Towards 40 000 hours of operation for Nedstack's FCS XXL PEM fuel cell stacks

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Nedstack manufactures and commercialises PEM fuel cell stacks for a wide variety of applications, from backup power to transportation, with more than 1000 PEM fuel cell stacks sold. The company also has extensive system integration experience, including the installation and operation of a 70 kW power plant at a chlor-alkali factory in the Netherlands, and a 1 MW unit in operation at a Solvay chemical plant in Belgium.

Introduction

Nedstack fuel cell technology BV is a privately owned company which manufactures and commercialises PEM fuel cell stacks for the various fuel cell markets. Our customers are system integrators of PEM fuel cells: manufacturers of backup power units (i.e. uninterruptible power supplies, UPS), manufacturers of power generators, shipyards, and bus manufacturers. Nedstack itself also has extensive system integration experience, including the installation and operation of a 70 kW PEM power plant in Delfzijl, The Netherlands and a 1 MW PEM power plant in Belgium, as well as several pre-commercial products for transport applications and power generation. Nedstack was established in 1999 as a buy-out of the PEM fuel cell activities of AkzoNobel.

During the last few years, more than 1000 commercial Nedstack PEM fuel cell stacks have been placed in the market, which has led to extensive experience with different operational conditions, and allowed for the improvement of stack production processes, stack performance, and stack lifetime. Nedstack now has a lean, high-quality production process, and is able to produce large numbers of stacks with a guaranteed stable performance and long life.

The company is a member of NEW-IG, the European Industrial Grouping Hydrogen and Fuel Cells, which is a member of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), and has been involved in several FCH JU projects. At present, Nedstack is project coordinator of STAYERS, a project that aims to improve the lifetime in real-life operation of PEMFC stacks up to 40 000 hours for stationary applications. Nedstack is also participating in several other projects, such as IMPALA (aiming at increased power density through improved gas diffusion layers, GDLs), ARTEMIS (development of high-temperature PEM fuel cells as a range-extender), SECOND ACT (optimisation and improving lifetime of fuel cells by degradation studies in existing fuel cell systems), and MATISSE (development of gradient electrodes for PEM fuel cells).

Nedstack's current products are PEM fuel cell stacks in the 2–10 kW range, with two distinct product lines: the FCS HP range for backup applications, and the FCS XXL range for stationary power and transport applications.

PEMFC power plants

Nedstack owns a 70 kW PEMFC power plant, located at a chlor-alkali factory on an industrial site in Delfzijl, in the north of Holland. This

Nedstack's proprietary PEM fuel cell stack design is being produced commercially, with more than 1000 stacks placed in the market.

plant contains 12 stacks of 75 cells each, for a total of 900 cells. Stack and cell performance can be monitored in real time from the Nedstack offices in Arnhem, 200 km south of the plant. The plant has been in operation since 2007, and has now reached a total on-grid time of over 40 000 hours, with over 2.5 GWh of electricity produced and provided to the grid. The plant has proven highly reliable, with an uptime of over 90% and low maintenance, since no major system components have had to be replaced since the start of operation.

The plant has a relatively simple design.[1] The industrial seaside air passes through a fuel cell grade filter, a compressor, and a humidifier. The high-purity hydrogen, which is a 'waste' product from the chlorine production, is obtained from electrolysis of brine, and cleaned in a gas-liquid separator, although it may have possible traces of sodium hydroxide (NaOH). It then passes directly to the humidifier, and is recirculated after passing through the fuel cell stacks. Relative humidities are high, around 80% for both anode and cathode. The operational temperature is 65°C, and typical currents are 100–120 A, producing 60–70 kW of electric power.

As well as providing electric power to the chlorine plant, the power plant is being used by Nedstack to test prototype stacks and membrane-electrode assemblies (MEAs). More than 25 different MEAs have now been tested in the plant, with different MEAs clearly showing different kinds of behaviour in the plant.

Most MEAs show not only irreversible decay over time, but also strong reversible decay, with the performance decreasing during operation and recovering every time the plant stops operation (which is around 10 times a year, either due to maintenance of the chlorine plant or stack maintenance/replacement). This reversible decay is considered to be related to contaminants in the air. Strong variations are also seen in lifetime (defined by a 10% performance decay); while some prototype stacks and MEAs did not even reach 2000 hours, Nedstack's own XXL stacks have been in operation in the plant for over 23 000 hours.

Nedstack also designed a 1 MW PEM Power Plant for Solvay in Lillo, Belgium, which has been in operation since early 2012. We are currently working towards several 2 MW plants.

Nedstack's PEM fuel cell stacks are deployed in a variety of different applications, including the HyTruck plug-in hybrid truck, the Lovers canal cruise boat in Amsterdam, and the HyMove fuel cell bus which was operated in the Arnhem region.

The STAYERS project

Over the last three-and-a-half years, Nedstack has been coordinating the FCH JU STAYERS project ('Stationary PEM fuel cells with lifetimes beyond five years'). In this project, Solvicore, Solvay Specialty Polymers, SINTEF and the Institute for Energy and Transport of the European Commission's Joint Research Centre (JRC-IET) are working with Nedstack towards an increased lifetime of at least five years for stationary PEM fuel cells.

Within the project, large numbers of MEAs designed for stationary operation have been tested in the 70 kW PEMFC power plant in Delfzijl. Different catalyst alloys, membranes, borders, seals, and cell plates were first tested *ex situ*, and the best-performing materials were used in prototype stacks in the power plant.

A detailed analysis of decay rates (including methods to determine them) was performed, as well as extensive analysis of the MEAs. In addition, accelerated stress tests (ASTs) were carried out for specific materials. The project is now in its final months, and significant improvements were obtained, indicating that five years of stack lifetime is now achievable.

Nedstack's 1 MW PEM Power Plant has been in operation with Solvay in Lillo, Belgium since early 2012.

Long lifetimes for FCS XXL stacks

Nedstack's FCS XXL stacks have shown stack lifetimes of over 23 000 hours in the 70 kW PEM Power Plant. This has allowed Nedstack to obtain detailed knowledge on stack performance and degradation through analysis of performance data, as well as extensive Beginning-of-Life (BOL), Middle-of-Life (MOL), and End-of-Test (EOT) analysis. Applied techniques include I-V curves, electrochemical impedance spectroscopy (EIS), and cyclic voltammetry (CV).[2]

Graphs of XXL stack performance during operation in the power plant show very stable behaviour for over 17 000 to 23 000 hours. Reversible voltage decay is small for these stacks. The irreversible voltage decay rate, as determined from the averaged linear regression for the data, was found to be only 2.3 mV per 1000 h. This implies a projected lifetime of around 30 000 hours for 10% performance decay.

Performance curves (I-V curves) taken at BOL and EOT allow comparison of the performance of used stacks with new stacks, and show the main causes for performance loss over time. It is thus confirmed that according to performance decay at the point of operation, at 20 000 hours these stacks are only at two-thirds of their total life. These curves further indicate that used stacks show somewhat increased hydrogen crossover, increased ohmic resistance, and increased mass transport problems.

This is further confirmed by the cyclic voltammetry, EIS, and hydrogen crossover measurements. CV measurements on the cathode show that the active catalyst surface area decreases, but is still higher than 50% of its original value. The decrease in anode catalyst surface area was very small. This indicates that cathode degradation was the predominant mechanism for performance decay. The averaged hydrogen crossover rate had doubled over time, but was still acceptable for Nedstack standards, although significant variation was seen between different membranes.

Electrochemical impedance measurements indicated that the ohmic, charge transfer, and mass transfer resistance had all increased; however, mass transport resistance showed the largest increase. One remarkable observation is that for different operational hours of between 17 000 and 23 000 hours, no further decrease in electrochemical properties could be detected, indicating that somehow, the MEAs had reached a relatively 'stable' region and that the principal decay in properties had occurred earlier.

It was further found that the application of a recovery procedure actually led to a significant increase in performance. Part of this improvement was related to the elimination of contaminants from the catalyst surface. Mass transport properties were also affected, possibly related to the electrochemical reduction of carbon surfaces during the recovery procedure, leading to improved hydrophobicity.

In order to continue obtaining information from these MEAs, selected MEAs from the oldest stacks were used to assemble a 'refurbished' stack. This stack has now been running for over 3000 hours, so the MEAs have now seen between 23 000 and 26 000 hours of use. No apparent further decay in performance is observed, confirming the idea that the main degradation occurred during earlier stages of operation.

Improved stack design

While the previously described stacks are from a 2009 stack design, since 2012 several FCS XXL stacks with an improved design have been placed in the PEM Power Plant, as part of the STAYERS project. These stacks show an improved performance and a projected stack lifetime of over 40 000 hours. The longest-running stack of this new generation of stacks has now been in operation without any problems for over 16 000 hours.

Accelerated stress tests

In order to improve stack performance and stack lifetime, over the years Nedstack has developed and implemented several accelerated stress tests (ASTs) for material and component testing. These allow simulating thousands of hours of operation within a few days.

One of these is an AST for sealing materials. This has allowed us to find improved sealing materials, with at least a three-fold increase in lifetime. We have also developed accelerated surface ageing tests for cell plate materials. Although these have shown changes in characteristics over time, we now know that performance and lifetime are not negatively affected by these changes, and will therefore not limit the stack lifetime. Further testing of different components is ongoing, and will allow the development of stacks and stack components with even further increased lifetimes.

Research interests in PEM fuel cells for stationary applications

Based on our experiences, we have now been able to identify a number of research topics for PEM fuel cells for stationary applications, which may lead to exceeding 40 000 hours of stack life as well as increasing market opportunities. These do not only apply to Nedstack, but to PEM fuel cells in general.

The first problem which still needs attention is a further reduction of stack production cost, which could involve (among others) a reduction of precious metal content, simplified manufacturing processes,

Nedstack owns a 70 kW PEMFC power plant at a chlor-alkali factory in Delfzijl, The Netherlands, with no major system components replaced since the start of operation in 2007.

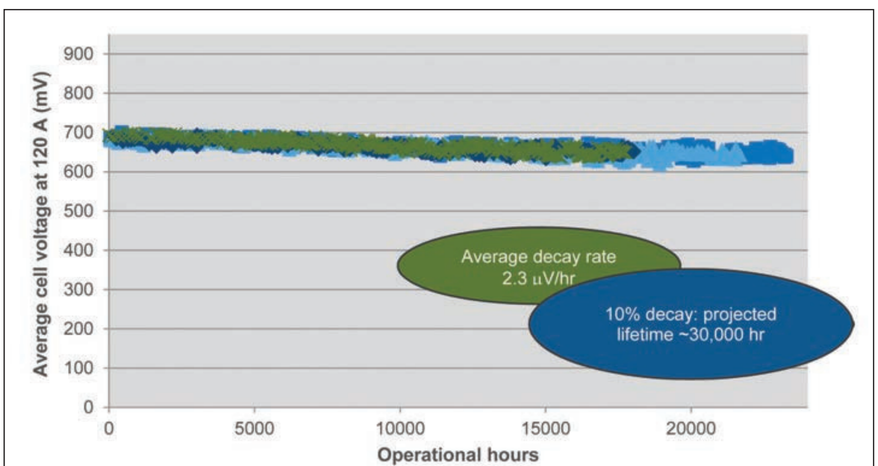
and increased production numbers. Also, the lifetime should be further increased, involving a reduction of degradation rates in MEAs by limiting membrane thinning and the possible formation of pinholes, as well as limiting catalyst surface area reduction. It also involves stack hardware since, once MEA lifetime starts to significantly increase, problems with other components – such as seals, borders, and cell plates – may arise and limit the stack life before reaching the end of life of the MEA.

Then, without increasing cost or reducing lifetime, the stack performance should still be increased, which implies that the stack power density (both by weight and by volume) needs to be increased. This involves different aspects such as a reduction in ohmic and activation losses, increased operational temperature, and increased fuel utilisation. It may therefore require modifications to the flow-field, GDL, and catalyst/support morphology.

Next, it is important to reduce the sensitivity to contaminants. On the cathode side this involves air contaminants, such as SOx and NOx, while at the anode it involves CO, CO_2, and sulfur compounds. This would make stacks more suitable for different fuel qualities (e.g. reformate gas) and environments, and reduce the need for gas filters and/or purification systems.

Finally, the balance-of-plant (BOP) should be reduced, which may imply modifications to the stack (e.g. MEAs suitable for reduced humidity), as well as increased system component efficiency. Obviously, and in the ideal case, each of these should be achieved without negatively affecting any of the other aspects.

For specific applications, fit-for-purpose solutions may be needed, which require detailed understanding of the effect of operational conditions on stack performance and degradation. Fundamental research which helps to understand underlying mechanisms is therefore still needed.



The Nedstack XXL stack performance in the 70 kW power plant in Delfzijl, showing average cell voltage (normalised to 120 A) for four different XXL stacks for 17 000 to 23 000 hours of operation.

Conclusions

Nedstack's proprietary stack design and production processes have proven highly suitable for a number of stationary applications, including extended backup and small and large power plants, as well as for transport applications, such as buses. Nedstack's XXL stacks have shown lifetimes of up to 23 000 hours, and the decay rates indicate that with the current generation of stacks, 40 000 hours may be reached. We will continue improving our stacks, applying detailed characterisation of the relevant technology, working with different stakeholders in the field, and looking for innovative solutions to current limitations for further market introduction.

Acknowledgments

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