PROJECT FINAL REPORT

Publishable Summary

FCH JU Grant Agreement number: 245113

Project acronym: KEEPEMALIVE

Project title: ***Knowledge to Enhance the Endurance of PEM fuel cells by Accelerated LIfetime Verification Experiments***

Funding Scheme: FCH-JU-2008-1, Collaborative Project

Period covered: from January 2010 to June 2013

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Executive Summary:

In the KeePEMalive project a comprehensive test program on fuel cell degradation has been carried out, accumulating more than 25 000 accelerated test hours on single cells. Performance data were analysed and compared to results from a Danish field test project (at Lolland) in which 32 fuel cell systems for combined heat and power are being deployed in households to identify detrimental operating conditions. By improving cell materials and optimising the system operation conditions the lifetime of these fuel cell systems has been increased from ½ to 2 years.

Project Overview

Fuel cells are expected to play a crucial role in the sustainable energy system of the future. Combined Heat and Power (CHP) constitute a potential market segment for fuel cells. However, high cost and limited durability represent two remaining key challenges to be solved prior to large scale market introduction of Proton Exchange Membrane (PEM) fuel cells. Whereas cost is less demanding, the durability requirements are especially stringent for CHP applications. This project is focusing on PEM fuel cells for residential applications in the micro (~kW) range (µCHP).

The main objective of the KeePEMalive project has been the establishment of:

- *improved understanding of degradation & failure mechanisms for stationary PEM fuel cells, with special focus on µCHP applications*

- *accelerated stress test (AST) protocols, a sensitivity matrix and a lifetime prediction model for stationary µCHP applications*

- thereby contributing to reaching the durability target for CHP applications of 40 000 hours.

The project was conducted by a consortium of European R&D institutions and companies with high expertize and long experience in the field. The involved industry partners possess advanced production capabilities to develop new improved Membrane and Electrode Assembly (MEA) materials as well as assembling and testing of PEM stacks and systems. The R&D partners are well equipped for material as well as cell and system performance characterization and provide expertise in statistical analysis data both from laboratory scale single cell, stack testing as well as real life system operation through related field tests in Denmark and France.

Comprehensive Accelerated Stress Test program

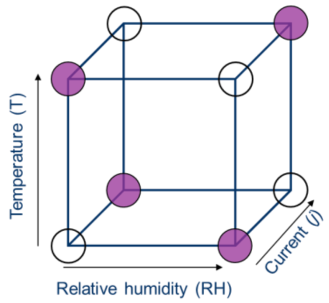
Initially, typical operation characteristics for the residential µCHP application were mapped, and based on this six key stressors were identified, resembling conditions that these fuel cells typically experience in real life during all seasons. Adequate electrochemical characterisation techniques were selected for a comprehensive Accelerated Stress Test (AST) program. Both natural gas (NG) and pure hydrogen were assessed as fuel for the systems, due to the link to two field tests, one at Lolland in Denmark (pure H_2) and a French field test at 4 locations all using NG as fuel and reformer technology.

Around 200 Membrane and Electrode Assemblies (MEAs) were studied during the AST program accumulating more than 20 000 single cell test hours. Supplemented by stack testing, this has revealed by statistical analysis, the most detrimental operating conditions causing degradation and cell failure.

A systematic approach aiming at statistically significant results

By carefully designing the AST program the experimental workload was reduced significantly to a manageable level. Main operation variables were relative humidity (RH), temperature (T) and current density (j). By varying these systematically, the interactions between main factors were identifiable.

A considerable database of test results has been built up linking degradation rates to single cell operation conditions. Statistical data analysis has shown that the presence of CO (arising from NG reforming) in the fuel, the relative humidity (RH) level and the operating temperature (T) of the cell are the key factors affecting performance degradation. Replicates have been used to estimate standard deviations and thereby enabled determination of the significance of the results.



Material development and selection

Development of PFSA based membrane materials has been a key activity in the project. In total 5 generations of membrane materials have been synthesized and characterized with respect to key properties. The initial batch production was successfully scaled up to continuous membrane series production in the range of 2000 m^2/year.

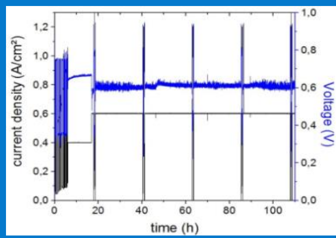
Partner CRNS showed that by introducing Ce-based radical scavengers the stability of the Membrane was further enhanced. Manufacturing of MEAs and stack assembly was done in-house by IRD.

The most stable and best performing fuel cells were obtained using reinforced membrane and a cathode catalyst with improved catalyst dispersion on an oxidant resistant support.

Fuel cell characterisation during operation

To quantify the degradation of the fuel cells at a reasonable speed, a set of Accelerated Stress Test (AST) protocols were developed and applied, exacerbating selected stressing conditions relevant for real life µCHP application, including:

- *Continuous operation*
- *Reformate operation*
- *Dead end operation*
- *Start-stop, shut-down*
- *Fuel Starvation*
- *Electric load cycling*

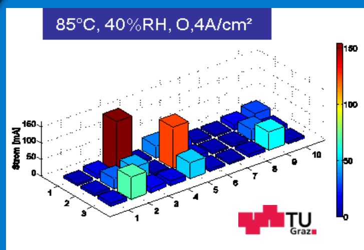


Distinct sets of experiments were run for each of these stressing conditions by systematically varying operating conditions such as fuel gas humidity, cell temperature and cell current.

After conditioning the fuel cell for 24 hours, the cell performance was mapped every 24 hour to identify changes as input for degradation rate quantification.

Fuel cells performance was assessed using:

- *Electrochemical Impedance Spectroscopy*
- *Hydrogen cross-over & Cyclic Voltammetry*
- *Carbon corrosion by NDIR*
- *Membrane degradation by Fluorine emission rates*
- *Segmented cell to reveal localised degradation*



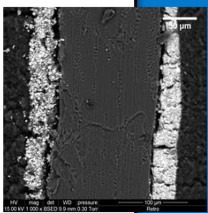
Material selection

Accelerated Stress Testing of Fuel Cells

Identification of material changes

Degradation quantification

Enhanced insight



Enhanced insight/understanding

Based on studies of more than 60 cells and assessment of corresponding material changes for some of these, the cause and effect relationships were identified.

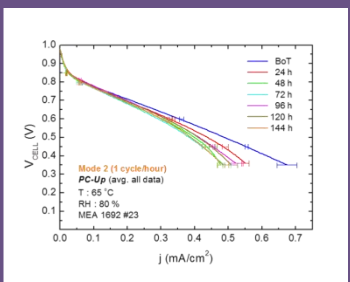
The complexity of processes taking place in PEM fuel cells were verified by statistical analysis showing that factors causing degradation are inter-related.

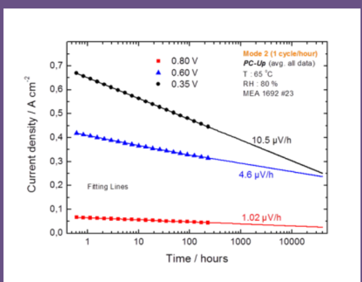
The enhanced insight provided a sound basis for selection of improved materials for next generation MEAs to be tested.

Quantification of degradation rates

Changes in performance with time were assessed and the degradation rate was calculated. The used fuel cell materials subject to stressing conditions were compared to pristine materials revealing corresponding material changes.

Statistical analyses has clearly shown that degradation depends on several factors and varies along the operation curve as illustrated below for load cycling over 144 hours AST.





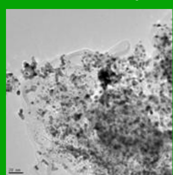
Identification of material changes

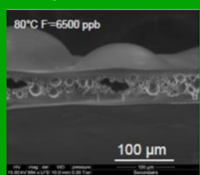
The following materials were subject to assessment:

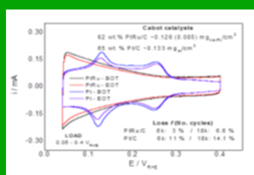
- *Catalyst materials (SINTEF)*
- *Catalyst layer surface & cross section (CNRS)*
- *Membrane materials (CNRS, Fumatech)*

and these MEA components' properties including eg:

- *Mechanical strength, membrane (Yuong modulus)*
- *Morphology, Microstructure*
- *Catalyst agglomeration and migration by (SEM)*
- *Electrode ElectroChemical Surface Area (ECSA)*
- *Membrane Conductivity, Ohmic resistance…*
- *Water-uptake, hydration number*







Impact

Assessment of the field data from real life operations (at Lolland) related to the KeePEMalive project has enabled the project system development partner IRD to improve the µCHP system and take the technology one step closer to fulfil the stringent requirements for long term durability. By exchanging some MEA precursors and further optimise the operational conditions in the Danish on-going field test the MEA durability was increased significantly e.g., the degradation rate was decreased five-fold from 20 to 4 µV/h, corresponding to increasing the system lifetime from the previous level of 3 500 hours to an expected 17 000 hours (~2 years). The heat and electricity demand and the related energy and emission savings from utilizing the CHP-units in Danish households have been mapped for various seasons and during the course of the project the electric system efficiency has been improved to 50%.

Dissemination activities

Dissemination activities have had a high focus in the project and the consortium acknowledges the importance of promoting the development of fuel cell technologies for sustainable and efficient utilization of hydrogen as energy carrier. Our public webpage (www.sintef.no/keepemalive) contains a complete list of dissemination activities.

Customer relationship has been a key activity in the KeePEMalive project ensuring public acceptance as a pre-requisite for the eventual mass market penetration of fuel cells as µCHP units in households. Here partner SEAS NVE's Jens Jacobsen in dialogue with one of the fuel cell system customers as part of the Danish Vestenskov field trial program in which 32 systems have been installed in private households.

More information can be obtained by contacting the project coordinator:
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Key KeePEMalive project info:
Start date: 1 January 2010
Duration: 42 months
Cost: €2.9 million
FCH JU funding: €1.3 million