Characterization of paddle-induced granular flow in convective mixers

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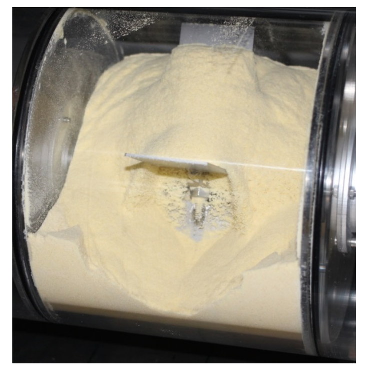
1. Context

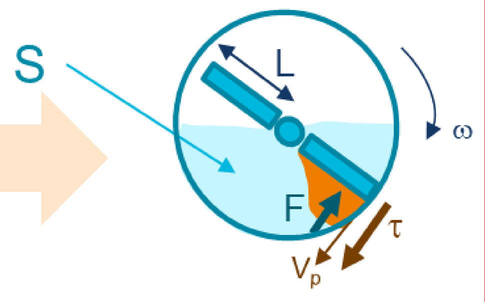
Numerous industrial sectors need to process granular materials through stirring operations in order to homogenize or mix particulate solids. Paddle-induced granular flow is still poorly understood and hardly predictable.

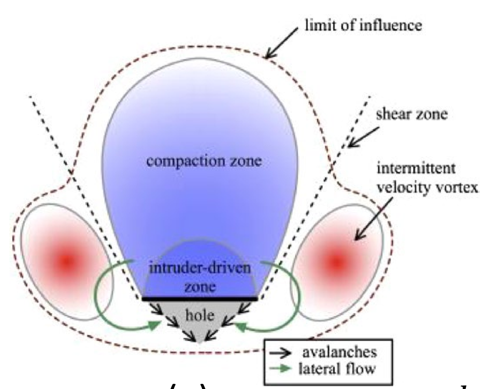
The aim of our work is to study extensively powder rheology to establish process-relations that allow designing and scaling-up industrial operations.

surface



Submerged area





(a)

In the submerged area, the flow is generated by frictitional forces inside sheared band of width = $K * d$

k: number of particles
d: particle mean diameter

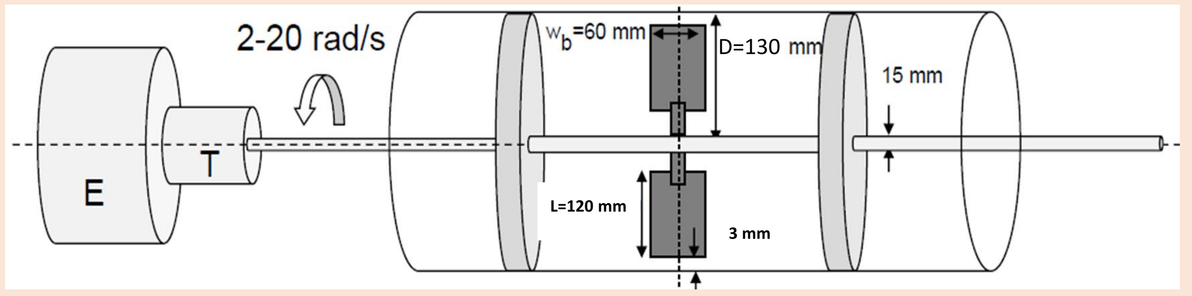
Semolina

D_{50}=312 µm
ρ_b= 679 kg/m³
ρ_p=1460 kg/ m³

Couscous

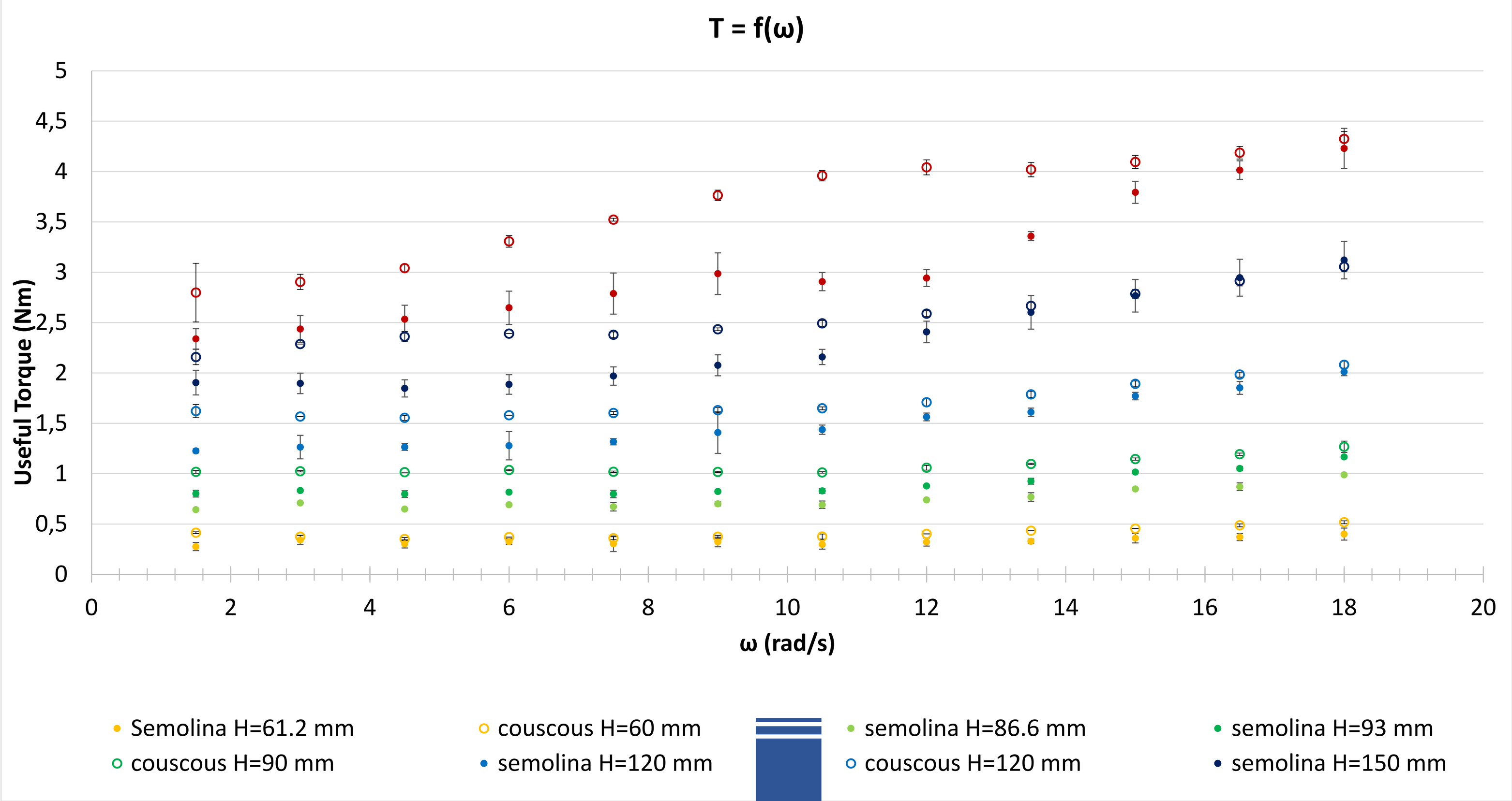
D_{50}=1005 µm
ρ_b= 854 kg/m³
ρ_p=1438 kg/ m³

2. In-System rheology



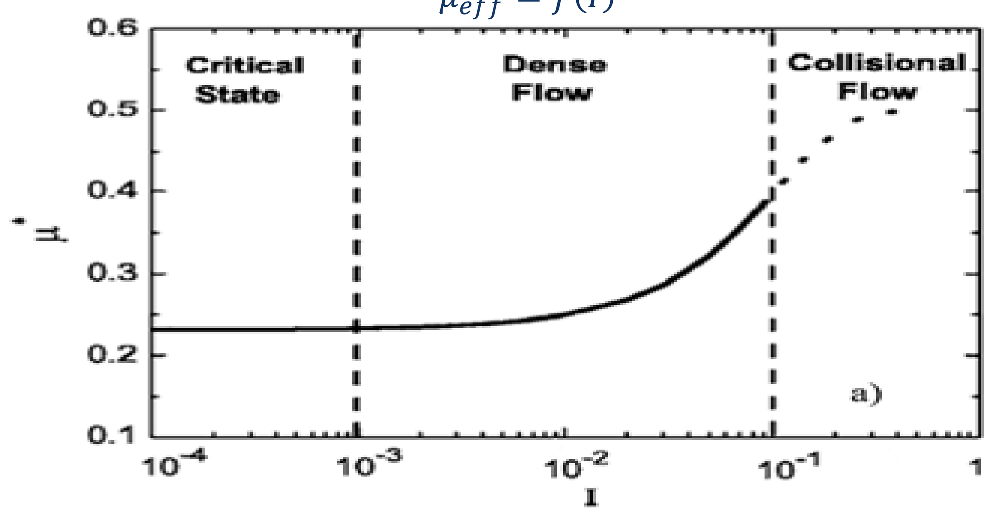
The **torque** is a descriptor used in the study of systems agitated by a rotating device.

Torque=f(rotational speed)



3. Meso-scopic rheology

$\mu_{eff} = f(I)$



(b)

Inertial number $I = \frac{Time\ of\ confinement}{Time\ of\ deformation} = \dot{\gamma} d \sqrt{\frac{\rho}{\sigma_n}}$

(c)

Effective friction coefficient $\mu_{eff} = \frac{\tau_w}{\sigma_n}$

4. Multi-scale rheology

$$\dot{\gamma} = \frac{V_p}{kd} = \frac{\omega L}{kd}$$

k=30

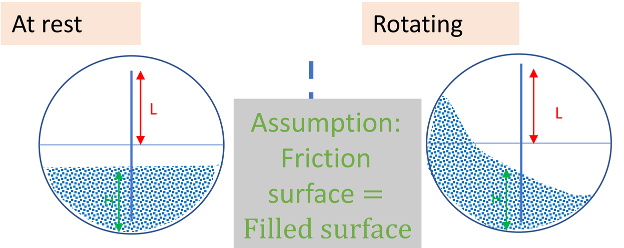
$$\tau = \frac{T}{SL}$$

$$\sigma = \rho_b g H$$

$$\mu_{eff} = \frac{\tau}{\sigma} = \frac{T}{\rho_b g S H L}$$

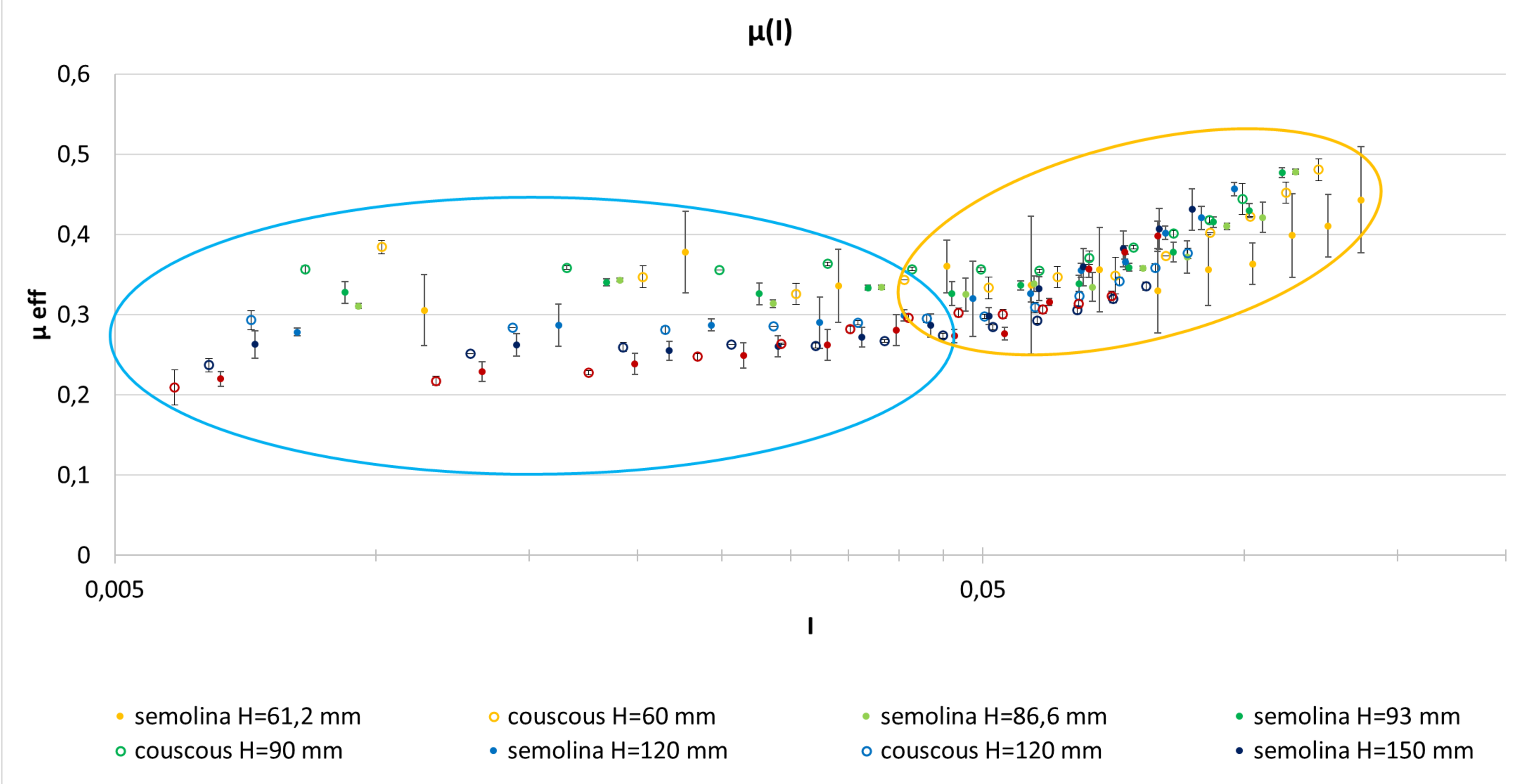
$$I = \dot{\gamma} d \sqrt{\frac{\rho_p}{\sigma}} = \frac{\omega L}{k \sqrt{\frac{\rho_b}{\rho_p} g H}}$$

H: powder bed height(m)
L: paddle length (m)
S : surface of powder bed
k: number of particles
ω: rotational speed (rad/s)
T: Torque (N.m)
ρ_b Powder density (kg/m³)
ρ_p Particle density (kg/m³)
$\dot{\gamma}$: shear rate (s^{-1})
d: particle mean diameter(m)
τ: shear stress (Pa)
σ : normal stress (Pa)



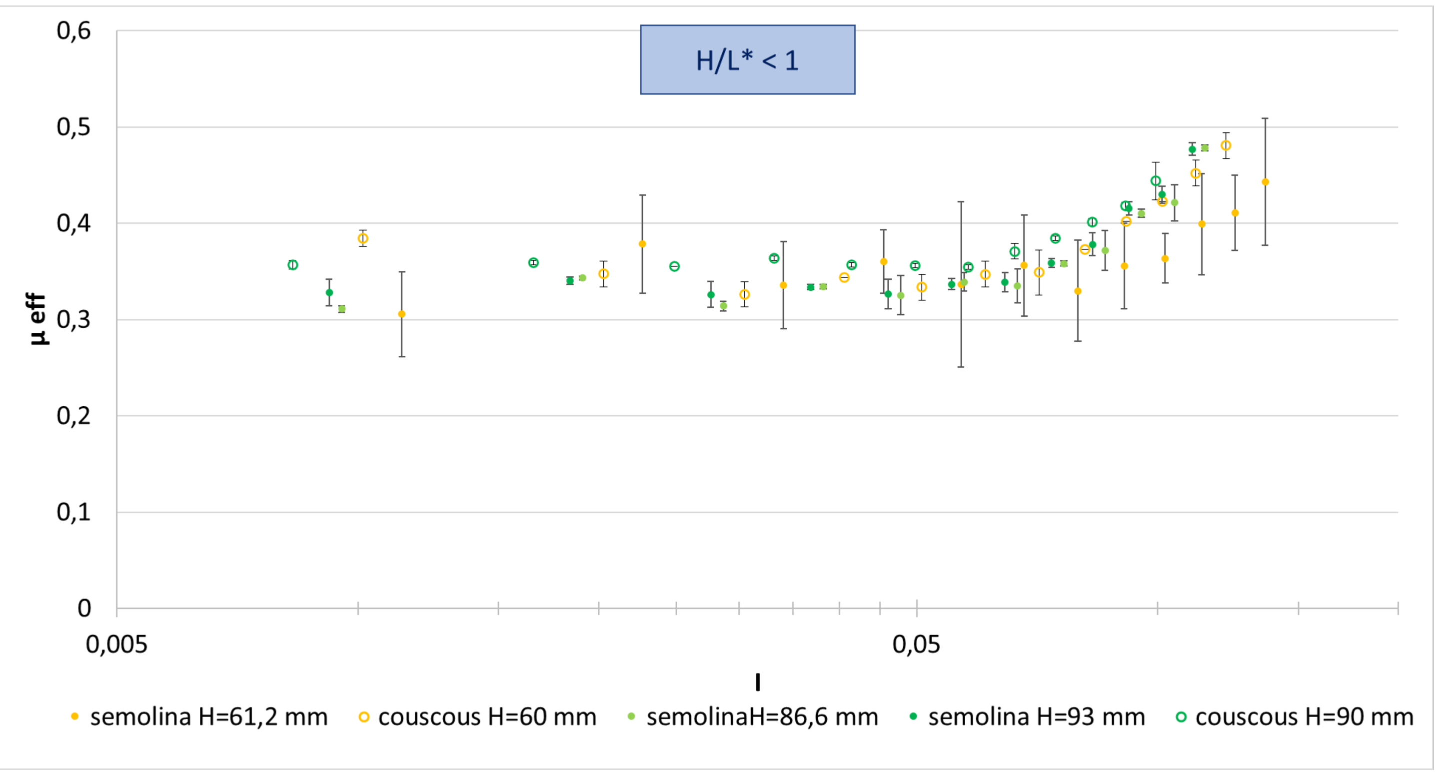
5. Results

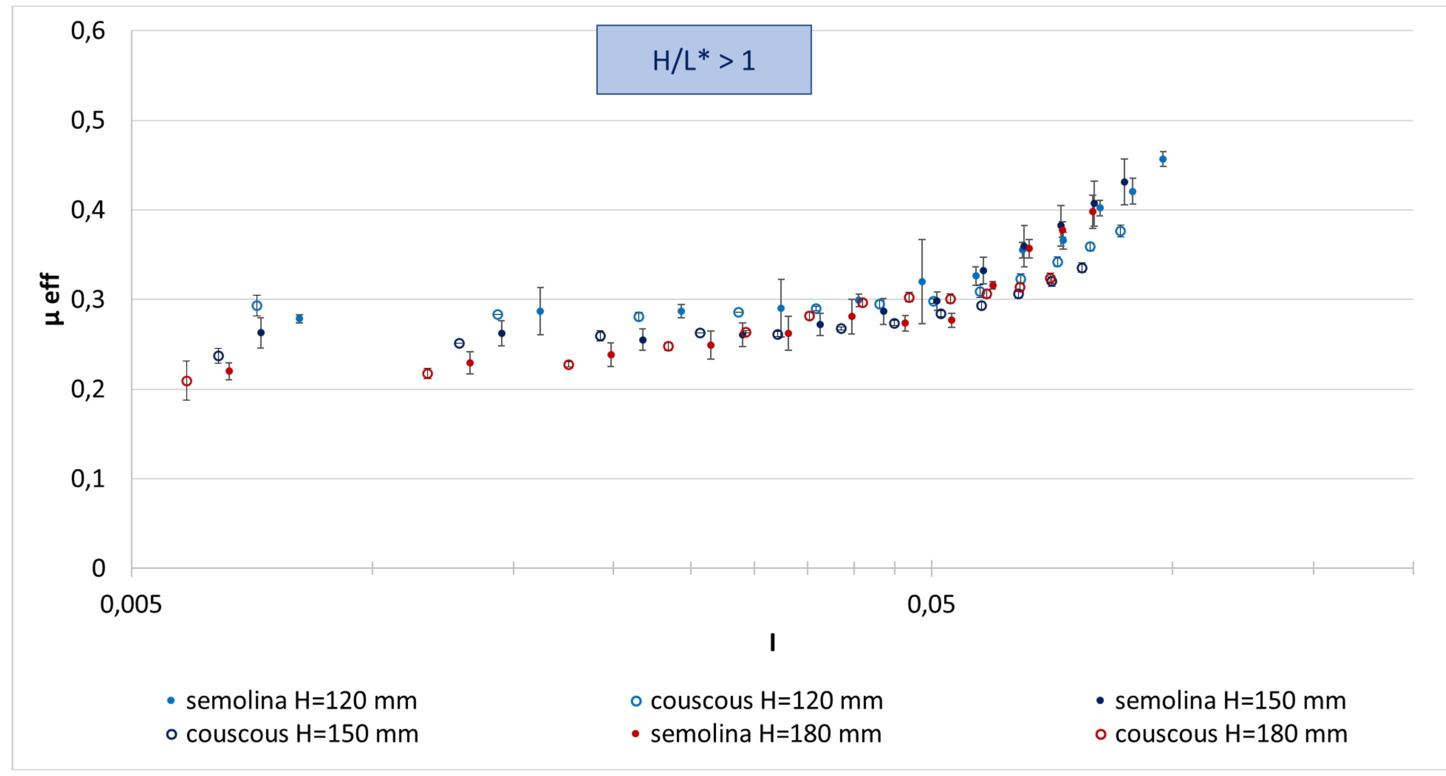
- Two distinct behaviors and a transition regime
- Filling ratio has greater impact at lower rotational speed.



- At higher rotational speeds, avalanches are of a greater magnitude, and can cause a significant "aeration" of the powder. However, the bulk density is considered constant in the correlation.
- For semolina and couscous, despite a different d_{50}, k is considered the same.

Flow regime observed is dense flow and results are in coherence with literature results.



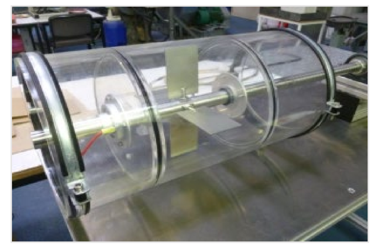


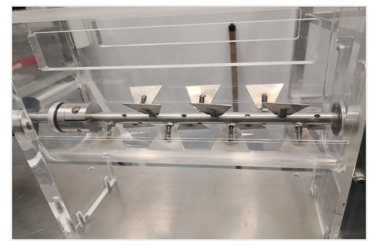
- Filling ratio has an impact on the powder behavior but not only (velocity, sheared band…).
- Bulk density and the width of the sheared band are still locally unknown.

*
H: powder bed height
L: paddle length (120 mm)

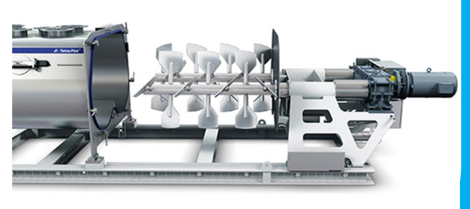
6. Conclusions and perspectives

- To consolidate the multi-scale rheology: $\boldsymbol{k}$, $\boldsymbol{\rho_b}$, and therefore the compacity of the powder locally, need to be assessed.
- A broader investigation of $\mu_{eff} = f(I)$:
  - Flow regimes
  - Diverse particle shapes and sizes
  - Cohesive powders (Bond number (d))
  - Mixtures: microstructures
  - Different volumes (lab to industrial scale)
  - Different mixer geometries: paddle inclination; number of paddles; number of shafts





2 l ➔ 60 l ➔ 3500 l



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