Investigations on polarization losses in planar Solid Oxide Fuel Cells

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Solid Oxide Fuel Cell (SOFC)

- At the anode:
  \[ H_2 + 2O_2^- \rightarrow 2H_2O + 4e^- \]
- At the cathode:
  \[ O_2 + 4e^- \rightarrow 2O_2^- \]
- The overall cell reaction:
  \[ O_2 + 2H_2 \rightarrow 2H_2O \]

Roles of Electrolyte:
- Oxygen ion conduction
- Physically separates the fuel from oxidant

Roles of Electrode:
- Hosts triple phase boundary to support electrochemical reactions
- Provides path for \( O^{2-} \) ions/electrons
- Provides channels for gas diffusion
- Gives mechanical support to system
Types of SOFC Design

SOFC

- Tubular
  - Interconnector
- Planar
  - Cathode supported
  - Anode supported

**Electrolyte supported**
- Cathode: ~50 µm
- Electrolyte: ~200 µm
- Anode: ~50 µm

**Cathode supported**
- Cathode: ~500 µm
- Electrolyte: ~10 µm
- Anode: 300-1000 µm

**Air Flow**

**Fuel Flow**
Background and Significance

- Solid Oxide Fuel Cell (SOFC) has been consistently rated as one of the top sources of alternative energy due to its high efficiency.
- It is essential to optimize various polarization losses to realize the maximum efficiency.
- Voltage losses associated with electrode and electrolyte can vary with different types of SOFC viz. anode, cathode and electrolyte supported SOFC.
- Voltage losses categorized as – activation, ohmic and concentration.
- Recent efforts in SOFC development centered on reducing these losses.
- So it is crucial to establish best possible configuration in the perspective of polarization loss.
Objectives

- To simulate solid oxide fuel cell (SOFC) using COMSOL Multiphysics
- To experimentally verify the simulated results
- To establish the polarization losses of different SOFC configurations such as anode, cathode and electrolyte supported designs
COMSOL Simulation

- **Geometry:** Single Channel SOFC

- **Meshing:** Face Mapped Mesh swept along the length of SOFC
Physics Involved:

- **Secondary current Distribution:** Determines current profile. Accounts for the effect of the electrode kinetics and losses due to resistance.

- **Transport of Concentrated Species:** Determines species flux across electrode. Involves flow of species across the porous electrodes via diffusion and transport of oxide ion.

- **Free and Porous Media Flow:** Determines flow profile. Accounts for flow in channel and porous media.
Experimental: Fabrication Procedure

- NiO-YSZ
- Slurry Preparation
- YSZ
- Tape Casting
- Doctor Blade
- Ceramic Slurry
- Green Ceramic Tape
- Drying
- Glass Plate
- Lamination
- LOAD
- Single layer electrolyte (YSZ) tape
- Multiple layers of anode (NiO-YSZ) tapes
- Binder Burn Out
- Sintering
- Screen Printing
- Cathode (LSM)
- Heat Treatment
- Single Cell

Anode Supported SOFC single cell

Microstructure of SOFC single cell
Experimental: Button Cell characterization

- Linear sweep voltammetry
- Performance study at various temperatures (700 °C - 800 °C)
- Exchange current density by Tafel plot
Exchange Current Density

- Exchange current density is an important electrochemical property
- It is a measure of electro catalytic activity of electrode
- Dependant on structure & material of electrode and also type of fuel used

\[ \log(i_0) = -3491.6\left(\frac{1}{T}\right) + 1.9692 \]

\[ \log(i_0) = -3944.6\left(\frac{1}{T}\right) + 2.6261 \]

Cathode Activation Energy = 29.03 kJmol\(^{-1}\)  
Anode Activation Energy = 39.73 kJmol\(^{-1}\)
Model Validation

Polarization Curve at 800°C

Electrolyte Supported Cell

- Electrolyte thickness: 1mm
- Anode: 100 μm
- Cathode: 100 μm

Anode Supported Cell

- Electrolyte thickness: 10 μm
- Anode: 1 mm
- Cathode: 100 μm
Effect of Parameters

Electrolyte Thickness

Temperature

Good agreement between experimental and simulated results!!
Simulation Results

- Effect of Electrolyte thickness
• Effect of Anode thickness
Effect of Cathode Thickness
Effect Of Support Thickness

ASC

CSC

ESC
Activation Over potential losses at the individual interface

(At Cell voltage 0.7V and 800°C)

- Drastic reduction in electrochemical reaction in electrolyte supported cell
- Cathode activity increases with cathode thickness in the thickness range of 10 - 100 μ
Effect Of Support Thickness

At Cell voltage 0.7V and 800°C

\[ R_{ohm} = \left( \frac{\delta_{\text{anode}}}{\sigma_{\text{anode}}} \right) + \left( \frac{\delta_{\text{electrolyte}}}{\sigma_{\text{electrolyte}}} \right) + \left( \frac{\delta_{\text{cathode}}}{\sigma_{\text{cathode}}} \right) \]

\[ \eta_{act} = \frac{RT}{anF} \sinh^{-1} \left( \frac{j}{2j_0} \right) \]

\[ \eta_{conc} = \frac{RT}{2F} \ln \left( \frac{P_{H2O_{tpb}}P_{H2}}{P_{H2O}P_{H2_{tpb}}} \right) + \frac{RT}{4F} \ln \left( \frac{P_{O2}}{P_{O2_{tpb}}} \right) \]
Optimization of Concentration Overpotential

(At 800°C)

- Concentration over potential dominates at low fuel inlet velocity
- A compromise needs to be made between fuel utilization and power output

Electrolyte thickness -10 μ
Anode – 1 mm
Cathode – 100 μ
Cell length – 50 mm
Operating cell voltage

(At 800°C)

Fuel inlet velocity = 0.35 m/s

- Efficiency maximizes around 0.7 V
- Fuel utilization drops at higher voltage due to low current generation for the given fuel

$$\varepsilon = \frac{W_c}{\dot{m}_{\text{f,in}} \Delta h_{\text{f,in}}} = \left\{ \frac{E_{\text{rev}}}{E_h} \right\} \left\{ \frac{E_{\text{cell}}}{E_{\text{rev}}} \right\} \left\{ \frac{(m h)_{\text{in}} - (m h)_{\text{out}}}{\dot{m}_{\text{f,in}} \Delta h_{\text{f,in}}} \right\}$$

$$\varepsilon = \varepsilon_{\text{REVU}}.$$
Conclusion

- Modeling and simulation of SOFC was carried out with COMSOL multiphysics.
- The experimental results validated the model.
- The deviation at any point of VI curve was less than 8%.
- Best agreement between simulated and experimental results was evident at 0.7 V Operating voltage.
- For a given support thickness, concentration polarization of ASC was twice that of CSC. However, activation over potential of CSC was marginally higher than ASC.
- Thus, in the perspective of polarization losses, cathode supported SOFC was found to be superior than anode supported design.
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