AC Impedance Spectroscopy Analysis of Improved Proton Exchange Membrane Fuel Cell Operation via Direct Inlet Gas Humidity Control

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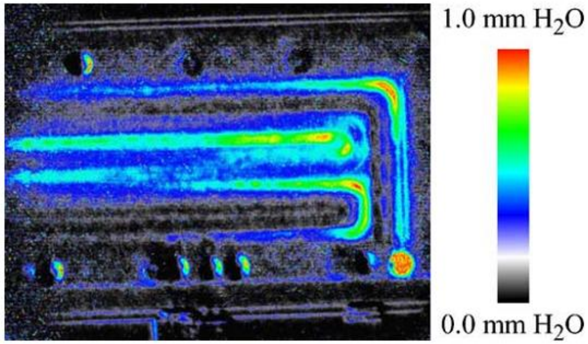
Introduction

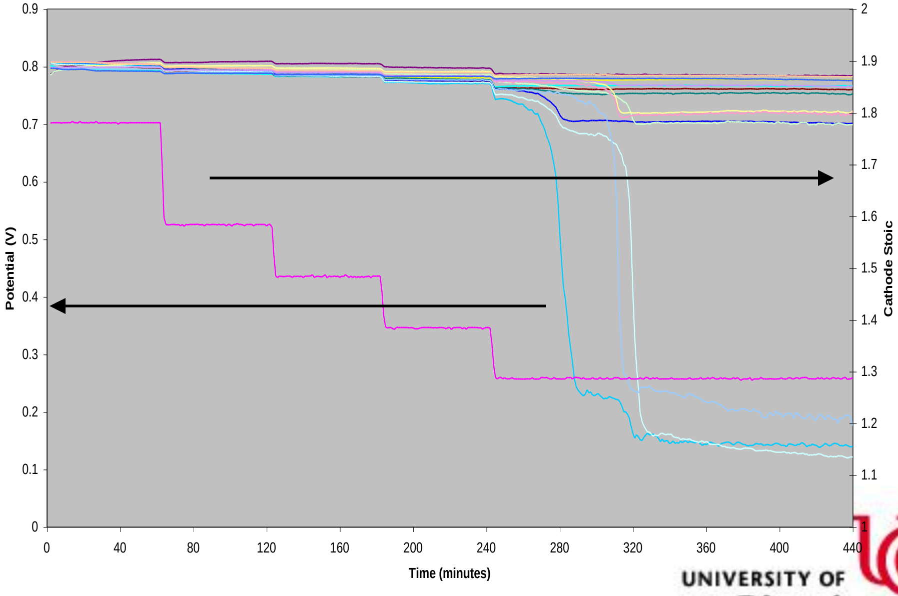
- Water Management
  - In-situ and ex-situ investigations demonstrate the importance of water management in PEM fuel cell components to overall system performance and can guide materials design and selection.

- Example: bipolar plate flooding
  - Neutron Imaging



Neutron Imaging Technique.
From Satija, R. et. al. *Journal of Power Sources*, 129, 238-245.

➢ Contributes to parasitic power losses



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Problem Statement

- Systematic investigation of how inlet relative humidity interacts with gas stoichiometry and current density to impact overall system performance for a given design has yet to be conducted.

$$vol.\,flow = stoic\ x \left(\frac{i}{nF}\right)\left(\frac{MW}{\rho}\right)$$

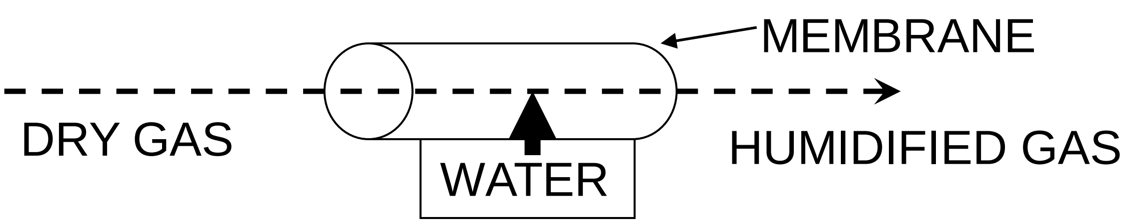
Mol. weight

Density

Faraday Constant

•Compared to bubblers, pervaporation method used in automotive has:

—No parasitic power loss due to passive humidification scheme
—Larger contact surface area, enabling smaller size



However, whether sizing is adequate to maintain thermodynamic control under conditions necessary for such a study is uncertain.

Objectives

- Investigate whether systematic control over inlet gas relative humidity and stoichiometry can provide new guidelines for optimizing PEM fuel cell performance.
- Determine impact of humidity on mechanisms that affect fuel cell performance.
- Determine whether thermodynamic control is achieved in a commercially available, pervaporation-based humidification system.

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Approach

- Direct measurement of relative humidity at the fuel cell inlet.

- Indirect measurement of fuel cell performance using polarization curve and AC Impedance Spectroscopy analyses.

- Maintain constant gas stoichiometry as current density is brought to the limiting value in any single experiment.

- Full factorial experiment covering full spectrum of inlet RH settings.

Cell temperature: 80 C
Stoichiometry: 1.5 and 3.0
Pressure: atmospheric

Exp #	Anode RH (%)	Cathode RH (%)
1	95	95
2	80	80
3	40	40
4	20	20
5	95	80
6	95	40
7	95	0
8	80	95
9	40	95
10	0	95

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Equipment and Materials

- MT571 Test Stand from Mound Technical Solutions, Miamisburg, OH
  - Pervaporators for anode/cathode humidity injection.
  - Capacitive inlet RH sensors integrated into a proprietary probe adapter .
  - Mass flow control with automated switching between low/high ranges (200 ml/min / 2 L/min).
  - TDI RBL 488 400 W Load
  - Gamry FC150 EIS Module
    - AC amp. at 7.5 % DC
      From 10 kHz to 0.01 Hz
- Softgoods: 25 cm^2 MEA with GDL:
  - Nafion® 112 membrane
  - 0.2mg Pt/cm^2 loading on anode
  - 0.4mg Pt/cm^2 loading on cathode
  - electrode area of 25 cm^2
- Dry grade air, pre-purified hydrogen,
  N_2 purge

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Results: Deviation from Thermodynamic Control

Humidifier water temperature used to achieve target RH. All measured test stand values can have an error of 2 C.

Humidifier Water Temperature(C)	Thermodynamically Controlled	Present Test Stand			
		<0.3L/min	0.3-0.6L/min	0.6-1L/min	1L/min and above
Water Temperature for 95%RH	78	68	72	74	75
Water Temperature for 80%RH	75	63	66	70	72
Water Temperature for 40%RH	59	48	52	55	57
Water Temperature for 20%RH	45	40	44	45	45

Hypothesis: amount of water being picked up from the reservoir in the lines between humidifier and inlet

Water Consumption (mL/hr)	Present Test Stand			
	<0.3L/min	0.3-0.6L/min	0.6-1L/min	1L/min and above
95%RH	2.9	3.8	4.3	4.9
80%RH	2.8	4.4	4.3	4.1
40%RH	1.1	1.5	1.5	1.2
20%RH	0.3	0.1	0.0	0.0
Assumed Flow Rate	0.3L/min	0.6L/min	1L/min	1.5L/min

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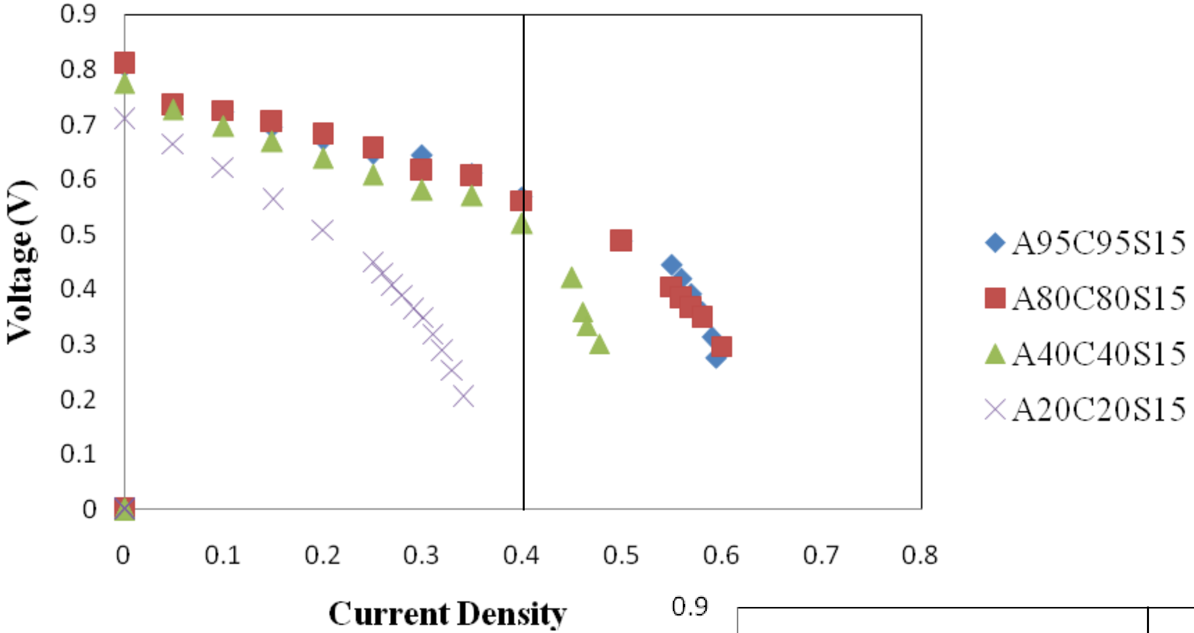
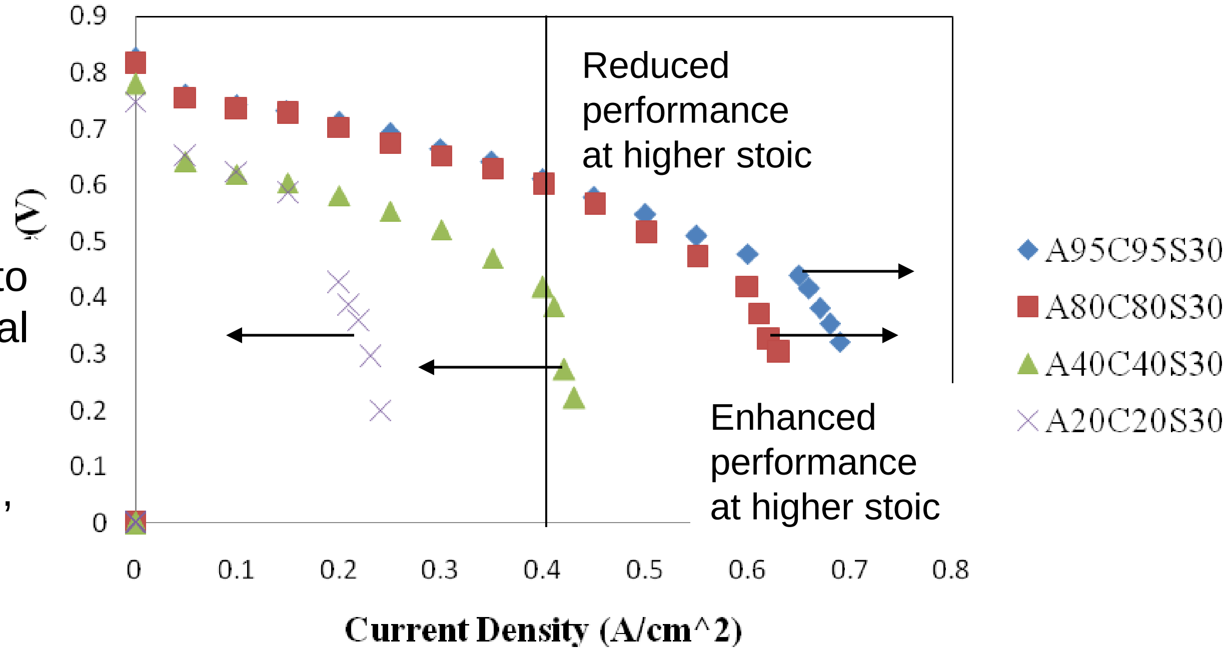
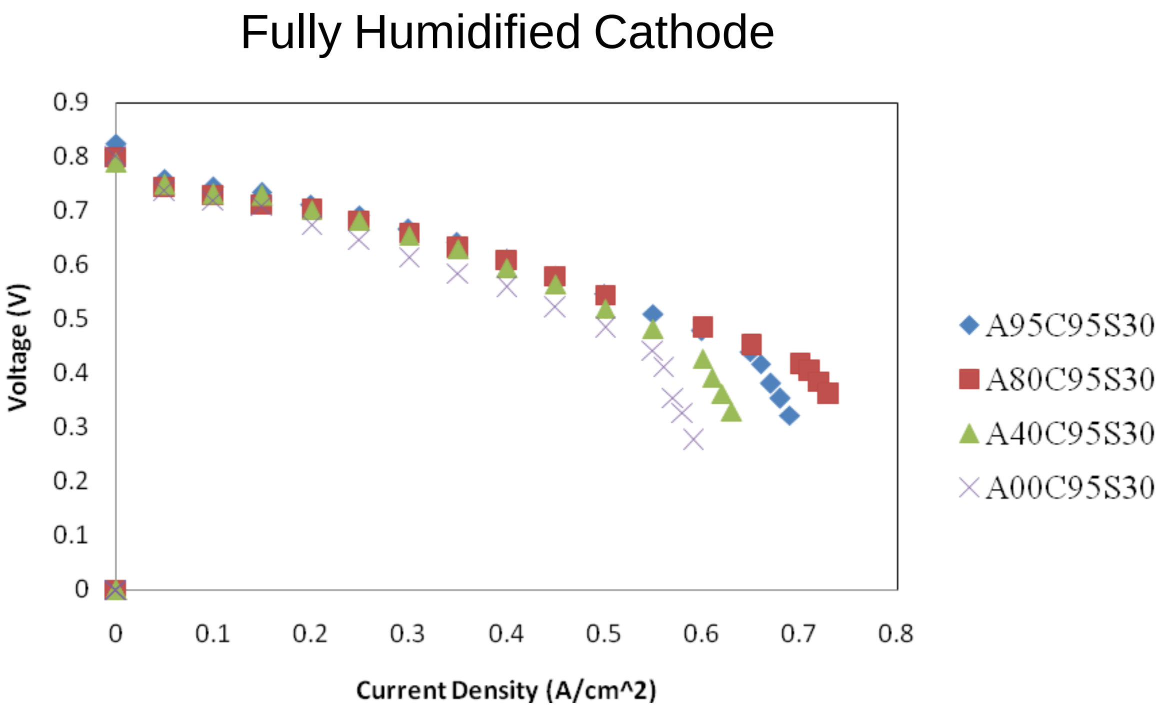


Equal Inlet RH

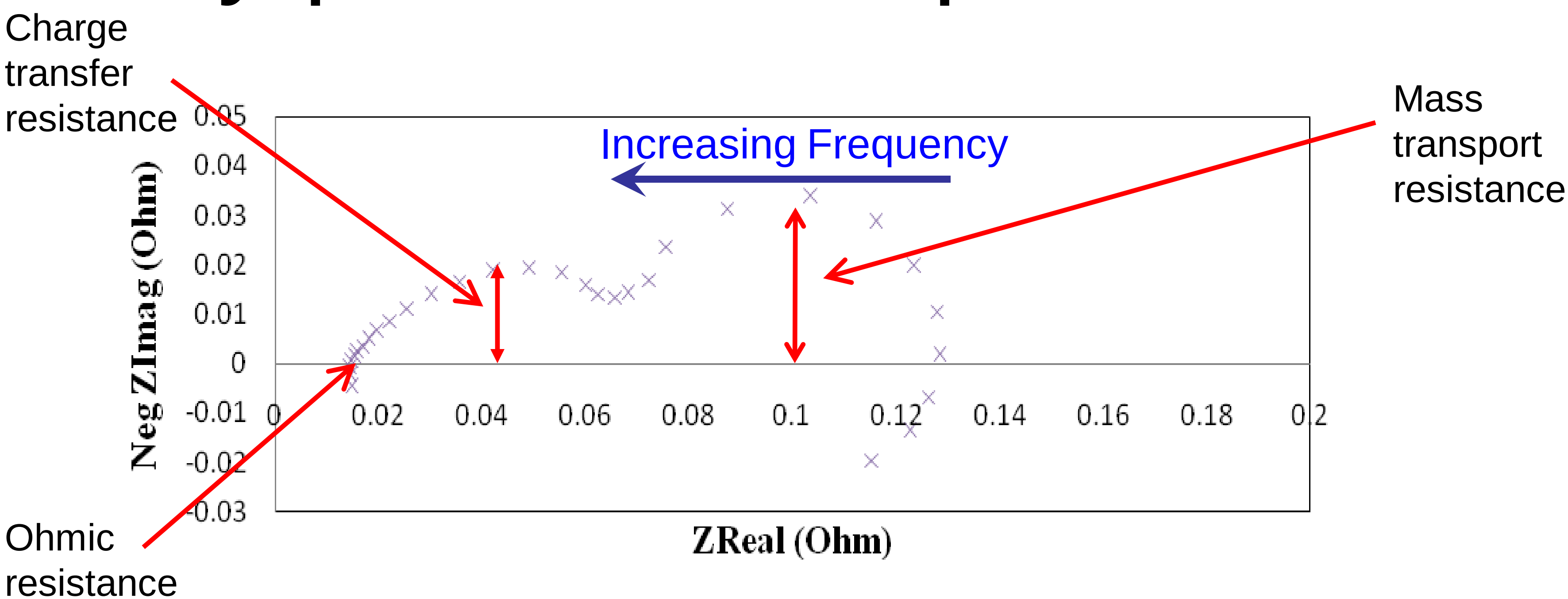


- Higher humidification leads to better performance in general
- Increasing air flow rate improves performance only when inlet RH is above 40%, otherwise, performance is worse

•Humidification of either electrode drastically improves the performance of the cell at both 1.5 and 3.0 stoich.
•Interestingly, optimum performance at A=80RH and C=95RH



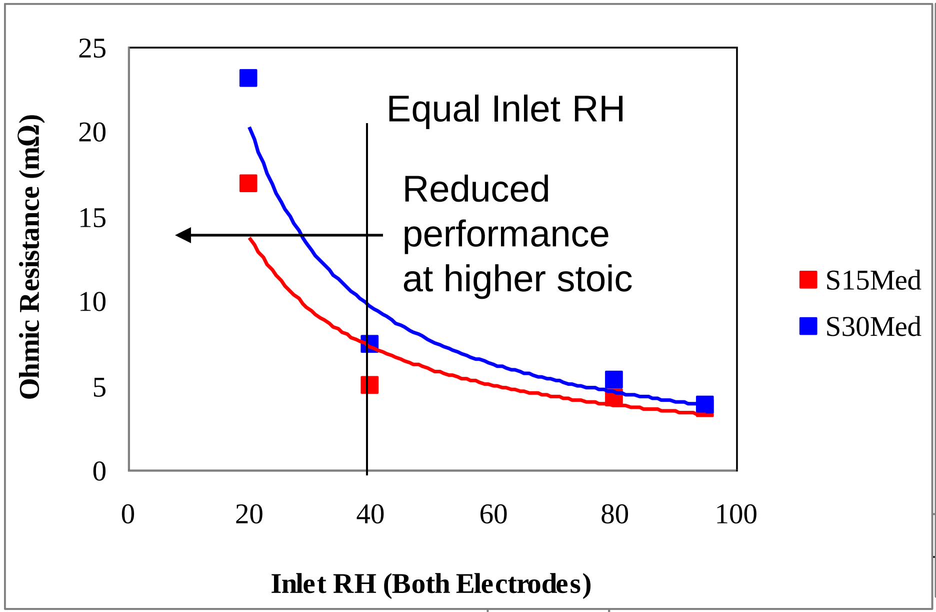
Nyquist Plot Interpretations

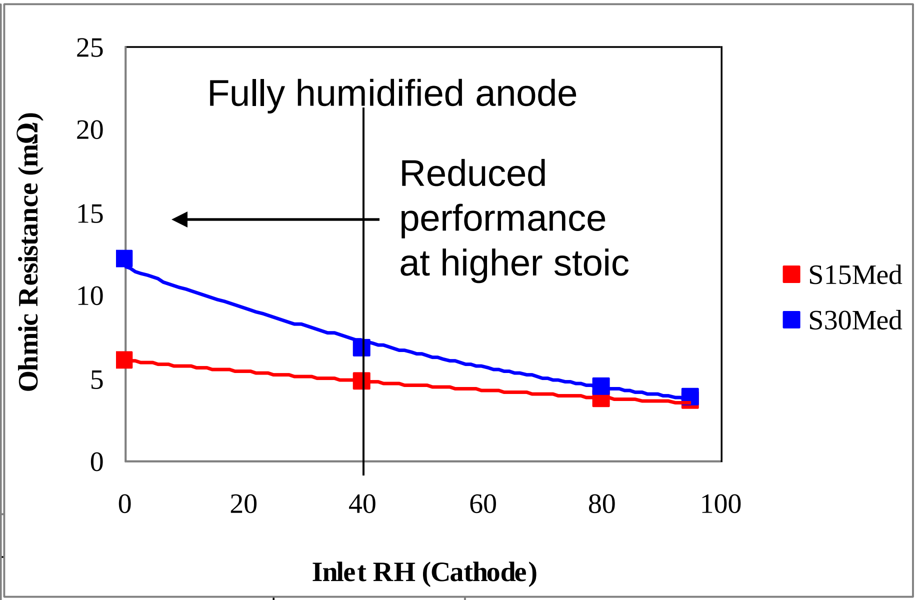


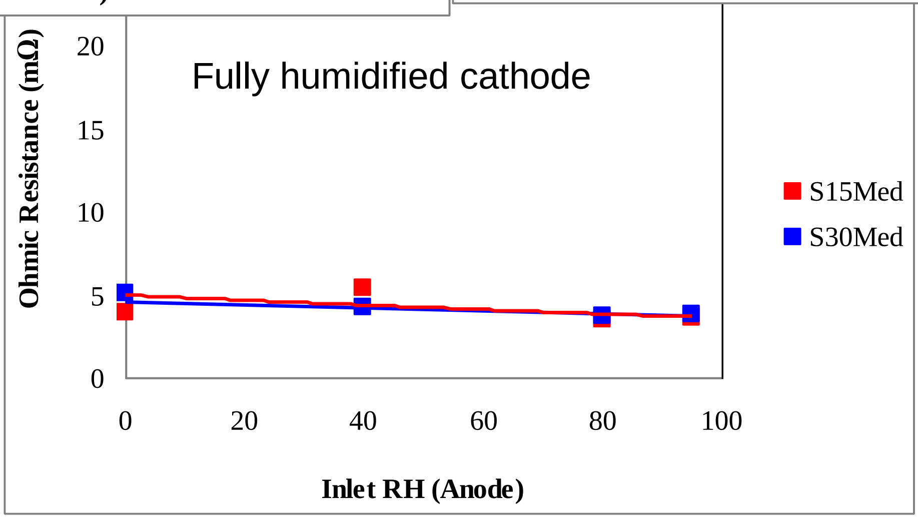
Typical Nyquist plot obtained in the present study. This particular one is generated under a anode 95%RH, cathode 95%RH, 1.5 cathode stoich, 2.5A (0.1 A/cm^2) DC current.

Ohmic Resistance

Keeping cathode fully humidified keeps ohmic resistance low







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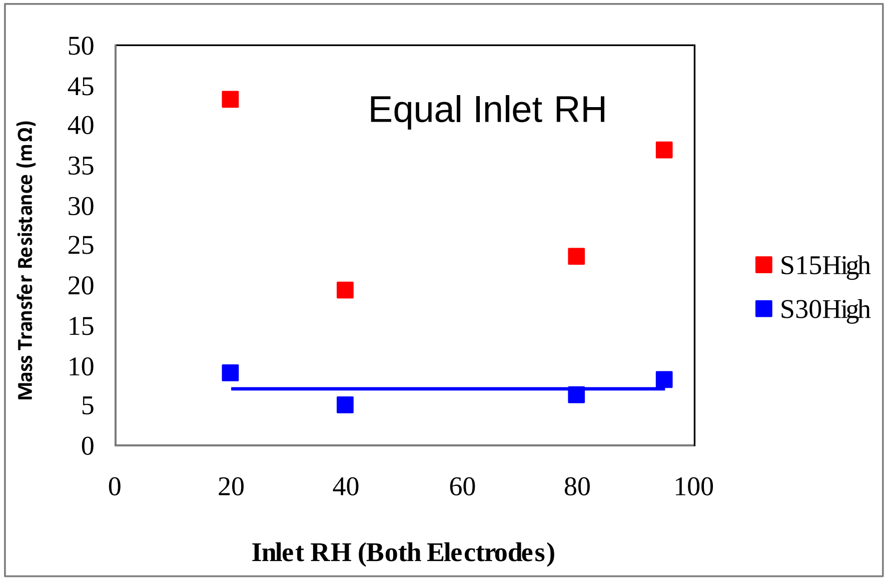
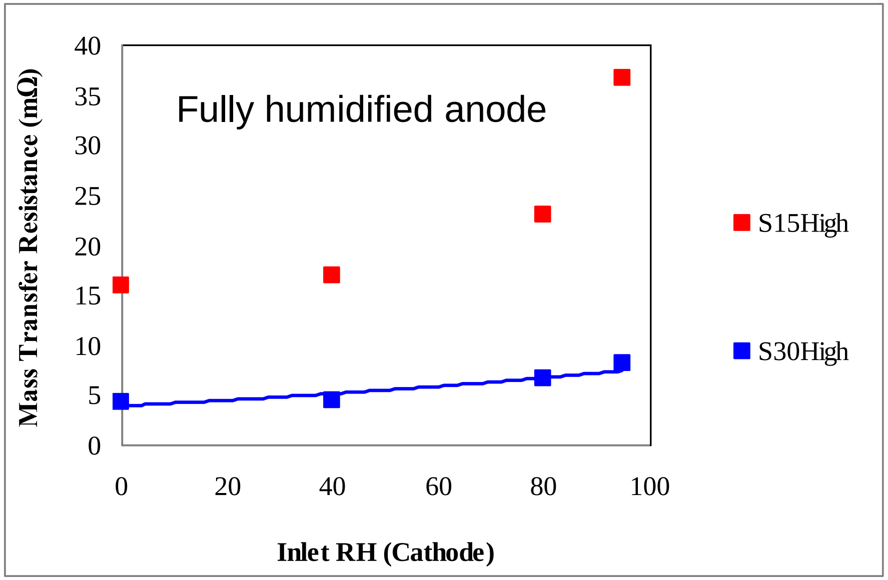
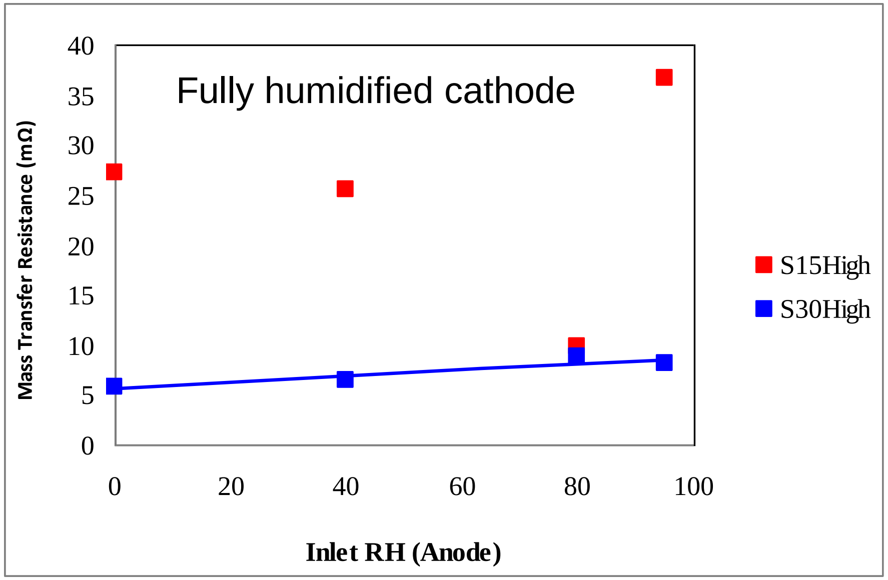
Mass Transfer Resistance

•Mass transport resistance is reduced at higher stoics but has optimum anode RH at lower stoic.







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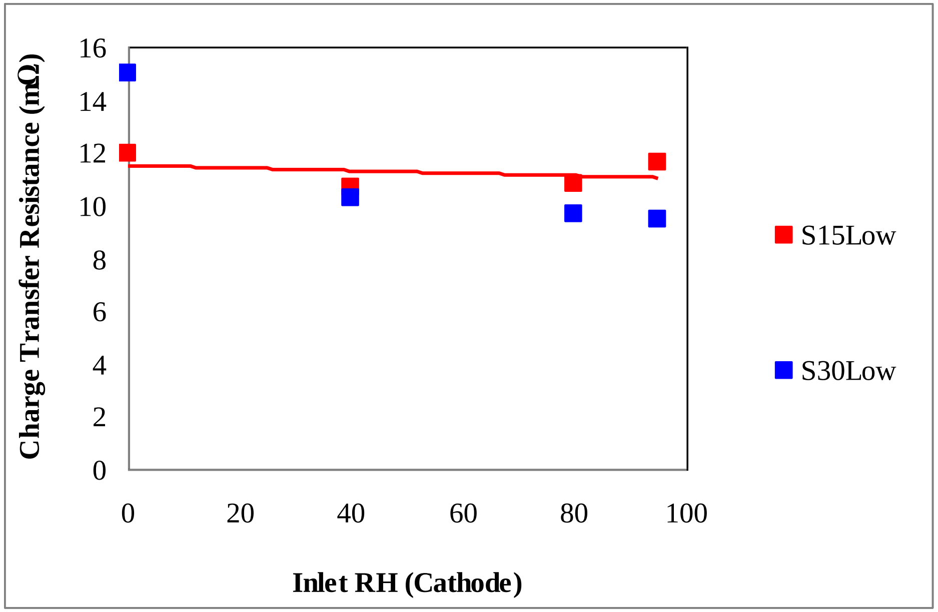
Charge Transfer Resistance

Charge transfer resistance appears to depend somewhat on cathode inlet RH at the higher stoic.

Fully humidified anode



Conclusions

- Optimal RH conditions exist for a given fuel cell design at a given Stoic and Current density:
  - Membrane hydration ensured by cathode humidifcation.
  - Balance between catalyst flooding and membrane hydration achieved by anode humidification.
  - Cathode catalyst performance enhanced by humidification
- Most effective way to humidify depends on air flow rate
  - Low air flow rate: anode humidification is more efficient
  - High air flow rate: must humidify air, otherwise cathode membrane dehydrates.
- Direct inlet humidity monitor is necessary for achieving desired RH level

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Acknowledgements

- General Motors Corporation
- Mound Technical Solutions

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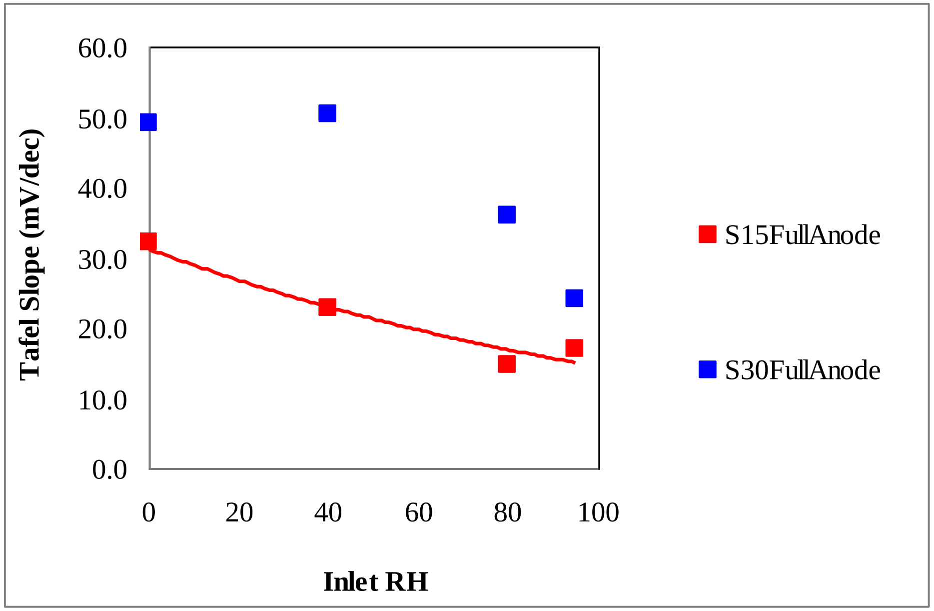
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Tafel Slope (mV/dec)
0
20
40
60
80
100
Inlet RH
S15FullAnode
S30FullAnode