Surface permeability and capillary transport

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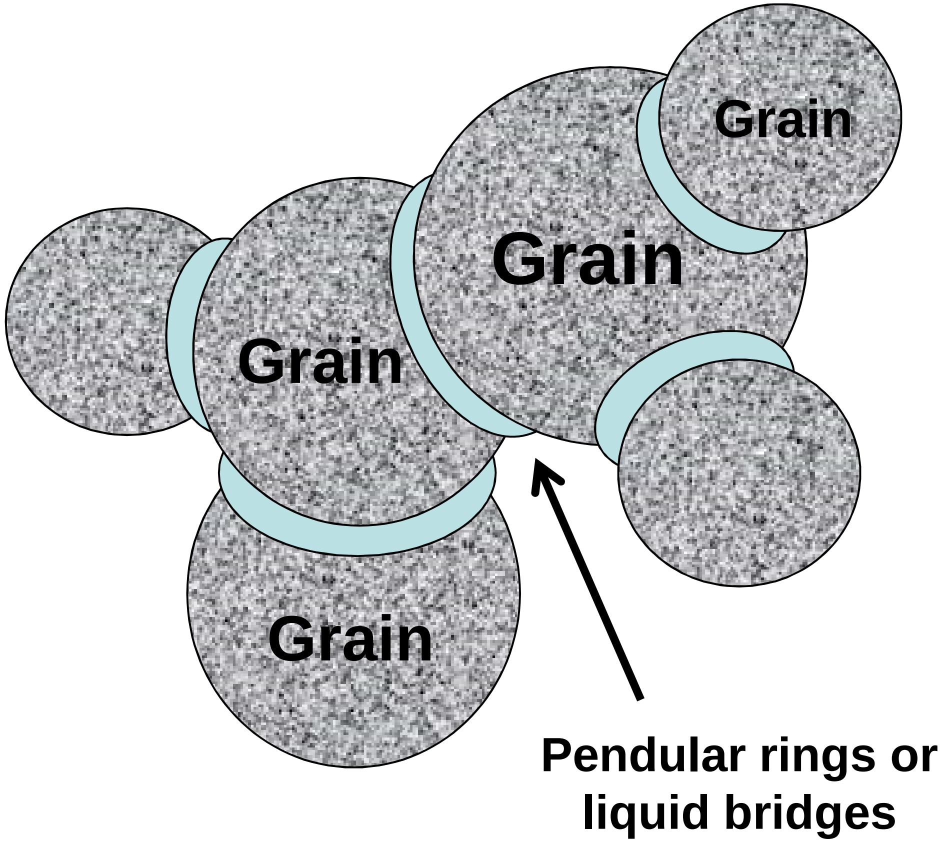
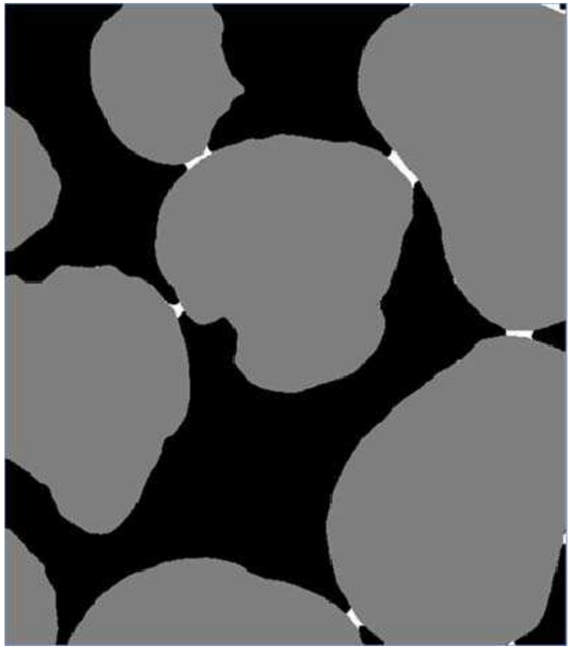
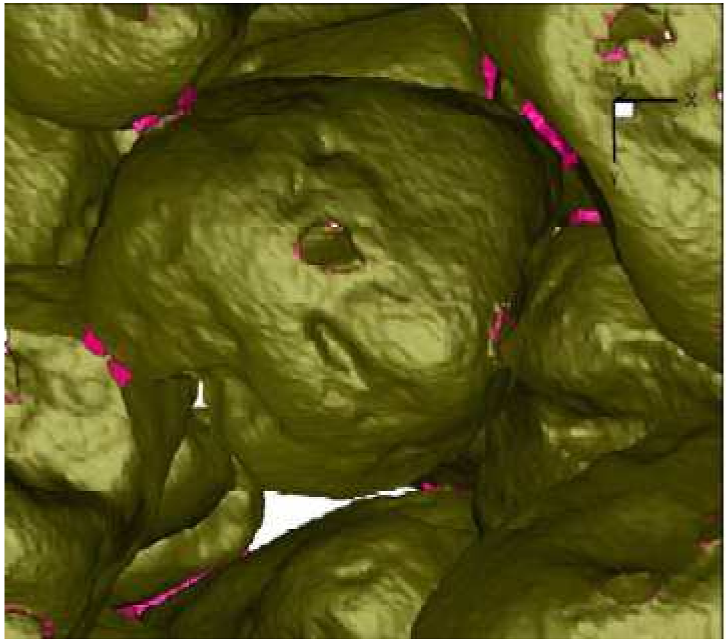
Pendular regime of liquid distribution in particulate porous media.
Saturation levels: min(s)<s<10%



Liquid distribution in sand in the pendular regime as it is seen by Micro X-ray Computer Tomography and by a Level-Set 3D reconstruction.



MicroXCT image of sand
at 3% saturation by TBP



A 3D level-set reconstruction
of the MicroXCT image (at left)

Mathematical model of liquid redistribution at very low levels of saturation – nonlinear superfast diffusion with a moving front

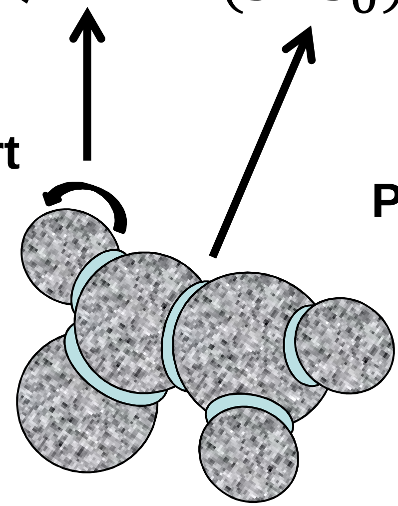
Macroscopic description

$$\frac{\partial s}{\partial t} = \nabla \cdot \left(D(s)\, \frac{\nabla s}{(s - s_0)^{3/2}} \right);$$

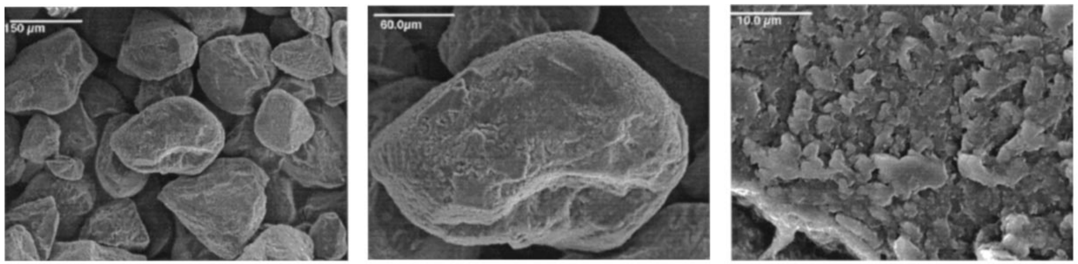
s – saturation

$s_0 = \min(s)$

$s > s_0$



Structure and properties of sand particles used in experiments and comparison with the model

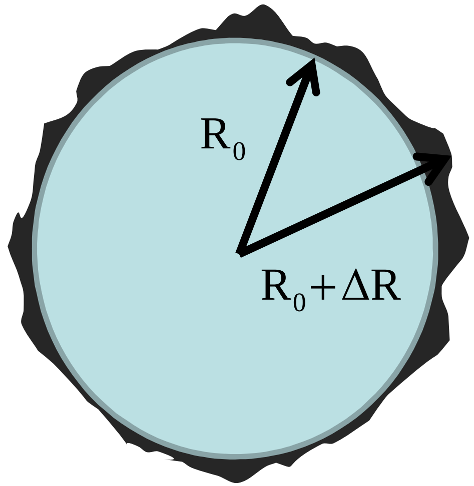


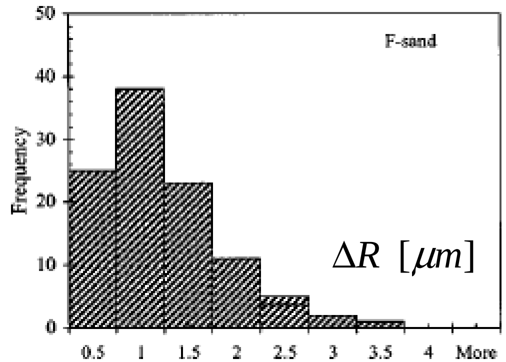
(a) F sand

Scanning electron microscopy images of standard Ottawa (Illinois) F sand

Source: Alshibli, K.A., Alsaleh, M.I., (2004) *J. Comput. Civil Eng.* 18 36-45.

$$\boldsymbol{R_0 \approx 250\mu m, \qquad 0.25 < \Delta R < 3\mu m}$$

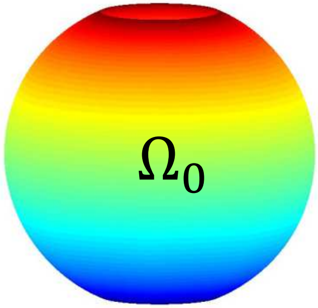


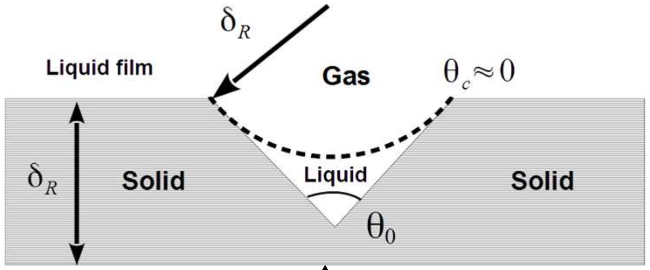


Distribution of roughness

Surface transport, permeability and the Laplace-Beltrami problem

$$\partial\Omega_2 \; p = p_2$$





Surface roughness groove

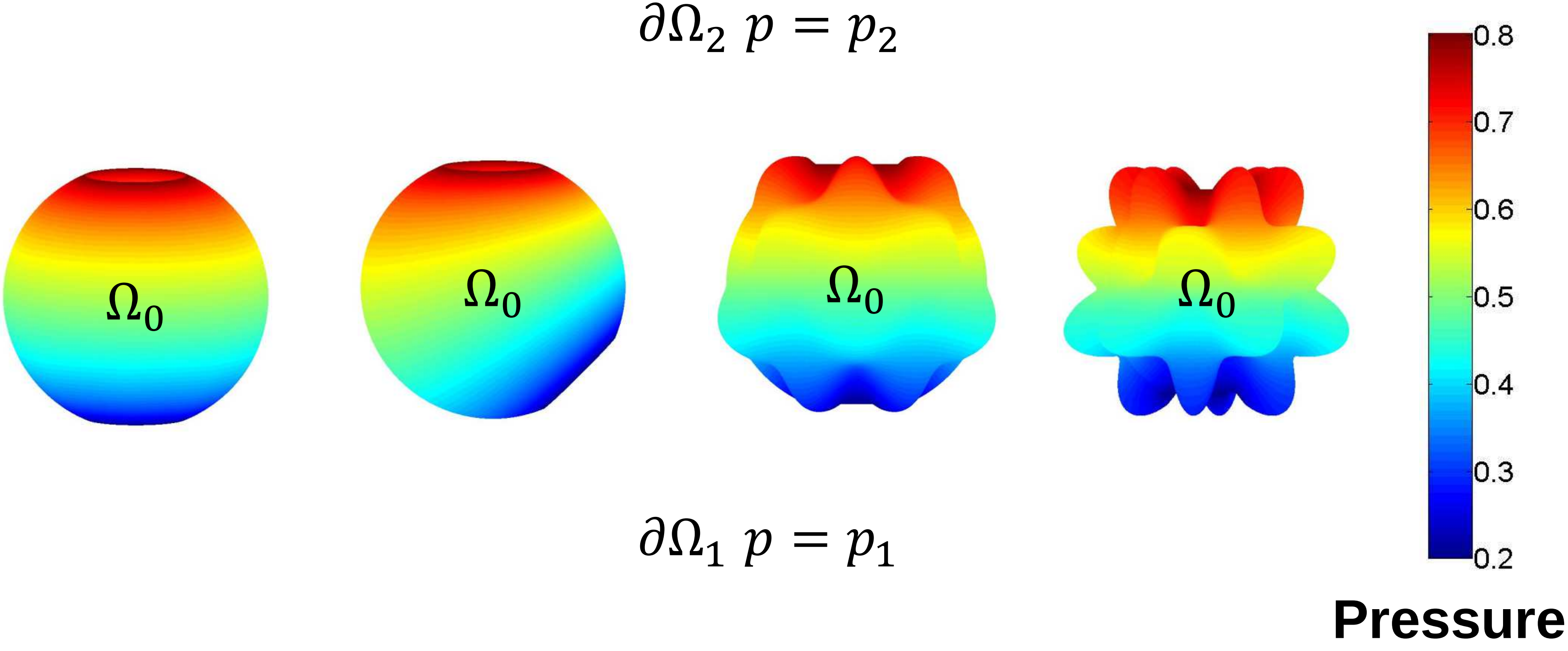
$$q = -\frac{\kappa}{\mu}\nabla p$$

$$\partial\Omega_1 \; p = p_1$$

Laplace-Beltrami problem

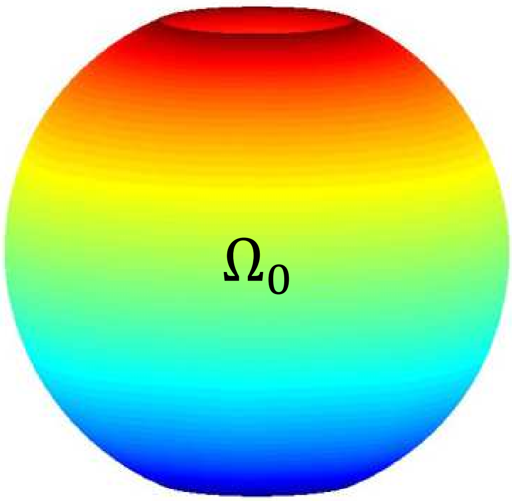
$$\Delta_{\Omega_0} p = 0$$

Laplace-Beltrami problems: boundaries and particle shapes



Laplace-Beltrami problem: azimuthally symmetric case

$$\partial\Omega_2 \; p = p_2$$

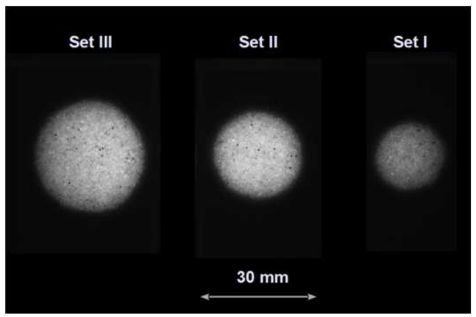


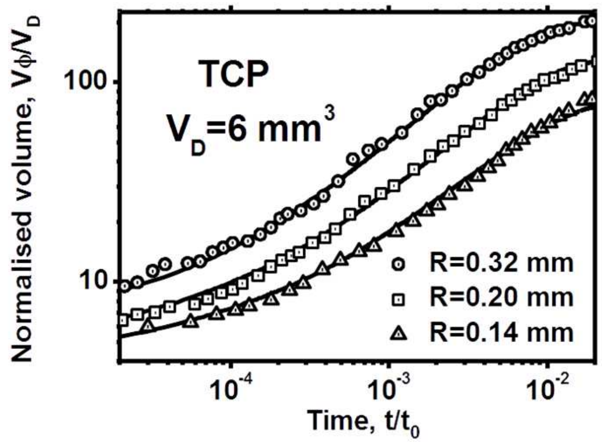
$$\partial\Omega_1 \; p = p_1$$

Permeability – diffusion coefficient

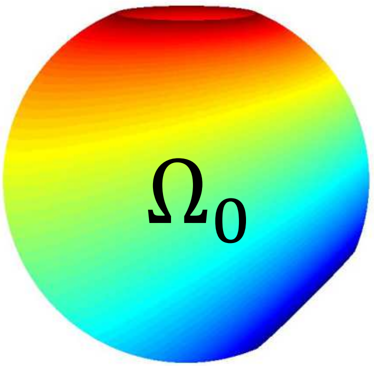
$$D(s) = \frac{1}{|\ln(s - s_0)|}$$

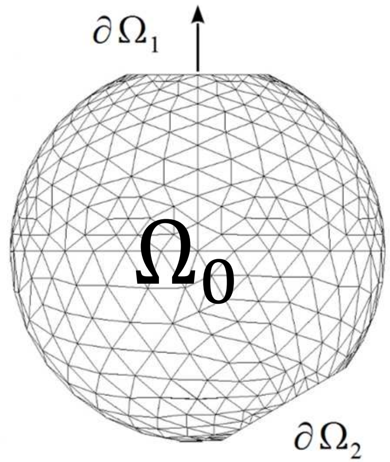
Comparison with experiments on drop dispersion in sands



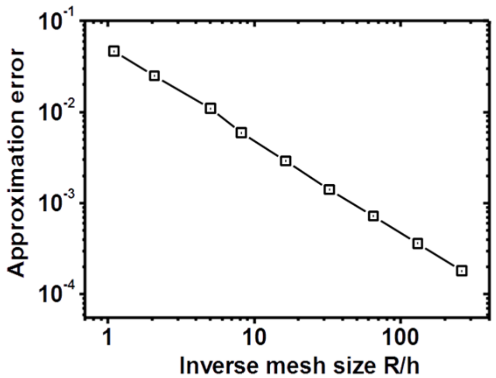


Laplace-Beltrami problem: boundary position

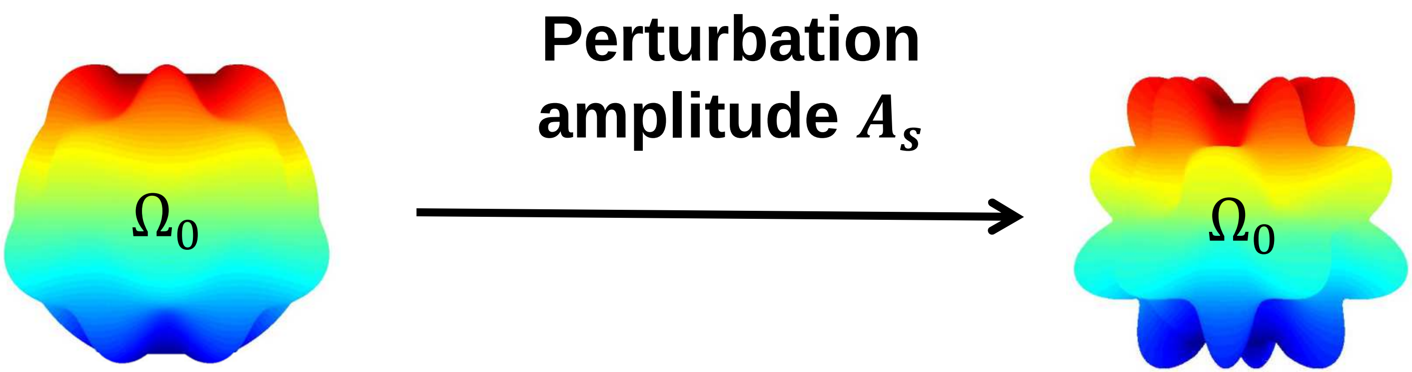


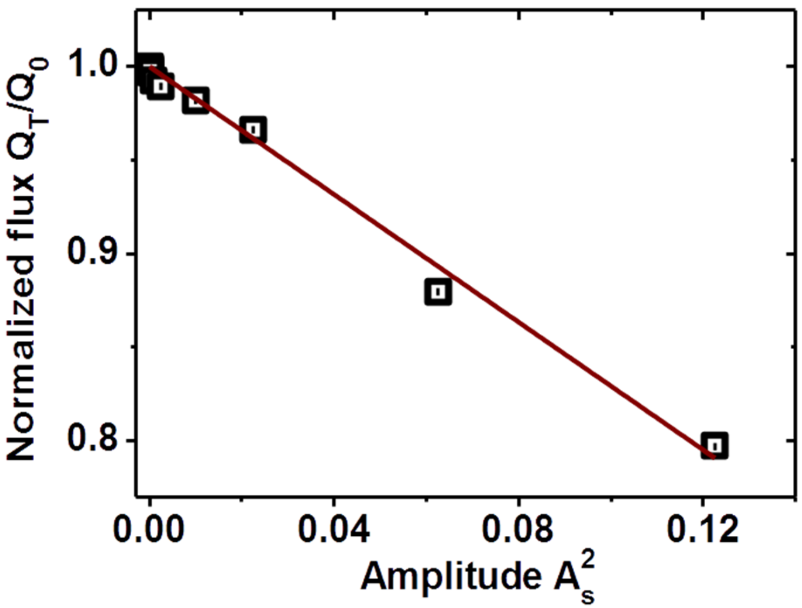


Surface finite element methods: error estimate



Laplace-Beltrami problem: particle shapes





Normalized flux

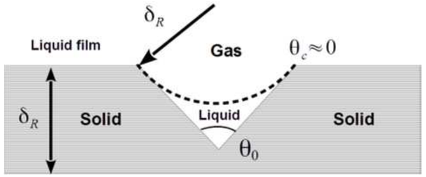
$$\frac{Q_T}{Q_0} = 1 - C_s {A_s}^2,\ C_s = 1.7$$

Pathways

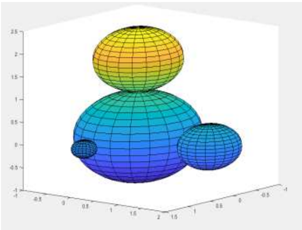
$$\mathrm{L} = 1 - C_s {A_s}^2,\ C_s = 3.5$$

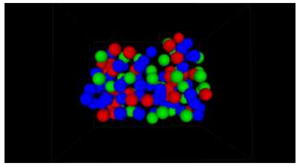
Applications and comments

1. Contribution of the shape may be less important than microscopic surface structure $\kappa \propto \delta_R{}^3$.

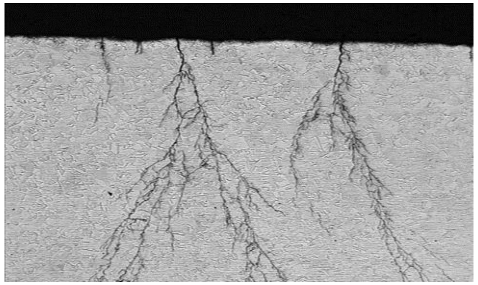


2. Multiparticulate domains, paper-like materials. Some experiments are planned in relation to lateral flow test pads.





3. Cracked surfaces, cleaning



Conclusions

- Surface finite element technique can be used to analyse surface permeability of complex particulate domains

- The method can be generalized to fractured surfaces

- In fact, simple pathways estimate can provide an upper limit of the permeability