Solid Oxide Cell and Stack Testing, Safety and Quality Assurance

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DELIVERABLE REPORT

D.3.1 – TEST MATRIX DOCUMENT	
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R	*Report*	*x*
P	*Prototype*	
D	*Demonstrator*	
O	*Other*	

SUMMARY	
Keywords	*Test matrix, test module*
Abstract	The present document defines the test matrix, i.e. a list of test modules relevant for different applications. According to the project objectives the applications are SOFC (stationary and mobile), SOEC (H_2-production) and combined SOFC/SOEC (electricity storage via H_2).

D.3.1 –TEST MATRIX DOCUMENT

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1 Introduction

The present document defines the test matrix, i.e. a list of test modules relevant for different applications. According to the project objectives the applications are SOFC (stationary and mobile), SOEC (H_2-production) and combined SOFC/SOEC (electricity storage via H_2). These test modules can be combined to form test programs in order to realize application-oriented testing.

This test matrix has been created based on a brief review of results from the precedent project - $FCTES^{QA}$ dealing with cell/stack/system testing procedures for three types of fuel cells (PEMFC, SOFC and MCFC) and the on-going project STACKTEST dealing with testing procedures for PEMFC stacks. Industrial stake holders who are developing SOFC/SOEC products have been contacted to gather information regarding the required operation modes during the lifecycle of the product for each application. Feedbacks from industrial stake holders have also been integrated.

2 Test matrix

The following table gives a set of 18 possible test modules. The relevance of each test module for the four major applications identified so far is indicated (“x”: relevant, “-“: irrelevant). The following section gives brief descriptions of all test modules.

Table 1: Test matrix for application-oriented testing

Generic Test Modules		Applications			
		Stationary SOFC-µCHP and distributed power generation	Mobile SOFC-APU	SOEC for H_2 production *power-to-gas*	Combined SOFC/SOEC for electricity storage *power-to-gas-to-power*
TM01	Leakage test	x	x	x	x
TM02	Start-up	x	x	x	x
TM03	Current-voltage characteristics	x	x	x	x
TM04	Electrochemical impedance spectroscopy	x	x	x	x
TM05	Current interruption	x	x	x	x
TM06	Cyclic voltammetry	-	-	-	-
TM07	Reactant utilisation	x	x	x	x
TM08	Reactant gas composition	x	x	x	x
TM09	Temperature sensitivity	x	x	x	x
TM10	Pressure sensitivity	-	-	x	x
TM11	Mechanical load sensitivity	x	x	x	x
TM12	Operation under constant current	x	x	x	x
TM13	Operation under varying current	x	x	x	x
TM14	Thermal cycling	x	x	x	x

TM15	Redox cycling	x	x	x	x
TM16	Shut-down	x	x	x	x
TM17	Vibration test	-	x	-	-
TM18	Emergency stop	x	x	x	x

3 Brief description of test modules

3.1 TM01: Leakage test

Gas-tightness is one of the most important requirements for an SOC stack. Insufficient gas-tightness leads to lower performance, lower efficiency and may create extra thermo-mechanical stress in the stack which shortens the stack lifetime. Leakage test can be performed in cold state (prior to the start-up and after the shut-down) or in hot state (during the stack operation). Both internal and external leakages are interesting to know. This test module will define the leakage test procedure.

3.2 TM02: Start-up

Start-up procedures are always needed for the test. First the stack has to be heated up to the operation temperature. If the stack has to be put into operation for the first time, reduction and conditioning will also be needed. In the case of APU-application, it might be necessary to draw current from the stack already during the heating-up phase in order to accelerate the temperature increase during the start-up process. All these procedures will be described in this test module. However, it should be noted that start-up parameters depend on the stack design and have to be given by stack manufacturers to avoid any damage.

3.3 TM03: Current-voltage characteristics

Measuring the current-voltage curve is a basic method to characterize the performance of an SOC stack. The main output will be the voltage of the stack as a function of current density. Current-voltage curves of all repeating units (RUs) in the stack can also be obtained if the voltages of RUs are measured separately. One test module from the previous project FCTES^{QA}, *Test Module TM SOFC ST M21 - "Polarisation curve for an SOFC Stack"*, can be used as a reference for this test module. Key parameters for measuring a current-voltage curve such as the current variation rate, gas flow rates, gas temperatures as well as the way to present the data will be defined. As the temperature of the stack usually changes while varying the current, it is necessary to plot also important temperature signals in the current-voltage curve plot.

3.4 TM04: Electrochemical impedance spectroscopy

While a current-voltage curve gives the performance and the overall internal resistance (often indicated by the so-called area specific resistance – ASR) of an RU or the whole stack, it does not supply detailed information on the different kinds of resistances of an RU. These resistances can be correlated e.g. to electron or ion transport, to electrochemical reactions at the electrodes or to gas transport processes within the cells. However, it is possible to use electrochemical impedance spectroscopy (EIS) to obtain this information. EIS is a very useful tool to identify the performance-limiting factor as well as the degradation mechanism. In this test module, the procedure to obtain the electrochemical impedance spectrum and the way to present the data will be defined.

3.5 TM05: Current interruption

The objective of the current interruption test is the determination of the ohmic resistance of an SOC stack or of an RU in the stack. The very fast change or interruption of the applied current induces a very fast or time independent variation in voltage due to the ohmic resistances and a slower or time dependent variation in voltage due to non-ohmic resistances. This module will define the procedure to perform current interruption test.

3.6 TM06: Cyclic voltammetry (CV)

Although cyclic voltammetry has already been used in SOFC research for instance for the investigation of electrochemical reactions taking place at the electrode, it is not yet commonly used for testing SOC stacks. Therefore, this test method will not be treated in the present project.

3.7 TM07: Reactant utilization

The purpose of this test module is to measure the performance of an SOC stack as a function of reactant stoichiometry, which can be translated to fuel utilisation, air utilisation in fuel cell mode and steam conversion in electrolysis mode. This test will help to identify possible gas distribution or gas transport limitations in the stack.

3.8 TM08: Reactant gas composition

In this test module, the effect of the reactant gas composition on the performance of an SOC stack is determined. In SOFC mode, possible fuel-electrode gases can be H_2, H_2/N_2, CH_4/H_2O, simulated reformate gases derived from natural gas or diesel using different reforming processes or other fuel mixtures such as biogas and syngas. Optionally reactant gas impurities, e.g. sulfur or poisoning hydrocarbons may be added. Depending on the application, different gas compositions may be relevant. On the oxidant side, the influence of O_2 concentration on the stack performance can be examined. In SOEC mode for the power-to-gas and the power-to-gas-to-power applications, the effect of the H_2 fraction (for instance in the range of 0.01-0.10) in the inlet gas should be determined.

3.9 TM09: Temperature sensitivity

The purpose of this test module is to determine the temperature dependence of the stack performance. The stack operating temperature is often indicated by endplate temperatures or gas inlet/outlet temperatures and varied through the variation of the oven temperature.

3.10 TM10: Pressure sensitivity

Operating the stack at elevated pressure can be beneficial for the SOEC operation since the generated H2 may need to be stored in a compressed form. Energy consumption required for compression can be significantly reduced in this way. It is therefore necessary to determine the pressure dependence of the stack performance. Here the same pressure is meant for the fuel compartment, the oxidant compartment and the environment surrounding the stack. Some stacks may allow a big pressure difference between the fuel compartment and the environment and between the fuel compartment and the oxidant compartment. In this case, it may be possible to operate the stack with an elevated pressure only in the fuel compartment while the oxidant chamber and the environment are kept at atmospheric pressure.

3.11 TM11: Mechanical load sensitivity

Usually a certain level of compression force is needed in the stack to ensure good electrical contacts between cells and interconnects and/or sufficient gas-tightness. For stack testing, this compression force is often realized through applying a mechanical load onto the stack. The purpose of this test module is to determine the dependence of stack performance on the compression force.

3.12 TM12: Operation under constant current

In order to determine or predict the lifetime of an SOC stack, long-term endurance test under steady-state conditions is often conducted. The stack is usually operated in galvanostatic mode (constant current). The major output will be the degradation rate of the stack. In this test module, issues like the drifting of the stack temperature (at a fixed oven temperature) as a result of degradation need to be addressed. The way to extract and present the degradation rate will also be defined. The operation conditions will have to be selected according to the application.

3.13 TM13: Operation under varying current

Many applications dictate a dynamic operation of the stack, varying load with time. In this test module, typical load profiles for each application will be defined to simulate the real-life operation modes. As for the endurance test under constant load, the major output will be the degradation rate.

3.14 TM14: Thermal cycling

The capability to withstand a certain number of thermal cycles is an important requirement for an SOC-based system. In this module, conditions to perform thermal cycling of the stack for each application will be defined. Key parameters include temperature ramp rate, temperature range, atmosphere etc. The major output will be degradation rate in terms of gas-tightness and performance upon thermal cycling.

3.15 TM15: Redox cycling

In the case of fuel interruption, the fuel electrode will be subject to re-oxidation and subsequent reduction when fuel is restored. The capability of the stack to withstand redox cycling is another important requirement for an SOC-based system. This module will define procedures to perform redox cycling test.

3.16 TM16: Shut-down

Similar to the start-up module, procedures of shut-down of the stack will be described in this test module. Parameters like gas composition, cooling ramp rate should also be given by stack manufacturers to avoid any damage.

3.17 TM17: Vibration test

Vibrational test can be important for the mobile application (SOFC-APU) to determine the tolerance of the stack to mechanical stresses induced by vibration of vehicles.

3.18 TM18: Emergency stop

In certain circumstances, the system may be forced to stop urgently. The degradation of the stack after a certain number of “emergency stops” should therefore be evaluated. Here it is important to know what kinds of protection measures are implemented in the system to derive conditions of the stack.