Porosity-Permeability Relations in Granular, Fibrous and Tubular Geometries

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Outline

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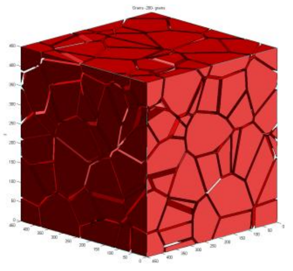
- Stochastic porous media geometry models
- Lattice Boltzmann method
- Permeability of tubular and granular geometries
- Permeability and drag force of fibrous geometries
- Summary

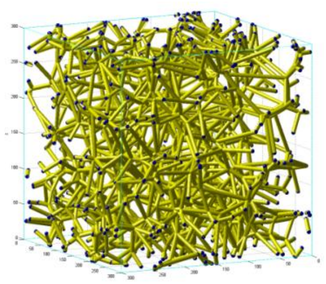
Motivations

- Porosity-permeability relations for idealized geometries are important guide to understand the porosity-permeability relations of real porous media
- Porosity-permeability relation in porous media with spherical particles is well-understood (Camen-Kozeny equation[1])

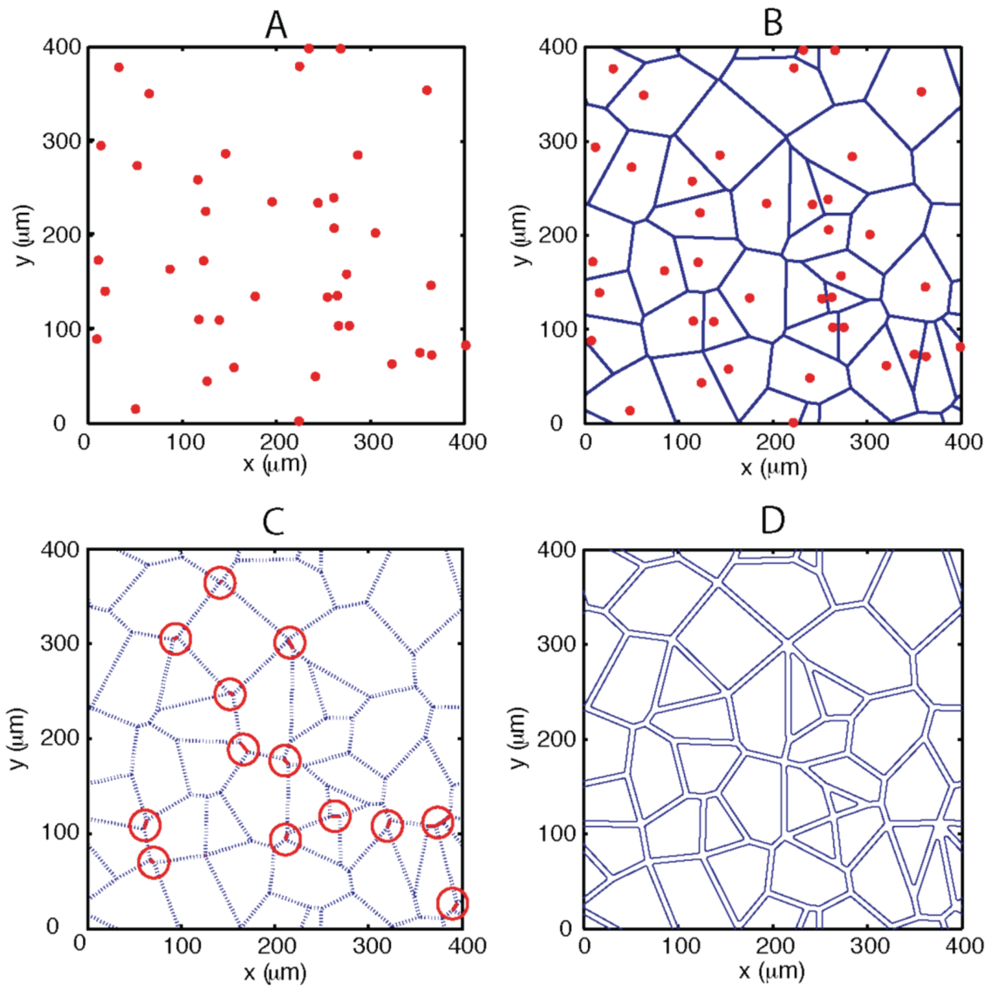
$$k = \frac{\varepsilon d^2}{180(1-\varepsilon)^2} \qquad d\text{ – diameter; } \varepsilon \text{ – porosity}$$

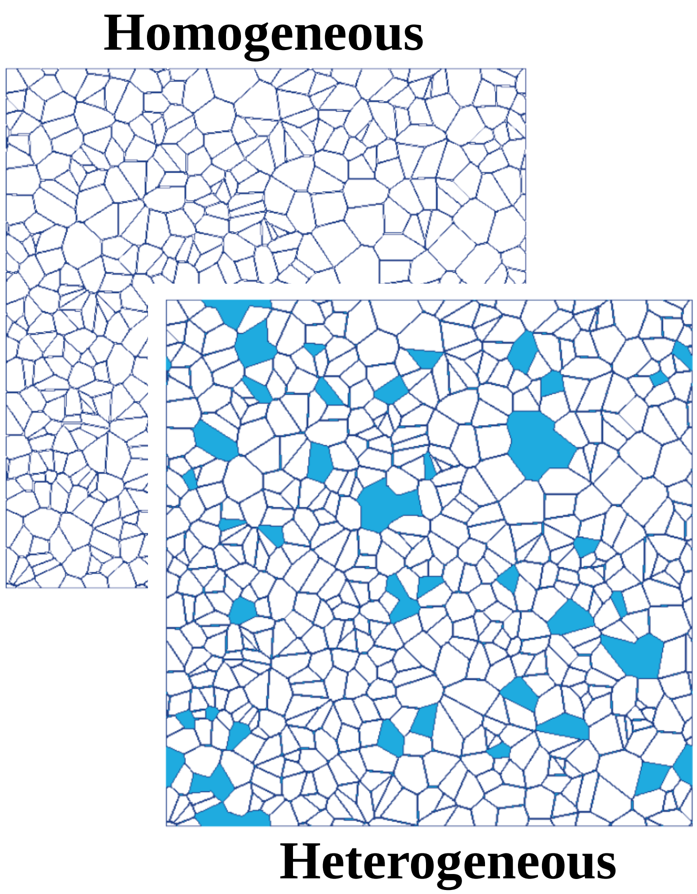
- Geometries with angular grains (henceforthly mentioned as "granular"), tubular and fibrous porous media requires more understanding
- Voronoi diagram will be used to create idealized granular, tubular and fibrous geometry models, and porosity-permeability data will be presented





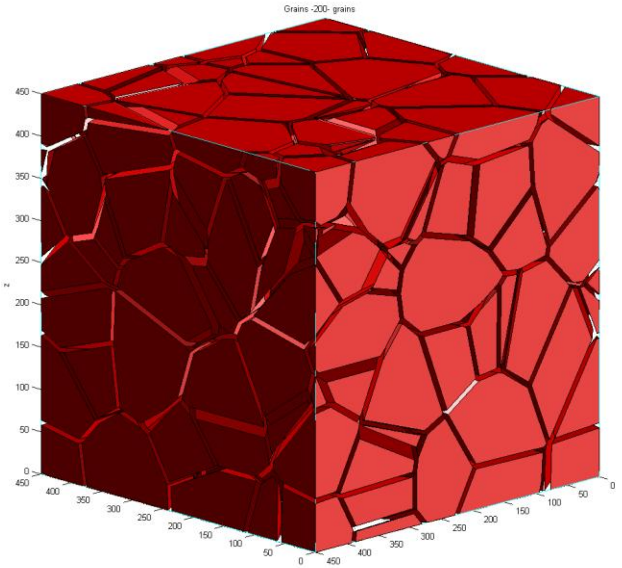
Stochastic porous media geometries

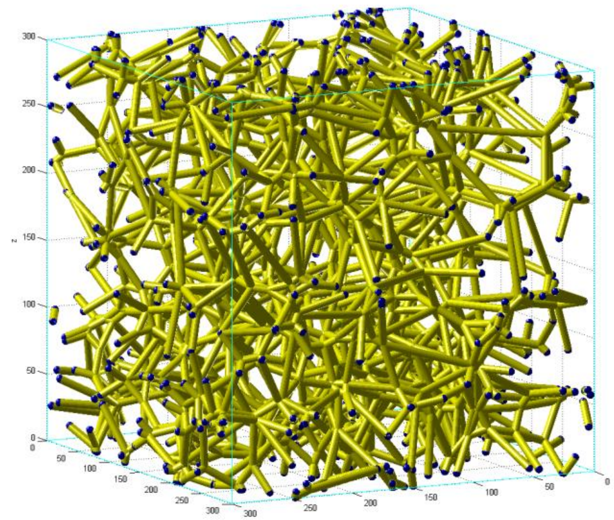




Stochastic porous media geometries

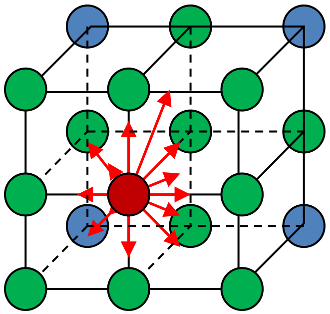
- Angular grains – “Granular”
- Tubular/Fibrous

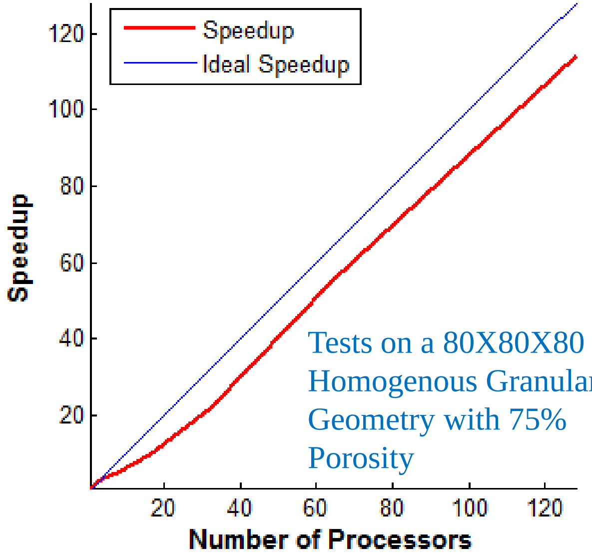




Lattice Boltzmann method

- Propagation model
  - D3Q19: 3 dimensional, 19 velocities
- Collision model
  - MRT – Multi-Relaxation Time for both shear and bulk viscosities, improved accuracy and stability
- Boundary condition
  - Bounce back on solid walls
- Parallel computing simulator
  - Nearly ideal speedup up to 128 processes
  - Largest system simulated contains ~1.3 billion voxels (fluid and solid)
- Simulation input parameters
  - Body force density   0.0001, 0, 0
  - Tau (Shear)   1
  - Tau_v (Bulk)   1

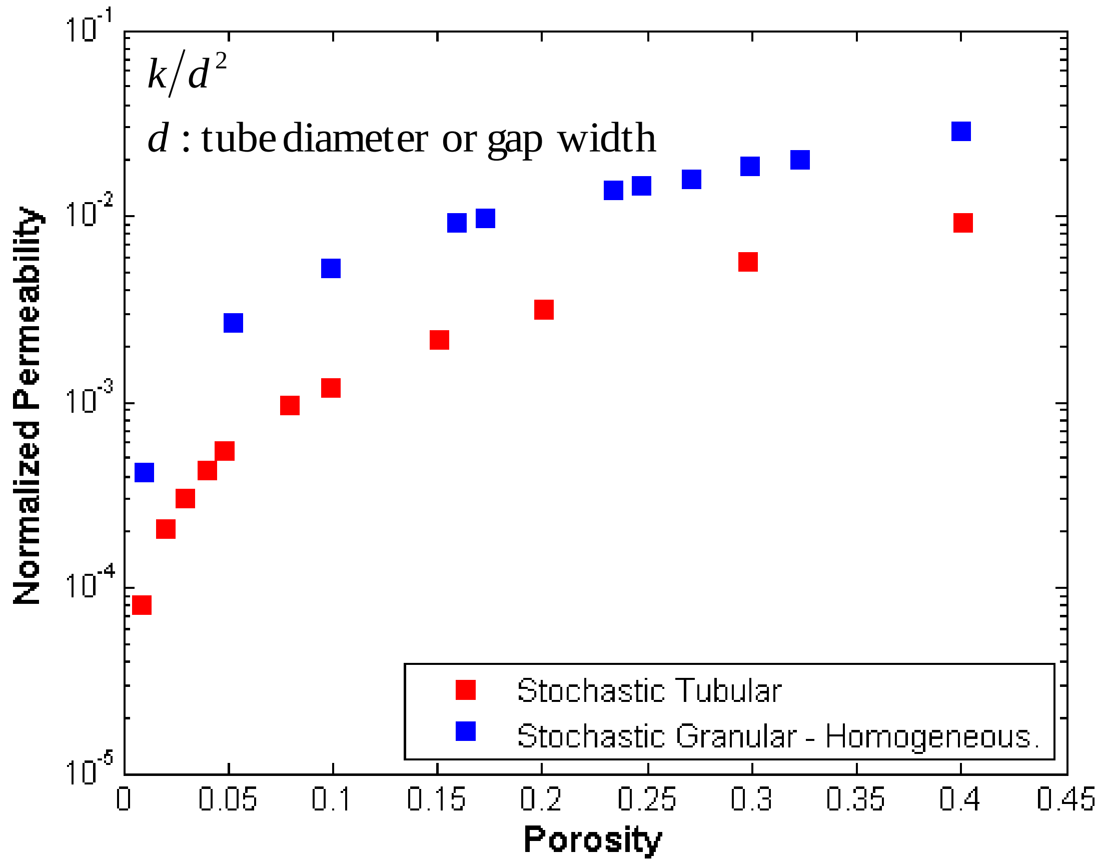




Tests on a 80X80X80 Homogenous Granular Geometry with 75% Porosity

Permeability of granular and tubular geometries

- Porosity-permeability relations established using the “obvious” length scales (gap and tube size) are qualitatively similar
- Granular (fractured) geometries have higher normalized permeabilities



Permeability of granular and tubular geometries

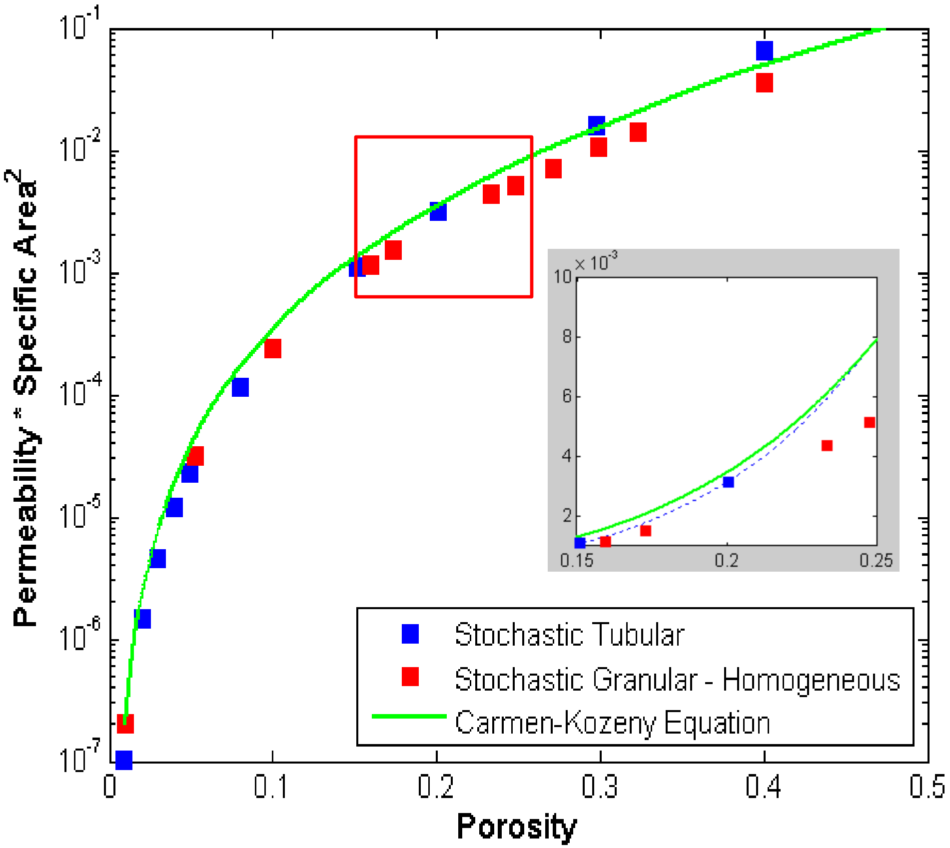
- Carman-Kozeny equation uses (specific surface area)$^{-1}$ as the length scale

$$s = \frac{\text{surface area}}{\text{solid volume}}$$

- When specific surface area is used, granular an tubular data are close

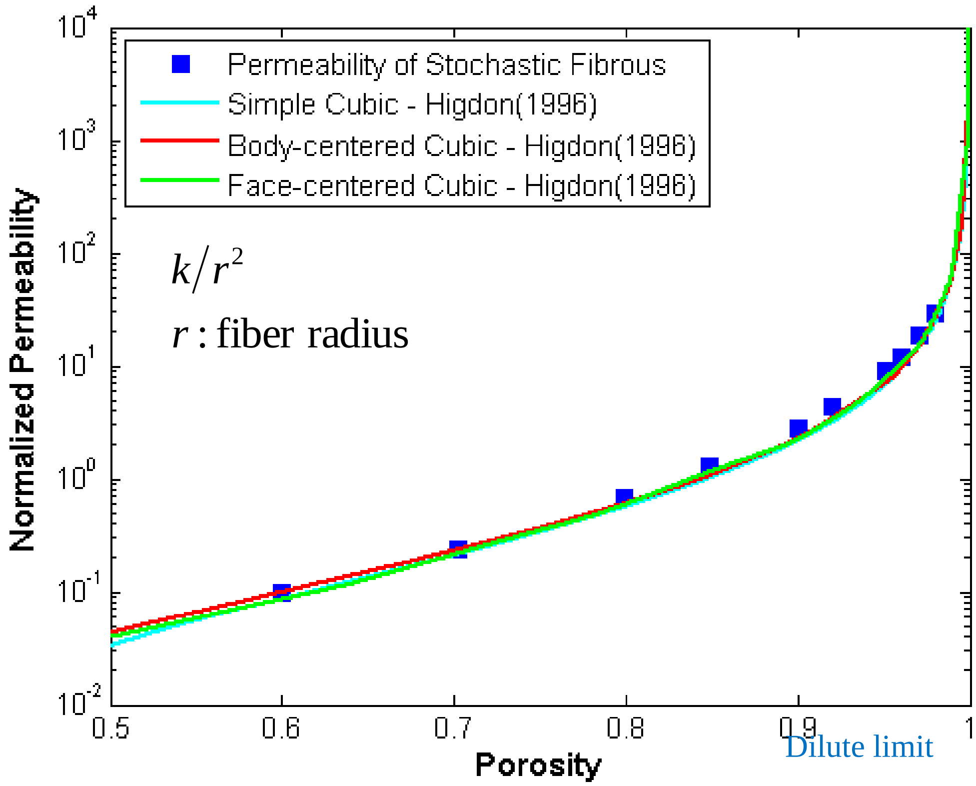
$$ks^2 = \frac{C\varepsilon^3}{(1-\varepsilon)^2} \qquad \text{C = 2.5 for tubes}$$

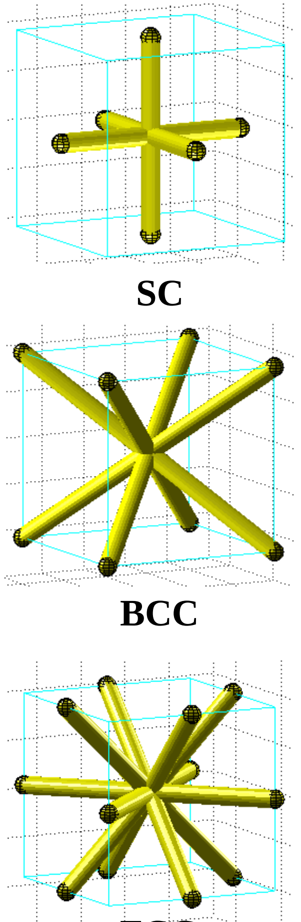
- When ε > 0.15, normalized tubular permeability is higher than normalized granular permeability
- When ε < 0.15, the difference is very small



Permeability of fibrous geometries

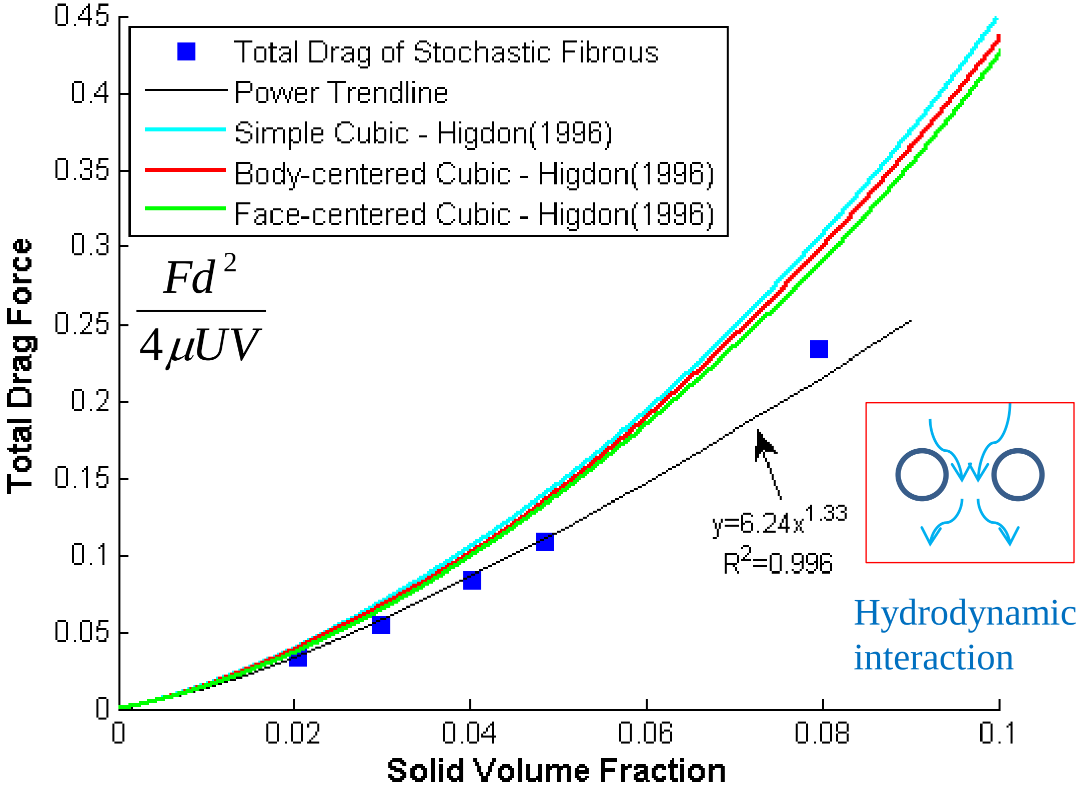
- The permeability rapidly increases and approaches infinity in the dilute limit
- Simulation agrees with Higdon's numerical data on idealized fiber conformations (1996)





Permeability of fibrous geometries: total drag

- Hydrodynamic interaction in the fibrous geometry is indicated by a power index of 1.33
- Greater deviation from Higdon (1996) at higher solid volume fraction is due to the difference in the structure: **lower coordination number in our geometry models than in SC/BCC/FCC**



Hydrodynamic interaction

Drag force per unit length of fibers

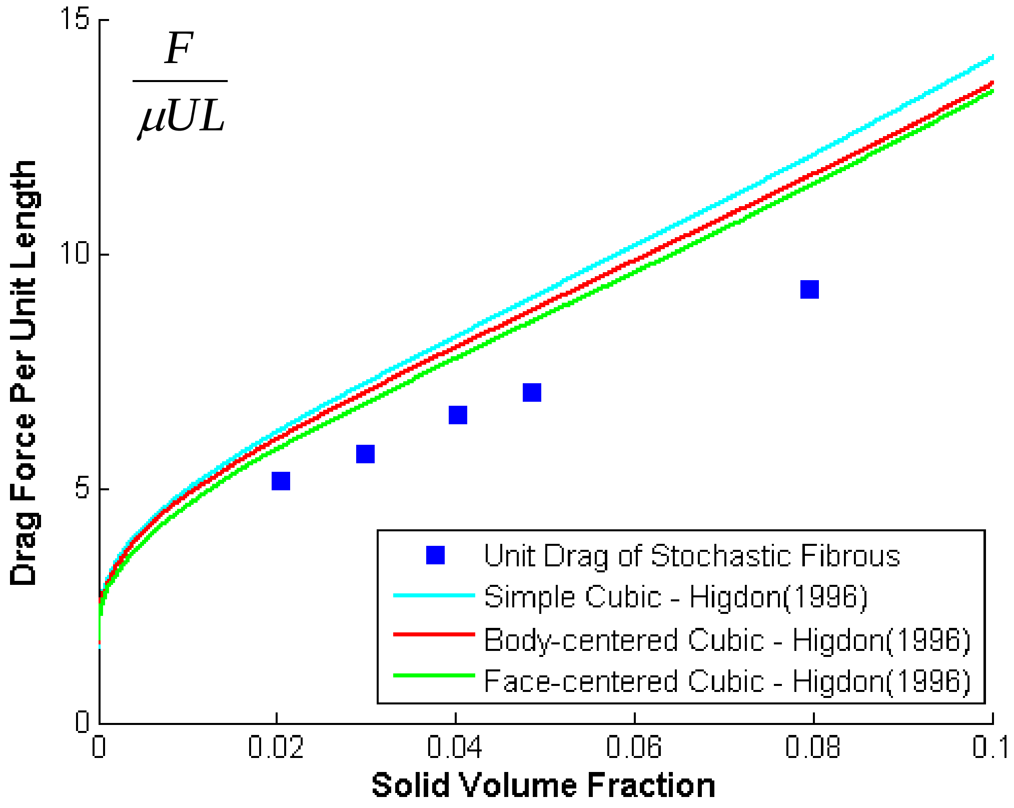
- Effective fiber length

  $L = 4V_s / \pi d^2$

- Hydrodynamic interaction is still significant in the dilute limit

- Higdon's data show rapid decrease in the drag force per unit length in the dilute limit, consistent with theories

- We plan to run more simulations in the dilute limit to study the scaling of the drag force



Summary

- Permeability normalized using specific surface area are close between granular and tubular geometries
- At high porosity (>0.15), tubular geometry is more permeable than homogeneous granular geometry
- Fibrous geometry simulation results shows a rapid increase of permeability in the dilute limit
- The effect of hydrodynamic interaction in our geometry model is weaker than in SC/BCC/FCC models (Higdon, 1996)

Acknowledgement

- RPSEA
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