Experimental Analysis of the Effects of CO and CO2 on High Temperature PEM Fuel Cell Performance using Electrochemical Impedance Spectroscopy
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**Introduction**

This work presents the results of using electrochemical impedance spectroscopy to analyse the behaviour of a BASF Cell P2100 MEA operated under varying operating conditions with different temperatures and gas concentrations. Figure 1 shows the experimental setup used for these measurements.

The setup uses two separate Labview Real Time systems, one for controlling the fuel cell mass flows and temperature, and one for conditioning the current and interpreting the fuel cell voltage response to the galvanostatic impedance measurements. The impedance measurement results are interpreted and converted into Nyquist plots, as shown in figure 2.

Nyquist plots comparing the impedance at different temperatures and adding CO and CO₂ to the anode gas reveals combined effects of increasing losses and additional cooling due to higher gas flows. The additional activation losses are suggested to increase local temperatures in the cell which in turn shift the Nyquist plot to the left. The additional CO increases the cell cooling and greatly affects the fuel cell at temperatures (see figure 9). The effect of adding CO₂ on the polarisation curve of the fuel cell is shown in figure 8.

The different operating conditions and their effect on the electrical fuel cell performance can be modelled by using simple equivalent electrical circuit models. Figure 10 shows the fitted parameters of the layout in figure 2 to the measurement conducted at different temperatures.

In figure 11 the variation in resistances and capacitances of the equivalent circuit is presented as a function of operating temperature.

**Conclusions**

Using electrochemical impedance spectroscopy, a BASF P2100 has been characterized in different operating points with varying temperature and gas concentrations. The developed experimental setup is designed such that measurements are consistent and reproducible. Increasing the number of measurements in each operating point increases the reliability of the conclusions drawn from these measurements.

The measurements conducted on pure hydrogen with varying temperatures, shows decreasing high frequency resistances with increasing temperatures, which was also expected, due to the better proton conductive abilities of the membrane at higher temperatures.

When introducing CO to the anode gas, a higher high frequency resistance is visible, this is expected to be due to the higher activation losses because of the additional CO. When increasing the CO content this high frequency resistance surprisingly decreases, which is expected to be due to increasing local temperatures because of the additional activation losses involved with the CO adsorption/desorption processes.

When adding CO₂ to the anode gas at the concentrations found in the output stream of a steam reformer, the DC resistance is also affected. Careful analysis of the Nyquist plot of these measurements suggests that multiple phenomena affect the impedance of the fuel cell. At 180°C and 160°C the high frequency impedance is lower when CO₂ is absent. At 140 °C and 120°C the additional CO₂ decreases this resistance. This effect is expected to be a combination of losses and locally higher temperatures due to CO and increased cooling due to the high flow of CO₂.

The experimental results gained from the electrochemical impedance spectroscopy measurements, can be used to model the nonlinear behaviour of the fuel cell as a function of temperature, CO and CO₂ content.

**Future Work**

Future work with this fuel cell setup will include scheduled testing during the break-in process, identifying the parameters changing during break-in, and also evaluating new break-in methods, that could speed up the sometimes time-consuming break process. Future work also includes more detailed physical models that describe the impedance behaviour in more detail than equivalent circuit models. Developments of implementing this method on operating fuel cells for state-of-charge diagnosis could provide an efficient way of giving system control inputs for optimal system performance.