Assembling, starting, and running a 5 cm^2 single cell PEM-fuel cell

TRA105 Fuel Cell Systems, Q1 2022

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Introduction

The aim of this project was to learn some of the fundamentals of a small-scale PEM fuel cell by participating in hands-on fuel cell assembly and conduction of experiments.

The experimental parts involved analysis and evaluation of extracted data to determine the fuel cell performance and identify which parameters that mainly influence the system's activity.

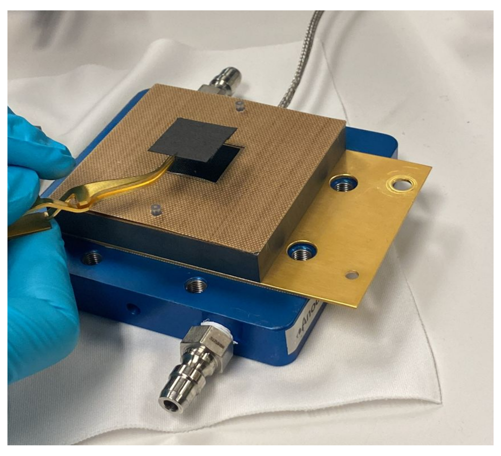
Fuel Cell Particulars

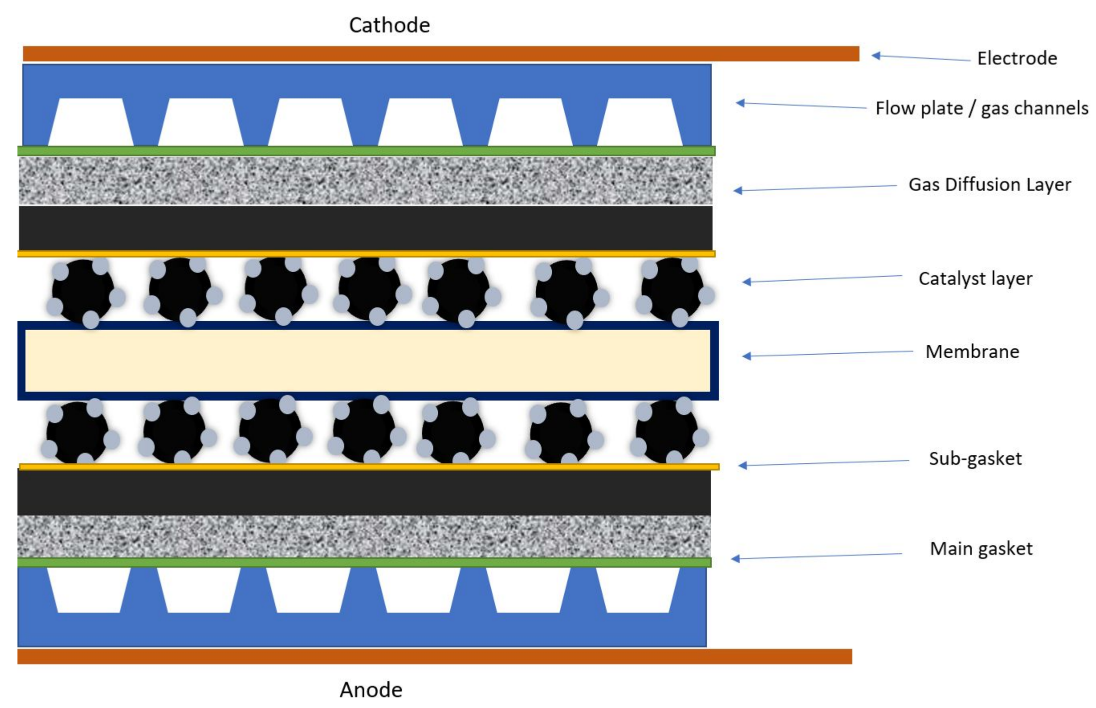
The fuel cell used in this project is a 5 cm^2 single cell Proton Exchange Membrane (PEM) fuel cell. Gas diffusion layers, sub-gaskets and end-gaskets were manually cut to the right size and assembled on each side of a pre-assembled Membrane Electrode Assembly (MEA). Bipolar plates and electrodes were attached to each side and clamped together by end-plates with 11.5 Nm torque. The humidity inside the Fuel Cell is more than 70%. The operating pressure is atmospheric pressure. The operating temperature is 50-80 deg C.

Materials used

Membrane - Nafion NR212
Anode - Fine carbon powder coated with Platinum (0.1 mg_{Pt}/cm^2_{geo})
Cathode - Fine carbon powder coated with Platinum (0.4 mg_{Pt}/cm^2_{geo})
Gas Diffusion Layer - Uulcun Carbon and Platinum.
Flow Plates - Graphite
Electrodes - Copper
Gasket - Teflon

Anode side reaction:
$$2H_2 \rightarrow 4H^+ + 4e^-$$
Cathode side reaction:
$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$
Net reaction:
$$2H_2 + O_2 \rightarrow 2H_2O$$





Methods

To determine the performance and overpotentials of the fuel cell, the following methods have been applied. Measurements have been made both on a fresh fuel cell and after 15,000 cycles for comparison.

Cyclic voltammetry (CV)

Cyclic voltammetry is used to investigate electrochemical reactions on individual electrodes. By the use of a potentiostat, a potential difference is applied between the working electrode and a reference electrode. The voltage is cycled between fixed values from low to high, and in reverse direction. The current is then plotted as a function of the applied voltage, known as 'cyclic voltammogram'. The performance of platinum loaded catalysts depends on the particles active surface area. By analyzing this reaction, the electrochemical active surface area (ECSA) of the cathode could be calculated. In order to concentrate the analysis to the reactions without the influence of oxygen, Argon was used instead of oxygen (air) on the cathode side.

CV experiment particulars

Cell temperature: 40°C
Gas Temperature: 45 °C
RH: 100 %
Gas flow rate
- Anode: H_2 100 ml/min
- Cathode: Ar 50 ml/min

High-Frequency Resistance (HFR)

The High Frequency Resistance (HFR) method is a subset of Electrochemical Impedance Spectroscopy (EIS), used to characterize the impedance of the fuel cell. An AC signal is applied to the electronic load to modulate the DC load current and the voltage and current AC response is measured by a frequency response analyzer. Unlike EIS, only a single frequency is used. This measurement is automatically performed periodically during normal test system operation and the result displayed in real time. Usually the Real (Z') component of the result is of interest and is displayed in milliohms. The corresponding 'polarization curves' showing the resistance and ohmic losses are presented in the Results section.

Polarization curve and HFR experiment particulars

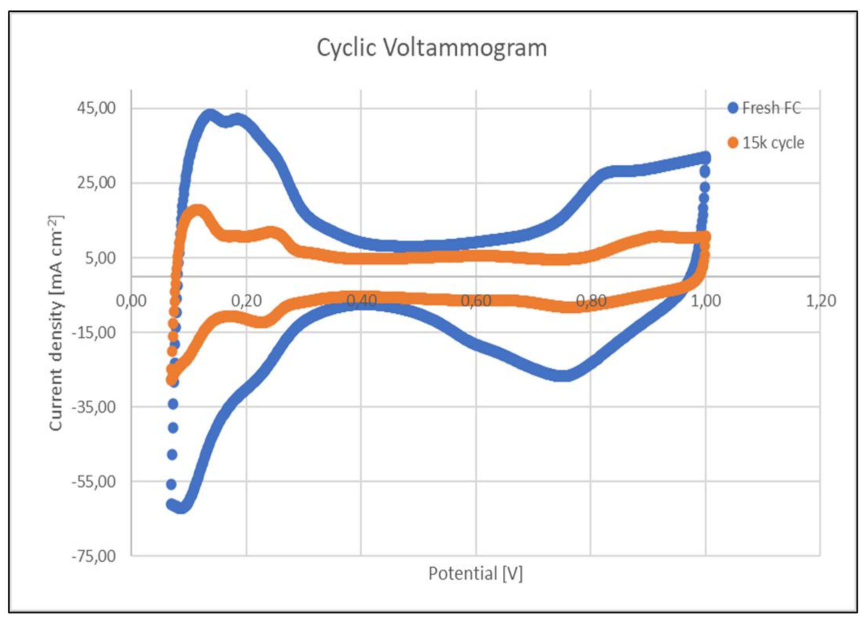
Cell temperature: 80°C
Gas temperature: 85 °C
RH: 100%
Gas Flow rate
- Anode: H_2 140 ml/min
- Cathode: Air 400 ml/min

Results

Cyclic Voltammetry

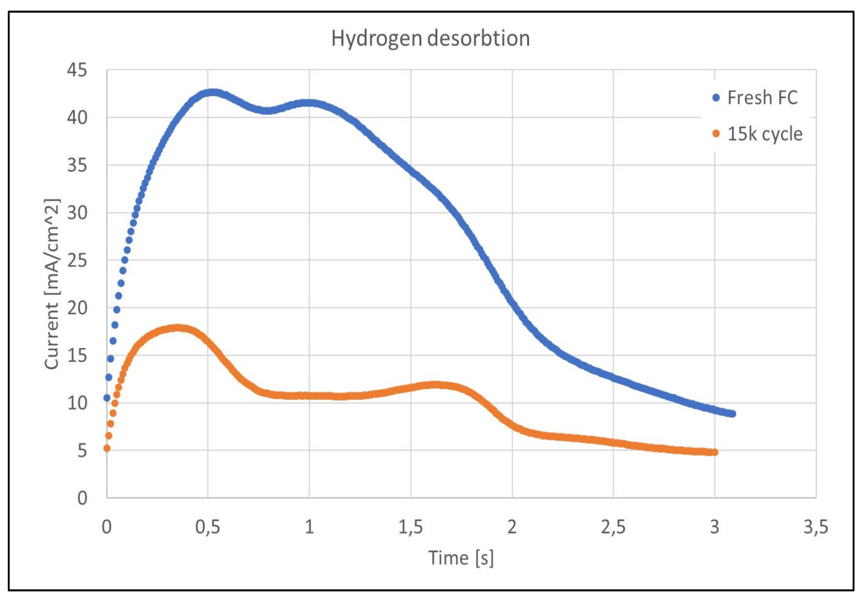
$$ECSA_{Pt,cat}(m^2\, g_{Pt}^{-1}) = \left[\frac{Q_{H-adsorption}(C)}{210\,\mu C\, cm_{Pt}^{-2} L_{Pt}(mg_{Pt}\, cm^{-2}) A_g(cm^2)}\right] 10^5$$

LPt= The working electrode Platinum loading.
Ag= The geometric surface area of the glassy carbon electrode.
ECSA= Platinum Electrochemical Surface Area



Active Surface Area:
Fresh Fuel Cell = 275.6 cm^2 Pt
Fuel Cell after 15k cycles= 77.5 cm^2 Pt

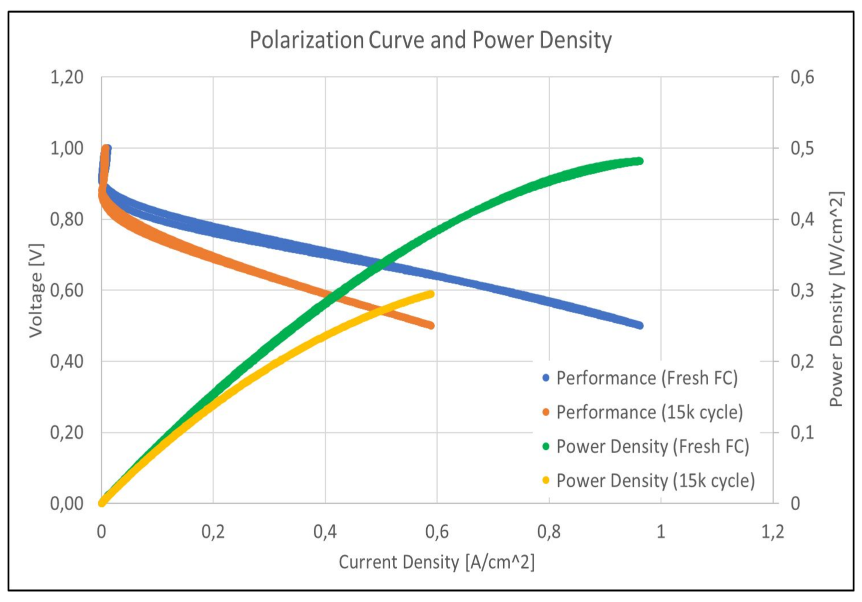
Platinum Electrochemical Surface Area (ECSA):
Fresh Fuel Cell ECSA = 70 m^2/g_{Pt}
Fuel Cell after 15k cycles ECSA= 20 m^2/g_{Pt}



Polarization Curve and Power Density

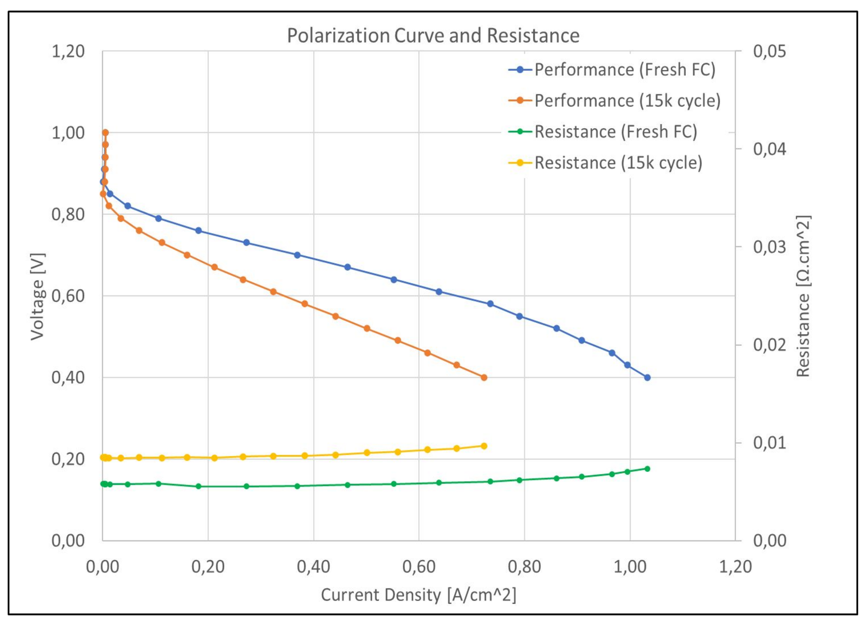
The polarization curve shows the cell voltage over a range of current densities. The plot indicates that the fresh cell has been tested over a higher range of current density while the 15k cycle was limited to lower current density in order to keep it safe from damage.

The power density is calculated as the product of voltage and current density. At very low currents, the power is identical. However, at higher currents, the power produced by a fresh cell is much higher than the 15k cycle case.



Polarization Curve and Resistance

The system resistance can be obtained by HFR experiments. The system resistance referred to the real part of the resistance when the imaginary part is equal to zero, i.e. the current and voltage are at the same phase. The results show that the system resistance for the 15k cycle case is slightly higher than the fresh FC, resulting in lower Ohmic loss and less voltage drop.

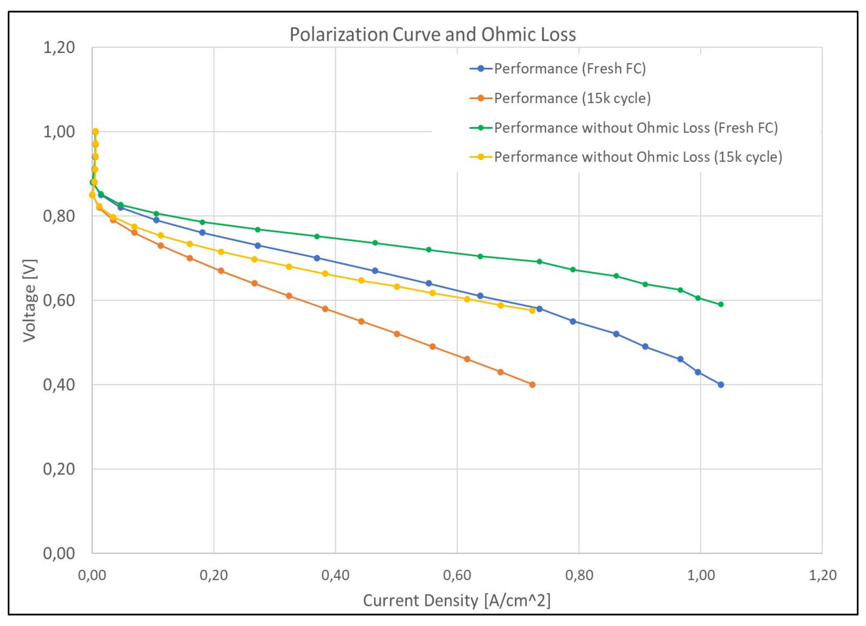


Polarization Curve and Ohmic loss

The Ohmic loss occurs due to the electrical resistance to the current and a linear voltage drop. The Ohmic loss is calculated as

$$\eta_{ohm} = \text{ir}$$

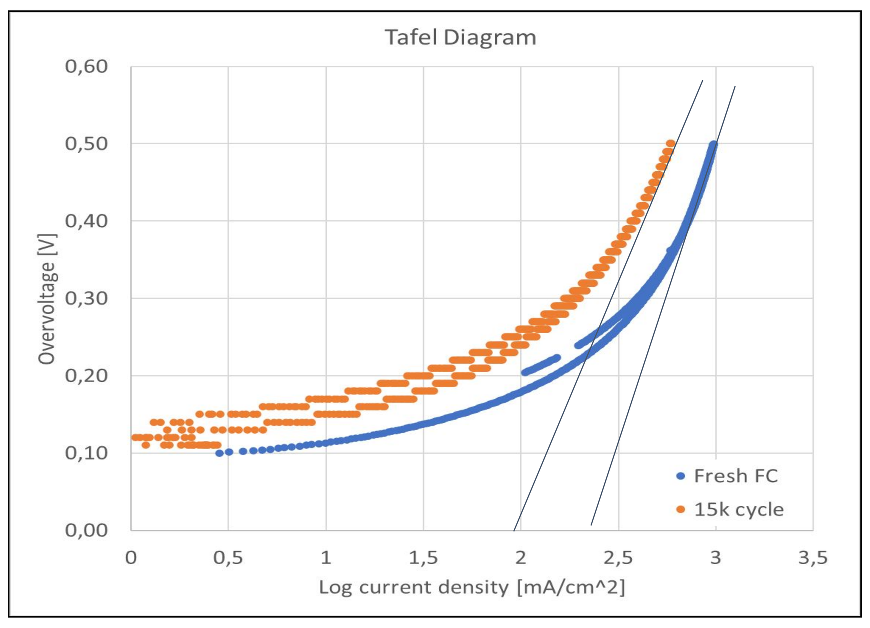
where i is current and r is the system resistance. The plot shows the effect of Ohmic loss on the voltage drop. For instance, If there is no Ohmic loss, the polarization curve for the fresh FC would be the green curve instead of the blue one.



Tafel Diagram

Tafel diagram is a plot to indicate the speed of reactions at the fuel cell. This plot is a tool to compare the activation losses in the two fuel cells. The tafel slope show how efficiently an electrode can produce current in response to change in applied potential. The results show that the slope of both curves are quite the same. However, the fresh FC generates higher current within the same voltage range; thus, the activation losses are smaller for this case.

$$\eta_{act} = A ln \frac{i}{i_0}$$



Discussion and conclusion

The main characteristics of a small scale fuel cell were measured and studied for two cases, a fresh FC and case after 15k cycles of operation. The results show that after 15k cycles, the catalyst's active surface area degrades, the chemical reactions are slower. In addition, electrical resistance, as well as the ohmic losses are higher than the fresh FC. Consequently, the power density of the fuel cell after 15k cycles will become smaller than the fresh cell. Therefore, it seems that the fuel cell performance will be reduced over a large number of operating cycles.