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Fuel cell technologies –
Part 7-2: Test methods – Single cell and stack performance tests for solid oxide fuel cells (SOFCs)

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FUEL CELL TECHNOLOGIES –

Part 7-2: Test methods – Single cell and stack performance tests for solid oxide fuel cells (SOFCs)

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 62282-7-2 has been prepared by IEC technical committee 105: Fuel cell technologies. It is an International Standard.

This first edition cancels and replaces IEC TS 62282-7-2 published in 2014.

This edition includes the following significant technical changes with respect to IEC TS 62282-7-2:2014:

a) users can substitute selected test methods of this document with equivalent test methods of IEC 62282-8-101 for solid oxide cell (SOC) operation for energy storage purposes, operated in reverse or reversible mode;
b) terms and definitions are aligned with the corresponding terms and definitions in IEC 62282-8-101;
c) symbols are aligned with the corresponding symbols in IEC 62282-8-101.

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

FDIS	Report on voting
105/847/FDIS	105/851/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/standardsdev/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 specifies test methods for a single cell and stack (denoted as "cell/stack" hereafter) that is required in power generation systems using solid oxide fuel cells (SOFCs).

SOFCs have a broad range of geometry and size. As such, in general, peripherals like current collectors and gas manifolds are unique to each cell or stack and are often incorporated into a cell or stack to form one integrated unit. In addition, they tend to have a significant effect on the power generation characteristics of the cell or stack. This document therefore introduces as its subject "cell/stack assembly units", which are defined as those units containing not only a cell or stack but also peripherals.

FUEL CELL TECHNOLOGIES –

Part 7-2: Test methods – Single cell and stack performance tests for solid oxide fuel cells (SOFCs)

1 Scope

This part of IEC 62282 applies to SOFC cell/stack assembly units, testing systems, instruments and measuring methods, and specifies test methods to test the performance of SOFC cells and stacks.

This document is not applicable to small button cells that are designed for SOFC material testing and provide no practical means of fuel utilization measurement.

This document is used based on the recommendation of the entity that provides the cell performance specification or for acquiring data on a cell or stack in order to estimate the performance of a system based on it. Users of this document can selectively execute test items suitable for their purposes from those described in this document.

Users can substitute selected test methods of this document with equivalent test methods of IEC 62282-8-101 for solid oxide cell (SOC) operation for energy storage purposes, operated in reverse or reversible mode.

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

IEC 60584-1, *Thermocouples – Part 1: EMF specifications and tolerances*

IEC 60584-3, *Thermocouples – Part 3: Extension and compensating cables – Tolerances and identification system*

IEC 61515, *Mineral insulated metal-sheathed thermocouple cables and thermocouples*

ISO 5168, *Measurement of fluid flow – Procedures for the evaluation of uncertainties*

ISO 6141, *Gas analysis – Contents of certificates for calibration gas mixtures*

ISO 6142-1, *Gas analysis – Preparation of calibration gas mixtures – Gravimetric method for Class I mixtures*

ISO 6143, *Gas analysis – Comparison methods for determining and checking the composition of calibration gas mixtures*

ISO 6145-7, *Gas analysis – Preparation of calibration gas mixtures using dynamic methods – Part 7: Thermal mass-flow controllers*

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

ISO 7066-2, *Assessment of uncertainty in the calibration and use of flow measurement devices – Part 2: Non-linear calibration relationships*

ISO 8573-1, *Compressed air – Part 1: Contaminants and purity classes*

ISO 8756, *Air quality – Handling of temperature, pressure and humidity data*

ISO 12185, *Crude petroleum and petroleum products – Determination of density – Oscillating U-tube method*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-485 and the following apply.

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

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

3.1.1
cell/stack assembly unit
unit including a single cell or stack, as well as gas supply parts, current collector parts, and any other peripherals as required for power generation tests

3.1.2
active electrode area
geometric electrode area upon which an electrochemical reaction occurs

Note 1 to entry: Usually this is the smaller of the anode and cathode areas.

3.1.3
current density
current divided by the active electrode area

3.1.4
average repeating unit voltage
cell/stack assembly unit voltage divided by the number of the cells in a series connection in the unit

3.1.5
standard temperature and pressure
STP
temperature of 0 °C and an absolute pressure of 101,325 kPa, respectively

3.1.6
anode gas
gas that is supplied to the inlet of the anode of a single cell/stack assembly unit

Note 1 to entry: Such a gas belongs to one of the following categories:

a) pure hydrogen or mixture that contains hydrogen as a principal component with water vapour or nitrogen;

b) reformed gas of raw fuel of SOFC such as methane or kerosene premixed with water vapour or air as oxidant;

c) simulated gas of reformate that contains hydrogen, water vapour, carbon monoxide, carbon dioxide, methane, nitrogen, etc., as main components;

d) methane, alcohols and other raw fuels directly supplied in pure form or mixed with water vapour and/or air.

3.1.7
cathode gas
gas that is supplied to the inlet of the cathode of a single cell/stack assembly unit

Note 1 to entry: Oxygen and nitrogen are its main components.

3.1.8
current collector
conductive material in a fuel cell that collects electrons from the anode side or conducts electrons to the cathode side

3.1.9
stable state
condition of a cell/stack assembly unit at which the unit is stable enough for any controlling parameter and the output voltage or output current of the unit to remain within its tolerance range of variation

3.1.10
theoretical current
current when the supplied anode gas or cathode gas is completely consumed in electrochemical reactions divided by the number of cells in a series connection

3.1.11
effective fuel utilization
ratio of the actual output current of the cell/stack assembly unit to the theoretical current

Note 1 to entry: The effective utilization is the utilization of reactants in the electrochemical reaction due to the actual current. This may be less than the actual or total utilization if there are gas inlet and cross leaks.

Note 2 to entry: Causes of less-than-optimal currents include losses due to electronic conduction within the cell/stack assembly, gas leaks and anode gas pass-through.

Note 3 to entry: A calculation method of effective fuel utilization is given in Annex B.

3.1.12
effective oxygen utilization
ratio of the actual output current of the cell/stack assembly unit to the theoretical current

Note 1 to entry: The effective utilization is the utilization of reactants in the electrochemical reaction due to the actual current. This may be less than the actual or total utilization if there are gas inlet and cross leaks.

Note 2 to entry: A calculation method of effective oxygen utilization is given in Annex C.

3.1.13
maximum effective fuel utilization
highest effective fuel utilization that the unit can operate at, without causing unacceptable degradation

Note 1 to entry: The acceptable degradation rate is usually obtained from the developer.

3.1.14
minimum cell/stack assembly unit voltage
lowest cell/stack assembly unit voltage specified by the manufacturer

3.1.15
open circuit voltage
OCV
voltage across the terminals of a fuel cell with cathode and anode gases present and in the absence of external current flow

Note 1 to entry: Also known as "no-load voltage".

3.1.16
power density
ratio of the power to the active electrode area of a cell/stack assembly unit

Note 1 to entry: Power density is calculated from the voltage multiplied by the current density ($P_d = V \times J$, where J is current density).

3.1.17
total impedance
frequency-dependent losses due to ohmic, activation, diffusion, concentration effects, stray (parasitic) capacitance and inductances

3.1.18
total resistance
real part of the low-frequency limit of total impedance

3.1.19
stoichiometric ratio

ratio between the number of moles of reactant gas flowing per unit time to that needed by the electrochemical reaction

Note 1 to entry: The terms, "stoichiometric ratio" and "reactant gas utilization," are related. The reciprocal of the fraction of the gas utilized is the stoichiometric ratio.

3.2 Symbols

Table 1 lists the symbols and units that are used in this document.

Table 1 – Symbols

Symbol	Definition	Unit
a	Error limit specified from specification of instrument	a
I	Current	A
J	Current density	A/cm^2
n	Number of transferred electrons	
N	Number of cells in a series connection	
p_a	Absolute pressure of anode gas	kPa
p_c	Absolute pressure of cathode gas	kPa
P	Output power	W
P_d	Output power density	W/cm^2
q_a	Flow rate of anode gas	l/min (STP)
q_c	Flow rate of cathode gas	l/min (STP)
q_j	Flow rate of fuel component j in anode gas	l/min (STP)
t	Time	s, min, h
T_{op}	Cell/stack assembly unit operating temperature	°C
u_I	Combined standard uncertainty for instruments	a
$u_{I,i}$	Standard uncertainty for instrument i	a

Symbol	Definition	Unit
U_f	Effective fuel utilization	%
U_{O2}	Effective oxygen utilization	%
U_I	Extended instrument uncertainty	[a]
V	Voltage	V
x_i	Molar fraction of component i or Mole percent of component i	mol/mol or mol % [b]
c_i	Concentration of component i	mol/m^3
ξ_j	Hydrocarbon conversion rate for hydrocarbon component j	%

[a] Denotes where the unit varies depending on the specification.

[b] Mole percent expressed as one hundred times mole fraction.

4 General safety conditions

An operating fuel cell uses oxidizing and combustible gases. Typically, these gases are stored in high-pressure containers. The fuel cell itself may be operated at pressures greater than atmospheric pressure. Those who carry out cell/stack assembly unit testing shall be trained and experienced in the operation of test systems and specifically in safety procedures involving electrical equipment and reactive, compressed gases.

The test personnel are responsible for obtaining and following all applicable safety codes and generally accepted engineering practices related to their test system, facility, fuels (with particular attention to compressed gases), and exhaust products.

Materials which are compatible with the use and storage of the reactant gases shall be used during testing. Local safety codes and standards for working with hydrogen, hydrocarbons and carbon monoxide should be followed.

In summary, safely operating a test station requires appropriate technical training and experience as well as safety facilities and equipment, all of which are outside the scope of this document.

5 Cell/stack assembly unit

A cell/stack assembly unit includes a cell or stack, gas supply, current leads, and such other peripherals as required for power generation tests. It shall be provided with single or multiple measuring points for temperature and voltage, and one set of current lead points, all to be specified by the manufacturer.

As shown in Annex A, the boundary of a cell/stack assembly unit goes through the anode gas supply port, cathode gas supply port, temperature measuring point, current lead points, voltage measuring points and mechanical load application points.

Some cell/stack assembly units may have no exhaust port for the anode gas or cathode gas because of the configuration of the cells. In such cases, the gas flow field pattern and its material shall be determined by the method recommended by the manufacturer. The load application method shall be also based on the recommendation of the manufacturer. The maximum operating temperature from the manufacturer shall not be exceeded.

If the components of a cell/stack assembly unit other than a cell/stack are not specified by the manufacturer, the following shall be described in the test report, as a minimum:

a) materials and geometry of the peripheral components to be used for testing;

b) flow patterns and directions of anode and cathode gases;

c) locations of temperature measurement, mechanical load application, voltage measurement and current leads;

d) magnitude of the mechanical load;

e) configuration of assembly unit and its assembling method.

6 Testing system

6.1 Subsystems in testing system

6.1.1 General

As shown in Figure 1, a testing system consists of an anode gas control subsystem, cathode gas control subsystem, cell/stack assembly unit temperature control subsystem, output power control subsystem, measurement and data acquisition subsystem and safety subsystem. It may also include a mechanical load control subsystem, anode gas and cathode gas pressure control subsystem and/or a test system control subsystem that controls the whole testing system, if needed.

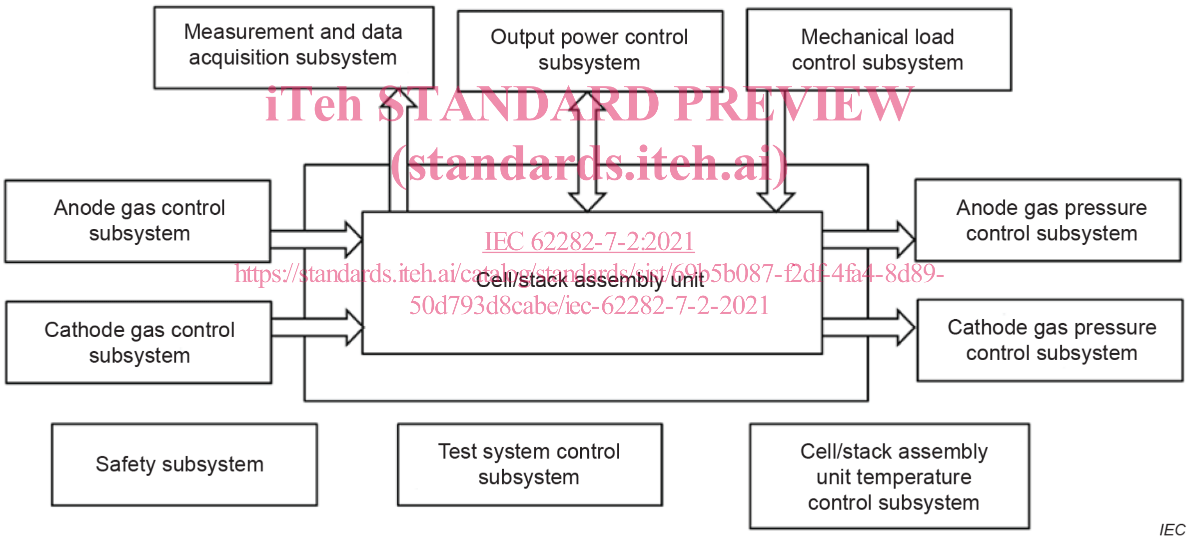

Figure 1 – Testing system

6.1.2 Anode gas control subsystem

The anode gas control subsystem controls the flow rate, composition and temperature of the anode gas supplied to the cell/stack assembly unit. If the gas composition is to be maintained throughout the piping, then attention shall be paid to the materials, temperature, inner diameter and length of the piping. Where necessary, the piping shall be heated and/or thermally insulated in order to prevent condensation of water vapour.

Care should be taken to avoid other phenomena, such as carbon deposits, and the evaporation and transport of undesired materials in the gas streams, such as chromium.

6.1.3 Cathode gas control subsystem

The cathode gas control subsystem controls the flow rate, composition and temperature of the cathode gas supplied to the cell/stack assembly unit.

6.1.4 Cell/stack assembly unit temperature control subsystem

The cell/stack assembly unit temperature control subsystem controls, at least, the electric furnace or the unit temperature. It maintains the operating temperature. The electric furnace shall be selected to maintain the temperature distribution within the specified tolerance level. Efforts should be made to minimize the electrical noise that the electric furnace generates while providing heat. It is assumed that all the test systems will use an electrical furnace for simplicity and safety reasons.

6.1.5 Output power control subsystem

The output power control subsystem controls the output current or output voltage of the cell/stack assembly unit.

6.1.6 Measurement and data acquisition subsystem

The measurement and data acquisition subsystem acquires and records the cell/stack assembly unit temperature, current, voltage, anode gas flow rate, cathode gas flow rate, and optionally, environmental conditions (ambient temperature, relative humidity, and atmospheric pressure) in accordance with the specified method. If necessary, it also acquires and records the mechanical load applied to the cell; the temperature, composition and pressure of the cathode gas and the anode gas; the flow rate, composition, temperature and pressure of anode and cathode exhaust gases; and cell/stack assembly unit impedance data, etc., in accordance with the specified method.

6.1.7 Safety subsystem

The safety subsystem functions as a detector and alarm system for malfunctioning of the test system based on predefined parameters and criteria. If it detects a serious fault, then it shall automatically establish a safe state in the test system. The anode should be purged with an inert gas, such as nitrogen, which could also contain hydrogen at concentrations below the lower flammability limit.

6.1.8 Mechanical load control subsystem

The optional mechanical load control subsystem regulates the mechanical load that is applied to increase the contact among components in the cell/stack assembly unit. The subsystem should be strong enough to apply the required mechanical load under the test conditions and to maintain the load for long term operation.

6.1.9 Gas pressure control subsystem for anode and cathode

The optional gas pressure control subsystem for anode and cathode gases regulates the pressure of these gases by the use of a back pressure control valve, etc.

6.1.10 Test system control subsystem

The test system control subsystem provides the integrated control for each control subsystem and data acquisition subsystem.

6.2 Maximum variation in control items of testing system

The tolerable variation of each control item in the testing system shall fall within the following ranges:

In the case of current control:	current: ±1 % relative to rated value point;
In the case of voltage control:	voltage: ±1 % relative to set point;
Temperature:	±1,0 % relative to set point;