<u>Application 2042</u>

H2FC European Infrastructure
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Water Profile Imaging in Alkaline Membrane Fuel Cells

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[Abstract]

Following successful first experiments in September of 2013 using the ICON neutron beam to imaging water in alkaline membrane fuel cells (AMFC's) in through-plane configuration, we propose to expand these measurements to single-cell in-plane measurements, as well as a multi-cell fuel cell stack. Both of these are aimed at addressing fundamental issues regarding water management in AMFC systems.

[Proposal]

Recently, the first-ever images of water in an operating alkaline membrane fuel cell (AMFC) were generated in a first H2FC transnational access project of Cellera, supported by PSI. That first experiment provided valuable information, while also defining follow-up imaging tests of great potential value. The experiments proposed here will also provide another world-first, namely the neutron imaging of a complete fuel cell stack under operation at >1kW of power generation.

Alkaline Membrane Fuel Cells (AMFCs) belong to the family of polymer electrolyte fuel cells (PEFCs), i.e., it has a pseudo-solid-state electrolyte with the ionic functions being part of the polymer structure , requiring only hydration by deionized water to provide high ionic conductivity. The AMFC is, however, strongly distinguished from the mainstream PEFC technology developed to date, in that its electrolyte conducts OH^- ions, instead of the H^+ ionic conduction in the mainstream PEFC ionomers. AMFC technology provides the ability to operate with non-noble electro-catalysts and to use inexpensive metal hardware and membranes. These features provide an important potential key for earlier market entry of fuel cells, particularly in automotive applications.

Perhaps the most important roadblock in the development of viable AMFC technology has been the highly demanding challenge of effective water management in an operating AMFC, as water is generated in such a cell at the fuel side (anode) of the AMFC, according to:

$H_2 + 2OH^- \rightarrow 2H_2O + 2e$

Consequently, the removal of excess liquid water generated at the anode cannot be done by use of high gas flow rates which would result in low utilization of the hydrogen fuel. At the same time, the AMFC water is consumed in the AMFC cathode,

$\frac{1}{2}O_2 + H_2O + 2e \rightarrow 2OH^-$

and the cathode side therefore has a strong propensity to dry out. Membrane, electrode and cell structures must therefore enable a high fraction of the water generated on the anode to pass through the cell membrane into the water consuming cathode and, in addition, the gas flow field on the anode side must be highly effective in removing liquid water, even under the very low average H_2 flow rates needed to secure high fuel utilization.

Our first experiments were carried out in a face-on configuration, allowing excellent resolution of details in the x-y plane of the cell. This allowed us to demonstrate the mechanism by which the first water management issue, namely removal of a large excess from the anode side while maintaining high fuel utilization, can be achieved with correct design of flow field and gas diffusion layer.

We have since requested beam time at the SINQ facility (PSI) for a second set of experiments aimed at completing the water distribution picture by imaging the thickness (z-) dimension of the AMFC ("side view" imaging). Detailed knowledge of water distribution in this axis in GDLs and flow channels is critical especially to the second part of the challenge, namely effective delivery of water to the consuming cathode side. This can be readily achieved using the differential flow cell available in PSI, already demonstrated with PEFC technology[1,2], and this set of experiments forms the basis for the current H2FC funding request.

Additionally, we aim for a more advanced mode of simultaneous "side imaging" of a large number of cells in a stack. Water management demands are significantly intensified when multiple cells are in play, but fundamentally, in through-plane neutron imaging, the neutron path length limits the number of stacked cells probed by the beam, and it also becomes difficult to resolve information from individual cells. Cellera's stack design combines neutron-transparent aluminum hardware and air-cooling that features significant separation between cells. This should allow direct "through plane" viewing (at a tight angle) of each cell in the stack in a single experiment, and would thereby establish a never-before utilized technique for fuel cell stack imaging, while providing further critical information towards AMFC stack design.

In summary, special features of the AMFC technology and strong recent performance advancements define it as an important potential key for earlier market entry of fuel cells, however water management remains a significant technological barrier. Further information from neutron water imaging in AMFCs, as proposed here, could be highly valuable technically and scientifically. We also intend to implement a new generic approach to simultaneous neutron imaging of cells in an operating stack.

In our proposal to PSI for beam time, we requested 3 days for "through-plane" (single-cell + stack) measurements, including station and beam setup; and 2 days including setup for in-plane measurements, for a total of 5 days' experimentation.