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Investigations on polarization losses in planar Solid Oxide Fuel Cells

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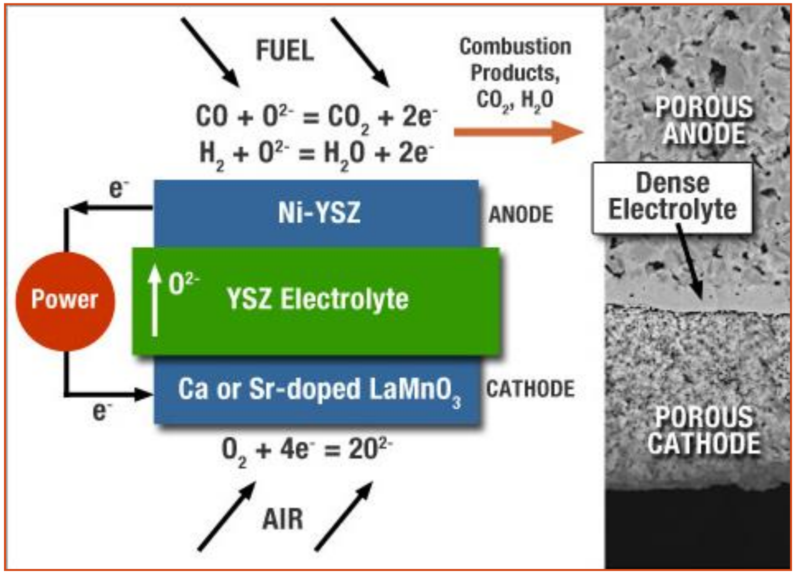
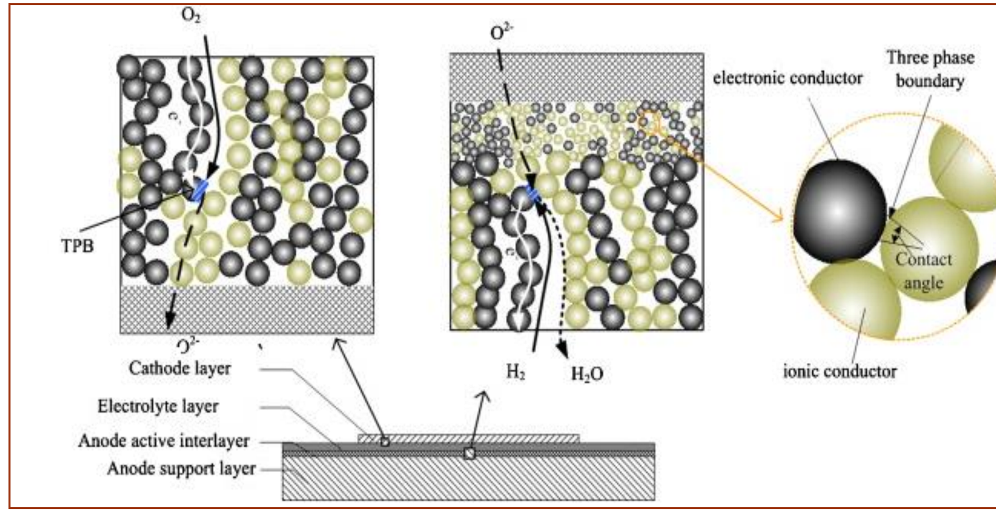
Solid Oxide Fuel Cell (SOFC)





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

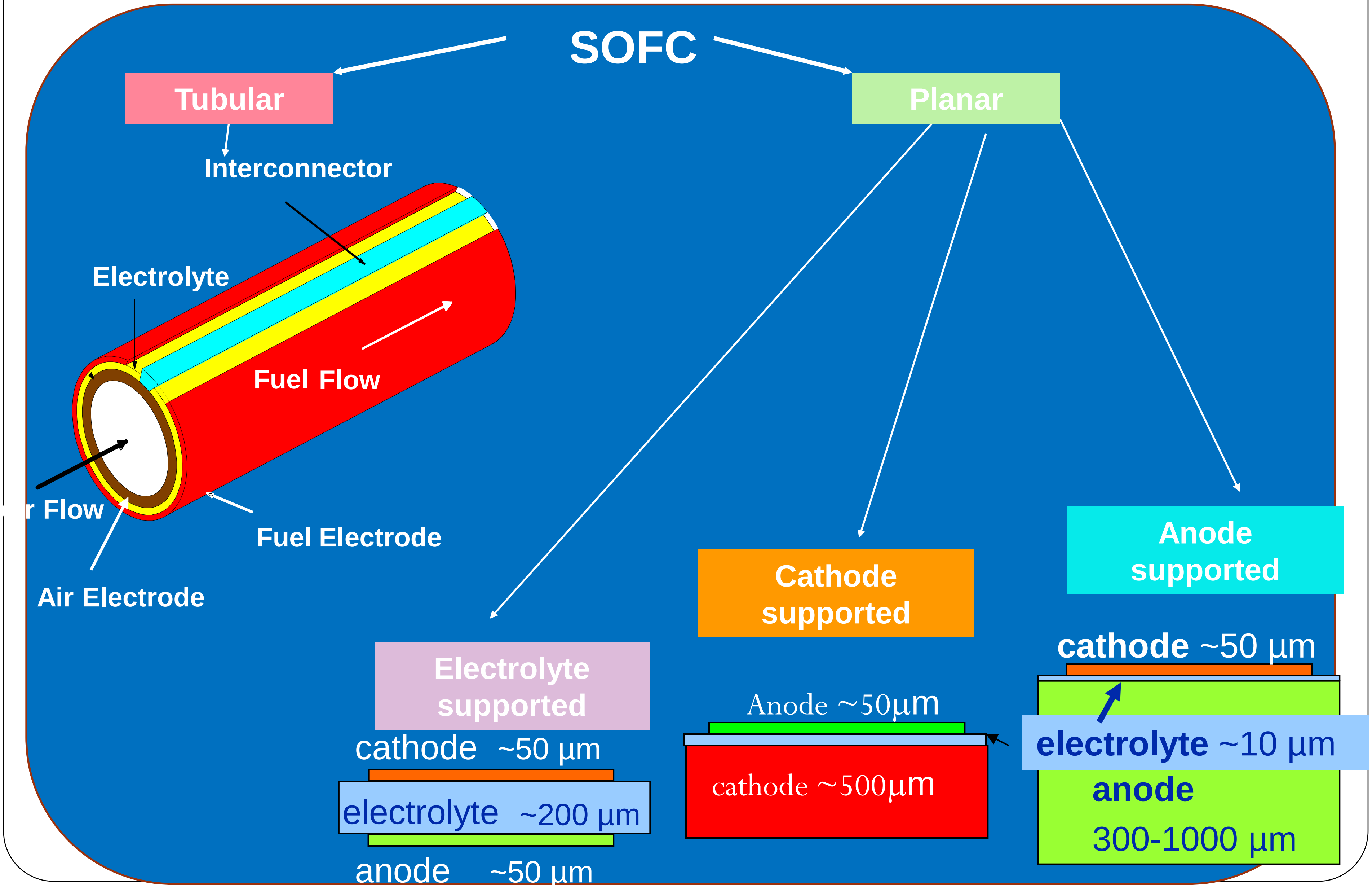
Roles of Electrolyte:

- Oxygen ion conduction
- Physically seperates 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



Background and Significance

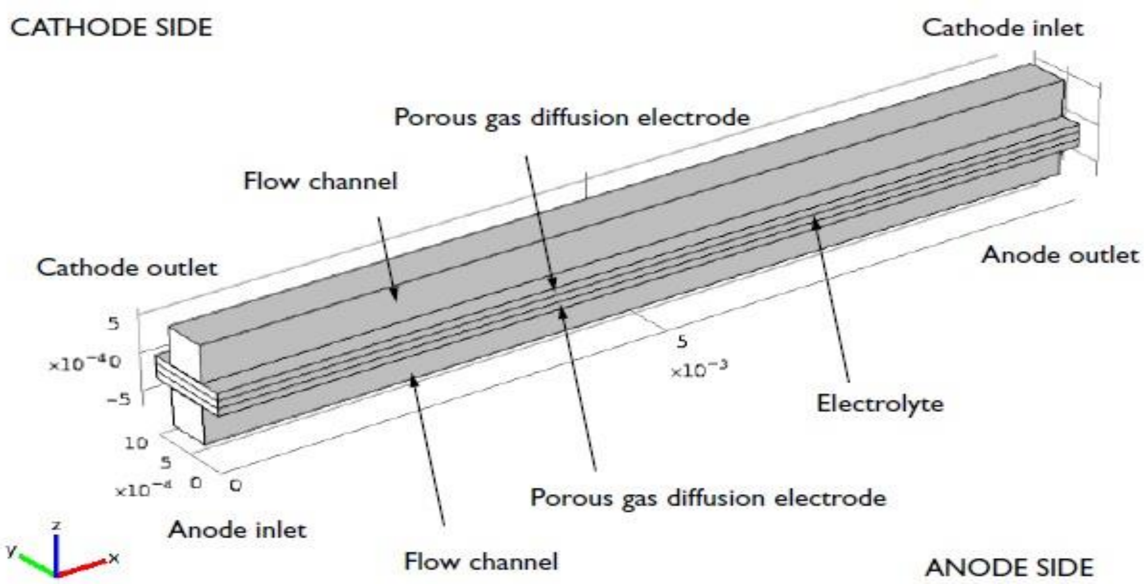
- Solid Oxide Fuel Cell (SOFC) has been consistently rated as one of the top sources of alternative energy due to its high efficiency
- It is essential to optimize various polarization losses to realize the maximum efficiency.
- Voltage losses associated with electrode and electrolyte can vary with different 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

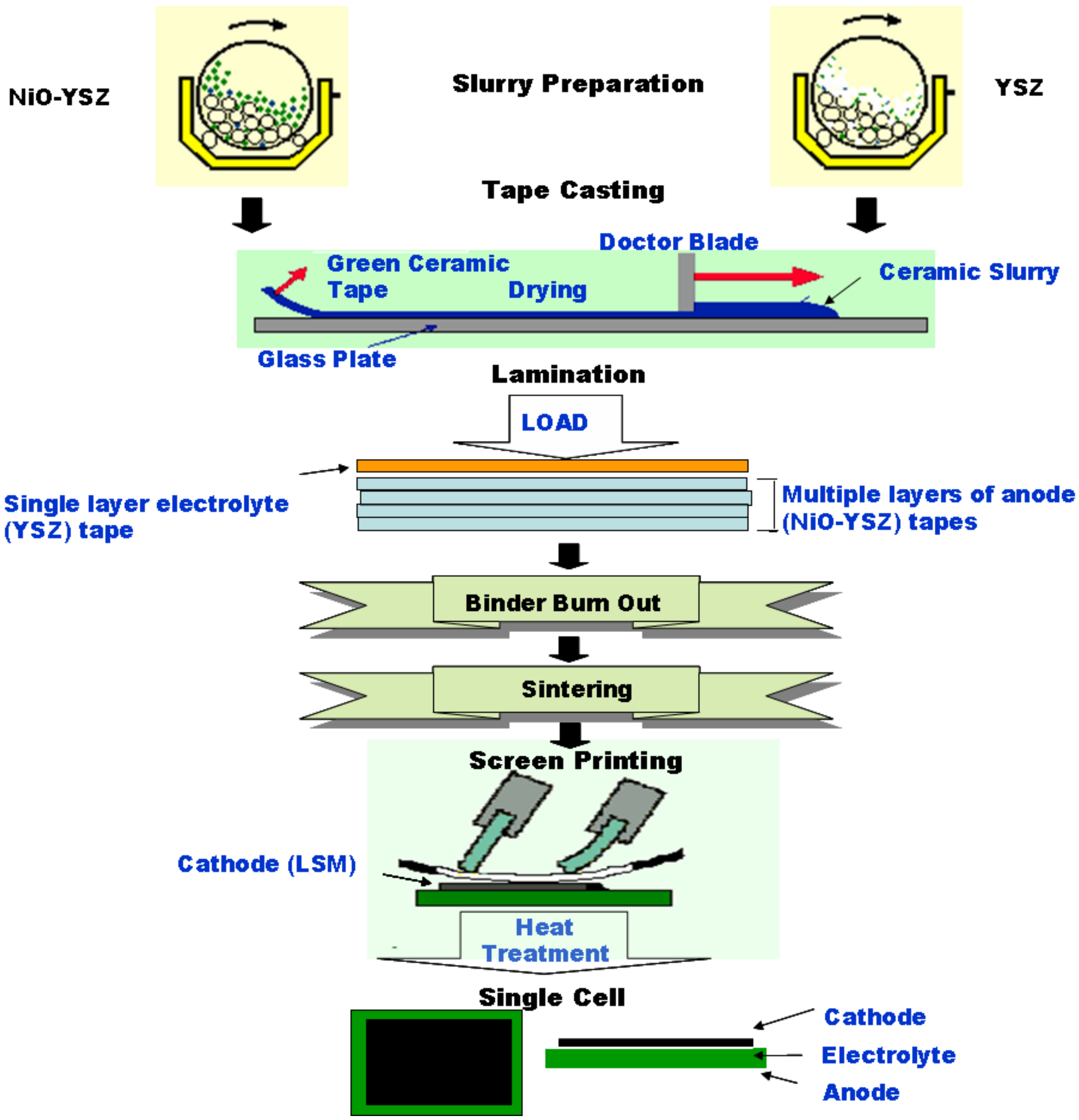
Physics Involved:

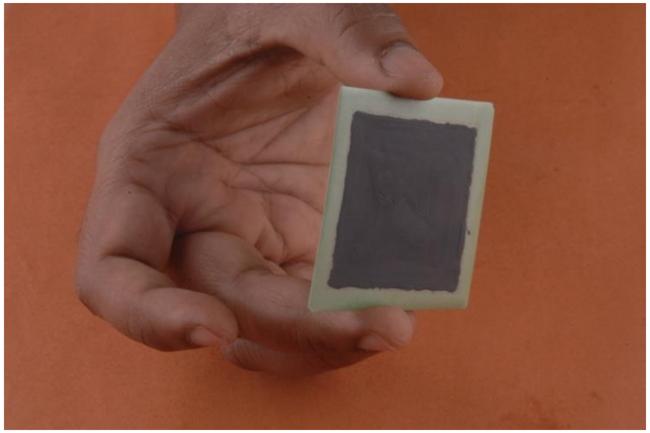
- **Secondary current Distribution:** Determines current profile. Accounts for the effect of the electrode kinetics and losses due to resistance.

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

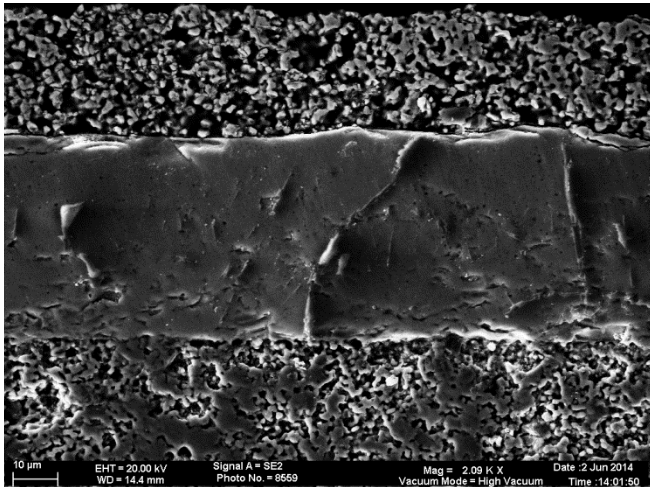
- **Free and Porous Media Flow:** Determines flow profile. Accounts for flow in channel and porous media

Experimental: Fabrication Procedure



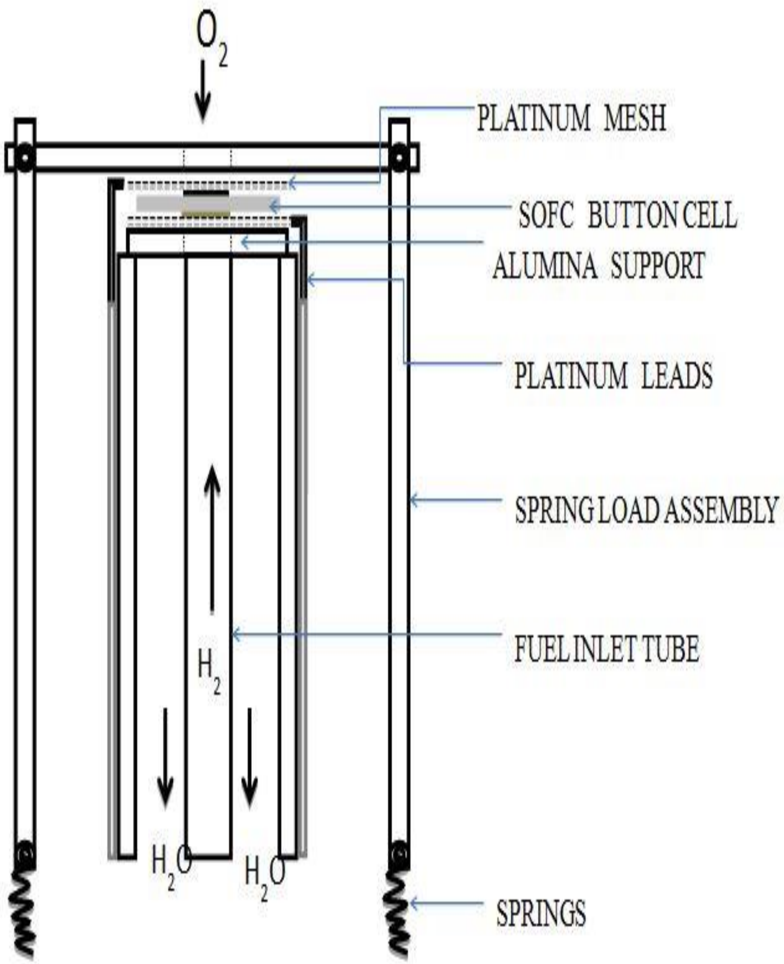


Anode Supported SOFC single cell



Microstructure of SOFC single cell

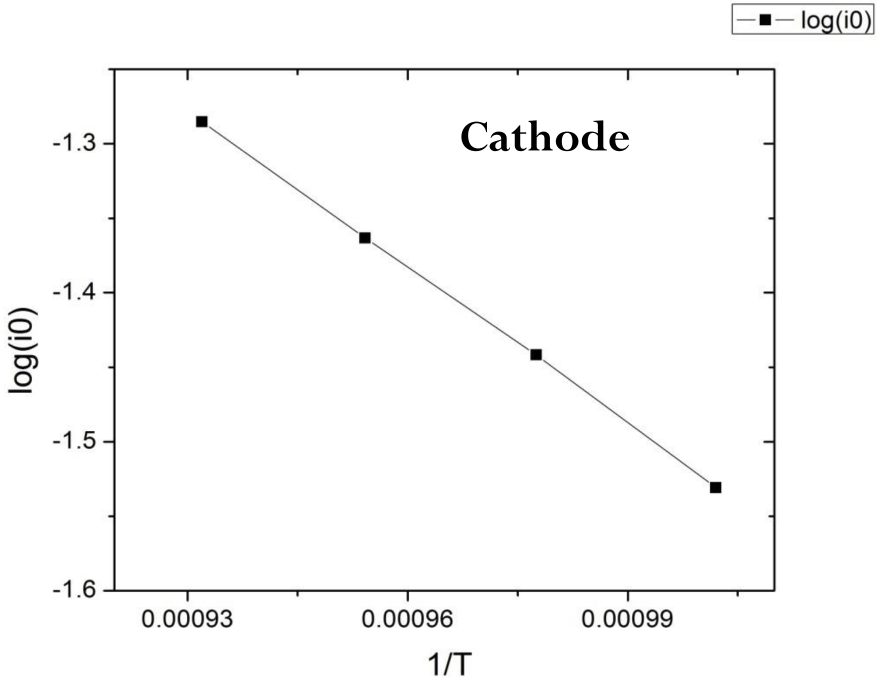
Experimental: Button Cell characterization

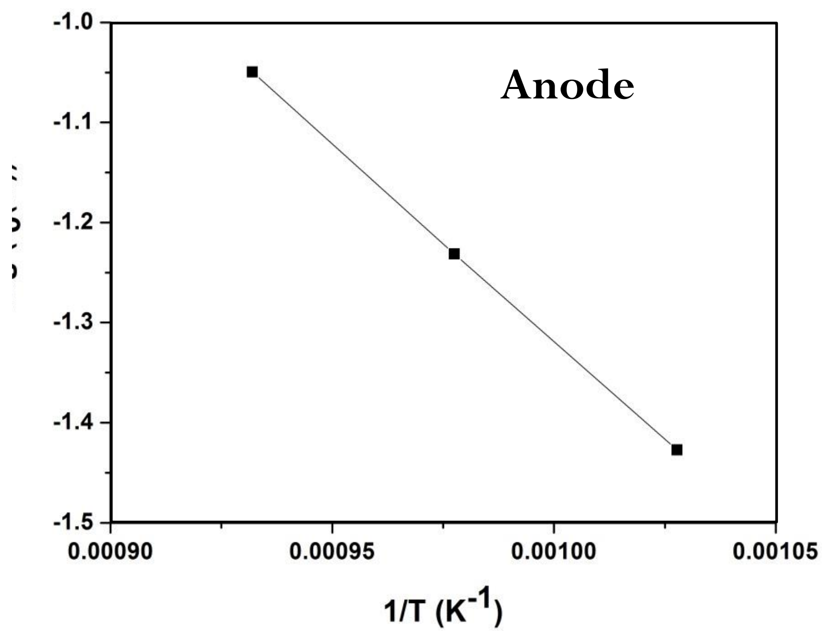


- Linear sweep voltammetry
- Performance study at various temperatures (700 °C -800 °C)
- Exchange current density by Tafel plot

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





$$\log(i_0) = -3491.6(\frac{1}{T}) + 1.9692$$

$$\log(i_0) = -3944.6(\frac{1}{T}) + 2.6261$$

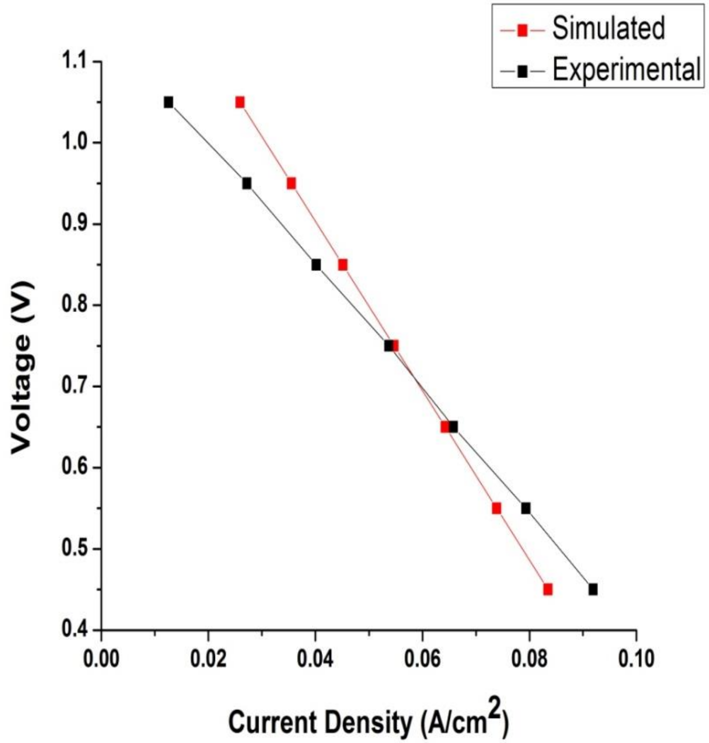
Cathode Activation Energy= 29.03 kJmol^{-1}

Anode Activation Energy= 39.73 kJmol^{-1}

Model Validation

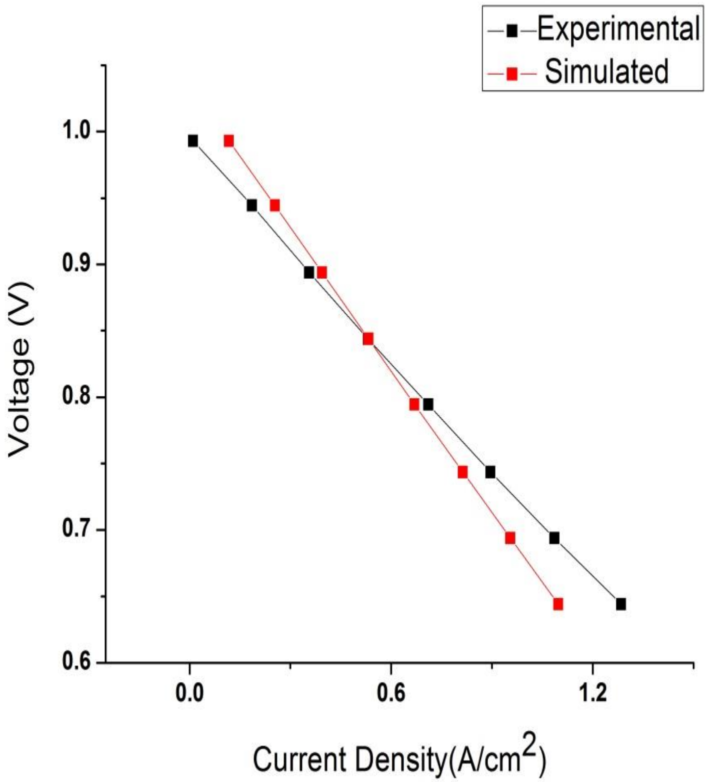
Polarization Curve at 800^0C

Electrolyte Supported Cell



Electrolyte thickness -1mm
Anode – 100 μ
Cathode – 100 μ

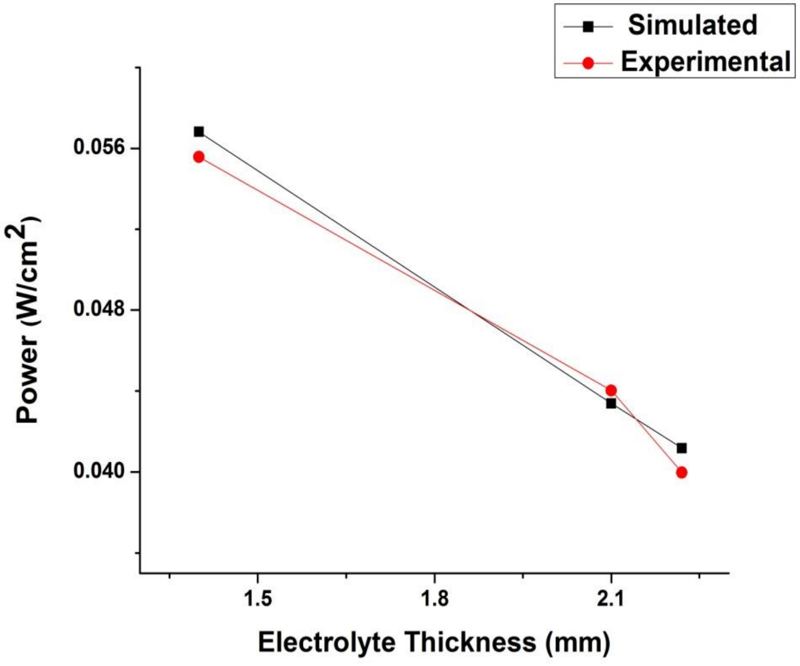
Anode Supported Cell



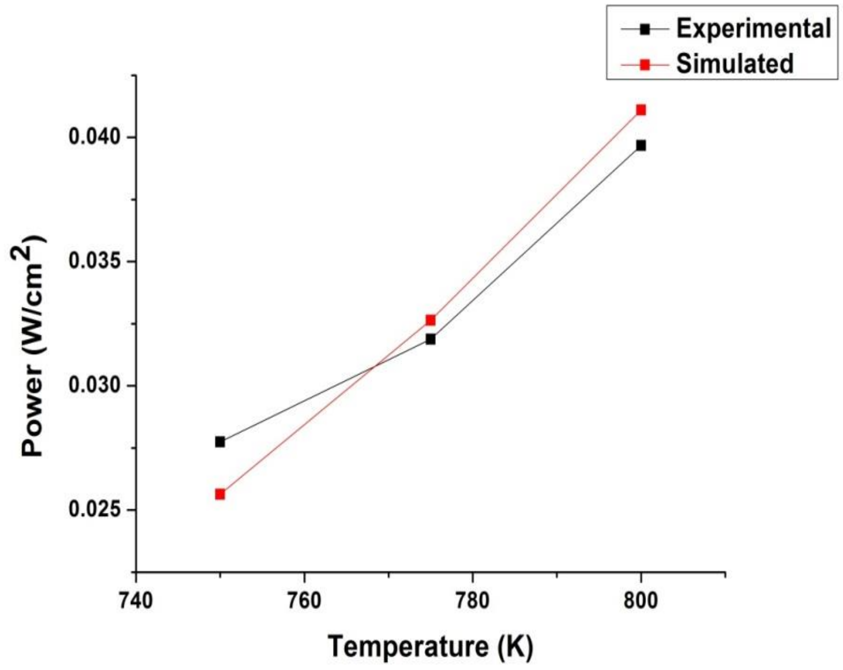
Electrolyte thickness -10 μ
Anode – 1 mm
Cathode – 100 μ

Effect of Parameters

Electrolyte Thickness



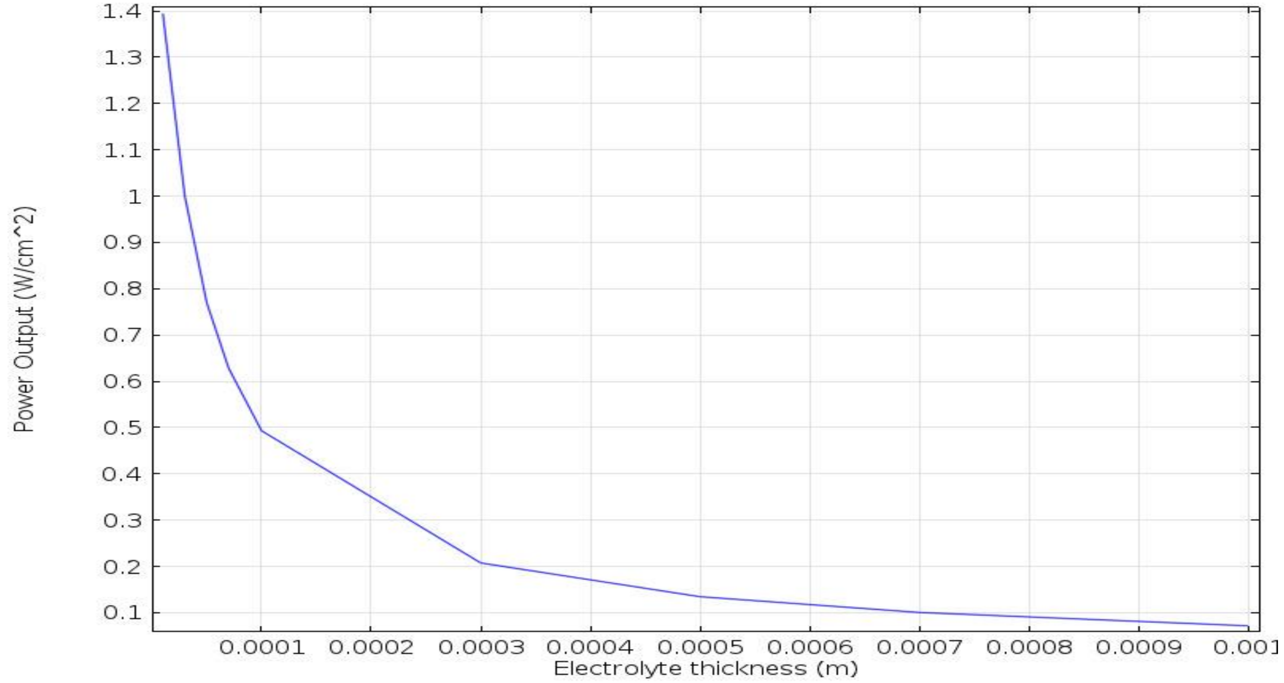
Temperature

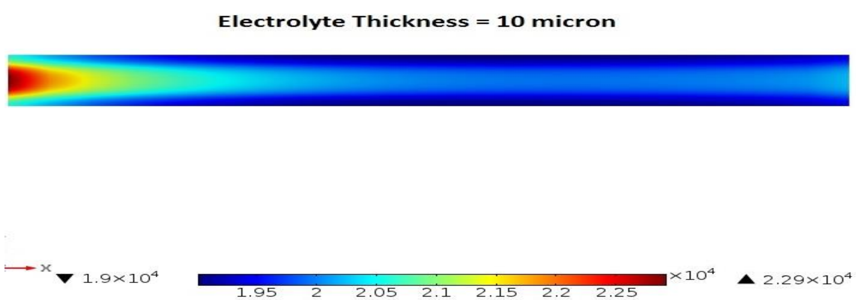


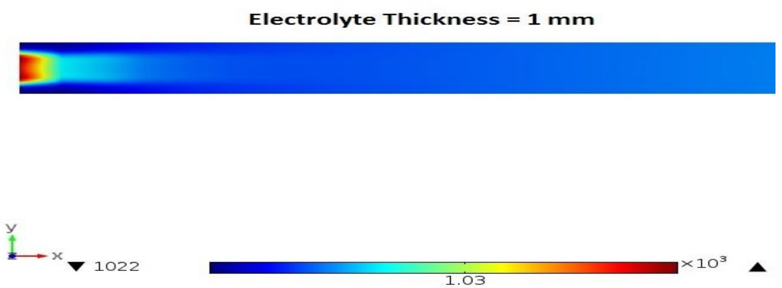
Good agreement between experimental and simulated results ! !

Simulation Results

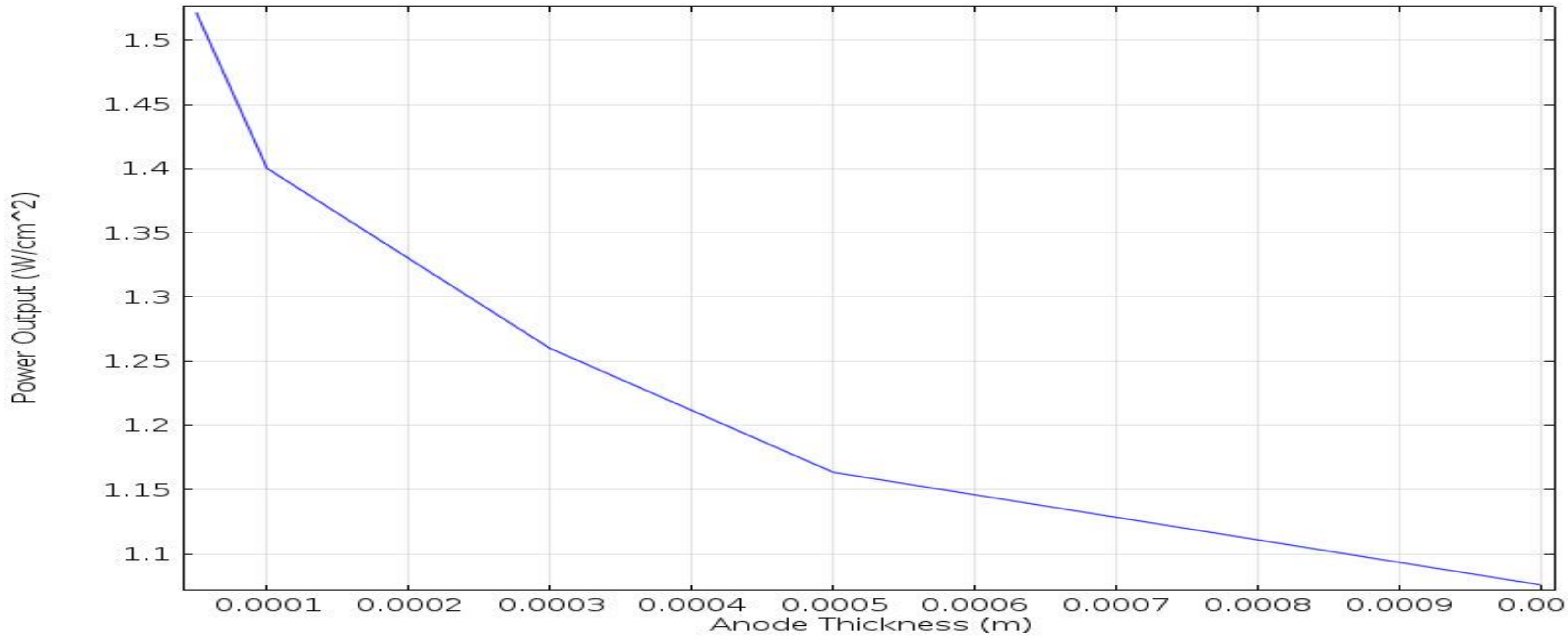
- Effect of Electrolyte thickness



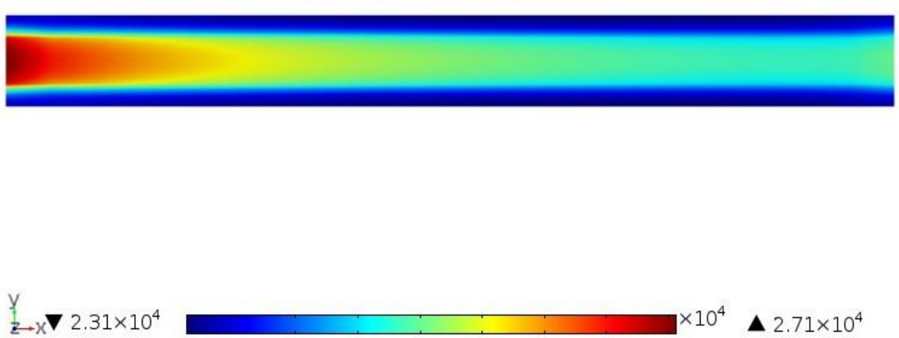




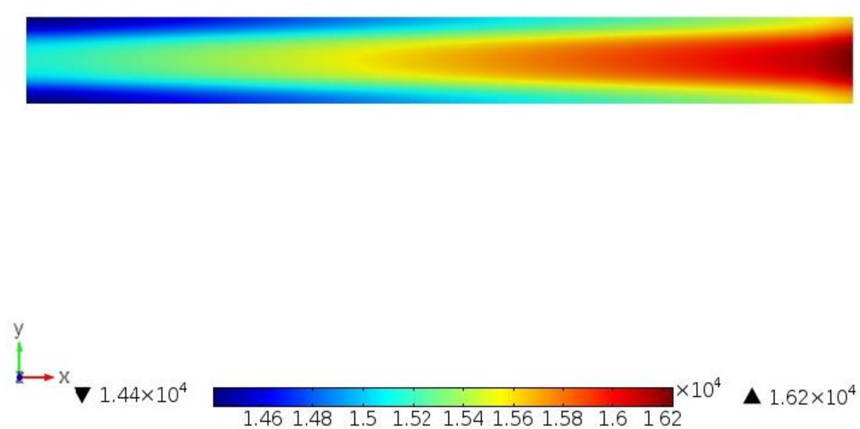
- Effect of Anode thickness



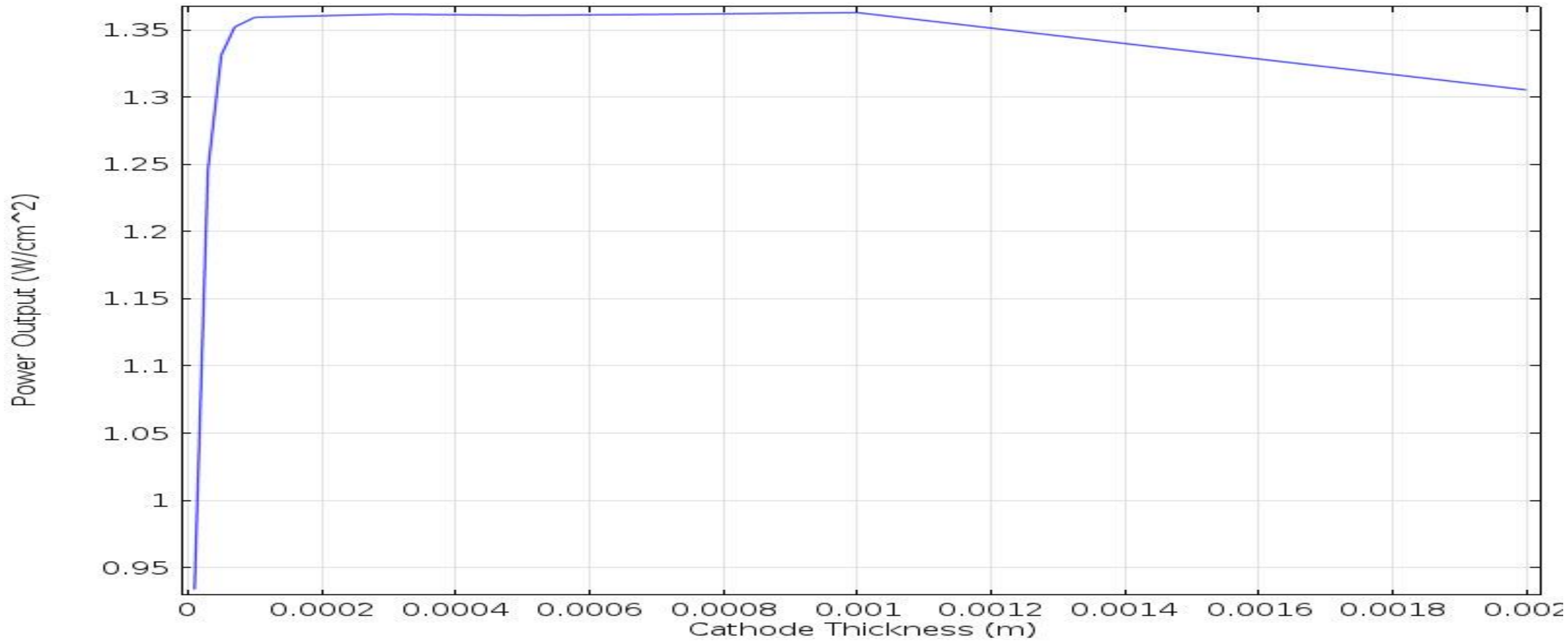
Anode Thickness = 10 micron



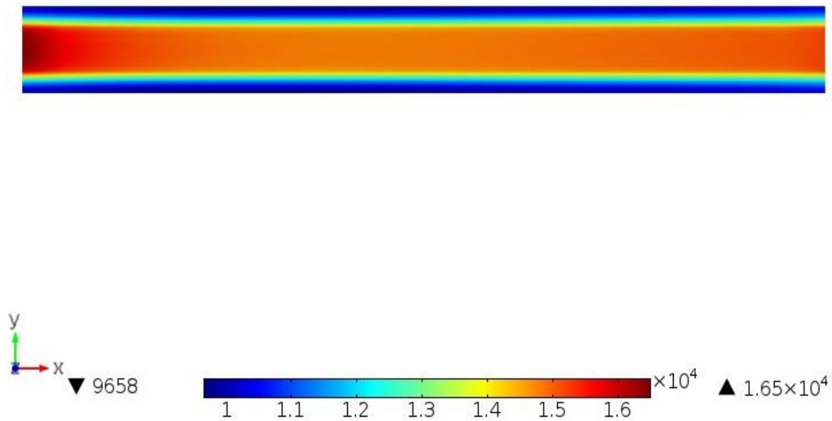
Anode Thickness = 1mm



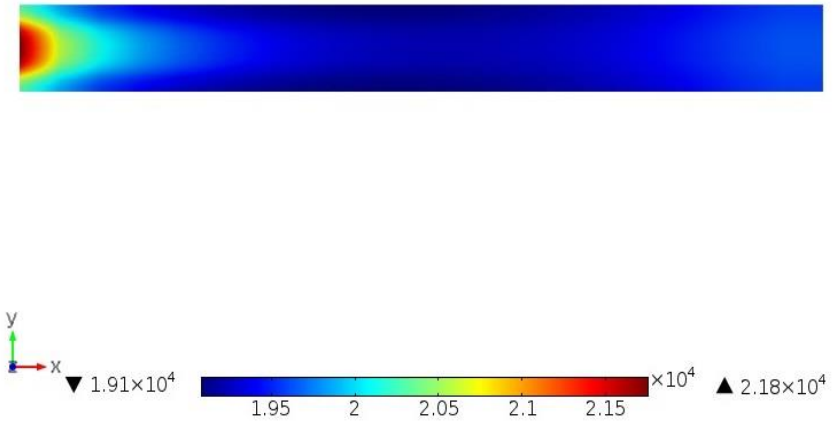
- Effect of Cathode Thickness



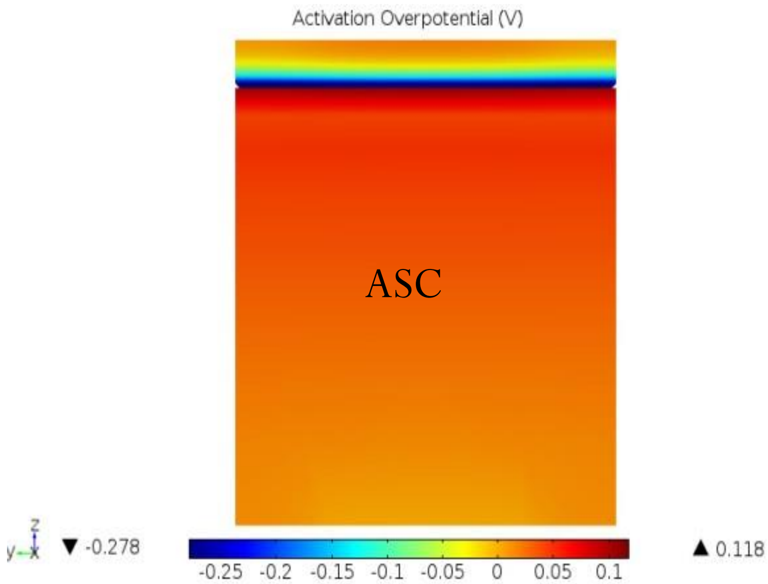
Cathode Thickness = 10 micron

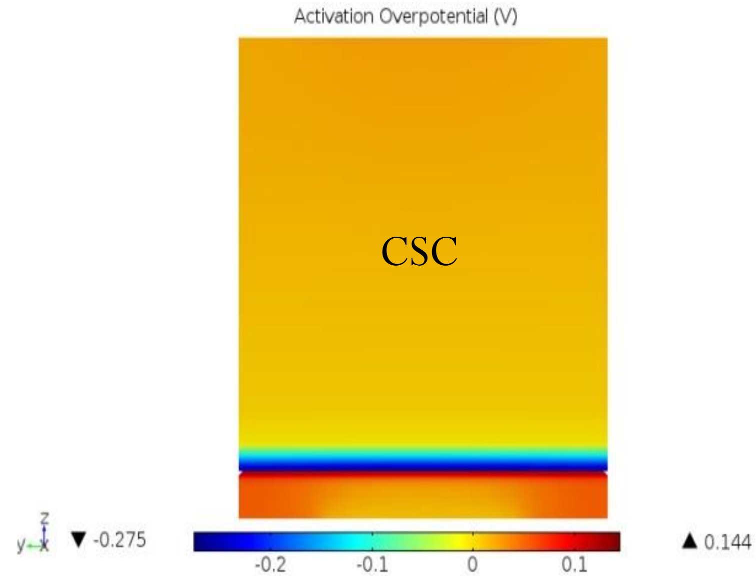


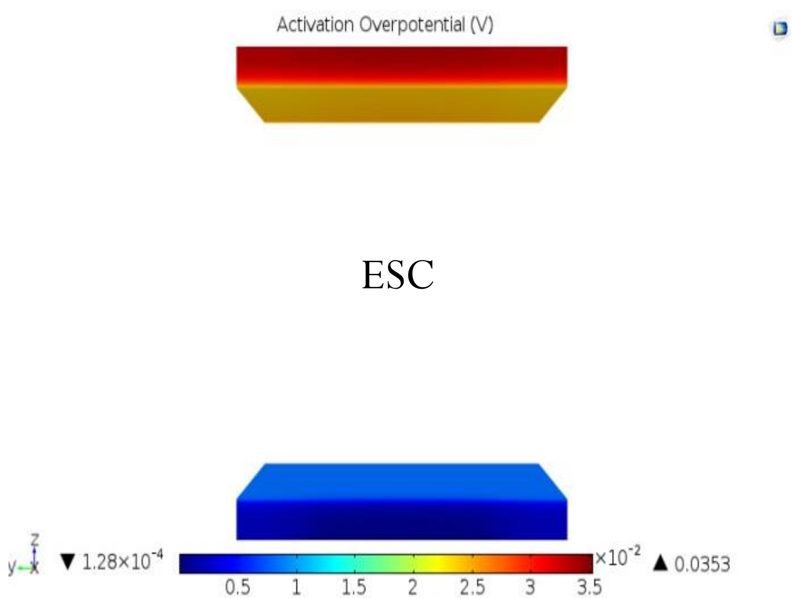
Cathode Thickness = 1mm



Effect Of Support Thickness

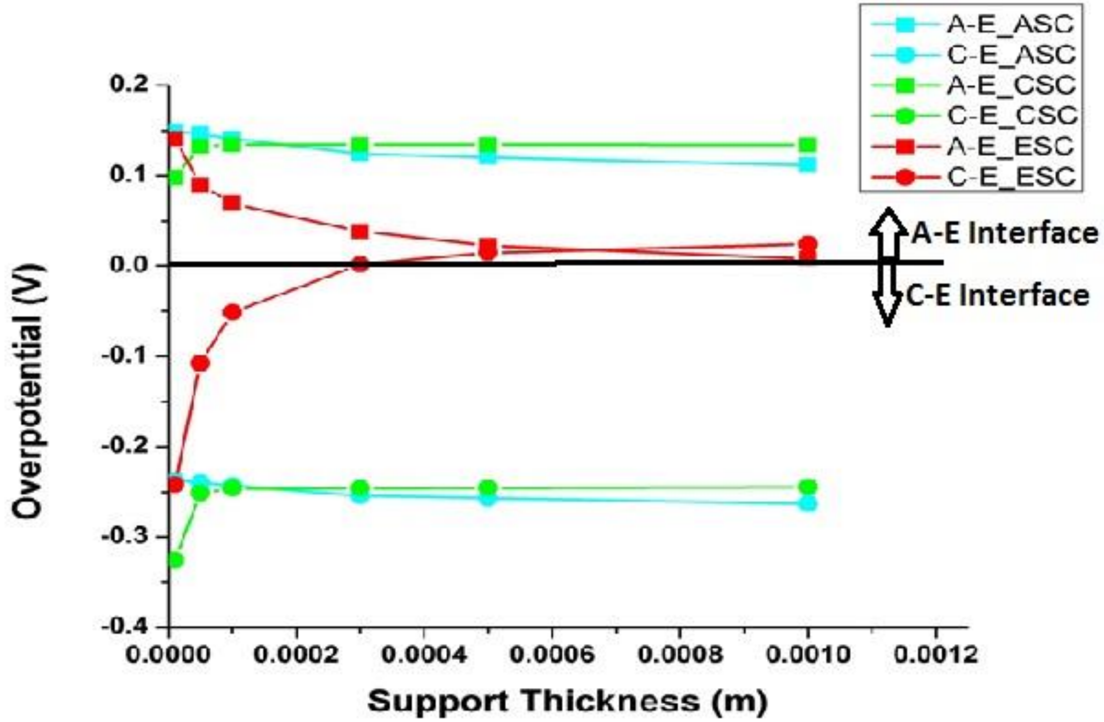






Activation Over potential losses at the individual interface

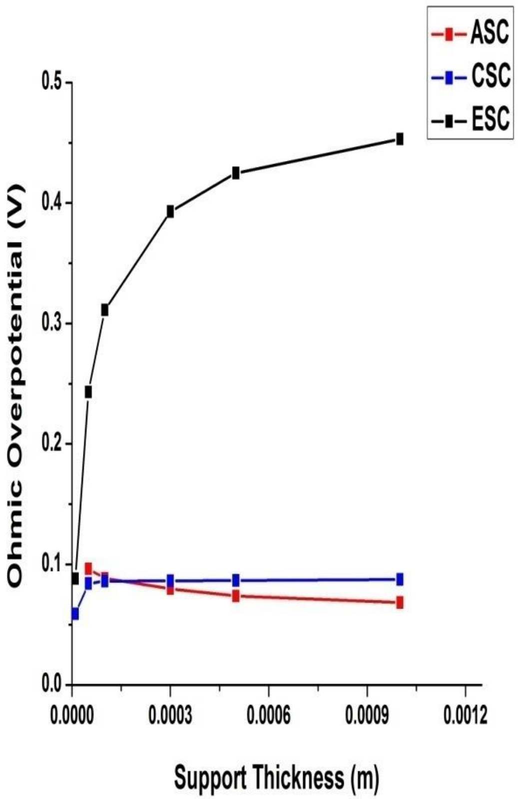
(At Cell voltage 0.7V and 800^{0}C)

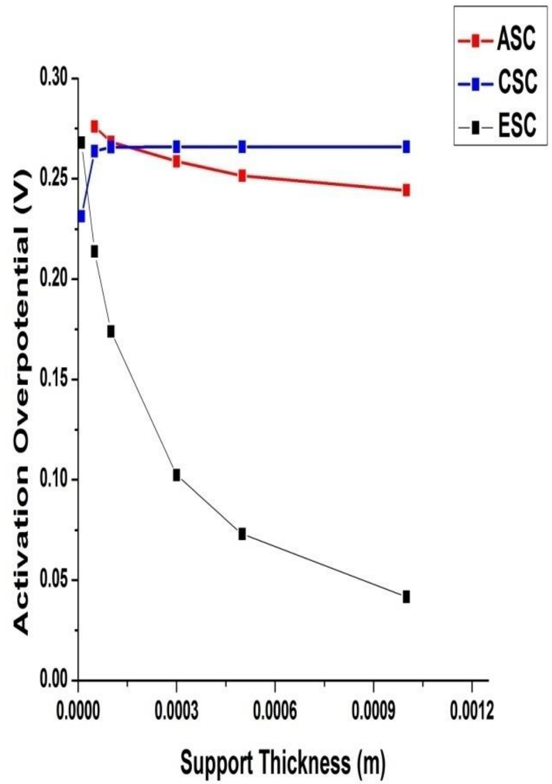


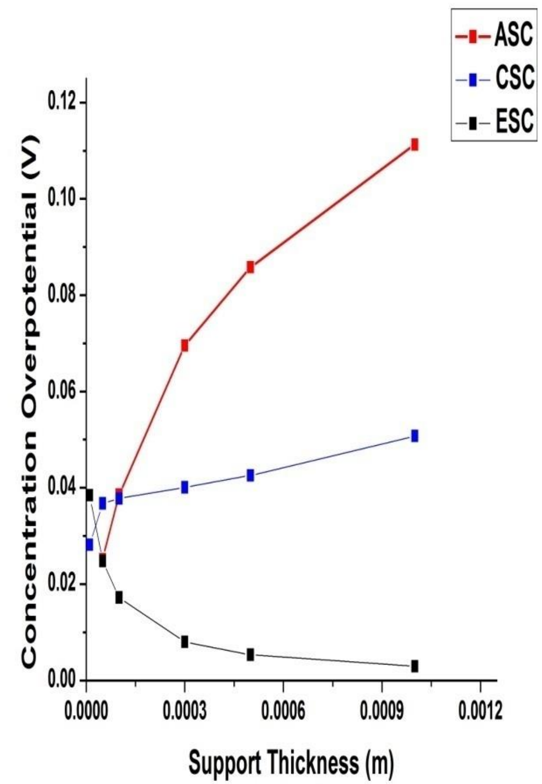
- Drastic reduction in electrochemical reaction in electrolyte supported cell
- Cathode activity increases with cathode thickness in the thickness range of 10 -100 μ

Effect Of Support Thickness

At Cell voltage 0.7V and 800^0C







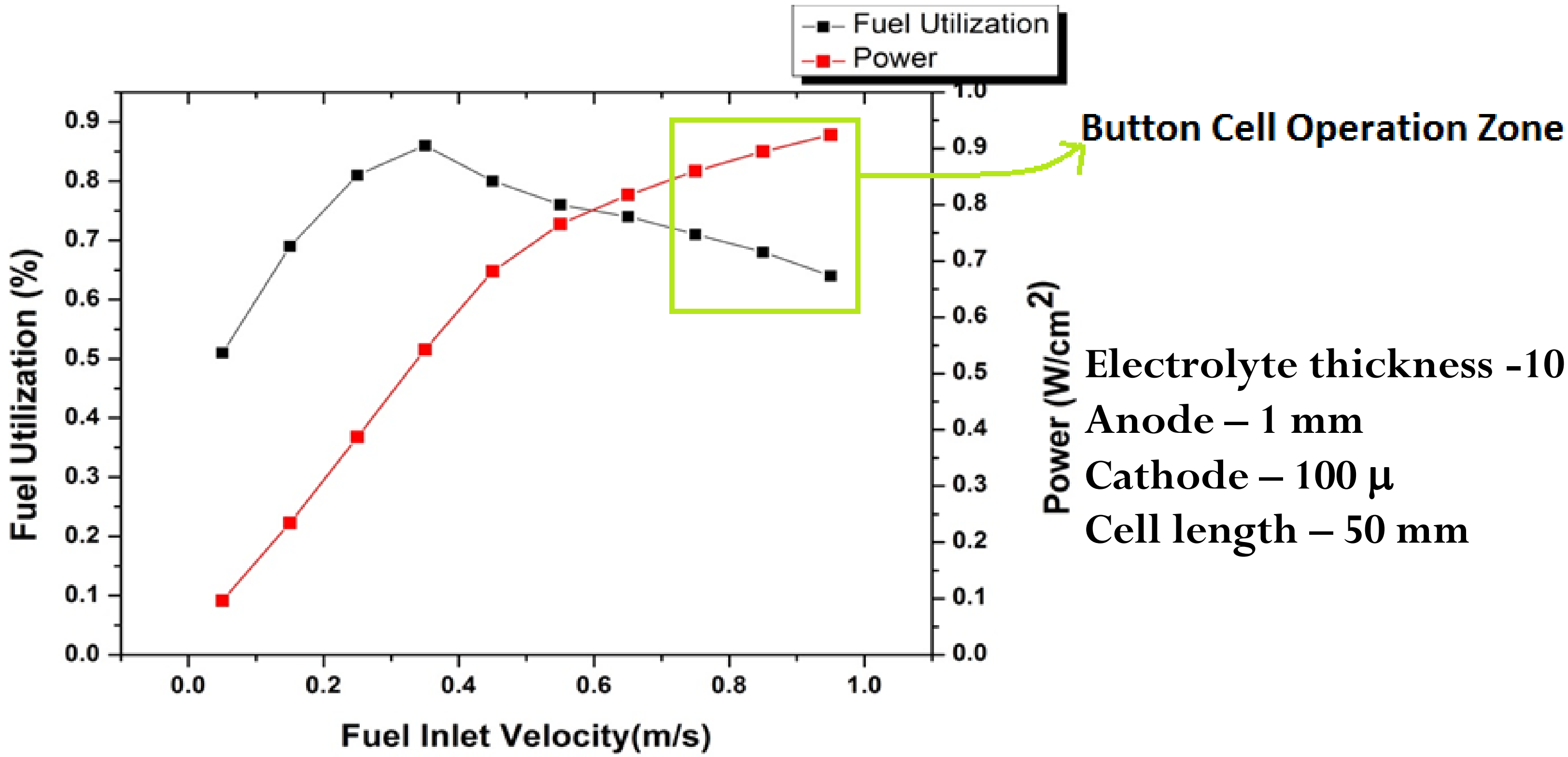
$$R_{ohm} = \left(\left(\frac{\delta_{anode}}{\sigma_{anode}}\right) + \left(\frac{\delta_{electrolyte}}{\sigma_{electrolyte}}\right) + \left(\frac{\delta_{cathode}}{\sigma_{cathode}}\right)\right)$$

$$\eta_{act} = \frac{RT}{\alpha nF} sinh^{-1}\left(\frac{j}{2j_0}\right)$$

$$\eta_{conc} = \frac{RT}{2F} ln\left(\frac{P_{H2Otpb}P_{H2}}{P_{H2O}P_{H2tpb}}\right) + \frac{RT}{4F} ln\left(\frac{P_{O2}}{P_{O2tpb}}\right)$$

Optimization of Concentration Overpotential

(At 800^0C)



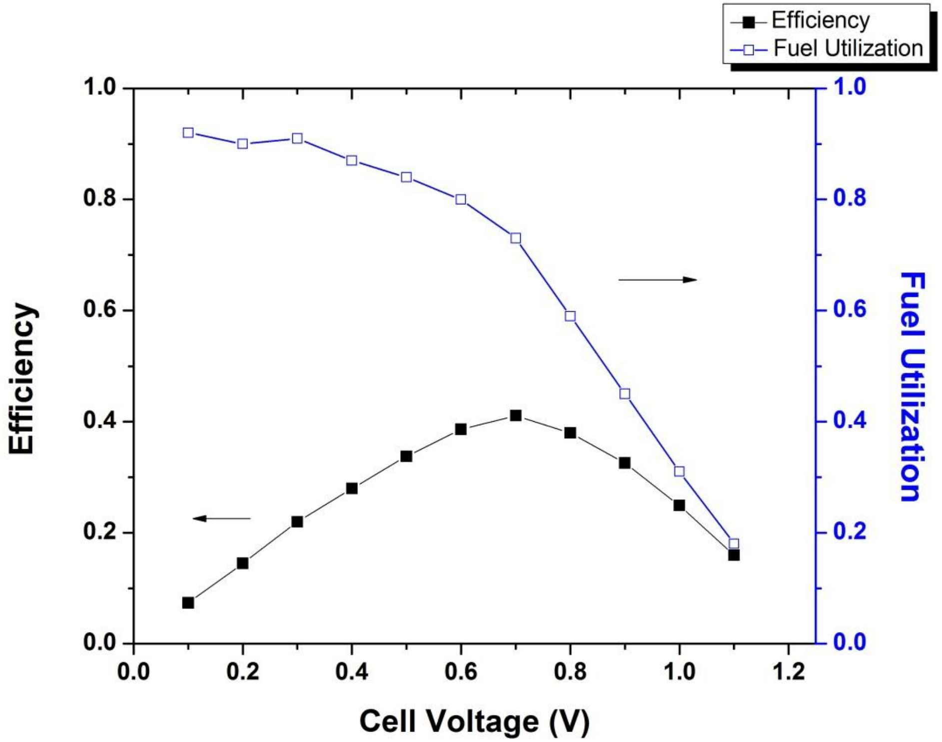
Electrolyte thickness -10 μ
Anode – 1 mm
Cathode – 100 μ
Cell length – 50 mm

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

Operating cell voltage

(At 800^0C)

Fuel inlet velocity = 0.35m/s



$$\varepsilon = \frac{W_e}{\dot{m}_{f,in}\,\Delta h_{f,in}} = \left\{\frac{E_{rev}}{E_h^\circ}\right\}\left\{\frac{E_{cell}}{E_{rev}}\right\}\left\{\frac{(\dot{m}h)_{in} - (\dot{m}h)_{out}}{\dot{m}_{f,in}\,\Delta h_{f,in}}\right\} = \varepsilon_R \varepsilon_V \varepsilon_U.$$

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

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 0.7V 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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Thank you