Effect of Membrane Thickness on Hydrogen Fuel Cell Performance

By Kayle Watson

What is a Hydrogen Fuel Cell?

- Electric cell is fed a constant stream of fuel for a sustained power output.
- Hydrogen fuel cells work by converting a continuous stream of oxygen and hydrogen into energy and water via reverse electrolysis: $2H_2(g) + O_2(g) = 2H_2O + e^-$
- The products of this reaction are water and energy.

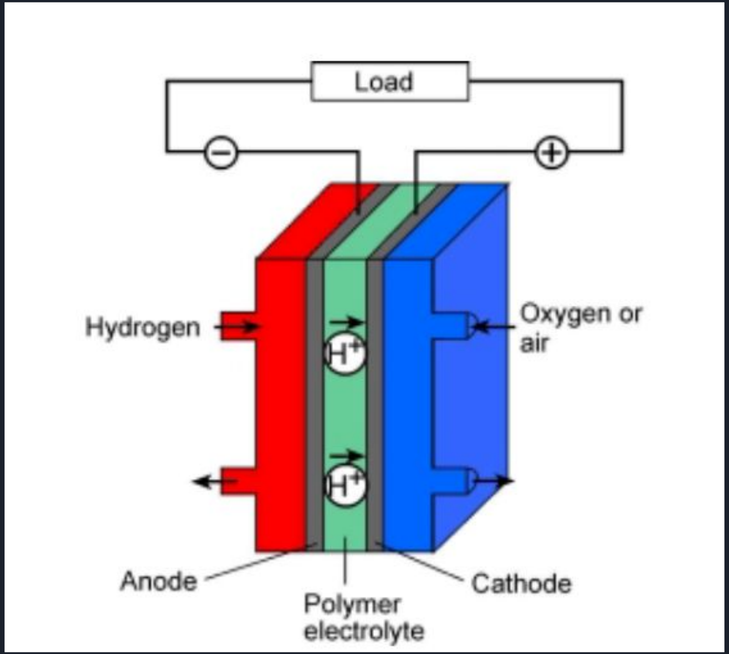


Image courtesy of Robert Cook,2001

Chemistry of the Fuel Cell

- At the anode the cell undergoes an oxidation reaction. Hydrogen bonds weakly to the platinum catalyst and gives up an electron.

- Hydrogen molecule bonds with surrounding water and forms Hydronium (H3O) which diffuses across the polymer membrane.

- Hydrogen from the fuel replaces the diffused hydrogen on the catalyst and the process repeats.

Anode reaction:	H_2	$\rightarrow 2H^+ + 2e^-$	(Eq. 3.1)
Cathode reaction:	$\frac{1}{2}O_2 + 2e^- + 2H^+$	$\rightarrow H_2O_{(l)}$	(Eq. 3.2)
Overall reaction:	$H_2 + 1/2\ O_2$	$\rightarrow H_2O_{(l)}$	(Eq. 3.3)

Image courtesy of Robert Cook,2001

The Polymer Membrane

- Membrane needs to transfer ions effectively, while also maintaining good mechanical strength to resist degradation with repeated use.
- One of the most common PEM’s is Nafion, a polymer that is a blend of Teflon and sulfonic acid, which allows for the conduction of ions.
- The membrane must be soaked to allow for ion transfer due to the way the polymer is structured: part of the polymer is hydrophilic while the other part is hydrophobic.

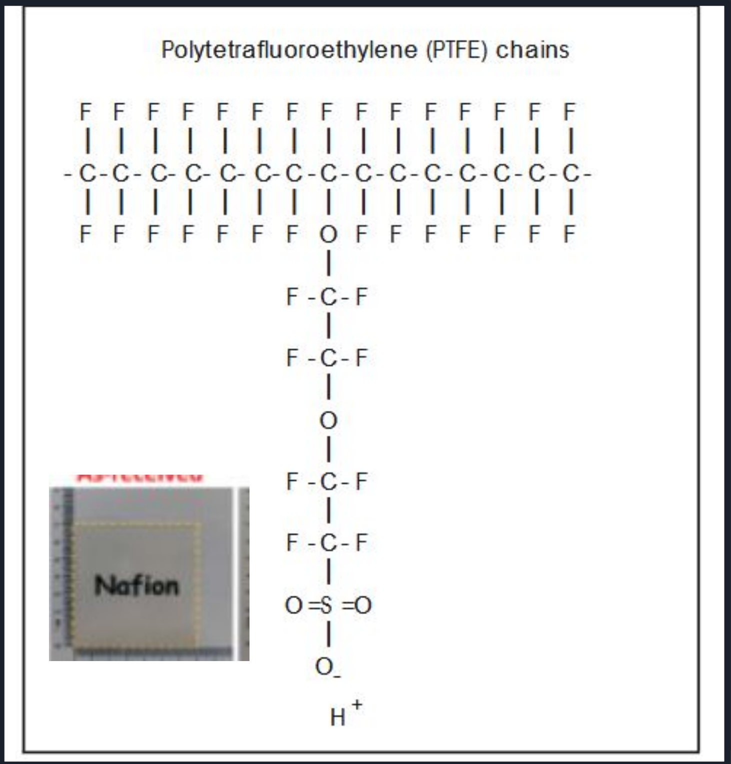


Image courtesy of Robert Cook,2001 and Nafion.com

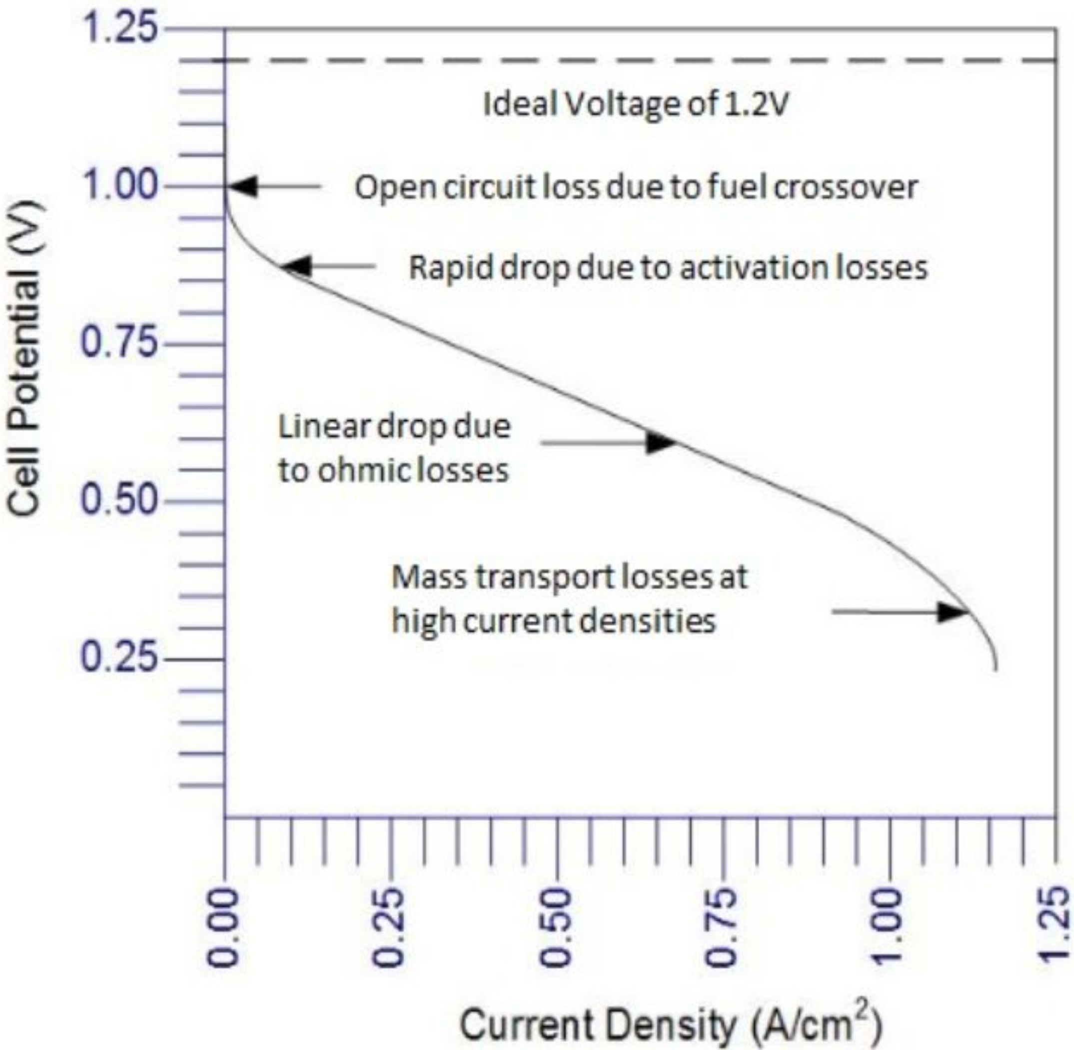
Example of a Polarization Curve

Activation loss region:
$V=a+b \ln(i)$

Linear region (ohmic loss):
$V=IR$

Mass Transport Region:
$V= c \ln(i_l-/i_l-i)$

Image courtesy of Colleen Spiegel 2017



Our Experiment

- We changed the thickness of the membrane: Nafion 115 and 117, which were .005 and .007 inches respectively. We expect this to have effects on the **ohmic resistance.**

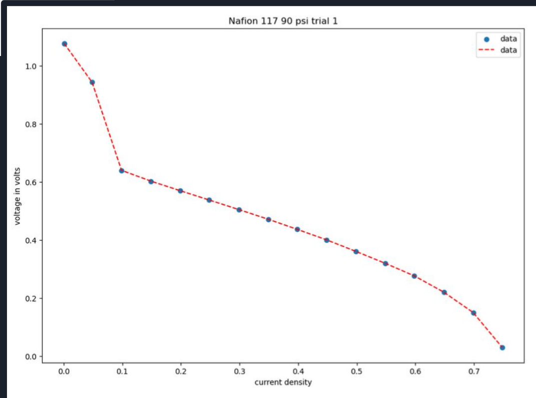
- We altered the pressure of the fuel canisters and thus the flow rate into the fuel cell. We expect this to effect when the **diffusion loss region begins.**

Fuel Cell Inc technologies Testing Station
-provided current at a constant step

```
Voltage(V),Current(A),Power(W)
1.0221,0.0010,0.00
1.0221,0.0010,0.00
0.8749,0.0485,0.04
0.6526,0.0987,0.06
0.6032,0.1488,0.09
0.5609,0.1983,0.11
0.5193,0.2483,0.13
0.4789,0.2988,0.14
0.4378,0.3491,0.15
0.3947,0.3981,0.16
0.3511,0.4486,0.16
0.3048,0.4986,0.15
0.2526,0.5489,0.14
0.1852,0.5982,0.11
0.0711,0.6484,0.05
0.0127,0.5828,0.01
0.0119,0.5415,0.01
```

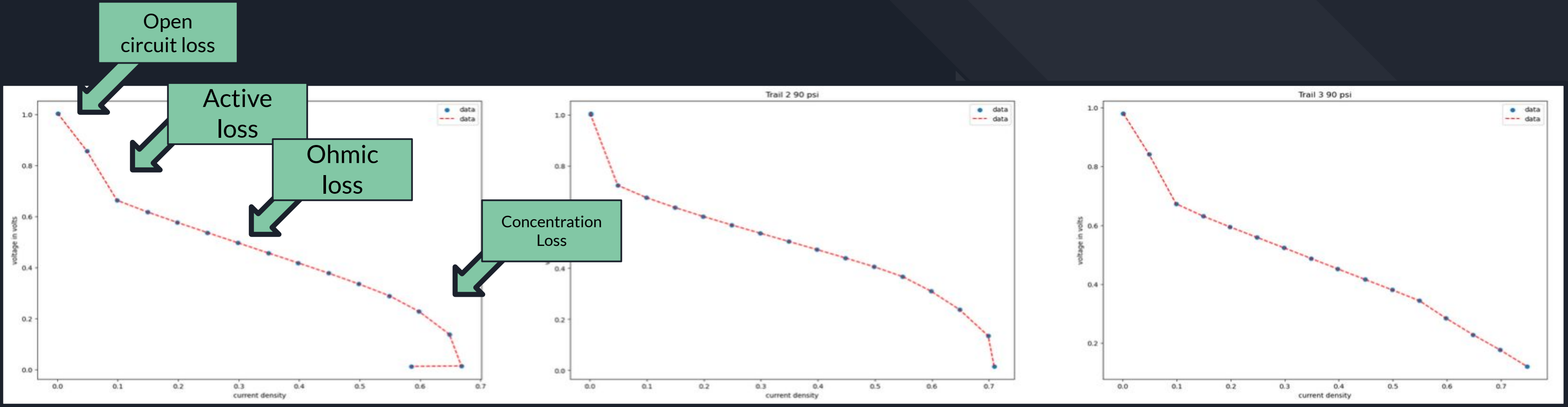
```python
import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
data=pd.read_csv('nafion 117 SCCM90 1.txt')
data.columns=['Voltage_V','Current_A','Power_W']
#trial 1 90 psi
```

```python
plt.figure(figsize=(80,8))
plt.subplot(1, 6, 1)
plt.scatter(data['Current_A'],data['Voltage_V'], label="data")
plt.plot(data['Current_A'],data['Voltage_V'],'r--', label="data
plt.ylabel("voltage in volts")
plt.xlabel("current in amps")
plt.title("Trail 1 90 psi")
plt.legend()
#^ the first trial
```



Experiment continued...

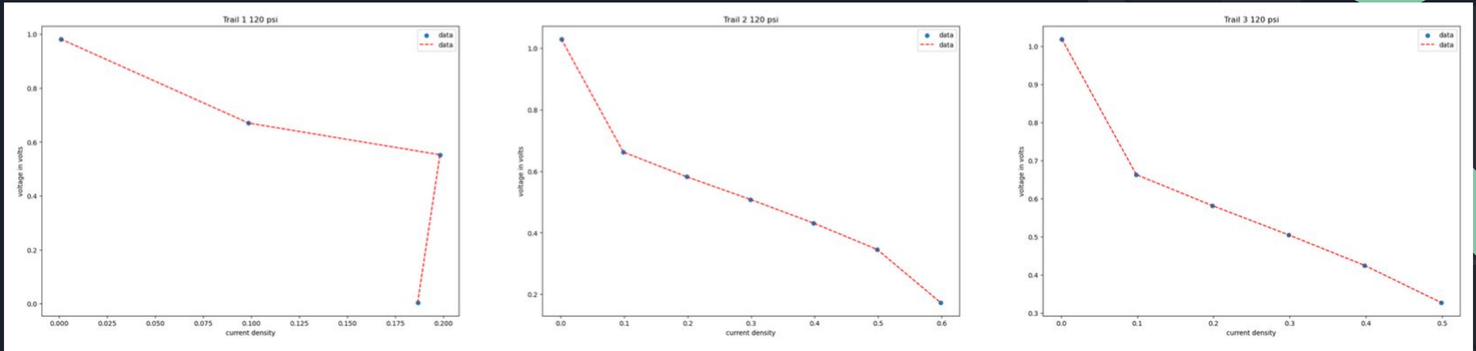
Sample Results:



Nafion 115 Polarization curves for 90 psi trials

Linear Interpolation for incomplete data

Nafion 117 at
120 psi
Trials 1-3



- Due to human error data is incomplete in some areas
- Linear interpolation will be performed after concatenating trials and averaging them

Experimental Results Summarized

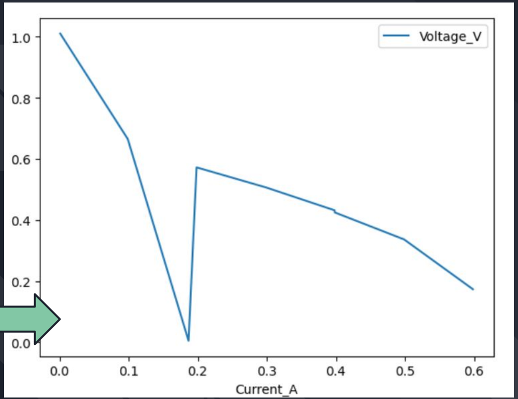
Sample	Pressure	Open circuit loss	Activation loss	Linear or Ohmic loss	Mass Transport loss	Maximum Power output
Nafion 117	60 psi	0.0-.05 A	.05-.1 A	.1-.4 A	.4-1.0 A	Unclear
	90 psi	0.0-.05 A	.05-.1 A	.1-.55 A	.55 -1.0 A	.2 Watts
	120 psi	Unclear	Unclear	.45-.65 A	.65- 1.0 A	.170 Watts
Nafion 115	60 psi	Unclear	Unclear	.045-.1 A	.1-1.0 A	Unclear
	90 psi	Unclear	Unclear	.4-.6 A	.6-1.0 A	.170 Watts
	120 psi	0.0-.05	.05-.1 A	.1-.6 A	.6-1.0 A	.150 Watts

Table 1: Summary of IV behavior for Nafion 117 and 115 across the varying pressure ranges. The open circuit and active loss region were found to stay constant across both materials at all pressures.

Finding the resistance with linear regression

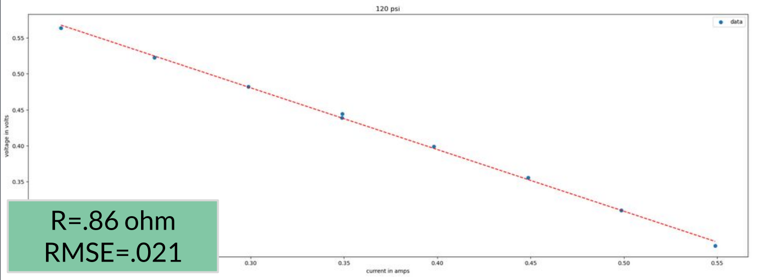
```
data4=pd.concat((data,data2,data3))
df=pd.DataFrame(data4)

df.describe()
#df.sort_index(axis=1)

df2=df.groupby("Current_A").mean().reset_index()
df3=df2[3:8]
print(df2)
#df[4:12]
df2.plot("Current_A","Voltage_V")
plt.show()
```

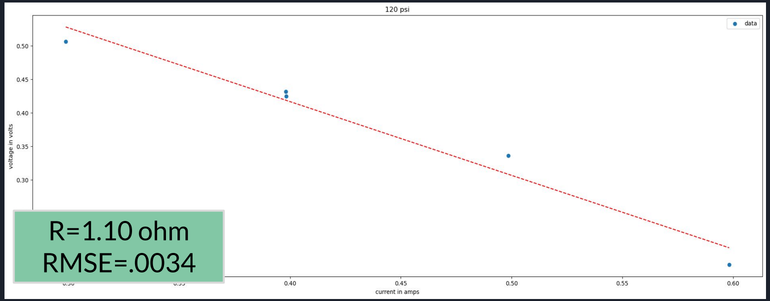
	Current_A	Voltage_V	Power_W
0	0.0010	1.010300	0.000000
1	0.0987	0.665133	0.070000
2	0.1867	0.004200	0.000000
3	0.1983	0.572133	0.116667
4	0.2988	0.506400	0.150000
5	0.3981	0.431500	0.170000
6	0.3983	0.424600	0.170000
7	0.4986	0.336200	0.16500
8	0.5982	0.173100	0.100000



-Concatenated data from trials into a data set using pandas
-averaged repeat values using pandas groupby function
- graphed combined curve

Finding the resistance with linear regression

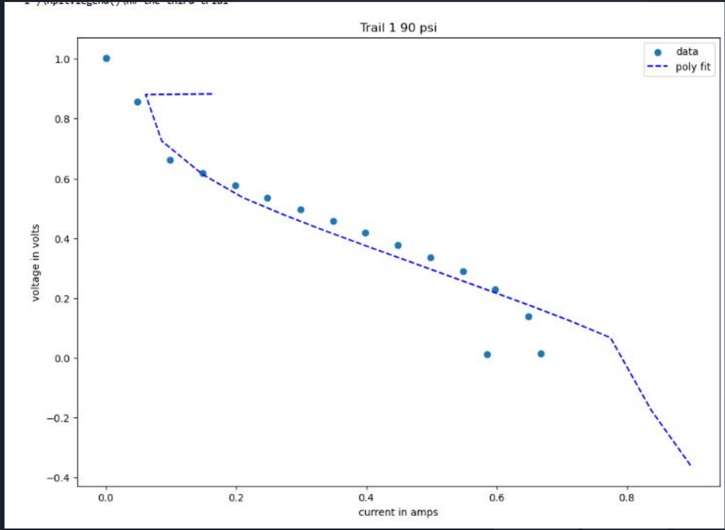




- Top figure Nafion 115 and bottom Nafion 117
- Plotted and fitted the ohmic loss using linear regression from sklearn
- The slope of this plot gave us the resistance of the membrane
- Cannot yet determine the bounds of the linear region

Fitting the polarization curve

```
#got to reshape b/c poly fit takes a 2d array and our data is 1d
x_r=x.reshape(-1,1)
y_r=y.reshape(-1,1)
#polyfit params:
poly=PolynomialFeatures(degree=1)
current_poly=poly.fit_transform(x_r)
voltage_poly=poly.fit_transform(y_r)
model = LinearRegression().fit(current_poly, y)
current_fit=model.predict(current_poly)
voltage_fit=model.predict(voltage_poly)
#goodness of fit
rmse = np.sqrt(mean_squared_error(y,current_fit))
```



- Fit polarization curve using sklearn
- Used a 1st degree polynomial
- Poor fit R^2 value of

Next Steps:

1. Fit Polarization curve using PolCurveFit 1.2.1 library
2. Obtain the exact currents at which the voltage regions change to get operating region of the cell
3. Compare against literature

Sources:

[1]An Introduction to Fuel Cells and Hydrogen Technology, Brain Cook,Heliocentris North America, 2001

[2]**A Practical Beginner's Guide to Cyclic Voltammetry** Noémie Elgrishi, Kelley J. Rountree, Brian D. McCarthy, Eric S. Rountree, Thomas T. Eisenhart, and Jillian L. Dempsey Journal of Chemical Education **2018** *95* (2), 197-206
DOI: 10.1021/acs.jchemed.7b00361

[3]Mohammad Bagher Karimi, Fereidoon Mohammadi, Khadijeh Hooshyari,
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