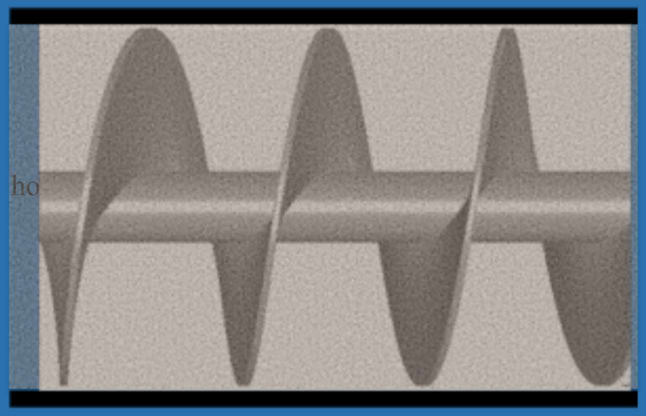


Precision powder feeding

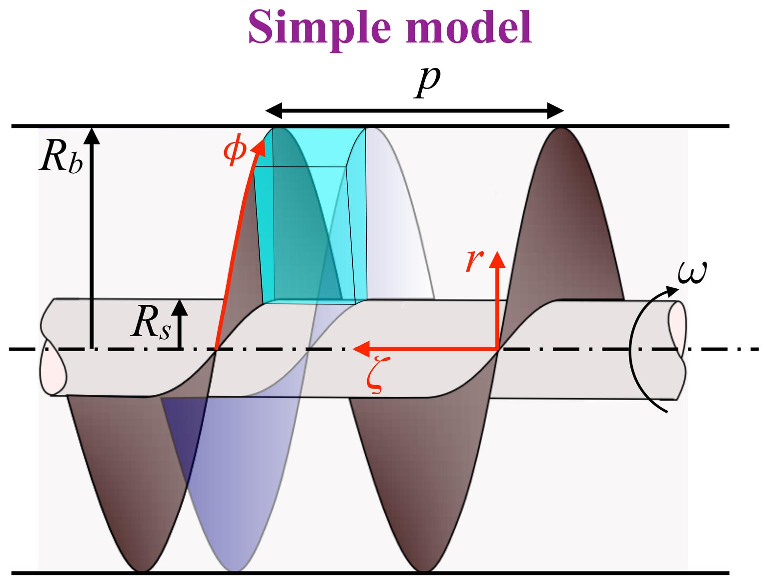
Prabhu Nott

Sanyogita, Gautam Vatsa

Indian Institute of Science, Bangalore

Summary of work in previous years

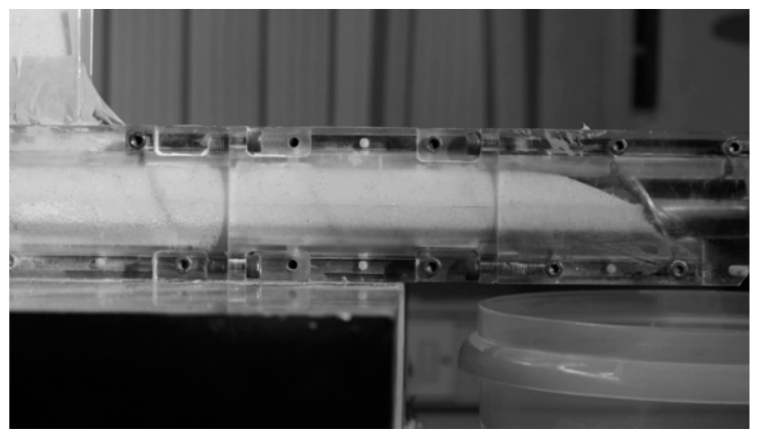
Simple model

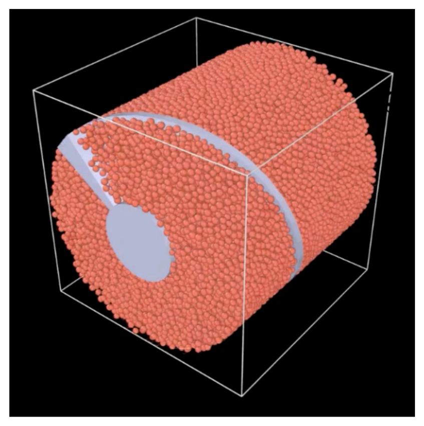


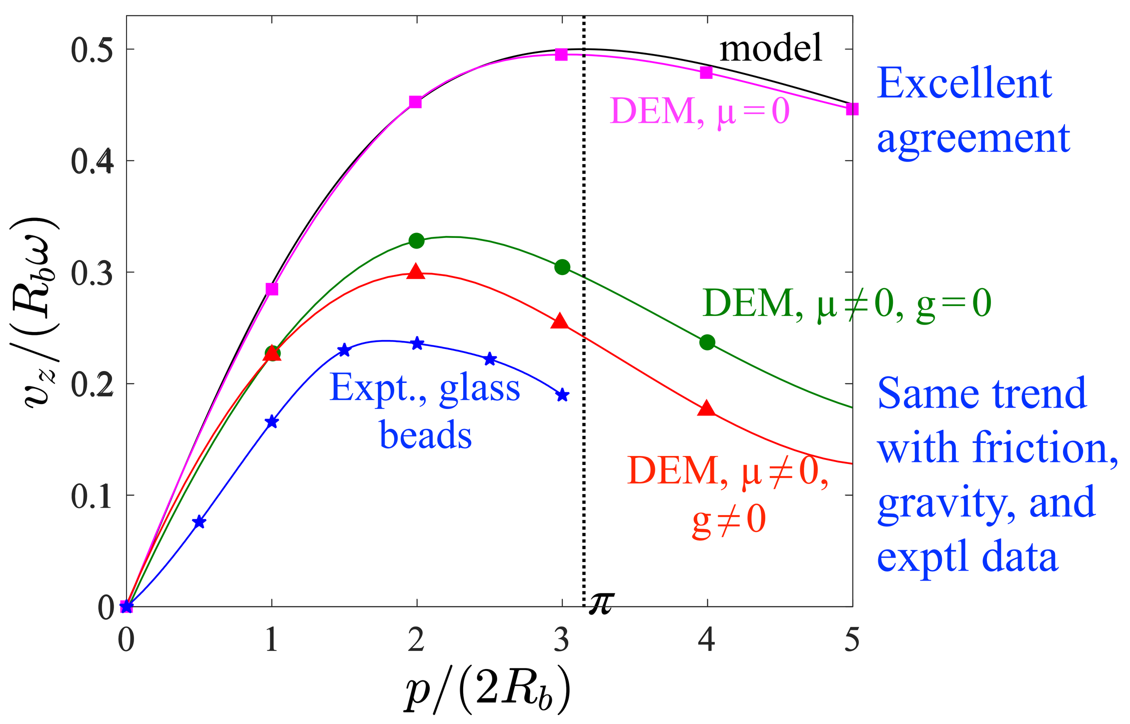
Assuming screw and shaft are *frictionless*, feeder is *fully filled*, and powder flows as a *plug*, the feed rate is

$$v_z = \omega R_b \frac{\pi p/(2R_b)}{\pi^2 + p^2/(2R_b)^2}$$

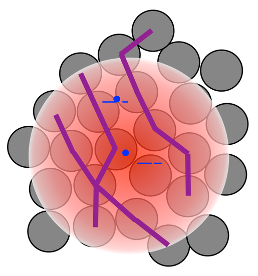
Experiments







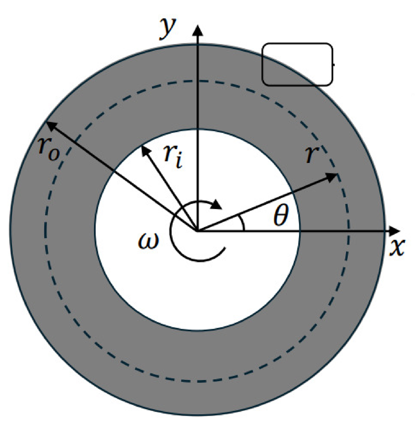
Non-local model

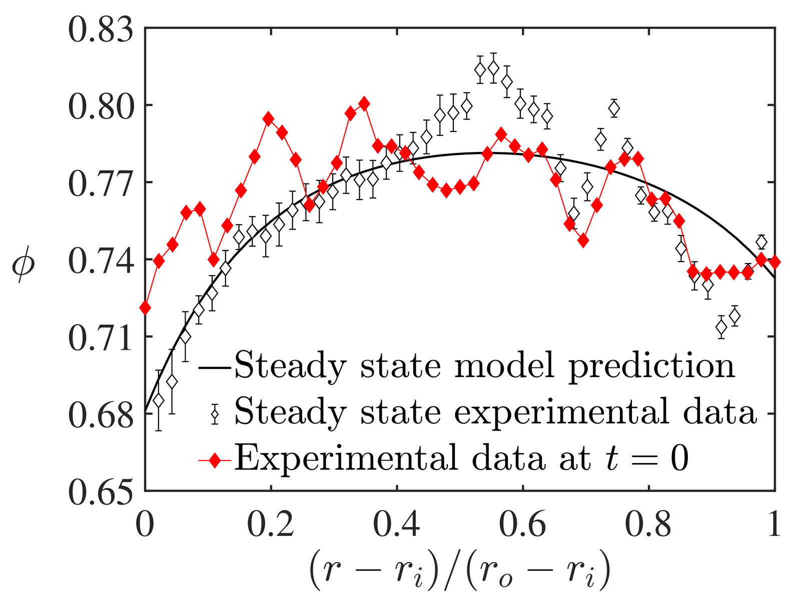


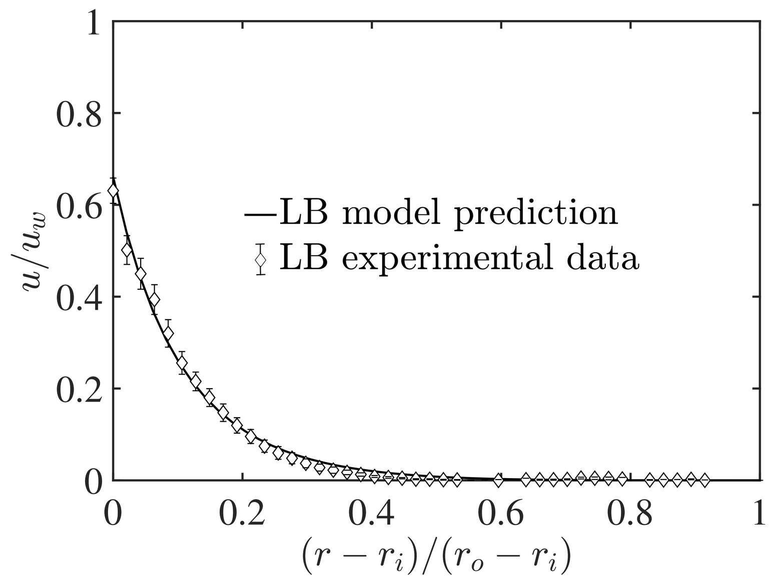
$$\boldsymbol{\sigma} = -p\,\boldsymbol{\delta} + \frac{2\mu}{\dot\gamma}\left(p_c\,\boldsymbol{D}' - \ell^2\,\Pi\,\nabla^2\boldsymbol{D}'\right), \qquad p = p_c\left(1 - \frac{\mu_b}{\dot\gamma}\boldsymbol{\nabla\cdot u}\right) - \ell^2\,\Pi\,\frac{\mu_b}{\dot\gamma}\nabla^2\boldsymbol{\nabla\cdot u}$$

$$p_c = \Pi - \ell^2\,\frac{d\Pi}{d\phi}\,\nabla^2\phi,$$

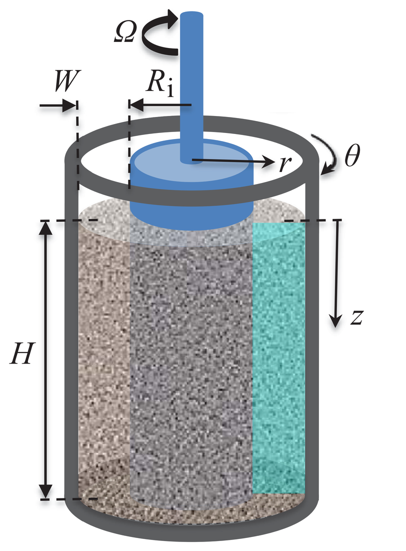
Validation of non-local model in a cylindrical Couette cell: IISc-NCSU collaboration

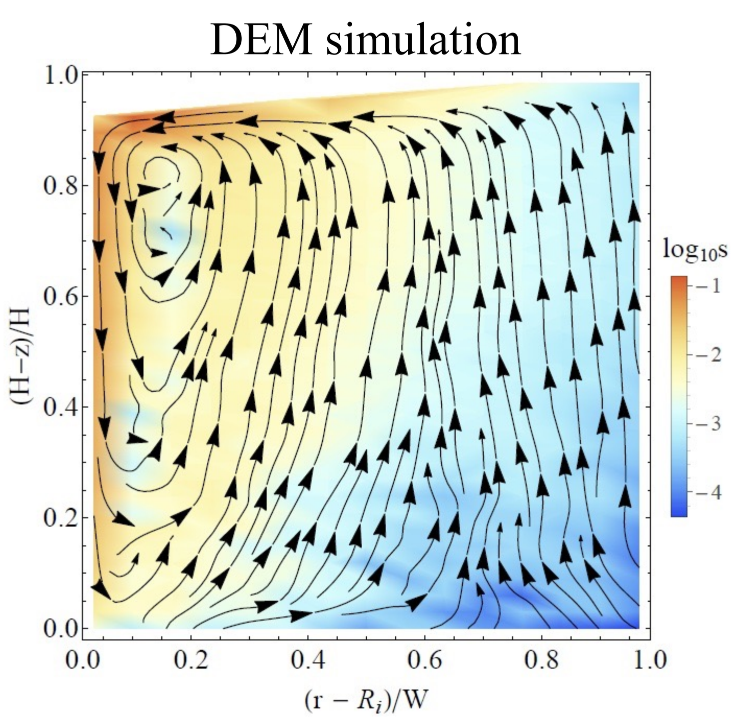




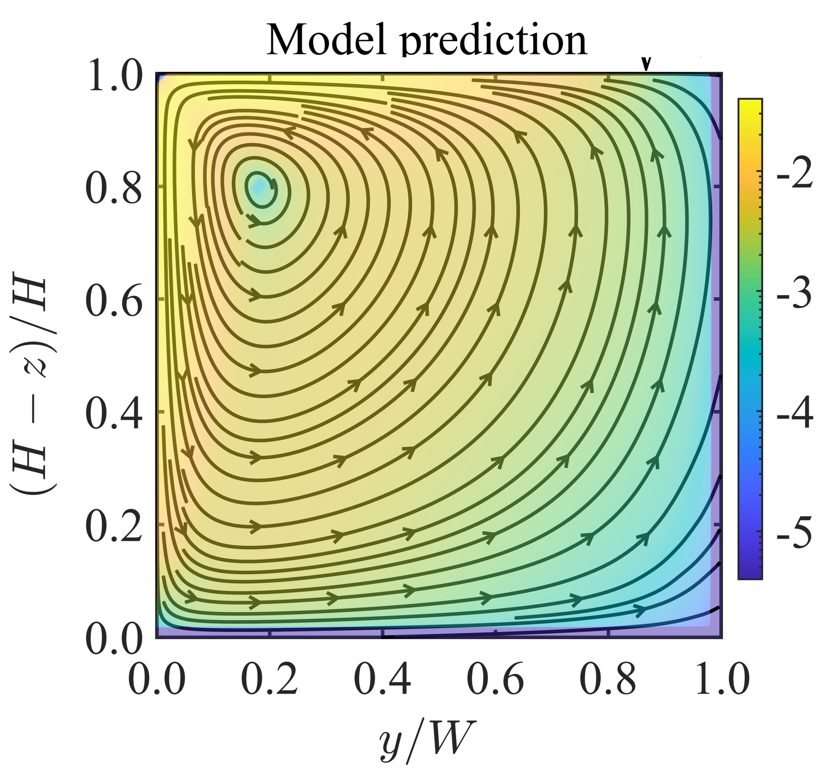


Stringent test of non-local model: secondary flow driven by dilatancy





Krishnaraj & Nott (*Nature Commun.*, 2016)

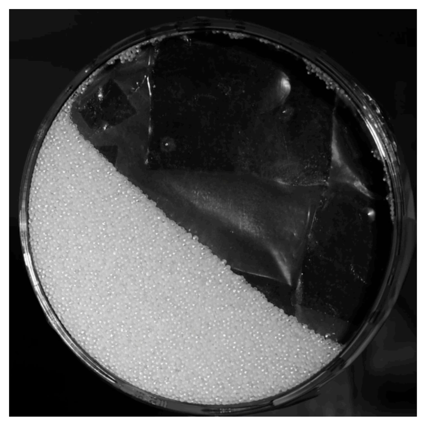


The model captures the strong coupling between packing fraction and velocity fields

Model cohesive powders: dry glass beads mixed with glycerol

0% glycerol

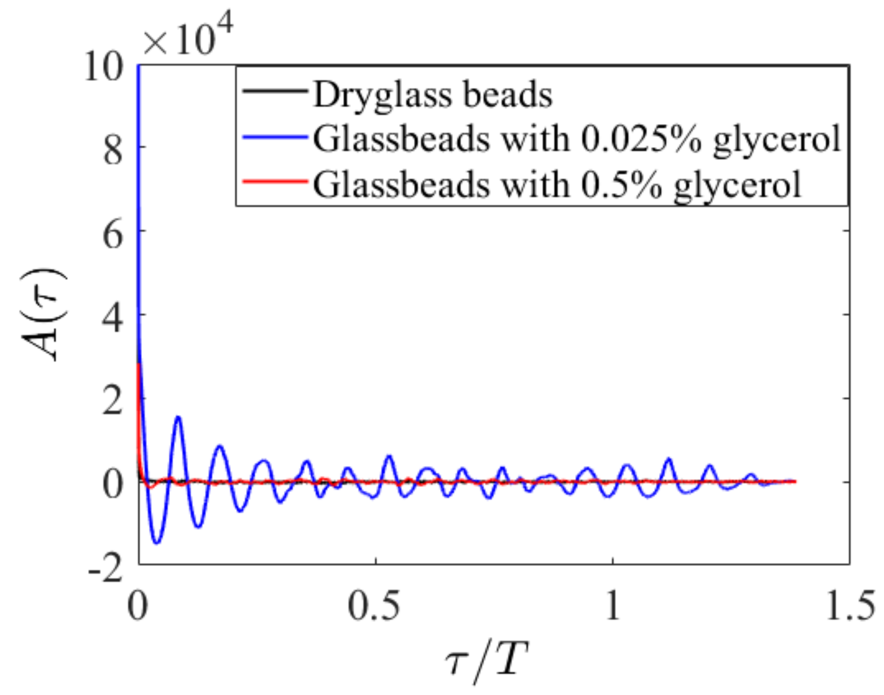
0.025% glycerol



0.2% glycerol

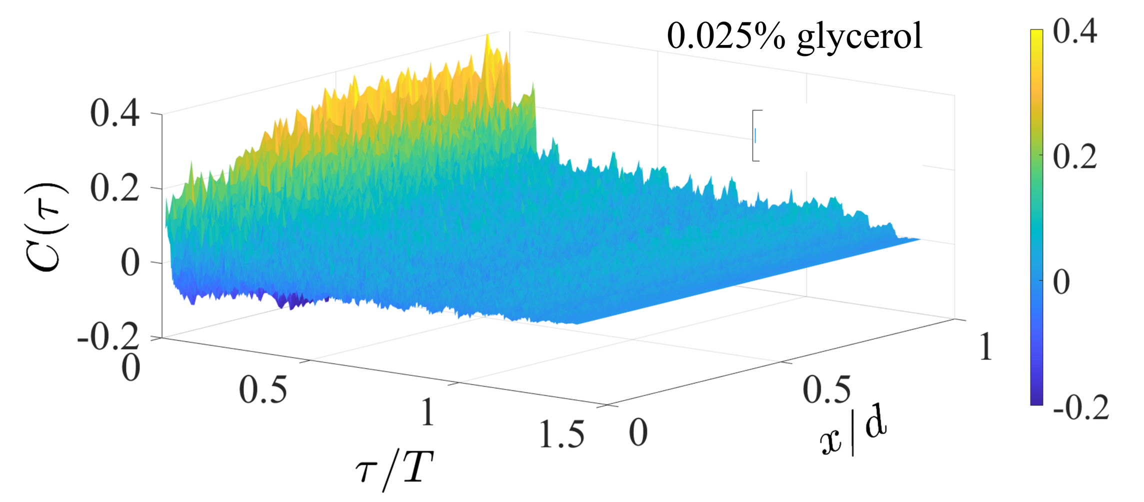
Quantifying flow fluctuations of cohesive powders

Autocorrelation
$A(\tau) = \langle v(t,x)\, v(t+\tau, x)\rangle$



Space-time correlation
$C(\tau,\delta) = \langle v(t,x)\, v(t+\tau, x+\delta)\rangle$

$\delta = 0.2\,L$

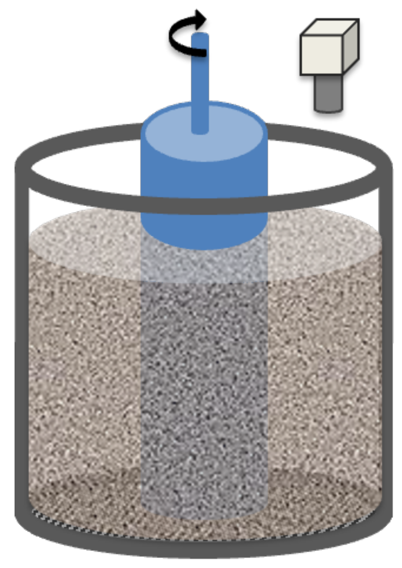


Incorporating fluctuations and correlations in a rheological model

Flow rule in our non-local model: $D_{ij} = \dot\lambda \dfrac{\partial F}{\partial \sigma_{ij}} + \ell^2 \nabla^2\left(\dot\lambda \dfrac{\partial F}{\partial \sigma_{ij}}\right)$ (fluidity: $\dot\lambda$)

Classically, cohesion only increases the yield stress: $F(\boldsymbol{\sigma}) = F_{\text{non-coh}}(\boldsymbol{\sigma}) - \tau_{\text{coh}}$

However, the experiments above show that fluidity too must depend on cohesion.



Our plan: Experiment to quantify the effect of cohesion on agglomeration, flow, and the stress.

- Measure simultaneously the stress and kinematics in a cylindrical Couette cell.
- Velocity and microstructure (agglomeration) will be determined by imaging the free surface.

Conclusions

- Non-local model predicts a complex, dilatancy-driven secondary flow. Captures the strong coupling between the velocity and packing fraction fields
- Model cohesive powders with controlled cohesion obtained by mixing dry glass beads with small amounts of glycerol.
- Flow intermittency and fluctuations for a range of glycerol fraction. Above critical glycerol fraction, cohesion-induced agglomeration promotes smooth flow.
- A set up for simultaneously measuring the stress, kinematics and agglomeration is being constructed. Will help develop constitutive model for cohesive powders.