

Strange Sample-Thickness Dependence of Complex Dielectric Permittivity Measurements on Sandstones*

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Abstract

Multifrequency complex dielectric permittivity measurements are widely used for material characterization. We used Keysight impedance analyzer E4990A and Keysight dielectric fixture 16451B to perform two-electrode complex dielectric permittivity measurements on 24%-porosity Berea sandstone and Shale samples from various shale plays in the frequency range of 100 Hz to 30MHz at ambient temperature and pressure conditions. The samples were studied in their dry state and also when fully saturated with deionized (DI) water and brine. All samples exhibit large frequency dispersion of complex permittivity and complex conductivity, which is attributed to the Maxwell-Wagner polarization mechanism. The dielectric constant of dry, DI-water-filled, and brine-filled samples vary smoothly from 3.5 to 15, 3.5 to 2000, and 20 to 105, respectively, for variation in frequency from 30 MHz to 1 kHz. The DI-water-filled samples and brine-filled samples exhibit peak dielectric loss factor within 1 kHz to 10 kHz and 10 kHz to 100 kHz, respectively. Conductivity estimates for the samples obtained between 100 Hz and 1 kHz are 50% lower than those obtained between 10 kHz and 1 MHz, which are 100% lower than those obtained above 10 MHz. The high-frequency permittivity measurements were compared against CRIM predictions based on AP-608 confined porosity measurements and fluid saturation estimates. In comparison to non-contact method, the contact method generates higher quality measurements. No significant change in permittivity estimates were observed upon cleaning the Berea and Shale samples with a mixture of toluene and methanol. The permittivity measurements decreased when the two transverse sample surfaces in contact with electrodes were polished to reduce the surface roughness. Permittivity measurements exhibit substantial low-frequency alteration below 20 kHz when the saturated samples were wrapped with parafilm to prevent water loss from the samples.

Complex permittivity is a geometry independent property nonetheless, the measured complex permittivities decrease with the decrease in sample thickness, such that the complex permittivity variation with thickness increases at lower frequencies. For DI-water-filled and brine-filled samples, multifrequency complex conductivity obtained from the complex permittivity measurements exhibit large deviation from those obtained from a resistivity cell.

Reference Cited

Anderson, B., T. Barber, M. Lüling, J. Rasmus, P. Sen, J. Tabanou, and M. Haugland, 2007, Observations of Large Dielectric Effects on LWD Propagation-Resistivity Logs: SPWLA Annual Logging Symposium, Austin, Texas, June 3-6, Paper BB.

Strange Sample-Thickness Dependence of Complex Dielectric Permittivity Measurements on Sandstones

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University of Oklahoma

Presenter: Siddharth Misra



Outline

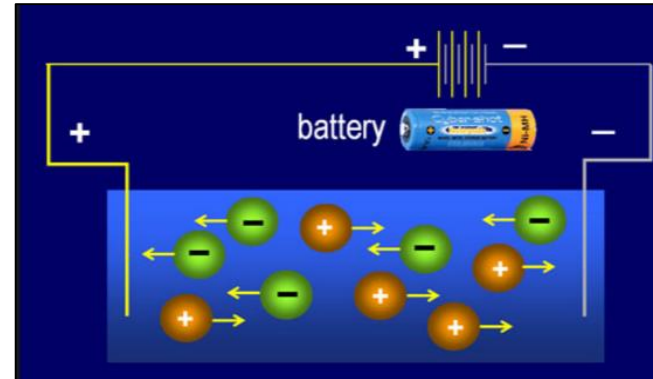
- Introduction and Motivation
- Methods and Materials
- Measurements
- Electrode Polarization Correction
- Comparison with Maxwell Wagner Polarization Model
- Comparison with various EM Mixing Models
- Conclusions

Introduction: Terminology

Conductivity

$$\sigma$$

Frequency independent
No phase, Real Number



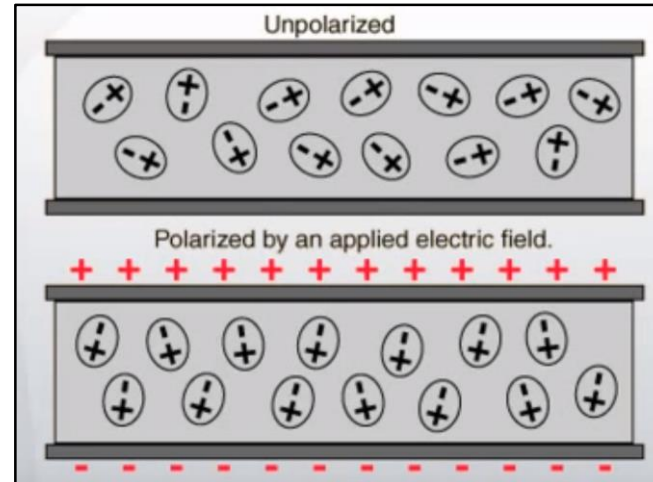
Flow

Permittivity

$$\epsilon^*(\omega) = \epsilon_r^*(\omega)\epsilon_0$$

Complex relative permittivity

$$\epsilon_r'(\omega) - i\epsilon_r''(\omega)$$



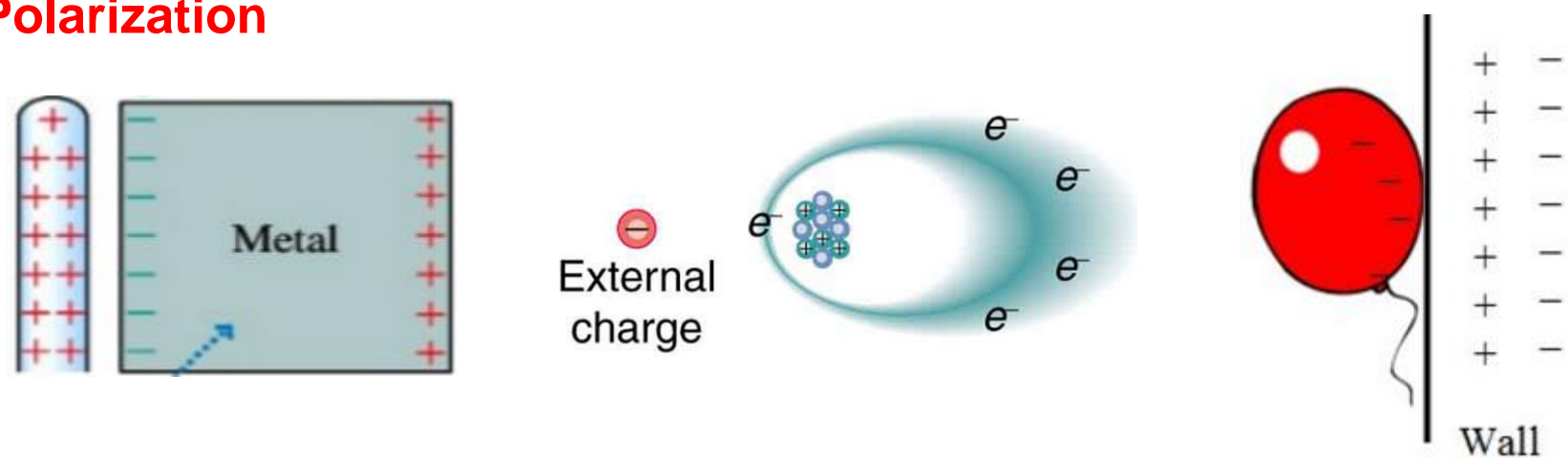
Storage

Conductivity measurement $(\sigma + \omega\epsilon_r''\epsilon_0) + i(\omega\epsilon_r'\epsilon_0)$

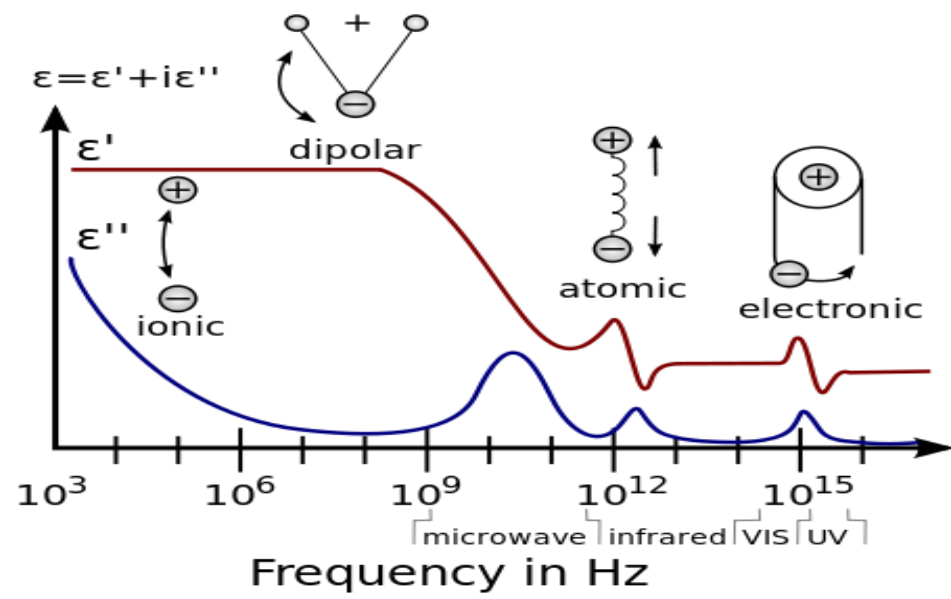
Relative permittivity measurement $\epsilon_r' - i\left(\epsilon_r'' + \frac{\sigma}{\omega\epsilon_0}\right)$

Introduction: Terminology

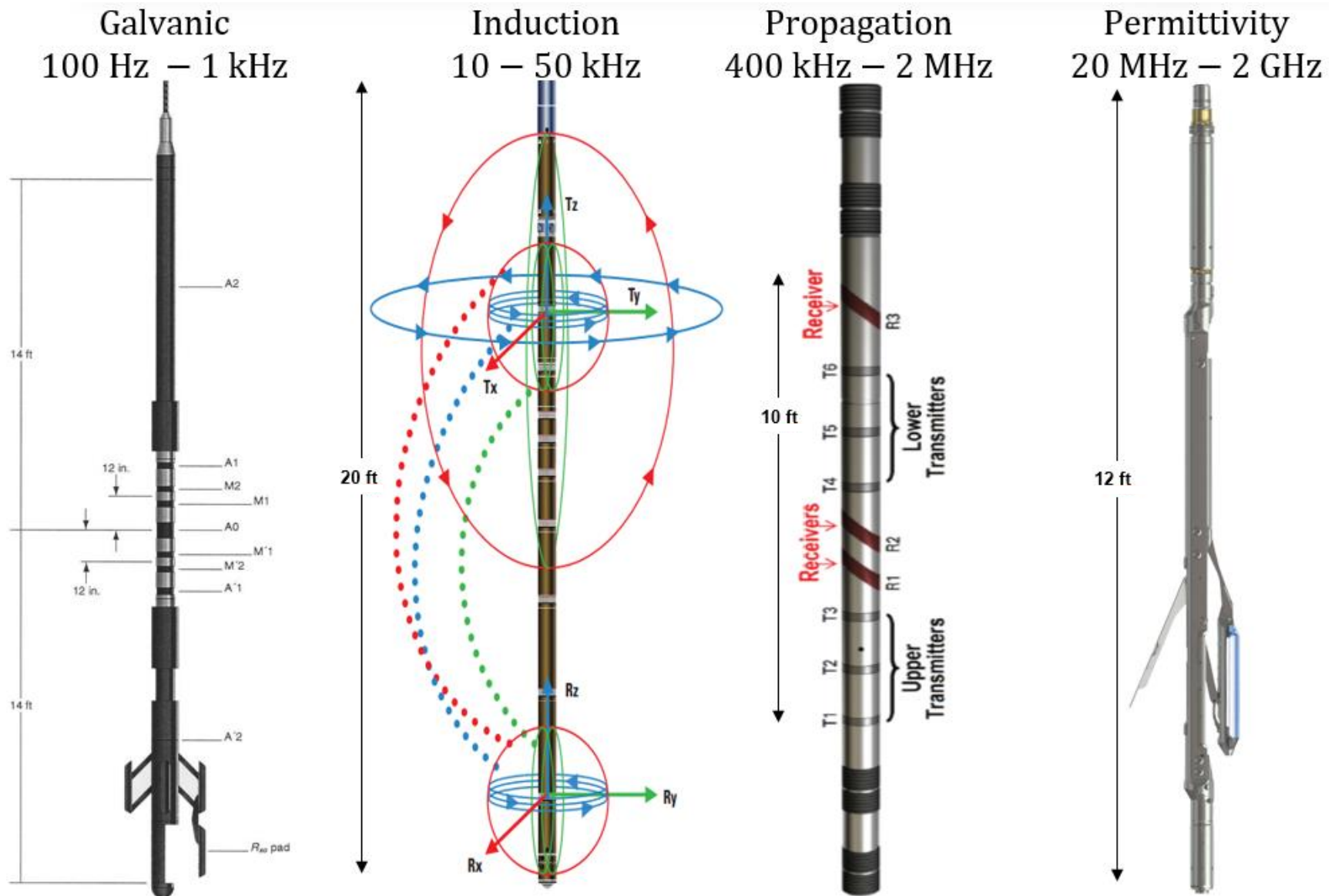
Polarization



Dispersion

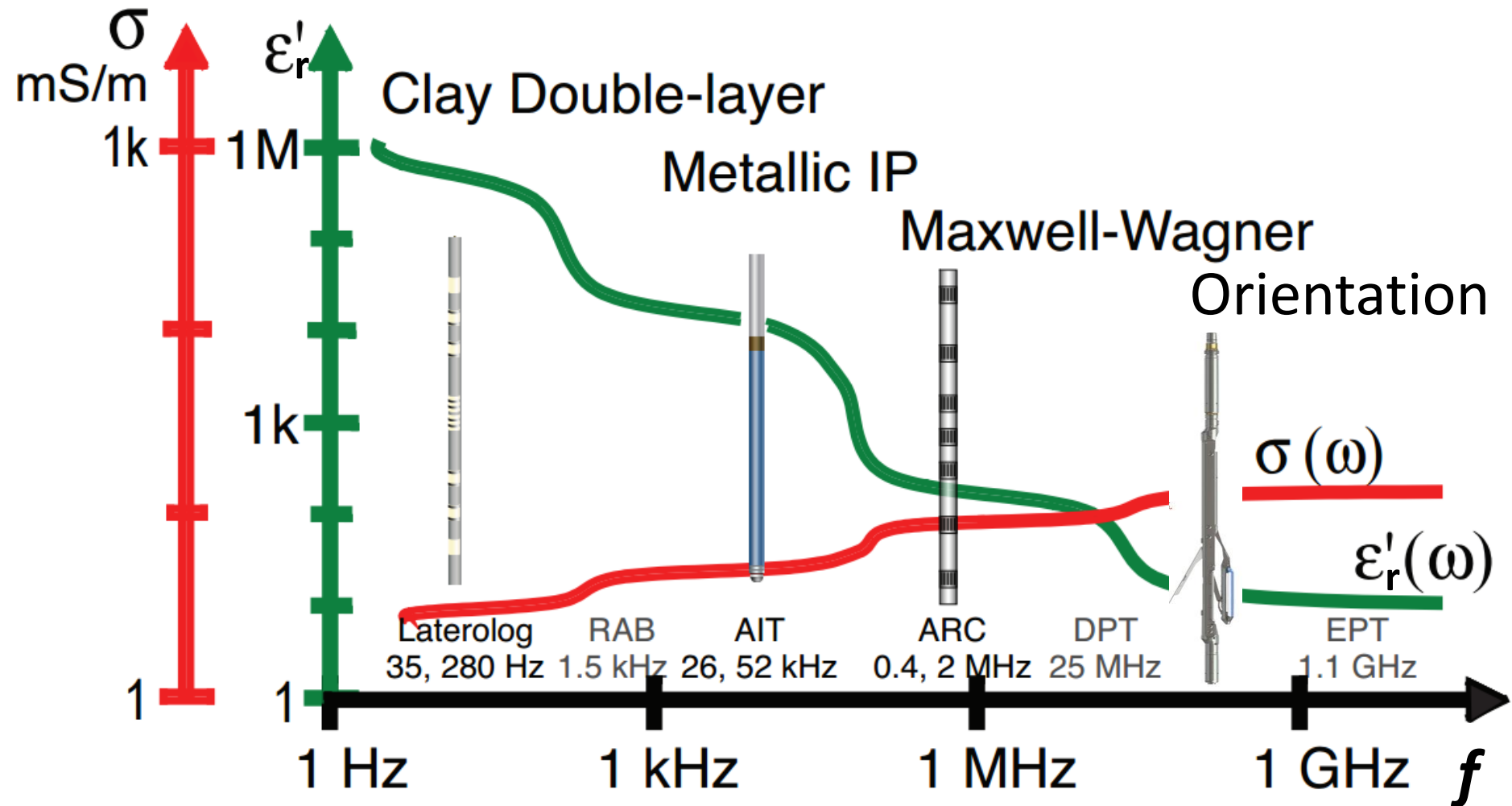


Introduction: Downhole EM Tools



Introduction: Polarization

Frequency dispersions of effective conductivity and permittivity



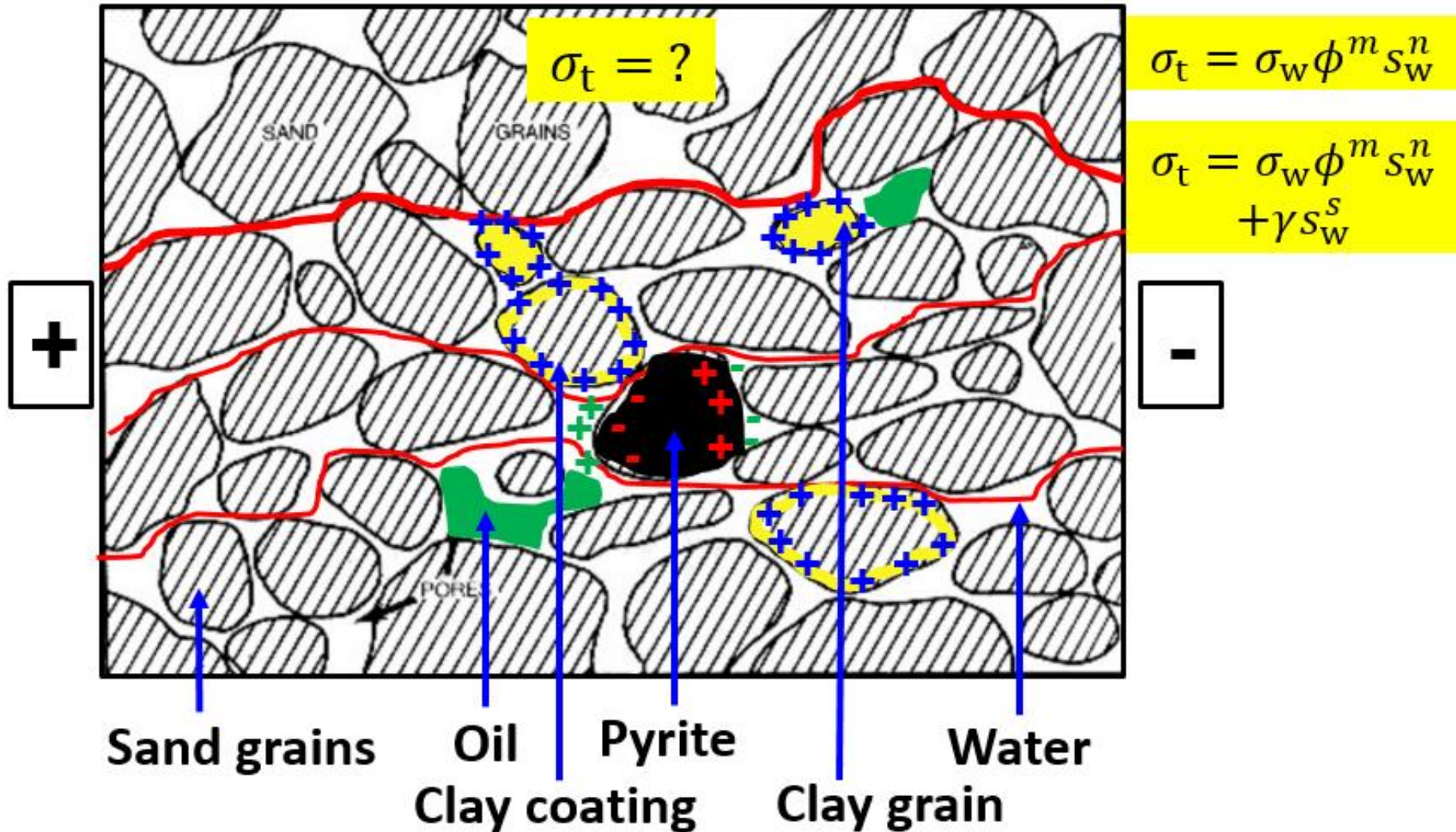
Anderson et al., 2007

AAPG-ES 2016

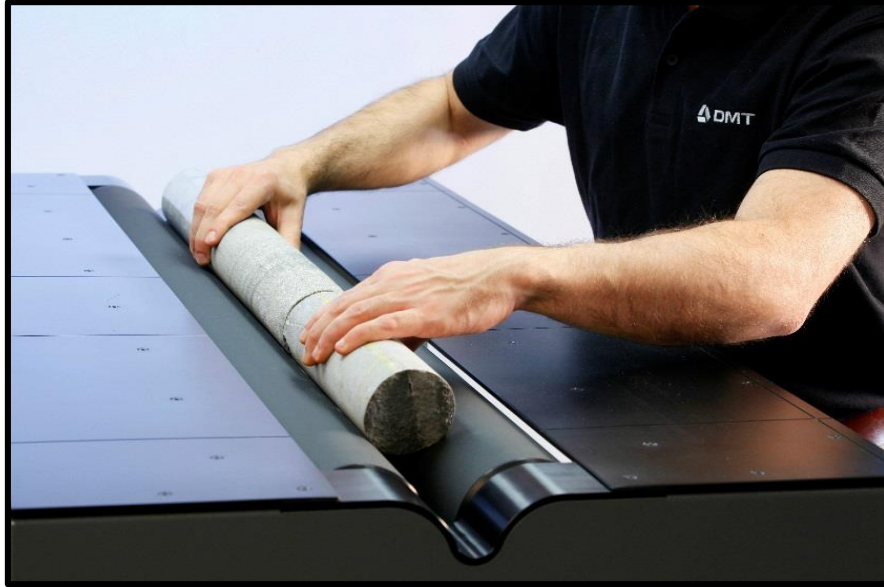
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Motivation



Motivation



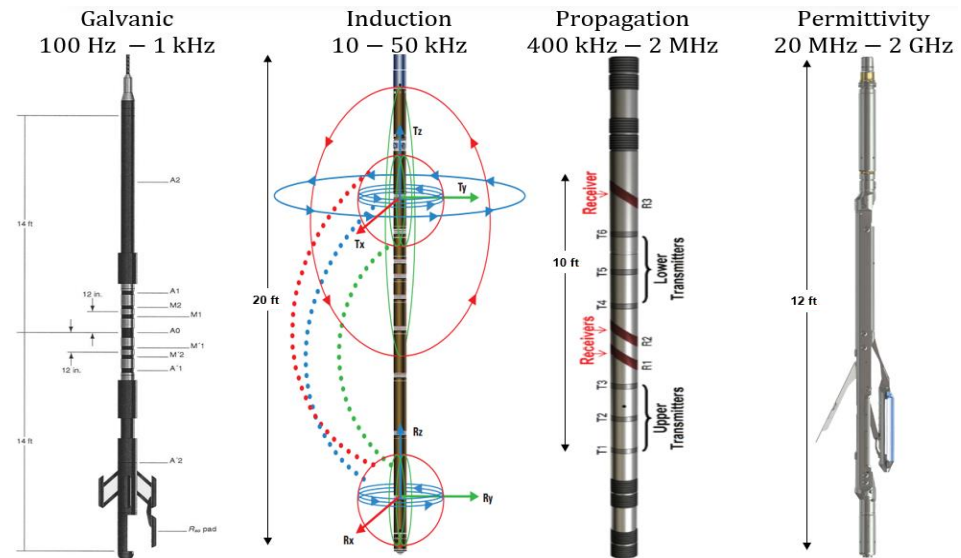
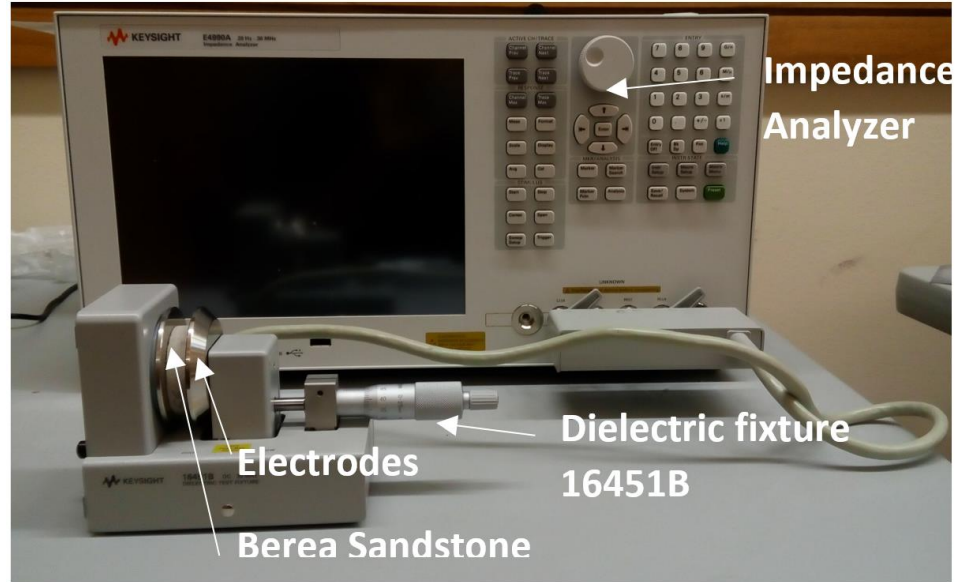
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Method: Apparatus

KeySight
E4990A Impedance Analyzer
16451B Dielectric Fixture
1 kHz to 30 MHz

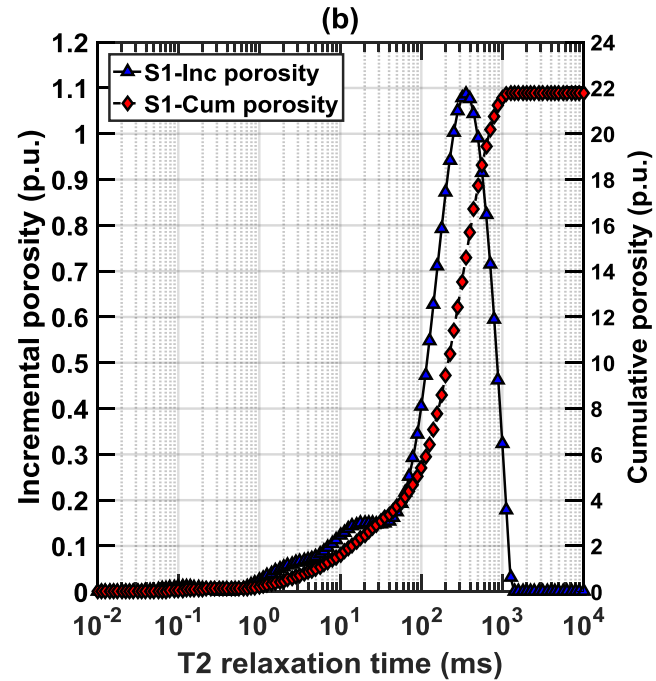
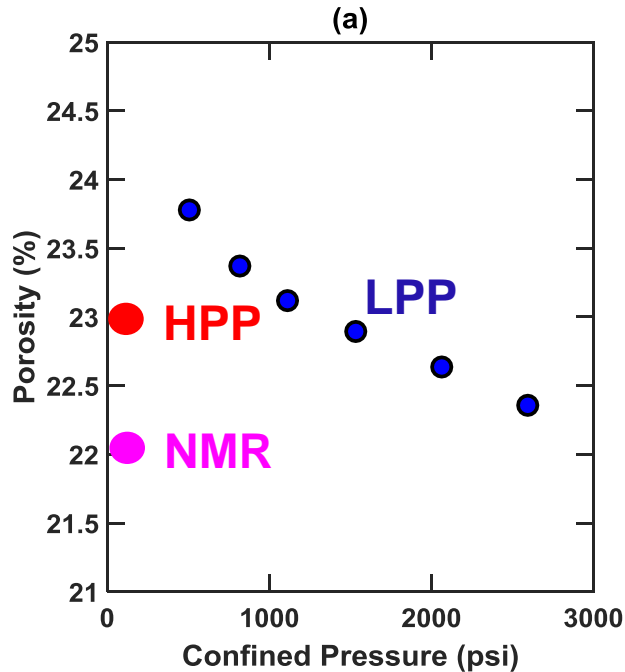


Method: Sample Preparation

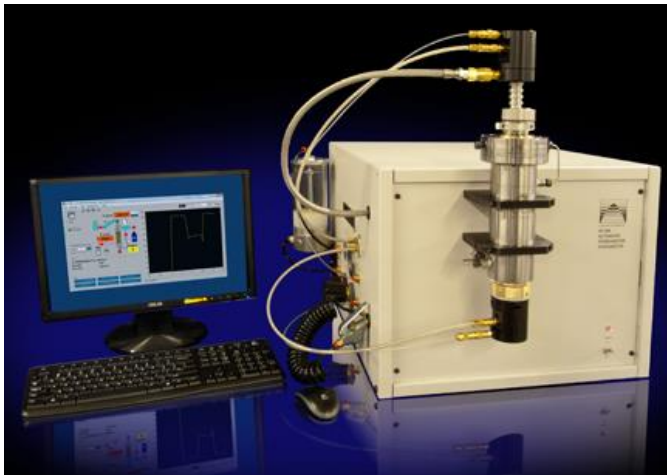
Sample	Diameter (mm)	Thickness (mm)	Mass before saturation (gm)	Mass after saturation (gm)
S1-Uncleaned	41.325±0.02	9.1±0.01	24.4	26.93
S2-Uncleaned	41.235±0.005	8.2±0.0005	21.96	24.21
S3-Uncleaned	41.71±0.02	6.8±0.02	18.42	20.35
S4-Uncleaned	41.71±0.06	6.42±0.01	17.37	19.23
S5-Uncleaned	41.69±0.02	7.54±0.01	20.35	22.49
S6-Uncleaned	41.67±0.03	7.75±0.02	20.96	23.18
S7-Uncleaned	41.63±0.03	9.09±0.008	24.7	27.3
S8-Cleaned	41.17±0.008	7.28±0.02	19.34	21.15
S9-Cleaned	41.235±0.05	5.59±0.05	14.73	16.56
S10-Cleaned	41.13±0.022	5.795±0.06	15.34	17.2
S11-Uncleaned	25.12±0.06	6.57±0.007	6.41	8.34
S12-Uncleaned	25.12±0.03	7.41±0.007	7.31	9.34
S13-Uncleaned	25.12±0.08	7.72±0.02	7.51	9.65
S14-Uncleaned	25.12±0.09	7.625±0.03	7.41	9.56

- **Cleaning:** Mixture of toluene and methanol (80:20) in Soxhlet apparatus was used for extraction, followed by heating in oven at 100 °C for 24 hours
- **Saturation:** Teledyne syringe pump to inject fluid into samples evacuated for 2 hours under pressure of 2500 psi
- **Polishing:** Surface grinding machine

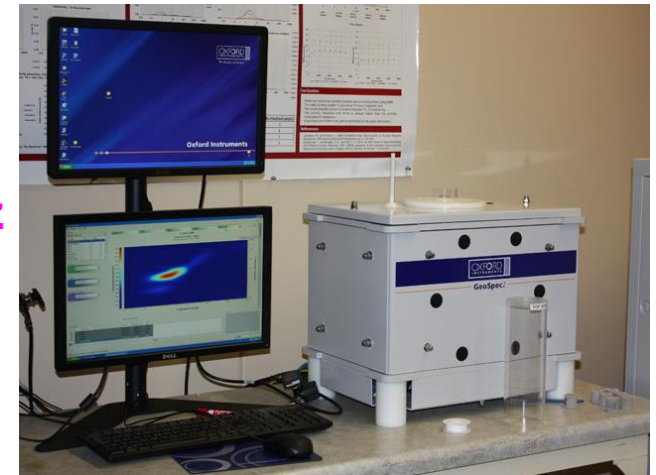
Method: Sample Porosity



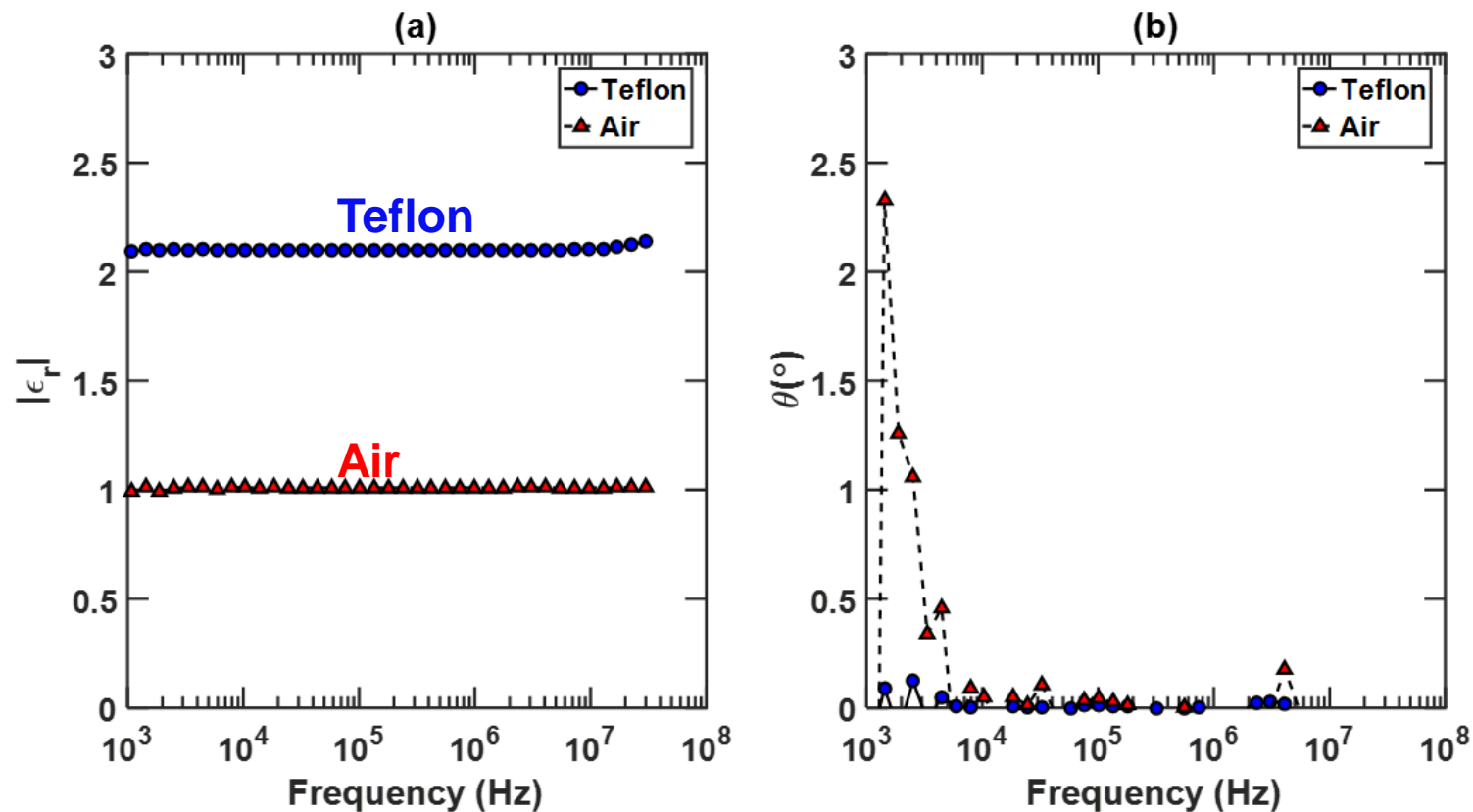
LPP
AP608



12 MHz
NMR

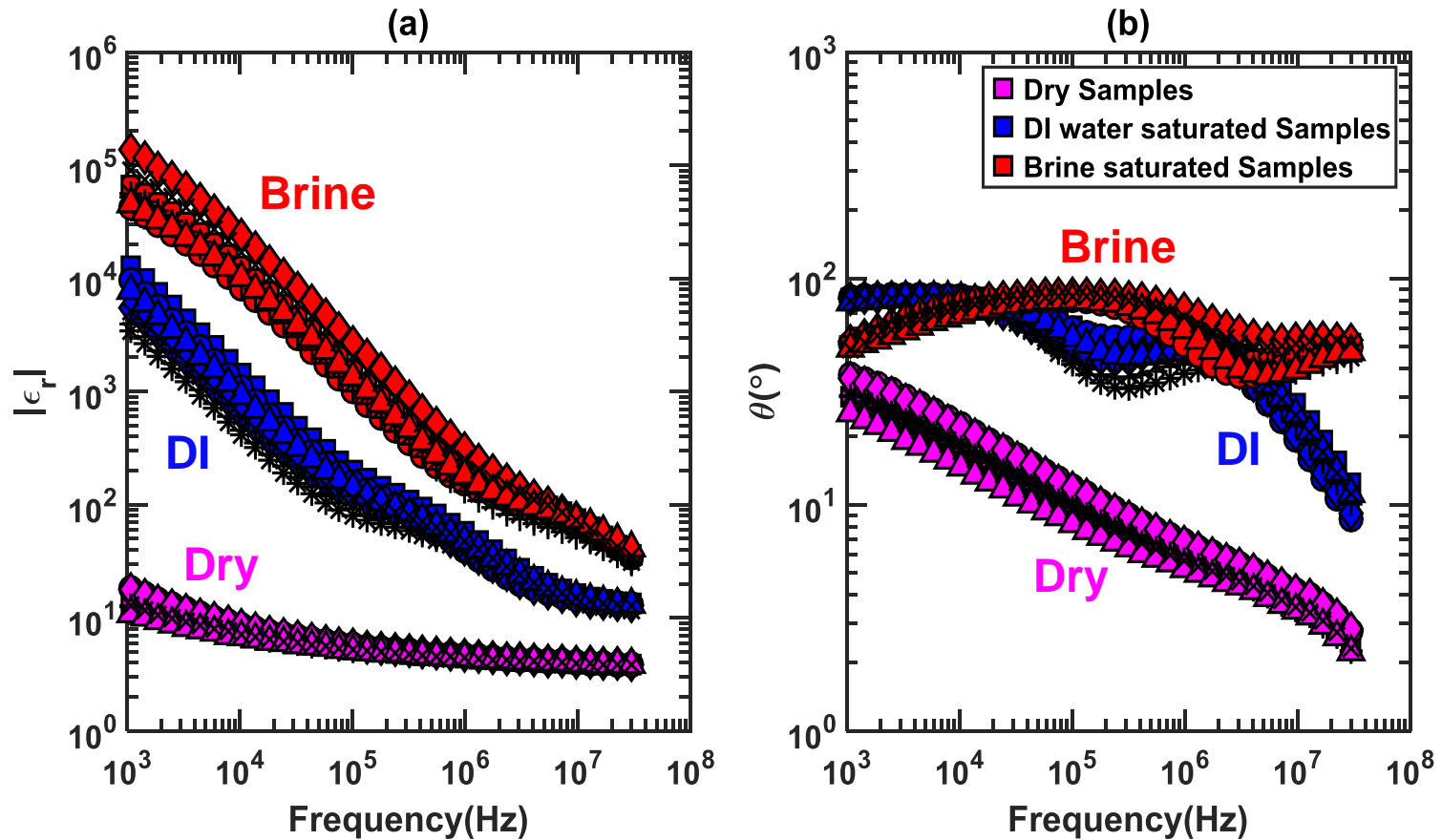


Method: Apparatus Calibration



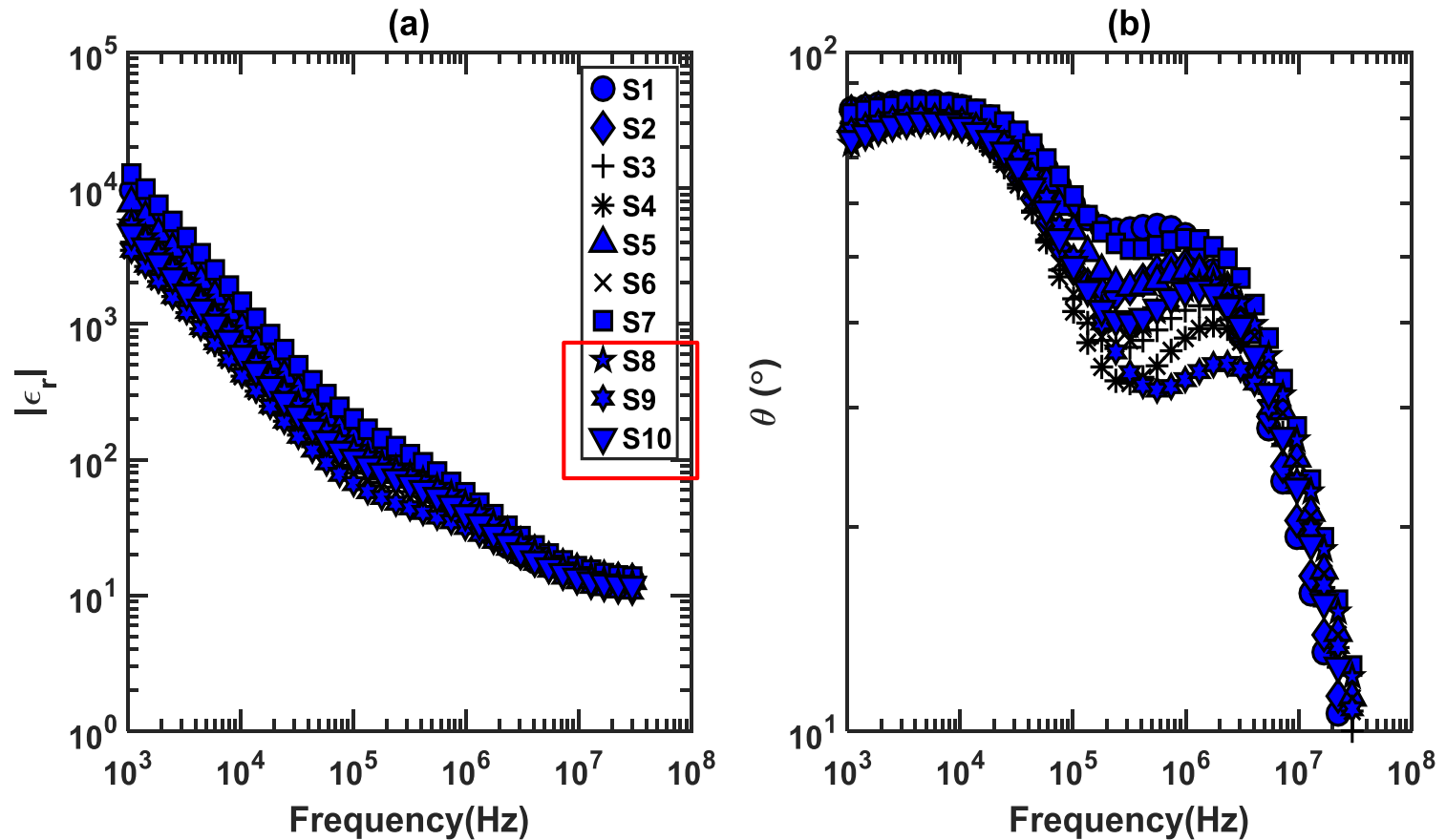
Measurements: Dry vs. DI vs. Brine

As-received samples



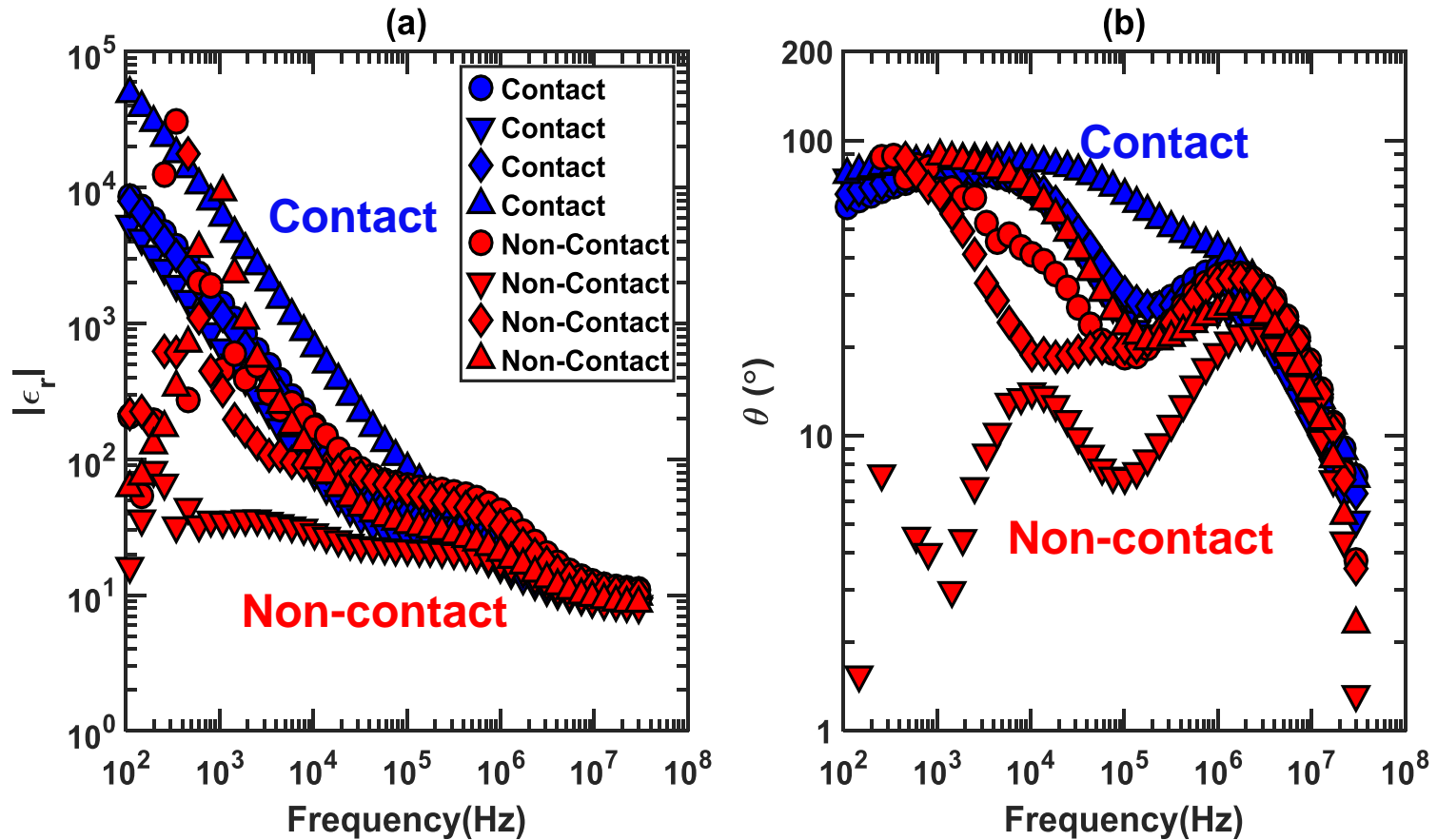
Measurements: Cleaned vs As-Received

DI-water saturated samples



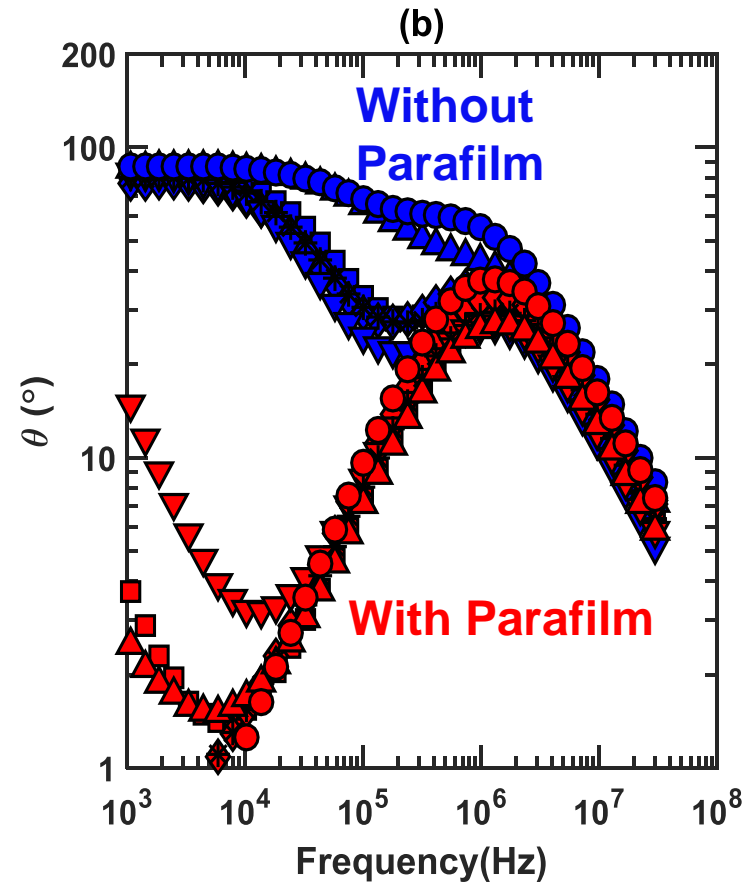
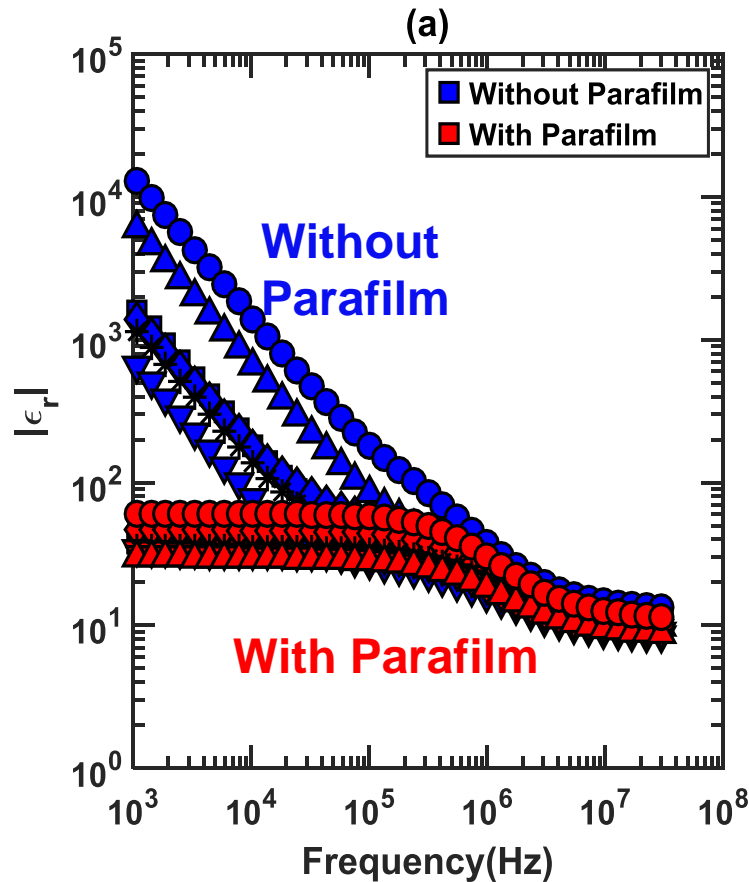
Measurements: Contact vs Non-Contact

Brine saturated samples



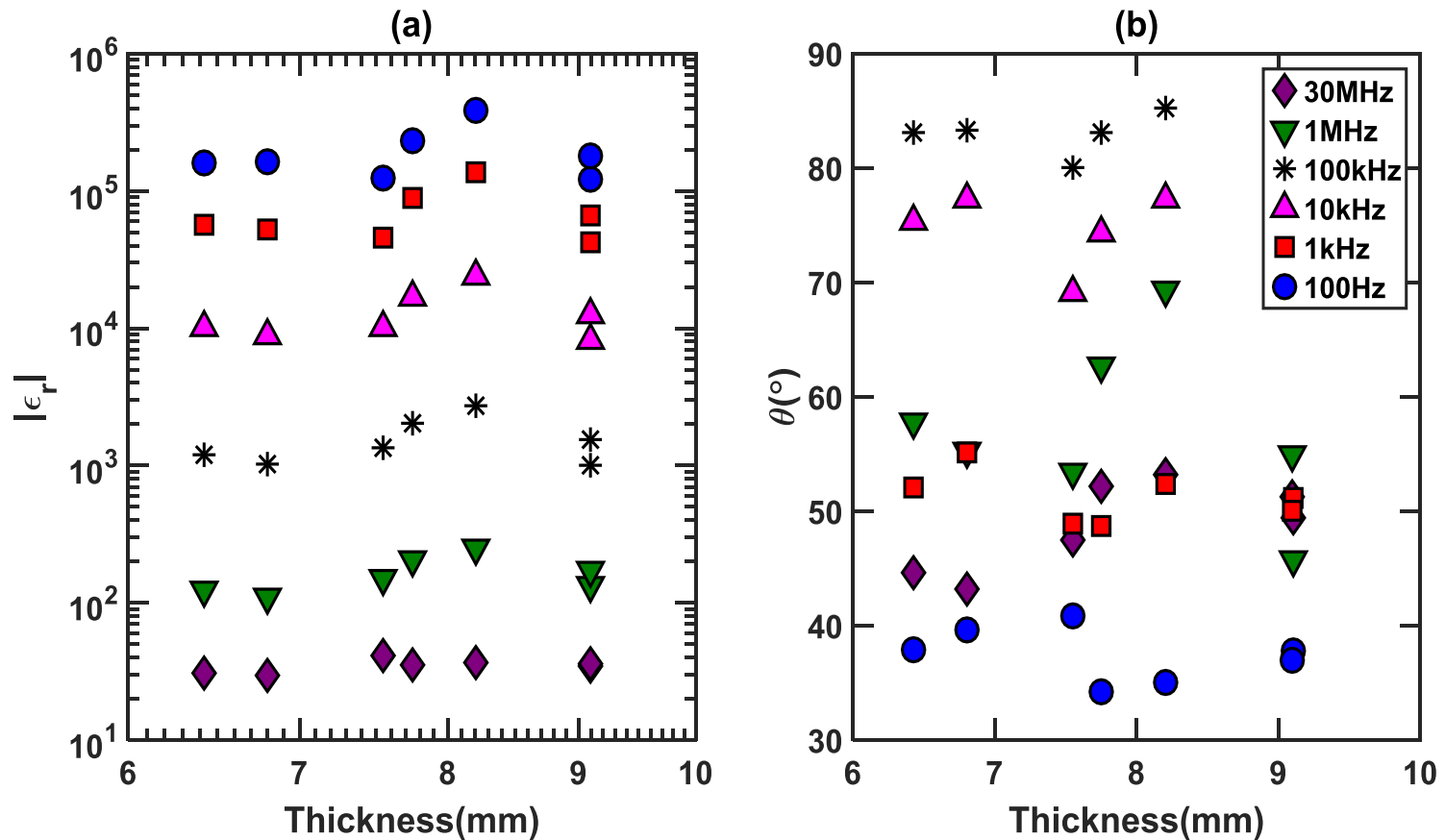
Measurements: With vs. Without Parafilm

DI-water saturated samples



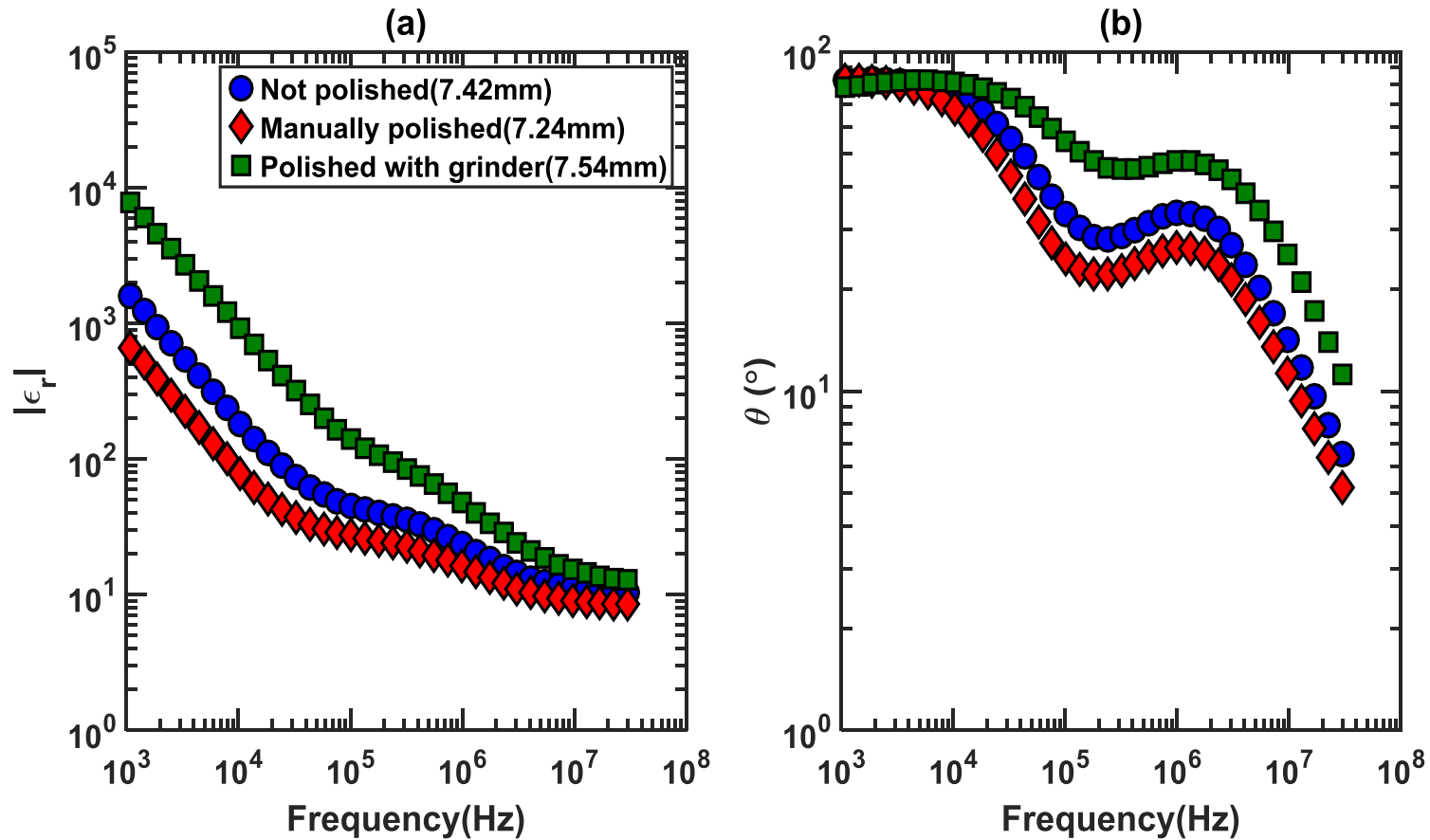
Measurements: Effect of Sample Thickness

Brine saturated samples

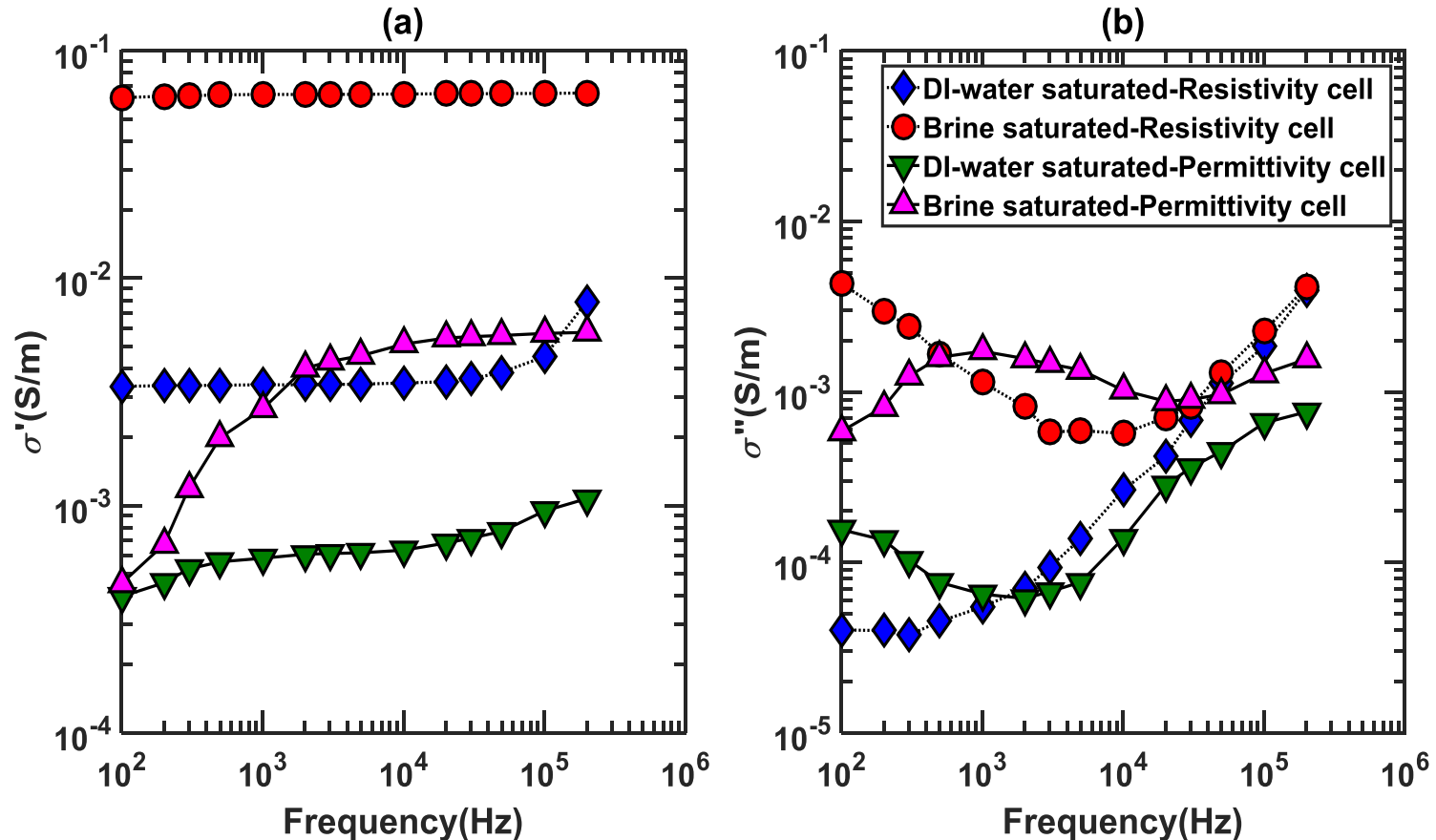


Measurements: Effect of Surface Roughness

DI-water saturated samples

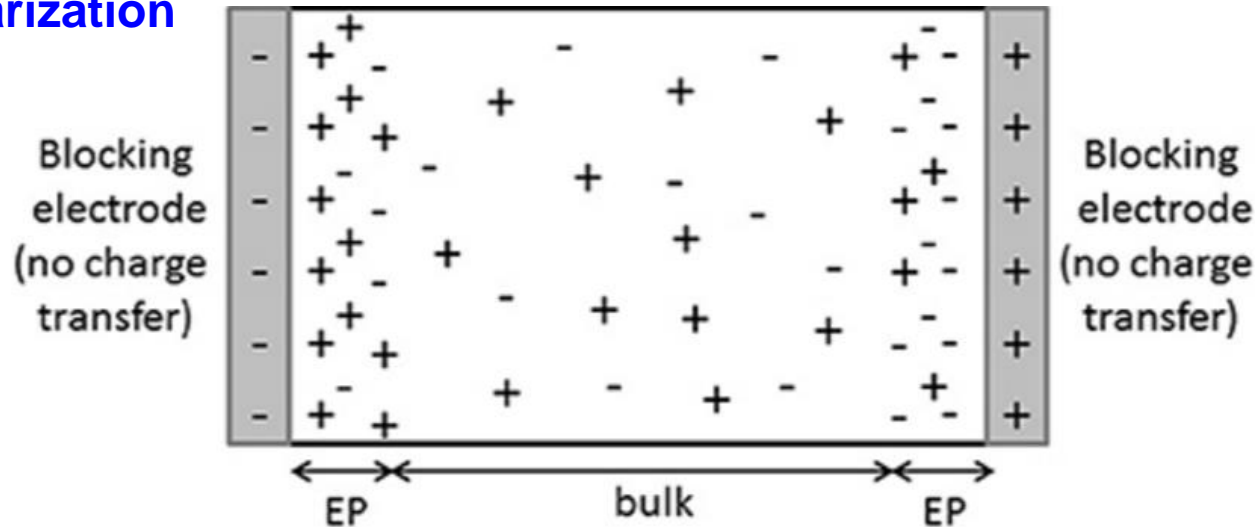


Measurements: Resistivity Cell vs. Permittivity Cell

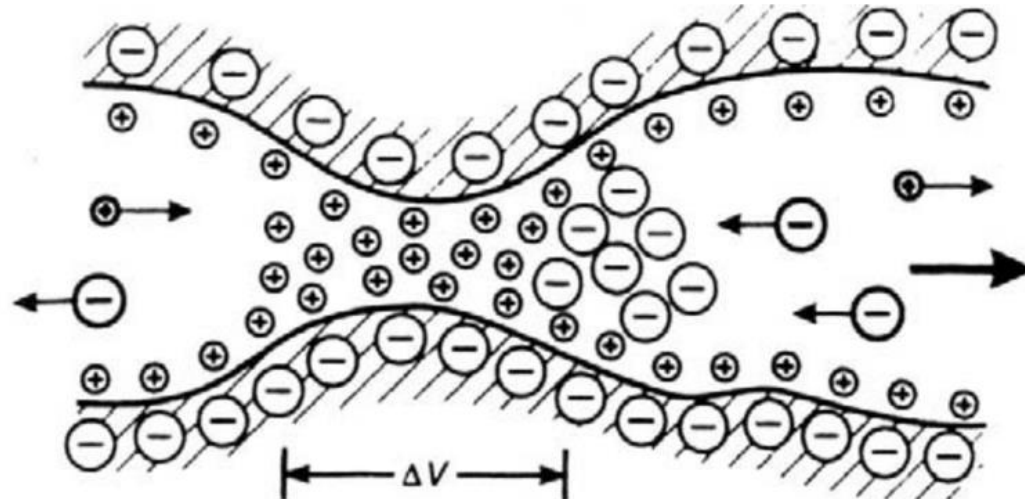


Polarization Mechanisms

Electrode Polarization



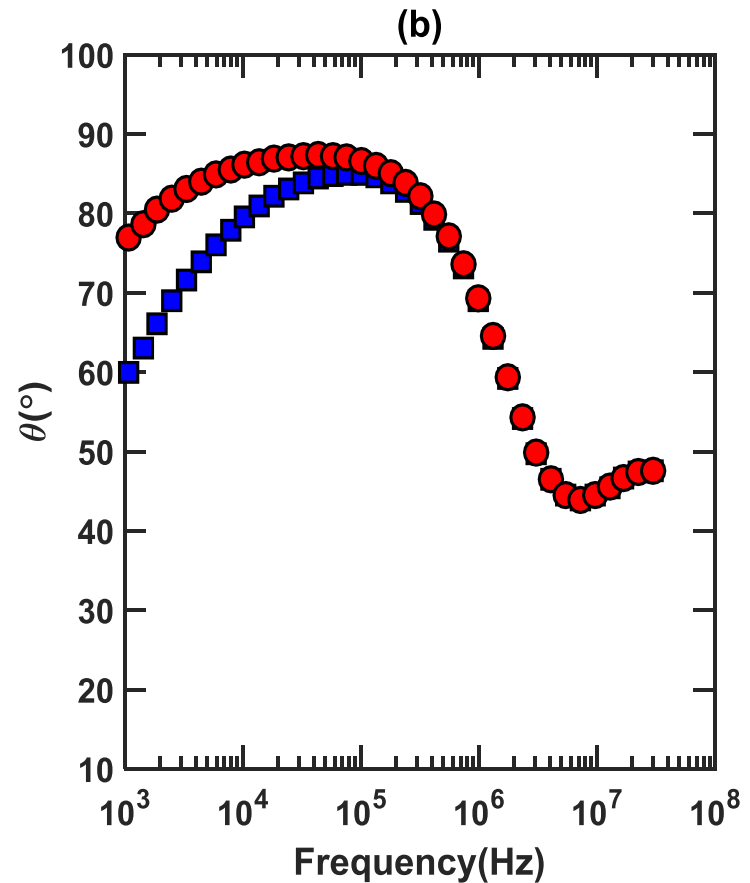
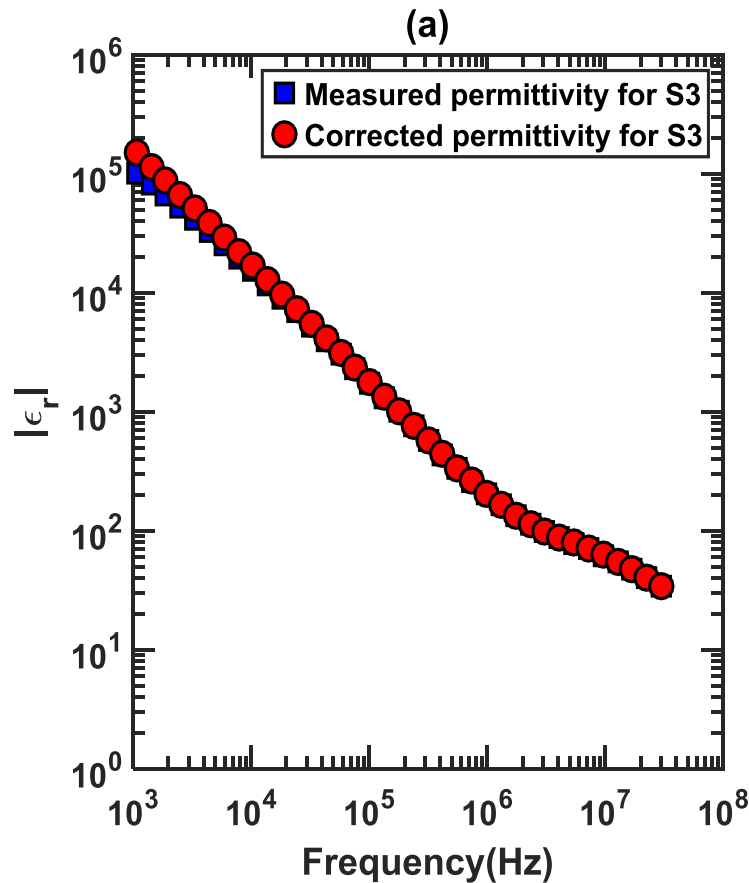
Maxwell Wagner Polarization



Electrode Polarization Correction

$$\frac{d}{d\omega} \operatorname{Re}[Z(\omega)] = Am\omega^{-(m+1)}$$

$$\frac{d}{d\omega} \frac{\operatorname{Im}[Z(\omega)]}{\omega} = \frac{2-n}{B} \omega^{n-3}$$

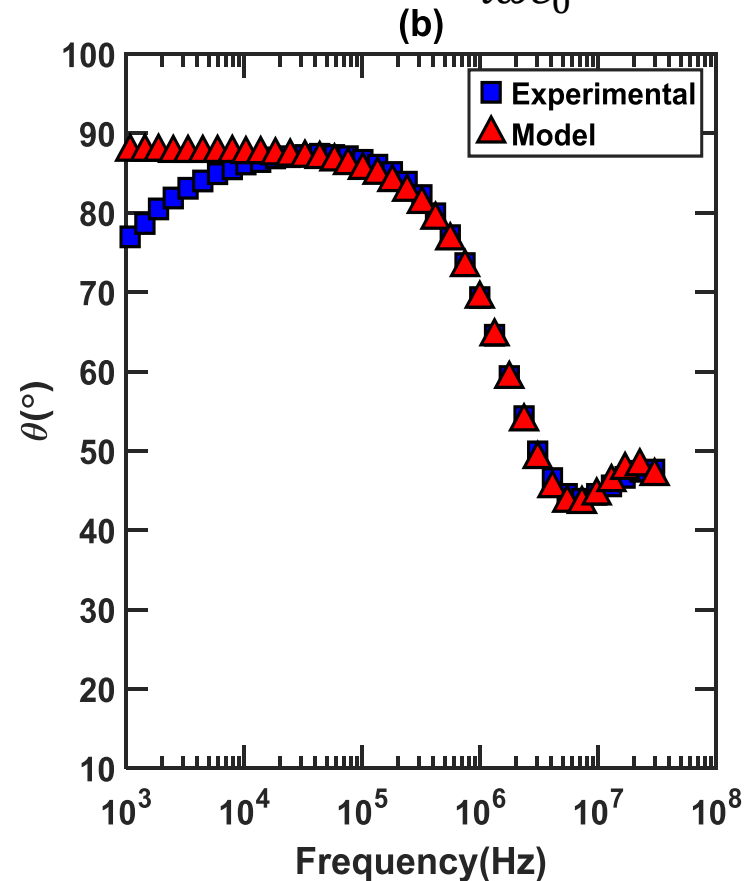
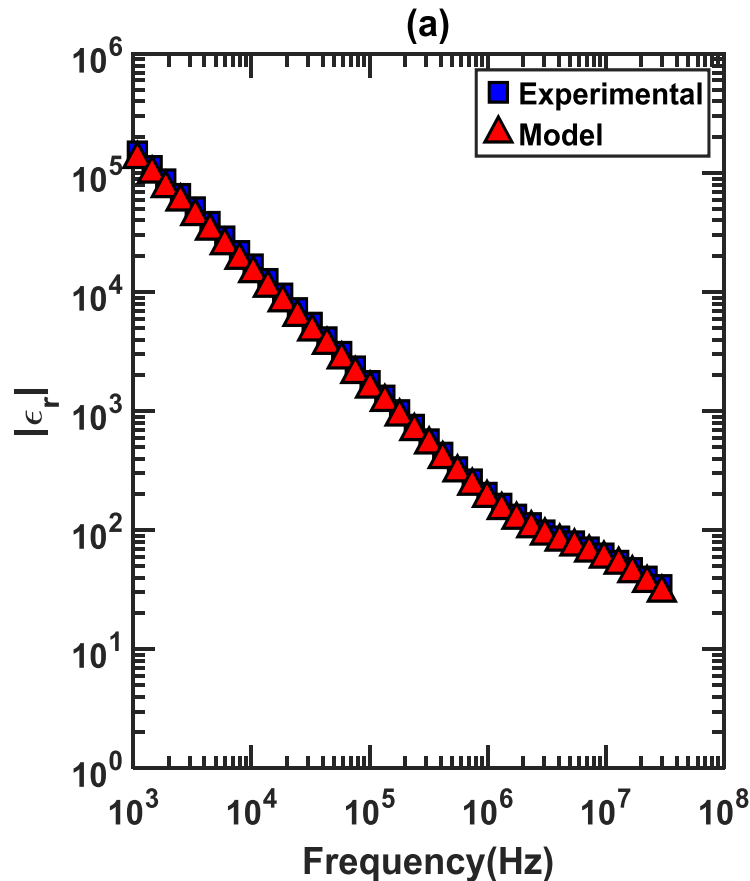


Maxwell Wagner Polarization Model

$$\varepsilon(\omega) = \varepsilon_{\infty} + \varepsilon_{MW}(\omega) + \varepsilon_{PL}(\omega)$$

$$\varepsilon_{MW}(\omega) = \frac{\Delta\varepsilon}{[1 + (i\omega\tau)^{1-\alpha}]^{\beta}}$$

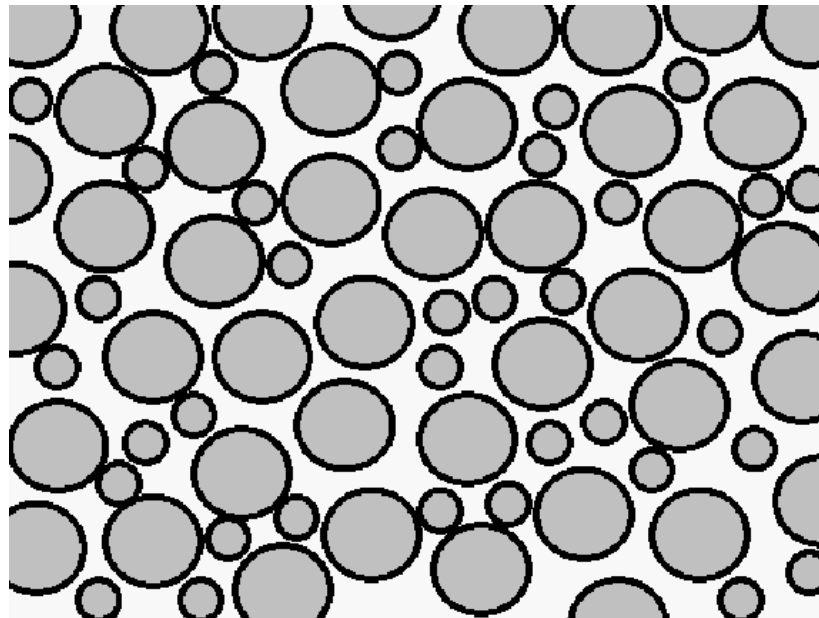
$$\varepsilon_{PL}(\omega) = \frac{B(i\omega)^N}{i\omega\varepsilon_0}$$



$\varepsilon_{\infty}, \Delta\varepsilon, \tau, \alpha, \beta, B$ and N are 13.7, 46, 1.37E-08s, 0.99, 1, 6.2E-03, and 0.026

Comparison with Various EM Mixing Model

Experimental	Theoretical $ \epsilon_r $				
$ \epsilon_r $ (30MHz)	Clausius-Mossotti Equation	Maxwell Garnett Equation	Mixing Equation	SSC Model	CRIM's Model
23	7.6	1.688	21.11	13.73	13.12



- The large frequency dispersion of complex permittivity of samples was modeled using Maxwell Wagner polarization
- Electrode polarization model could not account for the observed dispersions
- Measured complex permittivity values at low frequencies exhibit large sensitivity to sample thickness instead of sample surface roughness
- Complex conductivity values obtained from resistivity cell were significantly different from those obtained from permittivity cell
- Relative permittivity magnitudes measured at 30 MHz matches Sengwa's Mixing equation predictions

Thank You