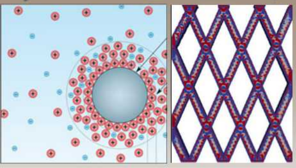
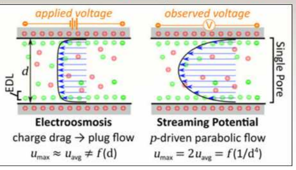
SAND2020-0671D





Characterization of Ultralow Permeability Geomaterials using Electrokinetics

Kristopher L. Kuhlman[1], Melissa M. Mills[1], Bwalya Malama[2], Narayana Aluru[3] & Pikee Priya[3]

[1] Applied System Analysis & Research Department (8844)
[2] Cal Poly San Luis Obispo [3] University of Illinois

Problem: **Low-permeability (k) rocks are critical as barriers and seals as well as source rocks for hydrocarbon, but difficult to characterize. Darcy methods require long-duration tests. Hydrogeophysics can help.**

Laboratory Electrokinetics (EK)

Streaming potential (SP): Move fluids → drag ions
Electroosmosis (EO): Move ions → drag fluids

Fluid Volume Density (Darcy's Law, SP):
$$\vec{J}_f = -\frac{k_0}{\mu}\nabla p - L_{12}\nabla\psi$$

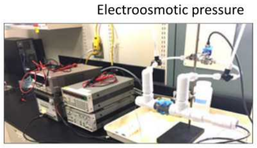
Electric Current Density (EO, Ohm's Law):
$$\vec{J}_e = -L_{21}\nabla p - \sigma_0\nabla\psi$$

Streaming potential:
$$K_S = \frac{L_{12}}{\sigma_0} = \left[\frac{\mathrm{V}}{\mathrm{Pa}}\right]$$

Electroosmotic pressure:
$$K_E = \frac{L_{21}\mu}{k_0} = \left[\frac{\mathrm{Pa}}{\mathrm{V}}\right]$$

Pressure Diffusion:
$$\frac{1}{\alpha}\frac{\partial p}{\partial t} = \nabla^2 p + K_E\nabla^2\psi$$

Electrical Conduction:
$$0 = K_S\nabla^2 p + \nabla^2\psi$$

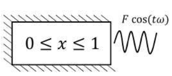


Estimate permeability via modification of Pengra et al. (1999) approach.

K_S and K_E are measured using low-frequency (<200 Hz) AC methods, which go to steady-state quickly. Measuring K_S and K_E, we estimate $k_0 = \frac{\sigma_0 \mu K_S}{K_E}$ since Onsager showed in general $L_{12} = L_{21}$.

Analytical Lab-Scale Coupled EK Solution

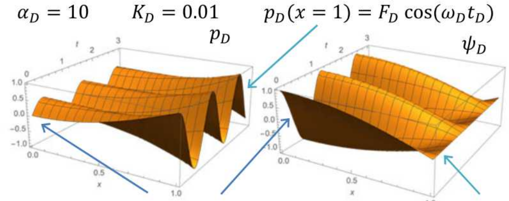
Apply generalized uncoupling approach to 1D flow in a box driven by periodic Type I BC on one end, insulating BC on other end:



$$\delta_{iSS}(x_D, t_D) = \Re\left\{\frac{jK_D F_D \zeta}{\omega_D \Delta\left(e^{\zeta}-1\right)}\left[e^{i\omega_D t_D + \zeta(1+x_D)} + e^{i\omega_D t_D - \zeta x_D}\right]\right\} \quad \zeta = \sqrt{j\omega_D/\Lambda_{ii}}$$

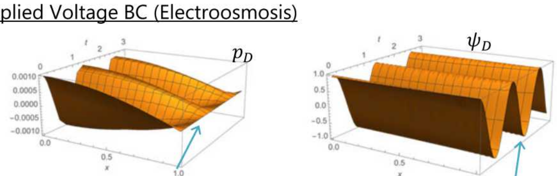
Applied Pressure BC (Streaming Potential)

$\alpha_D = 10$ $K_D = 0.01$ $p_D(x=1) = F_D\cos(\omega_D t_D)$



No-gradient BC ($x = 0$) $\psi_D(x=1) = 0$

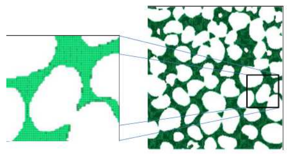
Applied Voltage BC (Electroosmosis)



$\psi_D(x=1) = 0$ $\psi_D(x=1) = F_D\cos(\omega_D t_D)$

Pore-Scale EK Modeling

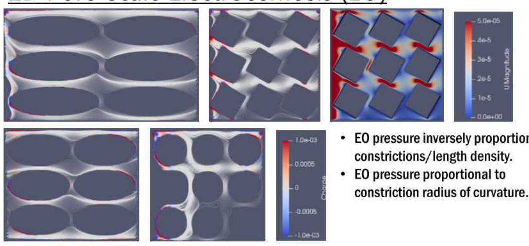
Pore-scale continuum electrokinetics modeling is being conducted at The University of Illinois through LDRD Academic Alliance (FY19-FY20).



OpenFOAM is being used to solve the transient coupled set of continuum equations governing pore-scale flow.

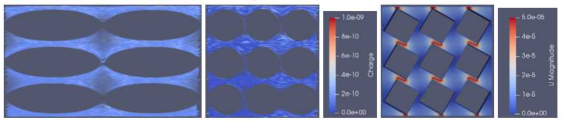
Charge Calculation: $\left(\rho_f = \sum_i q_i\left(C_i - C_i^{eq}\right)\right)$
Poisson (electrostatic): $\nabla^2\psi = -\frac{\rho_f}{\varepsilon}$)
Navier Stokes: $\rho\frac{\partial u}{\partial t} = -\nabla p + \mu\nabla^2 u - \rho_f\nabla\psi$)
Nernst Planck: $\frac{\partial c_i}{\partial t} = -\nabla.(c_i u) + \nabla.(D\nabla c_i) + \nabla.(\frac{z_i F D_i}{RT}\nabla\psi)$)

2D Pore-scale Electroosmosis (EO)



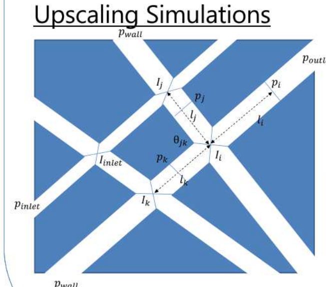
- EO pressure inversely proportional to constrictions/length density.
- EO pressure proportional to constriction radius of curvature.

2D Pore-scale Streaming Potential (SP)



- SP proportional to constriction radius
- SP inversely proportional to constrictions per unit length

Upscaling Simulations



State at Intersection/pore $S(I_i)/S(p_i) = [\vec{E_i}(r), \vec{U_i}(r), p_i(r), \rho_i(r), \vec{r}_a, \vec{r}_b]$
$S(p_{inlet}) = known$
$S(p_{outlet}), S(p_{wall}) = special\ cases\ of\ instance\ (2) below$
$S(I_{inlet}) = special\ case\ of\ instance\ (1) below$

r_a r_b $r = (\vec{r}_a, \vec{r}_b)$

1. $S(I_i) = f(S(p_j), S(p_k), l_j, l_k, \theta_{jk}, \rho_{surf}, C_{NaCl})$
2. $S(p_i) = f(S(I_i), l_i, \theta_{jk}, \rho_{surf}, C_{NaCl})$

Fit Artificial Neural Network

Exceptional service in the national interest

Built on LDRD Laboratory Directed Research and Development