Explaining Non-uniformity in Current Output Occuring in Fuel Cells

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Introduction

Fuel cells are highly efficient energy generators with minimal emissions and their performance is significantly influenced by operating conditions. This poster will examine the effects of non-uniform current distribution across the active area of the cell and its impact on overall performance and durability. Additionally, the influence of varying load conditions will be analyzed. Finally, recommendations will be provided to improve the durability and efficiency of fuel cells.

Background

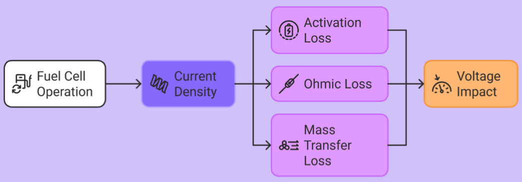
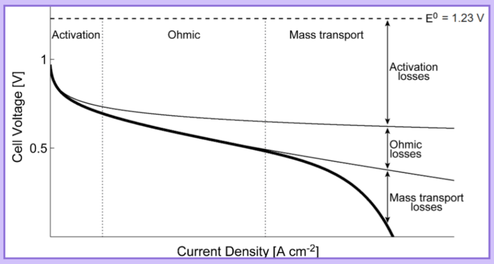


Figure 1: Polarization Curve of a Fuel Cell and Its Three Major Losses



1. Activation Losses: Dominant at Low Current Density

- In a fuel cell, reactions occur at the anode (hydrogen oxidation reaction, HOR) and cathode (oxygen reduction reaction, ORR).
- The oxygen reduction reaction (ORR) at the cathode is much slower than the hydrogen oxidation reaction, making activation losses more significant.
- At low current densities, the reaction rate is slow, meaning most of the voltage drop is due to the energy required to activate the reaction.

$$V_{\text{act}} = \frac{RT}{\alpha n F} \ln\left(\frac{i}{i_0}\right)$$

2. Ohmic Losses: Dominant at Medium Current Density

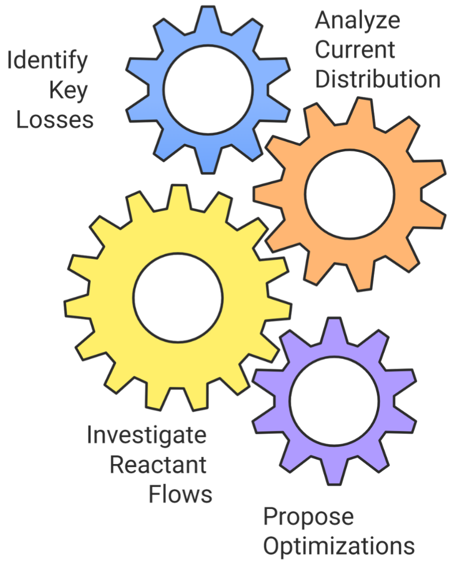
- Ohmic losses arise due to resistance to electron flow and resistance to proton transport.
- There are three primary sources of ohmic losses:
  a. Proton resistance in the membrane: The proton exchange membrane (PEM) must be hydrated to conduct protons effectively. If the membrane is dry, proton resistance increases.
  b. Electronic resistance in the electrodes and bipolar plates: Current must travel through the electrodes, gas diffusion layers (GDL), and bipolar plates, each of which has some inherent resistance.
  c. Contact resistance at interfaces: Poor contact between layers increases resistance.

$$V_{\text{ohm}} = iR_{\text{int}}$$

3. Mass Transport Losses: Dominant at High Current Density

- The primary cause of mass transport losses is difficulty in supplying sufficient reactants (O_2 and H_2) to the reaction sites.
- At high current densities, the fuel cell consumes oxygen and hydrogen at a high rate, which can amplify the concentration gradient of reactants over the active area of the cell

$$V_{\text{conc}} = -\frac{RT}{nF} \ln\left(1 - \frac{i}{i_{\text{lim}}}\right)$$



Method

The data values were pre-generated by Powercell in their lab and provided to the group for further processing. Powercell is a well-established company that primarily manufactures and develops proton-exchange membrane fuel cells, which was also the type used in the lab. The data contained current levels covering the active area of a single fuel cell. To visualize the variations in current, the points were plotted using python coding and matplotlib.

Results

The current is modelled in the graphs below, displaying results for two scenarios: high load and low/medium load. The fuel inlet occurs at the left short-end side of the cell.

Figure 2: Single fuel cell current variations - high load

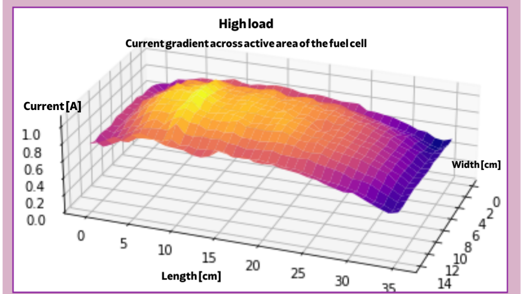


Figure 3: Single fuel cell current variations - low/medium load

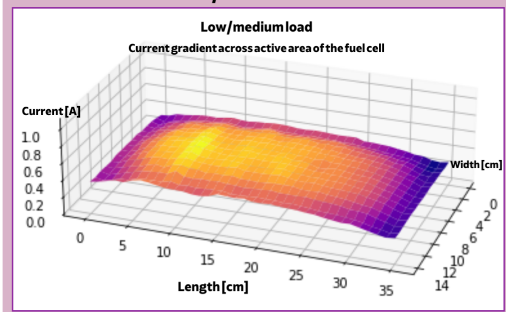


Figure 4: Flow directions in fuel cell

Discussion

The shapes of the models for the two scenarios differ slightly, as the high-load scenario shows greater variations in the produced current compared to the low/medium-load scenario. This is due to increased mass transfer losses at higher loads, resulting in a more uneven current distribution.

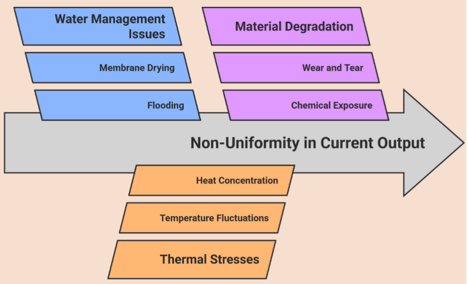
An **uneven distribution of reactants is the cause of the observed results.** Especially at high loads, the increased consumption of reactants exacerbates mass transport overpotential, leading to reactant diffusion issues. Water being produced at the cathode may accumulate or flood in areas which have a smaller reactant concentration such as channel bends or outlet regions, causing further blockage of flows.

Variations in current output compromise the performance and durability of the fuel cell. Since unevenly distributed reactants cause a pressure drop, the resulting voltage drop, according to the Nernst equation, leads to a reduction in the potential power output.

Nernst equation

$$E = E_0 + \frac{RT}{nF} \ln\left(\frac{P_{H_2} \cdot P_{O_2}^{1/2}}{P_{H_2O}}\right)$$

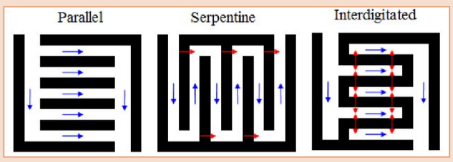
Describes the open circuit voltage in a fuel cell based o a few operating conditions, mainly temperature, reactant and product pressures.



Recommendations

1. **Efficient flow design** - Using either an interdigitated or a serpentine flow design helps to reduce these losses. Interdigitated flow improves reactant penetration. Serpentine flow reduces water pooling. Balance Channel to rib ratio.
2. **Enhanced GDL performance** - Use hydrophobic/hydrophilic coating to guide the water. Use combination of high & low porosity for the GDL. High porosity increases the gas permeability & low porosity brings stability & water flow.
3. **Use advanced material for BPP's** - Bipolar plates with high thermal conductivity keep the temperature uniform throughout, reduces possibility of localized heat zones which deplete the reactant.
4. **Manage operating conditions** - Maintaining gas pressure improves reactant diffusion & maintaining humidity balances membrane between drying & excess water accumulation. High reactant flow rate ensures optimal availability, avoiding concentration.
5. **Improved catalyst layer & microporous layer (MPL)** - Thinner catalyst layer makes reactant more accessible & lowers diffusion resistance. MPL enhance gas diffusion by avoiding water pooling in the GDL.

Figure 4: Three most common and basic flow fields blue arrow - bulk flow, red arrow - cross flow



References

Electrochemistry - Fuel Cells: Mass Transport
https://sites.chemistry.unt.edu/~tgolden/courses/Lecture%2018%20Fuel%20Cells_Mass%20Transport%202022.pdf

Fan Yang, Xiaoming Xu, Yuehua Li, Dongfang Chen, Song Hu, Ziwen He, Yi Du. A Review on Mass Transfer in Multiscale Porous Media in Proton Exchange Membrane Fuel Cells: Mechanism, Modeling, and Parameter Identification
https://www.mdpi.com/1996-1073/16/8/3547

Fuel Cell Handbook (Seventh Edition)
https://www.netl.doe.gov/sites/default/files/netl-file/FCHandbook7.pdf

García-Salaberri, P. A. A Numerical Assessment of Mitigation Strategies to Reduce Local Oxygen and Proton Transport Resistances in Polymer Electrolyte Fuel Cells. Materials, 16(21), 6935.
https://doi.org/10.3390/ma16216935

Mostafa Mortada, Haitham S. Ramadan, Jalal Faraj, Ahmad Faraj, Hicham El Hage, Mahmoud Khaled. Impacts of reactant flow nonuniformity on fuel cell performance and scaling-up: Comprehensive review, critical analysis and potential recommendations. International Journal of Hydrogen Energy, Volume 46, Issue 63, 2021, Pages 32161-32191, ISSN 0360-3199.
https://doi.org/10.1016/j.ijhydene.2020.06.013

Skill-Lync. Nernst's Equation & Polarization Curve. Skill-Lync.
https://skill-lync.com/student-projects/nernst-s-equation-polarization-curve