Measuring interfacial properties using Electroacoustics.

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What is Electroacoustics?

It is Electrokinetics at high frequency.

Why frequency being high is so important and different?

Liquid becomes compressible and supports sound waves.

What is Electrokinetics?

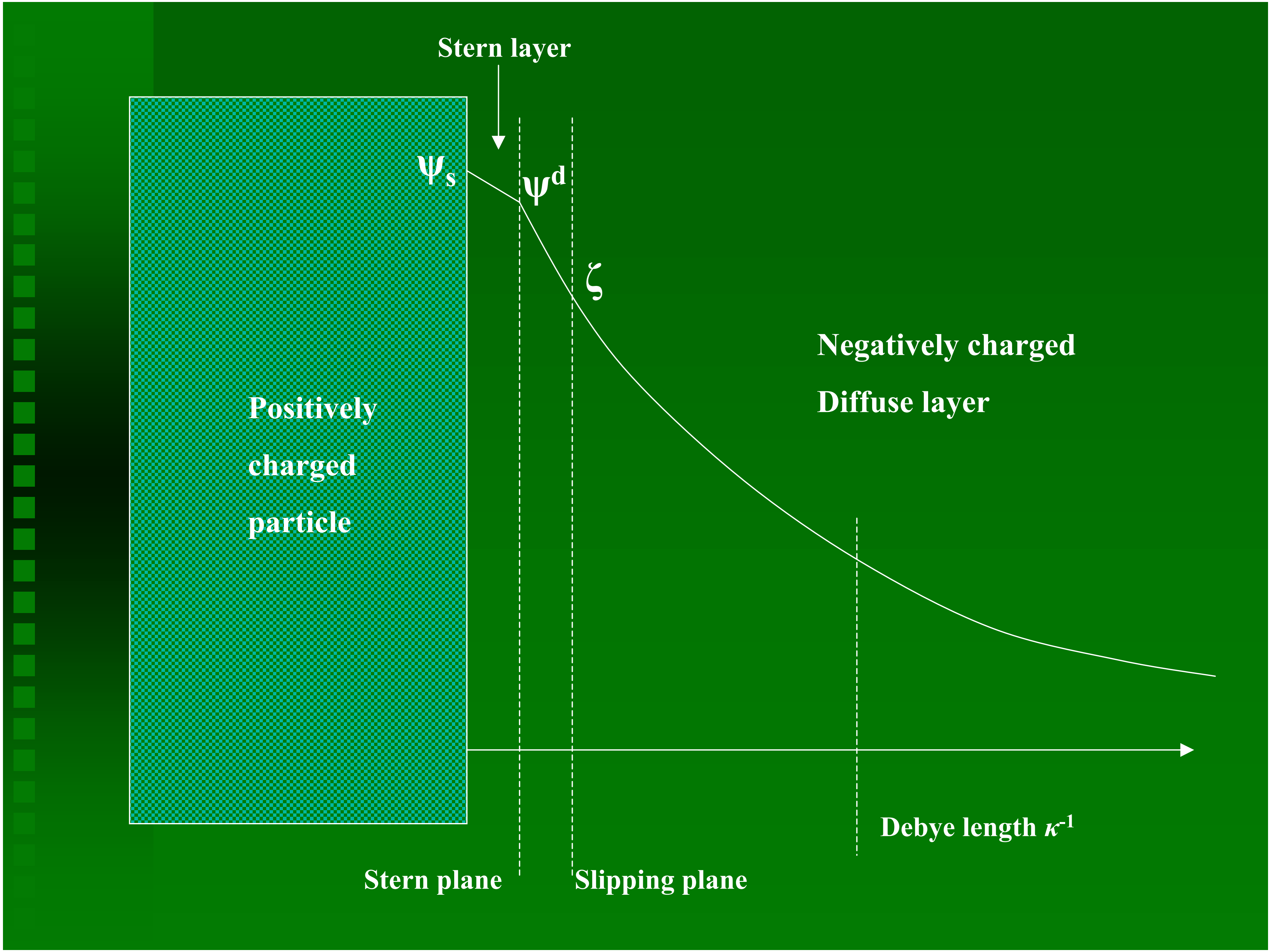
It is phenomena associated with electric charge separation at interfaces – structure known as Electric Double Layer.

Why electric charges separate at interfaces?.

- *adsorption of ionic species;*
- *dissociation of the surface chemical groups;*
- *liquid structuring near the surface causing variation in ions solubility;*

Why is it called Double Layer?

This structure consists of the surface charge layer that is bound to the one phase and screening diffuse layer of counter-ions located in the liquid phase.


Stern layer
ψ_s
ψ^d
ζ
Negatively charged
Diffuse layer
Positively
charged
particle
Debye length κ^{-1}
Stern plane
Slipping plane

Why do we need to know ζ-potential and Debye length?

1. Double layers protect particles against aggregation when they collide undergoing Brownian motion. Intensity of electrostatic repulsion depends on ζ-potential. Stability threshold is about 25 mV;

2. Characterizing adsorption of surfactants, even non-ionic;

3. Characterizing properties of macromolecules, proteins;

4. Micro-fluidic devices;

5. Controlling particulates adhesion, coatings;

6. Quality control, reproducibility of products.

Are there any other methods besides Electroacoustics for measuring ζ-potential ?

Particulates.

Electrophoresis – motion of particles under influence of electric field. Speed of motion depends on ζ-potential. There are two versions depending on method of monitoring particle motion – Electrophoretic Light Scattering and Micro-electrophoretic Image Analysis.

Porous bodies.

Streaming Current/Potential – electric signal generated by liquid moving through a porous body under influence of the pressure gradient.

Why do we need Electroacoustics if these other methods exist?

Electrophoresis is not suitable for characterizing concentrated systems. It requires dilution that could affect ζ-potential.

Electrophoresis has problems at high ionic strength, above 0.1 M due to high conductivity and related heat production.

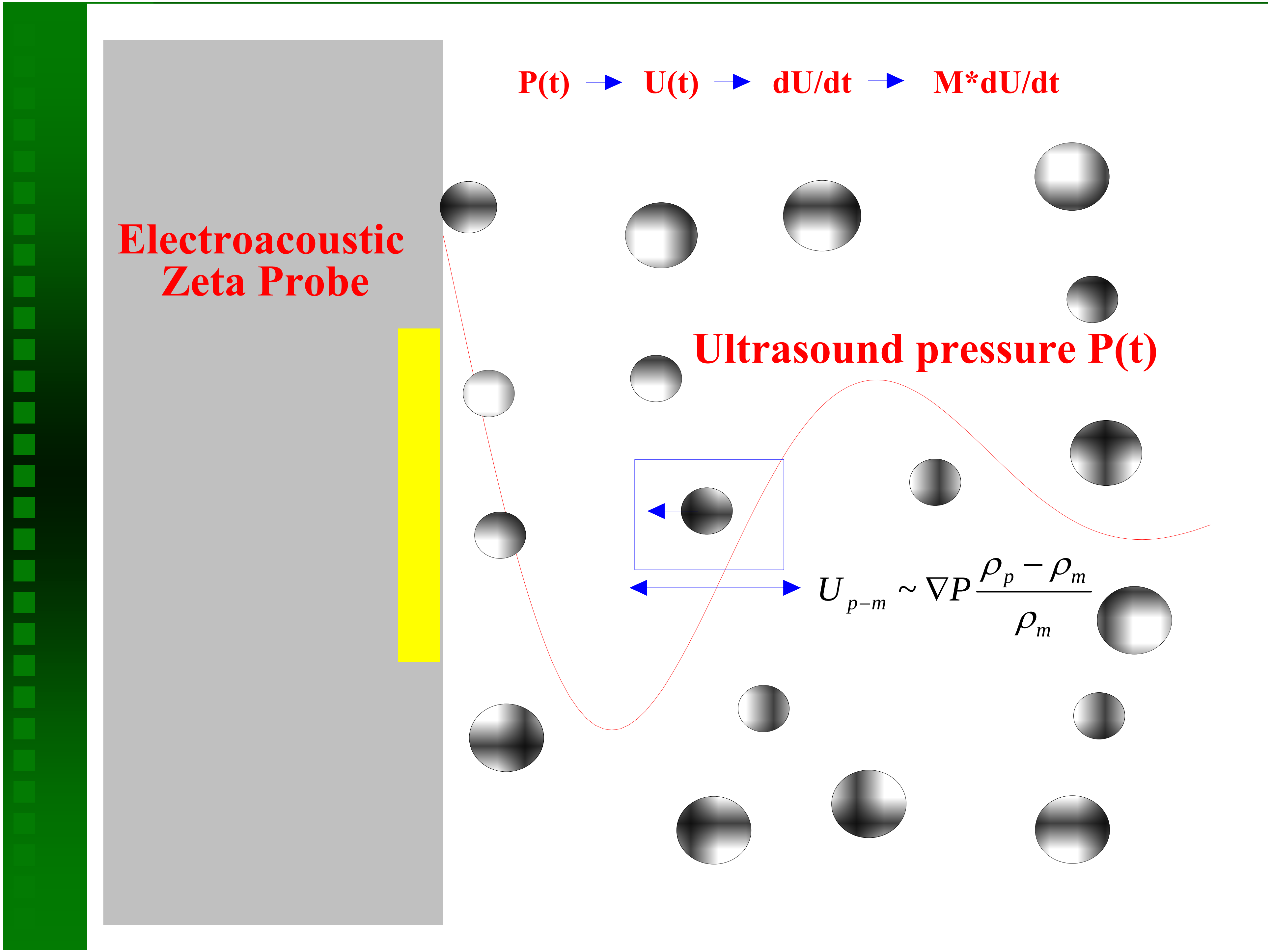
There is no method that would work for both, particulates and porous bodies.

Zeta potential probe.

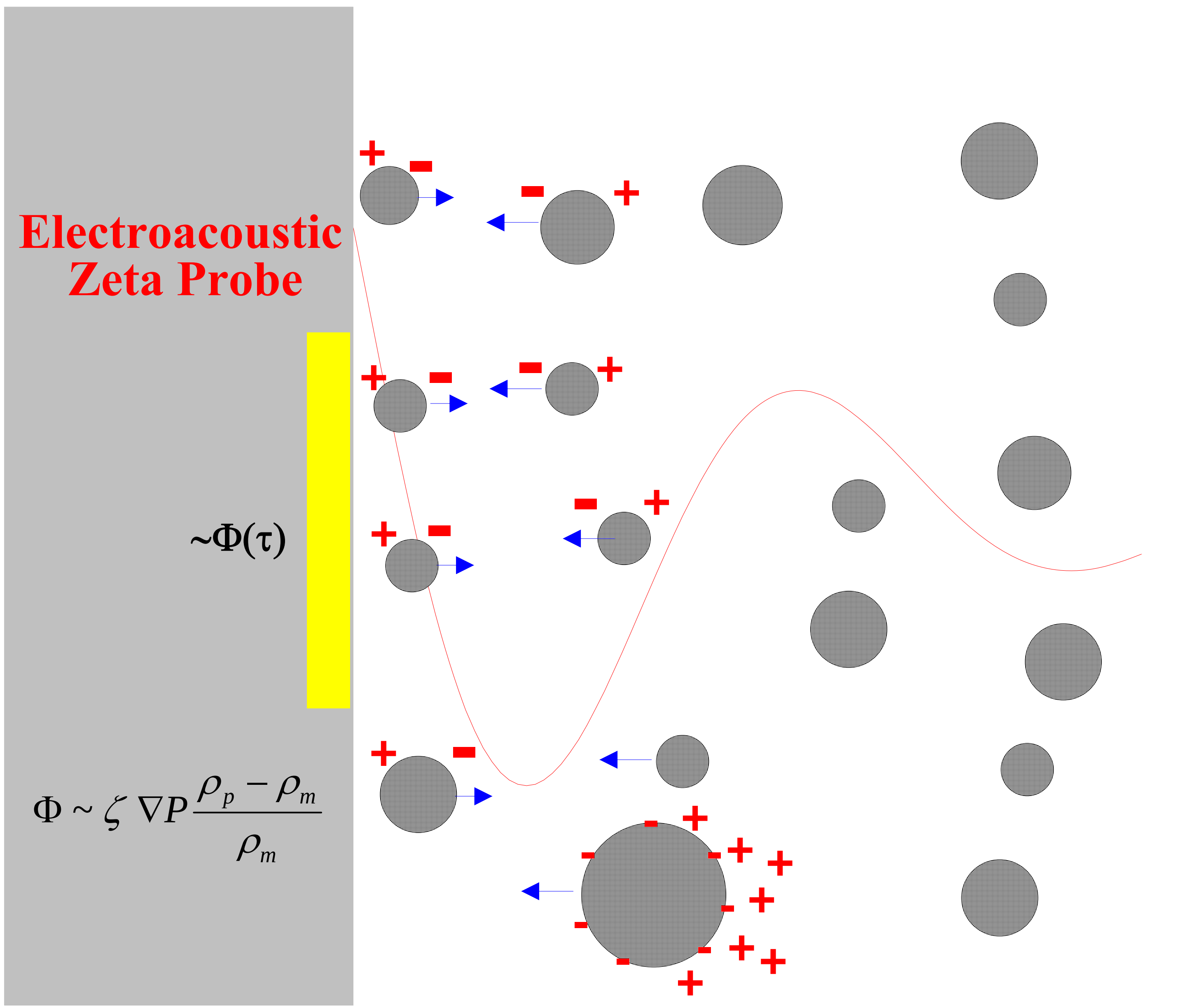
1. Means for generating relative phase motion: particles relative to the liquid, or liquid relative to the matrix of porous body.

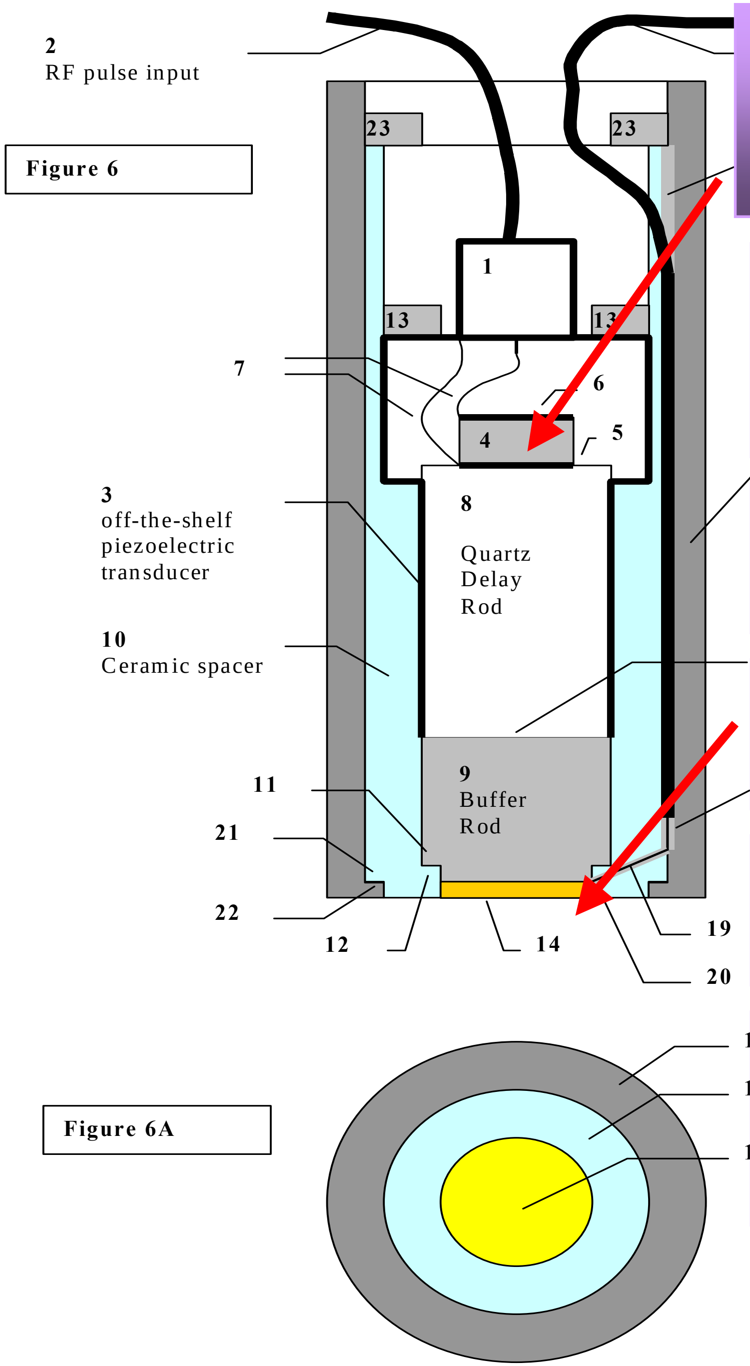
2. Means for monitoring generated signal.

3. Software based on appropriate theory for calculating ζ-potemtial from generated signal.


P(t) → U(t) → dU/dt → M*dU/dt
Electroacoustic Zeta Probe
Ultrasound pressure P(t)
$U_{p-m} \sim \nabla P \frac{\rho_p - \rho_m}{\rho_m}$

Ultrasound generates motion of particles relative to the liquid when their densities are different.





1. Piezo-crystal generates ultrasound pulse that eventually reaches dispersion through the gold electrode.

2. This Ultrasound generates motion of particles relative to the liquid when their densities are different.

3. This motion generates dipole moments for particles.

4. These dipole moments generate oscillating electric potential on GOLD electrode only.

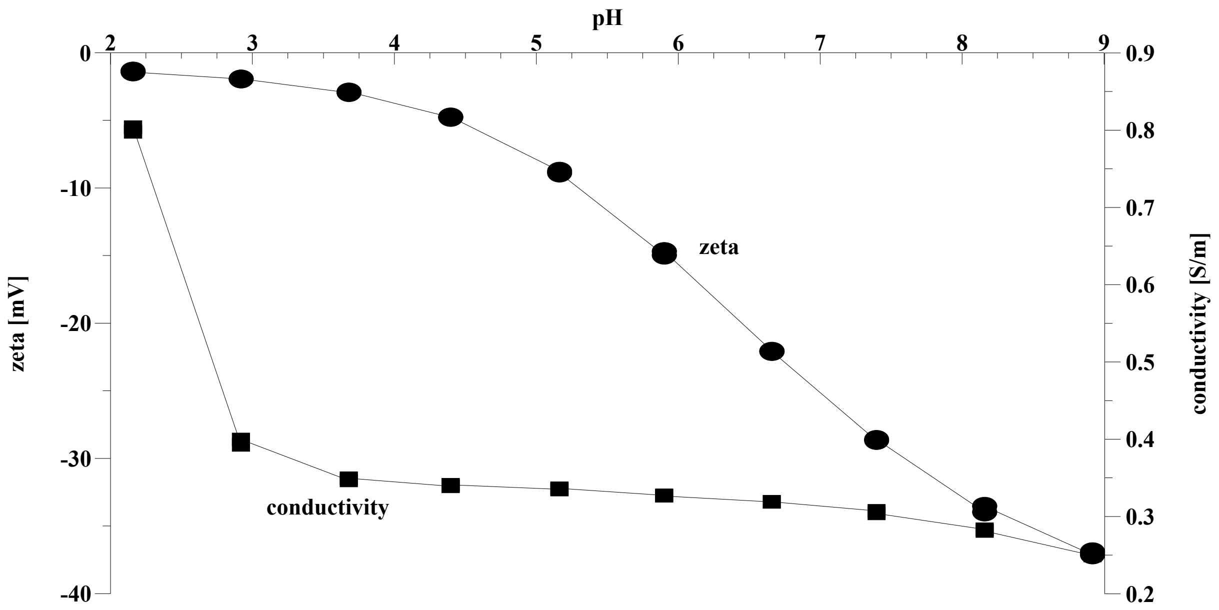
5. Stainless steel shell is outside of sound field with electric potential = 0.

6. Difference in electric potentials between Stainless steel shell and Gold electrode creates electric current : Colloid Vibration Current

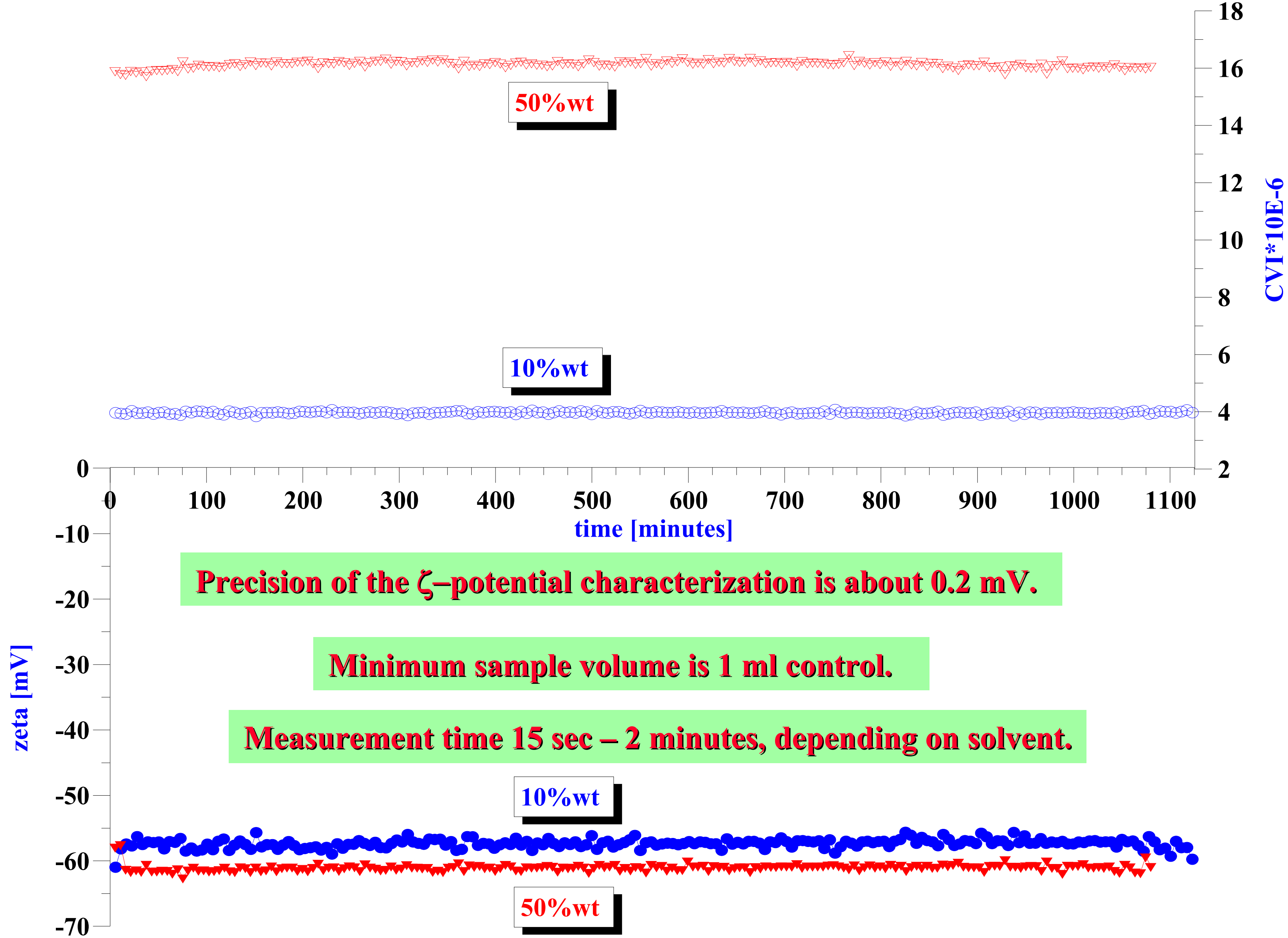
$$\Phi = A\frac{\varepsilon\zeta}{4\pi\eta}\nabla P\frac{\rho_p - \rho_m}{\rho_m}$$

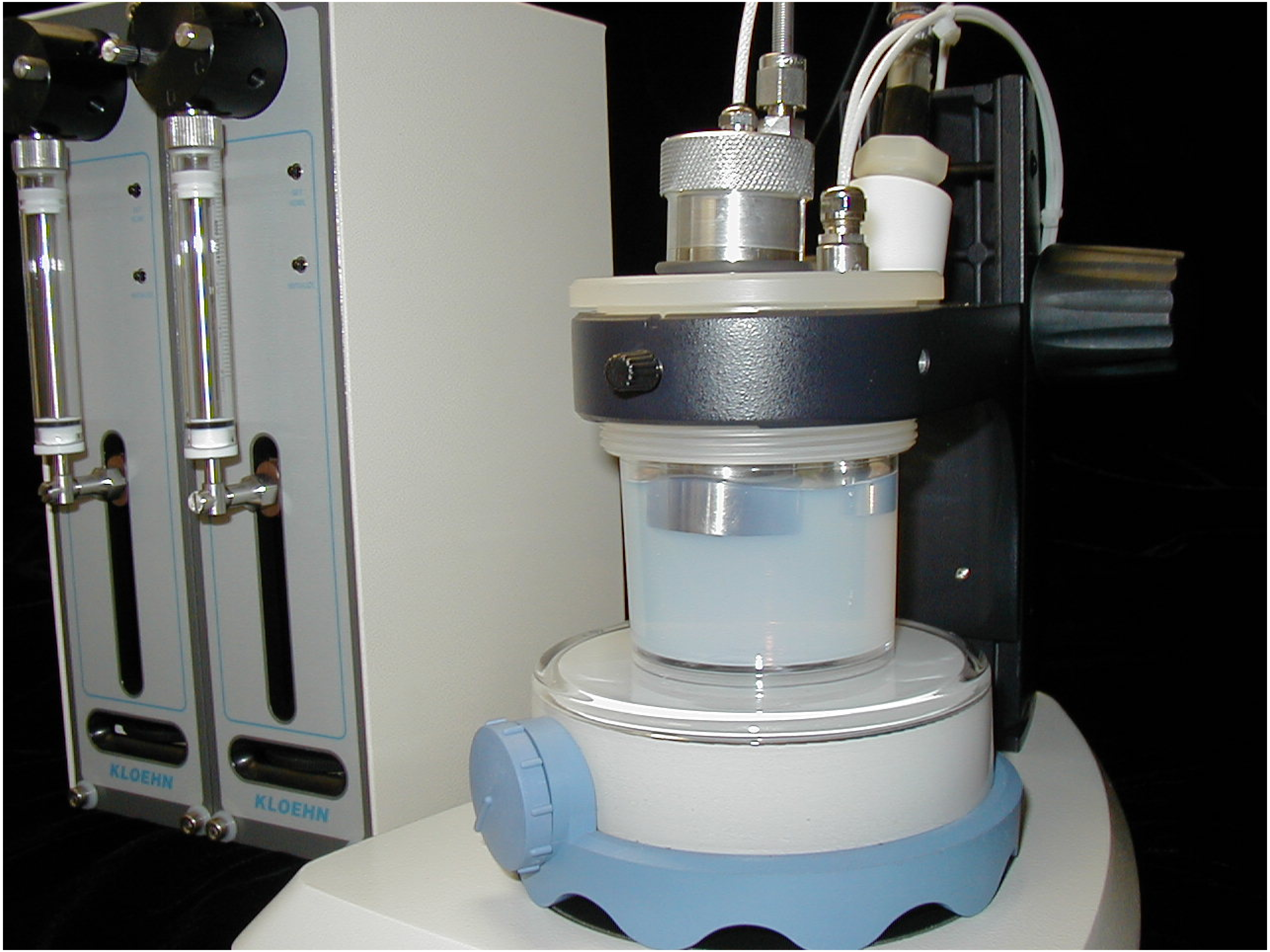
DT Colloidal Silica LUDOX TM for Calibration and Demonstration

Parameter	Mean Value	Lot variation	DT Precision
mean particle size [nm]	31	±1	1
ζ-potential [mV]	-38	±1	0.5
pH	9.3	+0.1, -0.4	0.01
conductivity [S/m]	0.170	±0.05	0.005
particles density [g/cm³]	2.2	-	0.01
weight fraction, %	10	-	-

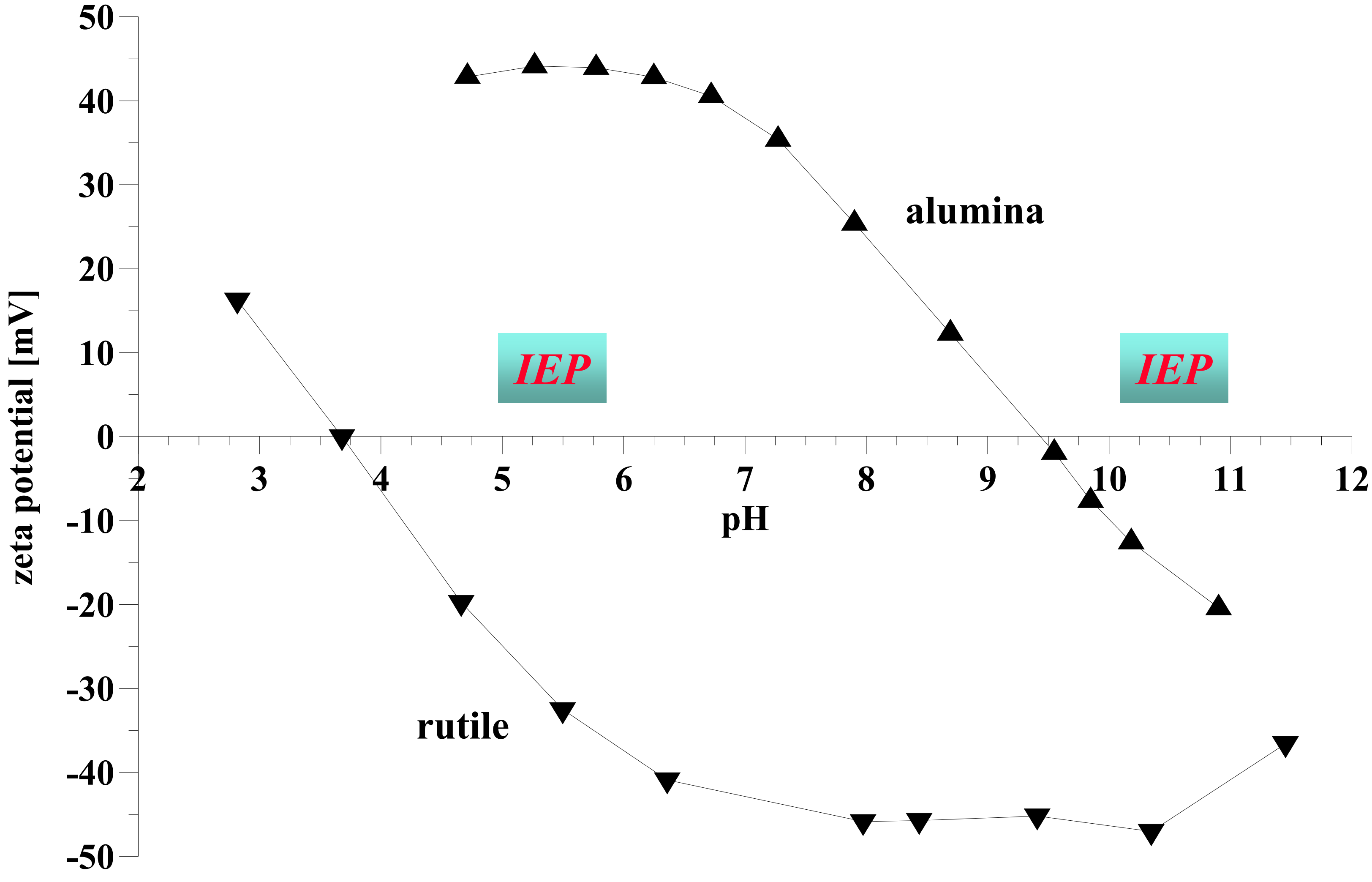


Colloid Vibration Current and corresponding ζ-potential for silica CMP 200 continuous measurements.

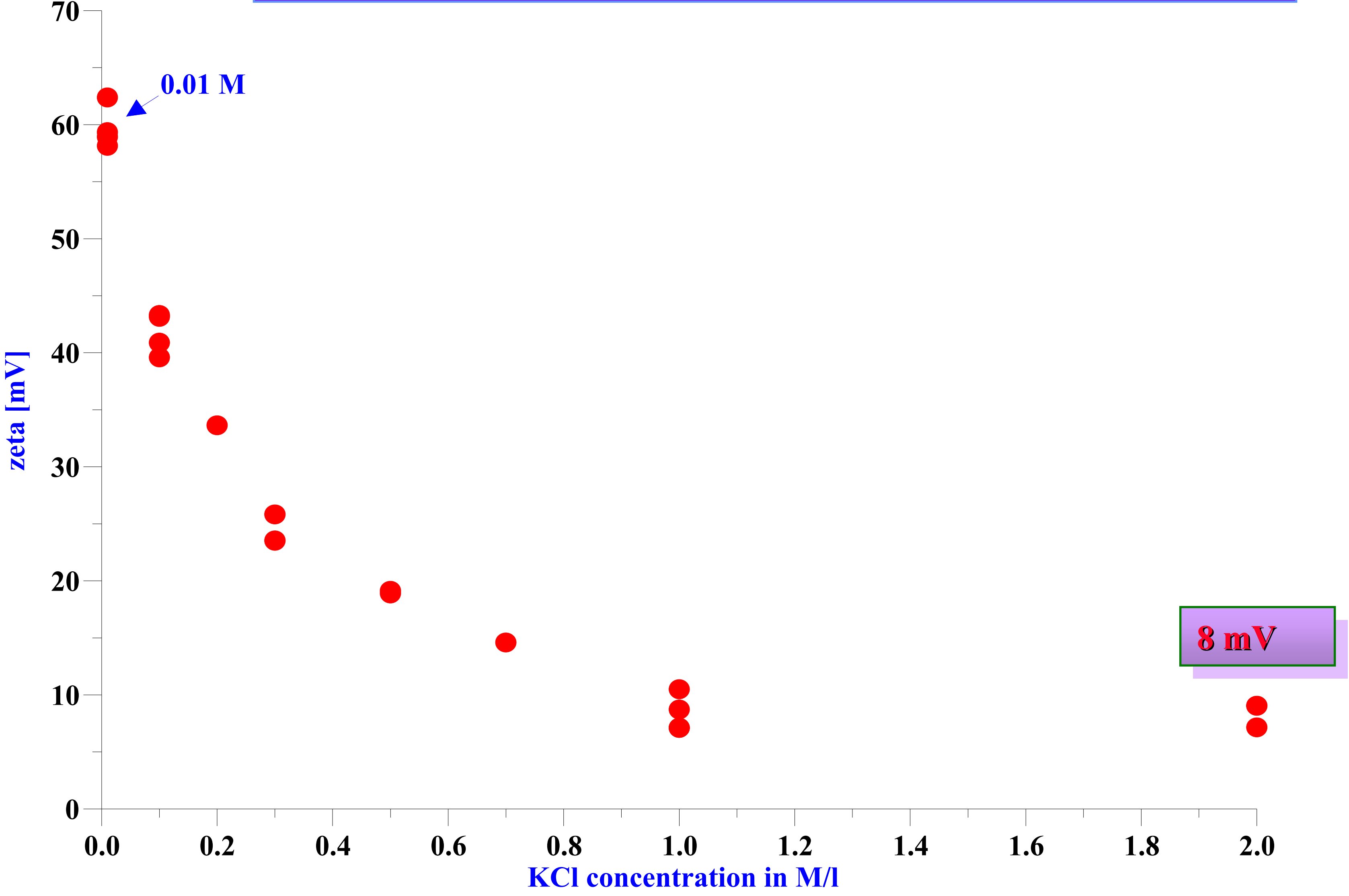


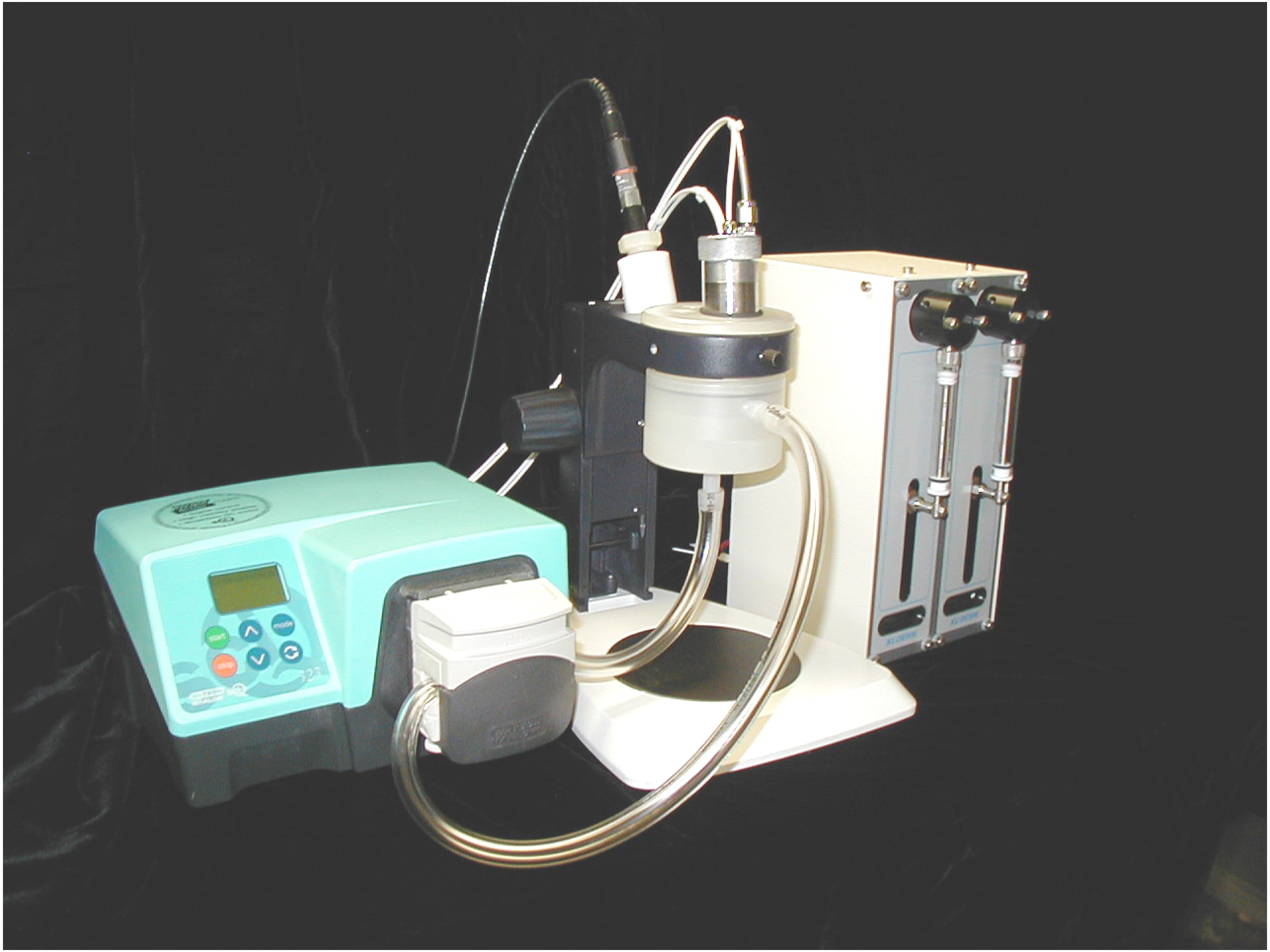

KLOEHN
KLOEHN

pH titration of rutile 7%vl and alumina 4%vl



Zeta potential of alumina AKP-30 at 3%vl versus KCl concentration




start
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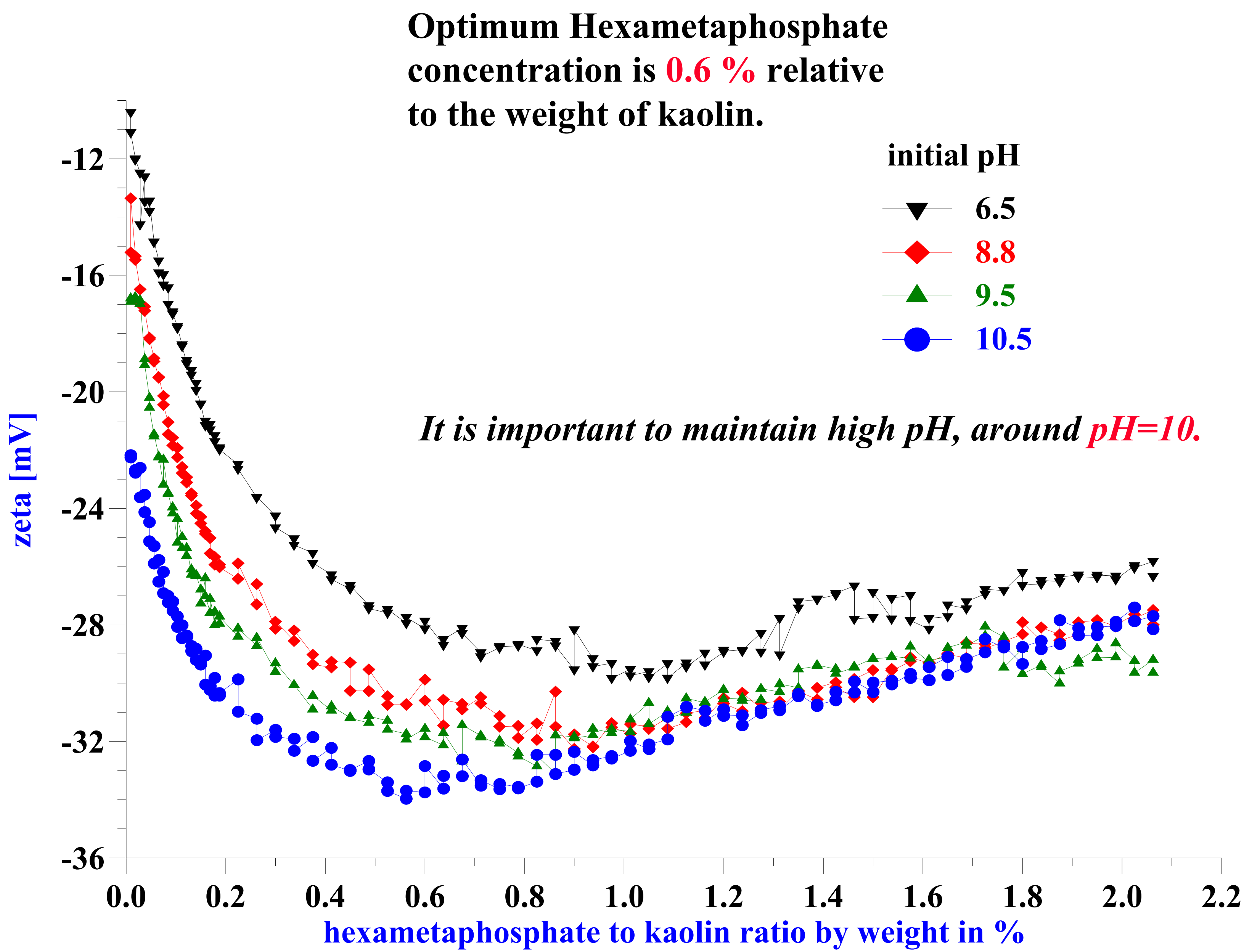
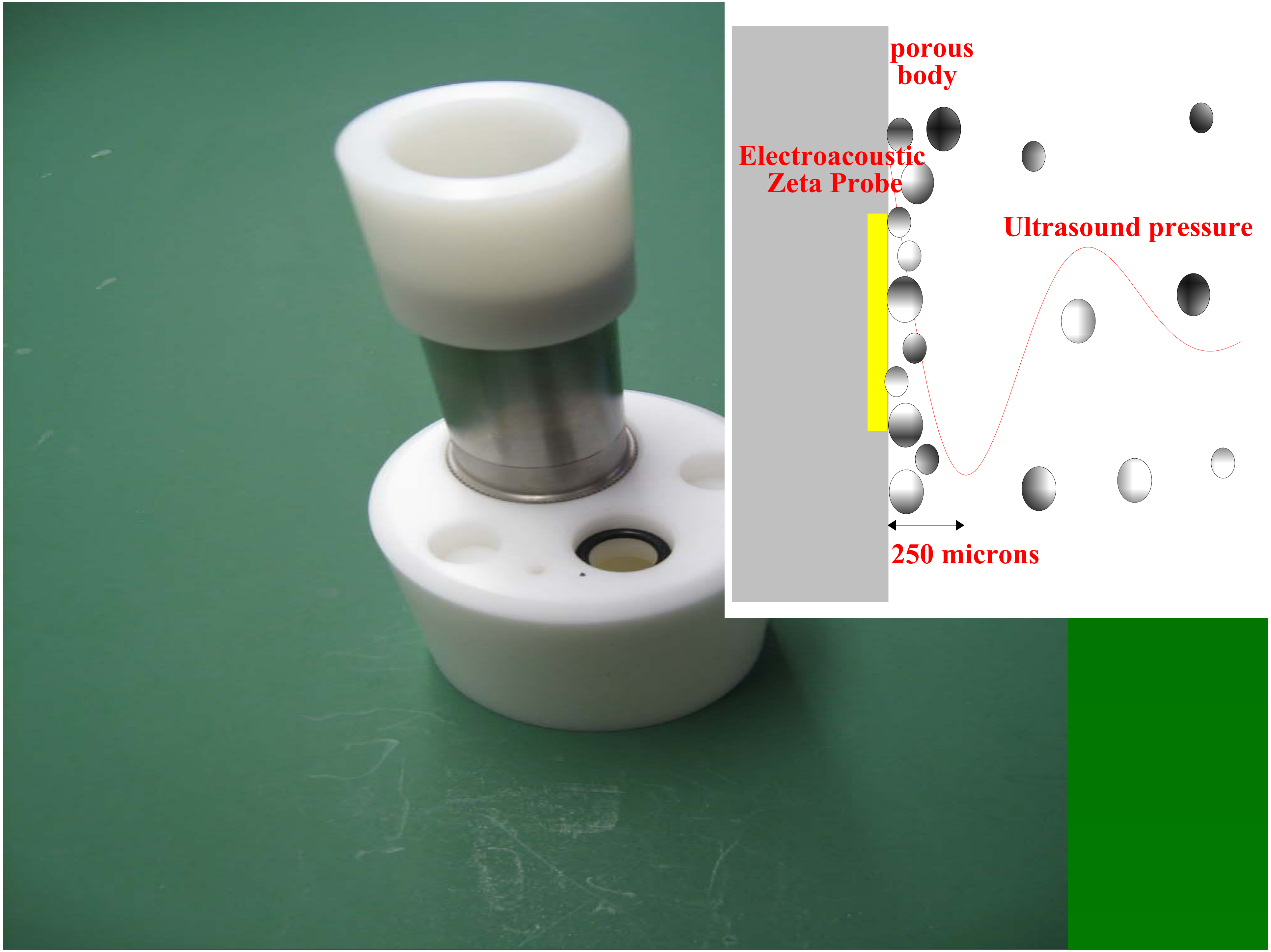
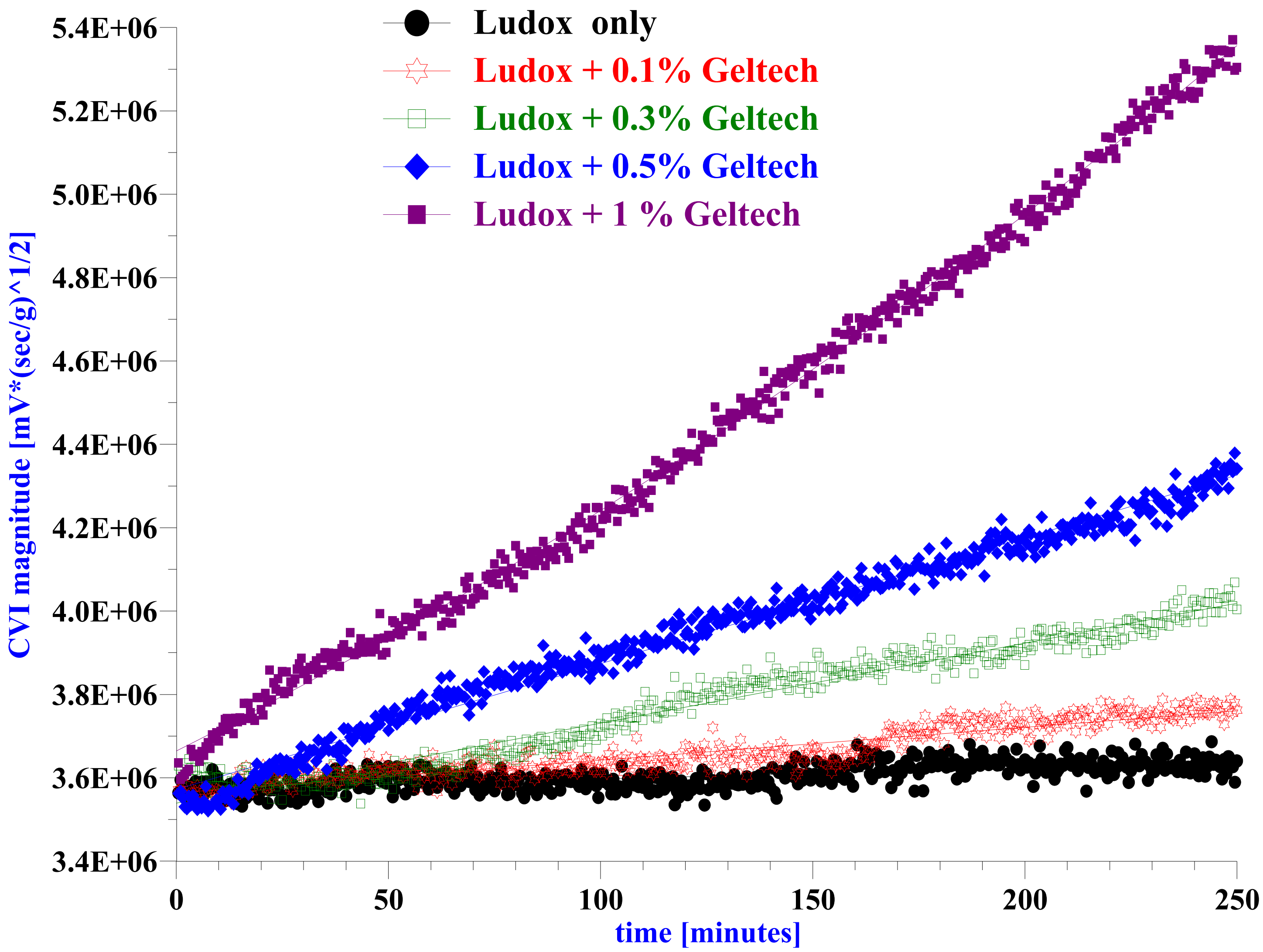
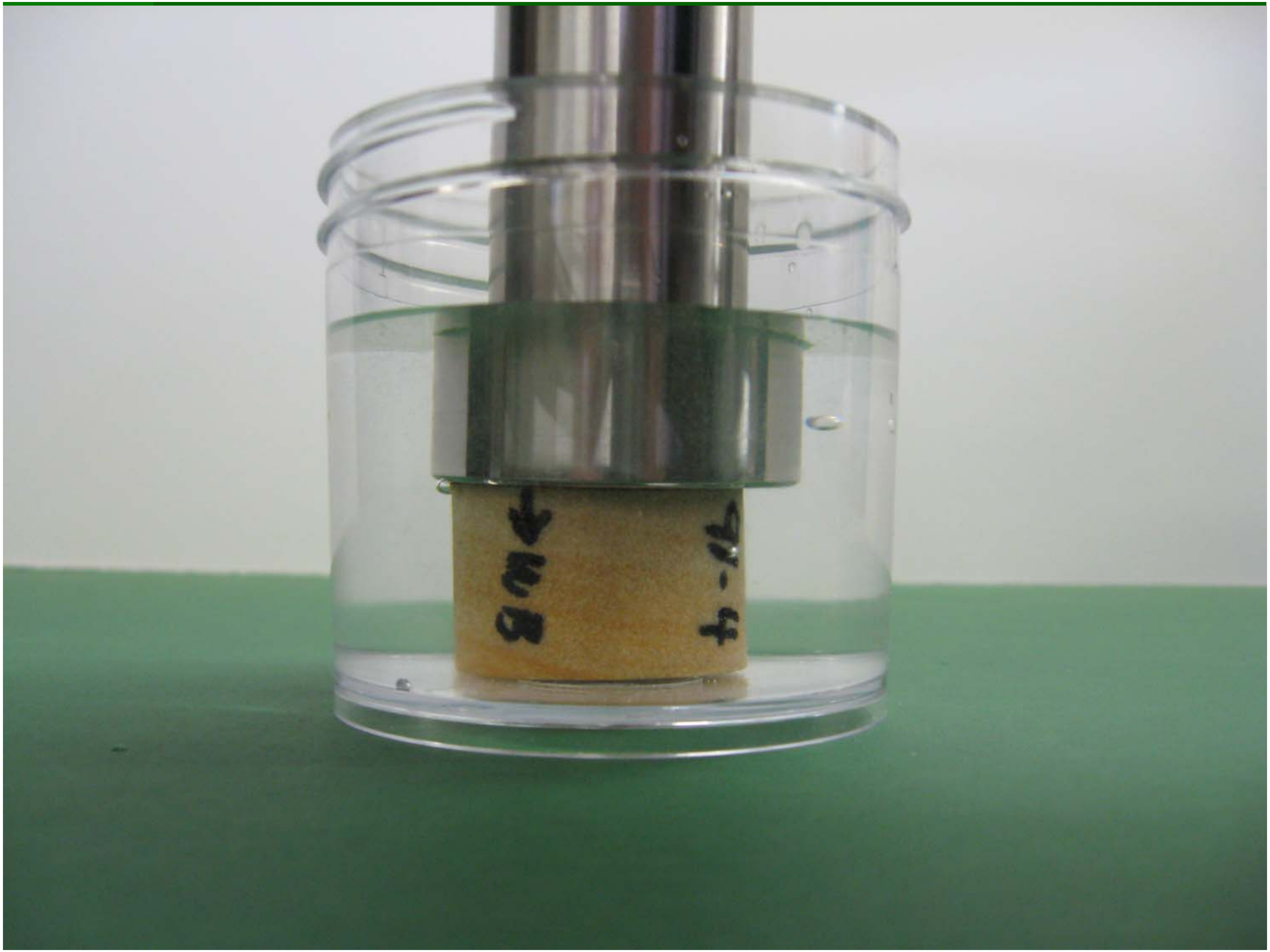
Titration of 40%wt kaolin slurry with hexametaphospate at different starting pH




porous
body
Electroacoustic
Zeta Probe
Ultrasound pressure
250 microns

Monitoring presence of sedimenting large particles / aggregates in opaque dispersions. Precision – 0.1% of the solid content.

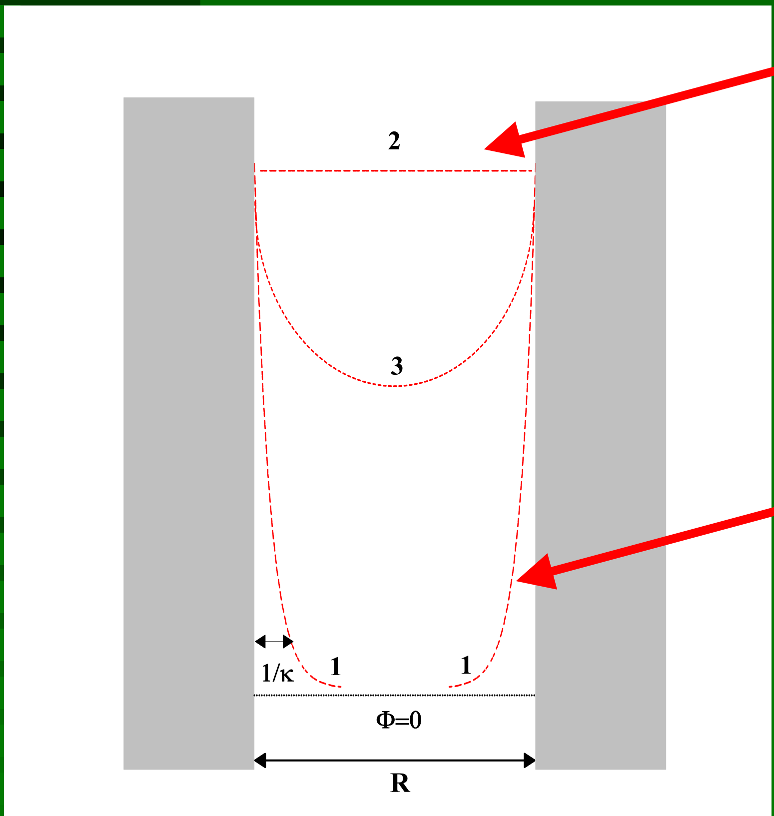




Seismo-electric current : Streaming current in non-isochoric mode.

1.Frenkel J. “On the Theory of Seismic and Seismoelectric Phenomena in a Moist Soil”, 1944

2.re-published, J. Engineering Mechanics, 131, 9, pp. 879-887 (2005).



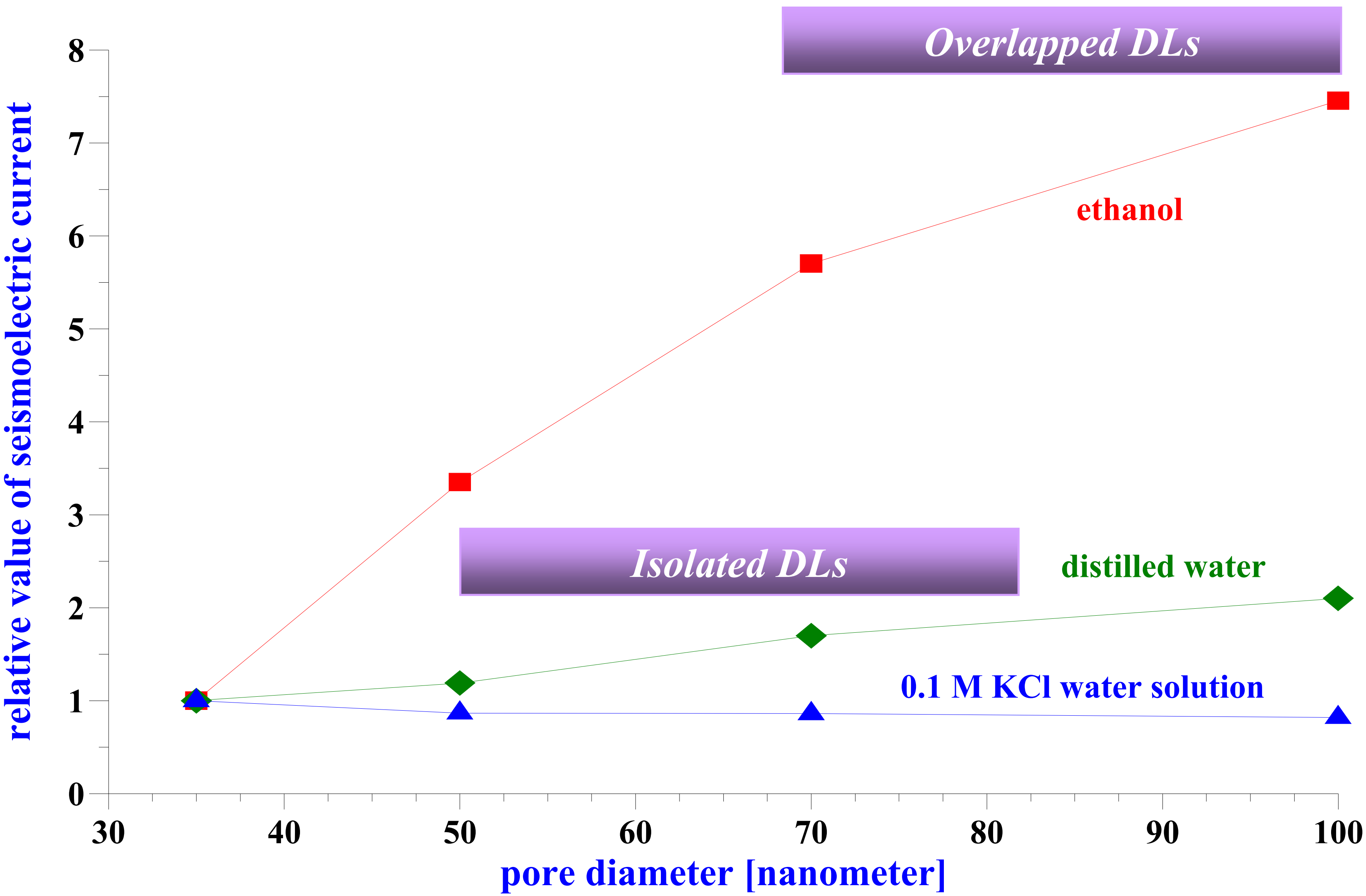
Overlapped DLs

$$I_{see} = \frac{RT\kappa^2 \varepsilon_m \rho_m \sinh\tilde{\zeta}}{F\eta\rho_s}\kappa_D(\sim r^2)\Omega_e \nabla P$$

Isolated DLs

$$I_{see} = \frac{\varepsilon_0\varepsilon_m\zeta}{\eta}\frac{K_s}{K_m}[\frac{1}{\Omega_e(1+\alpha_v)[\frac{E}{M_m}-\frac{E}{M_p}]+\frac{E-M_{sc}}{M_p}+1}-\frac{\rho_m}{\rho_s}]\nabla P$$

Porous chromatographic silica, 4 samples with the same porosity and different pore size – Quantahrome Corp.



CONCLUSIONS

Electroacoustic Zeta potential probe can perform functions of:

1. ***Electrophoretic instruments (ELS and Image)***
2. ***Streaming Current for porous bodies***
3. ***Sedimentation analysis***
4. ***Turbidity analysis of aggregative stability***
5. ***Porosimetry ????***
6. ***Particle sizing ????***

COMBINED in one instrument !!!

Measurement size of ions (nm) – combination of Acoustic and Electroacoustic 50-60 years ago – Bokris, Yeager, Zana.