Solid Oxide Cell and Stack Testing, Safety and Quality Assurance

Collaborative Project - *FCH JU GRANT AGREEMENT N° 621245*
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Test Module 09: Temperature Sensitivity

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Content

Abbreviations

nlpm	Normal litre per minute
OCV	Open circuit voltage
RU	Repeating unit
SOC	Solid oxide cell
SOFC	Solid oxide fuel cell
SOEC	Solid oxide electrolysis cell
slpm	Standard litre per minute
TIP	Test input parameter
TM	Test module
TOP	Test output parameter

TM 09 – Temperature Sensitivity

1 Objective and Scope

The purpose of this test module (TM) is to investigate the influence of the cell/stack nominal operating temperature on the cell/stack performance. The parameters that have a predominant role in this TM are: stack environment temperature (oven and pre-heaters) and current.

This test procedure has no specific target application. However, this test module describes a general characterization method that can be used in research and development of the SOC and for quality assurance in cell and stack production. This module is applied in combination with other test modules in a test programme. The test programme will be application-specific and also describe the operating conditions of the SOC in more detail. All the quantities used in TM09 are defined with their symbols and units in section 7 of TM00 “General SOC testing guidelines”. The test object for which this TM applies is also described in section 5 of the master document TM00.

Note: the parameters, values and range of values including uncertainties used throughout this document are recommended only.

2 Test Equipment and Set-up

This part is fully detailed in section 6 of the master document TM00. A complete test system is described with all its different subsystems around as well as the interfaces between the test object and the test system. Some figures are given showing the consequent test input and output parameters' locations on the test object as well as their measurement method and accuracy. Finally, some advice is supplied in regard to the mounting of the test object in the test system and to the quality of the test environment.

3 Test Input Parameters (TIPs)

There are two types of test input parameters (TIPs): variable TIPs and static TIPs (for definitions refer to Table 1 in TM00).

The measurement uncertainties, the sampling rates and the values given in the following tables are in compliance with the master document TM00. Deviations from the test module should be reported in the test report.

Table 1 lists the static TIPs for the temperature sensitivity analysis when the effect needs to be assessed of a variation different nominal operating temperature levels on cell/stack performance. The variable TIPs for this test are listed in Table 2.

Table 1: Static test input parameters TIPs in TM09 for SOFC and SOEC modes as defined in TM00

Description of quantity	Symbol	Unit often used	SI unit
Flow rate of the negative electrode gas stream at cell/stack inlet	$f_{neg,in}$	nlpm, slpm l_n min^{-1}, l_s min^{-1}	m^3 s^{-1}
Flow rate of the positive electrode gas stream at cell/stack inlet	$f_{pos,in}$	nlpm, slpm l_n min^{-1}, l_s min^{-1}	m^3 s^{-1}
Flow rate of component *i* in the negative electrode gas stream at cell/stack inlet	$f_{i,neg,in}$	nlpm, slpm l_n min^{-1}, l_s min^{-1}	m^3 s^{-1}
Flow rate of component *i* in the positive electrode gas stream at cell/stack inlet	$f_{i,pos,in}$	nlpm, slpm l_n min^{-1}, l_s min^{-1}	m^3 s^{-1}
Mole fraction of component i in the negative electrode gas stream at cell/stack inlet	$x_{i,neg,in}$	-	-
Mole fraction of component i in the positive electrode gas stream at cell/stack inlet	$x_{i,pos,in}$	-	-
Pressure of the negative electrode gas stream at cell/stack outlet	$p_{neg,out}$	mbar, kPa	N m^{-2} (Pa)
Pressure of the positive electrode gas stream at cell/stack outlet	$p_{pos,out}$	mbar, kPa	N m^{-2} (Pa)
Rate of oven temperature change	$\Delta T_{oven}/\Delta t$	K min^{-1}	K s^{-1}
Rate of pre-heater temperature change	$\Delta T_{PH}/\Delta t$	K min^{-1}	K s^{-1}

Table 2: Variable test input parameters TIPs in TM09 for SOFC and SOEC modes as defined in TM00

Description of quantity	Symbol	Unit often used	SI Unit
Electrical current through the cell/stack	I	A	A
Temperature of the oven	T_{oven}	°C	K
Temperature of the pre-heater for preheating the negative electrode gas stream	$T_{PH,neg}$	°C	K
Temperature of the pre-heater for preheating the positive electrode gas stream	$T_{PH,pos}$	°C	K

4 Test Output Parameters (TOPs)

The main output parameters are the average cell/stack temperature and voltages of the stack and RUs. These test outputs have to be recorded at the targeted cell/stack nominal operating temperature levels, while varying *I*, or the stack environment temperatures, $T_{PH,neg/pos}$ *and* T_{oven}. There can be many TOPs attending to the availability of apposite measurement/recording devices yet, Table 3 illustrates only the recommended parameters for this Test Module.

Table 3: Test output parameters TOPs in TM09 for SOFC and SOEC modes as defined in TM00

Description of quantity	Symbol	Unit often used	SI unit
Voltage of the stack	V_{stack}	V	V
Voltage of repeating unit (RU) i in the stack	$V_{RU,i}$	V	V
Voltage of the cell	V_{cell}	V	V
Temperature of the negative electrode gas stream at cell/stack inlet	$T_{neg,in}$	°C	K
Temperature of the negative electrode gas stream at cell/stack outlet	$T_{neg,out}$	°C	K
Temperature of the positive electrode gas stream at cell/stack inlet	$T_{pos,in}$	°C	K
Temperature of the positive electrode gas stream at cell/stack outlet	$T_{pos,out}$	°C	K
Temperature of the bottom plate of the stack	T_{BP}	°C	K
Temperature of the cell	T_{cell}	°C	K
Stack temperature	T_{stack}	°C	K
Temperature of the top plate of the stack	T_{TP}	°C	K

5 Derived quantities

The parameters listed in Table 4 are important and commonly used values calculated from input and output parameters.

Table 4: Derived quantities in TM09 Temperature sensitivity as defined in TM00

Description of quantity	Symbol	Unit often used	SI unit
Electrical current density through the cell/stack	j	A cm^{-2}	A m^{-2}
Electrical power of the cell/stack	P_{el}	W	J s^{-1} (W)
Pressure drop of the negative electrode gas stream over the cell/stack	Δp_{neg}	mbar, kPa	N m^{-2} (Pa)
Average temperature of the stack	T_{av}	ºC	K
Maximum temperature difference in the stack	ΔT_{max}	ºC	K

Some stack designs do not allow a direct measurement of the internal temperature of the stack. In this case an average temperature of the stack T_{av} should be calculated as a substitute for the internal temperature. The calculation can include the temperature of gases as well as the temperature of the end plates. Depending on which temperatures can be measured an average temperature can be calculated, for example, as follows:

$$T_{av} = \frac{T_{TP}+T_{BP}+T_{neg,in}+T_{neg,out}+T_{pos,in}+T_{pos,out}}{6} \quad (1)$$

A stack can be damaged during the temperature ramps if the temperature gradient between the gas inlets and the stack itself is too high. A value for the maximum temperature difference during temperature ramps can be calculated with the following formula if the internal temperature cannot be measured directly:

$$\Delta T_{max} = \left| \frac{(T_{neg,in}+T_{pos,in})}{2} - \frac{(T_{TP}+T_{BP})}{2} \right| \quad (2)$$

6 Test Procedure

6.1 Critical Parameters and Parameter Controls

6.1.1 Sensor position

It is recommended to measure the cell/stack temperature at a fixed location which should be as close as possible to the geometric centre of the cell/stack. Since usually it will not be possible to place a thermocouple (or similar) in the heart of a stack, it is suggested to measure the temperature in direct contact with the centre of the end plate(s) of the cell/stack assembly. For stack tests, if possible, it is recommended to use two temperature sensors, one at the top and one at the bottom end plate and take the arithmetic average of the two values. If direct measurement of the cell/stack temperature is not possible, the oxidant outlet temperature should be taken as reference, measured as close as possible to the cell/stack outlet.

6.1.2 Temperature stability

The reproducibility of the cell/stack performance with temperature during the measurement time has to be assured. Minor temperature variations are acceptable as long as the cell/stack voltage is not influenced significantly. Since the objective of the test is to determine the influence of cell/stack nominal operating temperature on cell/stack performance, changes in the cell/stack temperature caused by electrical load variation have to be considered. However, compensating changes in the cell/stack temperature caused by electrical load variation may be unfeasible, so that the *nominal* cell/stack temperature shall be taken at a given current density (either OCV or a nominal current density). Afterwards the *effective* cell/stack temperature at each test step, after the defined stabilisation time (see section 6.4 of TM00) and at which the corresponding cell/stack voltage shall be taken, shall be noted in the test output table.

At each test step, the cell/stack assembly unit shall be operated until it reaches the stable state in terms of temperature and voltage (stabilisation time). At stable state, measurements are taken for the entire duration of the prescribed sampling interval (measurement time). The average value of these measurements shall be the measured value for that step.

6.2 Preconditioning of the Stack

The preconditioning of the fuel cell stack is specified in the SOCTESQA master document and should be realized under nominal conditions given by the stack manufacturer.

6.3 Carrying out the Test for Temperature Sensitivity

6.3.1 Test Methodology

The cell/stack temperature ranges under investigation, the current load levels, the number of individual test steps and the test operating conditions, have to be defined before the test. The tested cell/stack temperatures have to be chosen considering the allowable operating conditions specified by the cell/stack manufacturer. Based on these parameters the test point matrix can be prepared.

Example

This test module can be used to determine the behaviour of a stack under 25, 50, 75 and 100% of the nominal load when the nominal operating temperature is varied by multiples of 50°C and $f_{neg/pos,in}$ remain constant. The resulting test point matrix is presented in Table 5.

Table 5: Test example

$T_{cell/stack}$ (ºC) @ I nominal	I (A)	$f_{neg,in}$ (nlpm)	$f_{pos,in}$ (nlpm)
700	**30.1**	10	20
700	**40.2**	10	20
700	**60.2**	10	20
700	**80.3**	10	20
750	**30.1**	10	20
750	**40.2**	10	20
750	**60.2**	10	20
750	**80.3**	10	20
800	**30.1**	10	20
800	**40.2**	10	20
800	**60.2**	10	20
800	**80.3**	10	20

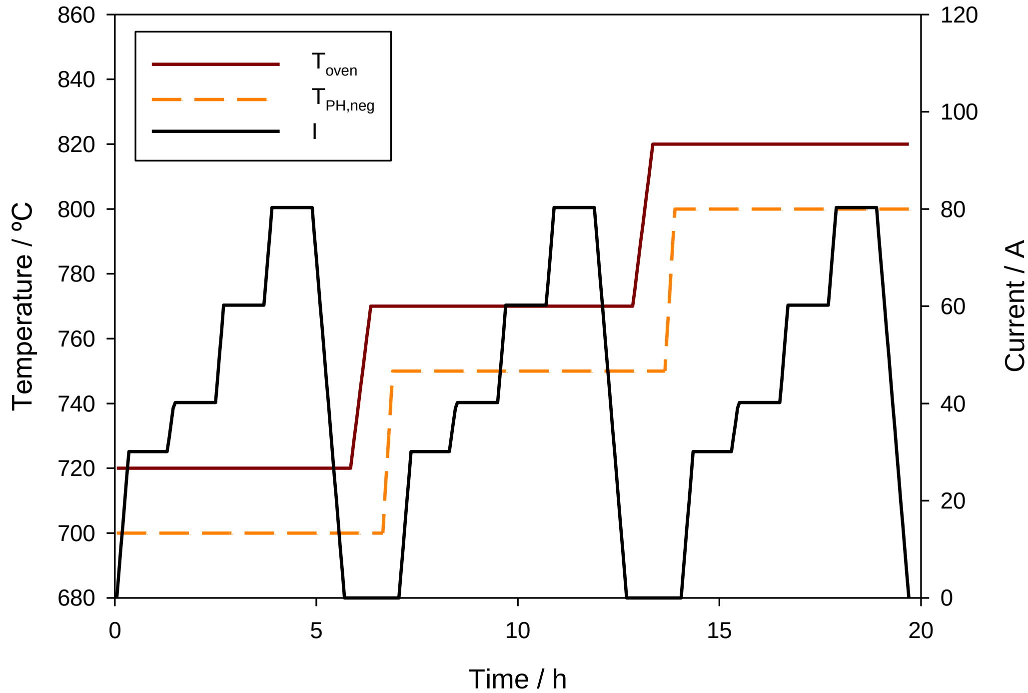

Figure 1: Qualitative representation of TIPs when carrying out TM09 using the values from Table 5.

6.3.2 Stabilization times

For stabilization times, please refer to the stack or cell manufacturer/supplier. In case a stabilization period is not provided, the procedure described in TM00 (Section 6.5) can be used.

The dwell-time (stabilisation time plus measurement time) for each test point is defined by the stability criteria of TIPs and TOPs (see TM00). Stabilisation time and measurement time will depend on the test objective. The following minimum time scale is recommended, but can be adjusted to the test objective to decrease the overall test duration:

- stabilisation time: 25 minutes
- measurement time: 5 minutes
- resulting dwell-time: 30 minutes

7 Data Post-processing and Representation

All of the TOPs can be represented in one single graph as a function of time. It is important to clearly define the cell/stack temperature that is maintained for results comparison, as the local temperatures in the cell/stack environment may vary significantly. This graph represents the results to an analogous case to that explained in the previous example, where the current and the oven temperature are the variable TIPs, while $f_{neg/pos,in}$ are static TIPs. More particularly, the three temperatures studied were $T_{cell/stack}$ = 720, 750 and 780ºC; the current densities requested to the short stack were: 300, 500 and 700 mA/cm^2.

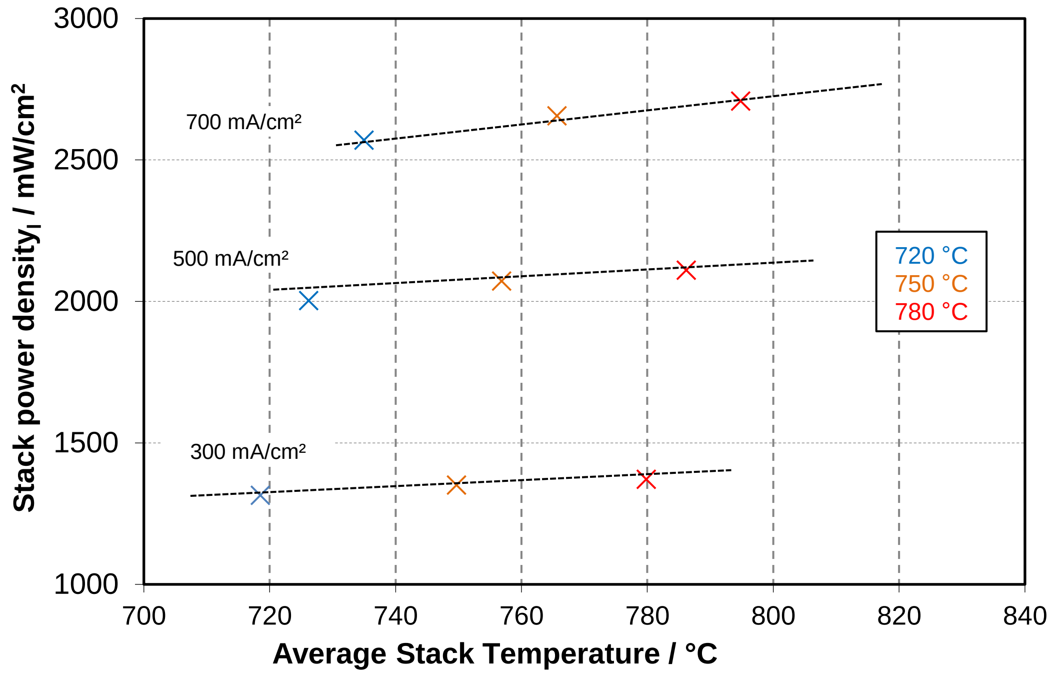

Figure 2: Temperature trends during the temperature sensitivity analysis when the current and the oven temperature are the variable TIPs.

8 Differences to Existing Procedures

No test procedures have been defined and elaborated in the international standardization literature specifically on the temperature sensitivity of a SOC cell/stack at the time of writing. This TM is particularly relevant as it can address the effects of temperature on the performance of the SOC when operating in power generation mode (SOFC) and electrolysis mode (SOEC). It must be noted that this TM is similar to the *Temperature Sensitivity* test module created in STACKTEST Project, aimed for polymer electrolyte fuel cells (PEMFCs).

9 Bibliography

[1] “Test Module 2.06: Temperature sensitivity”, Document of EU-Project Stacktest, Version 4.1, 02.07.2014, http://stacktest.zsw-bw.de.

[2] Test Module TM00 of SOCTESQA