DEPENDENCE OF STREAMING POTENTIAL ON GRAIN DIAMETER AND PORE THROAT RADIUS

Nicholas Déry & Paul Glover
Université Laval, Québec, Canada

Introduction

- The Helmholtz-Smoluchowski equation relates the streaming potential coupling coefficient (SPCC) to
  - zeta potential
  - Pore fluid dielectric permittivity
  - Pore fluid conductivity
  - Pore fluid viscosity

$$C_s = \frac{\Delta V}{\Delta P} = \frac{\varepsilon_r \, \varepsilon_o \, \zeta}{\eta \, \sigma_f^*}$$

$$C_s = \frac{\Delta V}{\Delta P} = \frac{\varepsilon_f \, \zeta}{\eta_f \left(\sigma_f + 2\Sigma_s / \Lambda\right)}$$

- No implicit dependance on grain size
- 1999 Revil produced equations implying a grain size dependent model
- This presentation: SPCC as a function of grain size
- This presentation: SPCC as a function of pore size
- This presentation: SPCC as a function of pore throat size

Introduction

- Previous experimental determinations – only two
  - Bull & Gortner (1932)
  - Bolève et al (2007)

- This presentation: A set of new high quality SPCC measurements as a function of grain size and pore throat size.

Theory

- SPCC as a function of grain diameter

Revil (1999) equations imply the model

$$\Lambda = \frac{d}{3(F-1)} \Longrightarrow C_s = \frac{\Delta V}{\Delta P} = \frac{d\,\varepsilon_f\,\zeta}{\eta_f\left(d\,\sigma_f + 6\Sigma_s(F-1)\right)}$$

Our model (after Glover et al., 2006)

$$\Lambda \approx \frac{d}{2mF} \Longrightarrow C_s = \frac{\Delta V}{\Delta P} = \frac{d\,\varepsilon_f\,\zeta}{\eta_f\left(d\,\sigma_f + 4\Sigma_s\,m\,F\right)}$$

Coïncident for spheres and F>>1

Theory

- SPCC as a function of pore radius

Our model for all geometries

$$C_s = \frac{\Delta V}{\Delta P} = \frac{r\,\varepsilon_f\,\zeta\sqrt{a}}{\eta_f\left(r\,\sigma_f\sqrt{a} + 4\Sigma_s\sqrt{2}\right)}$$

Our model for spherical particles (*a*=8/3)

$$C_s = \frac{\Delta V}{\Delta P} = \frac{r\,\varepsilon_f\,\zeta}{\eta_f\left(r\,\sigma_f + 2\Sigma_s\sqrt{3}\right)}$$

Theory

- SPCC as a function of pore throat diameter

Our model for all geometries

$$C_s = \frac{d_{PT} M_i \varepsilon_f \zeta \sqrt{a}}{\eta_f \left(d_{PT} M_i \sqrt{a}\, \sigma_f + 8\Sigma_s \sqrt{2}\right)}$$

a=8/3 for spherical particles

$$C_s = \frac{1.627 d_{PT} \varepsilon_f \zeta \sqrt{a}}{\eta_f \left(1.627 d_{PT} \sqrt{a}\, \sigma_f + 8\Sigma_s \sqrt{2}\right)}$$

Random

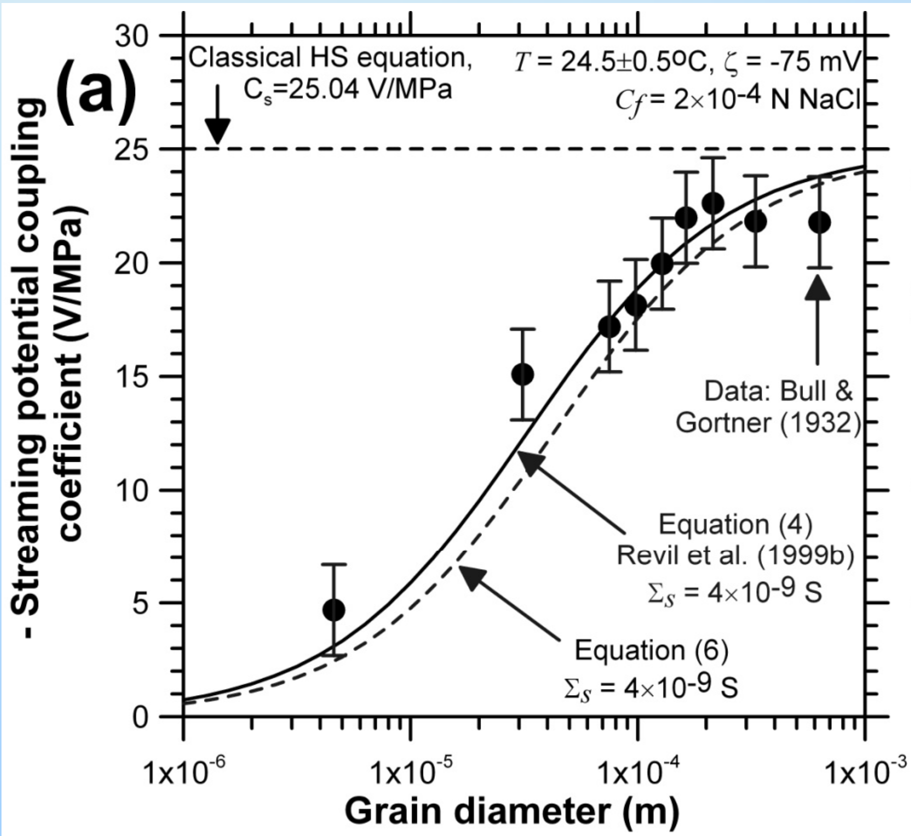
$$C_s = \frac{d_{PT} \varepsilon_f \zeta \sqrt{a}\left(\sqrt{3}-1\right)}{\eta_f \left(d_{PT} \sqrt{a}\left(\sqrt{3}-1\right)\sigma_f + 8\Sigma_s \sqrt{2}\left(\sqrt{2}-1\right)\right)}$$

Cubic

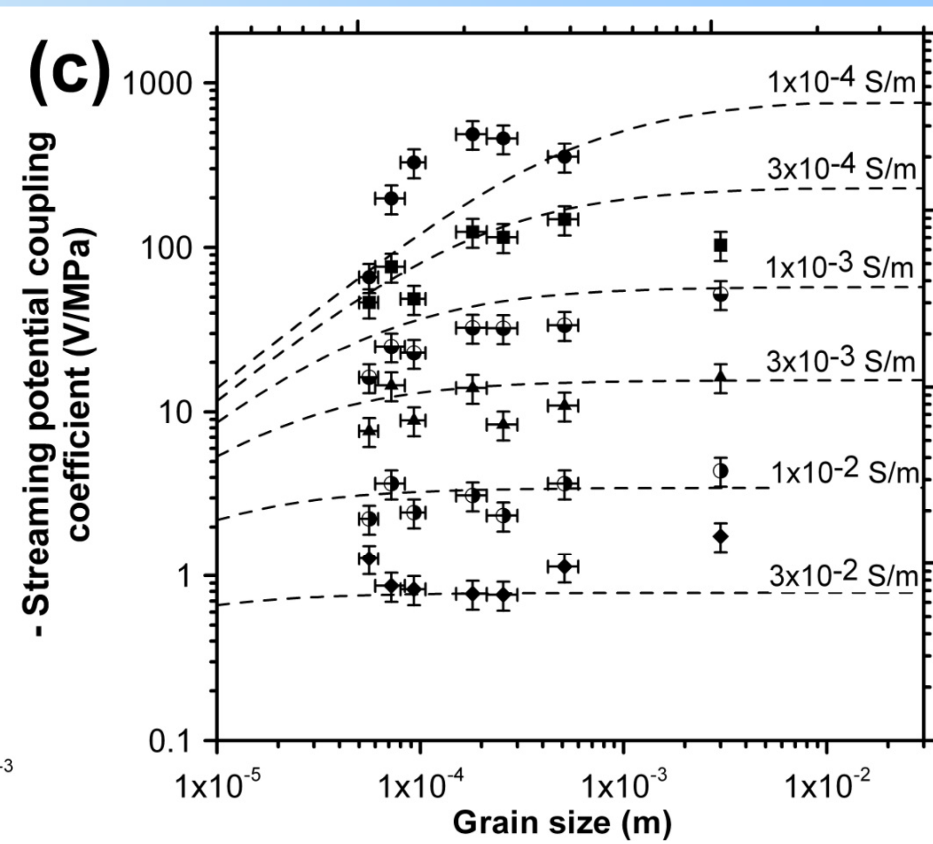
$$C_s = \frac{d_{PT} \varepsilon_f \zeta \sqrt{a}\left(3\sqrt{2}-2\sqrt{3}\right)}{\eta_f \left(d_{PT} \sqrt{a}\left(3\sqrt{2}-2\sqrt{3}\right)\sigma_f + 8\Sigma_s \sqrt{2}\left(4-2\sqrt{3}\right)\right)}$$

Hexagonal

Previous Measurements

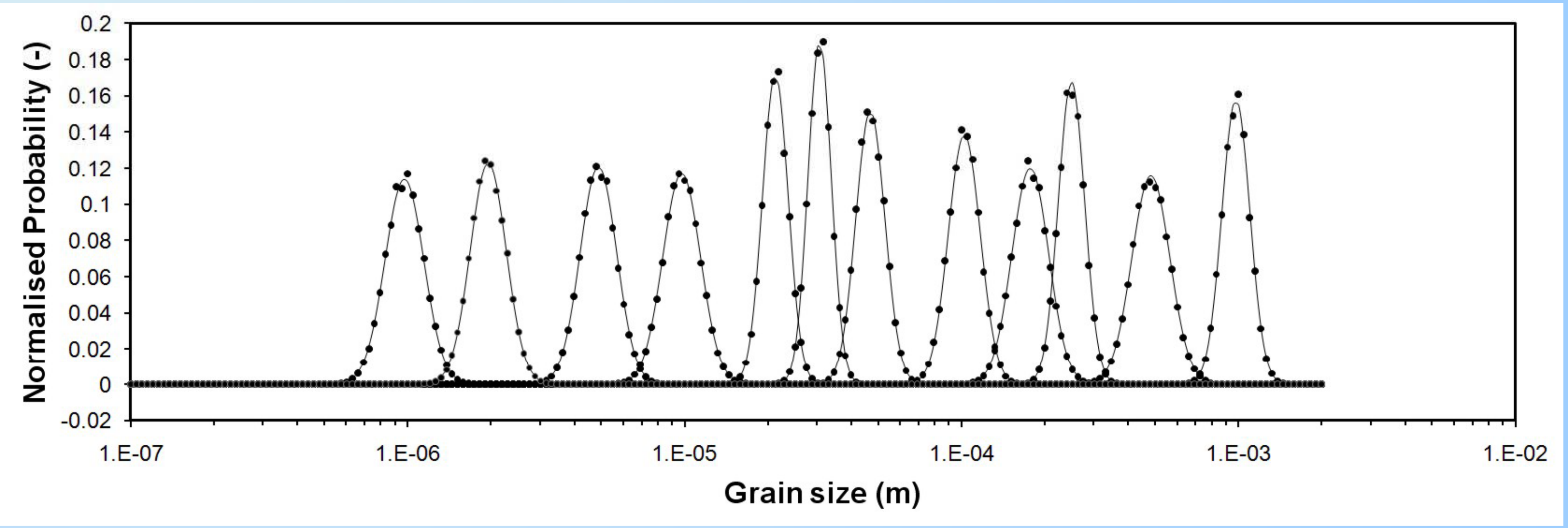


Bull and Gortner (1932)



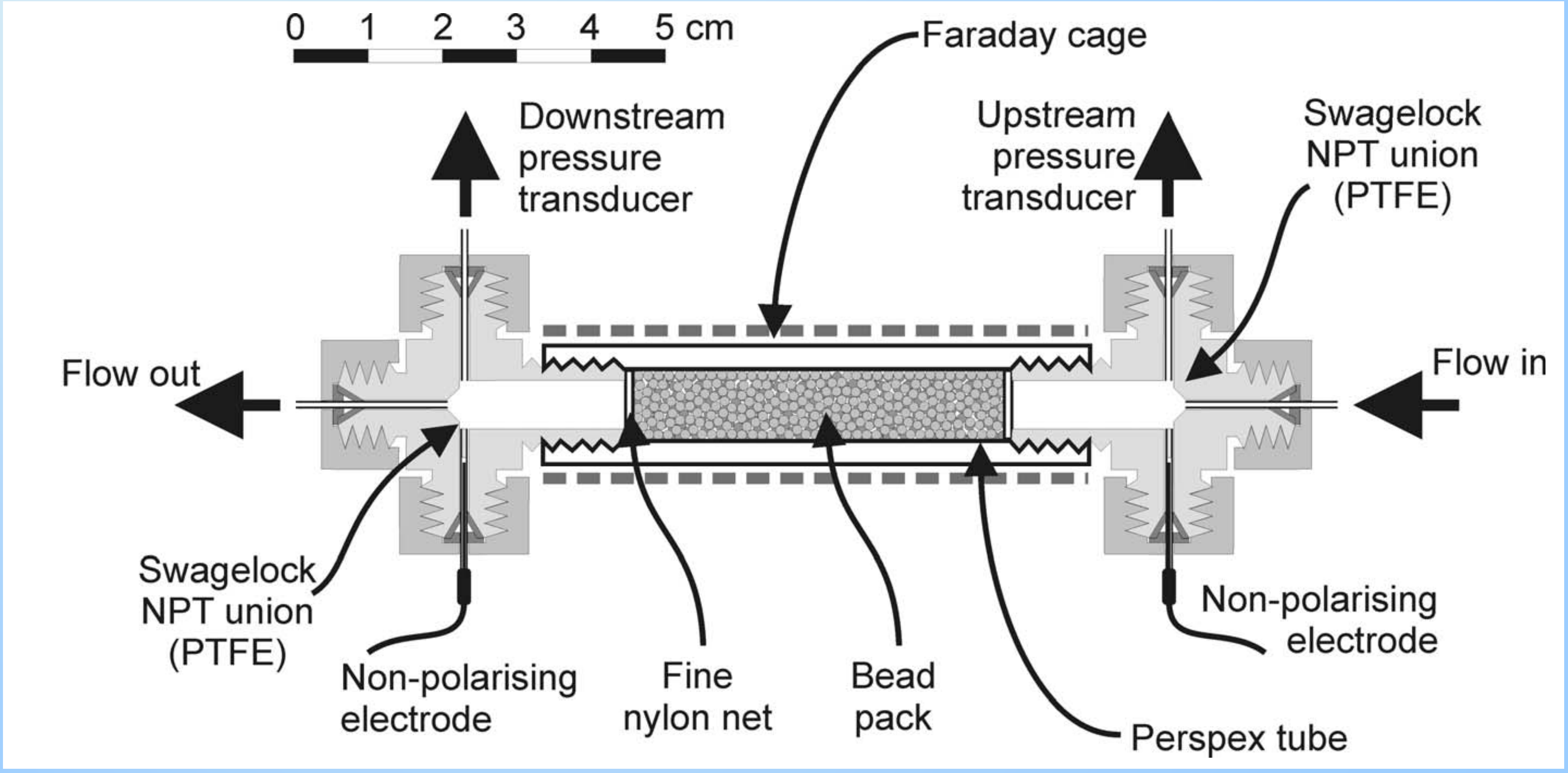
Bolève et al. (2007)

Experimental methods



- 12 grain sizes by laser diffractometry
- Measured pore throat diameters (Hg)
- Calculated pore radii (after Glover and Walker, 2009)
- Measured porosity (Hg and He)
- Measured permeabilities

Experimental methods



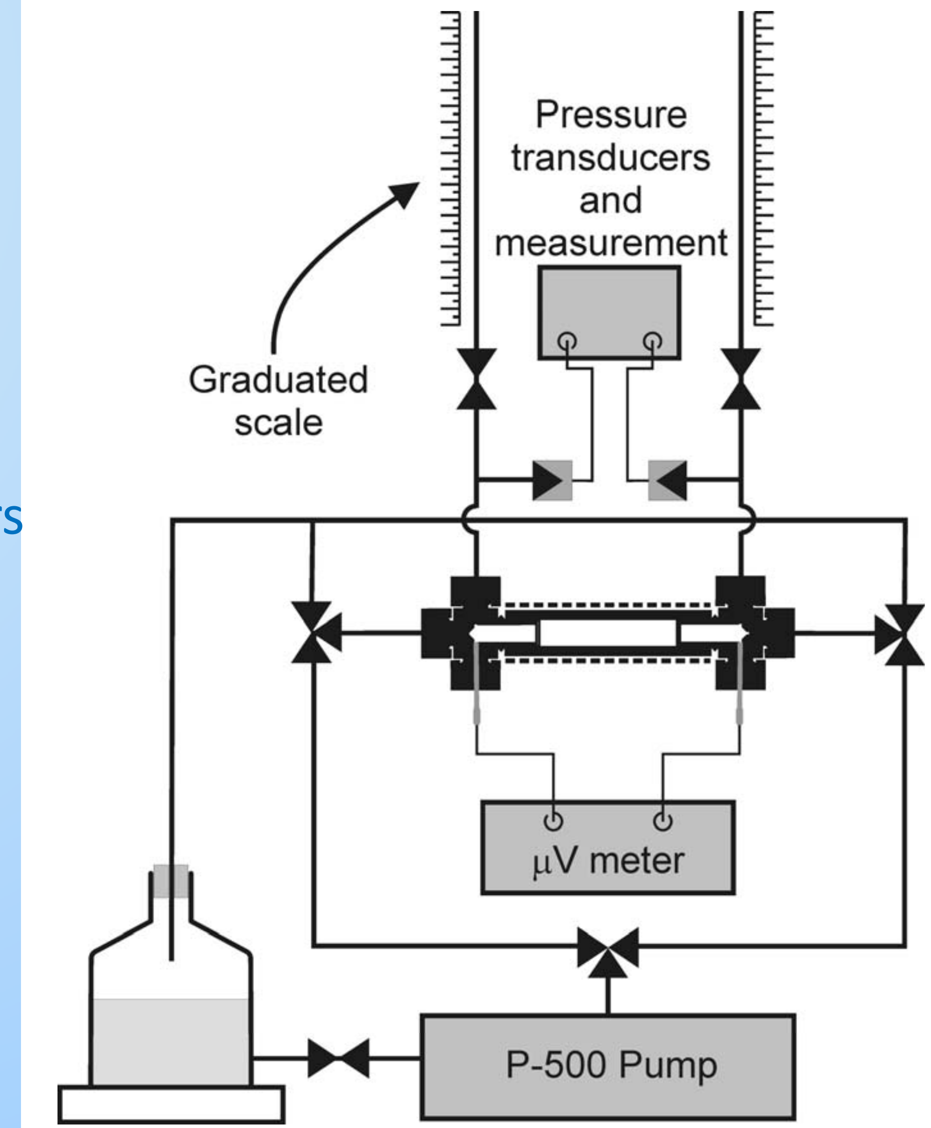
Experimental methods

- NaCl electrolyte
- pH 6.9
- $C_f = 2\times10^{-4}$ and 2×10^{-3} mol/L
- $\sigma_f = 2.44\times10^{-3}$ and 2.41×10^{-2} S/m
- T=25°C
- Omega PX302 pressure transducers
- Cypress Ag/AgCl electrodes
- Keithley microvoltmeter logger
- 4 flow rates

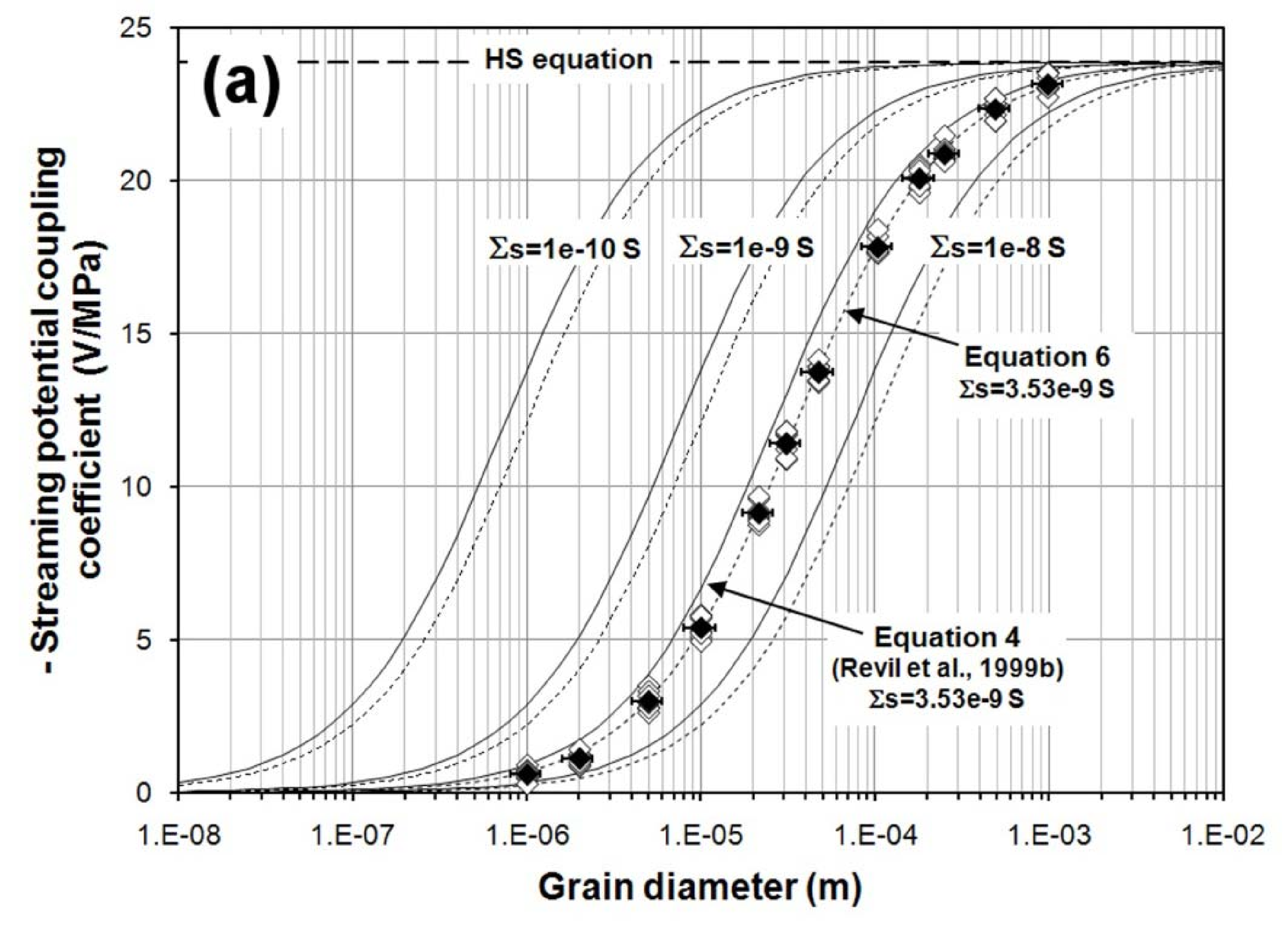
  × 2 directions

  × 12 grain sizes

  ×2 fluids



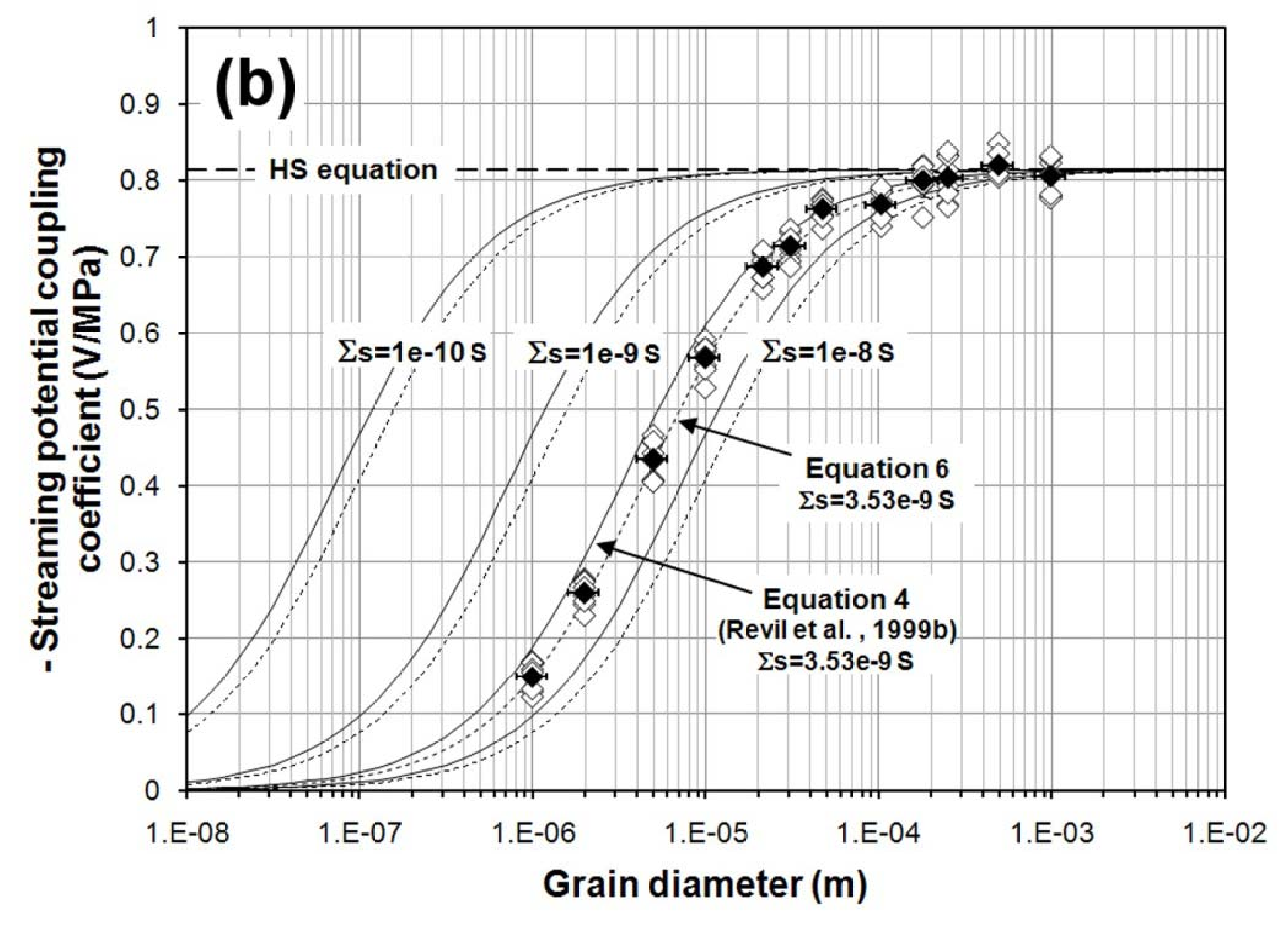
Results



High quality experimental data fit the *grain diameter dependent* SPCC models excellently

$C_f = 2\times10^{-4}$ mol/L

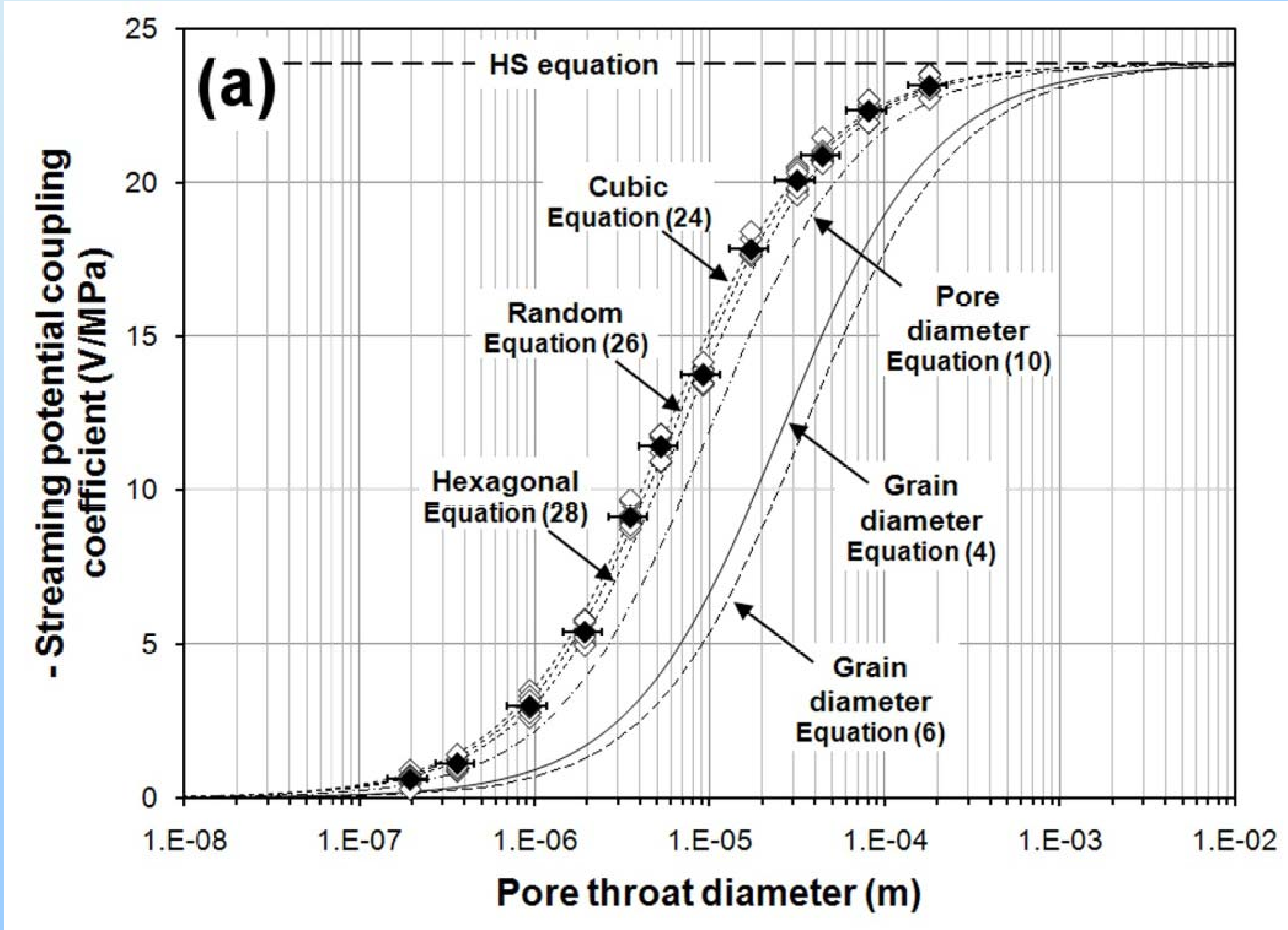
Results



High quality experimental data fit the *grain diameter dependent* SPCC models excellently

$C_f = 2\times10^{-3}$ mol/L

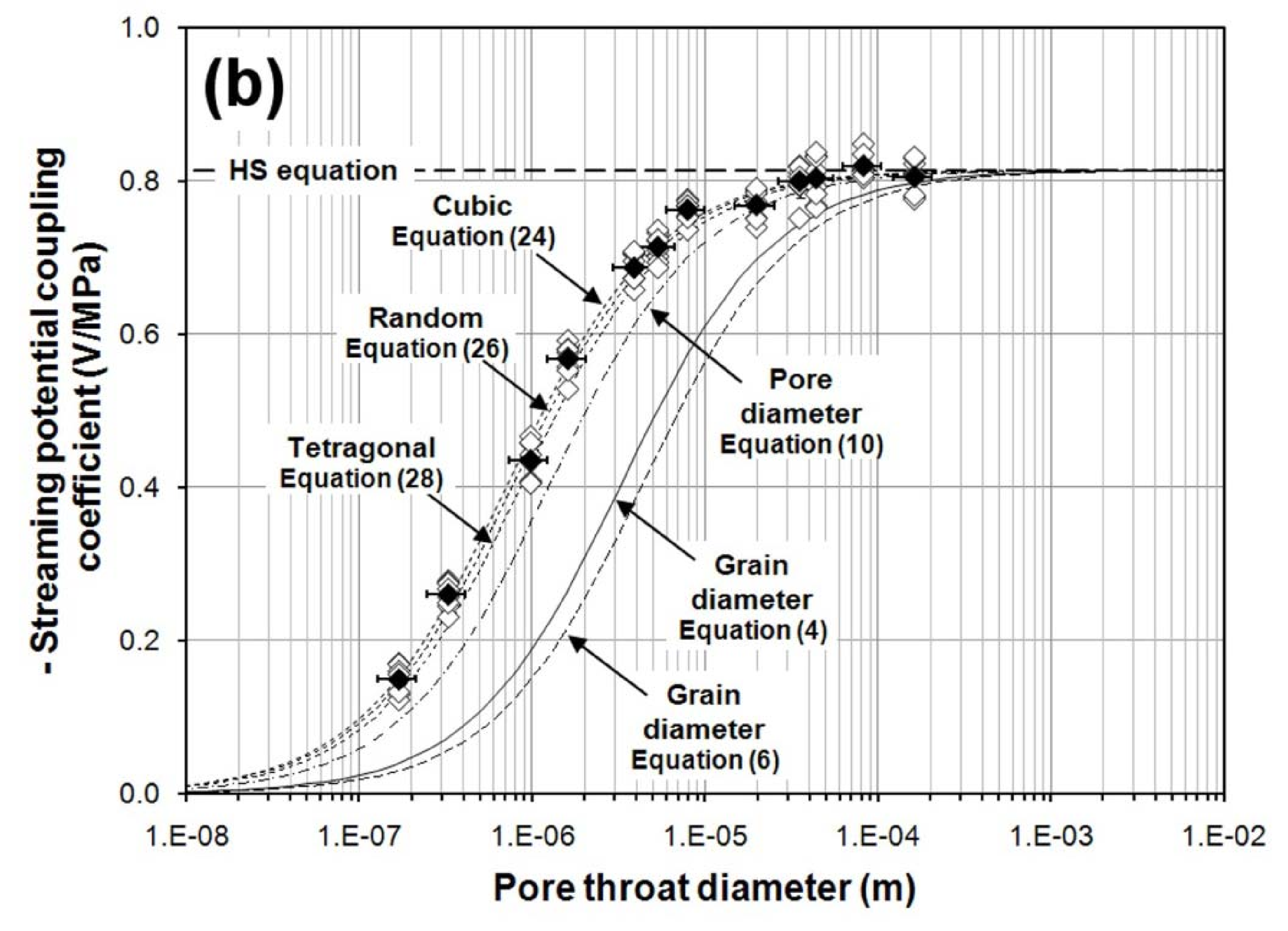
Results



High quality experimental data fit the *pore throat diameter dependent* SPCC models excellently

C_f = 2×10^{-4} mol/L

Results



High quality experimental data fit the *pore throat diameter dependent* SPCC models excellently

$C_f = 2\times10^{-3}$ mol/L

Conclusions

- The classical HS model cannot predict the SPCC as a function of grain size
- However, there are few data available to test the models
- New high quality measurements have been done as a function of
  - Grain size
  - Pore throat diameter
  - Pore size
    - for 12 particle sizes
    - 2 pore fluid salinities
    - 4 flow rates
    - each in 2 flow directions

Conclusions

- The Revil (1999) grain size dependent model agrees with the new high quality experimental data excellently
- The 'new' Glover and Déry grain size dependent model is an approximation of that by Revil (1999)
- It also performs very well
- A new pore radius dependent model has been developped.
- A new pore throat diameter dependent model has also been developped
- The pore throat diameter dependent model agrees with the new high quality experimental data excellently too

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