Agglomeration and Granulation Processes

Scale-Bridging Models for Transfer of Liquid in Dense Particle Beds

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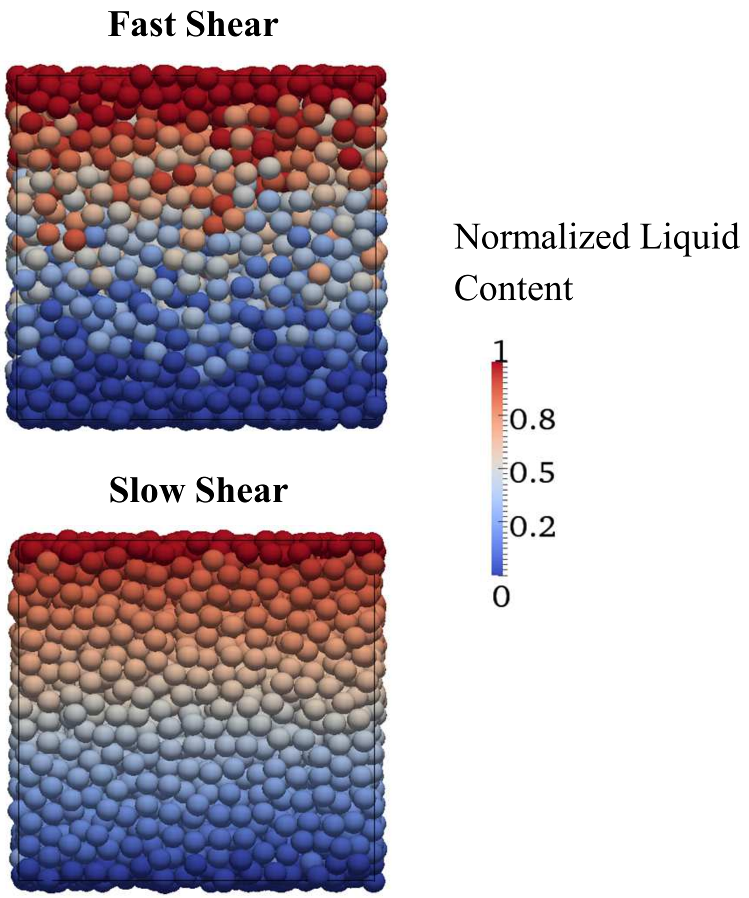
Talk : 303g

Atlanta

(14+4 mins)

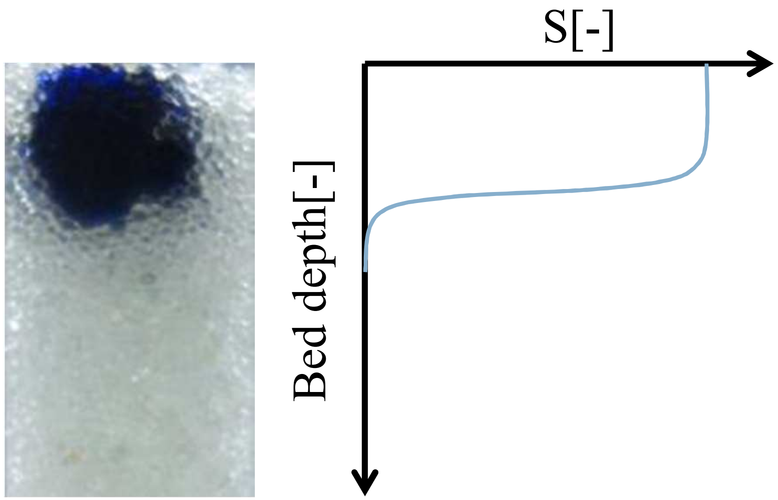


Key Question

What is the effect of

- **non-uniform wetting,**
- **surface roughness at**
- **high saturation levels**

on liquid transfer between particles?



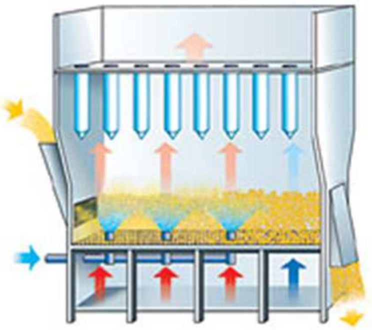
Liquid imbibition in a static dense particle bed.

Introduction

- Prediction of wet granular flow difficult → unknown rate of exchange during particle-particle collisions.

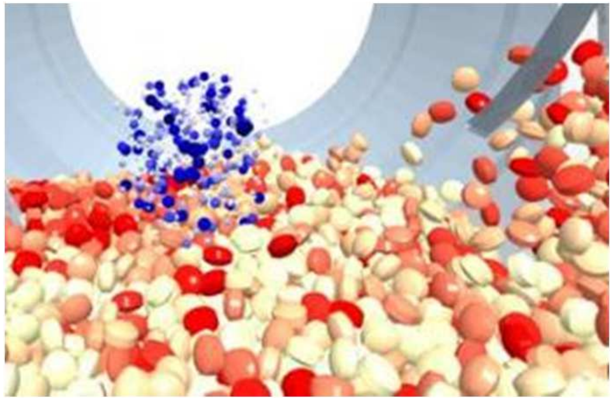
- More rigorous model would help to predict the distribution of liquid between particles more reliably in
  - **granulation,**
  - **mixing,**
  - **drying or coating**

  applications



[1]

- Focus of this work: **model for predicting wet collisions of rough particles** with partial surface coverage.



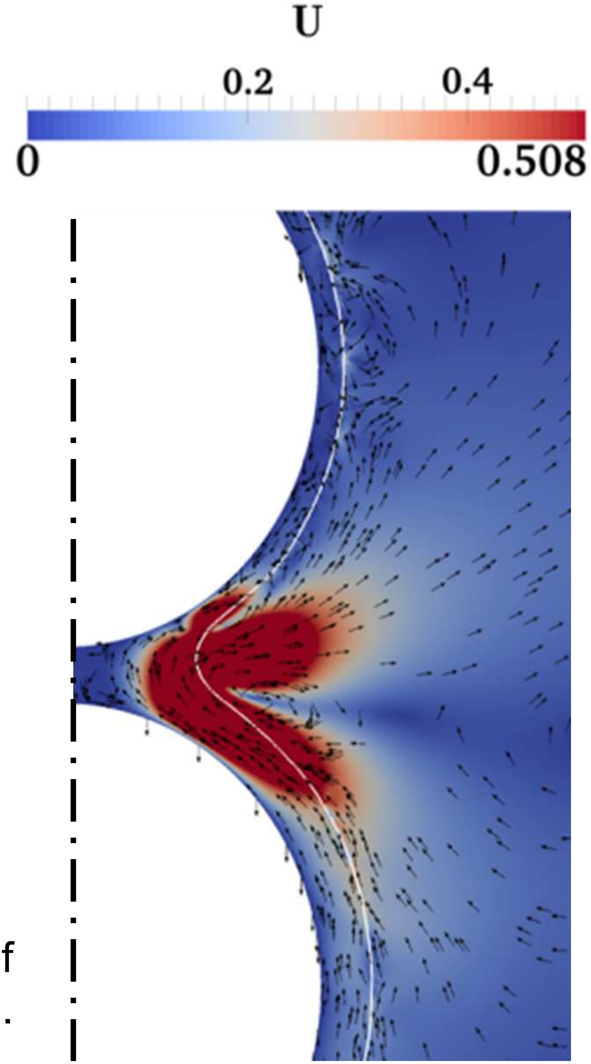
[2]

[1] Glatt Fluid bed granulator © www.glatt.com

[2] Toschkoff et al. *Chem.Eng.Sci* (2013)

Outline

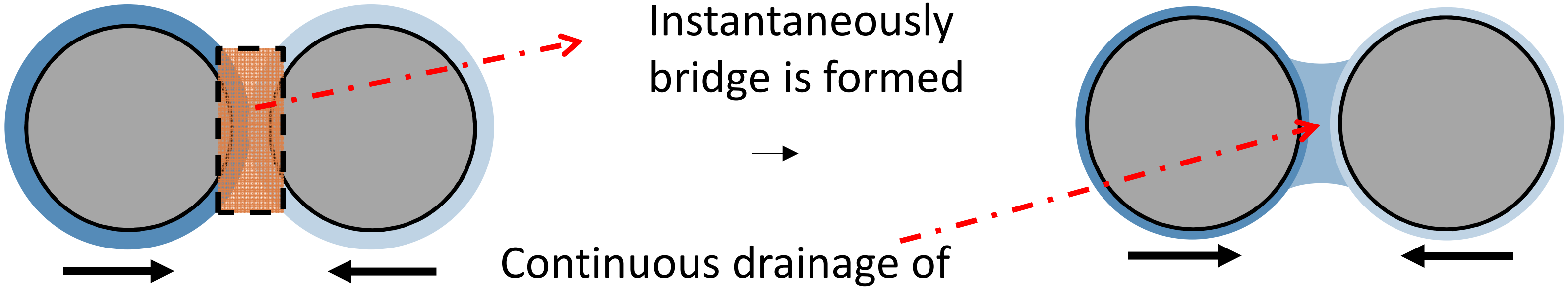
- **Proposed models**
- **Results for sheared particle beds**
- **Conclusions**



Flow field during the filling of
a single liquid bridge.

Proposed Models

Model Details: Formation of a Liquid Bridge



Instantaneously bridge is formed

Continuous drainage of liquid into the bridge

Model B2 (Standard)

Explicit calculation of bridge volume[3]

Instantaneous transfer of liquid into the bridge, no backflow possible

Model C (New)

Drainage of liquid from the film into the bridge based on t_{ref}

$$t_{ref} = r_{eff} \cdot \frac{\mu_l}{\sigma_l}$$

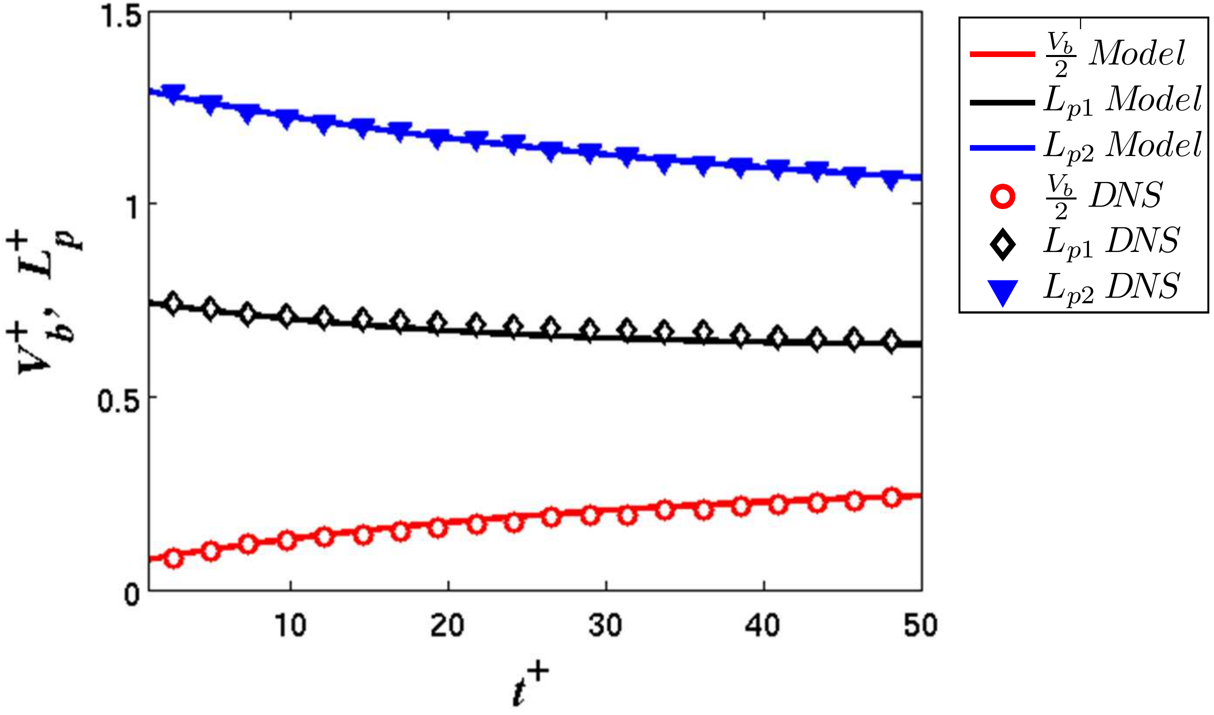
Backflow of liquid from the bridge to liquid film is possible

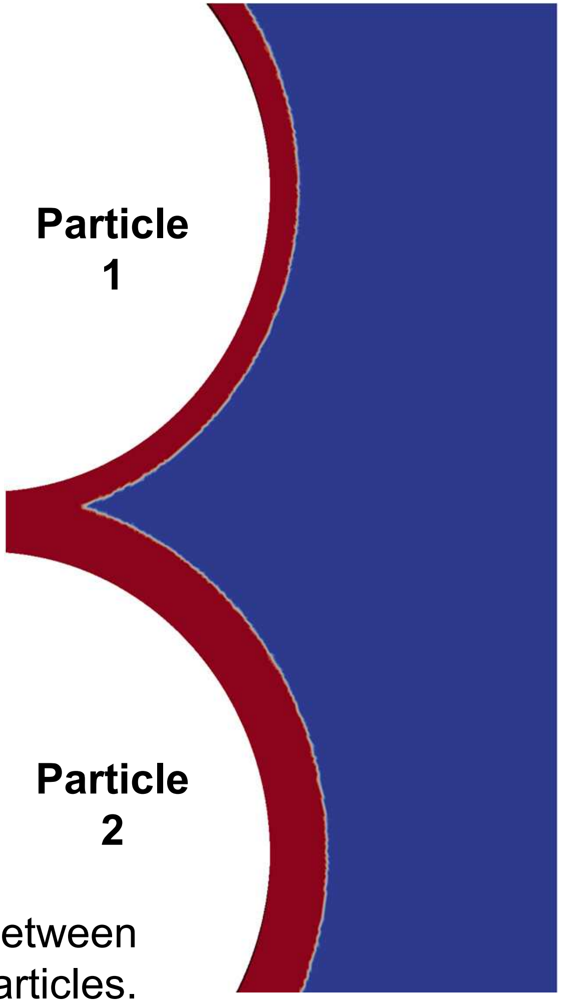
[3] Mohan et al, *Powder Technology*. (2014)

Proposed Models

Model Details: Formation of a Liquid Bridge

$$\varepsilon_1 = 0.1, \varepsilon_2 = 0.06, S_c^* = 0.045$$





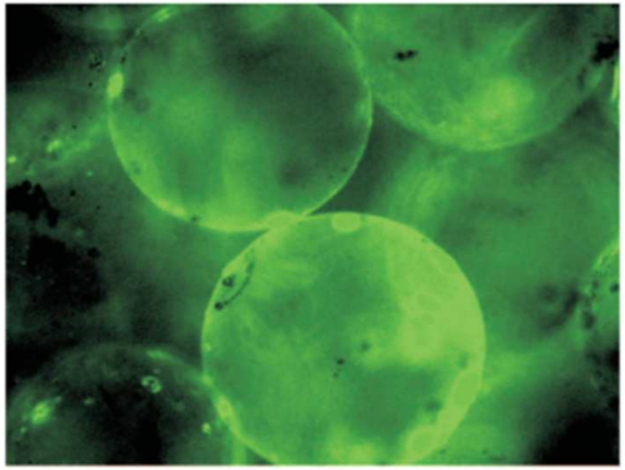
Filling of a single liquid bridge between unequally coated smooth particles.

Works well for smooth particles!

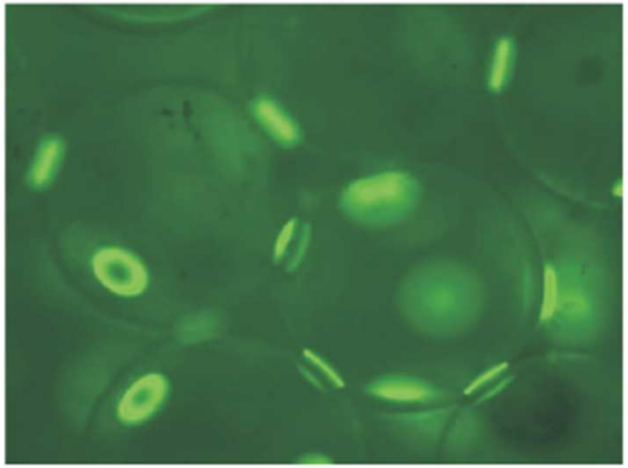
Proposed Models

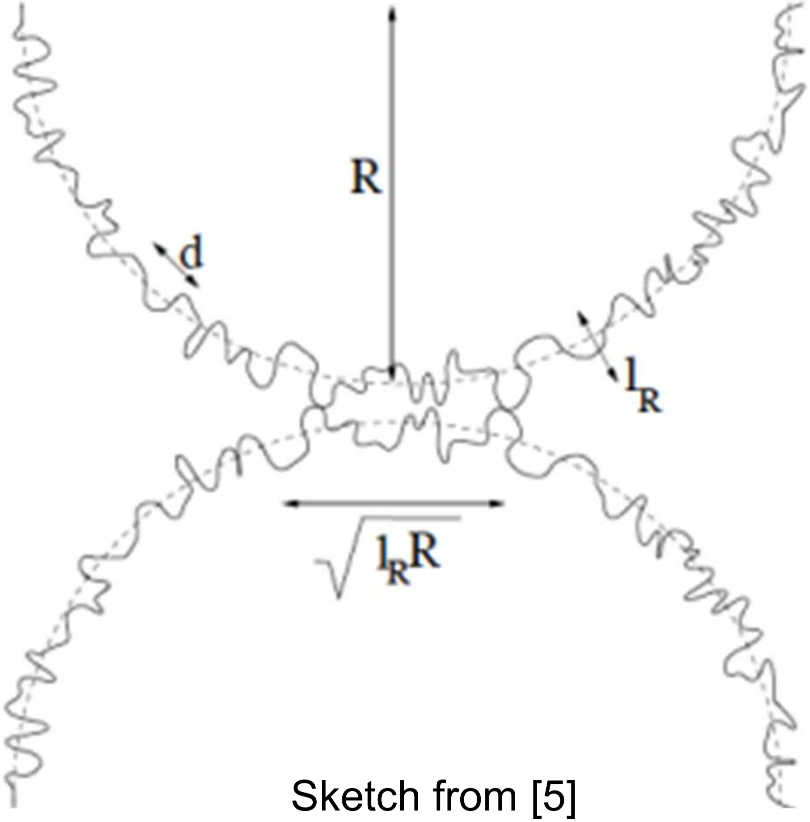
Sub-Model 1: Roughness

$$V_{rough} = d_p^2 \pi l_R$$



[4]





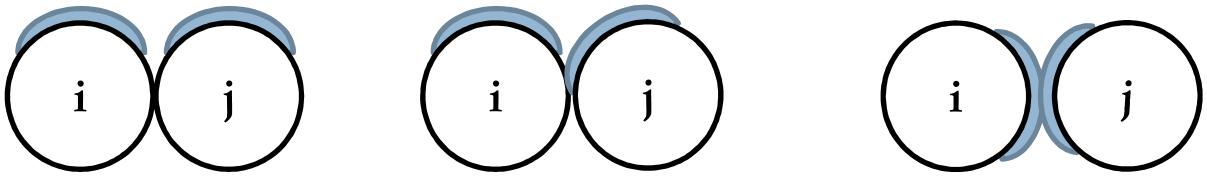
Sketch from [5]

[4] Herminghaus., *Advances in Physics* (2005)

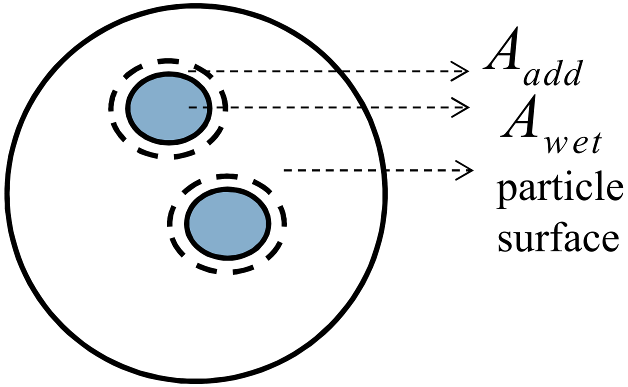
[5] Hasley and Levine, *Phy.Rev.Letters* (1998)

Proposed Models

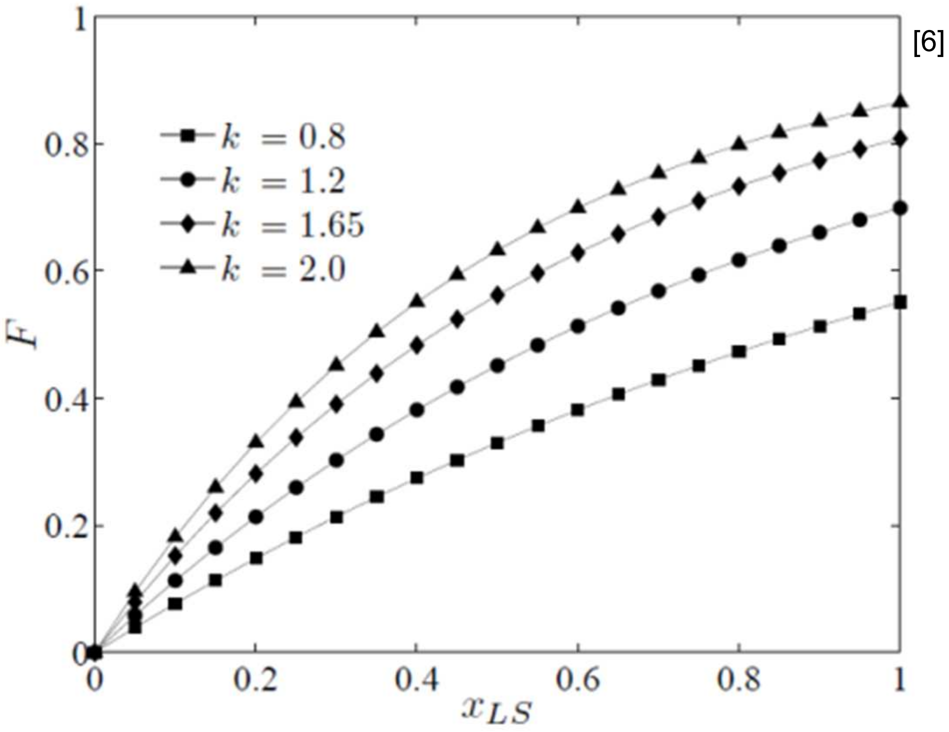
Sub-Model 2: Surface Coverage



Dry collision | Dry-Wet collision | Wet-Wet collision



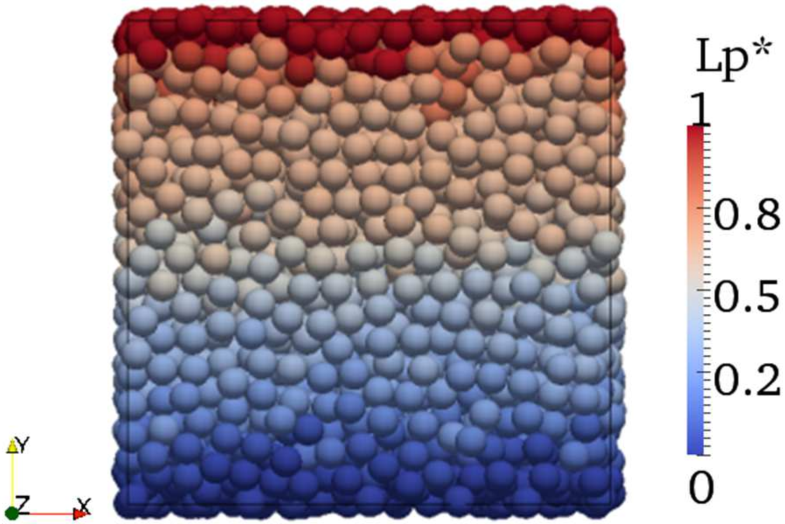
$$P_{eff} = \frac{\sum A_{wet} + \sum A_{add}}{\sum A_{part}} = F\left(1 + \frac{\sum A_{add}}{\sum A_{wet}}\right)$$



[6] Stepanek et al., *Langmuir* (2006)

Sheared Particle Beds

Simulation Setup



$$\mathbf{q}^{cond} = \frac{1}{V}\sum_{c} Q \cdot \mathbf{r}_{ij}$$

$$q_s = -\gamma \cdot \nabla_y L_{p,i} / d_p$$

- **Periodic box** (*$H/d_p=15$*). [7]
- Stiffness based on dimensionless shear rate
- Volume of liquid on the particle based on dimensionless liquid film thickness.
- Particles near the **top boundary are wet ($L_p^* = 1$)** and near the **bottom boundary are dry ($L_p^* = 0$)**.
- Conductive liquid flux (q_y^{cond}) made dimensionless using q_s

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[7] Lees and Edwards, *Journal of Physics C: Solid State Physics* (1972)

Sheared Particle Beds

$$\gamma^* = \gamma d_p^{3/2} / \sqrt{k_n / \rho_p}$$

Dimensionless shear rate
Range[8] : **10^{-4} to 1**

Based on dimensional analysis of main influencing parameters, we get three dimensionless numbers[3]

$$L^*_{rough} = l_R / d_p$$

Dimensionless roughness length
Range : **10^{-3} to 0.2**

$$\Gamma = t_{ref}/t_{shear} = \gamma \cdot r_{eff} \cdot \mu_l/\sigma_l$$

Range : **10^{-3} to 1**

$$\varepsilon = h_o/r_{eff}$$

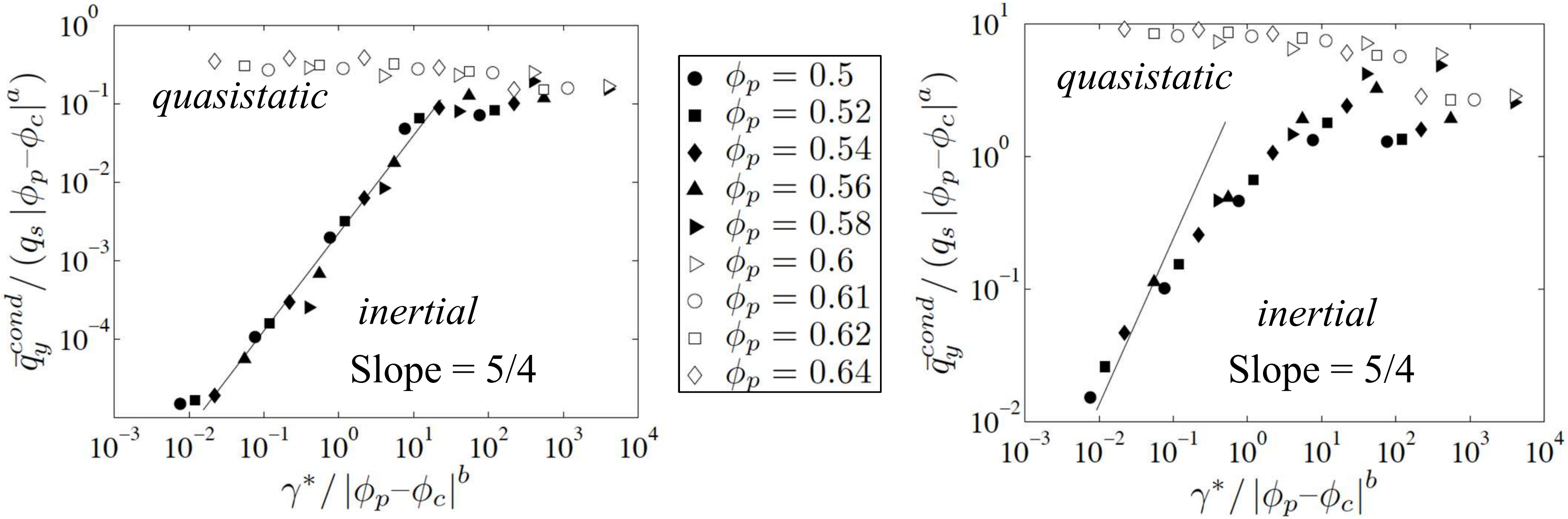
Dimensionless liquid film thickness

[3] Mohan et al, *Powder Technology*. (2014)
[8] Chialvo et al, *Phy Rev E*. (2012)

Sheared Particle Beds

Summary of Scaled Conductive Liquid Flux vs Dimensionless Scaled Shear Rate (Smooth Particles)

$\Gamma = 1$ $\varepsilon = 2.6 \cdot 10^{-6}$ $\Gamma = 10^{-3}$



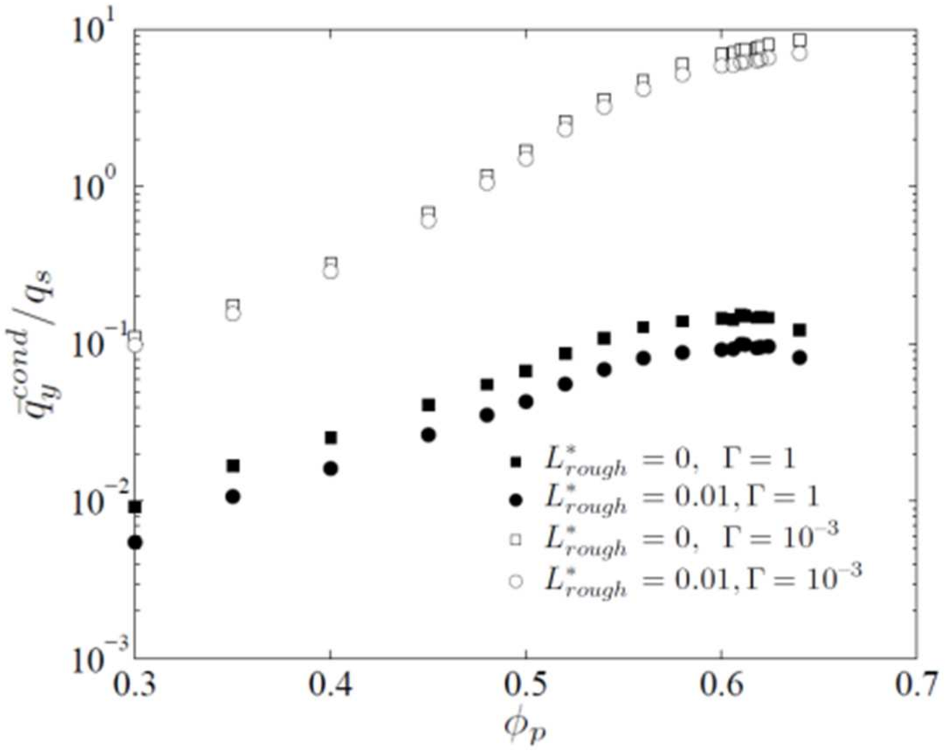
- Flow regimes determined by shear rate and volume fraction

[3] Mohan et al, *Powder Technology*. (2014)

Sheared Particle Beds

Sub-Model 1: Roughness

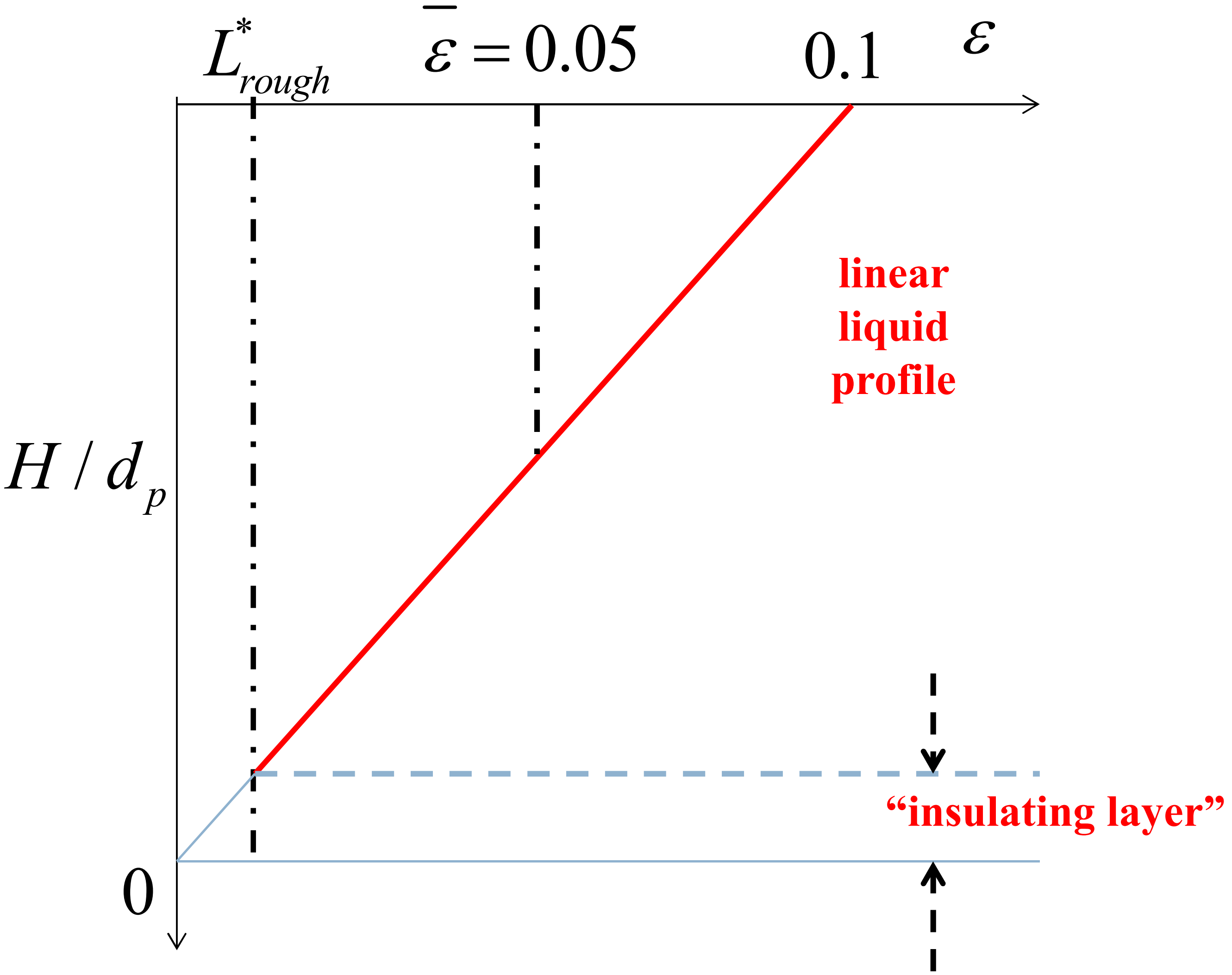
$$\varepsilon = 0.1, \gamma^* = 10^{-3}$$



- At high liquid film thickness the effect of roughness is small.

Sheared Particle Beds

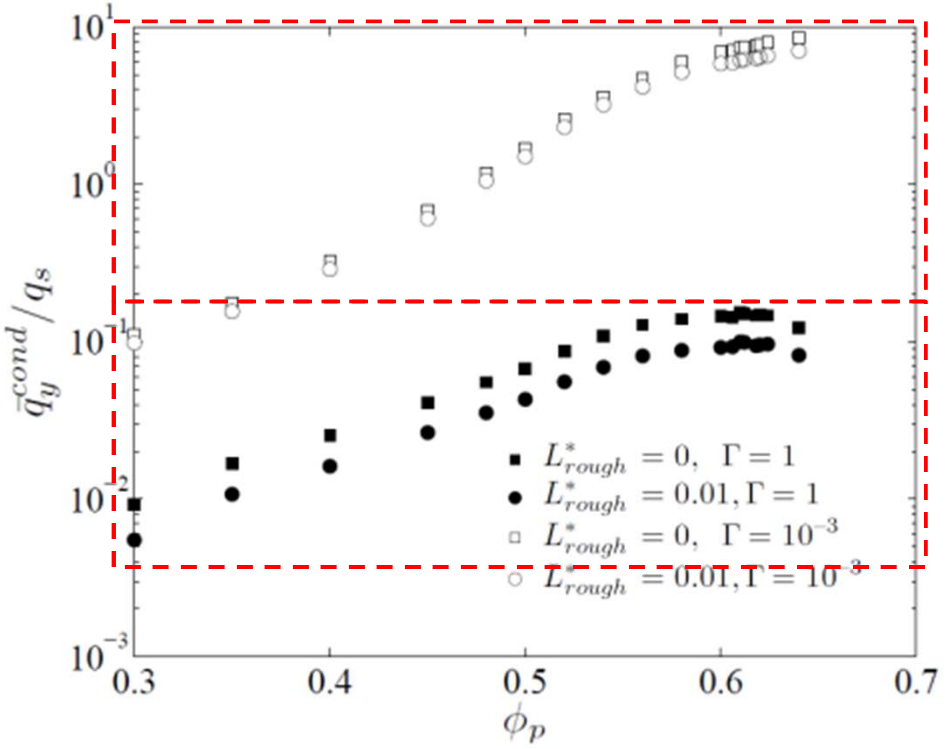
Sub-Model 1: Roughness



Sheared Particle Beds

Sub-Model 1: Roughness

$$\varepsilon = 0.1, \gamma^* = 10^{-3}$$



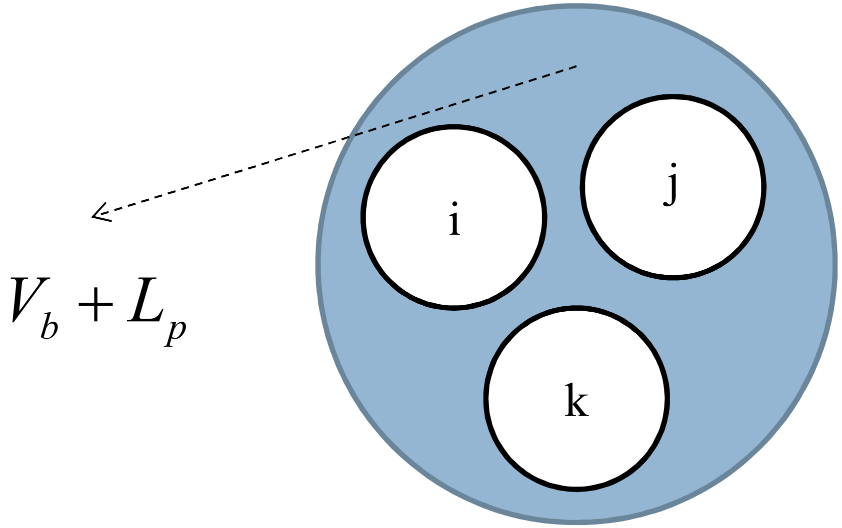
- Film thickness changes in the sheared particle bed
- In “insulating” layers, random particle motion becomes more important.

$$L^*_{rough} / \varepsilon = 0.1$$

Slow shearing	Fast shearing
$\Gamma = 10^{-3}$	$\Gamma = 1$
□ 10%	□ 25%

Proposed Models

Challenge: High Saturation Limiter



$$S = \frac{V_b + L_p}{V_p\left(\frac{1}{\phi_p} - 1\right)}$$

$$\text{Saturation}(S) = \frac{\text{Volume of liquid}}{\text{Volume of pores}} = \frac{V_b + L_p}{V_{pores}}$$

Conclusions

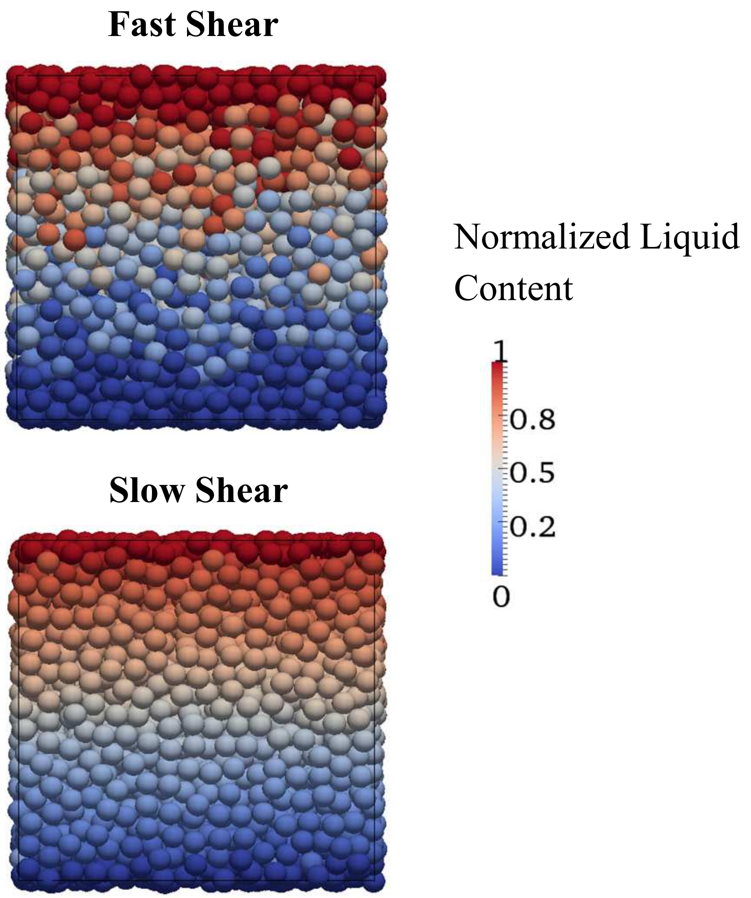
- **Filling rate based model for drainage of liquid into the bridge**, with explicit calculation of individual liquid bridge volumes, formation and rupture.

- Use **DNS data** to model and improve the existing models (smooth particles).

- Sub-models for effects due to **roughness** and **partial surface coverage**

- Future applications
    a) identification of the optimal liquid dispersion regime (**fast and uniform dispersion** at **low specific energy input**).
    b) simulation as design aid for **wet granulation processes**

Scale-Bridging Models for Transfer of Liquid in Dense Particle Beds



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