Diagnosis of PEMFC operation using EIS

Electrical Research Institute

*Hydrogen and
Fuel Cells Group*

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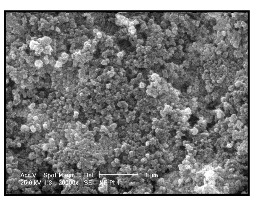
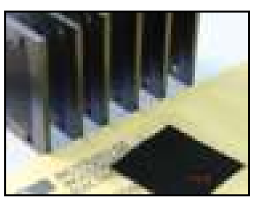
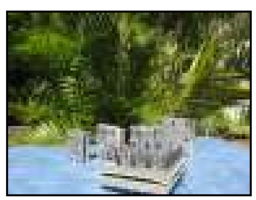
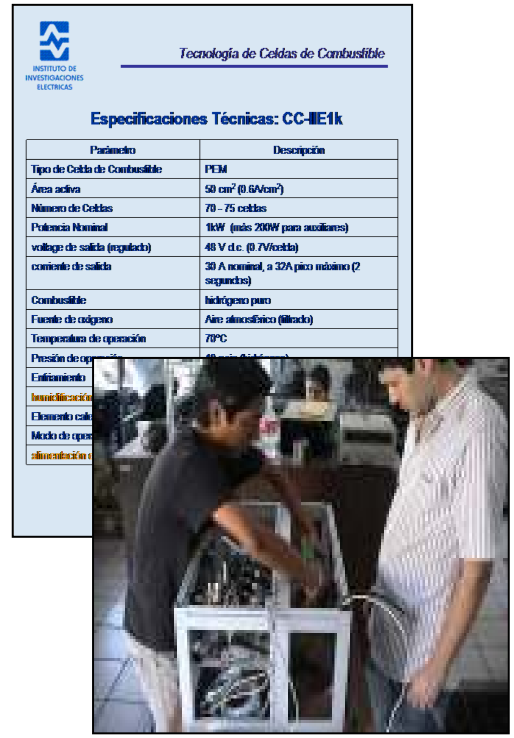






Parámetro	Descripción
Tipo de Celda de Combustible	PEM
Área activa	50 cm^2 (0.6A/cm^2)
Número de Celdas	70 – 75 celdas
Potencia Nominal	1kW (más 200W para auxiliares)
voltage de salida (regulado)	48 V d.c. (0.7V/celda)
corriente de salida	30 A nominal, a 32A pico máximo (2 segundos)
Combustible	hidrógeno puro
Fuente de oxigeno	Aire atmosférico (filtrado)
Temperatura de operación	70°C
Enfriamiento	[illegible]

MEA → STACK → SYSTEM

quality

performance

reliability

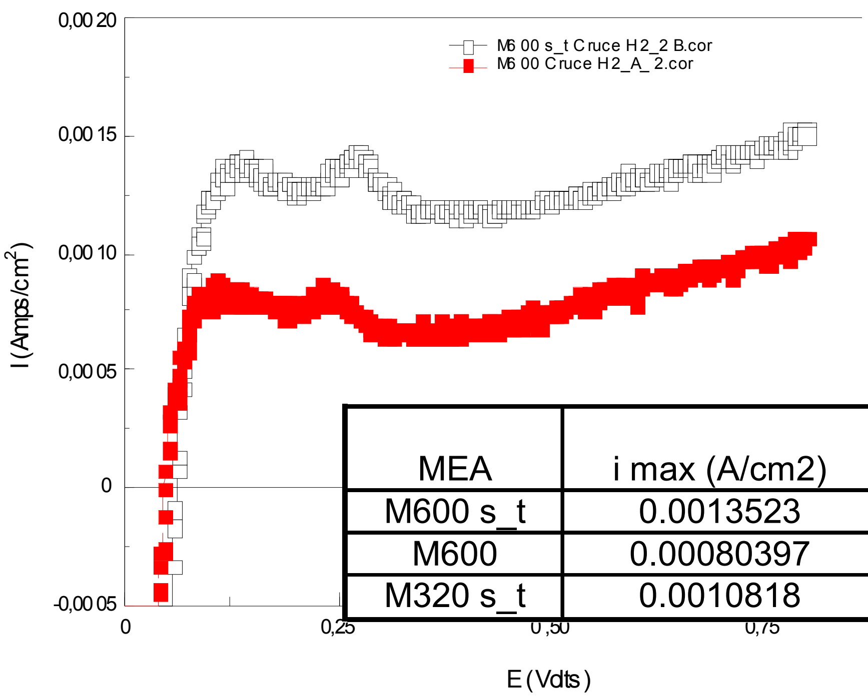
degradation

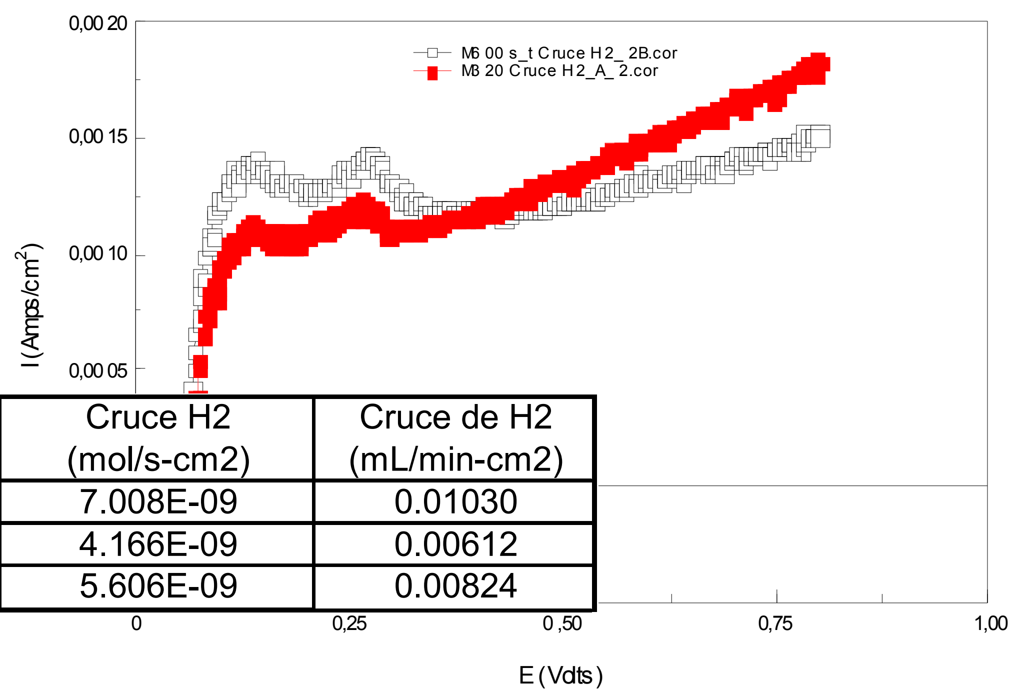
state of health

long life

Characterization using d.c. techniques:

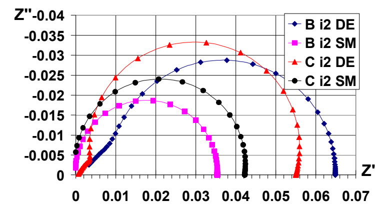
voltammetry – electrochem. active area
linear voltammetry – H_2 crossover (int. short circuit)
polarization curves – performance

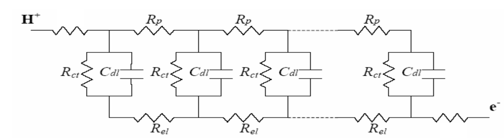




MEA	i max (A/cm2)	Cruce H2 (mol/s-cm2)	Cruce de H2 (mL/min-cm2)
M600 s_t	0.0013523	7.008E-09	0.01030
M600	0.00080397	4.166E-09	0.00612
M320 s_t	0.0010818	5.606E-09	0.00824

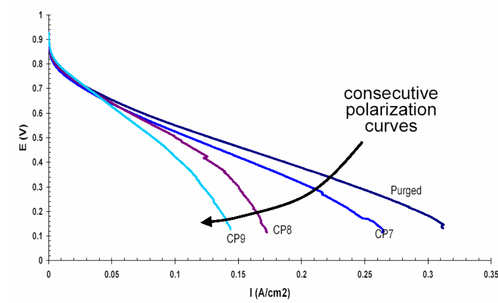
Interest on EIS as applied to Fuel Cells





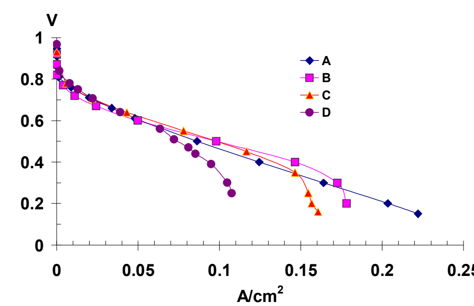
MEA development

- platinum activity follow-up
- bulk membrane resistance
- ionic conductivity at CL (through distributed element model)



Stack

- sensitivity to operating conditions



Systems control

- Potential flooding/drying detection

Steady-state and transient models

- Combination of experimentally determined kinetic parameters with EIS-determined parameters for PEMFC dynamic model

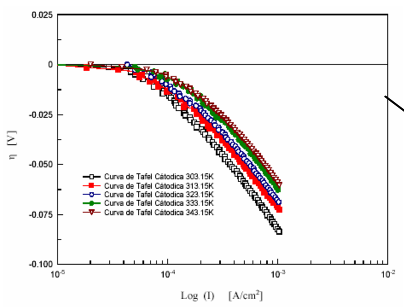
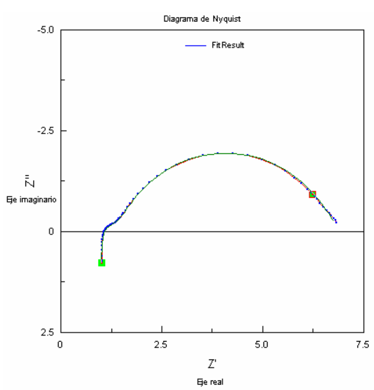
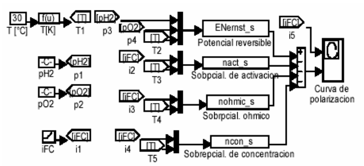


Figura 2. Curvas de Tafel obtenidas experimentalmente para el cátodo de una celda PEM





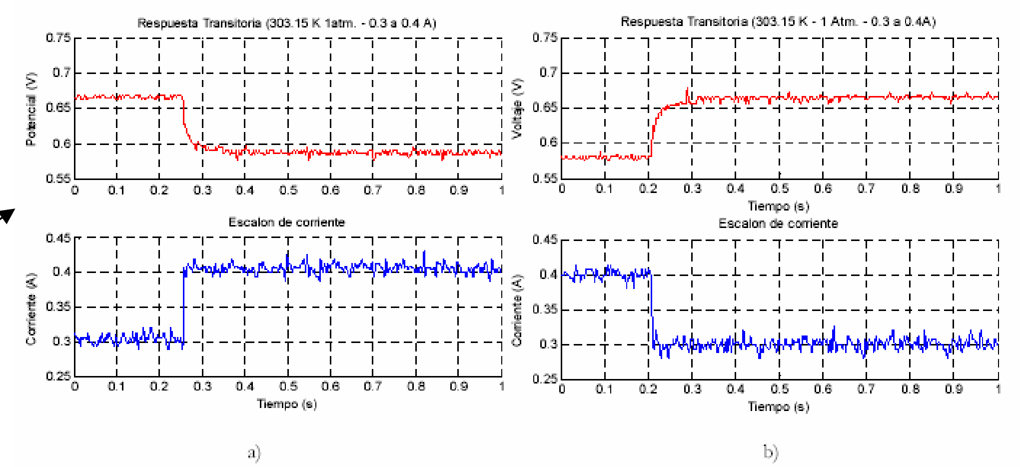


Figura 12. Respuesta transitoria de celda PEM: a) Flanco positivo. b) Flanco negativo

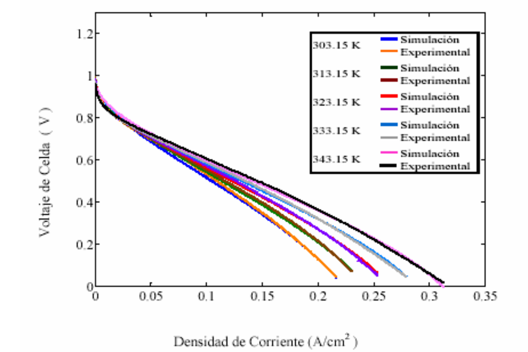


Fig. 3 Comparación de Respuestas (Modeladas vs. Experimentales)

Q = can EIS bu used as a diagnostic technique during operation near flooding/drying conditions?

Facts & warnings:

- **EIS highly sensitive to changes within the fuel cell**
- **EIS response is strongly dependent on design**
- **If gradients (heterogeneities) along active area exist, EIS will pick them up**
- **"Dry" and excess of water may coexist in different regions of FC (as well as other effects)**
- **EIS should not be seen as a black or white result but as a color pallette (i.e. interpreted as such)**

water dynamics near dry/wet limit

Dehydration Stage: (previously conditioned and purged)

- Tcell = 40 °C
- Cathode: P: 10psi; flow: air 0.5 L/min
- Anode: P= 10psi; gas exit closed
- t = 1hr, EIS for ohmic resistance @ Eoc

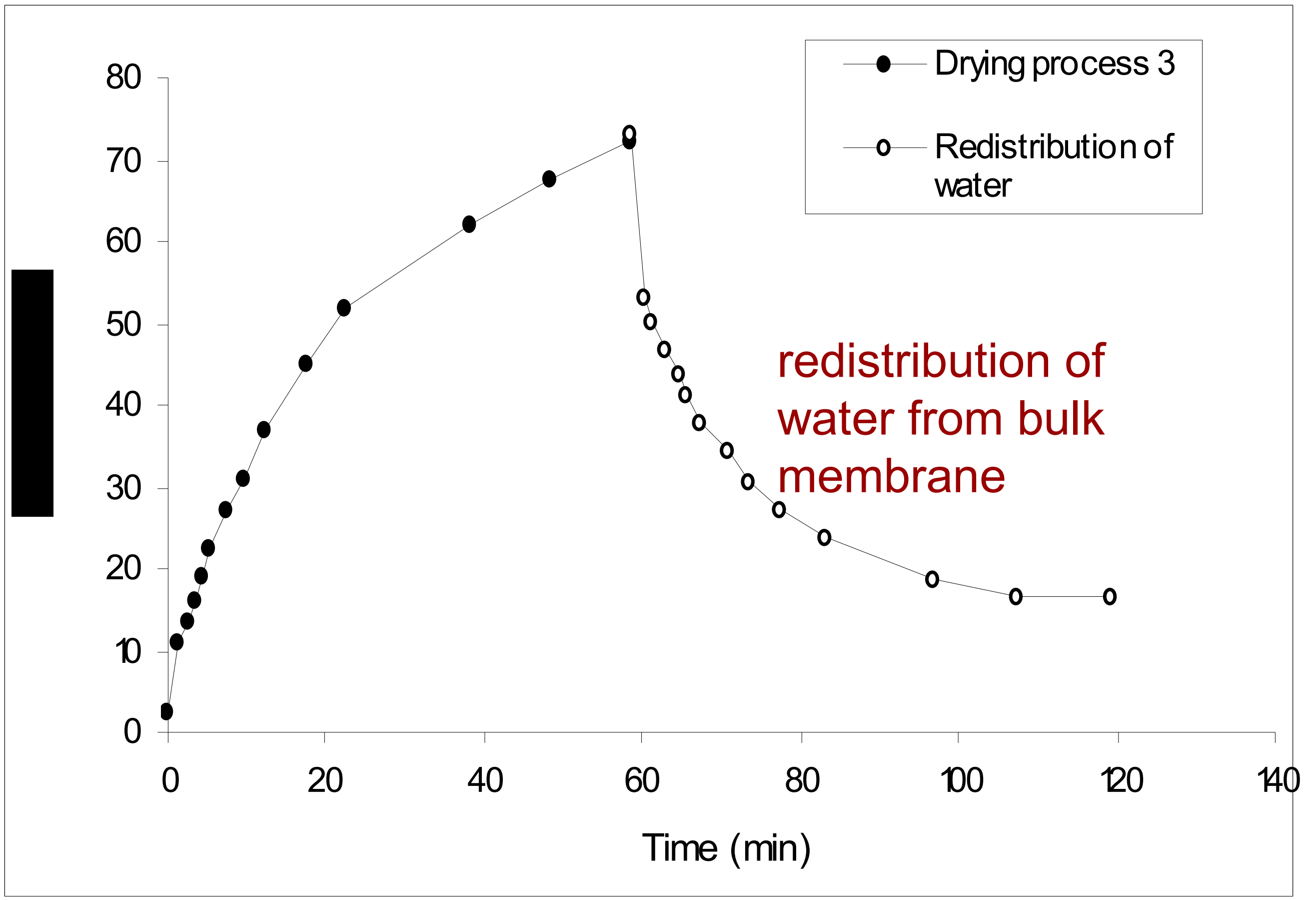
Rest Stage (no humidification)**:**

- Tcell = 40 °C
- Cathode, P = 10psi, Flow: air 0 L/min (just after dehydration process)
- Anode, P = 10psi, gas exit closed.
- t = 1hr, EIS for ohmic resistance @ Eoc

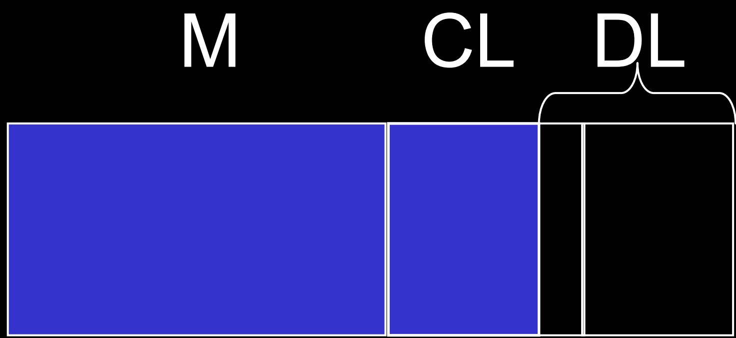
MEA: 25cm^2, Gore, Pt = 0.7 mg/cm^2, carbon paper, DL = 50μ,
GFF: simple serpentine

cell's ohmic resistance

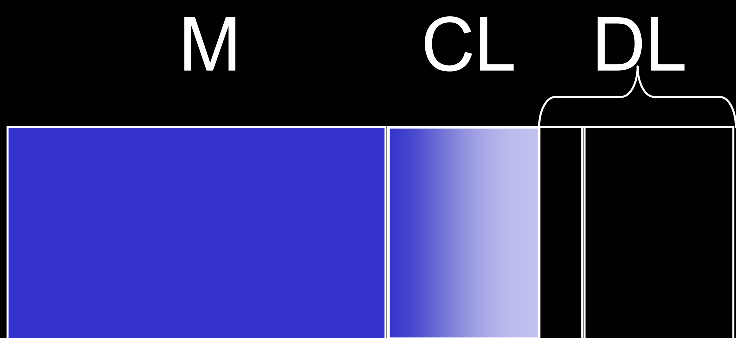
determined by high frequency intercept



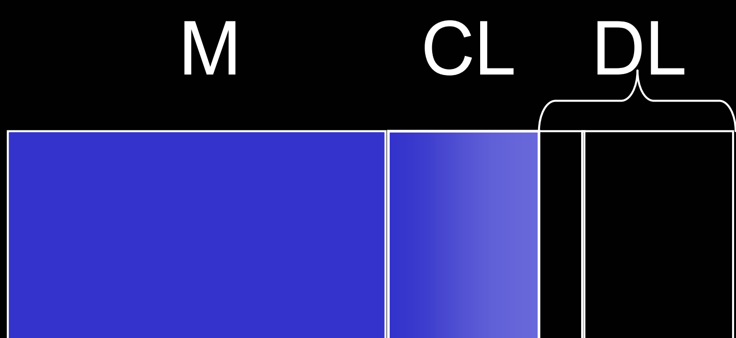
*low conductivity final current collectors plates used



after conditioning



after high air flux
CL w/H_2O gradient



after 1 hr rest
H_2O redistributes in CL

Real life is cruel for EIS:

Practical operating conditions are hardly under steady-state, it depends on specific application and design

Experimental approach:

- Initial conditioning

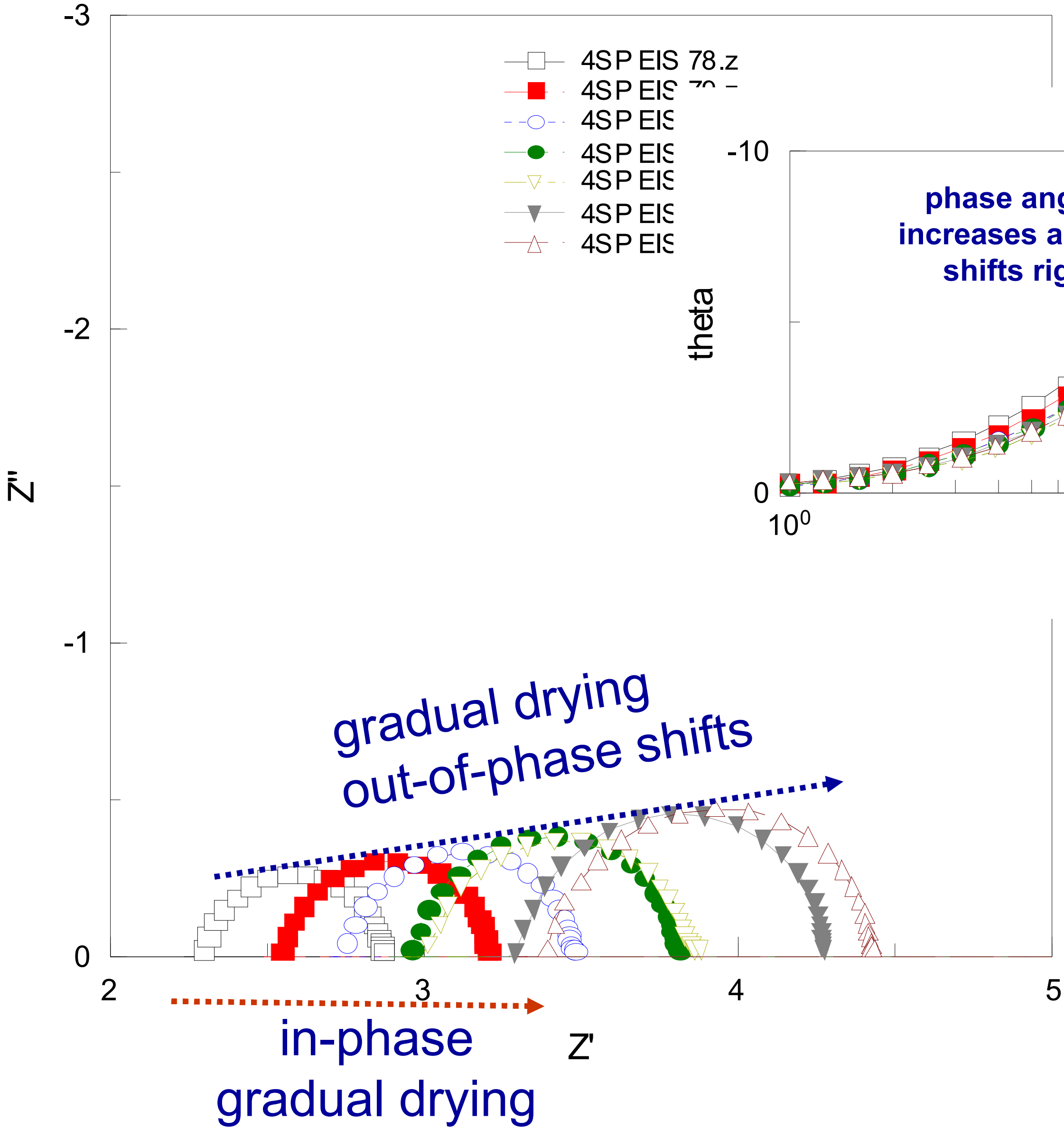
- Operating near the limit of drying/flooding

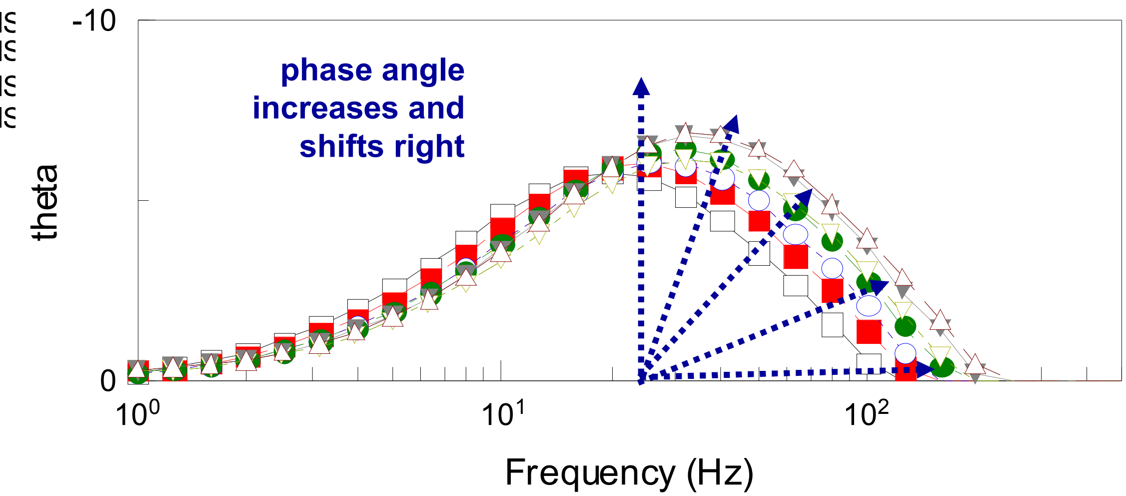
- **low T & stoich's**
- **dead ended configuration**
- **purge stages**
- **dry feeds**
- **use of O_2**

- EIS (1Hz to 1KHz), 10mV (Ecell = 0.4V)

Own 50 cm2 MEA, GFFc = 4ps, GFFa pch. 0.7 mg Pt/cm2, Nafion NRE-212. GDL-30-BC (C paper w/MPL). T=343.15 K (70°C) & 69 kPa (10 psi)

Drying

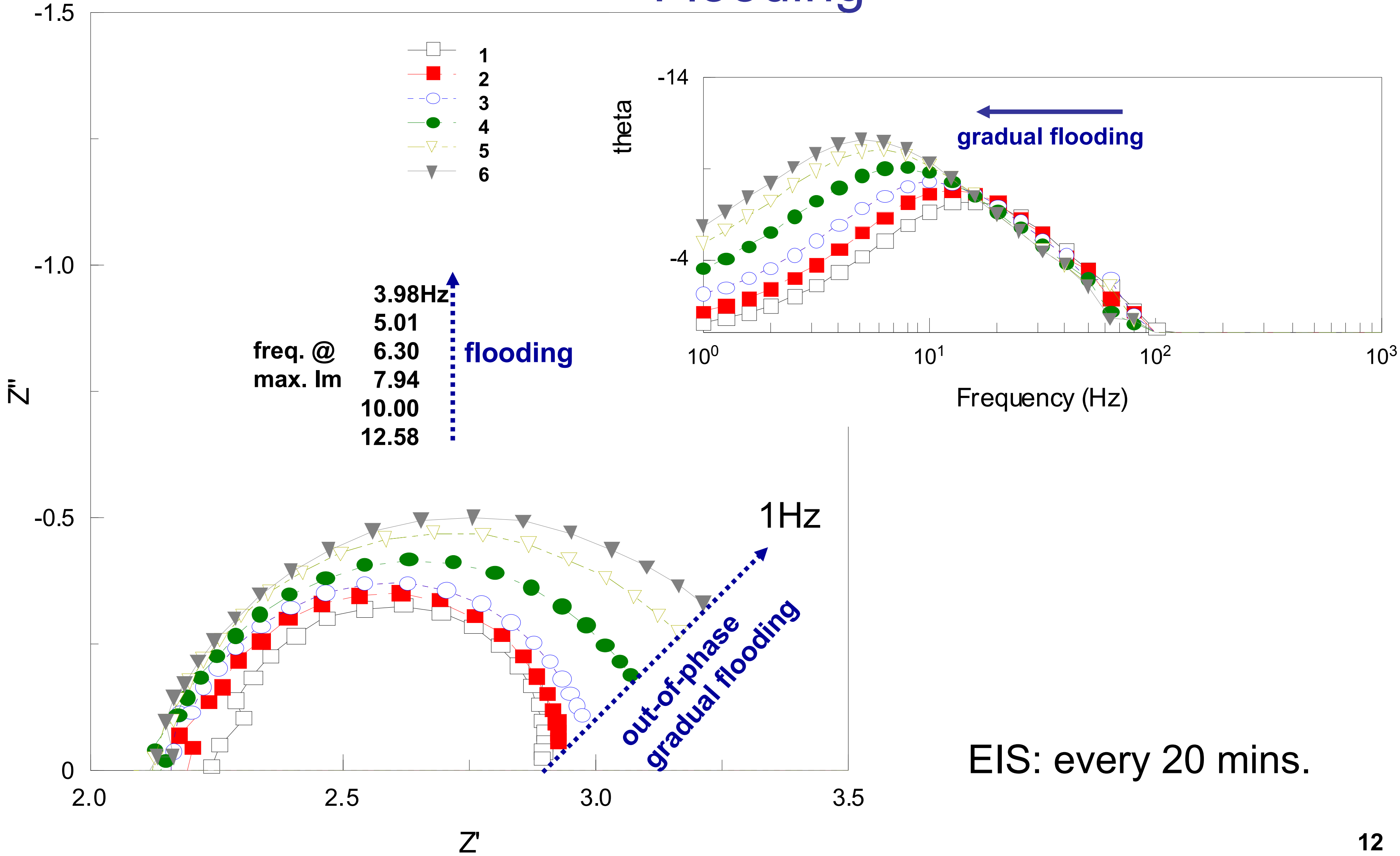




cathode stoichiometry = 4
not humidified

both Z" & Z' increase

Flooding



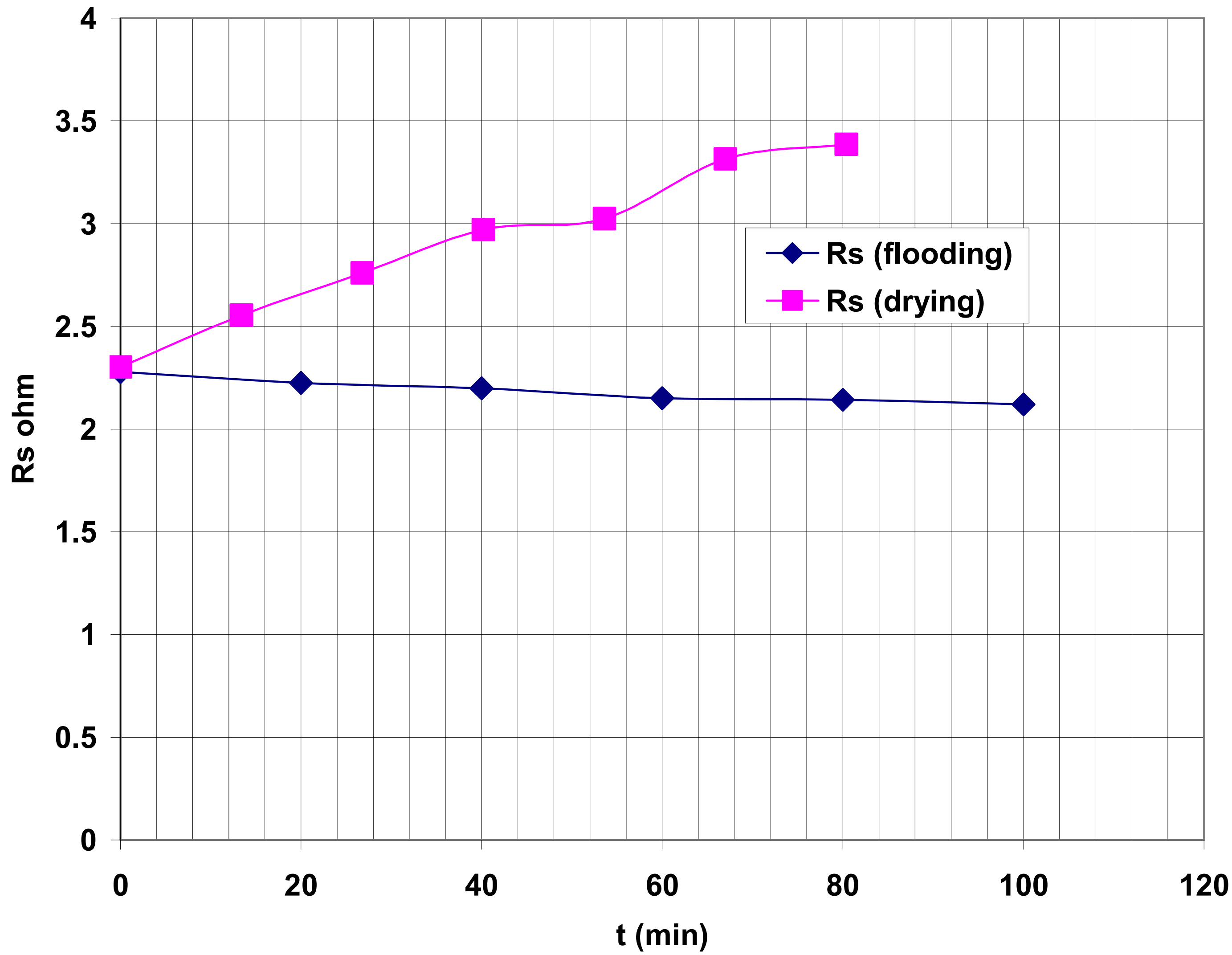
EIS: every 20 mins.

R_s = total ohmic resistance

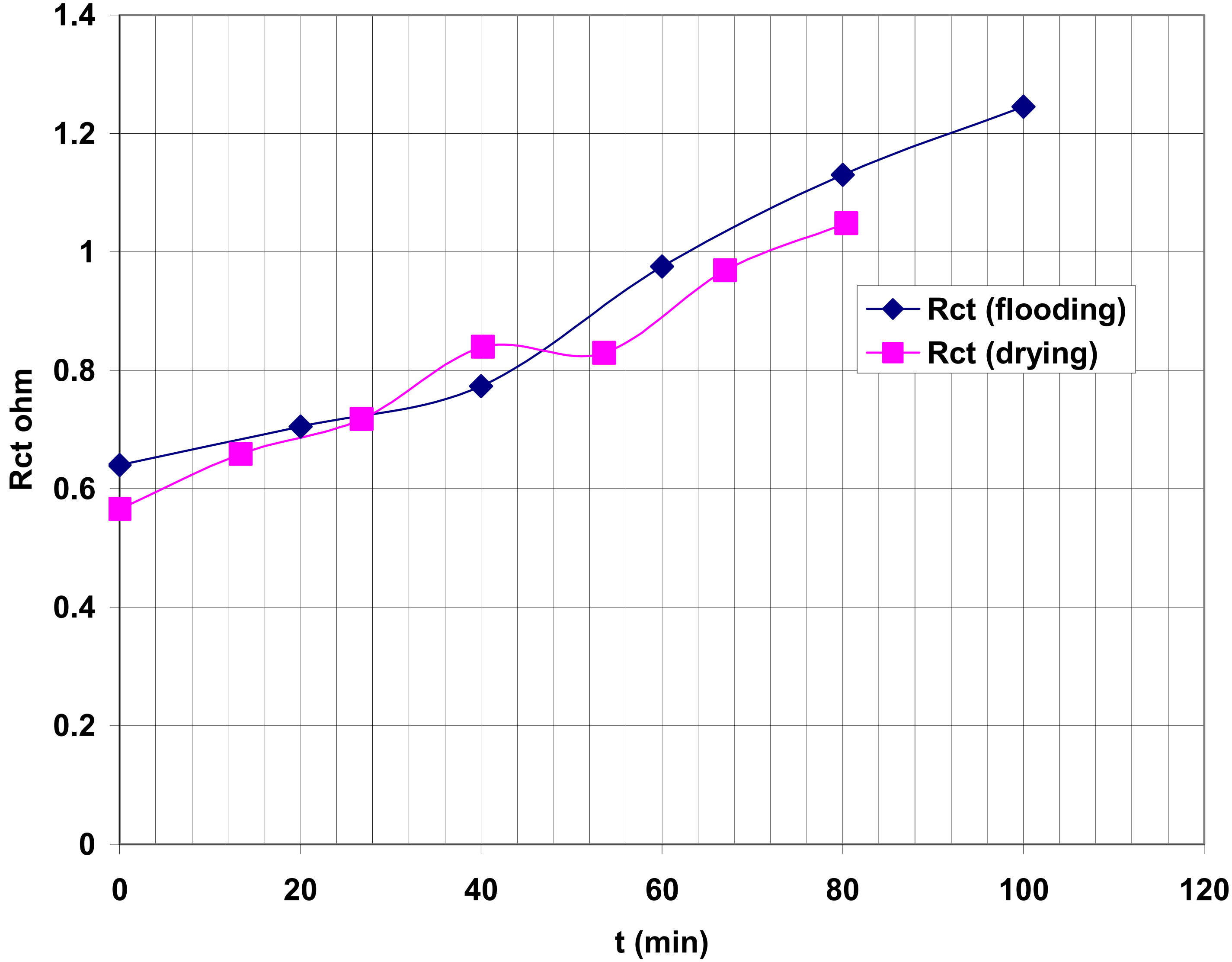
$R_{ct\ a}$ = anode charge transfer resistance
CPEa = non-ideal double layer capacitance anode

$R_{ct\ c}$ = anode charge transfer resistance
CPEc = non-ideal double layer capacitance anode

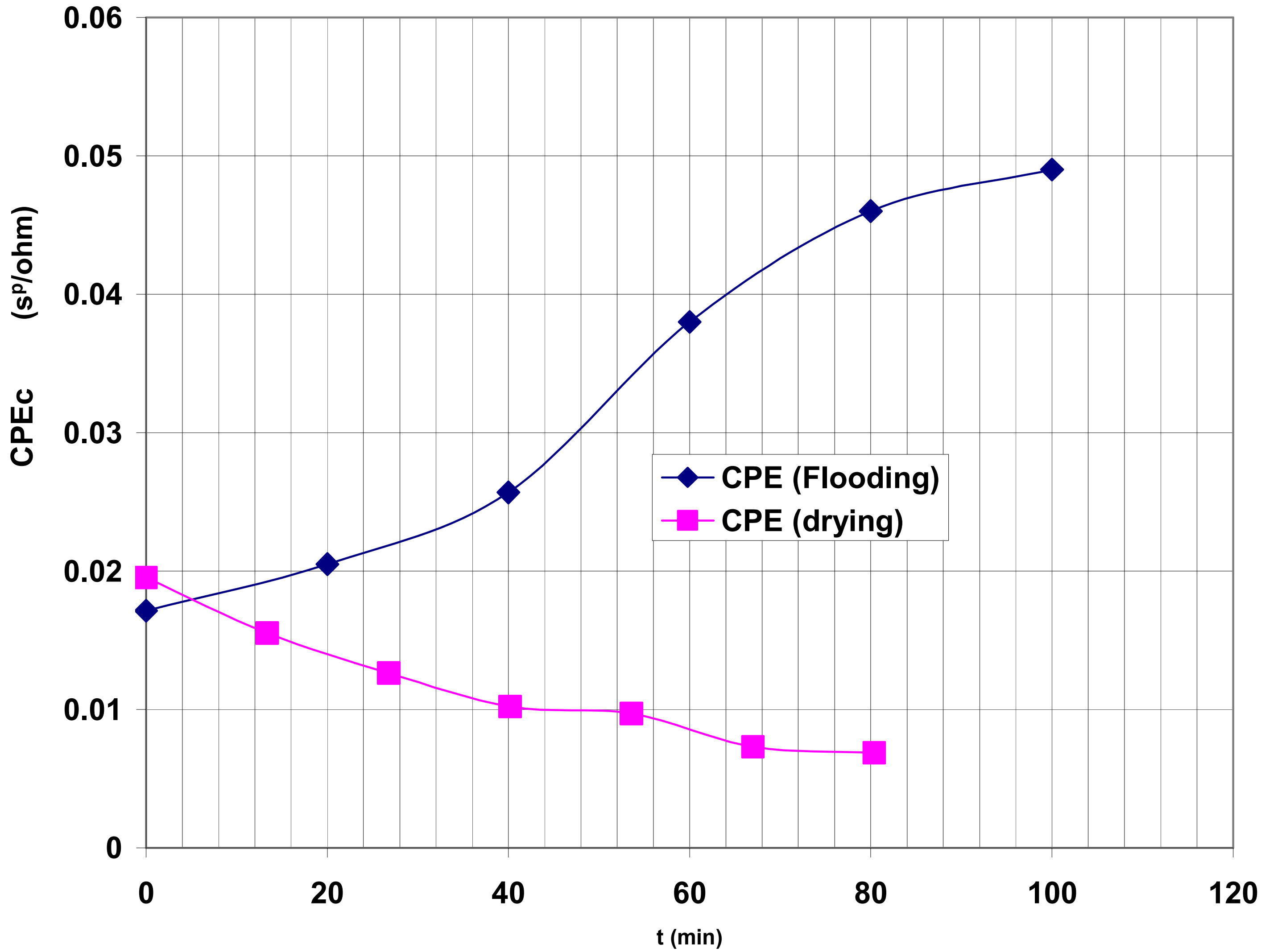
CPE = distributed element, diffusional process



resistive losses increase during drying



kinetic losses increase during drying and flooding



during drying CPE impedance increases (distributed nature of CL?)

during flooding CPE impedance reduces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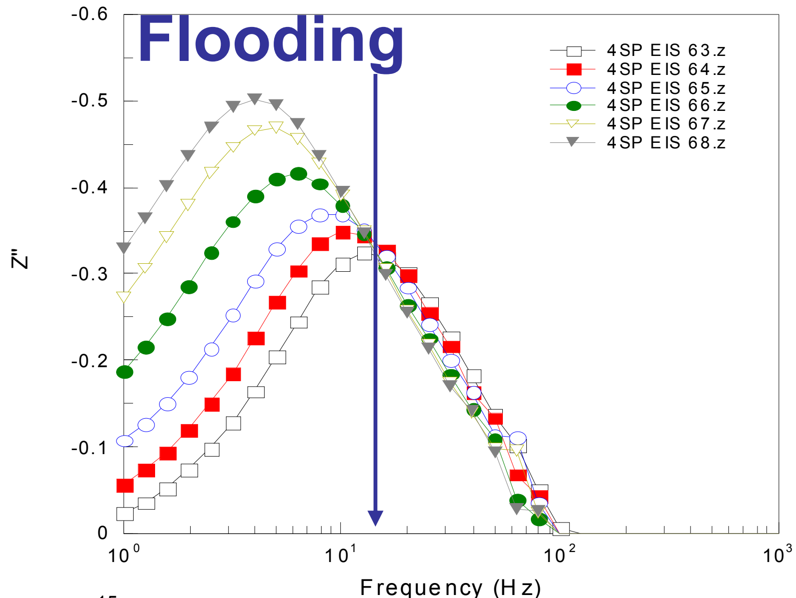
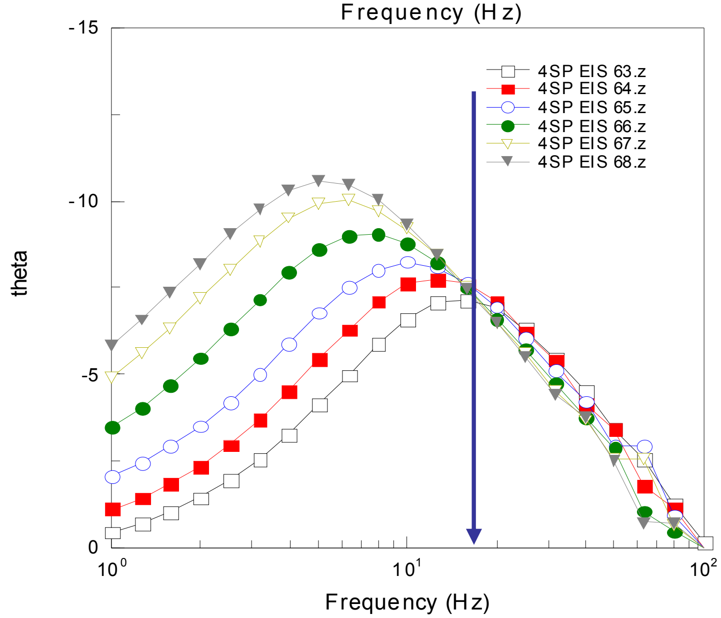
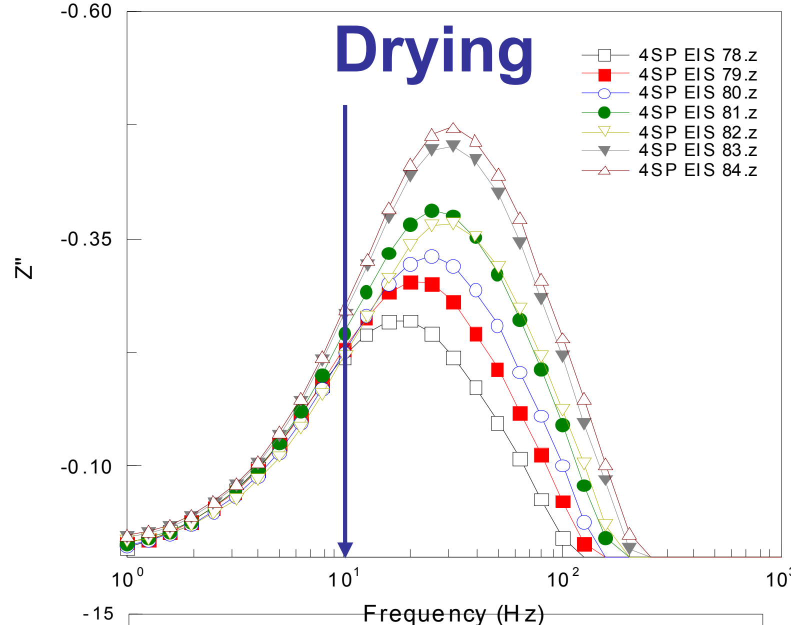
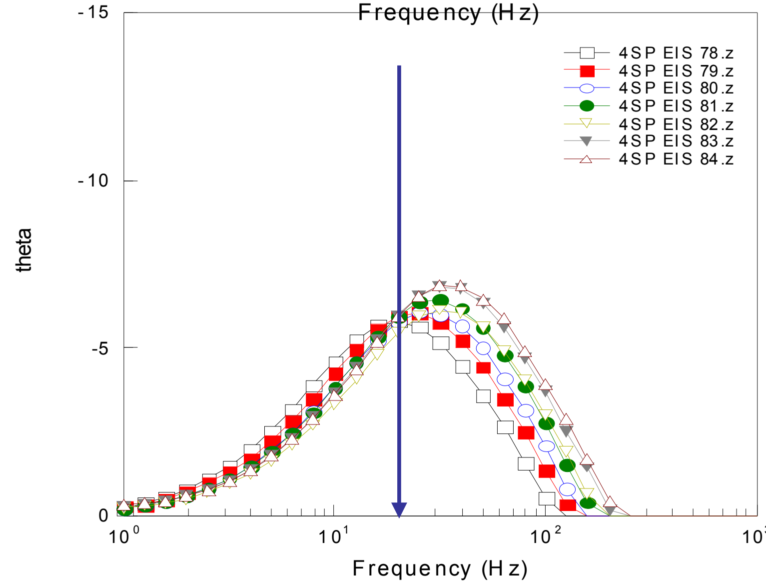

Flooding
Z''
Frequency (Hz)
4SP EIS 63.z
4SP EIS 64.z
4SP EIS 65.z
4SP EIS 66.z
4SP EIS 67.z
4SP EIS 68.z


theta
Frequency (Hz)
4SP EIS 63.z
4SP EIS 64.z
4SP EIS 65.z
4SP EIS 66.z
4SP EIS 67.z
4SP EIS 68.z


Drying
Z''
Frequency (Hz)
4SP EIS 78.z
4SP EIS 79.z
4SP EIS 80.z
4SP EIS 81.z
4SP EIS 82.z
4SP EIS 83.z
4SP EIS 84.z


theta
Frequency (Hz)
4SP EIS 78.z
4SP EIS 79.z
4SP EIS 80.z
4SP EIS 81.z
4SP EIS 82.z
4SP EIS 83.z
4SP EIS 84.z

Conclusions:

- During drying, both in-phase and out-of-phase impedance content increase

- During flooding only out-of-phase content increases

- For both cases it appears that there is one single frequency threshold (~10Hz) from which out-of-phase content starts to shift to:

    • smaller frequencies for flooding
    • larger frequencies for drying

Phase angle vs. Imaginary content:

- θ seems to better define initial drying/flooding process (one single frequency?)

- θ can be associated with concentration profiles (ac voltammetry?)

Recommendations:

- Minimize FC design effects (ε, GFF, GDL, CL, etc.), better base-line during testing
- specific frequencies might be design-dependent: need further studies
- dry/flooding case: comparison of states only as a short time forcast
- Different FC sizes might need different approaches for diagnosis
- Isolation of true dry and true flooding conditions is only possible if homogenous internal conditions are achieved
- Structural effects should be studied (carbon support as a conducting grid, i.e. additional capacitance or inductance effects?)

- Properties of components are needed particularly substack layers (i.e. capillary properties, etc.)

For your safety:

This presentation was AH1N1 free…!