Development of PEM Fuel Cell Stack Reference Test Procedures for Industry Stack-Test (FCH-JU GA: 303345)



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PROJECT OVERVIEW

- Call topic (e.g. SP1-JTI-FCH.2011.5.4)
- Application Area Cross Cutting Issues
- Duration: 01.09.2012 to 31.08.2015
- Total Budget: 5 638 T€ FCH JU contribution: 2 910 T€
- 11 partners
- Development and validation of harmonized test procedures to assess performance, endurance, safety and environmental properties of polymer electrolyte membrane fuel cell stacks.
- The project has finished 31.08.2015





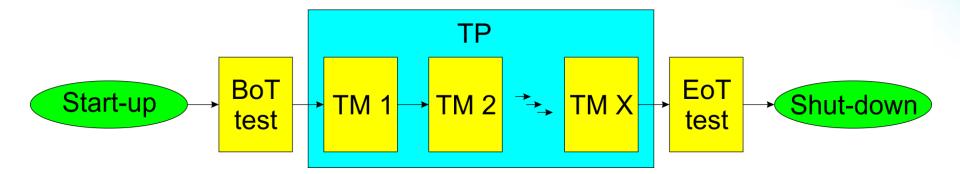


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Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
	M	AIP	
Development of a specific technology assessment framework	Definition and validation of Test Modules and Test Programs for PEM fuel cell stacks in two revisions.	Stack Test Modules and Test Programs for performance, endurance, and safety were written and finally validated.	Use of Test Modules and Test Programs as basis of testing within R&D- programs and transfer to international standardization
RCS strategy coordination	Liaison with Standard Developing Organizations. If deemed necessary initiation of new work item proposals.	Assessment of international standards for testing PEM fuel cell stacks. Preparation of a new work item proposal on PEFC-stacks performance testing	New work item proposal submitted to IEC TC 105

Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
	A	IP	
Performance, endurance, efficiency and safety tests under regular and harsh environments	Development of generic Test Modules and application oriented Test Programs for performance, endurance, and safety tests.	Test Modules and Test Programs were defined and validated in two stages. A proposal how to treat efficiency testing on a stack level has been developed	Use of Test Modules an Test Programs in other R&D-projects. Proposal to industry and international standardization.
Accelerated lifetime tests	Where possible combine output to a "Zero" version to accelerated lifetime testing.	Durability Test Program has been carried out.	Contribution to the understanding of degradation effects

- Develop and validate generic test modules (TM)
 - Variation of one Test Input Parameter (TIP)
 - Measurement of different Test Output Parameters (TOPs)
- Develop and validate application specific test programs (TP)
 - Combination of TMs to TP
 - Recommend specific parameter set for different applications
 - Combine the variation of different Test Input Parameters (TIP)



- Work based on previous projects FCTESTNET, FCTESQA, and FCTEDI. Reviewed, confirmed, and further improved methodology to describe PEM fuel cell stack testing.
- Assessment of international standards of PEM fuel cell stack testing given and updated.
- Feedback from stakeholders has been taken into account in writing the test modules and test programs.
 - Provision of a master document describing fundamental issues
 - One page abstract for each test module and test program (to be used by experts)
- Consistent test results achieved during validation experiments.
 - 2 types of PEM fuel cell stacks supplied to each partner for carrying out validation experiments.
- Series of documents are available from the web-page.
 - Still lots of paper but with the effort to avoid ambiguities
- Transfer of methodology to other projects where the partners are involved
 - Contribution to European effort on single cell testing
- Four dissemination workshop held

Structure of Test Modules and Test Programs

One page Abstract for Experts

- Summarize test
- Input and Output parameters
- Proposed data analysis and reporting format

Deatiled Description:

- Objectives and Scope
- Test setup
- Test execution
- Parameters and boundaries
- Reporting format



Objective and Scope

Determine the sensitivity of a PEM fuel cell stack to the variation in relative humidity of the used reactants at varying electrical load.

Test Input Parameters (TIPs)

The stack can operate under nominal conditions given by manufacturer or conditions of interest for the application. The variable TPBs are the parameters under test, namely the reactant humidity (dew point recommended) and the electrical load. Due to the significant impact of humidity on stack performance, the accuracy of the gas humidity at the stack inlet has to be assured over the entire gas flow range.



Test Procedure

As an example, a test procedure to study the impact of the cathode dew point at constant anode dew point is presented. It is recommended to vary the electrical load on each

electrical load on each humidification step rather than change the humidification level at

constant electrical load. This accelerates the attainment of stack equilibrium and shortens the test duration, especially when bubbler systems are used for humidification.

Critical Parameters and Parameter Controls

 All parameters with impact on the humidity level have to be monitored and controlled with care.

- The use of humidity sensors on the stack inlet is recommended.

 Temporary changes in the cell temperature caused by the electrical load variation have to be considered to avoid electrode flooding and correct humidity levels.

 High dew points in combination with high electric load / low stack temperature can result in electrode flooding.

Contact Stack-Test: <u>Stacktest.zsw-bw.de</u>

Test Outputs Parameters (TOPs)

TOPs	Туре
U _{av,cell}	calculated
Ustack	measured
Ucelli	measured
Paterick	calculated

- Stabilisation time and analysis time depend on the test objective. Recommended minimum values: o Stabilisation time: 10 minutes

o Analysis time: 5 minutes

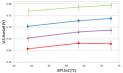
 The data received is evaluated in tabular and/or graphical way including mean value, standard deviation, and min. and max. deviation of variable TIPs and TOPs.

Test	DFT.S.C[*C]			DPT.S.C[*C]		LS [A]				
point	value	standard deviation	min. deviation	mex. deviation	Test point	value	standard deviation	min. deviation	mex. deviation	
1					1					
2					N					

-		U.SAve	6•1[V]	
point	value	atenderd deviation	min. deviation	mex. deviation
1				
2				
3				

Data Post Processing

It is recommended to present the test profile as well as the test results in figures as shown below.



The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint Technology Initiative under grant n° 303445.



Recommendation of Test Operating Conditions (TOC) for different application areas:

- Based on the state-of-the-art PEFC technologies
- Input from Industrial Advisory Board of Stack-Test and additional OEMs

Parameter	ameter Automotive applica			e application	Stationary			Portable Generators	
Name	Symbol	Propulsion ¹	Propulsion ²	Range extender ³	APU ⁴	Residential CHP ⁵	Backup Power ⁶	H ₂ -PEMFC ⁷	DMFC ⁸
Stack temperature (Coolant inlet)	T _{stack}	80 °C	68 °C	75 °C	75 °C	70 °C	65 °C	50 °C	70 °C
Reactant inlet temperature	T _{gas,in}	85 °C	73 °C	80 °C	80 °C	75 °C	70 °C	ambient	ambient
Fuel (H2) stoichiometry	λ_{fuel}	1.3	1.4	1.5	1.5	1.2	1.25	1.2	5.0
Oxidant (Air) stoichiometry	λ_{ox}	1.5	1.6	2	2.0	2.0	2	2	2.5
Fuel relative humidity	RH _{fuel}	50%	40%	80%	80%	80%	40%	50%	-
Dew point temperature fuel	DP _{fuel}	63.5 °C	48.2 °C	69.5 °C	69.5 °C	65 °C	45.5 °C	36.5 °C	_
Oxidant relative humidity	RH _{ox}	30%	50%	80%	80%	80%	40%	ambient	ambient
Dew point temperature oxidant	DP _{ox}	52.6 °C	52.7 °C	69.5 °C	69.5 °C	65 °C	45.5 °C	ambient	ambient
Fuel outlet pressure	p _{fuel}	220 kPa _{abs}	220 kPa _{abs}	150 kPa _{abs}	150 kPa _{abs}	ambient	120 kPa _{abs}	150 kPa _{abs}	ambient
Oxidant outlet pressure	p _{ox}	200 kPa _{abs}	200 kPa _{abs}	150 kPa _{abs}	150 kPa _{abs}	ambient	ambient	ambient	ambient

- Master-Document
 - Definitions
 - Requirements
- Performance Testing
 - 11 dedicated Test Modules
 - 5 Test Programs.
- Endurance Testing
 - 4 Test Modules
 - 1 Test Program
- Safety and Environmental Testing
 - 8 Test Modules
 - 3 Test Programs

Objective and Scene	Critical Parameters and Parameter Controls		
Objective and Scope This Test Module is used to investigate the voltage decay rate of a PEM fuel cell stack during steady-state operation	Critical Parameters and Parameter Controls The reactant flows have to be increased prior to an increase of the electrical load.		
for a prolonged period of time. The result is directly	 The electrical load has to be decreased prior to 		
influenced by the quality of the reactant media and the Test	decrease of the reactant flows.		_
Input Parameters, which can be varied within the range of the recommended operating conditions. This Test Module			
can be used within the durability Test Program TP D-01 to	Test Output Parameters (TOPs)		
evaluate the irreversible voltage decay rate caused by	Output Type		
specific operating conditions.	Output Type Urea measured	STACK-TEST	
Test Input Parameters (TIPs)	U _{m1} , measured	C. Other Photos	
Input Type	P _{elet} calculated		
P _m measured	U _{ev, mil} calculated Voltage decay rate calculated		
λ	(couge decay rate calcolated	ers and Parameter Controls	
DP measured Pri measured	Data Post Processing	delay times for the reactant flows	
key -	The voltage decay rate is calculated over the considered	p-up to avoid reactant starvation. The	
DPus measured	period of time. The slope can be evaluated sectionwise	to be evaluated individually. metry versus constant flow: Choose	
t _{iwi} measured	from the beginning to the end of test, see figures below:	metry if applicable to avoid possible	
t end-of-test criterion	10n-110n	low-load steps.	
Test Procedure	Visitage decay rate: 71 pV/h	meter (TOP)	
Start	T -		
¥) -	TOPs Type	y
$U_{\rm clash}=U_{\rm corr}$		U _{Math} measured	
	The second	U _{er.oct} calculated U _{ect} , measured	
I > 0 A cm ²	90%-110%	Puter calculated	
F	 60h - 110h; Voltage decay rate: 62 µV/h 	U _{deney} calculated	cks on Fue
Yes Tare +12 has	E =	calculated data can be visualized and	for Start
No	1 -	ly including mean value, standard	large rang quipment
Ne V	······································	and max deviation of variable TIPs and	he in- and
	a same of	ion is to plot the data as pseudo	rs of the
Yes U.a. SO3V	80h - 110h	deviated from the different load steps	To get co
	Woltage desay rate: SE uV/h	100	volumes s
1 = 0 A cm ⁺	I	ising	the durab proceeding
) -	ind single cell voltage can be evaluated	after oper
End of test	The second se	is within the load profile.	
		f identical load profiles are performed rsible degradation can be evaluated	
		efined performing of test blocks within	directly i
		Program (TP D-01), irreversible	es on ano stack, e.g
		can be evaluated. Intermediate	start, e
	results has received funding from the European Union me (FP7/2007-2013) for the Fuel Cells and Hydrogen Joint	give additional input within a Durability	
Statktest.25W-DW.0e Technology Initiative under g			to use the
		Fuel Cell - Dynamic Load Profile	down as
		0.8	lure as
The electrical	load is varied with different loads and	0.1 2	
	imes according to the type of application. In	E as 5	ed operating co
	e a generic load cycle as well as a load cycle		
this test module			
	applications and a CHP load profile is	-UAucalM 0.2 -UAucalM 0.1	Stack current to ant pressures to

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Technology Initiative under grant n° 303445.

during Long-Stop. Anode compartm

and Start-up.

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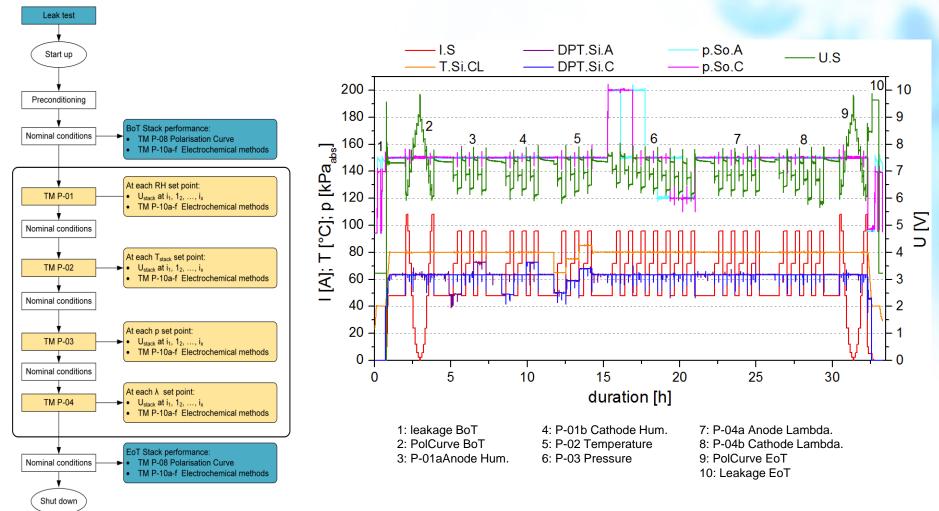
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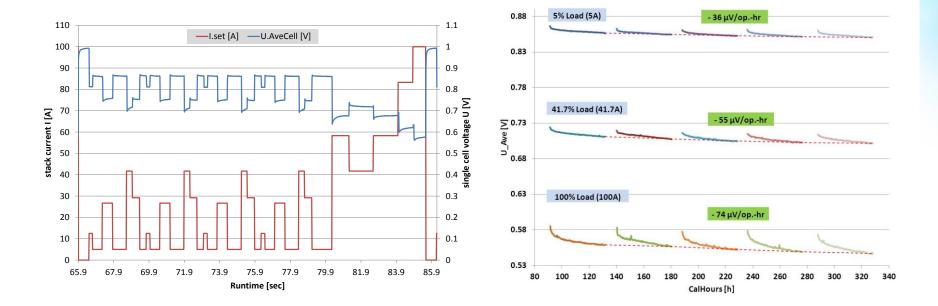
Test Program TP P-02: Stack Performance Mapping

Leak test



Progress Has Been Made But There Are Still Issues Remaining! A way to represent "Degradation" has been agreed upon, however, test-bench results need further validation in field systems.

'Fuel Cell Dynamic Load Cycle': Repetition of identical test blocks-Degradation investigation:



RISKS AND MITIGATION

- Analysis of Endurance Test Data revealed non linear behavior
 - Separation of reversible and irreversible degradation phenomena is complicated.
 - Processes involved in reversible degradation include cathode catalyst surface oxidation, water redistribution and anode catalyst surface poisoning.
 - First results indicate effect mitigation by controlled start-stop procedures
- Definition of Accelerated Lifetime Tests on stack level need a more in depth understanding and separation of reversible from irreversible degradation effects.

SYNERGIES WITH OTHER PROJECTS AND INITIATIVES

- Project builds on previous projects, particularly FCTESTNET, FCTEDI and FCTESQA.
- One partner received national funding to cover differences of project cost and FCH-JU funding.

FCH and FP projects	Interaction and/or joint activities
AutoStack-CORE	Transfer of validated Test Modules and Test Programs
IMPACT	Support in test definition
IMPALA	Support in test definition
NanoCat	Support in test definition
SAPPHIRE	Support in test definition
SOCTESQA	Transfer of methodology and document exchange
HYCORA	Transfer of validated Test Modules and Test Programs

HORIZONTAL ACTIVITIES

- Training and education

 PhD-students were working in the project
- Safety, regulations, codes & standards

 A New Work Item Proposal (NWIP) on stack testing has been submitted to IEC TC-105
- General public awareness
 - A total of 4 public workshops have been organized

DISSEMINATION ACTIVITIES

- Contributions to more than ten national and international conferences
- Organization of four public workshops for stakeholders
- Four publications in peer reviewed journals
 - Further publications will follow

EXPLOITATION PLAN/EXPECTED IMPACT

- The project provided validated test modules and test programs to assess performance, endurance and safety / environmental related issues in PEM fuel cells at stack level.
 - Project results are used in other FCH-JU projects
 - Project results provide a basis for PEM fuel cell stack assessment
- The project triggered a New Work Item Proposal on PEM fuel cell stack testing in international standardization

Acknowledgement

Thank you very much for your kind attention!



The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) for Fuel Cell and Hydrogen Joint Technology Initiative under Grant nº 303445 (Stack-Test).

