RESEARCH ON SOFC ELECTRODES

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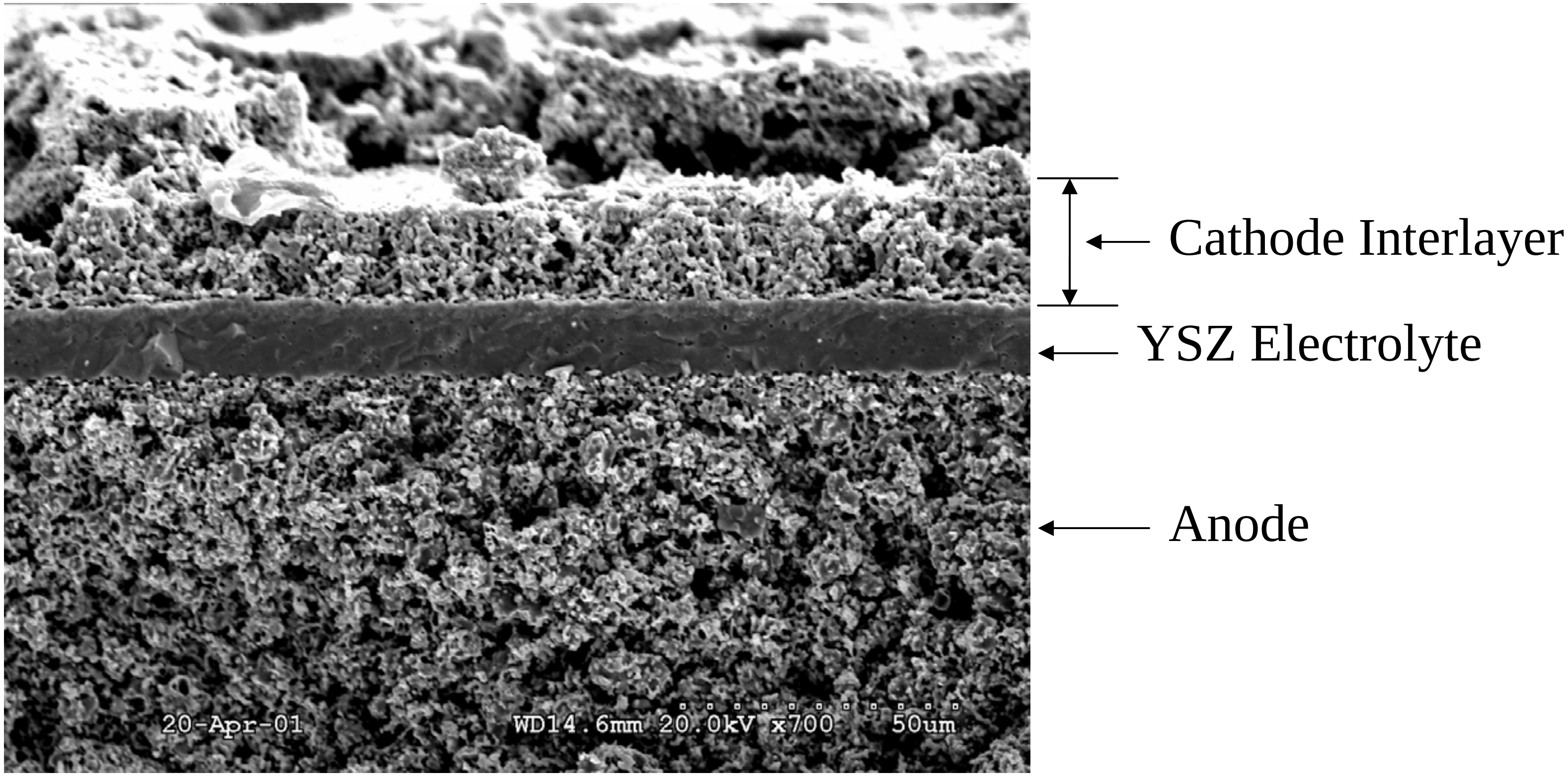
Principal Project Objectives

1) To investigate the effect of electrode microstructure on electrode polarization.
2) To fabricate and test high performance, anode-supported solid oxide fuel cells; relate performance to electrode microstructure.
3) To investigate thermo mechanical issues related to electrolyte film cracking or delamination under the action of residual stresses.

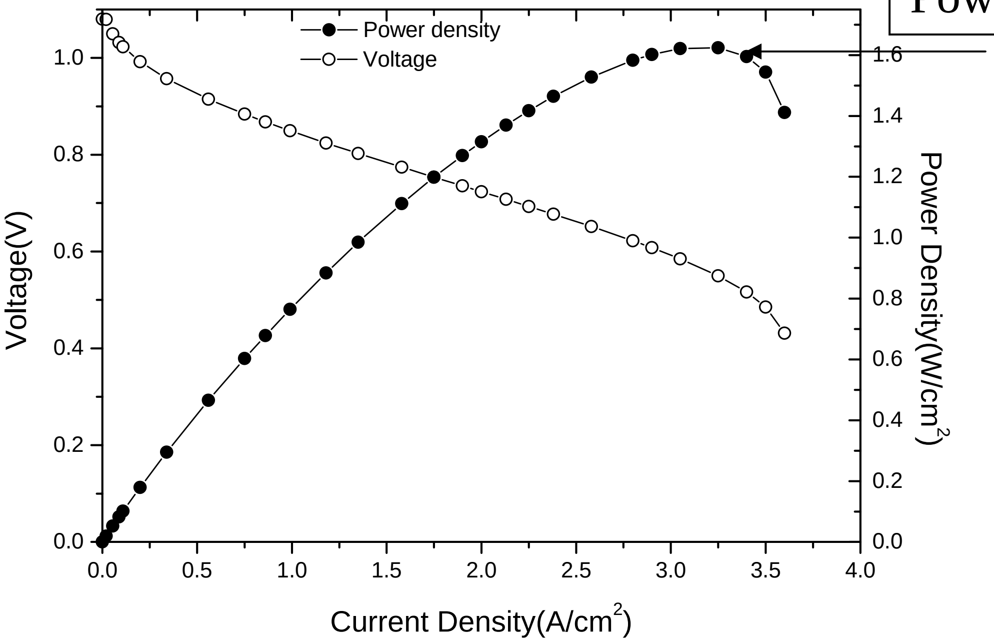
Outline of Presentation

1) Effect of cathode interlayer thickness on cathode polarization.
2) Measurement of gas transport through porous cathodes.
3) Effect of fuel gas composition on anode performance.

SEM Micrograph of a Cell



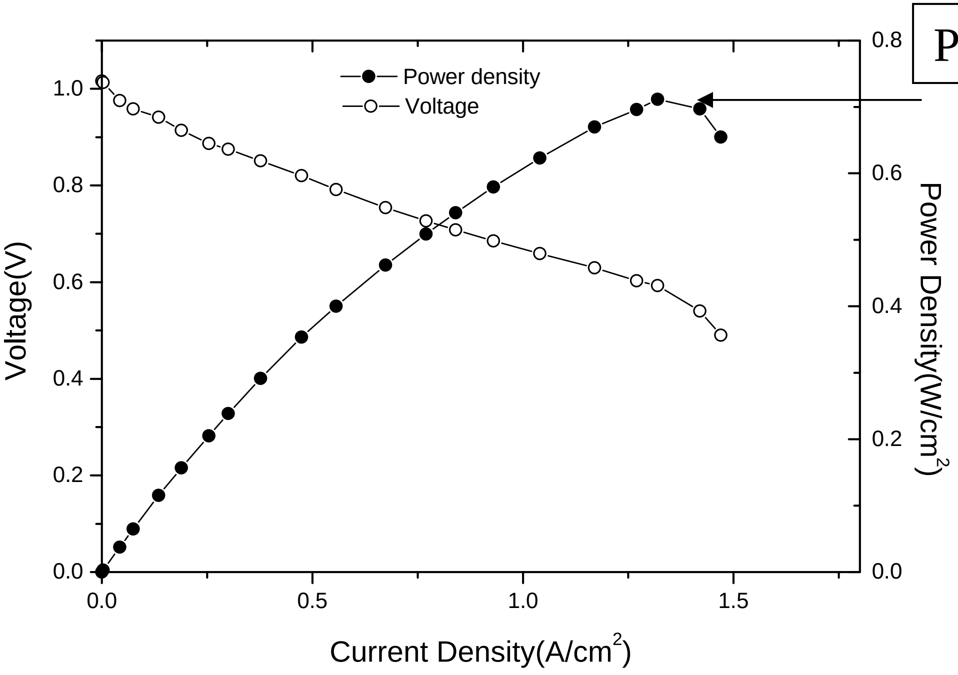
Cell Performance: Cathode Interlayer Thickness ~ 27 μm



Power Density ~1.6 W/cm^2

Test Conditions:
Fuel: Hydrogen
Oxidant: Air
Temperature: 800°C

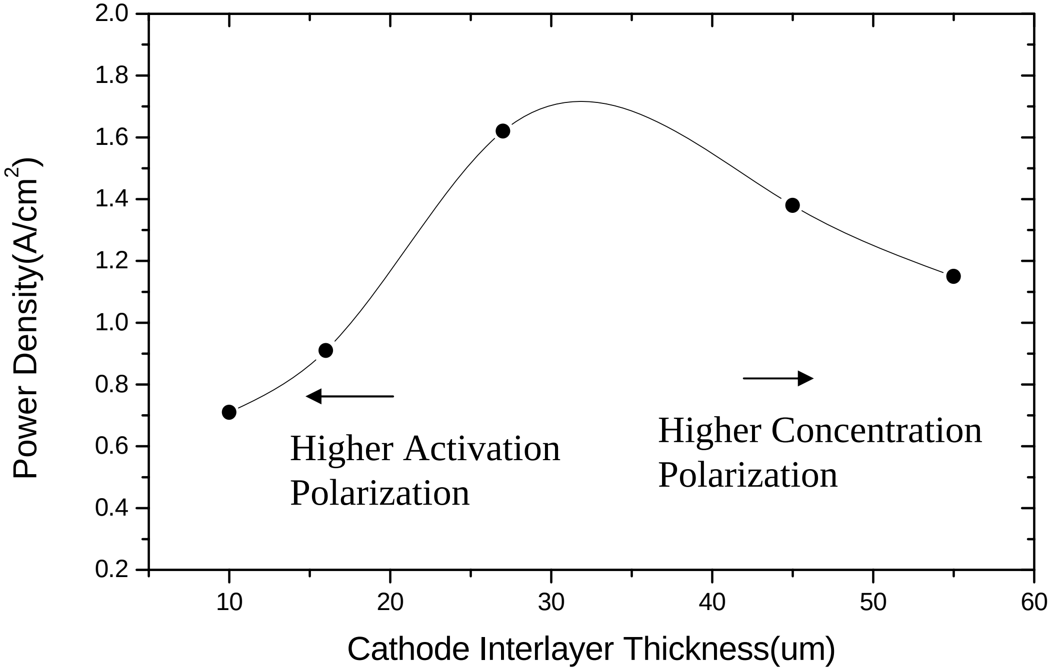
Cell Performance: Cathode Interlayer Thickness ~ 10 μm



Power Density ~0.7 W/cm^2

Test Conditions:
Fuel: Hydrogen
Oxidant: Air
Temperature: 800^{o}C

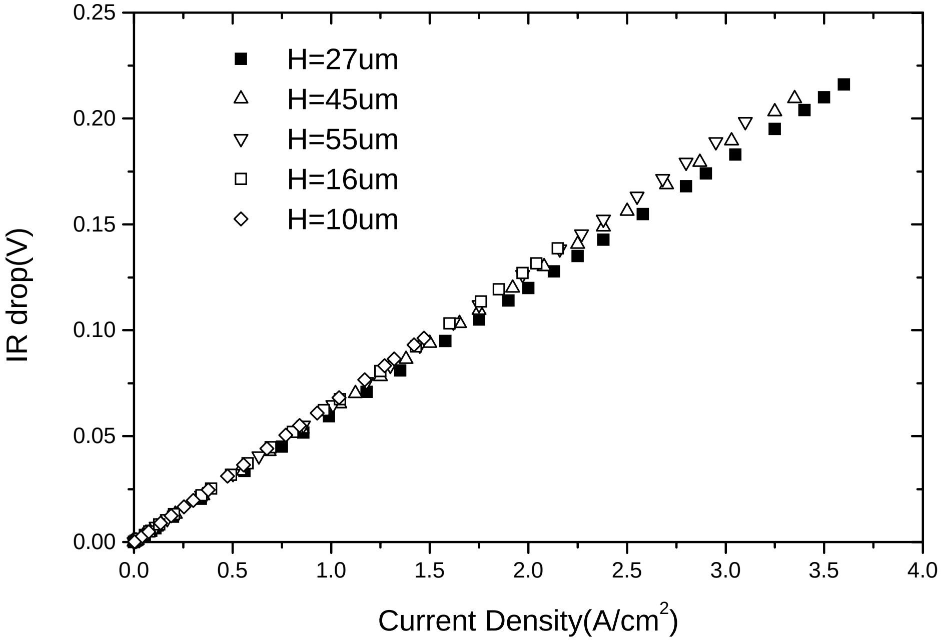
Power Density as a Function of Cathode Interlayer Thickness

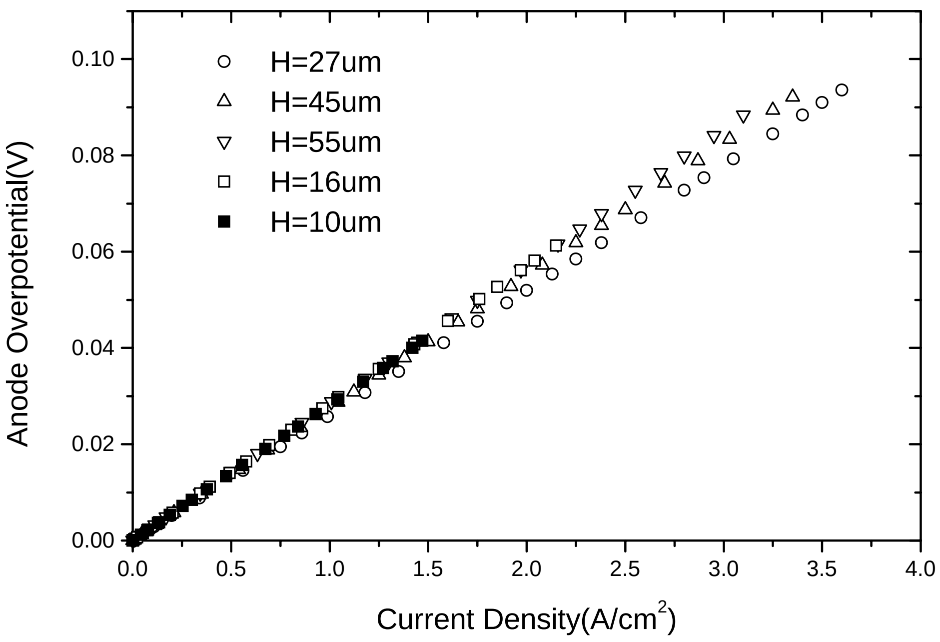


Higher Activation Polarization

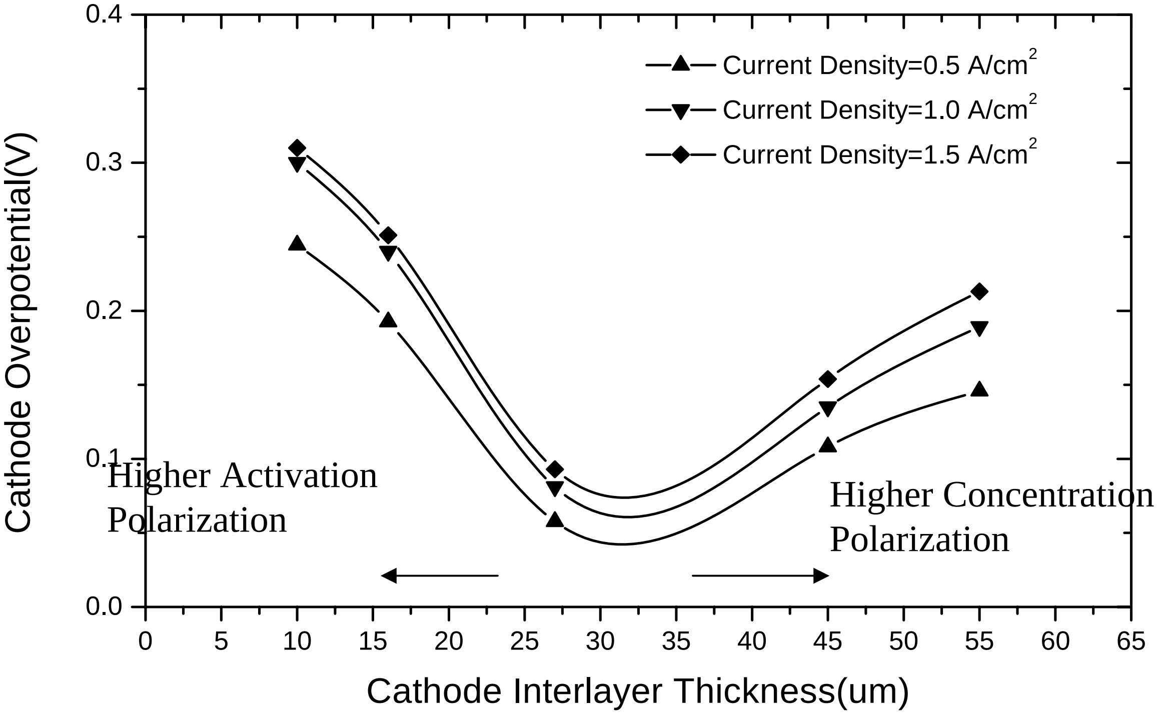
Higher Concentration Polarization

Ohmic Loss and Approximate Anodic Overpotential





Approximate Cathodic Overpotential at Various Current Densities



Higher Activation Polarization

Higher Concentration Polarization

Fitting Parameters for the Cells Tested

Cathode Interlayer Thickness (μm)	10	16	27	45	55
R_i (Ωcm^2)	0.077	0.079	0.082	0.083	0.078
I_o (mA/cm^2)	20.9	30.0	68.1	**48.4**	**53.5**
Cathode Limiting Current Density I_{cs} (A/cm^2)	32.1	19.2	10.5	6.3	5.8
Anode Limiting Current Density I_{as} (A/cm^2)	5.5	5.7	5.9	5.8	5.8
R_{cell} (Wcm^2)	0.225	0.209	0.147	0.168	0.199
Maximum Power Density (W/cm^2)	0.74	0.91	1.62	1.38	1.16

Transport through Porous Bodies

$$J_A = -D_A \nabla n_A + X_A \delta_A J - X_A \gamma_A \left(\frac{nB_o}{\mu}\right) \nabla p$$

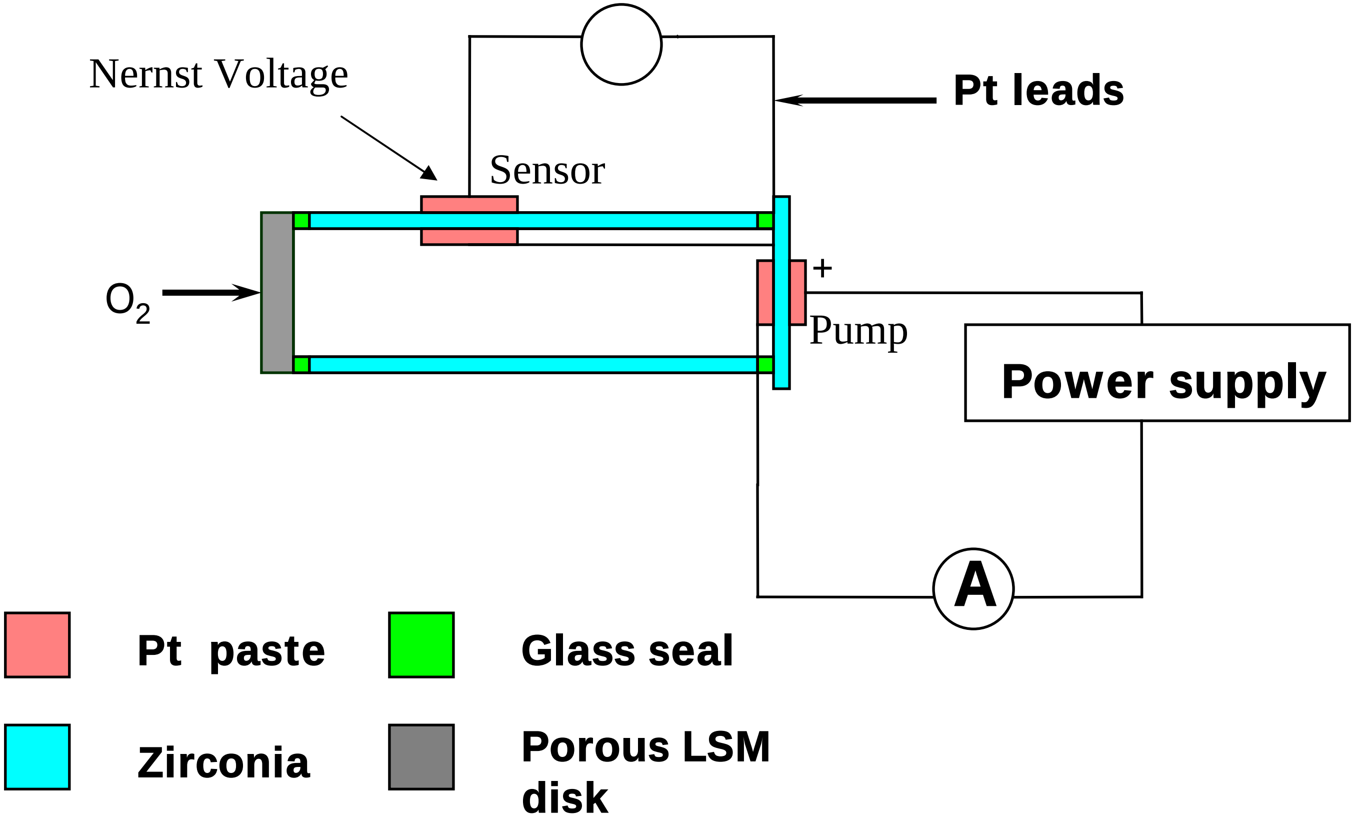
$$J_B = -D_B \nabla n_B + X_B \delta_B J - X_B \gamma_B \left(\frac{nB_o}{\mu}\right) \nabla p$$

$$\frac{1}{D_A} = \frac{1}{D_{AK}} + \frac{1}{D_{AB(eff)}} \qquad \delta_A = \frac{D_{Ak}}{D_{Ak} + D_{AB(eff)}} \qquad \gamma_A = \frac{D_{AB}}{D_{Ak} + D_{AB(eff)}}$$

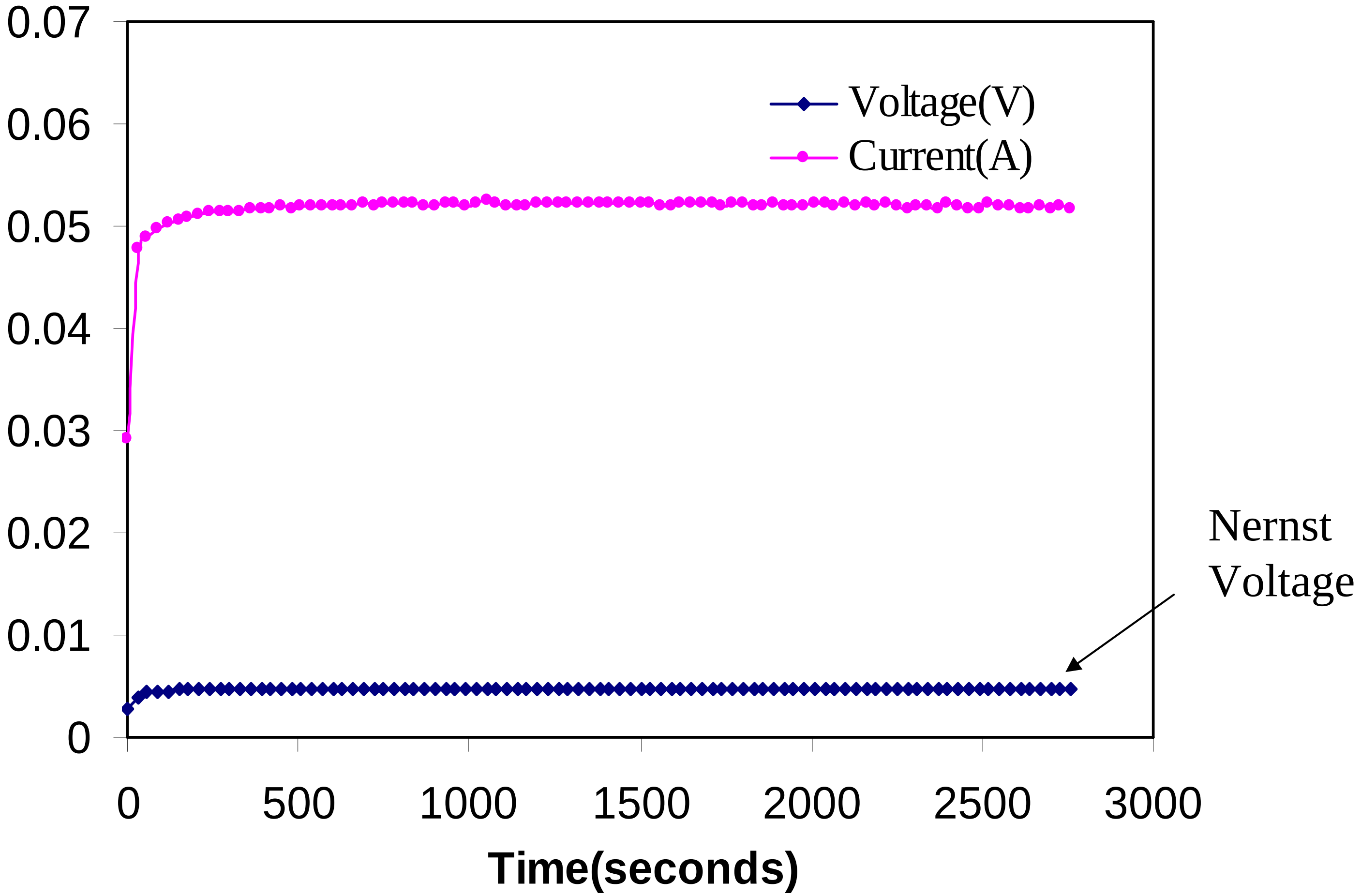
$$\frac{1}{D_B} = \frac{1}{D_{BK}} + \frac{1}{D_{AB(eff)}} \qquad \delta_B = \frac{D_{Bk}}{D_{Bk} + D_{AB(eff)}} \qquad \gamma_B = \frac{D_{AB}}{D_{Bk} + D_{AB(eff)}}$$

J_A and J_B are the fluxes of A and B.
$D_{AB(eff)}$ is the effective binary diffusivity.
D_{AK} and D_{BK} are Knudsen diffusivities.
n_A and n_B are the concentrations.
B is the permeability.
μ is the viscosity.
At high pressures, both D_A and D_B approach $D_{AB(eff)}$ the effective binary diffusion coefficient.

A Schematic Diagram of Experimental Set up for the Measurement of Effective Binary Diffusivity through Porous Bodies

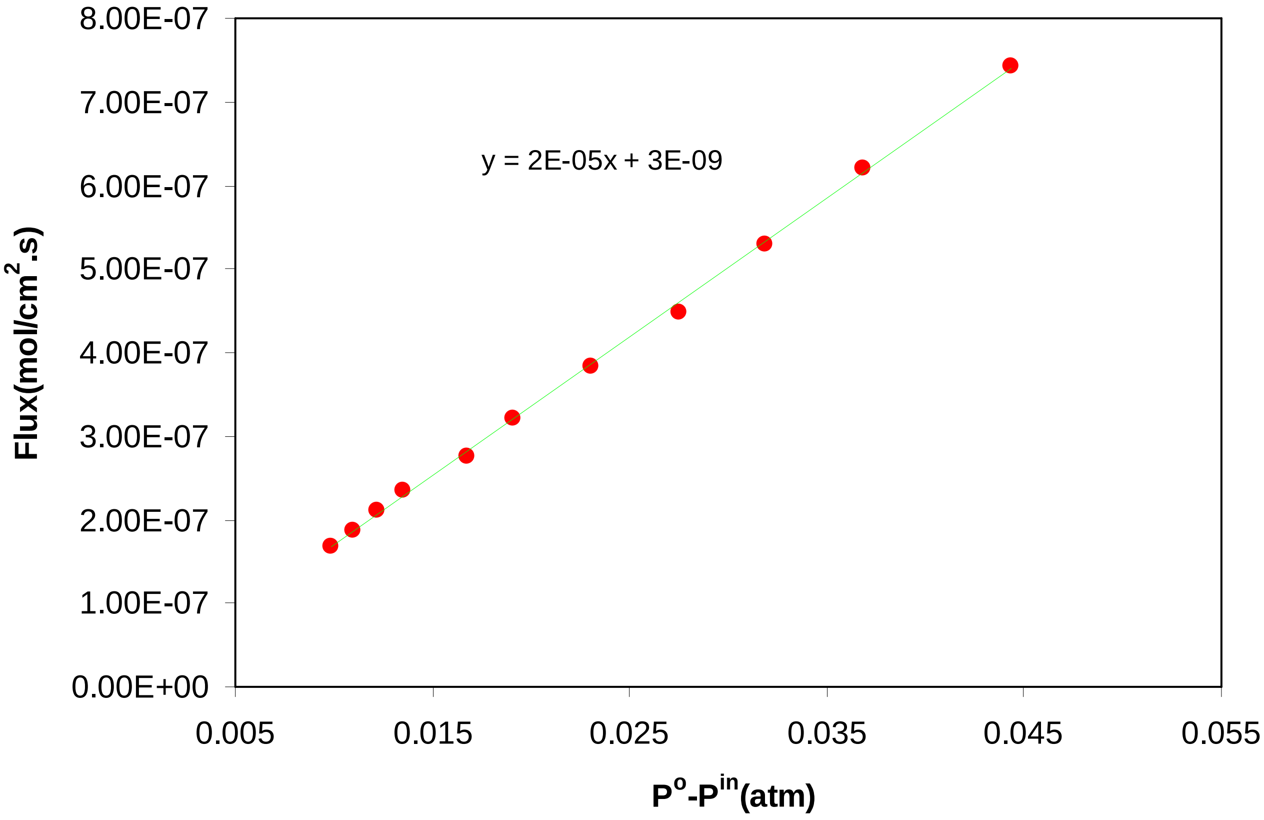


Typical Data
Current and Nernst Voltage vs. Time

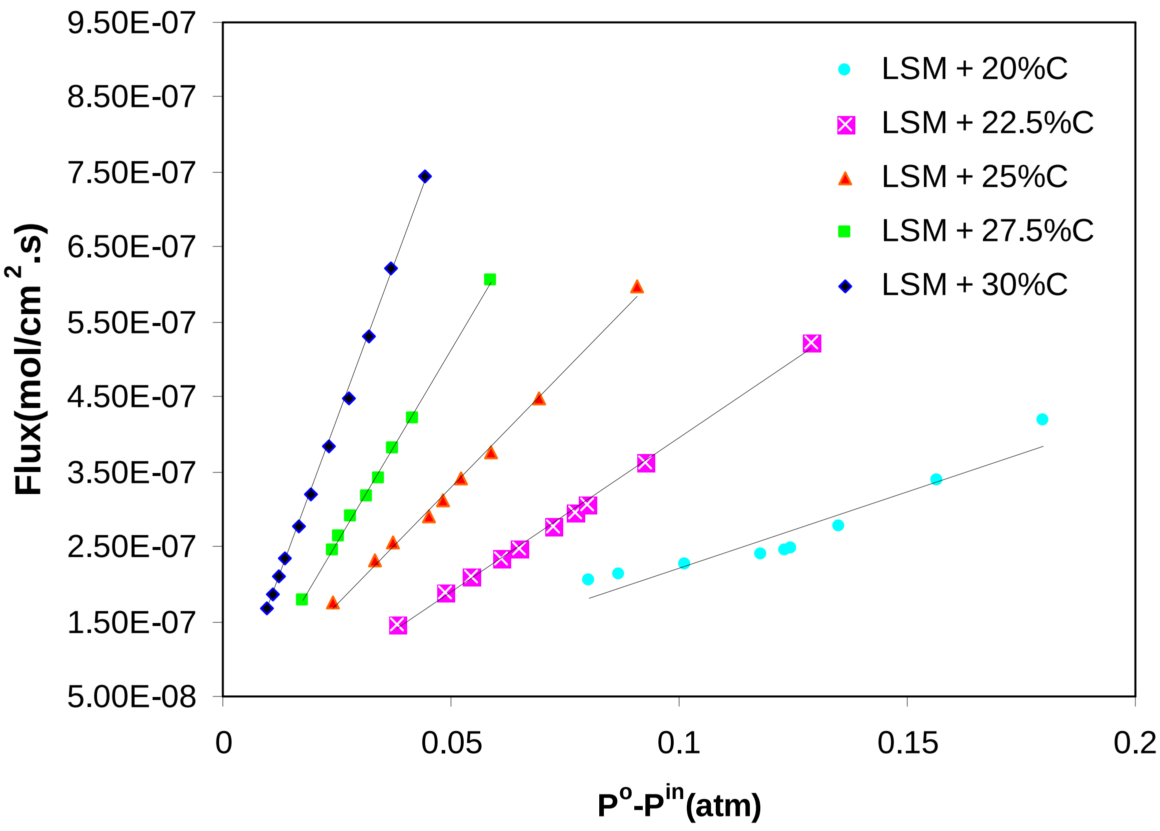


Nernst Voltage

Typical Data
Flux vs. Pressure Differential



Flux vs. Pressure Differential Effective Diffusivities

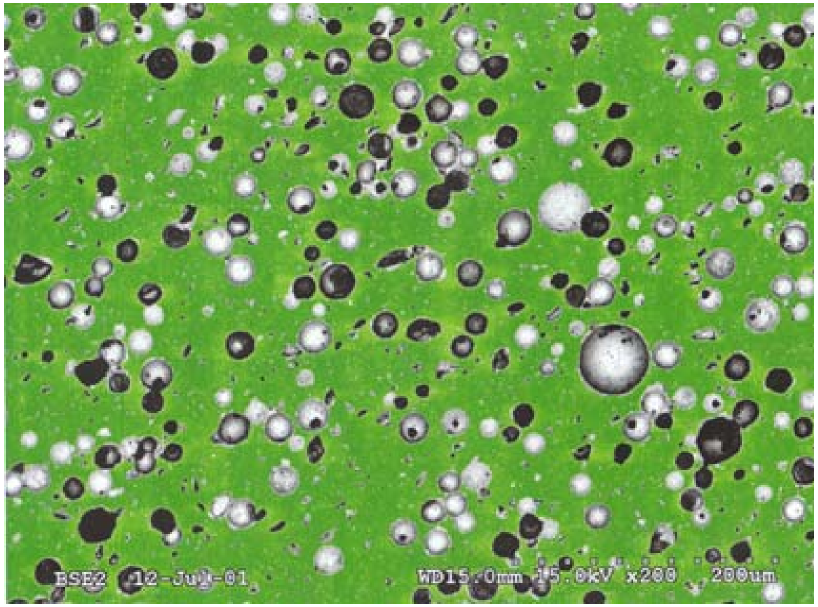


Sample	D(eff) Cm^2/s
20%C	0.0163
22.5%C	0.0277
25%C	0.0462
27.5%C	0.0709
30%C	0.1172

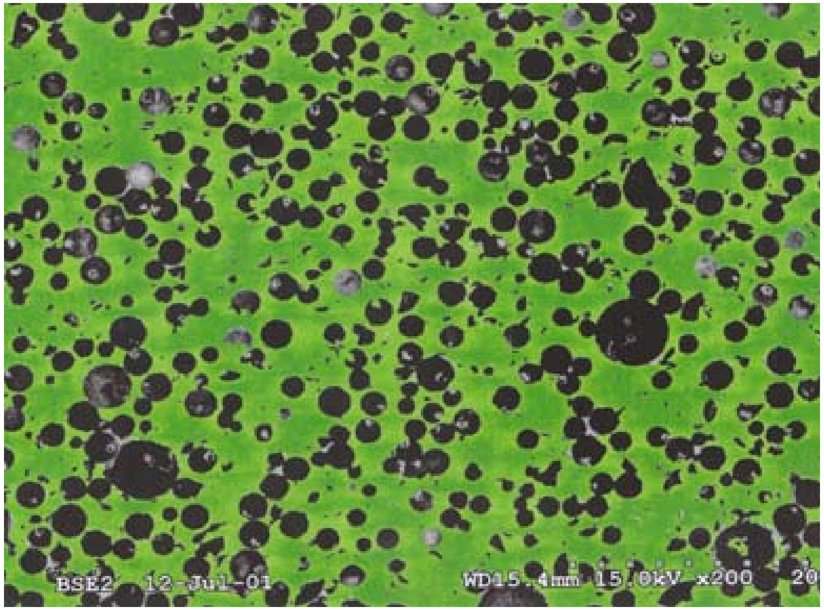
Carbon Addition and Porosity

Carbon Addition	W_a	W_{aw}	W_w	Density (g/cm^2)	**Open porosity**	Total porosity	Closed porosity
20%	0.6915	0.7144	0.5655	4.642	**0.154**	0.289	0.134
22.5	0.7171	0.7576	0.5915	4.329	**0.245**	0.337	0.092
25	0.7009	0.7644	0.5878	3.982	**0.347**	0.39	0.043
27.5	0.5574	0.6139	0.4656	3.627	**0.403**	0.444	0.041
30	0.2687	0.3032	0.225	3.415	**0.438**	0.477	0.039

SEM Micrographs

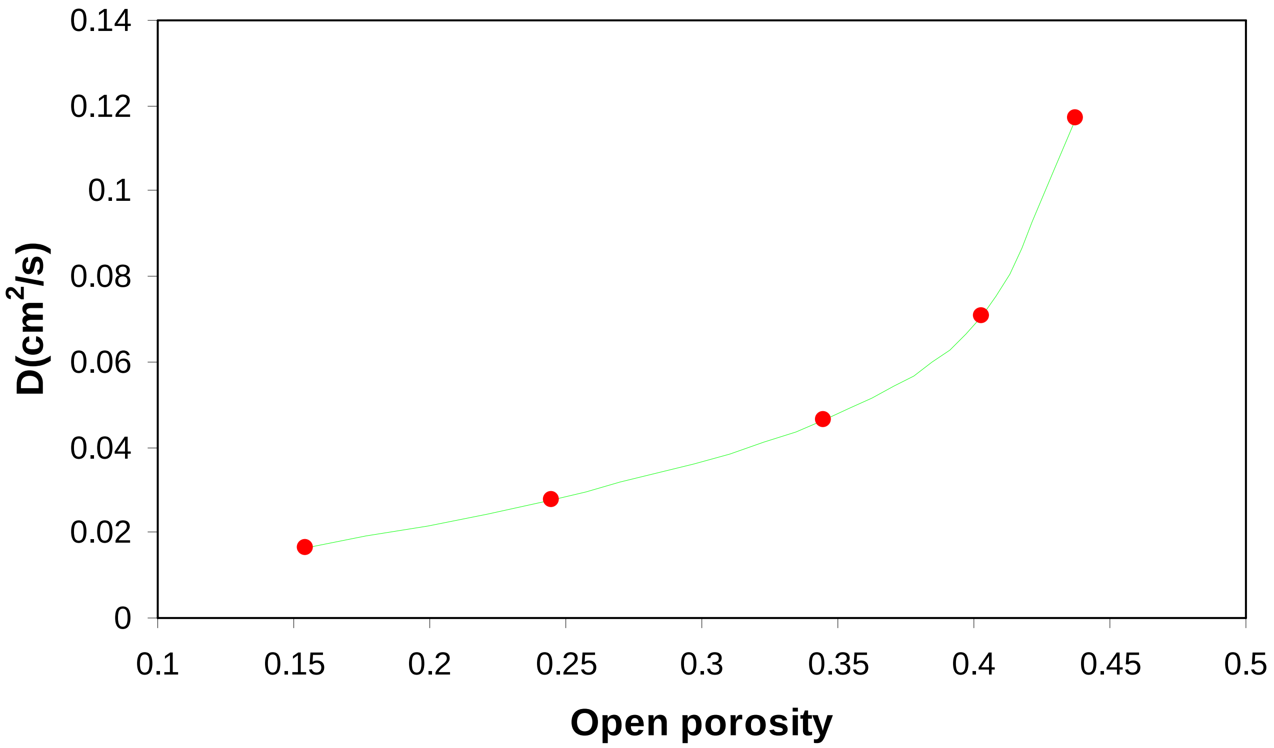


20% Carbon

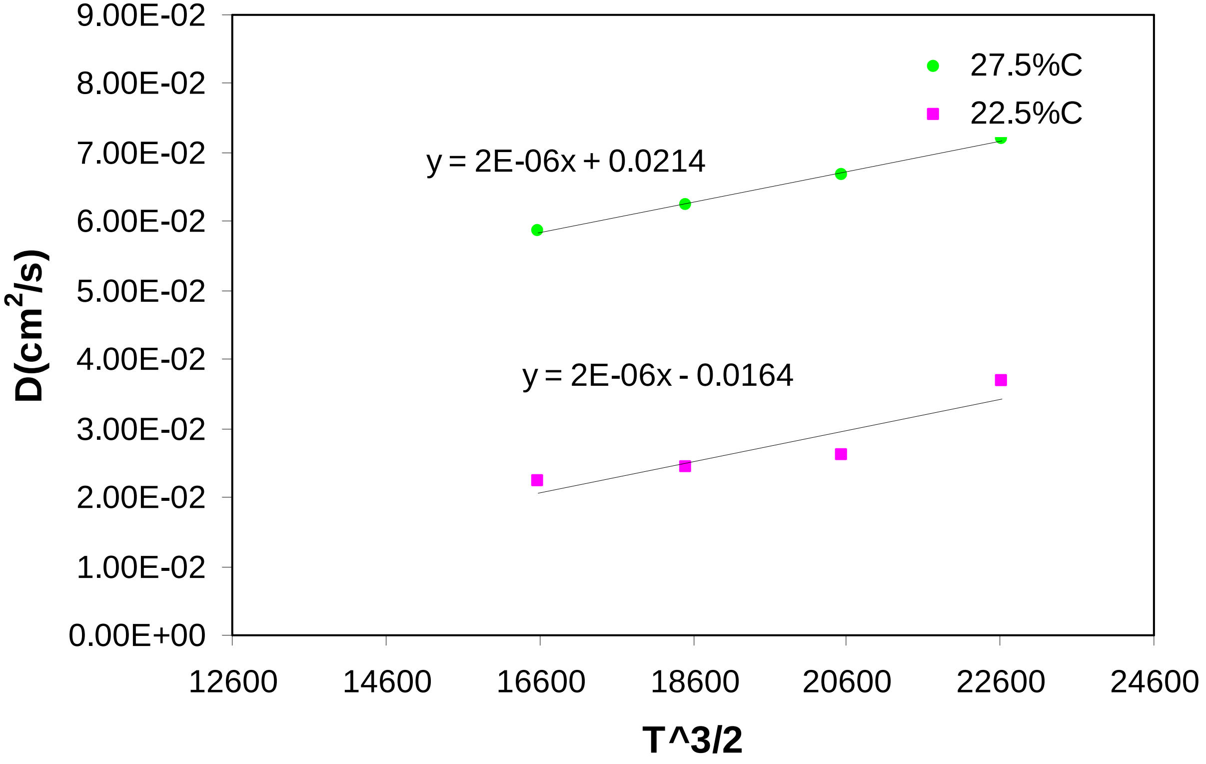


30% Carbon

Effective Diffusivity vs. Open Porosity



Temperature Dependence of Effective Diffusivity



Estimation of Tortuosity

According to Chapman-Enskogg model

$$D_{12} = \frac{\mathbf{0.00186}\boldsymbol{T}^{\frac{3}{2}}\left(\frac{\mathbf{1}}{\boldsymbol{M}_{1}}+\frac{\mathbf{1}}{\boldsymbol{M}_{2}}\right)^{\frac{1}{2}}}{\boldsymbol{P}\boldsymbol{\sigma}_{12}^{2}\boldsymbol{\Omega}}$$

M_1, M_2 are molecular weights of the two species.
Ω is the collision integral.
σ_{12} is the collision diameter.

The $D_{O2\text{-}N2}$ at 800 ^{o}C is 2.076 cm^2/s.

From the equation $D_{eff} = V_V \frac{D}{\tau}$, the tortuosity factor can be estimated.

D_{eff} is the effective diffusion coefficient.
V_v is porosity.
τ is the tortuosity.

Sample	D_{eff}	Open Porosity	Tortuosity
20c	0.0163	0.1542	19.69
22.5c	0.0277	0.2443	18.3
25c	0.0462	0.3466	15.57
27.5c	0.0709	0.403	11.8
30c	0.1172	0.4377	7.76

Tortuosity at Different Temperatures

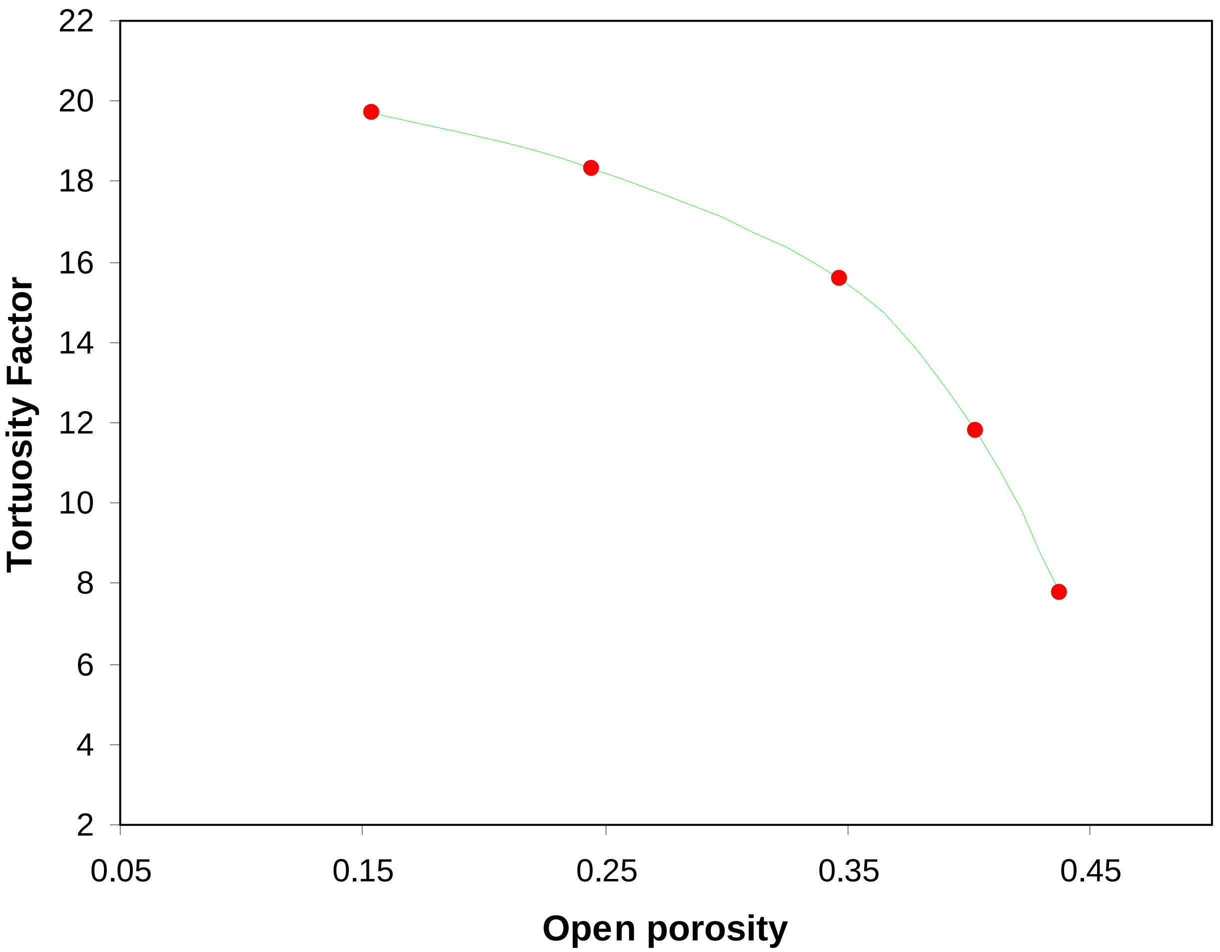
22.5% C

Temperature	D(eff) from experiment	D calculated from C-E equation	Open porosity	Tortuosity factor
650	0.02236	1.6556	24.43%	18.08
700	0.0245	1.792	24.43	17.87
750	0.0261	1.9319	24.43	18.03
800	0.029	2.075	24.43	17.44

27.5% C

Temperature	D(eff) from experiment	D calculated from C-E equation	Open porosity	Tortuosity factor
650	0.0585	1.6556	40.3%	11.39
700	0.0624	1.792	40.3	11.57
750	0.0668	1.9319	40.3	11.64
800	0.072	2.075	40.3	11.6

Tortuosity vs. Open Porosity

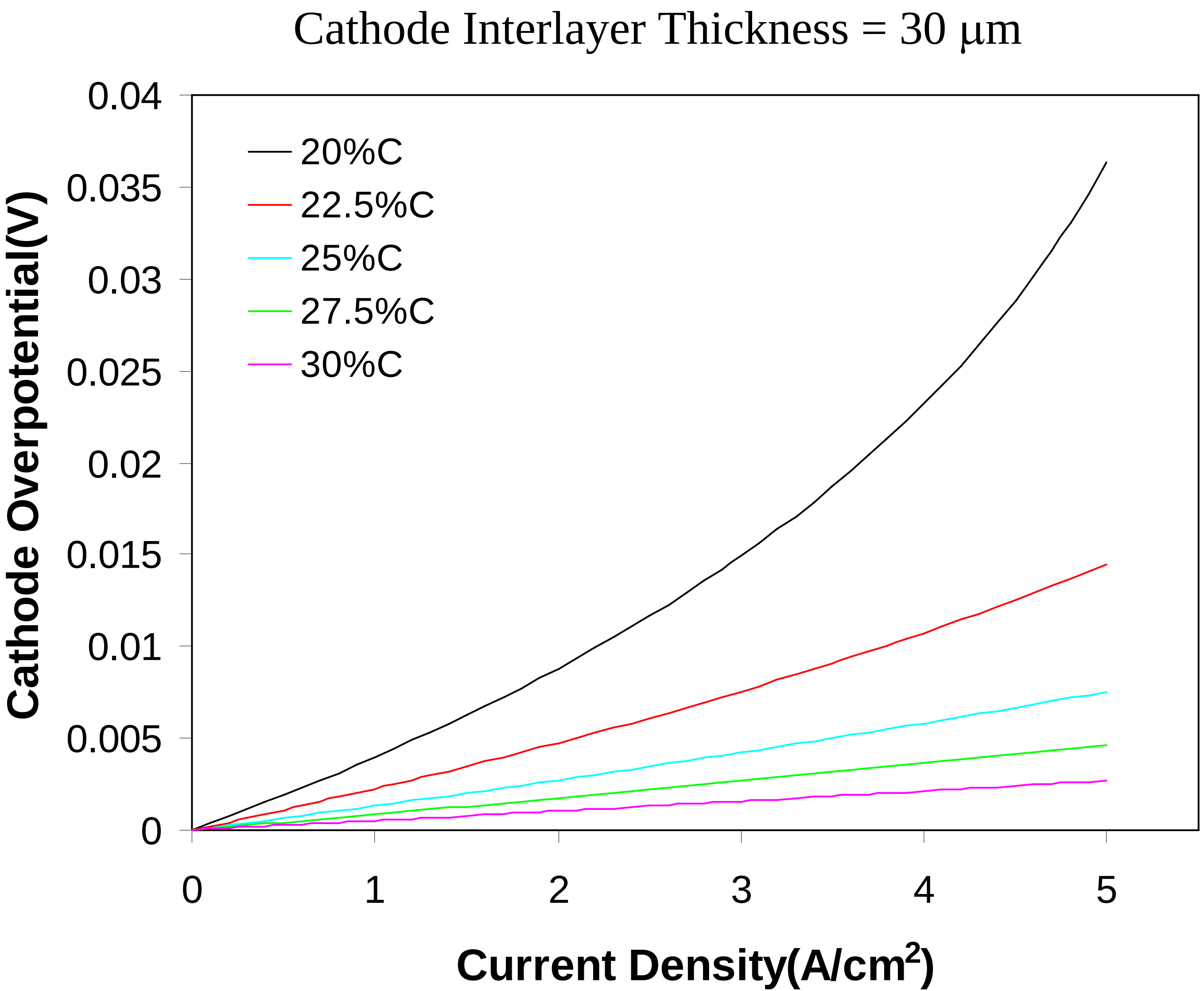


Calculated Cathode-Limiting Short Circuit Current Density

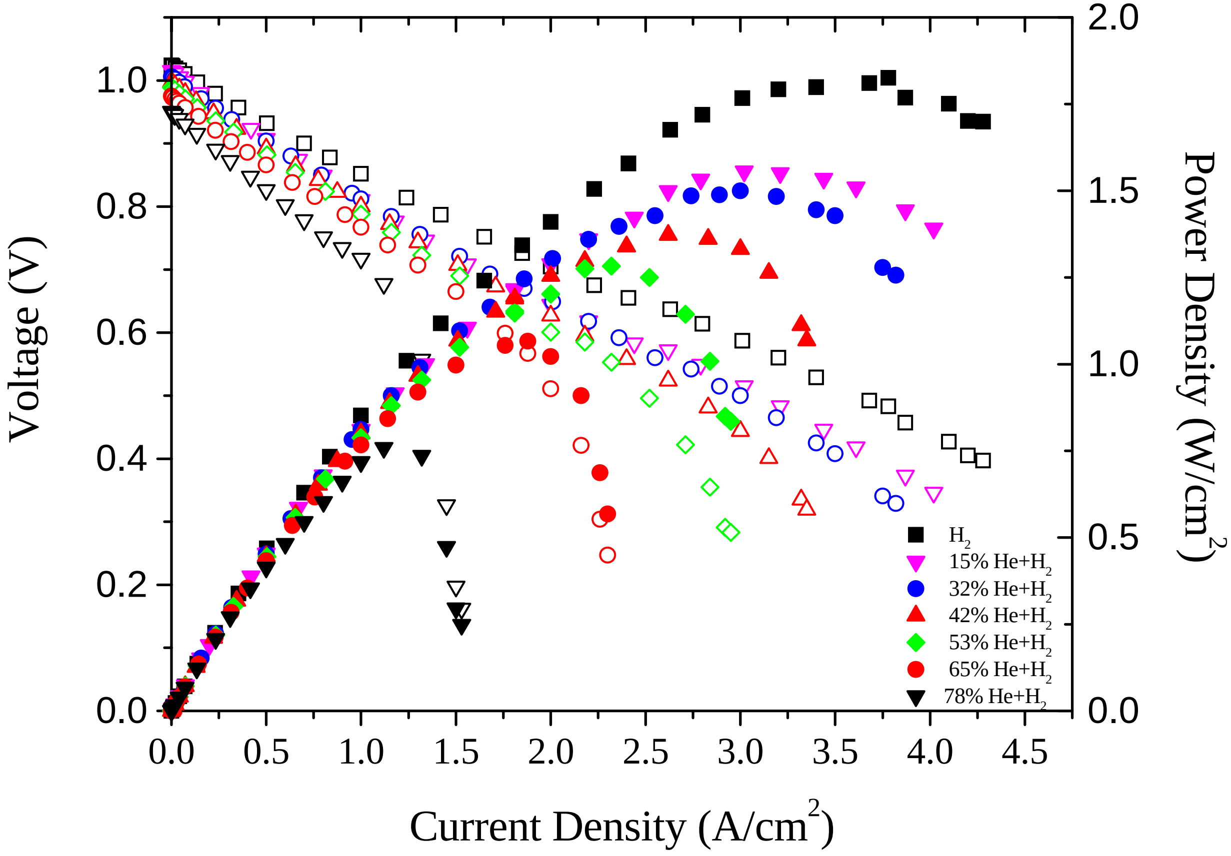
Cathode Interlayer Thickness = 30 μm

Sample	D(eff) (cm^2/s)	I_{cs} (A/cm^2) Cathode Limiting Short Circuit Current Density
20%C	0.0162	6.31
22.5%C	0.0277	10.76
25%C	0.0462	17.95
27.5%C	0.0709	27.53
30%C	0.117	45.50

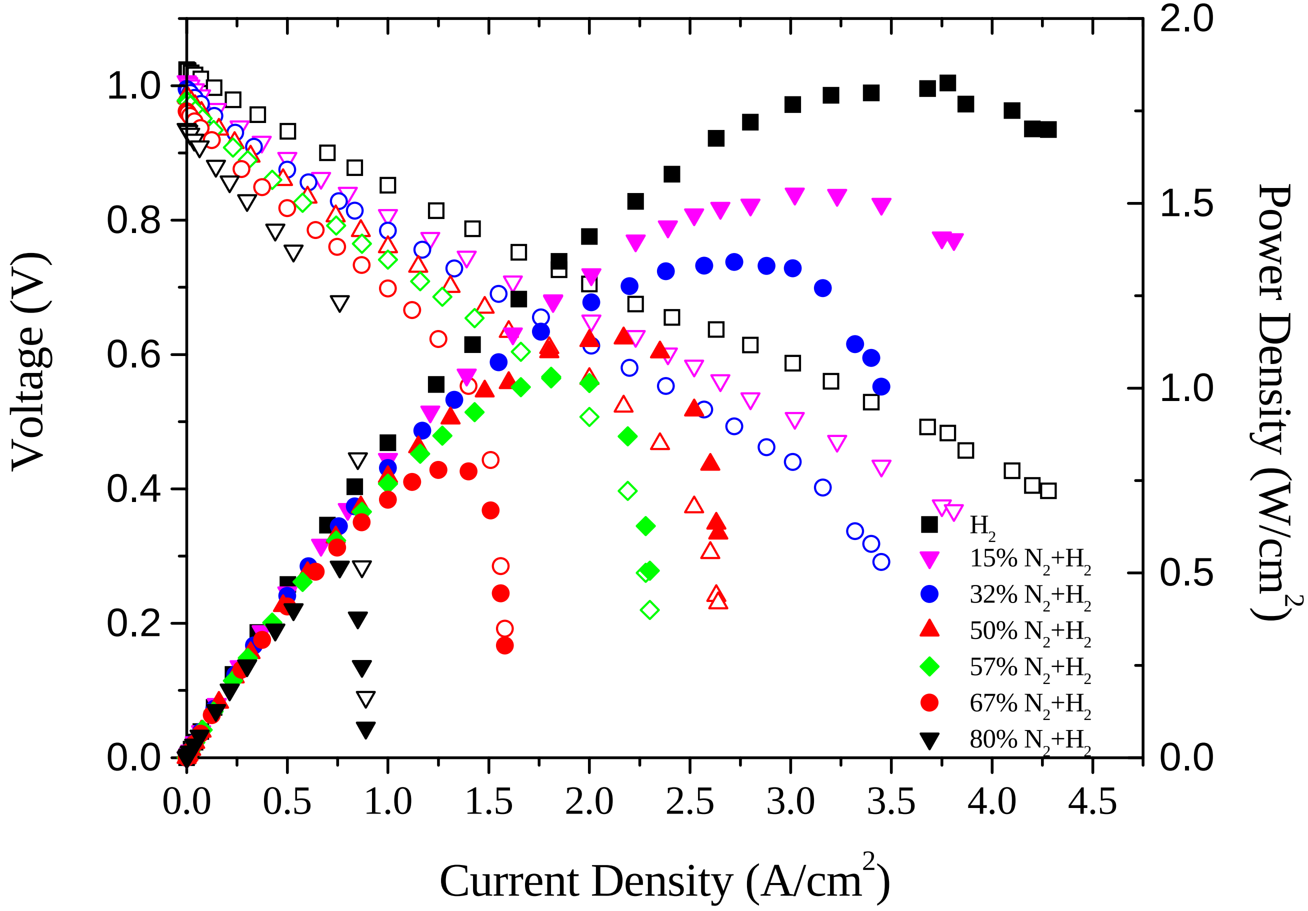
Calculated Cathodic Concentration Polarization



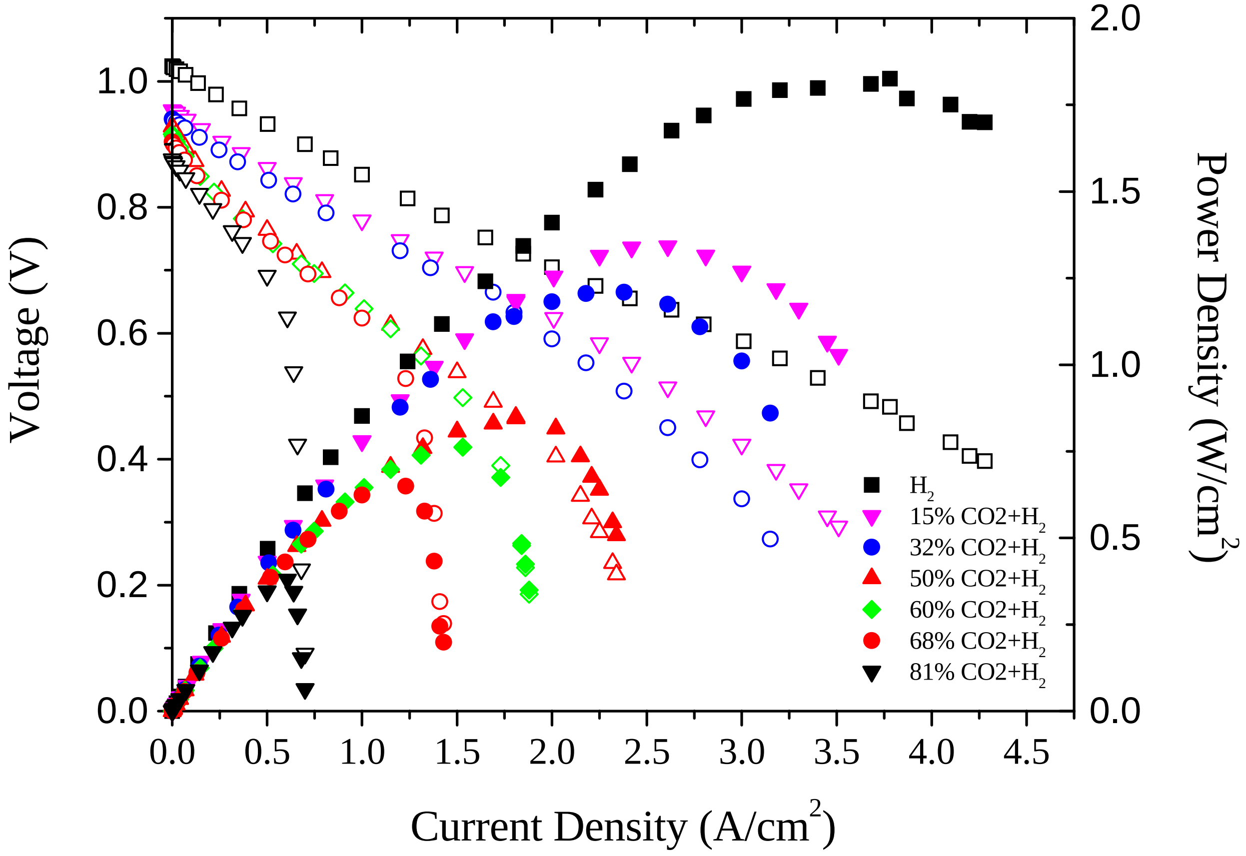
Effect of a Diluent in Fuel gas on Cell Performance (He)



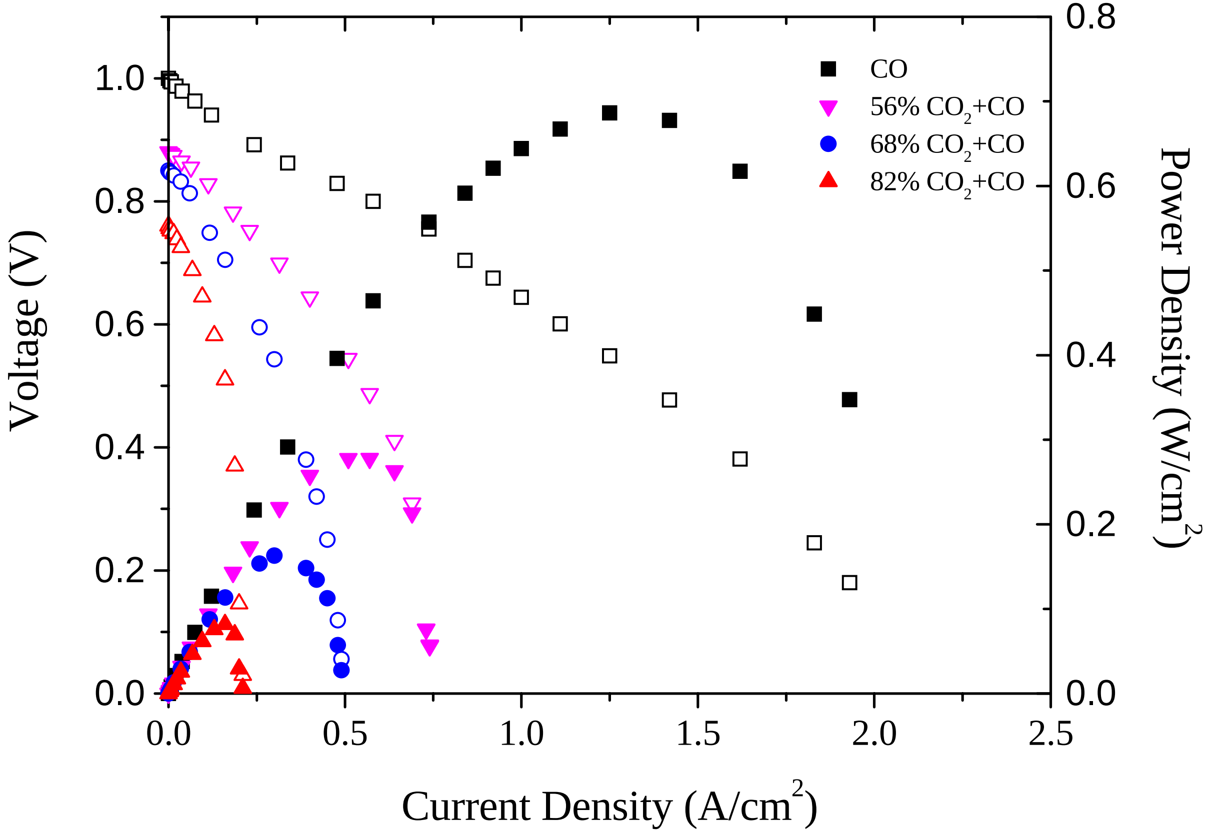
Effect of a Diluent in Fuel Gas on Cell Performance (N_2)



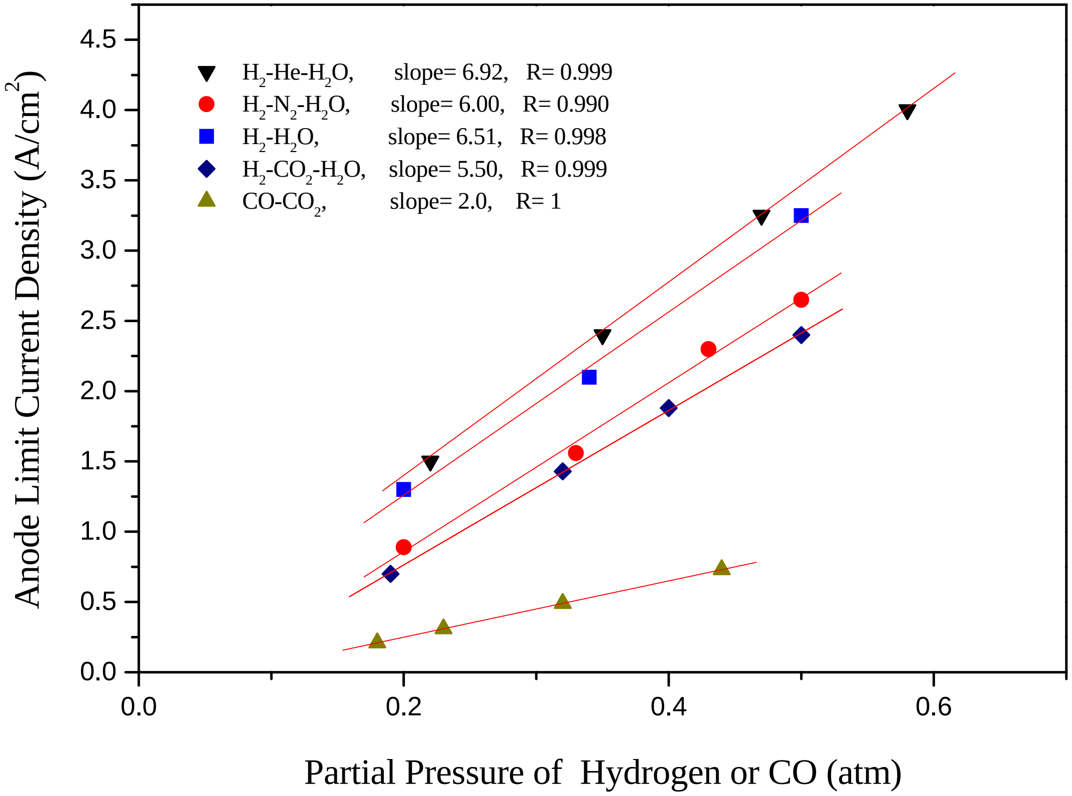
Effect of a Diluent in Fuel Gas on Cell Performance (CO_2)



Cell Performance with CO-CO_2 as Fuel



Anode-Limiting Current Density (Concentration Polarization)



Summary

1) Cathode interlayer thickness has a significant effect on cell performance. At too small a thickness, performance is limited by activation polarization. At too large a thickness, performance is affected by concentration polarization.
2) An electrochemical method was developed for the study of effective binary diffusion through porous cathodes. The estimated effective diffusivity is substantially influenced by porosity.
3) Anode-limiting current densities are qualitatively consistent with expectations based on multi-component gaseous diffusion.