Agglomeration and Granulation processes

Transport Rates of Adhering Liquid Films in Sheared Particle Beds
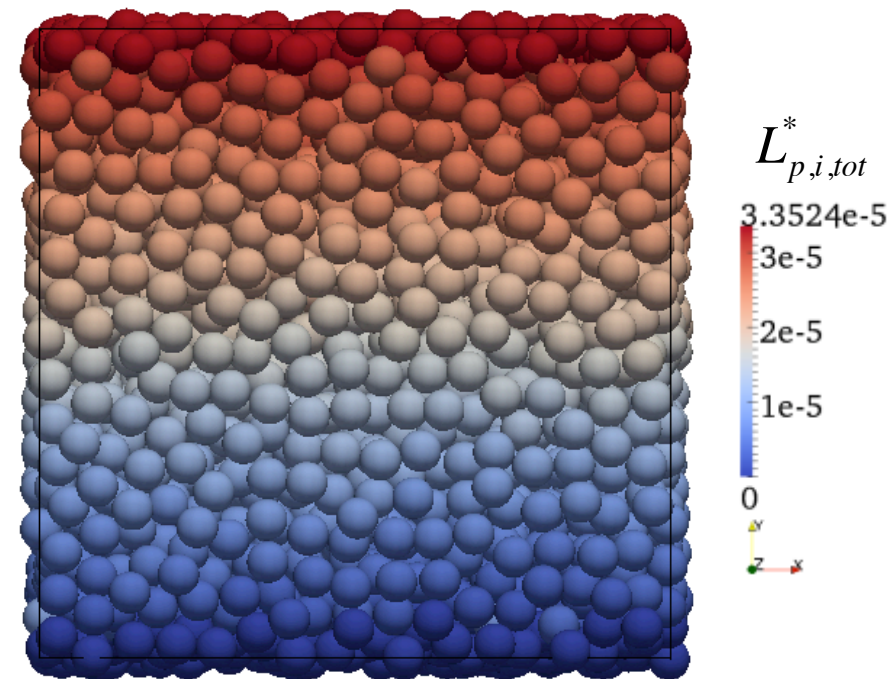
Bhageshvar Mohan, Johannes G.Khinast, Stefan Radl

November 5, 2013

Talk : 159c

San Francisco

(14+4 mins)

$$L^*_{p,i,tot}$$

3.3524e-5
3e-5
2e-5
1e-5
0

Outline

- **Introduction**

- **Proposed models**

- **Single particle-particle collision**

- **Sheared particle beds**

- **Perspective – Rotating drum**

- **Conclusions**

Introduction

- Granular materials show extremely complex flow features.

- Prediction of wet granular flow difficult due to difficulties in describing liquid exchange during particle-particle collisions.

- A more rigorous model that is valid for all regimes would be of paramount industrial importance, e.g., to predict the distribution of liquid between particles more reliably in a
  - **granulation**,
  - **mixing**,
  - **drying or coating** applications

- Four liquid transfer models to predict the formation and rupture of liquid bridges and model for the conductive liquid flux for different flow regimes.

Proposed Models

- **Model – A**
  - Conduction based simple liquid transfer rate model[1]

- **Model – B1**
  - Instantaneous liquid transfer model based on surface contact of particles[2]

- **Model – B2**
  - Instantaneous liquid bridge formation and rupture

- **Model – C**
  - Filling rate based model for drainage of liquid into the bridge
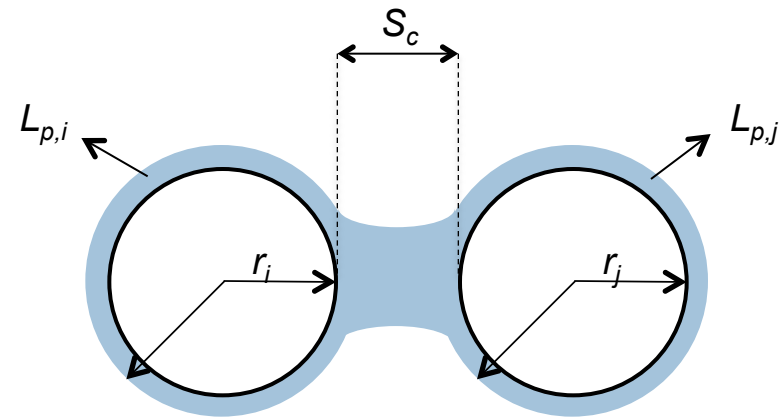
[1] Tomassone et al, Powder Technology 2012

[2] Shi and McCarthy, Powder Technology 2008

Proposed Models

Liquid transfer happens

Liquid transfer happens
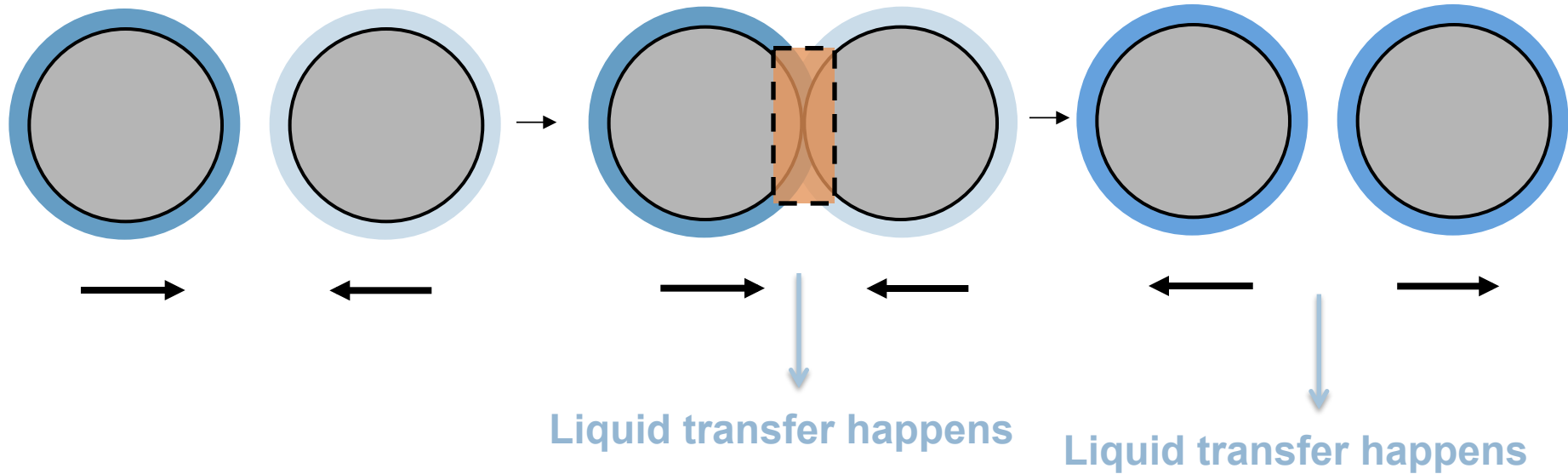
Model A

Model B1

Transfer rate based on Γ

Calculation of bridge volume[2]

Transfer of liquid between particles instantaneously

[2] Shi and McCarthy, Powder Technology 2008

Proposed Models

Formation of liquid bridge

Instantaneously bridge is formed

$\rightarrow$

Continuous Drainage of liquid into the bridge
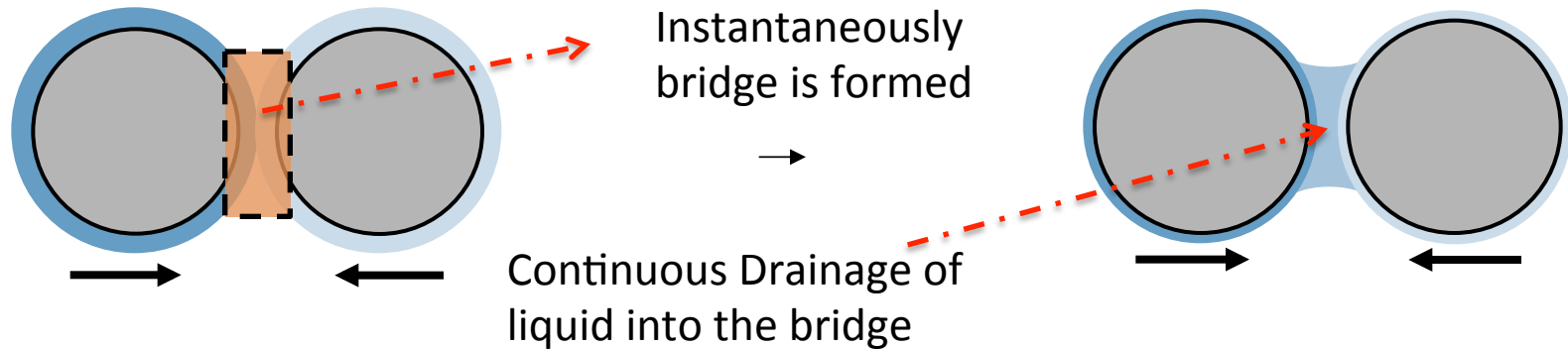
Model B2

Explicit Calculation of bridge volume[2]

Instantaneous transfer of liquid into the bridge
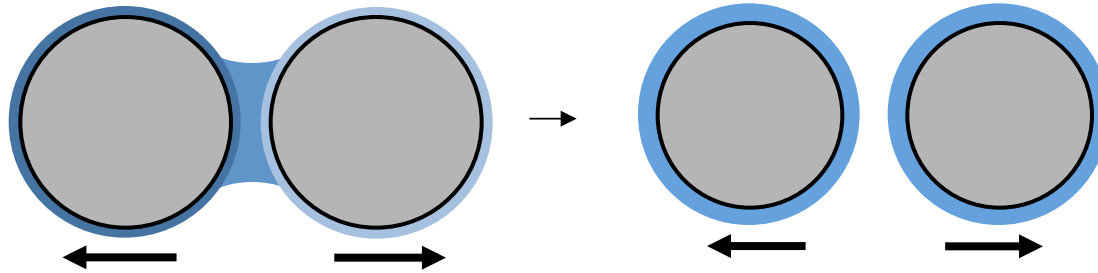
Model C

Drainage of liquid from the film into the bridge 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

Proposed Models

Rupture of liquid bridges

Calculation of rupture distance

$$s_c = \|\boldsymbol{\delta}\| - r_i - r_j$$

$$\boxed{s_r = (1 + 0.5\theta)\, V_b^{1/3}} \quad \text{[3]}$$

$$s_c \geq s_r$$

On rupture of liquid bridges

$$Q_i = \frac{V_b \cdot n}{\triangle t}$$

$$Q_j = \frac{V_b \cdot (1 - n)}{\triangle t}$$

[3] Lian et al., Journal of colloid and interface science 161, 138–147

Proposed Models

Key differences	Model A	Model B1	Model B2	Model C
Account of liquid Film thickness	No	No	**Yes**	**Yes**
Explicit calculation of Bridge volume	No	Not really (just at the end of collision)	**Yes**	**Yes**
Rupture distance	No	No	**Yes**	**Yes**
Effect of liquid viscosity and surface tension	**Yes**	No	No	**Yes**

Dimensional analysis

$$\gamma^* = \gamma \cdot d_p / \sqrt{k_n / (\rho_p \cdot d_p)}$$

Dimensionless shear rate
Range[4] : **10⁻⁴ to 1**

Based on dimensional analysis of main influencing parameters, we get two dimensionless numbers

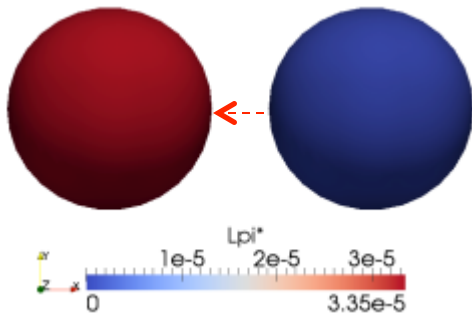$$\Gamma = t_{ref}/t_{shear} = \gamma \cdot r_{eff} \cdot \mu_l / \sigma_l$$

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

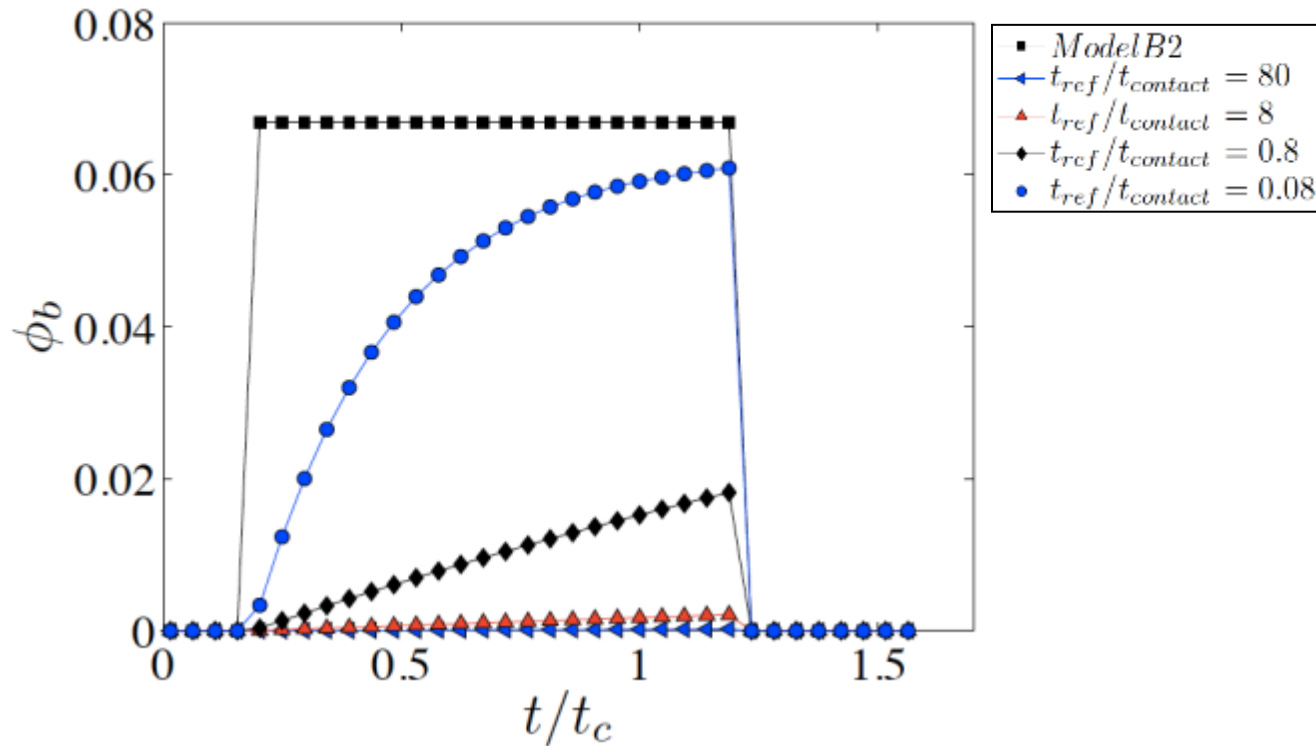Range : **10⁻³ to 1**

Dimensionless liquid film thickness : **0.02**

[4] Chialvo et al, Physical Review E. 85 (2012).
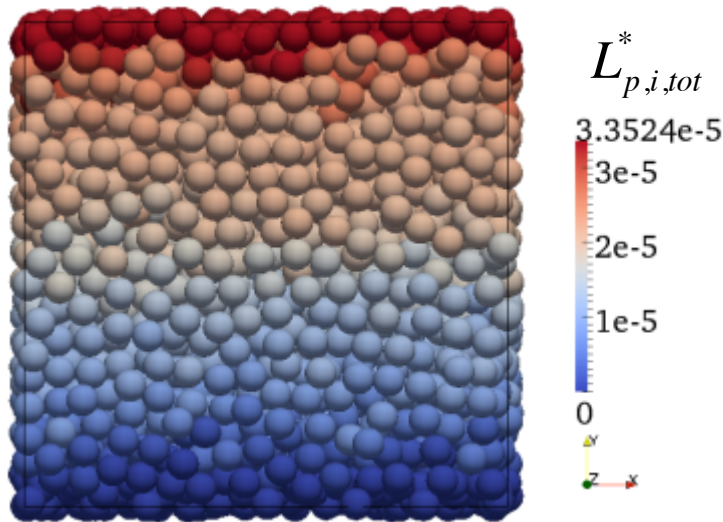
Single particle-particle collision setup

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

$$\phi_b = \frac{Liquid\ in\ the\ bridge}{Total\ liquid\ on\ the\ particles}$$

- Smooth
- Equal sized particles
- No force models
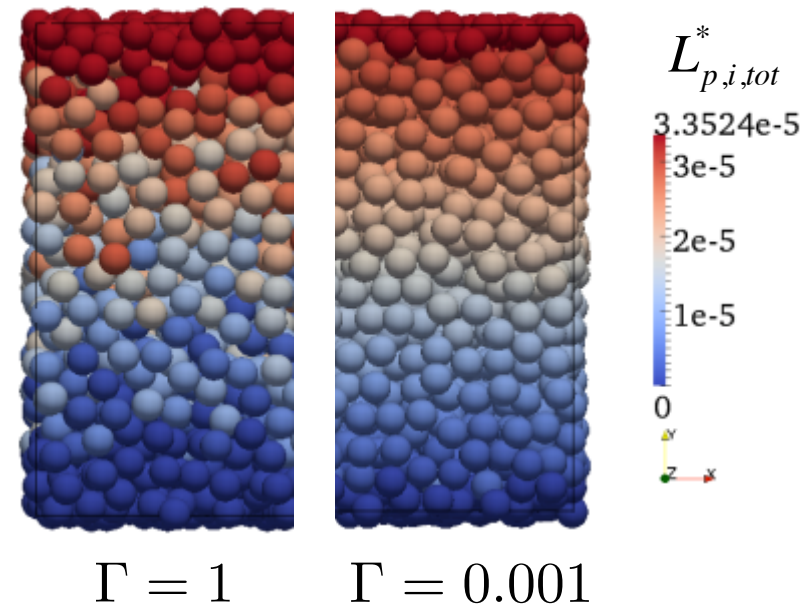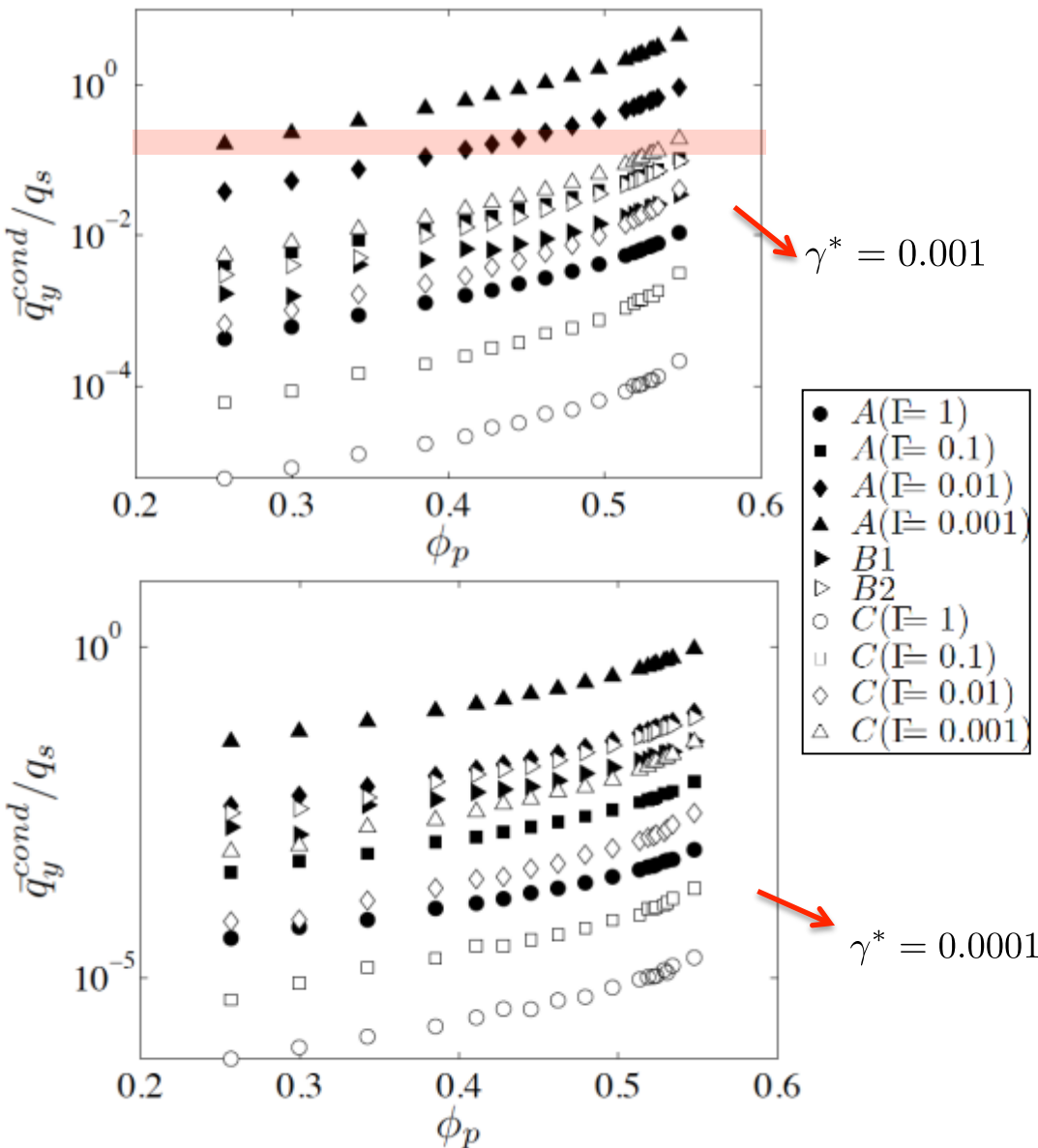
Sheared Particle Beds

Simulation Setup

$$L^*_{p,i,tot}$$

$$L^*_{p,i,tot} = L_{p,i,tot}/(r_{eff})^3$$

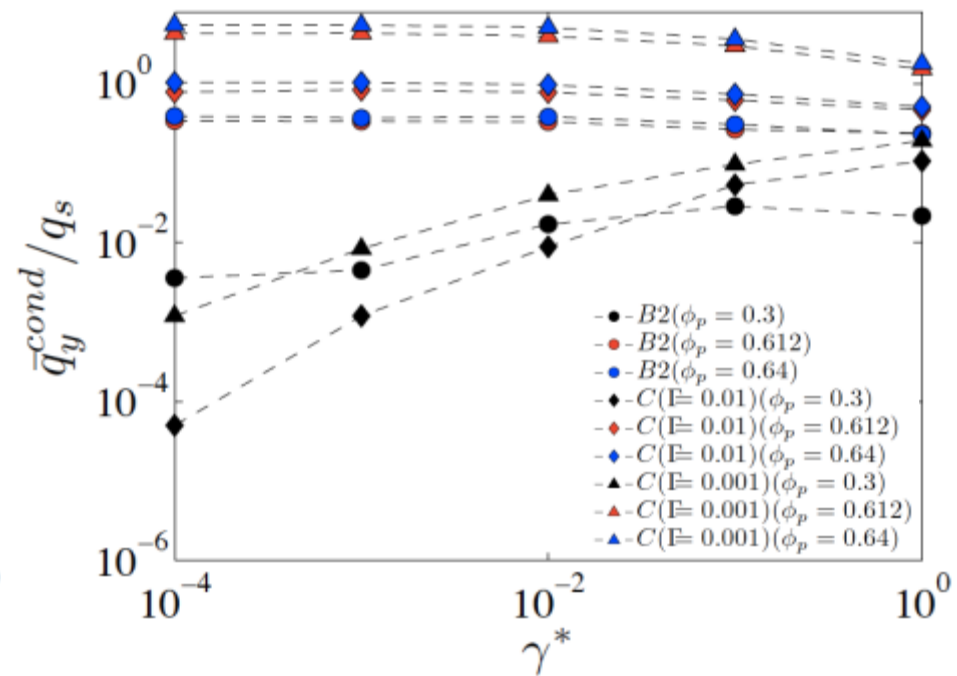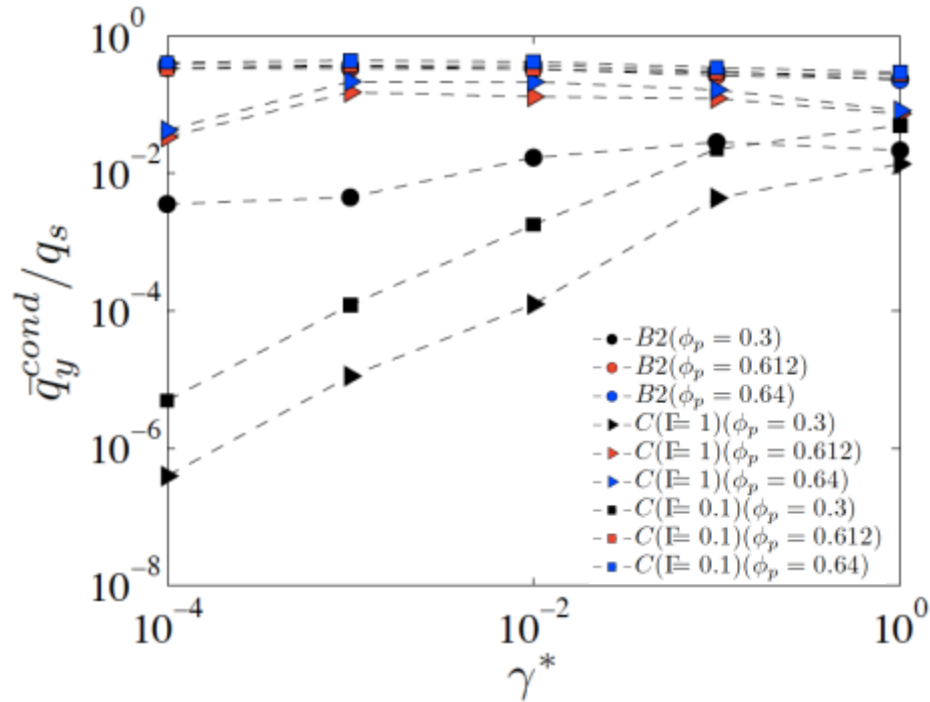$$\mathbf{q}^{cond} = \frac{1}{V}\sum_c Q \cdot \mathbf{r}_{ij}$$

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

- Particles placed in a **periodic box** (H/d_p=15).

- Particles stiffness based on dimensionless shear rate

- Dimensionless liquid film thickness is 0.02

- Particles near the **top boundary were fixed to be wet ($L_{pi,tot}{}^*$ = 3.35e-5)** and near the **bottom boundary were fixed to be dry ($L_{pi,tot}{}^*$ = 0)**.

- Lees-Edwards boundary conditions[5] used.

- Conductive liquid flux ($q_y{}^{cond}$) made dimensionless using q_s as the reference conductive liquid flux in the solid material the particles are made of.
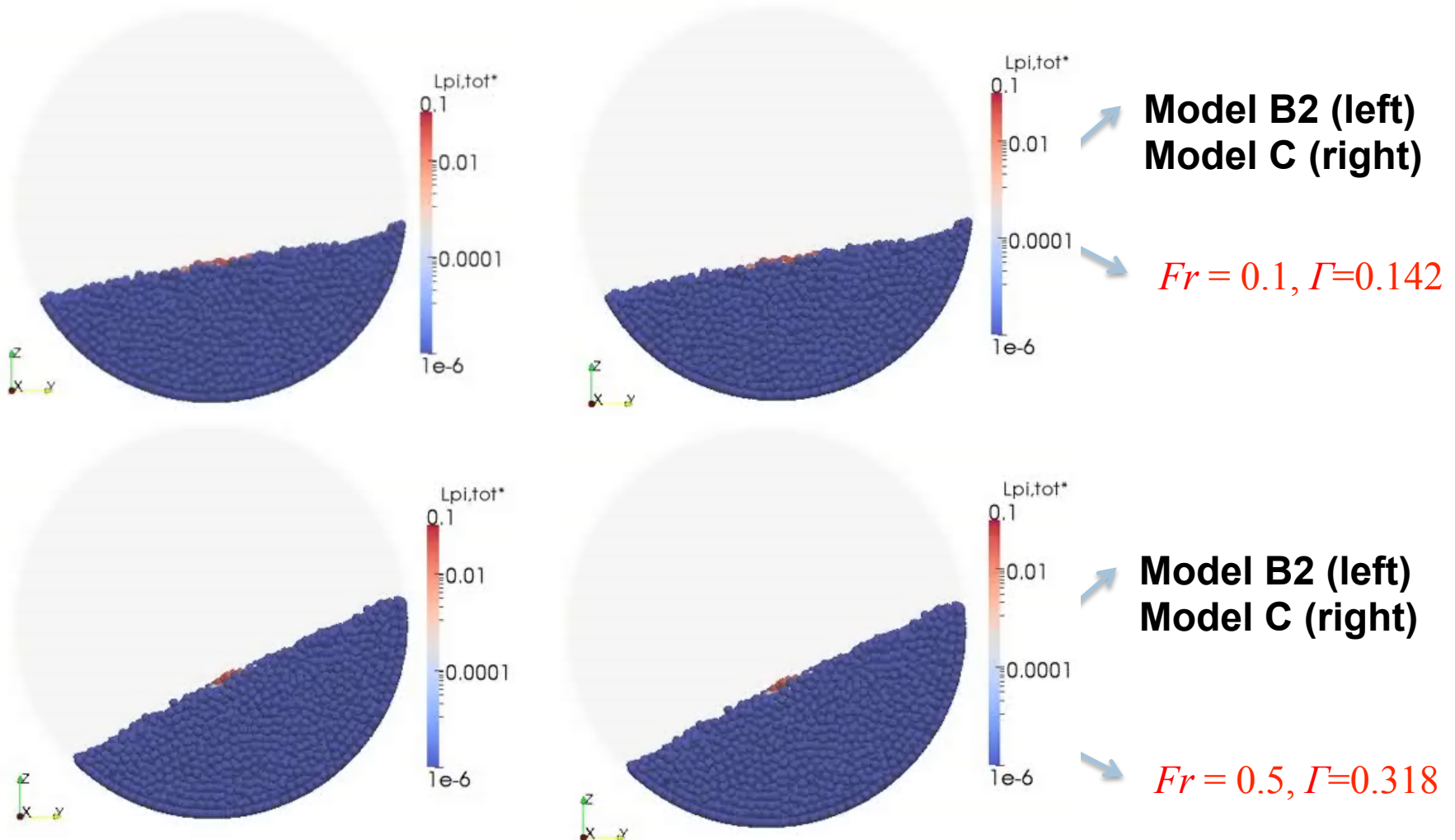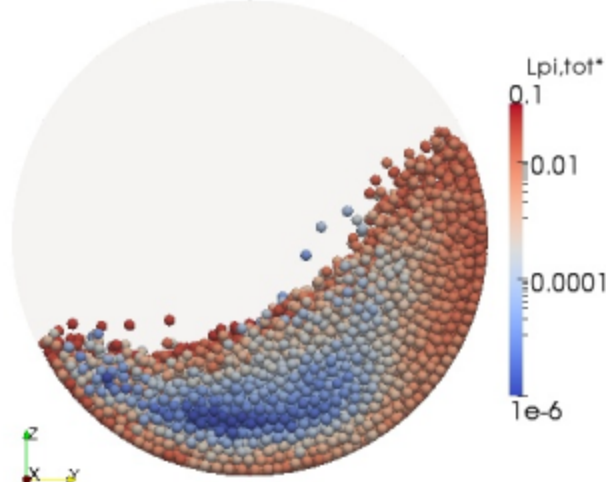
[5] Lees and Edwards, Journal of Physics C: Solid State Physics 1921 (2001).   11

Sheared Particle Beds

Results

$\gamma^* = 0.001$

$\gamma^* = 0.0001$

●	$A(\Gamma = 1)$
■	$A(\Gamma = 0.1)$
◆	$A(\Gamma = 0.01)$
▲	$A(\Gamma = 0.001)$
▶	$B1$
▷	$B2$
○	$C(\Gamma = 1)$
▫	$C(\Gamma = 0.1)$
◇	$C(\Gamma = 0.01)$
△	$C(\Gamma = 0.001)$

$L^*_{p,i,tot}$

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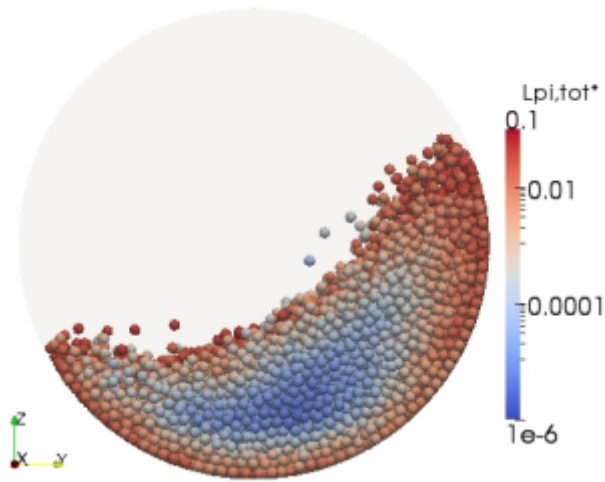
$\Gamma = 1$ $\Gamma = 0.001$

Sheared Particle Beds

Summary of conductive liquid flux vs dimensionless shear rate

Perspective

Animations of Liquid injection in rotating drums - Model B2 and C

Model B2 (left)
Model C (right)

$Fr = 0.1, \Gamma = 0.142$

Model B2 (left)
Model C (right)

$Fr = 0.5, \Gamma = 0.318$
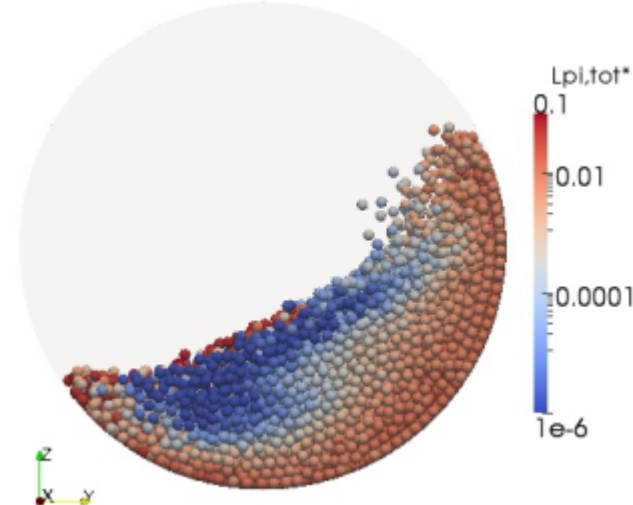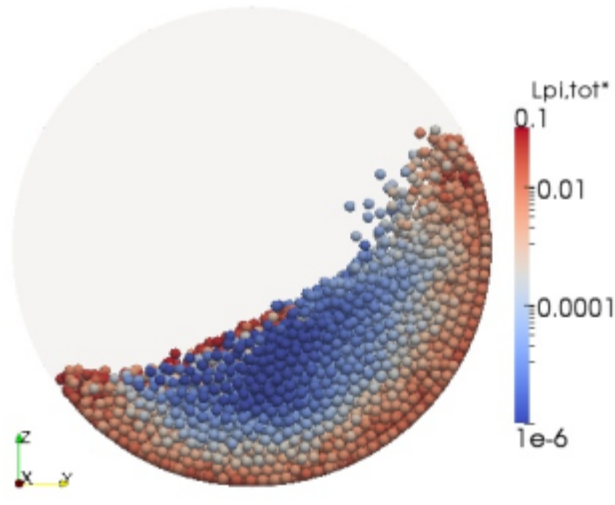
Perspective

Snapshots of Liquid injection in rotating drums - Model B2 and C

Model B2 (left)
Model C (right)

$Fr = 0.1, \Gamma = 0.142$

Model B2 (left)
Model C (right)

$Fr = 0.5, \Gamma = 0.318$

Conclusions

- Simplified models for liquid transfer based on different definitions of liquid transfer rates that predicts the liquid bridge formation and rupture.

- Use this model for conductive liquid fluxes to plug in later to a continuum model.

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

- Reference time scale for the liquid bridge filling process

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

Agglomeration and Granulation processes

Transport Rates of Adhering Liquid Films in Sheared Particle Beds

Acknowledgement

Austrian Science Foundation (FWF)

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