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Joey Wehrley
Macalester College, jwehrley@macalester.edu

James Doyle
doyle@macalester.edu

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Polymer Electrolyte Membrane (PEM) electrolysis is a form of electrolysis that is heavily used in commercial capacities. It functions by using a membrane and an electric charge in order to perform electrolysis water, splitting it into its component parts - Hydrogen and Oxygen. These parts can then be used in a number of different applications, including reversing the electrolysis process to regenerate some energy in the form of electricity. During this experiment, multiple currents were run through a PEM cell, and voltages across the membrane were measured. It was found that a standard R/C charging model can be fit to low current applications of the PEM cell, but beyond very small currents, there is little to no correlation between the data results and the model predictions

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Electrical Analysis of a PEM Electrolysis Cell

Joey Wehrley[1] and Dr. Jim Doyle[1]

[1]*Department of Physics & Astronomy, Macalester College, 1600 Grand Avenue, Saint Paul, MN 55105, USA*

Abstract

Polymer Electrolyte Membrane (PEM) electrolysis is a form of electrolysis that is heavily used in commercial capacities. It functions by using a membrane and an electric charge in order to perform electrolysis water, splitting it into its component parts - Hydrogen and Oxygen. These parts can then be used in a number of different applications, including reversing the electrolysis process to regenerate some energy in the form of electricity. During this experiment, multiple currents were run through a PEM cell, and voltages across the membrane were measured. It was found that a standard R/C charging model can be fit to low current applications of the PEM cell, but beyond very small currents, there is little to no correlation between the data results and the model predictions.

1. LITERARY MODEL

There have been many models created for PEM electrolysis processes, and publications on these are easy to find. As such, a model was taken from Ni et al. (2006) to create a predictive analysis of a current vs voltage relationship would be. With a base equation of

$$V = E + \eta_{ohmic} + \eta_{act,a} + \eta_{act,c} \tag{1}$$

where

$$E = 1.23 - 0.9 * 10^{-3}(T - 298) + 2.3\frac{RT}{4F}log(P_{H_2}^{\ 2} P_{O_2}) \tag{2}$$

$$\eta_{ohmic} = JR_{PEM} \tag{3}$$

$$\eta_{act,i} = \frac{RT}{F} sinh^{-1}(\frac{J}{2J_{0,i}} \tag{4}$$

These equations provide a Voltage relationship that is dependent on some inherent qualities of the PEM cell and the material that the membrane is made of, temperature, and current. By fixing the variables related to the construction of the cell as well as temperature, a model of the Current Voltage relationship was constructed (Fig. 1)

This model was used against lab results taken from experimental data for comparison.

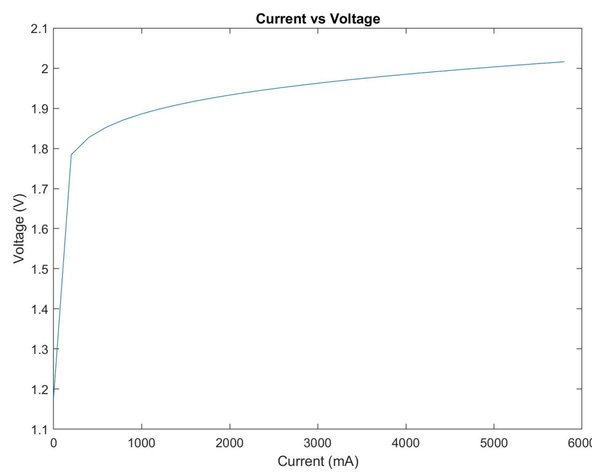

Figure 1. Voltage Current Model

jwehrley@macalester.edu

doyle@macalester.edu

2. PROCEDURE

The PEM cell was connected to a computer program that worked twofold; it could both send and regulate currents going into the cell, as well as measure the voltage across it. Two different kinds of trials were run - increasing vs decreasing currents over time, and fixed currents over time. For varying charges, the cell was initially stabilized at a 15 milliamp (mA) charge, which was then reduced by 0.2mA every 20 minutes until it reached 0mA. This procedure was then reversed, with the cell being stabilized at a 0mA current, and increased by 0.2mA every 20 minutes until it reached 15mA. For the fixed current trials, data was taken after zeroing out the cell between each trial, and then applying charges of 1, 2, 3, 6, 9, and 12mA for 60 minutes. Further data was collected at 5, 7, and 8mA charges through the same method for a time of 120 minutes. The voltages measured during all of these trials were then compiled into a number of graphs to show the relationship between current and voltage for the PEM cell, and compared to the expectations based on the model. Taking into account the capacitative nature of the cell, a comparison was also made between the fixed current charges and a simple R/C charging model in order to check for correlation.

3. RESULTS

Fig. 2 is a dual graph showing the voltages measured while increasing and decreasing the current that was applied to the PEM cell

Fig. 3 is the initial slew of fixed currents, where the current was held at varying constants over the course of one hour

Fig. 4 is a select few middle level currents that were held for two hours

Fig. 5 is taking certain fixed charge data and comparing it to the expected result, if a standard R/C charging model were used

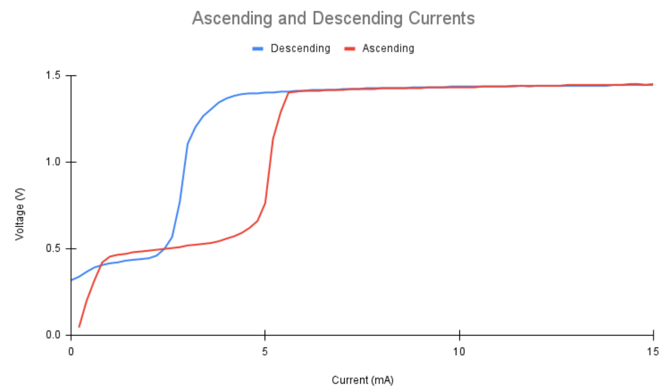

Figure 2. Ascending vs Descending currents

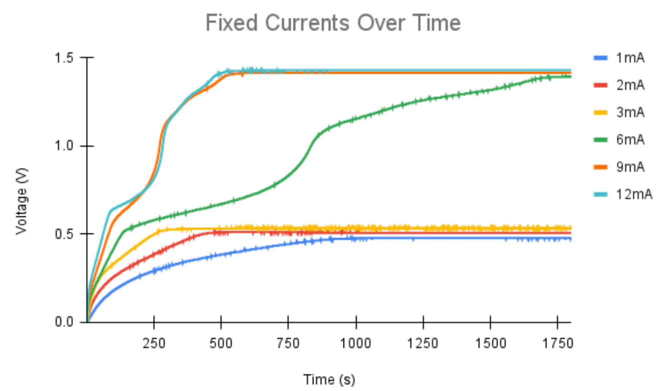

Figure 3. Fixed currents over 1 hour

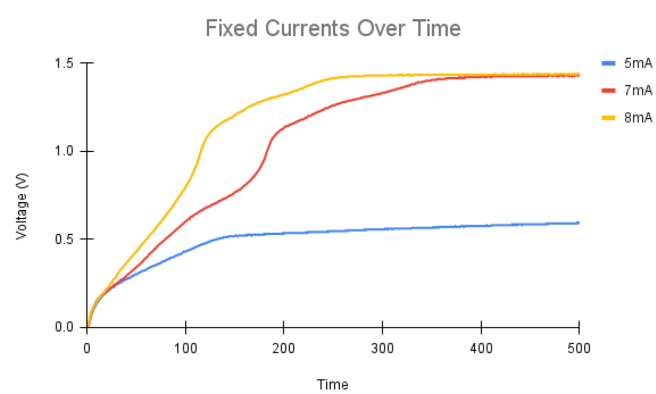

Figure 4. Fixed currents over 2 hours

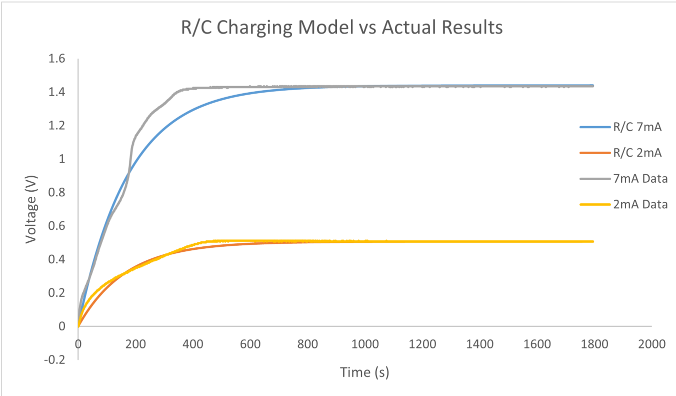

Figure 5. Specific data fixed to R/C model

4. CONCLUSIONS

4.1. *Changing Current*

With the ascending vs descending graph, there is a significant deviation from the approximated model. There are variations both in the results from the differing directions of current build up, as well as a plateau in the data around the mid range currents. Neither of these aspects were represented in the model graph, so there must be some sort of deviation from expectation within the experiment. The difference between the two trials could be attributed to one or both of two separate things: discharge times and hysteresis. With any capacitor, and the PEM cell essentially acts as one, there is a period of discharge that takes place after a charge has been applied. With a charged membrane, it is possible that in the trial where a high charge was initially applied and then reduced over time, the time interval between changes in charge simply was not enough for the cell to discharge its built up charge in order to read properly. This would explain why at 0mA, there was still some latent voltage associated with the cell, and why the descending charges read higher voltages throughout the decline of the slope. Hysteresis could also be at play, wherein the data collecting tools maintain a pseudo memory of the data that was just collected, and err on the side of reproducing the same result. This would lead the data collected in the increasing currents trial to read as lower voltages, and that from the decreasing trial to read higher voltages. Since it is impossible to conclude from the data collected if it is only one of, or both of these factors at play, a true idea of the voltage current dependency cannot be determined. If it was solely the charge build up, then the increasing current model would be completely accurate, and if it were only hysteresis effects, then the true line would be around the average of the two. Most likely, there is a combination of both effects present, and the true values would be found somewhere in the difference between the two data sets, but it would not be possible with the current data to accurately pinpoint exactly where. The bigger concern is the plateau in the data around 0.5 V. This is not a result that had been predicted, and another model depicting this behavior could not be found in the literature. The only real conclusion that this brings is that the cell that was used for this experimentation does not follow a predictable charging pattern, and is not a reliable model for a commercial PEM cell.

4.2. *Fixed Currents*

The fixed current results both fit and do not fit expected models from a standard R/C charging prediction. At the lowest currents applied to the cell, 1, 2, 3, and possibly 5mA, there seems to be a simple curve relationship that adheres well to the simple R/C model that would be expected. At higher charges there is slight correlation to this model, however there is some structure early on in each of the higher trials (7, 8, 9, 12maA) that deviates significantly from the model's curve. While this could be simple data fluctuation and dismissed as practical noise, it seems to repeated and structurally similar to the erratic patterns viewed in the 6mA current data to be thrown out entirely. With the 6mA current, and possibly more, there is very little resemblance to an expected standard R/C model, and it is clear that it does not follow this relation. More data would need to be collected in order to provide a clear and accurate depiction of the actual relation that this cell follows, however it is at this point in the data collection that the equipment being used was broken, so further collection was no longer a possibility.

4.3. *Important Considerations*

It is important to note that throughout these experiments, models and predictions were taken from the expectations of a commercial level PEM fuel cell. That which was used for data collection was a classroom issue model that had been left unused for many years. While the data collected, and the conclusions drawn from it are accurate for this specific cell, it is possible, and likely, that they only apply to the specific model of cell used, and possibly even the specific individual piece of equipment. In all other instances and publications in which this data has been collected, none of these types of relationships have been documented. It is also worth noting that the currents used for this experiment are orders of magnitude lower than those typically used for PEM Electrolysis. The nature of these results might still apply to all PEM cells, however they would be largely inconsequential due to the impracticality of running such a piece of equipment on such low currents.

REFERENCES

Ni, Meng, Leung, Michael K. H., Leung, Dennis Y. C. 2006, WHEC, 16, 13-16.