

Executive Summary

This research characterizes the influence of operating temperature and pressure on the performance of a Polymer Electrolyte Membrane (PEM) fuel cell. Using a 5 cm^2 active area cell and Hydrogen/Air reactants, the current density and voltage performance was modeled via a modified Tafel equation across temperatures of 40–80°C and pressures of 0–2 psig using the Scribner 850 Data was analyzed using Excel Solver to extract kinetic parameters of the semi-empirical Model of the Nernst Equation. Ongoing analysis focuses on comparing the calculated the temperature (α) and pressure (β) dependence variables against established literature to further refine experimental precision. These results validate the testing system and establish procedures for future electrochemical research.

Background

As the global energy sector transitions toward low-carbon technologies, proton exchange membrane (PEM) fuel cells have emerged as a highly efficient alternative to combustion-based systems. A PEM fuel cell facilitates the direct conversion of chemical energy into electrical energy through the electrochemical reaction of hydrogen and oxygen, generating water as the sole byproduct. In the ideal case, fuel cell performance is governed by the thermodynamics of these reactions, with two moles of electrons produced for every mole of hydrogen consumed. While the standard theoretical potential (E_o) is approximately 1.18 V for water vapor formation at 25 °C, the actual theoretical cell voltage (E_{theory}) under non-standard conditions must be determined using the Nernst equation. In practice, when a load is applied and current flows, the cell voltage decreases due to irreversible polarization losses.

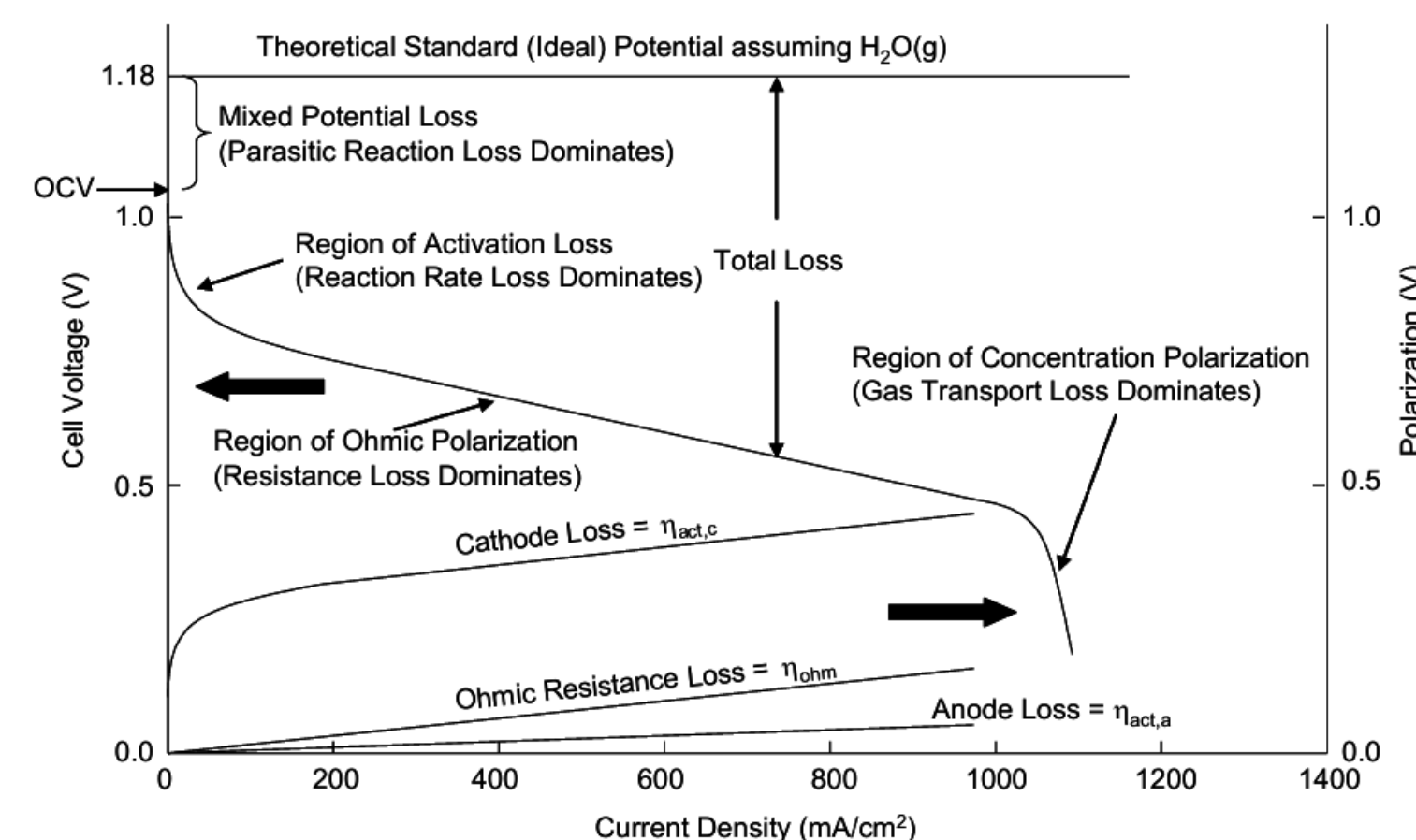


Figure 1. Representative Polarization curve with sources of voltage loss. (Cooper).

Experimental Setup

Testing was conducted using a Scribner 850g fuel cell testing system equipped with an integrated back pressure regulator. Gas outlet pressures were maintained at 55 psig for both hydrogen and air reactant streams, with nitrogen purge supply set at 60–65 psig. Prior to testing, the membrane electrode assembly (MEA) pinch was calculated using a Mitutoyo micrometer to measure dry and hydrated thicknesses of the MEA, membrane, and gaskets, following the procedure outlined in the Scribner Fuel Cell Lab Manual. Dry MEA pinch was calculated at 12% and hydrated MEA pinch at 17.2%.

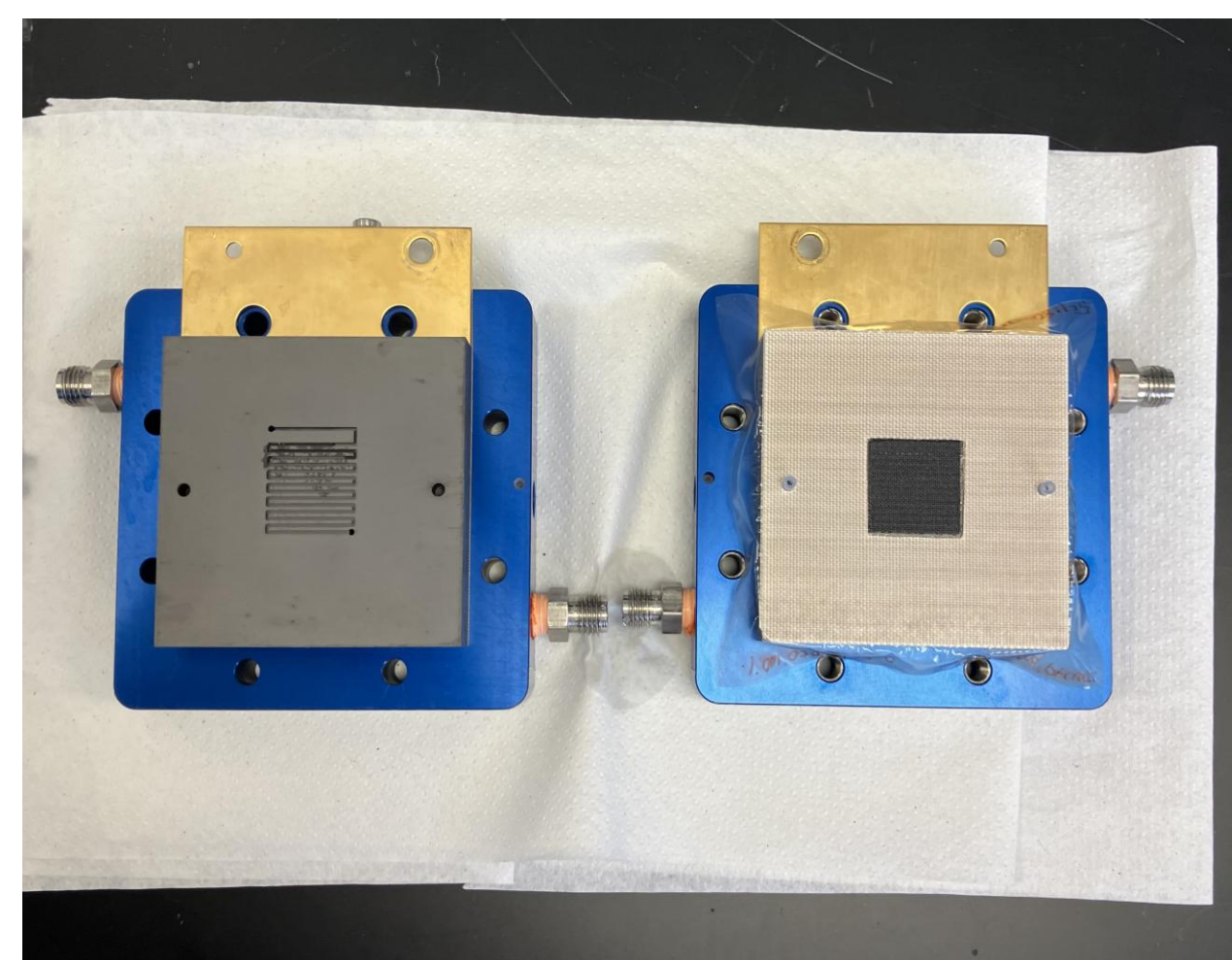


Figure 2. Fuel Cell apparatus with MEA and Gaskets

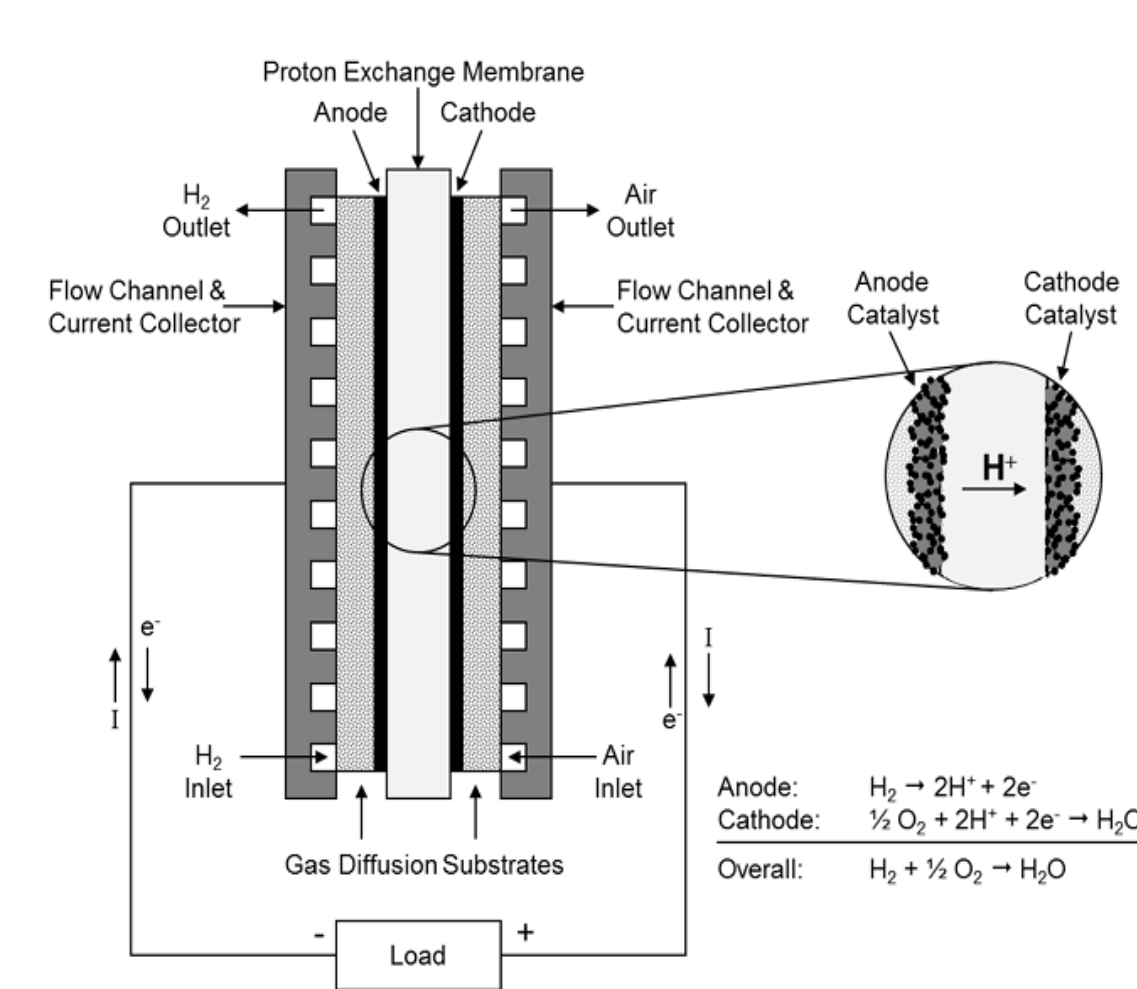


Figure 3. Cross Section of a PEM Fuel Cell

Experimental Test Plan

Polarization curves were collected across two experimental sets to isolate the effects of temperature and pressure on cell voltage. Variable temperature tests were conducted at 40°C, 60°C, and 80°C at both 0 and 2 psig. Variable pressure tests were conducted from 0 to 30 psig at a constant 60°C. Tests used scan voltage protocols in Scribner FuelCell software: 0 V vs. open circuit to 0.3 V absolute, 0.05 V increments, 15 seconds per point. To characterize these effects across the experimental sets, a semi-empirical model was utilized:

$$E(V) = E_o - b \ln(i) - iR + C \ln\left(1 - \frac{i}{i_{lim}}\right)$$

Equation 1. Semi-Empirical Model of Polarization loss

The term $-b \ln(i)$ captures activation polarization, $-iR$ captures ohmic losses, and $C \ln(1 - i/i_{lim})$ captures concentration polarization as current approaches the transport-limited value i_{lim} . Cell voltage was modeled using Equation 1.

Accounting for temperature and pressure dependence, the equation becomes:

$$E = E_o + \alpha(T - T_o) + \beta \ln(P_{cell}/P_{ref})$$

Equation 2. Simplified Model of Polarization loss

where $\alpha = dE/dT$ captures the temperature sensitivity of open-circuit voltage and $\beta = 1.5 \cdot B_{press}$ represents the combined Nernst pressure correction. Parameters were extracted by fitting the model in Equation 1 to experimental data using Excel Solver, minimizing the sum of squared errors.

Experimental Results

Polarization curves at variable pressure (Figure 3) showed consistent trends: as cell pressure increased, both kinetic and ohmic performance improved, reflected in higher cell voltages at equivalent current densities. Temperature results were less conclusive. At 2 psig, performance differences between 40°C, 60°C, and 80°C were difficult to distinguish. At 0 psig, the 80°C case showed anomalous behavior, likely attributable to membrane dry-out at low pressure.

Quantitative extraction of α and β from the model fits was not possible at this time. Mathematical coupling between E_o and the Tafel slope b introduced parameter instability, making reliable isolation of temperature and pressure dependence from the fitted coefficients infeasible. Reported fit values are therefore considered qualitative indicators only.

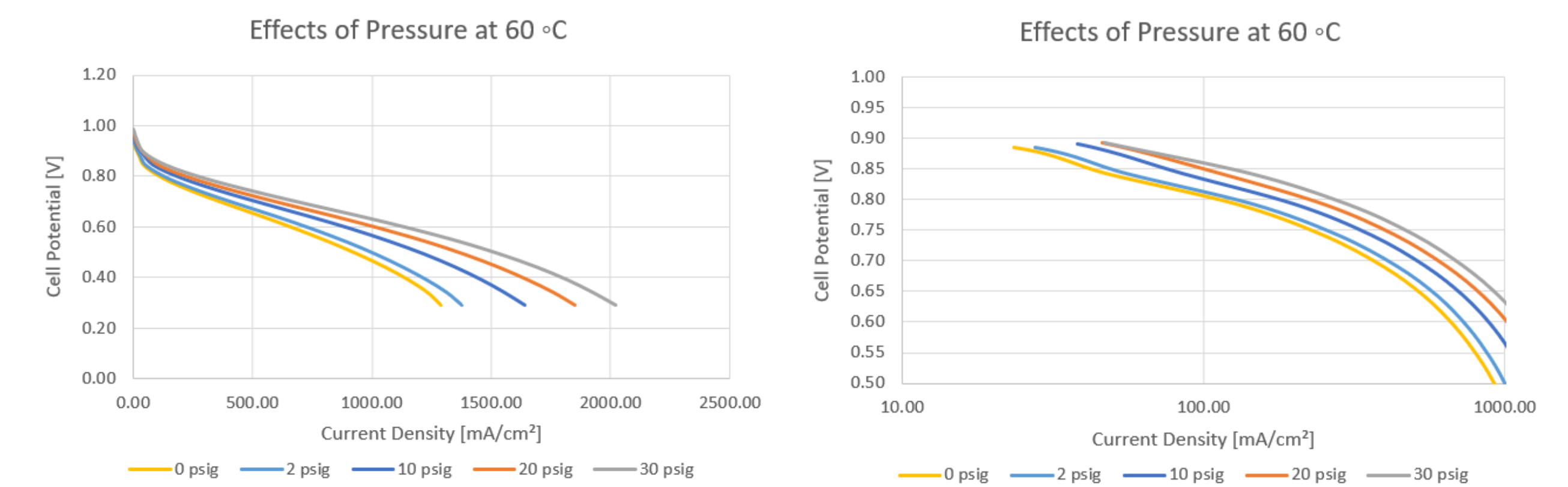


Figure 3. Polarization curves at different pressures in a) Decimal and b) Log scale

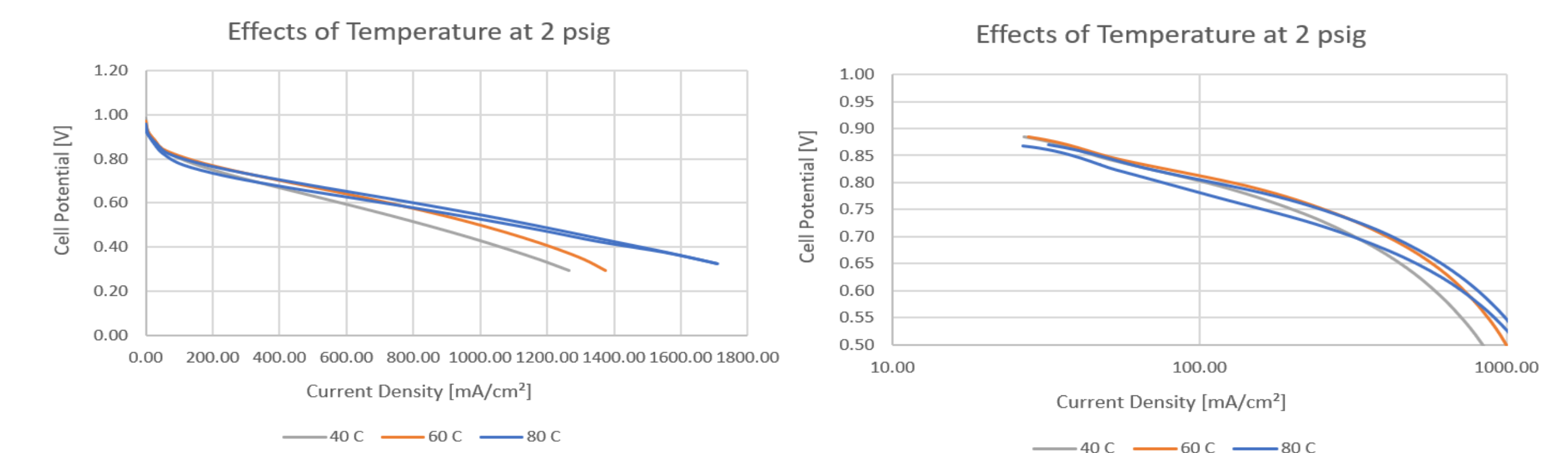


Figure 4. Polarization curves at different temperatures in a) Decimal and b) Log scale

Conclusions

The Scribner 850g system produced polarization data consistent with theoretical expectations, confirming the test station is functional for future research. Pressure effects on cell performance were qualitatively resolved: increasing pressure consistently improved cell voltage with higher-pressure curves producing greater voltage at equivalent current densities. Temperature effects could not be conclusively characterized due to partial pressure interactions at low gauge pressure and membrane dry-out at 80°C and 0 psig. Quantitative values for α and β could not be reliably extracted due to parameter coupling in the semi-empirical model fit. Future work should implement a refined fitting approach — such as fixing the Tafel slope to a theoretical value — to reduce mathematical noise and enable reliable parameter extraction. The anomalous 20 psig data point should be investigated for potential gas supply fluctuations, and 80°C trials at low pressure should be repeated with improved humidity control.

References

- Cooper, K. R., Ramani, V., Fenton, J. M., & Kunz, H. R. (2025). *Experimental Methods and Data Analyses for Polymer Electrolyte Fuel Cells*. (Ed. 1.22). Scribner.