram for single cell testing**

Materials used for all components which will be in contact with humidified gas or humidifier water shall be compatible with the gas or water to prevent the extraction of impurities from the material. Example materials include stainless steel and fluoro-plastics.

The gas humidification system shall be designed to avoid removing the test impurities from the gas stream prior to the gas entering the cell.

NOTE Impurities are given in ISO/TS 14687-2:2008, *Hydrogen fuel – Product specification – Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles.*

If this test is not to be executed, a bubbler saturator can be used for fuel humidification.

Variations to this configuration are acceptable providing that the functional requirements of this document are met.

### 7.3 Maximum variation in test station controls (inputs to test)

The fuel cell test station shall have the following recommended maximum variation in its controls:

a) current control ±1 % relative to set point;

b) voltage control ±1 % relative to set point;

c) cell temperature control ±1 °C at set point (at steady state);

d) humidity dew point control ±2 °C at set point (at steady state);

e) flow rate control ±5 % relative to set point;

f) pressure control ±3 % relative to set point.

# 8 Measurement

## 8.1 Instrument uncertainty

The maximum instrument uncertainty for the measurements (test outputs) in the tests shall be as follows:

| | |
|---|---|
| a) current | ±1 % of maximum expected value; |
| b) voltage | ±0,5 % of maximum expected value; |
| c) temperature | ±1 °C; |
| d) dew point | ±2 °C; |
| e) flow rate | ±2 % of maximum expected value; |
| f) pressure | ±3 % of maximum expected value. |

NOTE At low current, voltage and flow rates, the uncertainties may be very large with respect to the measured values.

## 8.2 Measuring instruments and measuring methods

### 8.2.1 General

Measuring instruments shall be selected in accordance with the range of values to be measured. The instruments shall be calibrated regularly in order to maintain the level of accuracy described in 10.1. All measuring devices must be calibrated to traceable standards.

### 8.2.2 Voltage

A voltage meter shall be connected to the anode and cathode flow plates or current collectors, minimizing the influence of electrical contact resistances. The electrical contact resistances between the connections of the voltage meter, either anode and cathode flow plates or output terminals of anode and cathode current collectors, shall be measured and reported, if not negligible.

### 8.2.3 Current

A current measuring device shall be located in the current-carrying circuit of the cell. The current-measuring device may consist of a low-impedance ammeter or a calibrated shunt resistor, which develops a precisely known voltage reflecting the current flowing. The current may also be measured using the features of an electronic load.

### 8.2.4 Internal resistance (IR)

Recommended IR measuring methods are a current-interrupt method and an electrochemical impedance spectroscopy (EIS) method. An AC resistance method using AC milliohm meter is also acceptable. Although the frequency of the milliohm meter is typically 1 kHz, the value of the measurement frequency should be reported.

Plus/minus sense leads of these measuring instruments shall be connected to the output terminals of cathode and anode current collectors, respectively.

### 8.2.5 Fuel and oxidant flow rates

Fuel and oxidant flow rates shall be measured by means of a volumetric meter, a mass flow meter, or a turbine-type flow meter. If such a method is not practical, flow measurement by a nozzle, orifices, or venturi meter is recommended. The location of a flow meter shall be upstream of the humidifier.

If the flow meter requires pressure compensation, a static pressure measuring port shall be located immediately upstream of the flow meter to be corrected.

### 8.2.6 Fuel and oxidant temperature

The recommended sensor for direct temperature measurement is a thermocouple, resistance thermometer with a transducer or a thermister.

The temperature sensor shall be located immediately downstream of the single cell. It is recommended to position another sensor immediately upstream of the single cell.

If the fuel and/or oxidant flow meter require temperature compensation, the sensor for such correction shall be located immediately upstream of the flow meter.

### 8.2.7 Cell temperature

The recommended sensor for direct temperature measurement is a thermocouple, resistance thermometer with a transducer or a thermister.

The temperature sensor should be located as close as possible to the center of the cathode active area. Ideally, it should be at the center of both anode and cathode flow plates. (See 5.5 and Annex A for more details.)

### 8.2.8 Fuel and oxidant pressures

For measuring fuel and oxidant pressures, calibrated pressure transducers are the preferred method. Other acceptable methods include calibrated manometers, dead-weight gauges, bourdon tubes or other elastic type gauges.

A static pressure measuring port shall be located immediately upstream of the single cell. If necessary, another pressure-measuring port shall be also placed immediately downstream of the single cell.

Connecting piping shall be checked to verify that it is leak-free under working conditions in advance of the performance tests. Liquid water in the piping must be avoided.

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

Pressures shall be measured as static pressures with the effect of velocity considered and eliminated.

### 8.2.9 Fuel and oxidant humidity

For measuring fuel and oxidant humidity, a chilled mirror, aluminum oxide, bulk polymer resistive or capacitance type hygrometer can be used to obtain humidity values, depending on the fuel and oxidant temperatures.

Humidity shall be expressed as a dew-point temperature.

A humidity measuring port shall be located upstream of the single cell, or the humidity sensor can be in the reactant gas before testing commences. In the case of using ambient or synthetic air as oxidant, the dew point shall be measured and reported.

### 8.2.10 Ambient conditions

It is recommended that the ambient temperature, pressure and humidity shall be measured and recorded.

For the direct measurement of ambient temperature, thermocouples with transducer or a resistance thermometer with transducer is recommended.

For the direct measurement of ambient pressure, a mercury barometer is recommended.

For direct measurement of ambient humidity, a hygrometer is recommended.

### 8.3 Measurement units

Table 1 identifies the parameters and their measurement units for the tests.

**Table 1 – Parameters and units**

| Parameter | Unit |
|---|---|
| Temperature | °C |
| Fuel and oxidant pressures | kPa[c] |
| Dew points of fuel and oxidant | °C |
| Fuel and oxidant flow rates (NTP[a]) | $cm^3\ min^{-1}$, $cm^3\ s^{-1}$ |
| Fuel and oxidant stoichiometries | |
| Current | A |
| Current density | $A\ cm^{-2}$ |
| Voltage | V |
| Output power | W |
| Power density | $W\ cm^{-2}$ |
| Area-specific cell resistance | $\Omega cm^2$ |
| Fuel composition[b] | $(mol)\ mol^{-1}$ |
| Oxidant composition[b] | $(mol)\ mol^{-1}$ |

[a] NTP = normal temperature and pressure: 0 °C and 101,325 kPa (absolute). Unless otherwise noted, NTP is used for the flow rate.

[b] Impurities shall be listed as $(\mu mol)\ mol^{-1}$.

[c] ISO recommends using absolute pressure (kPa), if possible. If gauge pressure is used, it should be noted as such and be given in kPa(G).

## 9 Gas composition

### 9.1 Fuel composition

#### 9.1.1 Hydrogen

Hydrogen purity shall be 0,999 9 mol/mol or better. Details regarding the impurities in the hydrogen are given in ISO/TS 14687-2 (2008).

#### 9.1.2 Reformed gases

The simulated reformed gas may be specified by the cell or component manufacturer. The purity and composition of the reformed gas shall be determined by chemical analysis. The results of the chemical analysis shall be reported.

### 9.2 Oxidant composition

If air is used as oxidant, then either atmospheric or synthetic air may be used. In the case of atmospheric air, it is recommended that the air shall be oil- and particulate-free. The oxidant composition, including the concentration of impurities, shall be reported.

## 10 Test preparation

### 10.1 Standard test conditions

The following shall be specified by the cell and/or cell component manufacturer as the standard test conditions before commencing a test. If no specifications are given, the conditions will depend on the study to be performed. These conditions must be reported.

a) Cell temperature (recommended: center of cathode flow plate).

b) Fuel operating pressure (representative value: immediately upstream of the cell).

c) Oxidant operating pressure (representative value: immediately upstream of the cell).

d) Fuel humidity at fuel cell operating temperature (representative value: immediately upstream of the cell).

e) Oxidant humidity at fuel cell operating temperature (representative value: immediately upstream of cell).

f) Fuel composition.

g) Oxidant composition.

h) Fuel stoichiometry.

i) Oxidant stoichiometry.

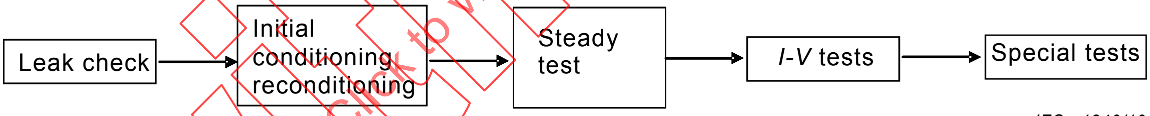
j) Rated current density.

k) Rated voltage.

l) Maximum current density.

m) Minimum cell voltage.

Performance tests shall be carried out under standard testing conditions unless otherwise specified in the description of the respective test methods. A typical testing flowchart is given in Figure 2.



*IEC 1240/10*

**Figure 2 – Typical testing flowchart**

### 10.2 Ambient conditions

For each test run, it is recommended that the following ambient conditions be measured:

a) temperature,

b) pressure, and

c) relative humidity.

### 10.3 Frequency of measurement

The recommended data sampling rate is 1 per second. One measurement value is defined as an average value over 1 min (i.e., 60 single measurements).

### 10.4 Repeatability and reproducibility

The entire *I-V* curve shall be measured three times and the average voltage values calculated at each current density.

### 10.5 Maximum permissible variation in measured values

Values for three or more measurements of the test input and output parameters shall be within the range of ±5 % of their average except for the long-term operation test.

### 10.6 Number of test samples

Tests can be conducted either in sequence with one sample or in parallel with multiple samples. The repeatability and reproducibility specifications are limited to *I*-*V* curves only. The measurements shall be performed consecutively. Between measurements, the fuel cell shall be shut down and re-conditioned from the ambient start-up conditions.

### 10.7 Leak check of gas circuit with inert or test gas

All materials used for leak checking the gas circuit shall be compatible with the gas piping and cell components. After setting the single cell in the stand, check for gas leaks using inert or test gas and using a liquid leak detector test on all connections.

### 10.8 Initial conditioning and stable state check

Initial conditioning shall be applied to a newly assembled cell. The main purpose of initial conditioning is to bring the cell to a stable state in performance for subsequent testing.

Initial conditioning shall be

a) carried out in accordance with the MEA or component manufacturer’s instruction,

b) or as proposed by the manufacturer of the test object,

c) or one that is common practice at the testing organization.

Representative initial conditioning procedures are provided for information in Annex D.

### 10.9 Shutdown

Shutdown procedure shall be carried out to bring a cell to a storage state (cold state). The general purpose of the shutdown procedure is to cool the cell to ambient temperature while avoiding leaving liquid water in the cell at ambient temperature.

Shutdown procedure shall be carried out in accordance with the MEA or component manufacturer’s instruction.

A representative shutdown procedure is provided for information in Annex E.

### 10.10 Re-conditioning

Reconditioning procedures shall be used upon restarting a cell after shutdown to ensure that MEA is properly humidified.

Reconditioning shall be carried out in accordance with the MEA or component manufacturer’s instruction.

Representative reconditioning procedure is provided for information in Annex F.

# 11 Performance tests

## 11.1 Steady test

### 11.1.1 General

The objective of this test is to verify output voltage or current and output power under standard test conditions.

### 11.1.2 Test methods

There are two similar methods to perform this test.

a) Set all test input parameters to desired values. Set the current corresponding to the rated current density ($i_{st}$) and maintain it until the cell voltage is stabilized within ±5 mV for 15 min. Record cell voltage ($V_{st}$). Power output under the standard test condition ($P_{st}$) is calculated from the test results.

b) Set all test input parameters to desired values. Set the voltage ($V_{st}$) corresponding to the desired value and maintain it until the cell current is stabilized within ±2 % for 15 min. Record cell current ($I_{st}$). Power output under the standard test condition ($P_{st}$) is calculated from the test results.

## 11.2 *I-V* characteristics tests

### 11.2.1 *I-V* characteristic at constant flow rate

#### 11.2.1.1 General

The objective of this test is to determine the evolution of cell voltage (and, in parallel, of power density) when varying the current density under constant gas flow condition.

#### 11.2.1.2 Test method

Set the fuel and oxidant flow rates to correspond to the standard stoichiometries at a maximum current density, $i_{max}$, that is specified by the cell manufacturer. Set current $I_{max}$ and maintain the current until the cell voltage is stabilized within ±5 mV for 15 min.

Obtain *I-V* characteristic of the cell by varying the current in the range of 0 to $I_{max}$ at a suitable interval, while maintaining the fuel and oxidant flow rates constant. The minimum requirement for voltage stabilization is ±5 mV for 5 min for each current density value. The exact procedure shall be reported. Typical current density increments are given in Annex G.

This test can also be performed by varying the voltage in the range of OCV to minimum voltage and allowing the current to stabilize to within ±2 % for 5 min.

Since the fuel and oxidant flow rates are constant in the range of 0 to $I_{max}$, both fuel and oxidant stoichiometries will change as the current changes. Although this may be different from the actual condition of fuel cell operation, cell conditions such as temperature, pressure and humidity are maintained stable even under variable current at the constant flow rates.

### 11.2.2 *I-V* characteristic at constant gas stoichiometries

#### 11.2.2.1 General

The objective of this test is to determine the evolution of cell voltage (and, in parallel, of power density) when varying the current density under constant gas stoichiometry condition.

#### 11.2.2.2 Test method

Set the fuel and oxidant flow rates to correspond to the stoichiometries at maximum current $I_{max}$ that is specified by the cell manufacturer. Set current $I_{max}$ and maintain the current until the cell voltage is stabilized within ±5 mV for 15 min. Obtain *I*-*V* characteristic of the cell in the range of 0 to $I_{max}$ by varying the current from 0 to $I_{max}$ at a suitable interval, while maintaining the fuel and oxidant stoichiometries constant at each current level. The minimum requirement for voltage stabilization is ± 5mV for 5 min for each current density value. Typical current density increments are given in Annex G.

NOTE This test can also be performed by varying the voltage in the range of OCV to minimum voltage and allowing the current to stabilize to within ±2 % for 5 min.

Since the fuel and oxidant stoichiometries are held constant in the range of 0 to $I_{max}$, both fuel and oxidant flow rates naturally change as the current changes. This is similar to the actual condition of fuel cell operation. However, due to a different flow rate at each current level, local heat and water balances are changed as the current varies. It requires a substantial amount of time to reach a new steady-state point after each current change. Specifically, under low current values including 0, voltage becomes unstable due to a low gas flow rate. For current $I_{min}$ specified by the cell manufacturer, the constant minimum flow rate specified by the cell manufacturer is usually applied in order to avoid such unstable voltage. If not specified, $I_{min}$ can be assumed to be 10 % of $I_{max}$.

## 11.3 IR measurement

### 11.3.1 General

The objective of this test is to determine the electrical resistance of the cell at different current densities. Measuring techniques described in 8.2.4 shall be used for IR measurement. Measuring technique should not disturb the steady state, if the IR measurements are conducted in parallel with *I*-*V* characteristic. If the measurement will disturb steady state, record the voltage and current density values, then perform the IR measurement. The *I*-*V* characteristic is measured according to 11.2.1 or 11.2.2.

### 11.3.2 Test method

Connect an IR measuring instrument to the cell. Record the instrument reading in parallel with obtaining *I*-*V* characteristic of the cell in the range of 0 to $I_{max}$ by varying the current from 0 to $I_{max}$ at a suitable interval. The area-specific resistance (ASR), Ω cm$^2$, is calculated from the following equation: ASR/(Ω cm$^2$) = Resistance/Ω × Electrode area/cm$^2$.

NOTE This measurement can be performed during all the following test procedures.

## 11.4 Limiting current test

### 11.4.1 General

The objective of this test is to evaluate the cell mass transport limitations within an MEA.

#### 11.4.1.1 Test method

Set the fuel and oxidant flow rates to correspond to the standard stoichiometries at rated current density $i_{st}$ specified by the cell manufacturer. Increase current step by step in small increments while maintaining the fuel and oxidant stoichiometries constant (that is to increase fuel and oxidant flow rates step by step). Record the cell voltage at each step. When voltage sharply goes down to near, but not to, 0 V, record the current, and decrease the current at once so as not to damage the MEA.

Use the extrapolated value to 0 V as the limiting current.

For this method, caution should be exercised to prevent the cell voltage from going to 0 V or below which may cause irreversible degradation for MEA. Also precautions must be taken to use load cables capable of handling limiting current.

## 11.5 Gain tests

### 11.5.1 Hydrogen gain test

#### 11.5.1.1 General

The objective of this test is to evaluate the diffusion capabilities of anodes. A hydrogen gain test is conducted to evaluate MEAs which use reformed gas (a mixture of hydrogen, carbon dioxide, nitrogen and the other impurities) for fuel in actual use.

#### 11.5.1.2 Test method

This test can be performed using one of two methods, constant flow rate or constant gas stoichiometries. They are described in 11.2.1 and 11.2.2, respectively. Once a method is selected, it must be used throughout the entire test. The test shall then be conducted as set out below.

First, use hydrogen as the fuel on the anode side of the cell using the desired flow rates, humidification and pressure. Measure the *I-V* characteristic with hydrogen and air using the selected method.

Next, use a hydrogen and nitrogen gas mixture as the fuel. Here, nitrogen replaces the non-hydrogen constituents in the reformed-gas mixture, and the composition of the reformed gas is specified by the manufacturer. Obtain the *I-V* characteristic with the hydrogen-nitrogen mixture and air using the selected method.

Compare *I-V* characteristic of hydrogen to that of the gas mixture. If the difference between these two *I-V* characteristics is larger than the theoretical value predicted from Nernst equation, it may indicate a diffusion issue for the anode.

NOTE 1 The reason why nitrogen is used instead of carbon dioxide is that carbon dioxide may produce trace of carbon monoxide by the reaction with hydrogen which poisons anode. This test purely evaluates the diffusion capability of the anode.

NOTE 2 The CO concentration in the hydrogen gas must be at or below that described in 9.1.1.

### 11.5.2 Oxygen gain test

#### 11.5.2.1 General

The objective of this test is to evaluate the diffusion capabilities of cathodes. An oxygen gain test is conducted to evaluate MEAs which use air for oxidant in actual use.

#### 11.5.2.2 Test method

This test can be performed using one of two methods, constant flow rate or constant gas stoichiometries. They are described in 11.2.1 and 11.2.2, respectively. Once a method is selected, it must be used throughout the entire test. The test shall then be conducted as set out below.

Measure the *I-V* curve using air using the selected method.

Then, use oxygen instead of air using the same flow rates, humidification and pressure. Obtain *I-V* characteristic using the selected method.

Compare the *I-V* characteristic of oxygen to that of air. If the difference between these two *I-V* characteristics is larger than the theoretical value predicted from Nernst equation, it may indicate a diffusion issue for the cathode.

NOTE 1 Cross-over leakage using $O_2$ can result in a rapid exothermic event resulting in hardware damage and potentially personnel injury.

NOTE 2 $O_2$ system needs to be designed and cleaned to special requirements.

## 11.6 Gas stoichiometry tests

### 11.6.1 Fuel stoichiometry test

#### 11.6.1.1 General

The objective of this test is to evaluate the diffusion capabilities of anodes, as in 11.5.1, Hydrogen gain test.

#### 11.6.1.2 Test method

Set the current density as specified under the standard test conditions. Set the oxidant stoichiometry to be in the range of that given in the standard test condition to at least four times that specified under the standard test conditions. Change the fuel flow in a certain range as specified by the cell manufacturer and record the cell voltage.

NOTE 1 This test is not conducted on hydrogen because there are no notable performance changes while hydrogen flow is decreased until starvation occurs. This test uses reformate gas.

NOTE 2 Care must be taken with this test since it intentionally stresses the anode by almost starving it. Starvation can cause irreparable damage to the anode.

### 11.6.2 Oxidant stoichiometry test

#### 11.6.2.1 General

The objective of this test is to evaluate the diffusion capabilities of cathodes, as in 11.5.2, Oxygen gain test. The tests shall be conducted as set out below.

#### 11.6.2.2 Test method

Set the current density as specified under the standard test conditions. Set the fuel stoichiometry to be in the range of that given in the standard test condition to at least two times that specified under the standard test conditions. Change the oxidant flow in a certain range as specified by the cell manufacturer and record the cell voltage.

NOTE 1 This test is not conducted on oxygen because there are no notable performance changes while the oxygen flow is decreased until starvation occurs. This test uses air.

NOTE 2 Care must be taken with this test since it intentionally stresses the cathode by almost starving it.

## 11.7 Temperature effect test

### 11.7.1 General

The objective of this test is to measure the effect of cell temperature on cell performance. Temperature is expected to affect the electrode reaction rates and electrolyte conductivity.

### 11.7.2 Test method

Set cell temperature at $T_1$, $T_2, \cdots T_n$ where the values of $T_1$, $T_2, \cdots T_n$ are specified by the cell manufacturer, and $T_n$ is the maximum operating temperature; additionally, keep anode and cathode relative humidities at the fuel cell operating temperature constant by increasing/decreasing the dew points and gas inlet temperatures. At each temperature level, obtain *I-V* characteristic of the cell. The procedure given in either 11.2.1 or 11.2.2 may be used.

## 11.8 Pressure effect test

### 11.8.1 General

The objective of this test is to measure the effect of fuel and oxidant pressures on cell performance. Care must be taken to keep the pressure difference across the membrane constant. High pressure increases the density of reactant gases, which is expected to increase the electrode reaction rate.

### 11.8.2 Test method

Set the fuel or oxidant pressure at $P_1$, $P_2, \cdots P_n$, where the values of $P_1$, $P_2, \cdots P_n$ are specified by the cell manufacturer, and $P_n$ is the maximum operating pressure. Simultaneously, change the other pressure accordingly to keep the pressure differential constant. At each pressure level, obtain *I-V* characteristic of the cell. The procedure given in either 11.2.1 or 11.2.2 may be used.

Care must be taken so as not to unintentionally damage the cell or membrane. The tester should be alert for indications of leaks through the membrane, such as pinholes, which may lead to internal ignition.

## 11.9 Humidity effect tests

### 11.9.1 Fuel humidity effect test

#### 11.9.1.1 General

The objective of this test is to measure the effects of varying the humidity of the fuel on cell performance. Humidity in fuel is expected to affect the electrolyte conductivity as well as gas diffusion into anodes.

#### 11.9.1.2 Test method

This test can be performed using one of two methods, constant flow rate or constant gas stoichiometries. They are described in 11.2.1 and 11.2.2, respectively. Once a method is selected, it must be used throughout the entire test. The test shall then be conducted as set out below.

Set the oxidant humidity at the standard conditions. Set fuel humidity at several levels corresponding to desired dew-point temperatures and obtain *I-V* characteristic.

### 11.9.2 Oxidant humidity effect test

#### 11.9.2.1 General

The objective of this test is to measure the effects of varying the humidity of oxidant on cell performance. Humidity in oxidant is expected to affect the electrolyte conductivity as well as gas diffusion into cathodes.

#### 11.9.2.2 Test method

This test can be performed using one of two methods, constant flow rate or constant gas stoichiometries. They are described in 11.2.1 and 11.2.2, respectively. Once a method is selected, it must be used throughout the entire test. The test shall then be conducted as set out below.

Set the fuel humidity at the standard conditions. Set oxidant humidity at several levels corresponding to desired dew-point temperatures and obtain the *I-V* characteristic.

## 11.10 Fuel composition test

### 11.10.1 General

The objective of this test is to measure the effect of the composition of reformed gas on cell performance. This test is to check the electrode capability for different types of fuels. Reformed gas contains hydrogen, CO, and inert gases such as $CO_2$ and/or $N_2$; the ratio of which depends on the difference in raw fuels and reforming methods. The inert gas is expected to affect the diffusion of hydrogen into the electrodes.

### 11.10.2 Test method

This test can be performed using one of two methods, constant flow rate or constant gas stoichiometries. They are described in 11.2.1 and 11.2.2, respectively. Once a method is selected, it must be used throughout the entire test. The test shall then be conducted as set out below.

Using the standard fuel, obtain *I-V* characteristic using the selected method. Change the standard fuel to another fuel which has different composition from standard gas. Obtain *I-V* characteristic using the selected method.

## 11.11 Overload test

### 11.11.1 General

The objective of this test is to evaluate the electrical overload durability of the cell. The overload durability is affected by the catalyst activity and gas diffusion ability of electrodes.

### 11.11.2 Test method

Set load at more than the rated and less than limiting current. Set the fuel and oxidant flow rates to correspond to the standard stoichiometries and then set current. Operate the cell for a period of time as specified by the cell manufacturer. Record the cell voltage during the operation.

## 11.12 Long-term operation test

### 11.12.1 General

The objective of the long-term operation test is to determine the evolution of the voltage of a cell operating for a long period of time in the specified, constant-current conditions. Long-term operation test is mainly performed in steady state, but qualifies the cell performance at fixed intervals over the duration of the test by measuring recurrent *I-V* characteristics and cell resistance.

### 11.12.2 Test method

Run the cell for an extended period of time under the standard test conditions in accordance with the allowable operating time specified by the cell manufacturer. Record the cell voltage during the operation. If desired, obtain the *I*-*V* characteristic of the cell and cell resistance under the standard test conditions at regular intervals. The suggested minimum number of these measurements is ten. The basic procedure is given in either 11.2.1 or 11.2.2 for *I*-*V* characteristic measurement and 11.3 for cell resistance measurement.

## 11.13 Start/stop cycling test

### 11.13.1 General

The objective of the start/stop cycling test is to determine the evolution of the performance of a cell operating in specified conditions as a function of start/stop profile count.

It can be used as a specific test to qualify the life-time of MEAs for a specific application with adapted operating conditions.

### 11.13.2 Test method

Optionally, gas flow and temperature control can be part of this test.

After operating the cell at 100 % load (rated current density) for definite period of time, switch off the load (open circuit) for a definite period of time. After that, switch the load and operate at 100 % load. Repeat the procedure while recording voltage (Load start/stop profiles and operating duration are specified by cell manufacturer. A typical start/stop cycling profile and its operating duration are given in Annex H).

NOTE Operating a fuel cell at open circuit voltage for long periods of time can accelerate the degradation of the electrode materials.

## 11.14 Load cycling test

### 11.14.1 General

The objective of the load cycling test is to determine the evolution of the voltage of a fuel cell operating in specified conditions as a function of current density following a dynamic profile versus time.

It can be used as a specific test to qualify the life-time of MEAs for a specific application with adapted operating conditions.

### 11.14.2 Test method

After operating the cell at 100 % load (rated current density) for definite period of time, switch load from 100 % to a partial load with the gas stoichiometries maintained constant and operate for definite period of time at a partial load. After that, increase load again to 100 %. Repeat this procedure while recording the voltage (Load profile and operating duration are specified by cell manufacturers). A typical load profile and its operating duration are given in Annex I.

## 11.15 Impurity influence tests

### 11.15.1 Fuel impurity influence tests

### 11.15.1.1 Influence of impurity-containing fuel and the recovery of the cell at rated current density

#### 11.15.1.1.1 General

The objective of this test is to determine the influence of impurities in fuel on cell performance and the degree of recovery of the cell from performance damage at rated current density. A cell is subjected to steady tests and operated with a fuel containing some impurities.

NOTE Impurities are given in ISO/TS14687-2 (2008), *Hydrogen fuel – Product specification – Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles.*

#### 11.15.1.1.2 Test method

The tests shall be conducted at several levels of impurities in fuel in order to determine the highest impurity level that does not affect the cell performance.

The tests shall be conducted as set out below.

Operate the cell at rated current density with clean fuel and clean air until the voltage is stabilized within ±5 mV for 15 min. Change the clean fuel to an impurity-containing fuel with the impurity species and their quantities specified by cell manufacturers. Run the cell until a stable voltage within ±5 mV for 15 min is attained and record the voltage.

Then, change the impurity-containing fuel to the clean fuel. Run the cell until a stable voltage within ±5 mV for 15 min is attained and record the voltage.

NOTE Some impurities, such as $H_2S$, may react with the exposed surfaces of the components of the test station (for example, gas supply piping and gaskets). Care must be taken to be sure that the test station materials are compatible with the impurity being used.

### 11.15.1.2 *I-V* characteristics with impurity-containing fuel

#### 11.15.1.2.1 General

The objective of this test is to determine the influence of impurities in fuel on *I-V* characteristic of the cell. The tests shall be conducted at several levels of impurities in order to determine the highest impurity level in fuel that does not affect the cell performance.

#### 11.15.1.2.2 Test method

Measure the *I-V* curve using clean fuel and clean air at constant flow rate or at constant gas stoichiometries in the same way as 11.2.1 or 11.2.2, respectively.

Change clean fuel to the impurity-containing fuel. Obtain *I-V* characteristic of the cell in the same method as that used in the previous measurement.

### 11.15.2 Oxidant impurity influence tests

### 11.15.2.1 Influence of impurity-containing oxidant and the recovery of the cell at rated current density

### 11.15.2.1.1 General

The objective of this test is to determine the influence of impurities in the oxidant on cell performance and the degree of recovery of the cell from performance damage at rated current density. A cell is subjected to steady tests and operated with an oxidant containing some impurities.

### 11.15.2.1.2 Test method

The tests shall be conducted at several levels of impurities in oxidant in order to determine the highest impurity level that does not affect the cell performance.

The tests shall be conducted as set out below.

Operate the cell at rated current density with clean fuel and clean air until the voltage is stabilized within ±5 mV for 15 min. Change the clean air to an impurity-containing air with the impurity species of impurities and their quantities specified by cell manufacturers. Run the cell until a stable voltage within ±5 mV for 15 min is attained and record the voltage.

Then, change the impurity-containing air to the clean air. Run the cell until a stable voltage within ±5 mV for 15 min is attained and record the voltage.

### 11.15.2.2 *I-V* characteristics with impurity-containing air

### 11.15.2.2.1 General

The objective of this test is to determine the influence of impurities in air on *I-V* characteristic of the cell.

### 11.15.2.2.2 Test method

The tests shall be conducted at several levels of impurities in order to determine the highest impurity level in air that does not affect the cell performance.

The tests shall be conducted as set out below.

Measure the *I-V* characteristic using clean fuel and clean air at constant flow rate or at constant gas stoichiometries in the same way as 11.2.1 or 11.2.2, respectively.

Change the clean air to the impurity-containing air. Obtain *I-V* characteristic of cell in the same method as that used in the previous measurement.

## 12 Test report

### 12.1 General

Test reports shall accurately, clearly and objectively present sufficient information to demonstrate that all the objectives of the tests have been attained. A suggested template for the test report for *I-V* characteristic test is given in Annex J.

### 12.2 Report items

The report shall present the following information, at a minimum:

a) title of the report,
b) authors of the report,
c) entity conducting the test(s),
d) date of the report,
e) standard number/test procedure number,
f) location of the test,
g) test data (see 12.3 for details).

### 12.3 Test data description

Test data shall include the following information:

a) title of the test(s),
b) measurement conditions (see 12.4 for details),
c) measurement data,
d) date and time when the test(s) was conducted,
e) ambient test conditions,
f) name and qualifications of person(s) conducting the test,
g) test cell data (see 12.5 for details).

### 12.4 Measurement condition description

The measurement condition description shall include the following information, at a minimum:

a) cell temperature,
b) fuel and oxidant pressures,
c) dew-points of fuel and oxidant,
d) fuel and oxidant compositions,
e) fuel and oxidant stoichiometries,
f) flow rates of fuel and oxidant.

### 12.5 Test cell data description

Test cell data shall include the following information:

a) active electrode area,
b) product name and brand name of MEA (optional),
c) type and thickness of membrane (optional),
d) types and amounts of anode and cathode catalysts (optional),
e) type of gas flow path (optional),
f) type of GDL material (optional),
g) clamping pressure (optional).

# Annex A
(informative)

## Flow plate

Figure A.1 shows an example design for the flow plate according to this Technical Specification. The example design is intended for an active area of 25 $cm^2$. Both anode and cathode flow plates have a horizontal serpentine single-groove as the gas flow channel on their faces that contact the MEA. The recommended channel configuration is as follows:

- width: 1,0 mm;
- depth: 1,0 mm;
- interval: ~1,0 mm.

The size of 50 mm × 50 mm should be slightly smaller than that of electrodes and GDLs to prevent the membrane from being cut by the edge of the channel. Use an assembly procedure that avoids direct contact of the membrane and the edge of channel.

Both fuel and oxidant are to flow from the top of the channel to the bottom.

Figure A.2 shows another example design for the flow plate which is also used in this Technical Specification. The example design is intended for an active area of 25 $cm^2$. The difference between Figures A.1 and A.2 is that Figure A.1 has a single-serpentine flow channel and Figure A.2, a triple serpentine flow channel.

*Dimensions in millimetres*

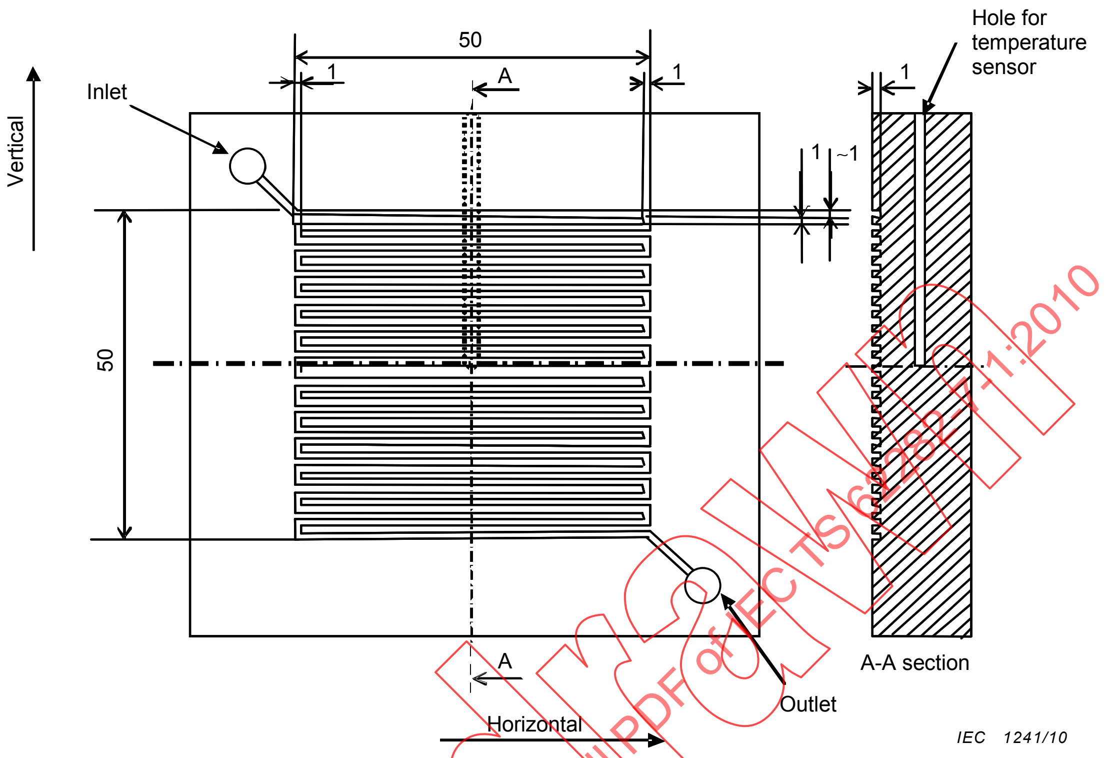


**Figure A.1 – Design for flow plate (single serpentine flow channel)**

*Dimensions in millimetres*

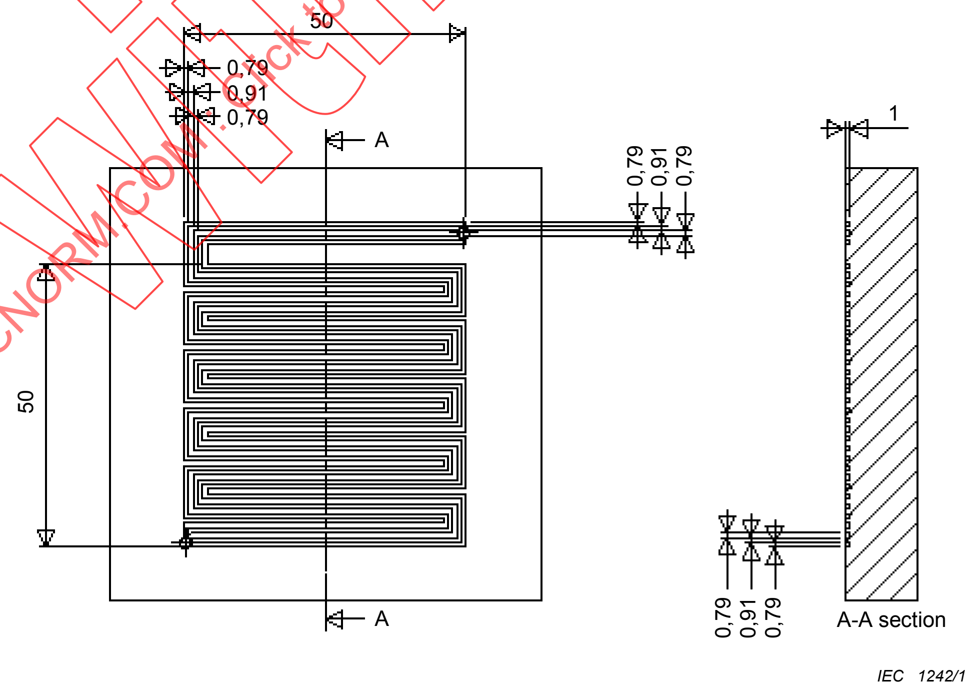


**Figure A.2 – Design for flow plate (triple serpentine flow channel)**

# Annex B
(informative)

## Cell component alignment

Figure B.1 shows a single cell assembly using typical components; these are compressed together with bolts and nuts. If necessary, spring washers or spring disks can be placed on the bolts in order to prevent loosening.

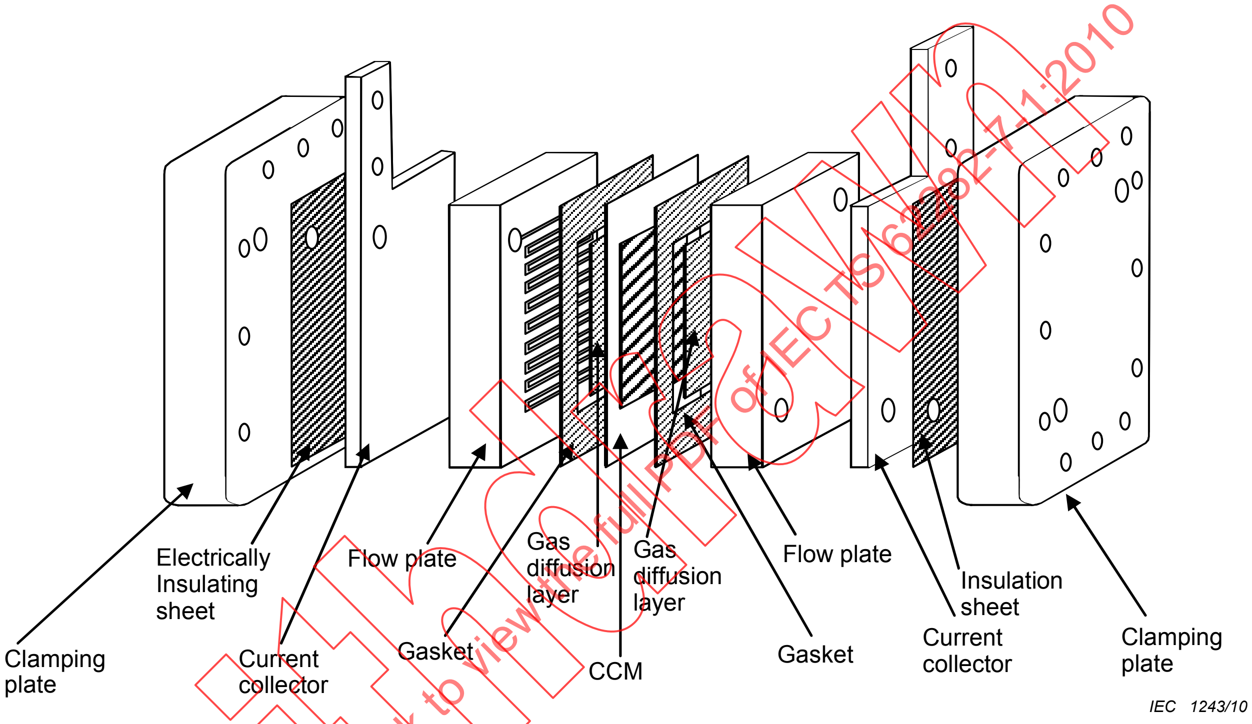


Figure B.1 – Single cell assembly using typical components

# Annex C
(informative)

# Leak test

Typical leak test protocols are described below.

a) Procedure 1:

Inject nitrogen into both anode and cathode sides. Set the backpressure to nearly 0 kPa(G), then shut off the exit valves of anode and cathode gases. First, pressurize the anode side to 50 kPa(G) (or 150 % of the maximum operating pressure) and the cathode side to 30 kPa(G) (or 125 % of the maximum operating pressure) simultaneously. Shut off the inlet valves of anode and cathode gases to seal the gas in the cell. Keep the cell in this condition for 10 min while monitoring the pressures on the anode and cathode sides respectively.

Second, pressurize the cathode side to 50 kPa(G) (or 150 % of the maximum operating pressure) and the anode side to 30 kPa(G) (or 125 % of the maximum operating pressure) simultaneously. Shut off the inlet valves of anode and cathode gases to seal the gas in the cell. Keep the cell in this condition for 10 min while monitoring the pressures in the anode and cathode sides, respectively.

In the above procedures, the pressure change after 10 min shall be less than 5 kPa(G) on both anode and cathode sides.

In the first step, if the pressure in the anode side falls and that in the cathode side rises, gas crossover through the membrane occurred. In the second step, if cathode pressure drops and anode pressure rises, gas crossover in the other direction occurred. If either pressure drops independent of the other, then an overboard leak occurred. If both pressures drop, external leaks are suspected.

b) Procedure 2:

Inject nitrogen into both anode and cathode sides. Set the backpressure to nearly 0 kPa(G), then shut off the exit valves of anode and cathode gases. First, pressurize both anode side and cathode side to 30 kPa(G) simultaneously. Shut off the inlet valves of anode and cathode gases to seal the gas in the cell. Keep the cell in this condition for 10 min while monitoring the pressures in the anode and cathode sides respectively. Document this leakage out of the cell.

Second, pressurize the anode side to 30 kPa(G) and the cathode side to 0 kPa(G) simultaneously. Shut off the inlet valves of anode and cathode gases to seal the gas in the cell. Keep the cell in this condition for 10 min while monitoring the pressures in the anode and cathode sides respectively. Document this crossover from anode to cathode side.

Third, pressurize the cathode side to 30 kPa(G) and the anode side to 0 kPa(G) simultaneously. Shut off the inlet valves of anode and cathode gases to seal the gas in the cell. Keep the cell in this condition for 10 min while monitoring the pressures in the anode and cathode sides respectively. Document this crossover from cathode to anode side. In the above procedures, the pressure drop after 10 min shall be less than 5 kPa(G) on both anode and cathode sides.

If the cell operates at higher pressures, the test pressure should be roughly equivalent.

# Annex D
(informative)

## Initial conditioning

As an alternative to the MEA supplier's initial conditioning procedure, four examples of conditioning protocols are described below.

a) Procedure A:

1) Set up the test station to operate the cell.
2) Purge both anode and cathode with purge (e.g., nitrogen) gas. The flow rates are similar to those used in the subsequent tests and will be used until the cell is purged completely.
3) Warm up the cell to 80 °C using a cell heater or other appropriate heating methods. Introduce fully humidified $N_2$ gas. The flow rates will be similar to those used in the subsequent test. During warm-up, maintain the cell temperature, inlet and outlet gas piping temperatures to be higher than the gas dew point at all times in order to prevent water condensation in the system.
4) Wait until the cell temperature and gas humidity are stabilized. Introduce fully-humidified reactant gases in the appropriate stoichiometries, for example, 1,4 for hydrogen and 2,5 for air, with respect to 1 000 $mA/cm^2$. Increase the load gradually while keeping the cell voltage above 0,4 V until the current density reaches 1 000 mA $cm^{-2}$.
5) Maintain the load (the current density) at 1 000 mA $cm^{-2}$ with stoichiometry of 1,4 for $H_2$ and 2,5 for air until the cell voltage variability settles to less than 5 mV over 5 h. Fulfilling this criterion indicates the completion of cell break-in.

b) Procedure B:

At standard operating conditions to be used during the subsequent test, run the cell on pure hydrogen at open circuit voltage (OCV) for 15 min, run at 600 mV for 75 min, then run three cycles consisting of holding at 850 mV for 20 min followed by 600 mV for 30 min. The total time for conditioning is approximately 4 h.

c) Procedure C:

Set up the test station to operate the cell. Set the standard operating conditions to be used during the subsequent test. In potentiostatic mode, hold at 500 mV for 5 min, run *I*/*V* cycle at constant gas flow rates from 800 mV to 300 mV in 50 mV steps for 10 s each step and back from 300 mV to 800 mV at same speed and time. Hold the cell at 500 mV for 5 min. Run the cycle until the variations of current density at 500 mV are below ±10 mA $cm^{-2}$ in 5 min and the deviation of current density in 3 subsequent cycles is below ±10 mA $cm^{-2}$.

d) Procedure D:

Operate the cell in galvanostatic mode at the selected operating temperature and at the gas conditions given in the standard test conditions. Increase the current density in steps of 100 mA $cm^{-2}$ or at a rate not greater than 10 mA $cm^{-2}$ $s^{-1}$, while keeping the cell voltage higher than 500 mV until reaching the current density identified for the conditioning. The current density for the conditioning of the cell will correspond either to the maximum current possible at 500 mV in the selected conditions or to a current density specified by the specific objective of the test.

The conditioning step shall last at least 24 h with a cell voltage variation of less than ±5 mV in the last hour before starting the test.

# Annex E
(informative)

## Shutdown

A typical shutdown protocol is described below.

a) Decrease the electrical load to values corresponding to the steps in the polarization curve in the reverse sequence (that is, decrease current density from $i_{max}$ to 0 while keeping gases flowing). Disengage the electrical load.

b) Purge anode and cathode with humidified nitrogen at flows corresponding to the lowest polarization curve load step until the cell cools to ambient temperature. During cool-down, maintain the cell temperature and gas piping temperature higher than the gas dew point at all times in order to prevent water condensation in the system.

c) After the cell has reached ambient temperature, switch to dry nitrogen flows on the anode and cathode for 5 min to 10 min (this step is optional, depending on the final level of membrane hydration desired).

d) Disconnect the cell and tightly cap the anode and cathode inlets and outlets.

# Annex F
(informative)

# Reconditioning

Typical reconditioning protocols are described below.

a) Procedure A:
   1) Repeat steps 1) to 5) of the Procedure A of Annex D. One hour should be enough for step 5) for stabilization of the cell condition.
   2) Specify test condition(s) appropriate for the test to be carried out and maintain the condition(s) until they are stabilized.

b) Procedure B:
   1) Supply fully-humidified gases with a hydrogen stoichiometry of 1,4 and an oxidant stoichiometry of 2,5 through the cell for 1 h while heating to 80 °C, using a current of 400 mA $cm^{-2}$.
   2) Operate the cell under these conditions for 4 h; the cell is conditioned when the voltage is equilibrated.

# Annex G
(informative)

## *I-V* characteristic test

Typical current density increments used for *I-V* characteristics test are given below.

If the expected maximum current density is known (e. g., indicated by the manufacturer or due to previous measurements), select the current steps as given in Table G.1.

**Table G.1 – Current density increments if maximum current density is known**

| Step | Percentage of expected maximum current density |
|---|---|
| 0 | 0 (OCV) |
| 1 | 2 % |
| 2 | 5 % |
| 3 | 10 % |
| 4 | 20 % |
| 5 | 30 % |
| 6 | 50 % |
| 7 | 70 % |
| 8 | 90 % |
| 9 | 100 % |
| NOTE More points may be necessary at low current if Tafel slope analysis is of interest. | |

If the maximum current density is unknown, use the current increments given in Table G.2.

## Table G.2 – Current density increments if maximum current density is unknown

| **Step** | **Current density (mA cm$^{-2}$)** |
|---|---|
| 0 | 0 (OCV) |
| 1 | 20 |
| 2 | 50 |
| 3 | 100 |
| 4 | 200 |
| 5 | 400 |
| 6 | 600 |
| 7 | 800 |
| 8 | 1 000 |
| 9 | 1 200 |
| 10 | 1 400 |
| 11 | 1 600 |
| 12 | 1 800 |
| 13 | 2 000 |

NOTE The test must be ended when the maximum current density is reached or if the cell voltage goes below 0,3 V or the minimum voltage value recommended by the manufacturer (in order to avoid irreversible damage to the cell components).

# Annex H
(informative)

## Start/stop cycling test

A typical start/stop cycling profile and its operating duration are described below.

The cycling will follow the following profile:

a) “off” phase = 15 min at 0 A $cm^{-2}$;
b) “on” phase = 15 min at $i_{st}$ A $cm^{-2}$ ($i_{st}$: rated current density).

It is recommended to increase the current density step by step in order to avoid important voltage drop. The current shall be increased from 0 to $i_{st}$ in four steps of 10 s increasing the current of $i_{st}$ /4 at each step:

a) ¼ $i_{st}$ A $cm^{-2}$ during 10 s;
b) ½ $i_{st}$ A $cm^{-2}$ during 10 s;
c) ¾ $i_{st}$ A $cm^{-2}$ during 10 s;
d) $i_{st}$ A $cm^{-2}$ during 14 min 30 s.

The duration of this step depends on the specific objective of the test and on the related specific “ending” criterion: fixed life time test or fixed performance losses (considering the power, the voltage on load or the open circuit voltage).

Apart from the different possible ending criteria specifically defined, the test shall be stopped (gases, temperature controllers and load off) if the cell voltage goes below 0,3 V or the minimum value recommended by the manufacturer (in order to avoid irreversible damage of the cell components).

# Annex I
(informative)

## Load cycling test

Typical load cycling profiles and length of the test are given below.

Two current density profiles allowing the cell to operate between two current density levels are proposed: one is more dynamic, with the profile lasting 1 min, and the other less so, with the profile lasting 1 h.

The current density is fixed at $i_{100\ \%}$ (rated current density) for a first high power phase to stabilize the operating conditions before starting the cycling phase. Then the load cycling shall be performed with one of the two current density profiles shown in Figures I.1 and I.2.

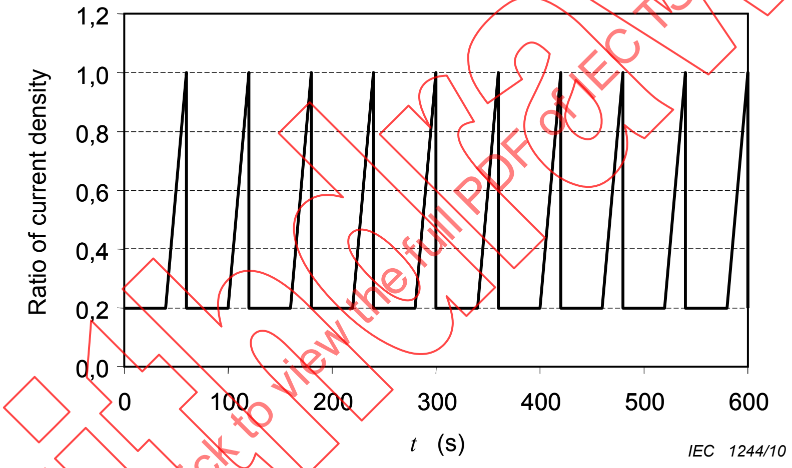


Figure I.1 – First load cycling profile

The profile is divided into two sections: low current density phase = 40 s at $i_{20\ \%}$ A cm$^{-2}$ ($i_{20\ \%}$: 20 % current density of $i_{100\ \%}$); and high current density phase = 20 s with an increase of $i$ from $i_{20\ \%}$ to $i_{100\ \%}$ A cm$^{-2}$.