Analysis of passive water removal from the anode chamber under dead-ended conditions in an innovative design of air-breathing PEM fuel cell.

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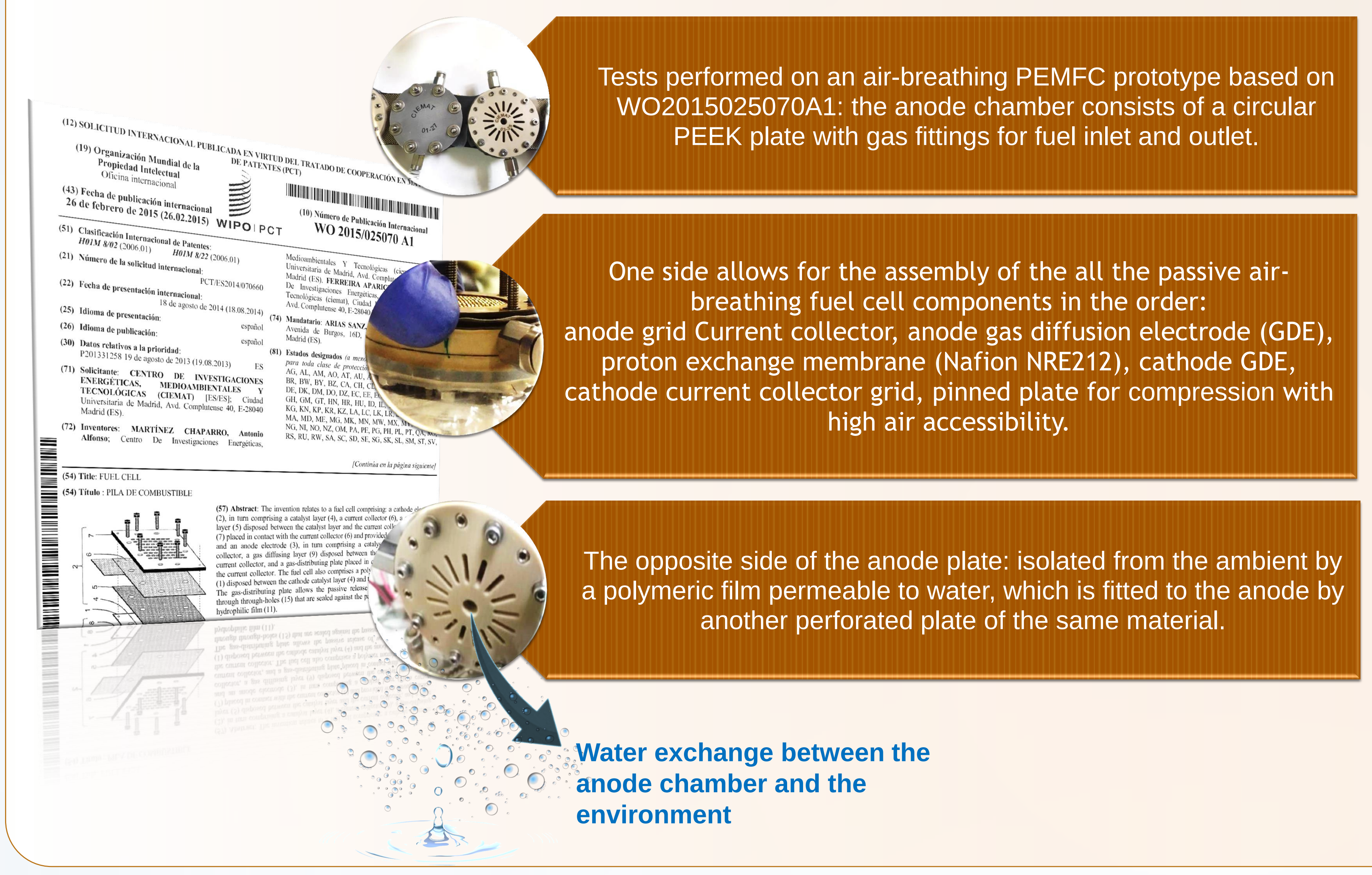
Introduction

Operation of proton exchange membrane fuel cells under **dead-ended anode mode** is more convenient from a practical perspective in order to **increase fuel utilization**. However, the process of water back-diffusion from the cathode increases progressively anode water content until its catalytic layer becomes flooded. Then, hydrogen starvation begins to degrade irreversibly the anode gas diffusion electrode. **Avoiding anode flooding** requires implementing mechanisms in the system for water removal, such as fuel recycling or periodical fuel release for purging. For the particular case of micro-fuel cell systems, their volume, weight and extra-consumption of fuel and power for subsidiary components must be kept to a minimum.

A **passive water regulation system** has been developed by **CIEMAT** and evaluated in a micro-fuel cell. This solution consists of an **anode chamber that allows free water exchange with the ambient through the surface of a gas-tight membrane**. The cell design according to WO2015025070A1 has been assembled and operated under completely passive conditions. The cell behavior regarding the passive removal of water from the anode is analyzed here in detail.

Scientific Approach



Tests performed on an air-breathing PEMFC prototype based on WO2015025070A1: the anode chamber consists of a circular PEEK plate with gas fittings for fuel inlet and outlet.

One side allows for the assembly of the all the passive air-breathing fuel cell components in the order: anode grid Current collector, anode gas diffusion electrode (GDE), proton exchange membrane (Nafion NRE212), cathode GDE, cathode current collector grid, pinned plate for compression with high air accessibility.

The opposite side of the anode plate: isolated from the ambient by a polymeric film permeable to water, which is fitted to the anode by another perforated plate of the same material.

Water exchange between the anode chamber and the environment

Cell tests performed:

- Dead ended anode operation under potentiostatic conditions

  Chronoamperometric and electrochemical impedance spectroscopy measurements were registered during repetitive cycles of potentiostatic steps between 0.8 and 0.0 V of cell voltage.

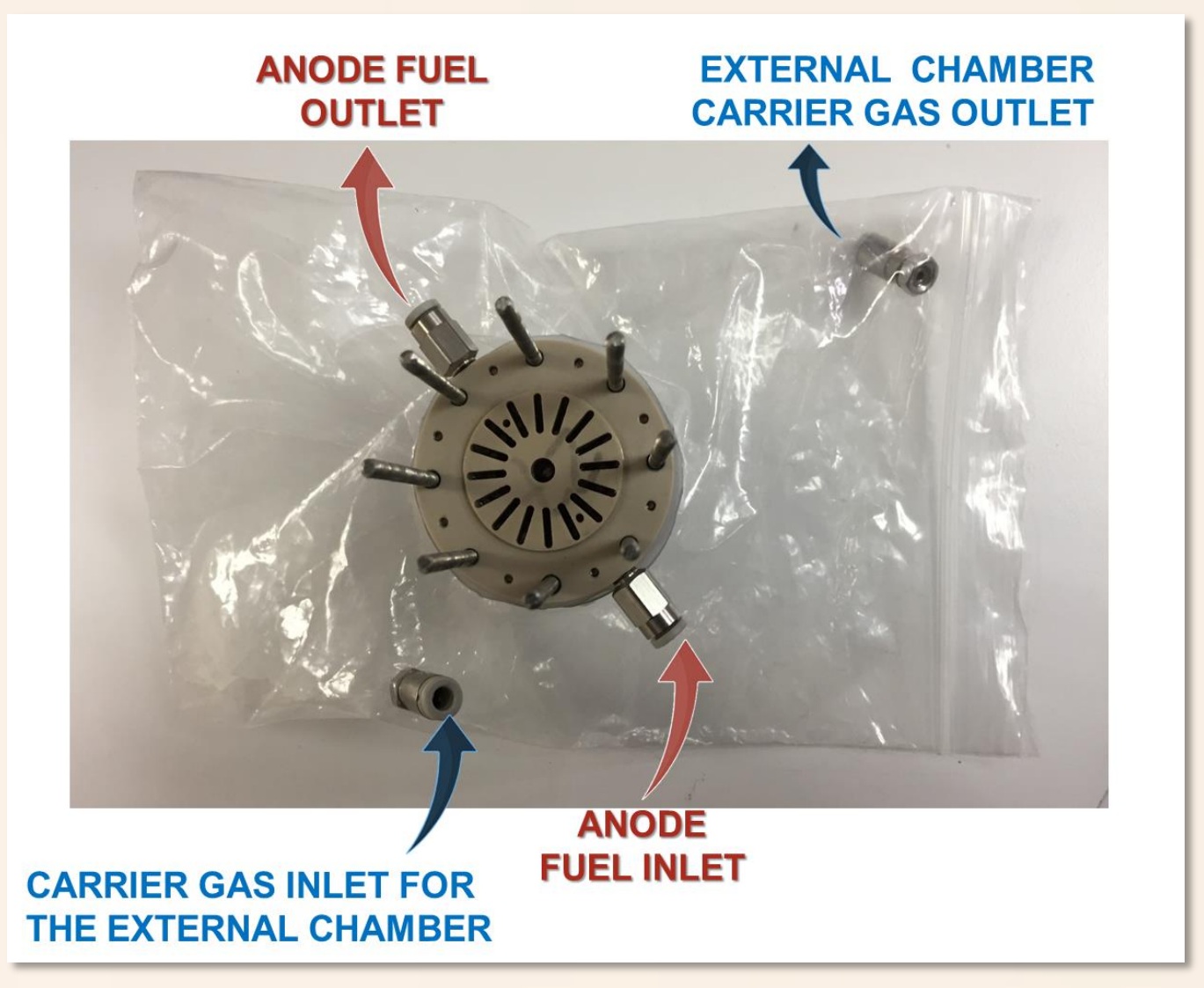
- Analysis of the water exchange in the anode chamber with the ambient

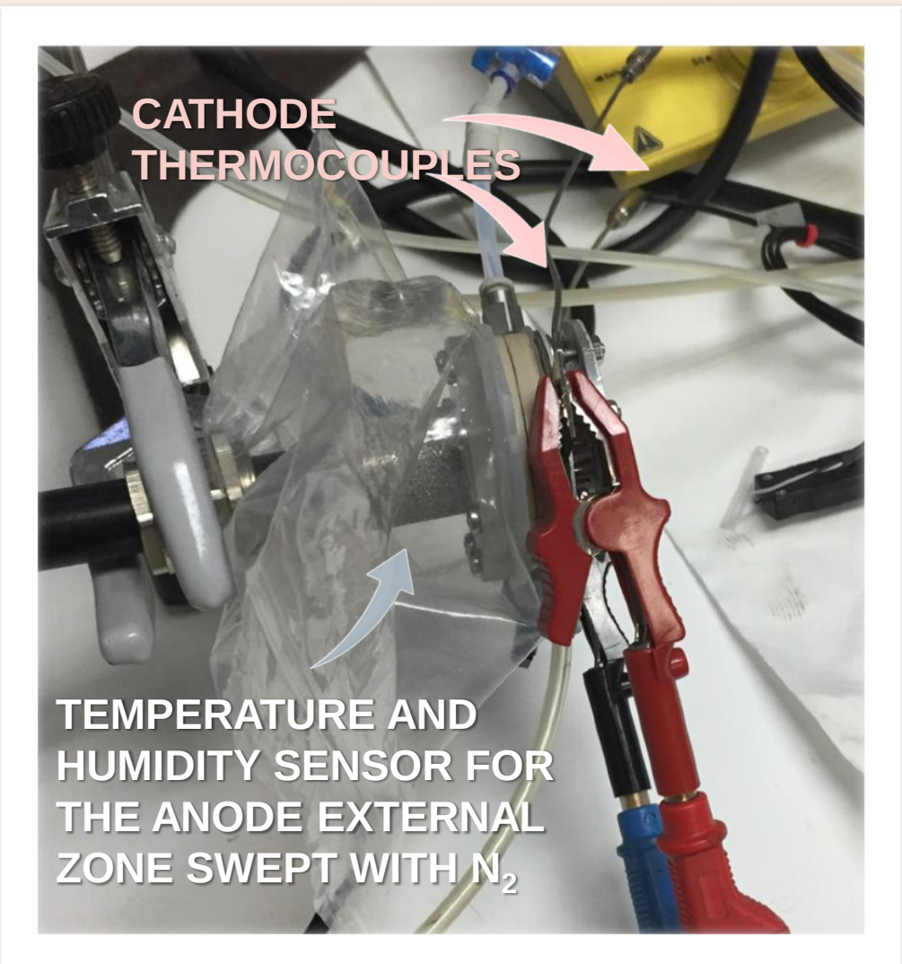
  EXTERNAL ANODE ENVIRONMENT: The external part of the cell anode was assembled inserting a zipper gas-tight plastic bag between silicon seals with the anode external plate component.

  RELATIVE HUMIDITY MEASUREMENT: The isolated anode external chamber has been equipped with fittings for a carrier gas inlet and outlet and a temperature and gas humidity sensor (PCE 313A).

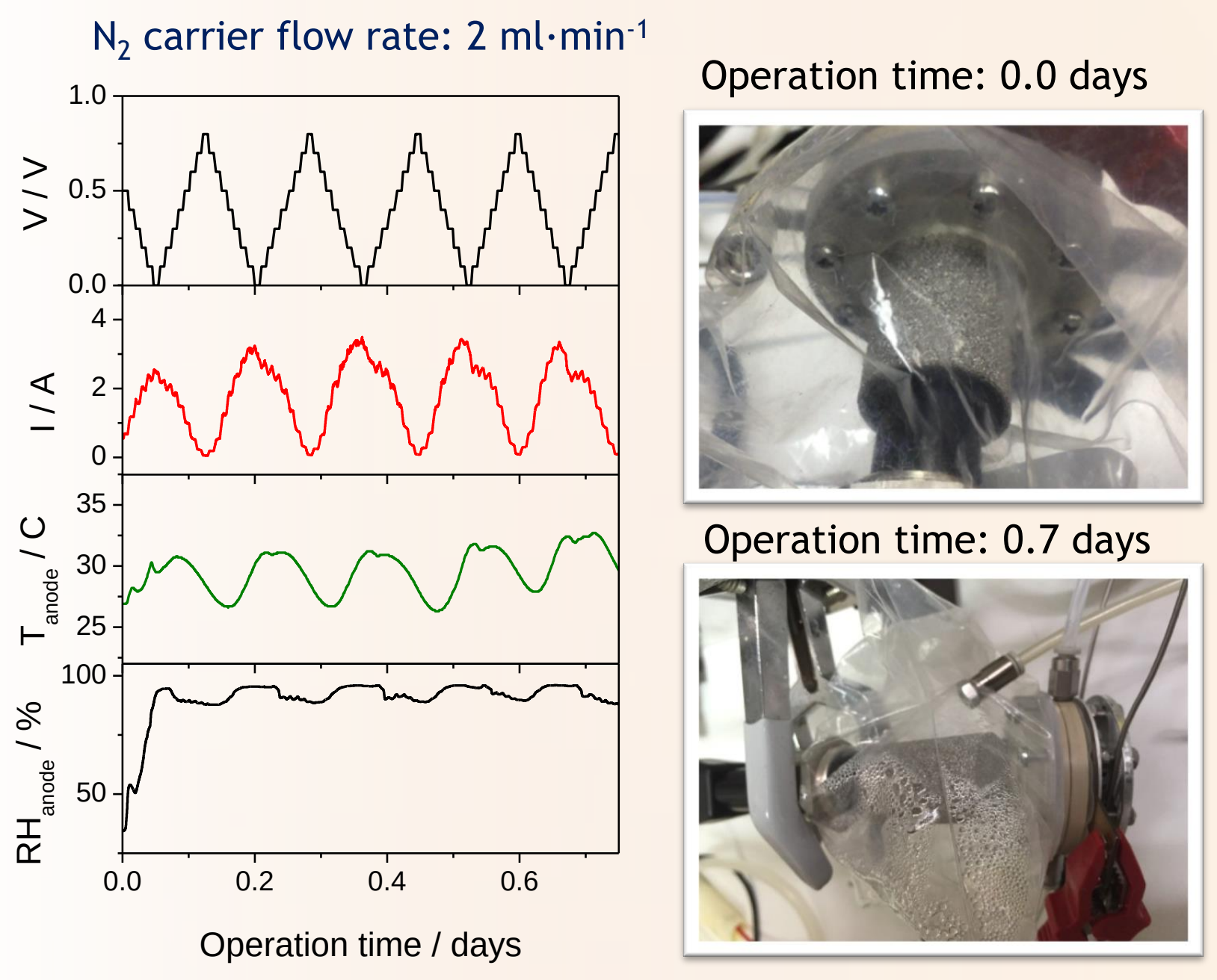
  CARRIER GAS: A small flow rate of N_2 initially set at 10 ml·min^{-1} was used to simulate the exchange with the environment.

  FEEDING: The cell was fed with pure dry H_2 under Dead End Anode (DEA) mode using a closed three-way manual valve at the fuel outlet.



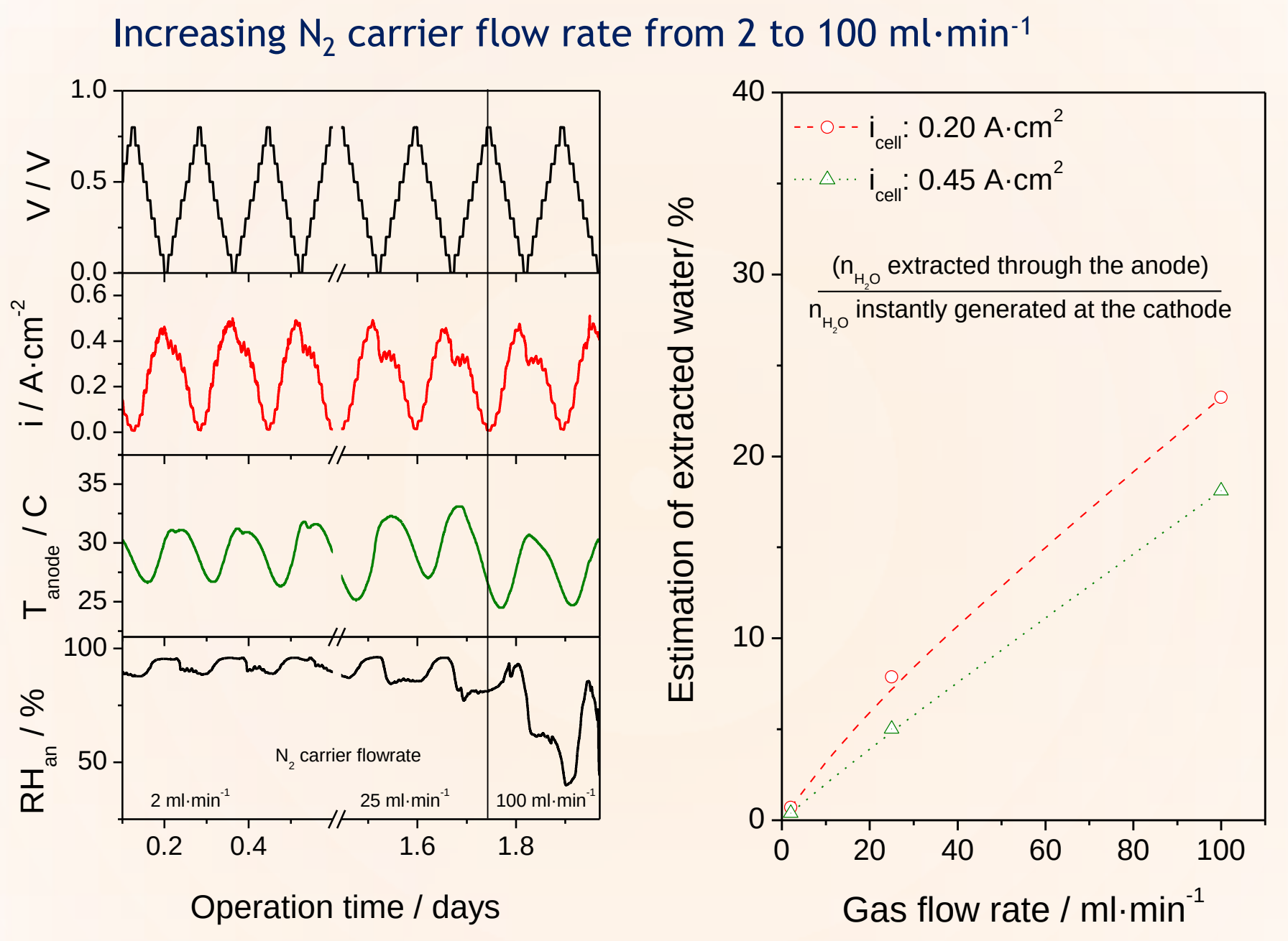


Initial test: checking water exchange



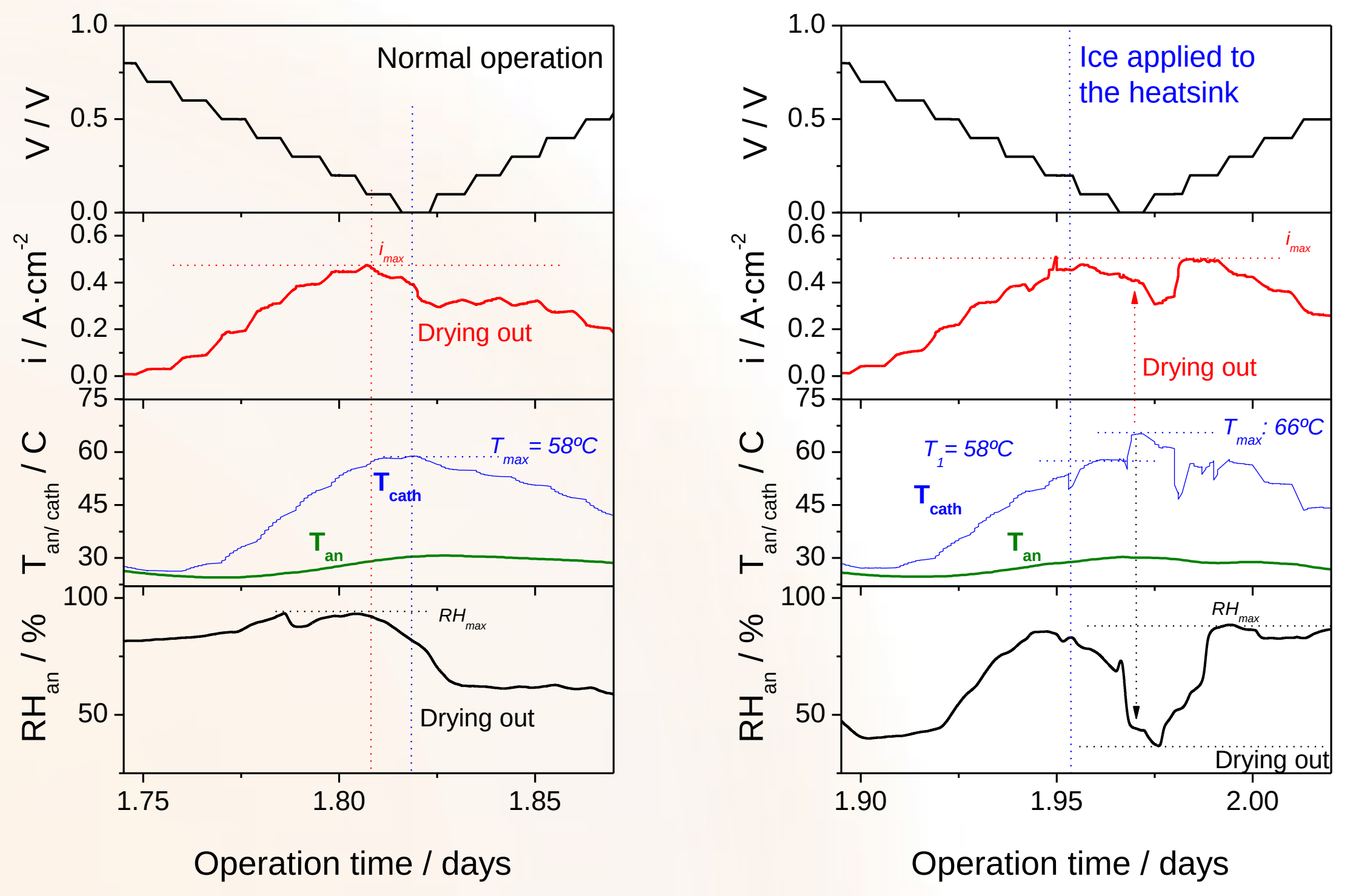
Operation parameters of the CIEMAT ABPEMFC assembled to analyze the humidity released from the dead-end anode chamber and the temperature variation in the sensor.

Analyzing the effect of the sweep gas



Operation parameters of the CIEMAT ABPEMFC assembled to analyze the humidity released from the dead-end anode chamber as a function of the sweep gas flow rate.

Drying out of the MEA by excessive temperature during an operation cycle



The novel configuration of this dead ended anode is able to exchange water passively with the external environment.

The rate exchange depends on the ambient relative humidity and air convection.

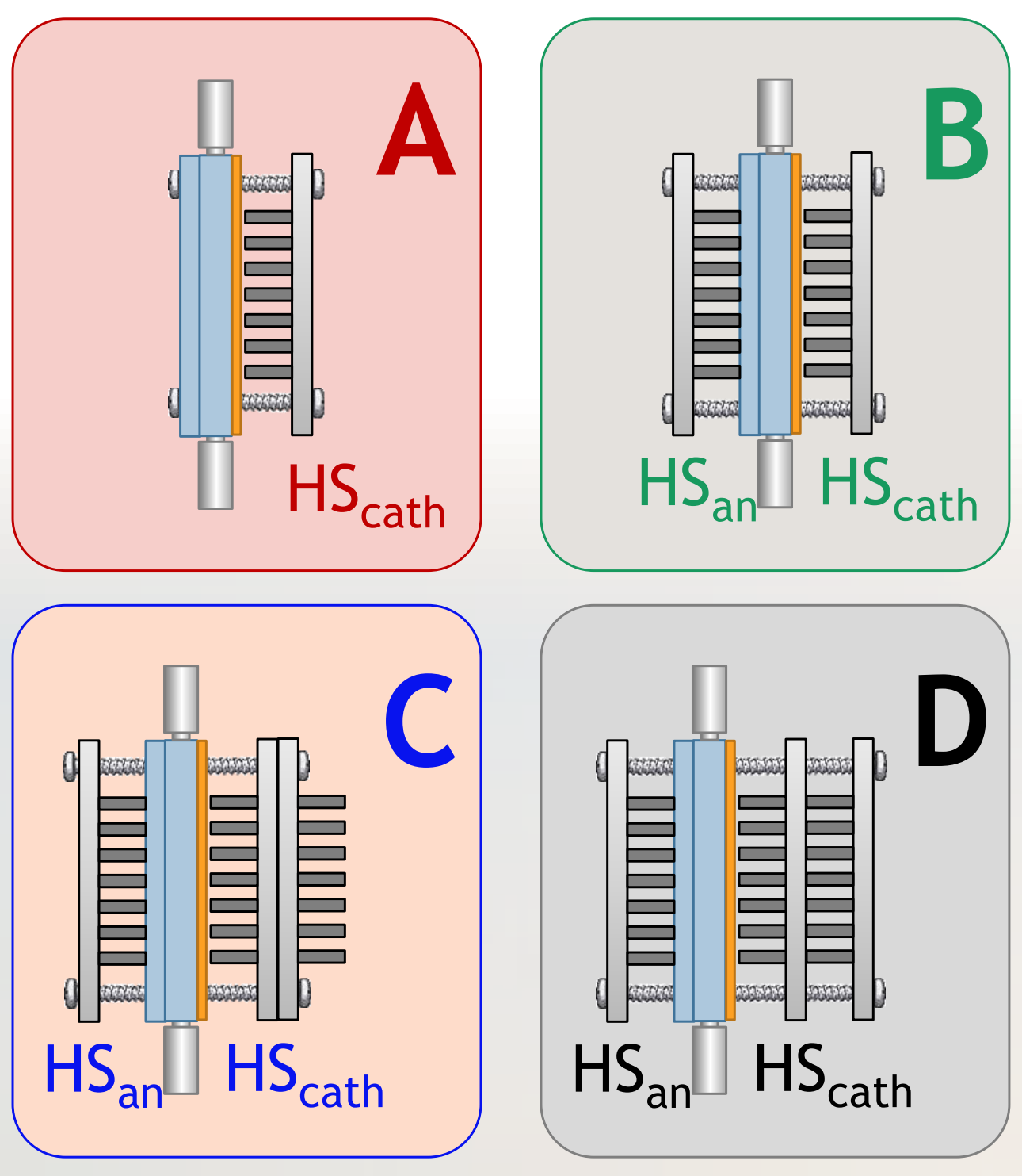
The high temperature reached in the MEA during cell operation causes membrane drying out.

Heat removal from the cathode mitigates excessive drying and improves cell performance.

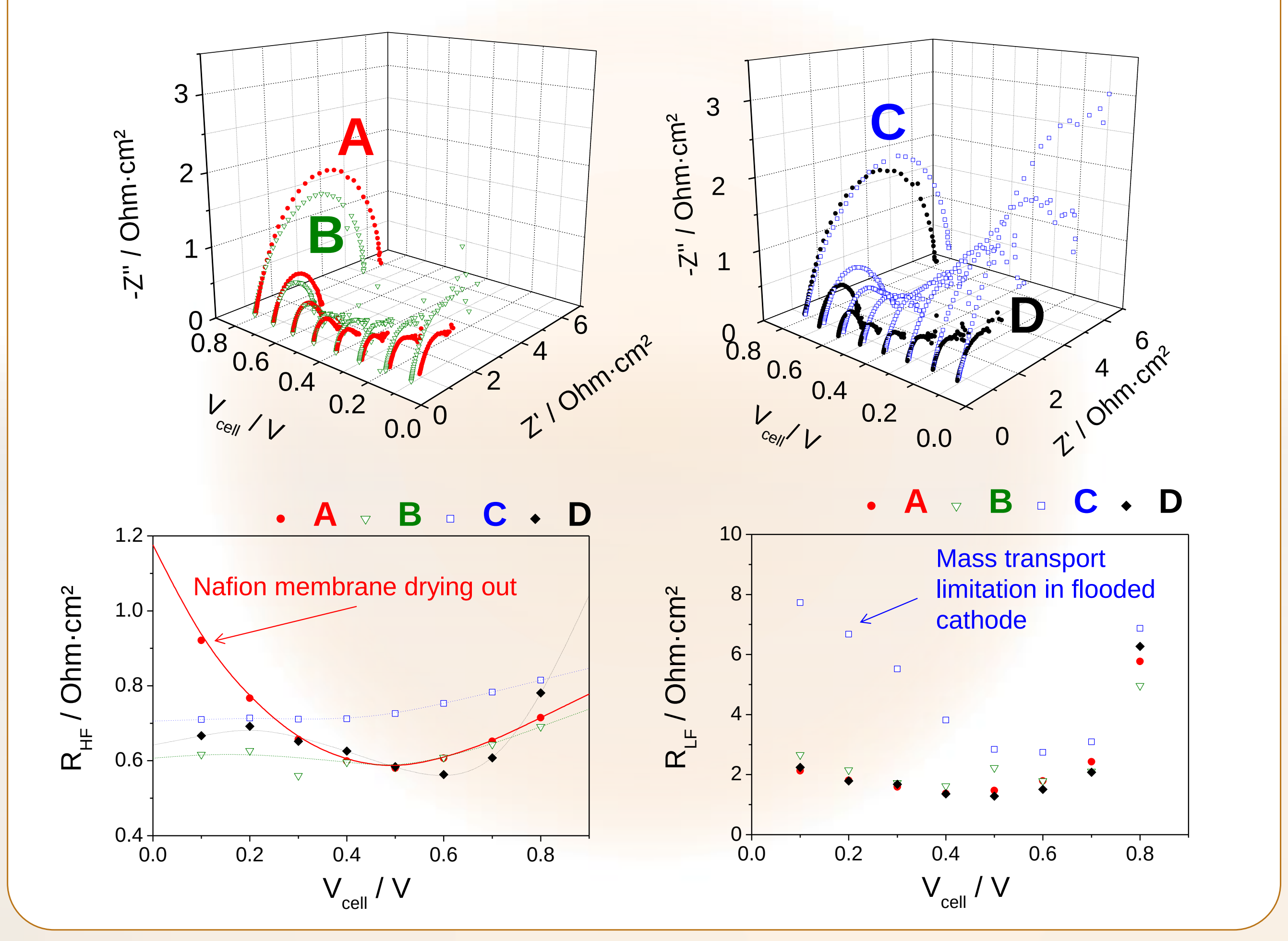
Improving passive heat management for better passive water management

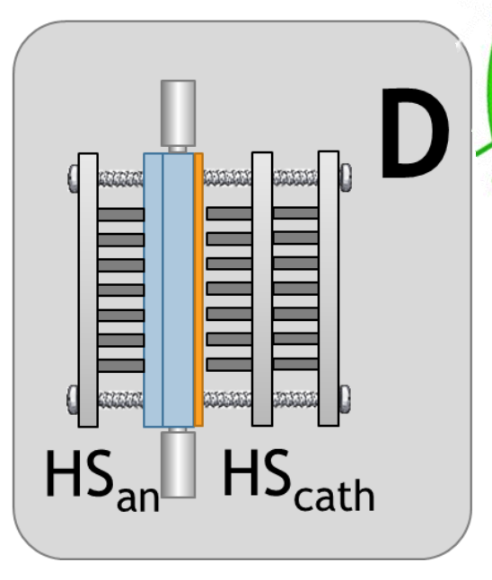
Heat sinks assembly configuration for fast heat dissipation

$W_A<W_B<W_D<W_C$

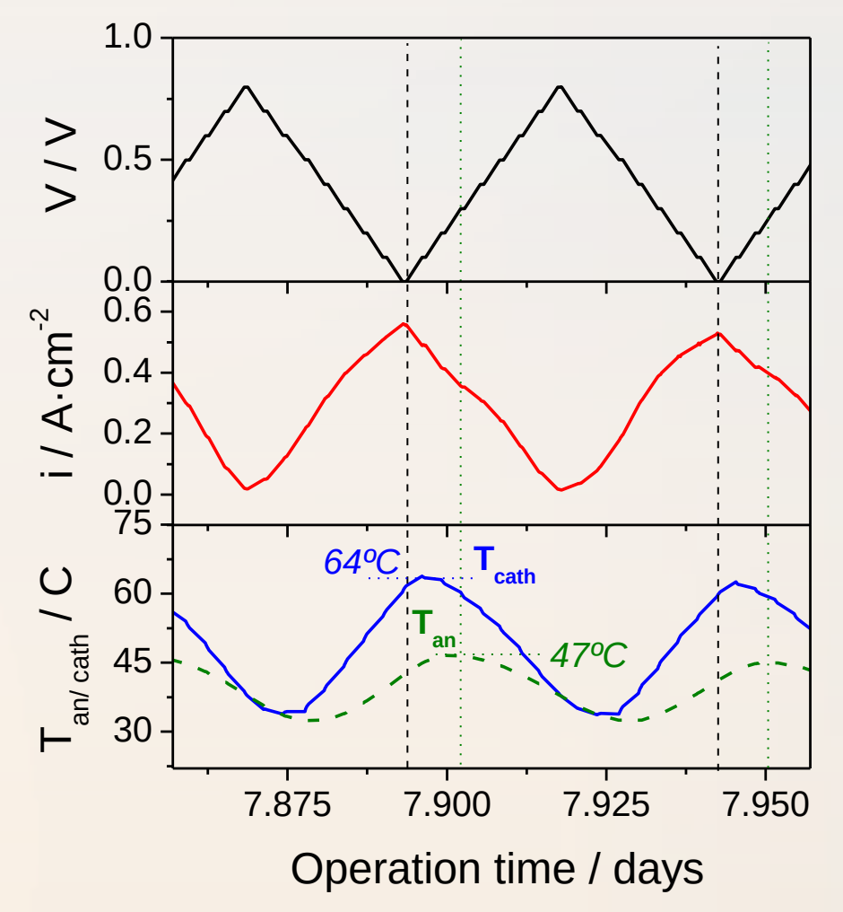


EIS analysis

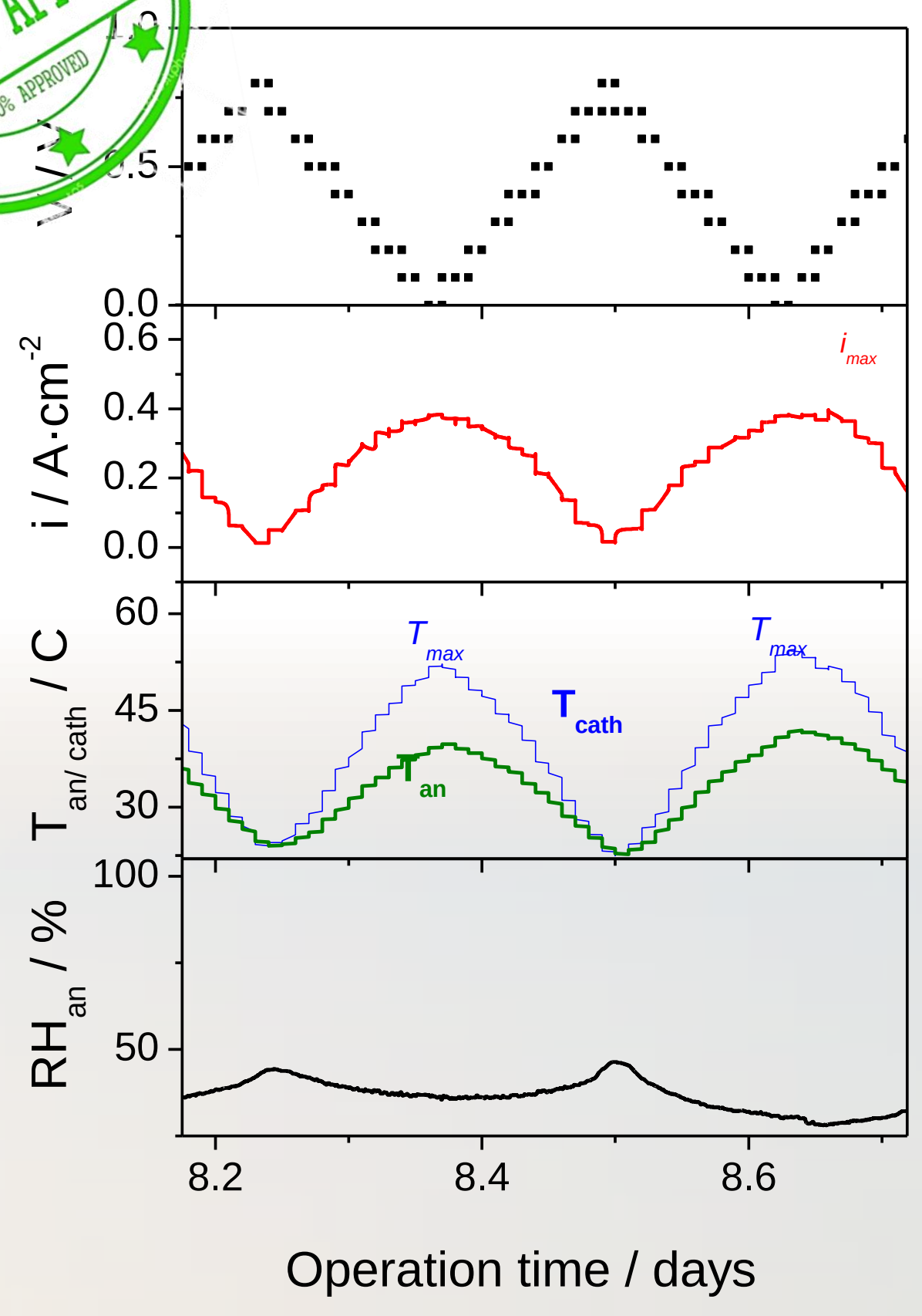




Optimizes heat and water management:
minimizes performance losses by membrane drying out



Optimized performance



The operation of the novel configuration for the dead ended anode in WO2015025070A1 (ES2466590A1) and according to the utility model application number U201930869 (ES), has been verified and analyzed in detail.

The completely passive air-breathing E-LIG-E fuel cell is able to operate continuously under dead ended anode mode allowing for complete (≈100%) hydrogen fuel utilization, with no need of auxiliary systems for venting, purging or cooling.

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