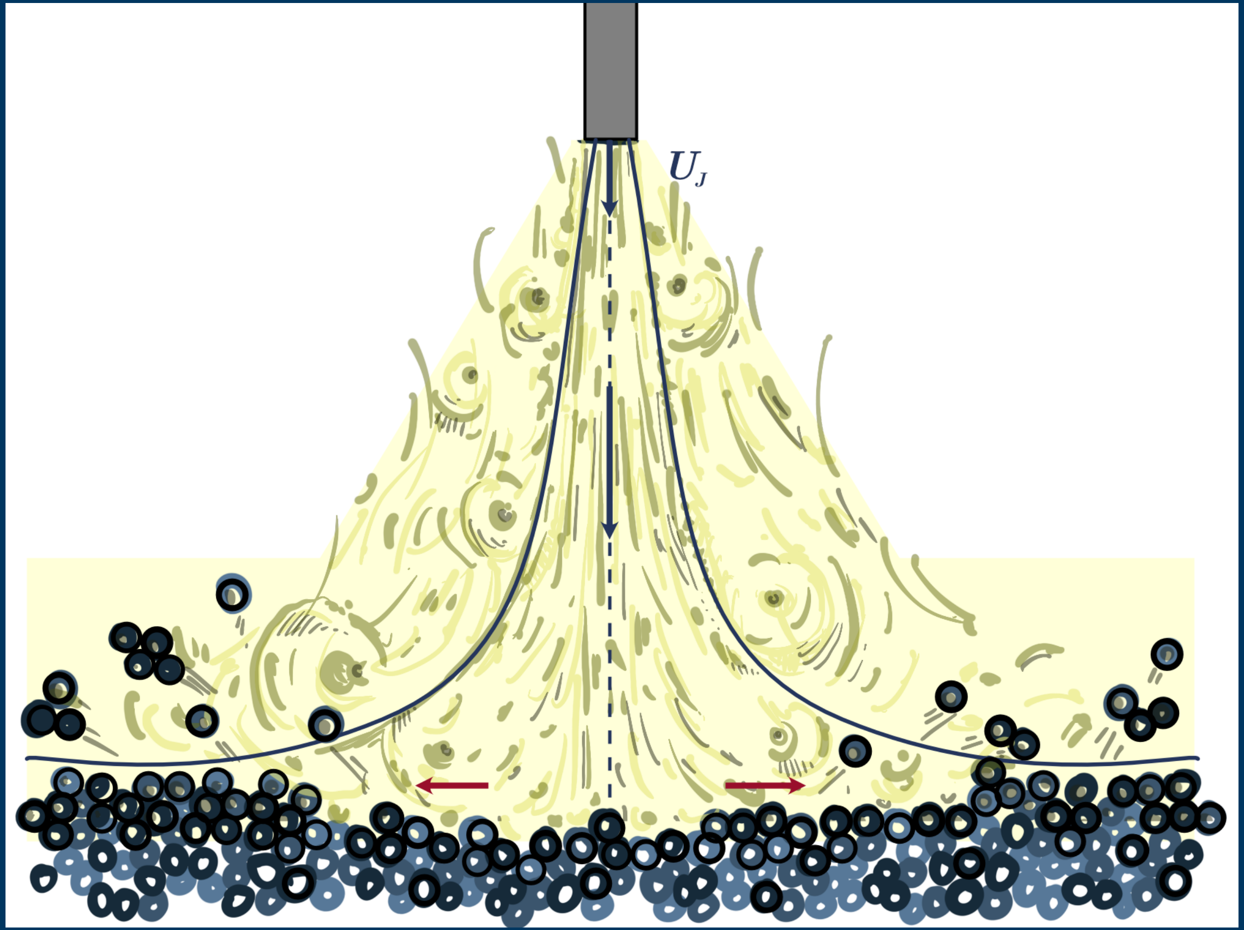
DEVELOPMENT OF INNOVATIVE TOOLS TO CHARACTERIZE THE DRYING OF WET POWDERS UNDER SHEAR

Ram Sudhir Sharma, Sreeram Rajesh,
Alban Sauret



IFPRI
International Fine Particle Research Institute

M&M Flow Lab
Multiphase & Multiscale

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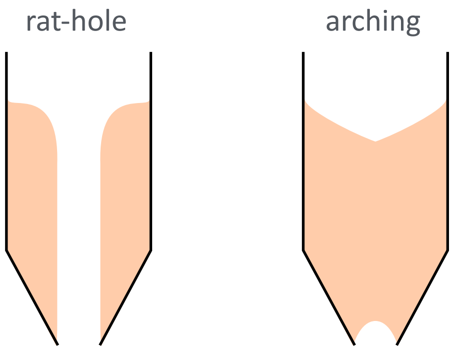
Cohesion of wet grains: From the hourglass to the sandcastle

+ wetting liquid →

Mitarai and Nori, Adv. Phys. (2006)

Arching and "rat-hole" formation

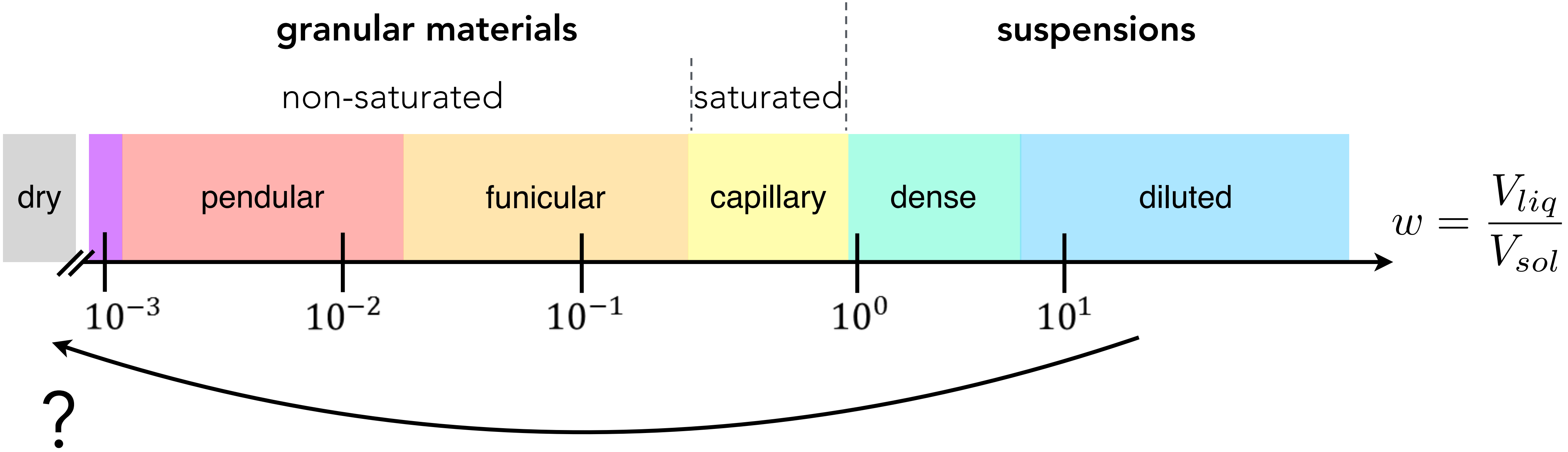
fine powders or exposure to humidity →

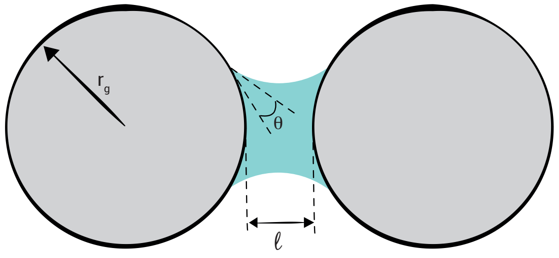


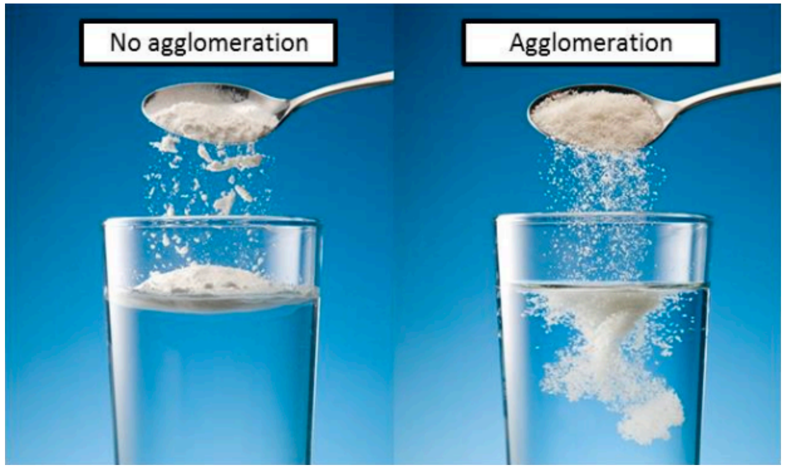
Granulation processes

+ liquid binder →

DRYING OF POWDERS: FORMATION OF AGGLOMERATES







Objective and Approach

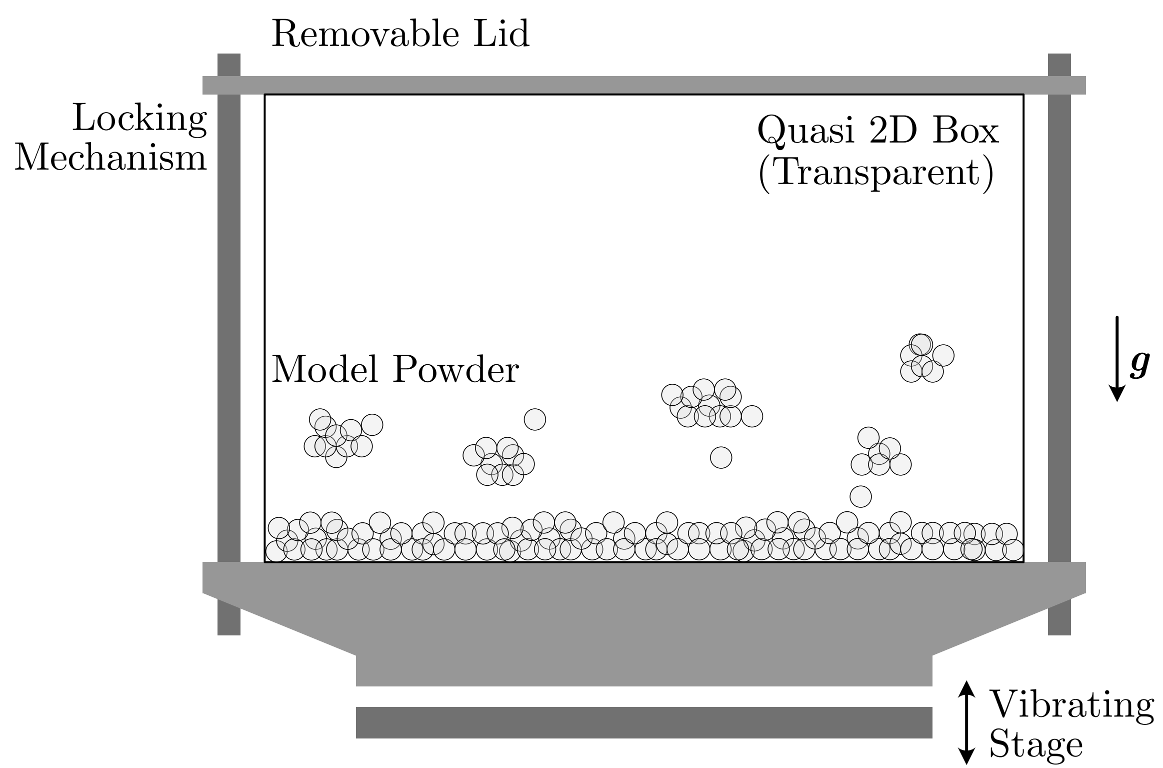
Objective

Characterize how shear can affect the state of agglomeration of products undergoing drying

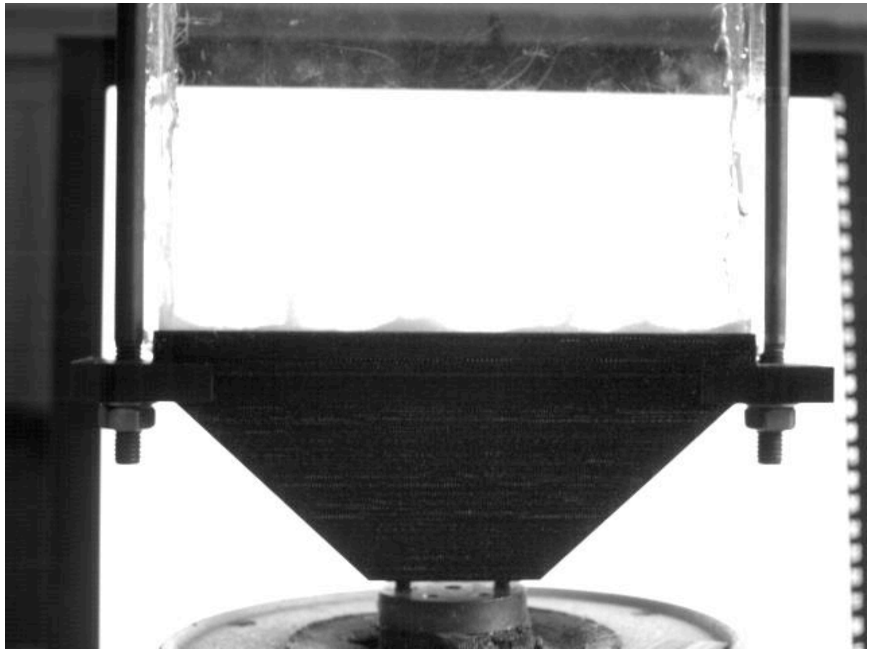
Approach

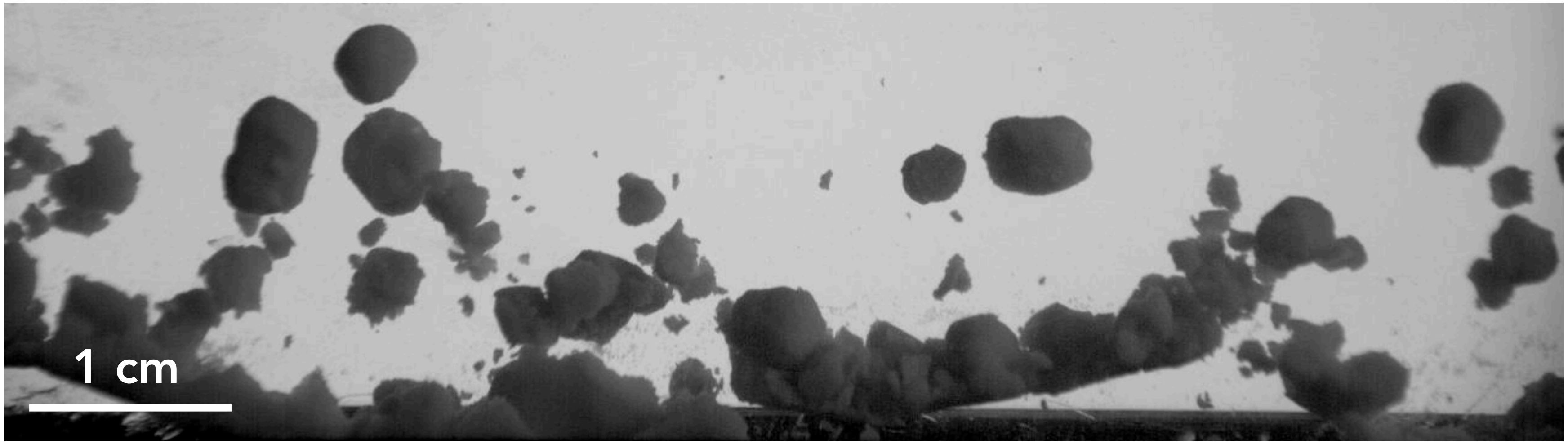
Experimental approach - Develop laboratory-scale tools for studying the drying of wet grains and powders with controlled shear and estimate the time evolution of the agglomerates during the drying process and the final product.

First Approach: Shear induced by collisions



Slowed down 10x

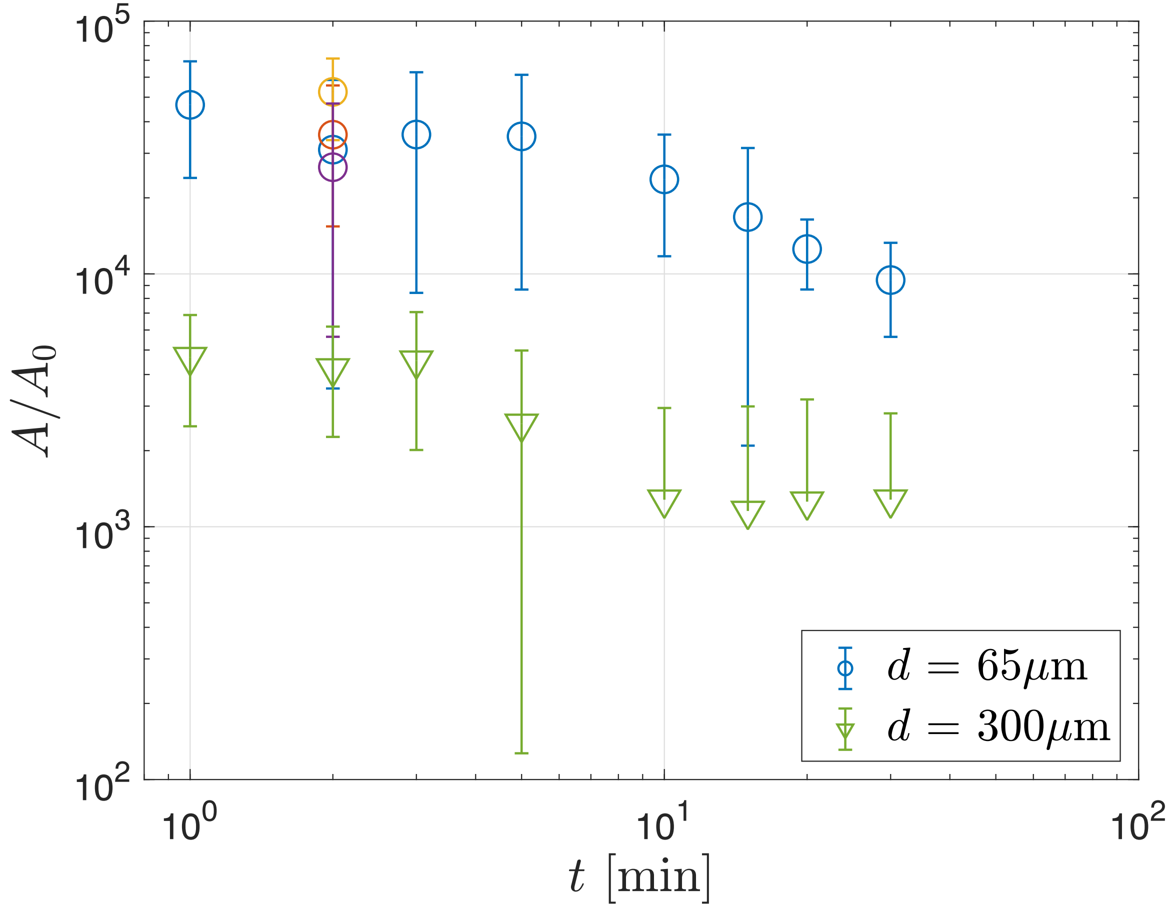




TESTS: NO MOISTURE EXCHANGE

Agglomerate Size

$$A_0 = \pi(d/2)^2$$



Analysis using thresholding and area estimation of agglomerates using ImageJ

Normalized by the projected area of a single grain

$\Longrightarrow$ Estimate of agglomerate size

Smaller grains $\Longrightarrow$ more grains per agglomerate

Over time agglomerates becoming smaller

BUT - PRIMARY FEEDBACK FROM IFPRI AGM 2023

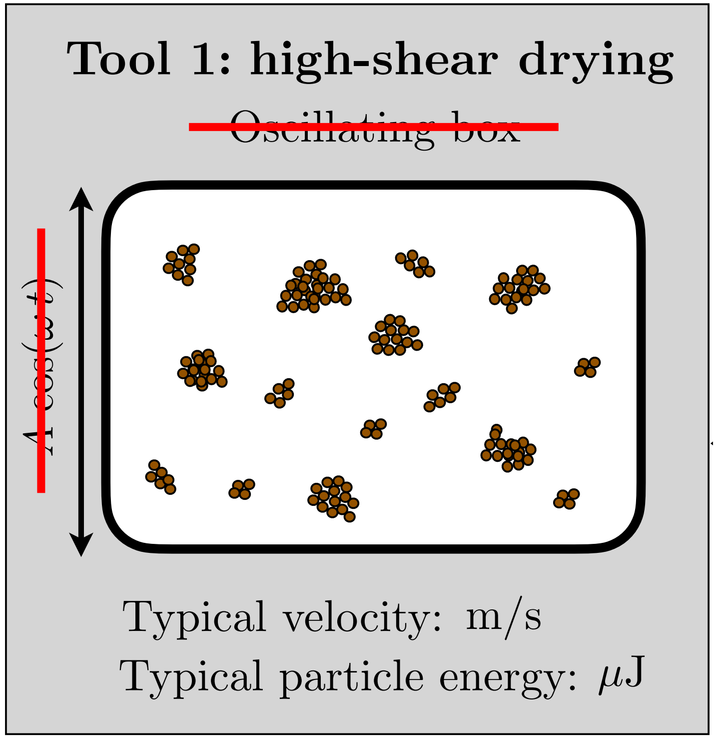
How you will create shear that matches what is seen in industrial dryers?

Members felt strongly that this question is "essential"

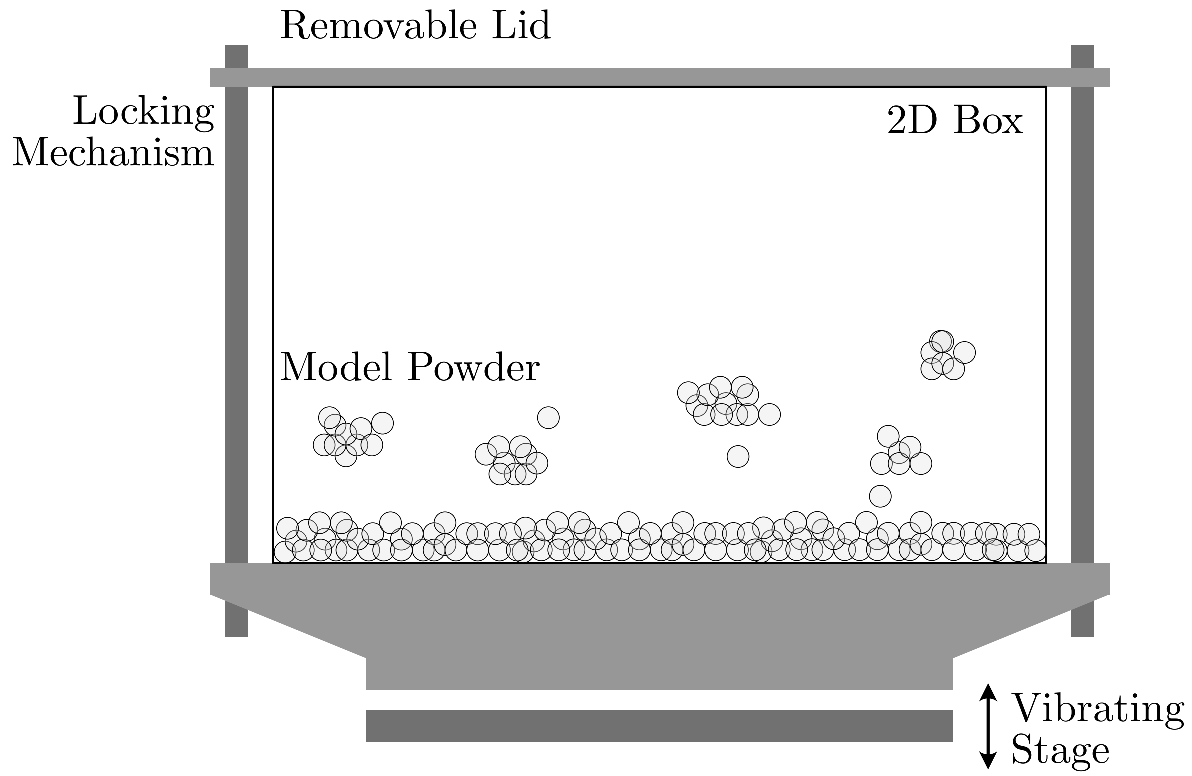
How will you measure/estimate the actual energy absorbed?

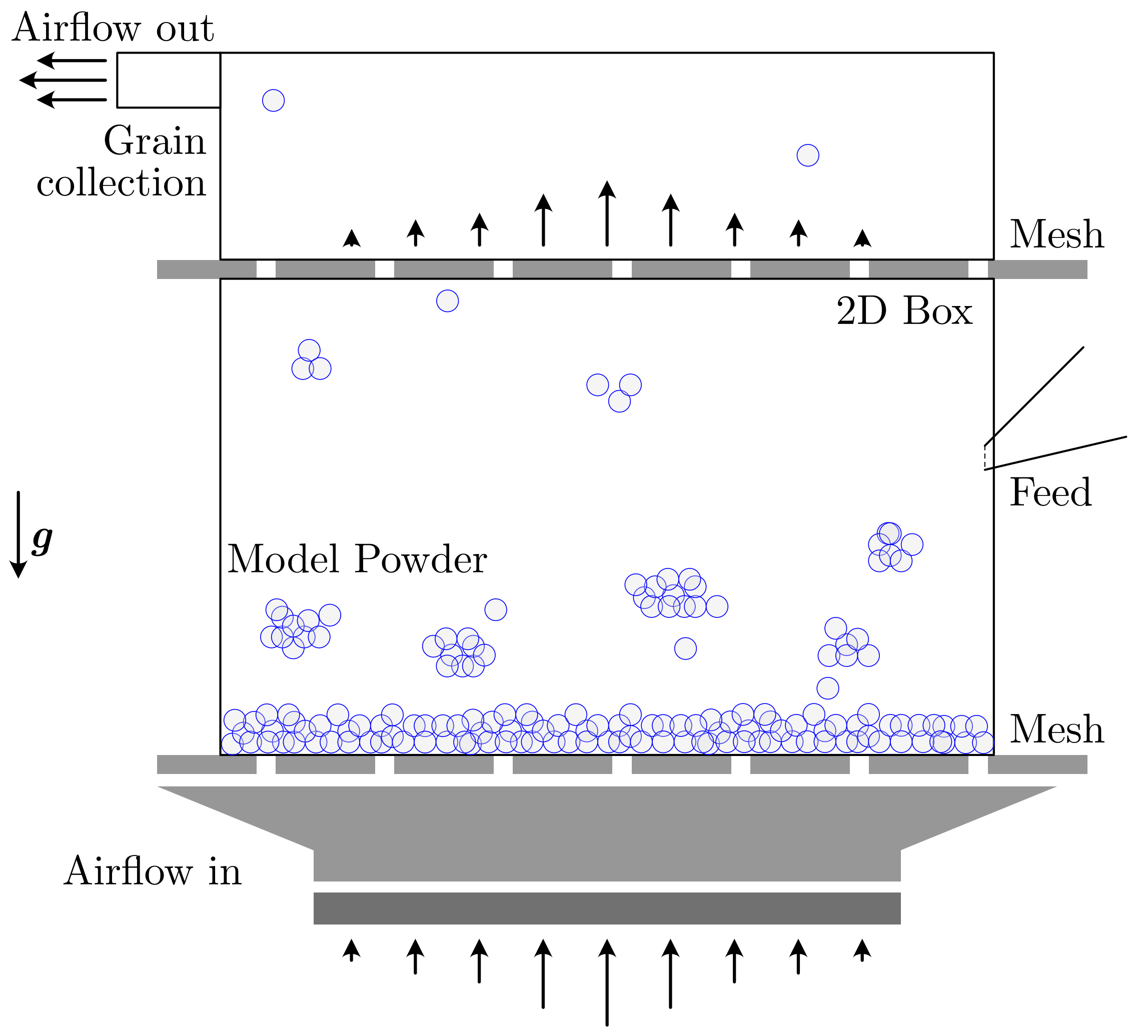
What range of shear inputs will you be able to create?

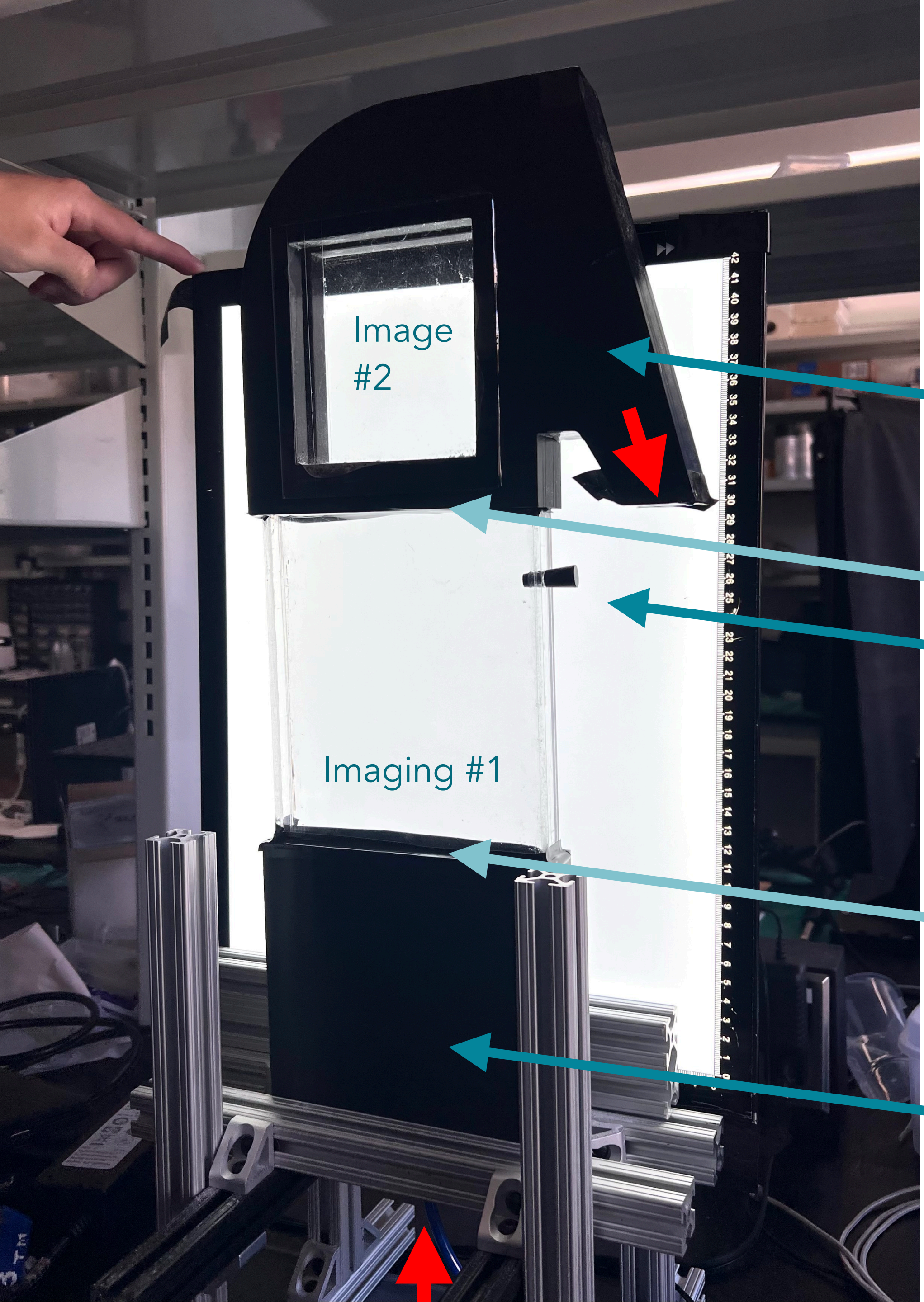
Development of the best proxy for the testing of the drying of wet powders with shear



Input from IFPRI Members: Shear by Air







Inputs: Wet material (of some mass), Flow rate, sieve sizes

(future) Temperature, Humidity

Study: Agglomerate details (dynamics), Final collected grains (cumulative)

Outcome: Regime map of agglomerates behavior as depending on some relevant properties: wetness %, shear strength, grain properties.

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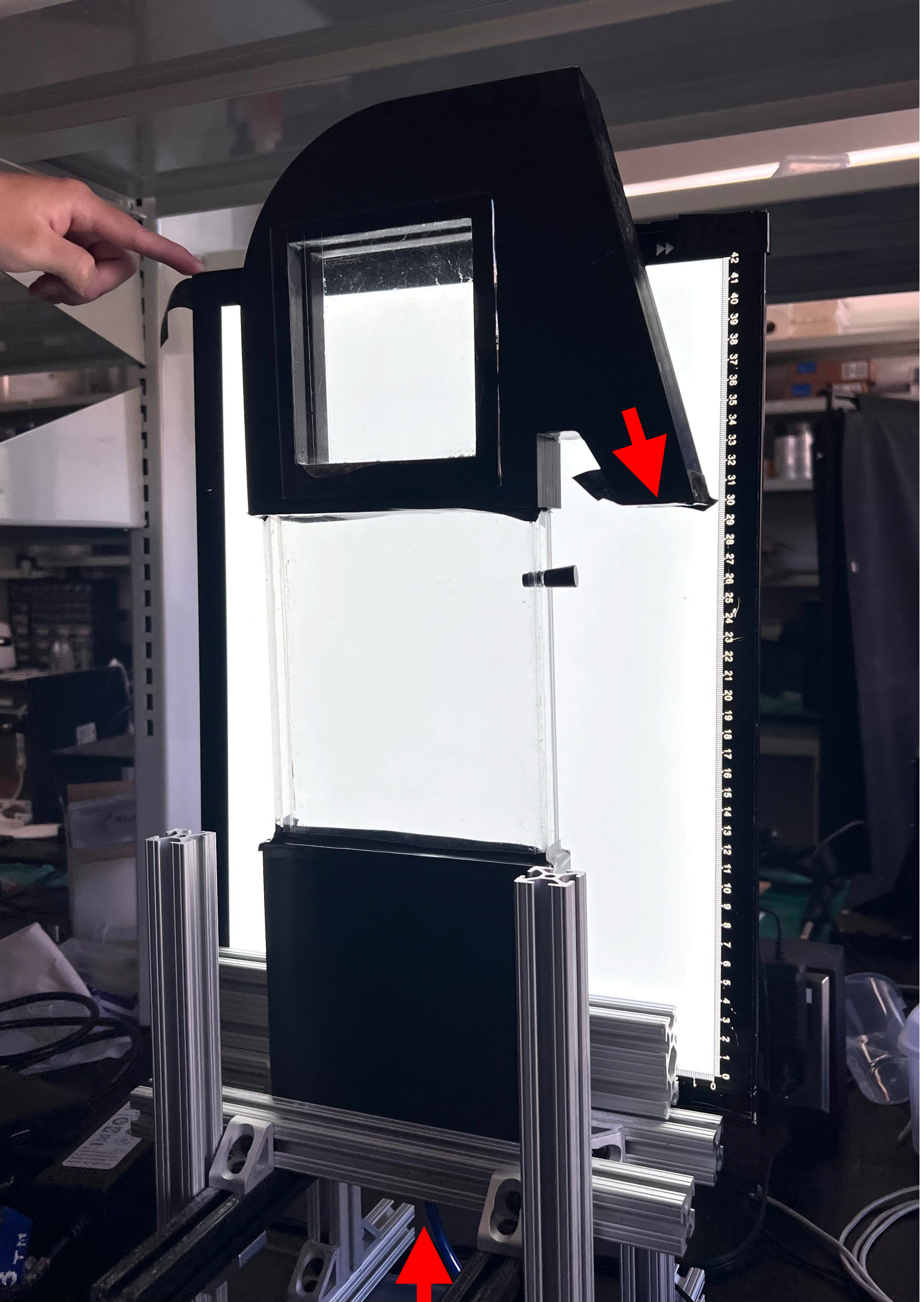
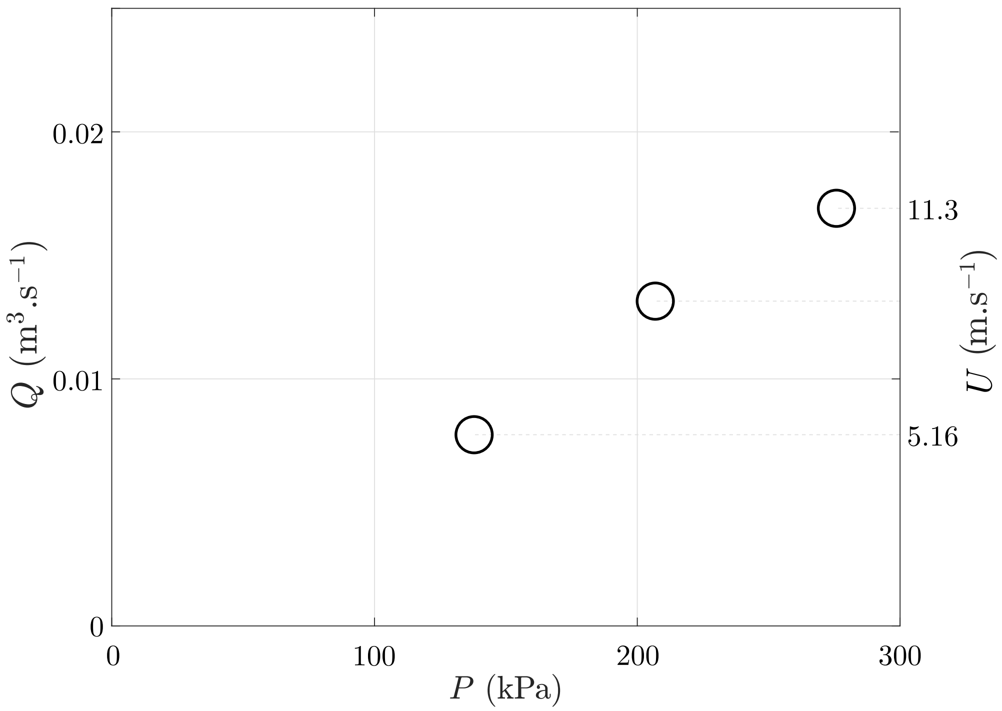




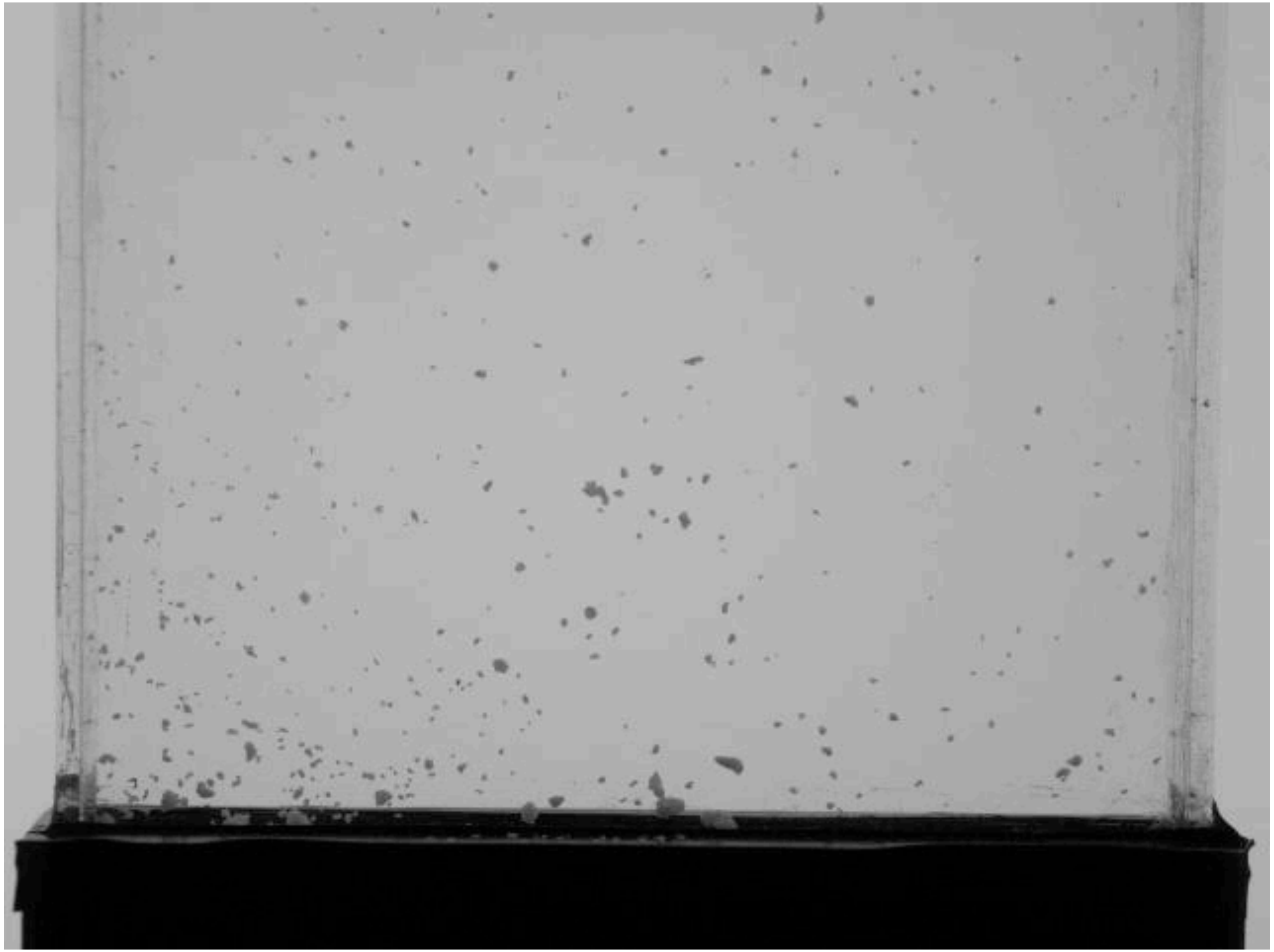
Pressure controlled: up to 40 psi - 100 psi

Using dimensional analysis and an average velocity, *U*: max shear stress around 0.1-1 Pa.

However, the presence of turbulence and particles means that a simple average is likely a large underestimate of stresses.

P = 30 psi

U ~ 5 m/s



d = 70 um

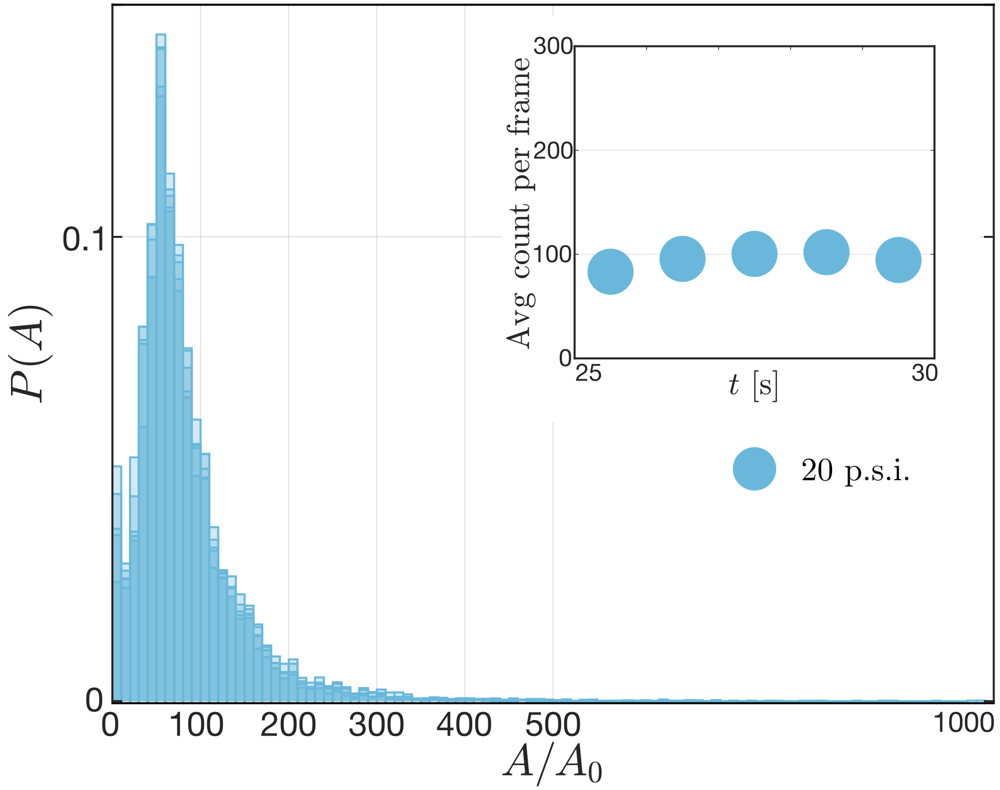
m = 3g

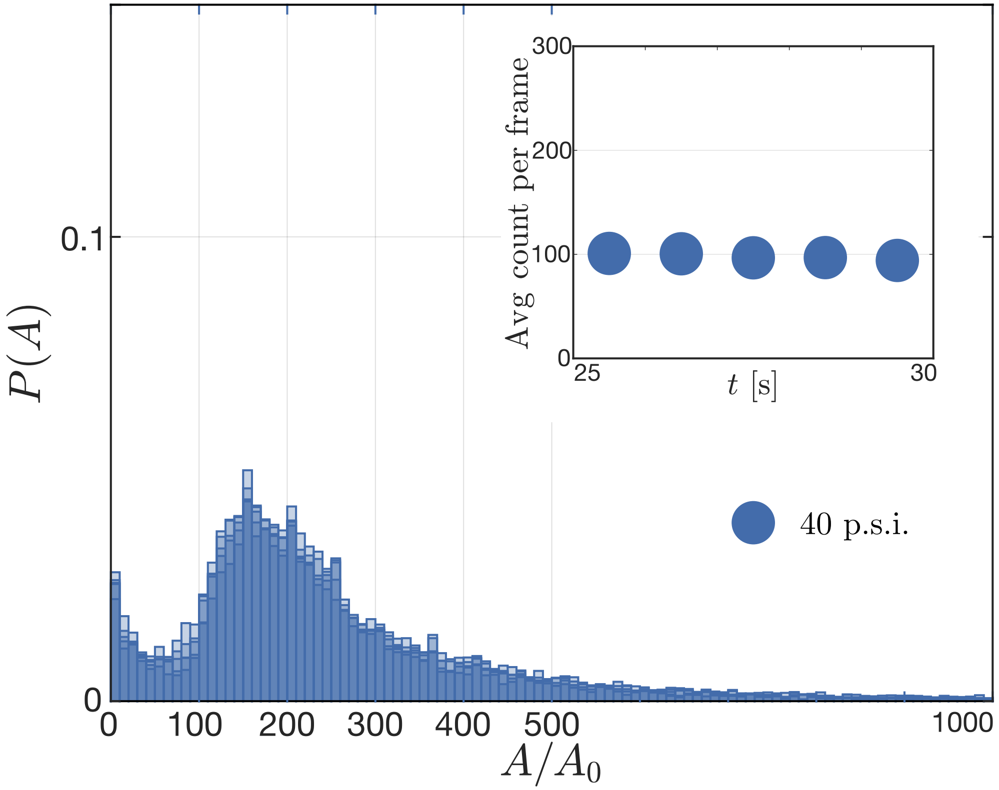
w = 0.3 [/ vol.]

Distributions after some time: Effects of input velocity

Agglomerate sizes after some time: t =30, 31 s

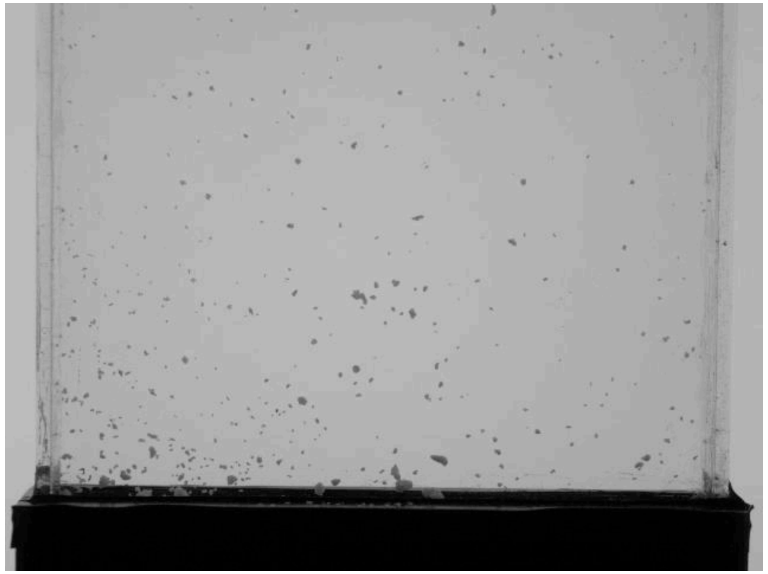
5 Different trials shown





Increase in the input velocity leads to larger stable agglomerates

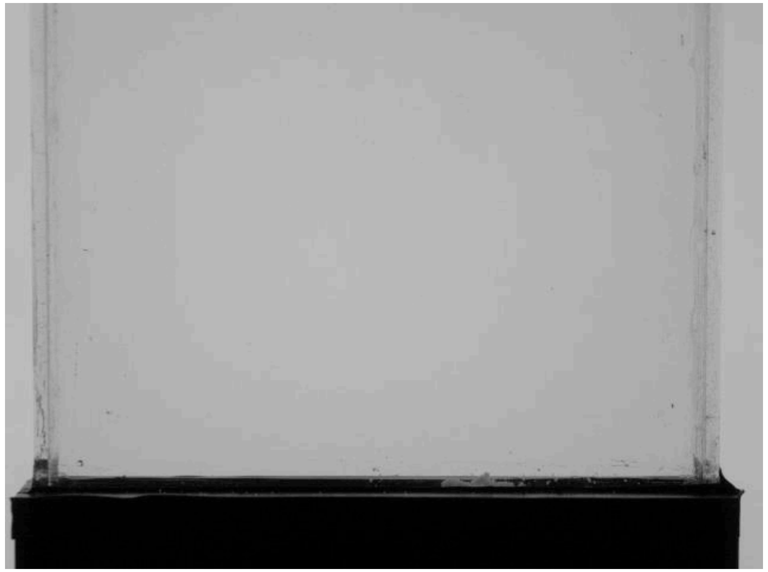
Distributions after some time: Effects of mass



P = 30 psi

U ~ 5 m/s

m = 3g

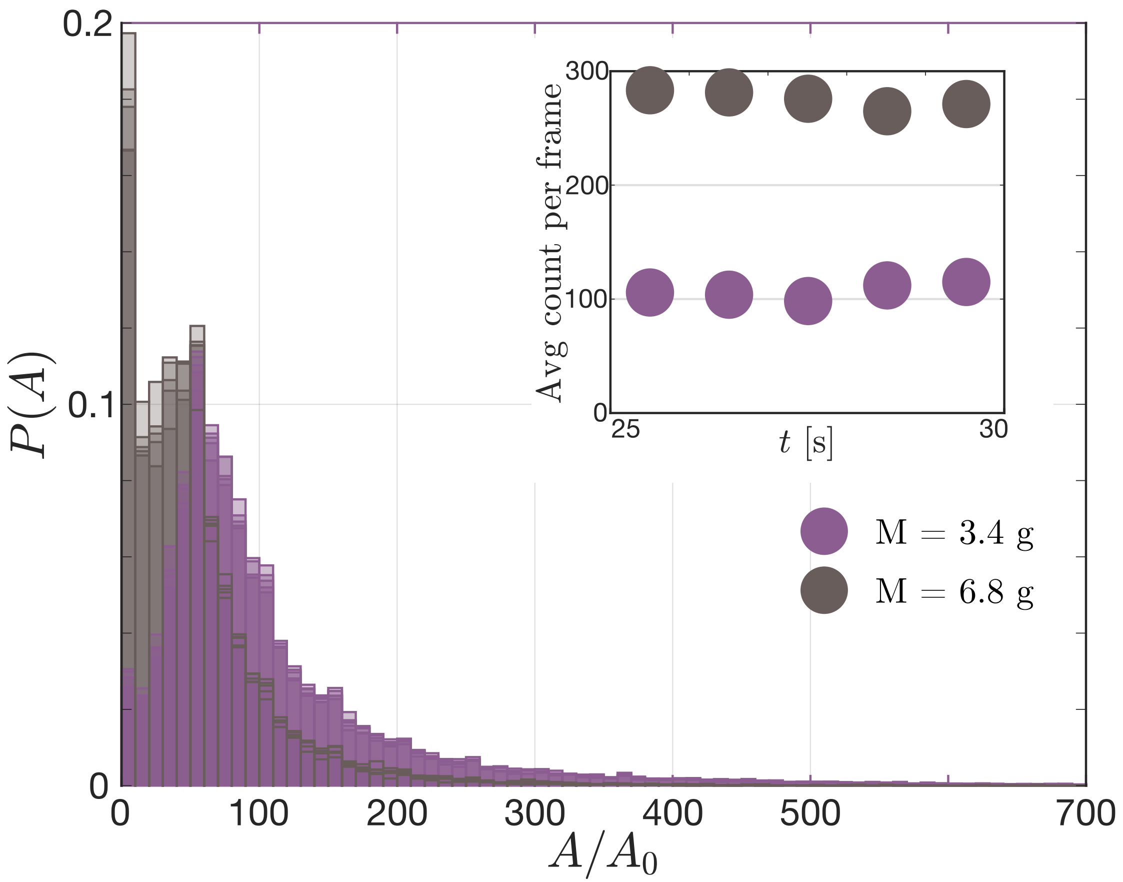


P = 30 psi

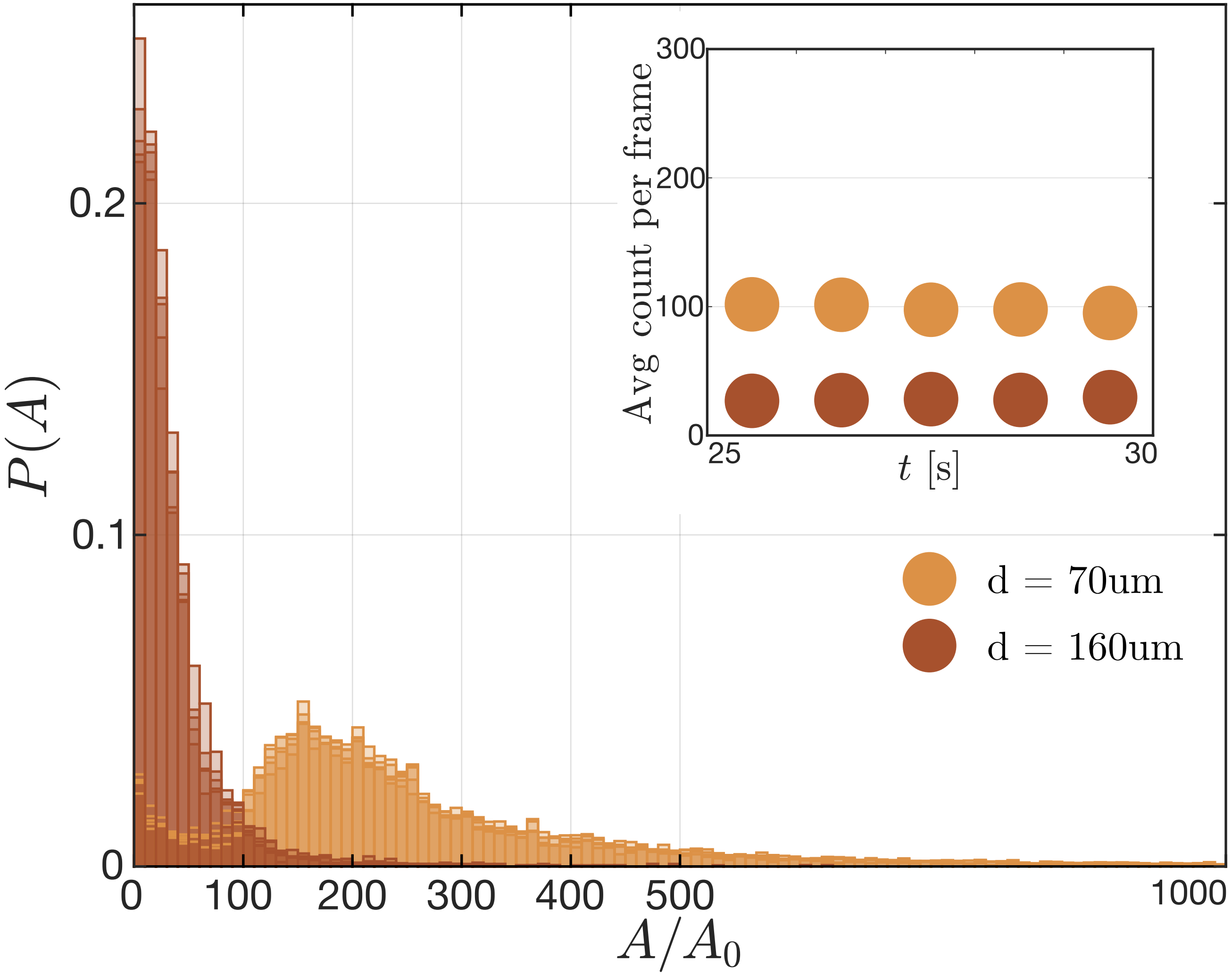
U ~ 5 m/s

m = 7g

d = 70 um



Distributions after some time: Effects of grain size



Larger grains lead to smaller overall agglomerates

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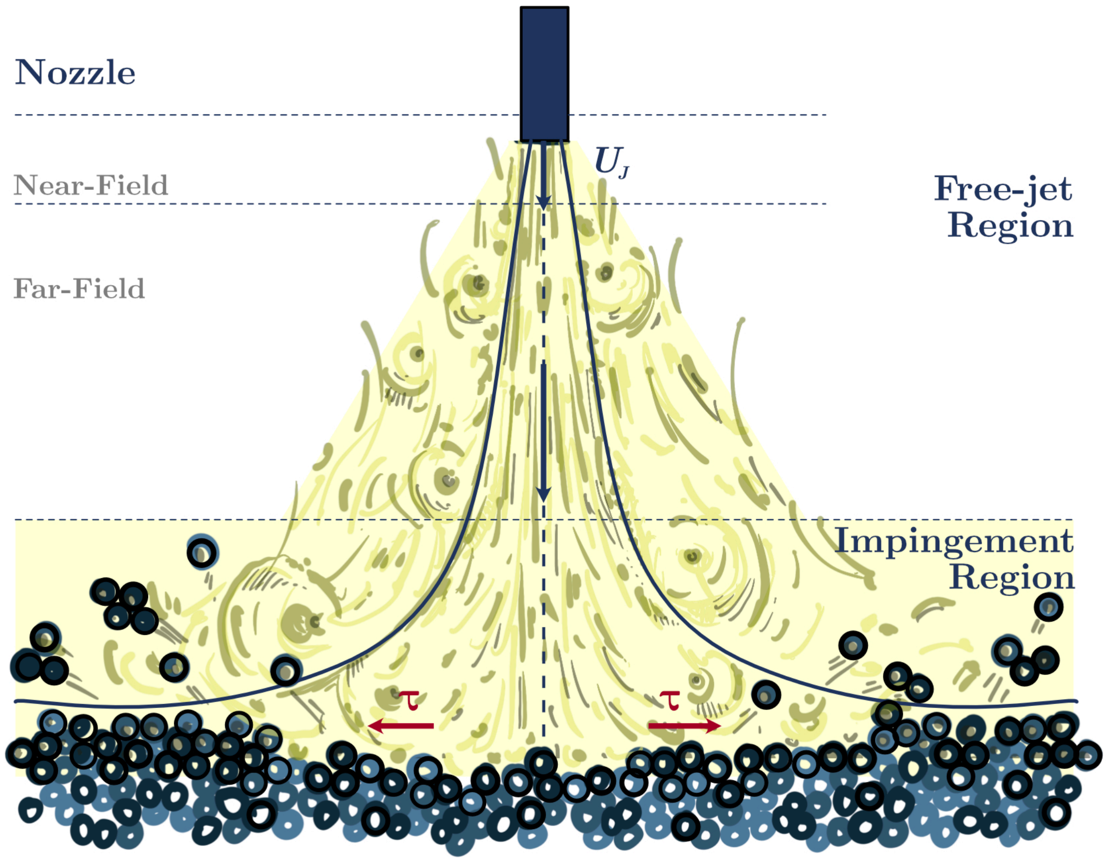
Towards Higher Shear Forces…

Impinging Turbulent Jet



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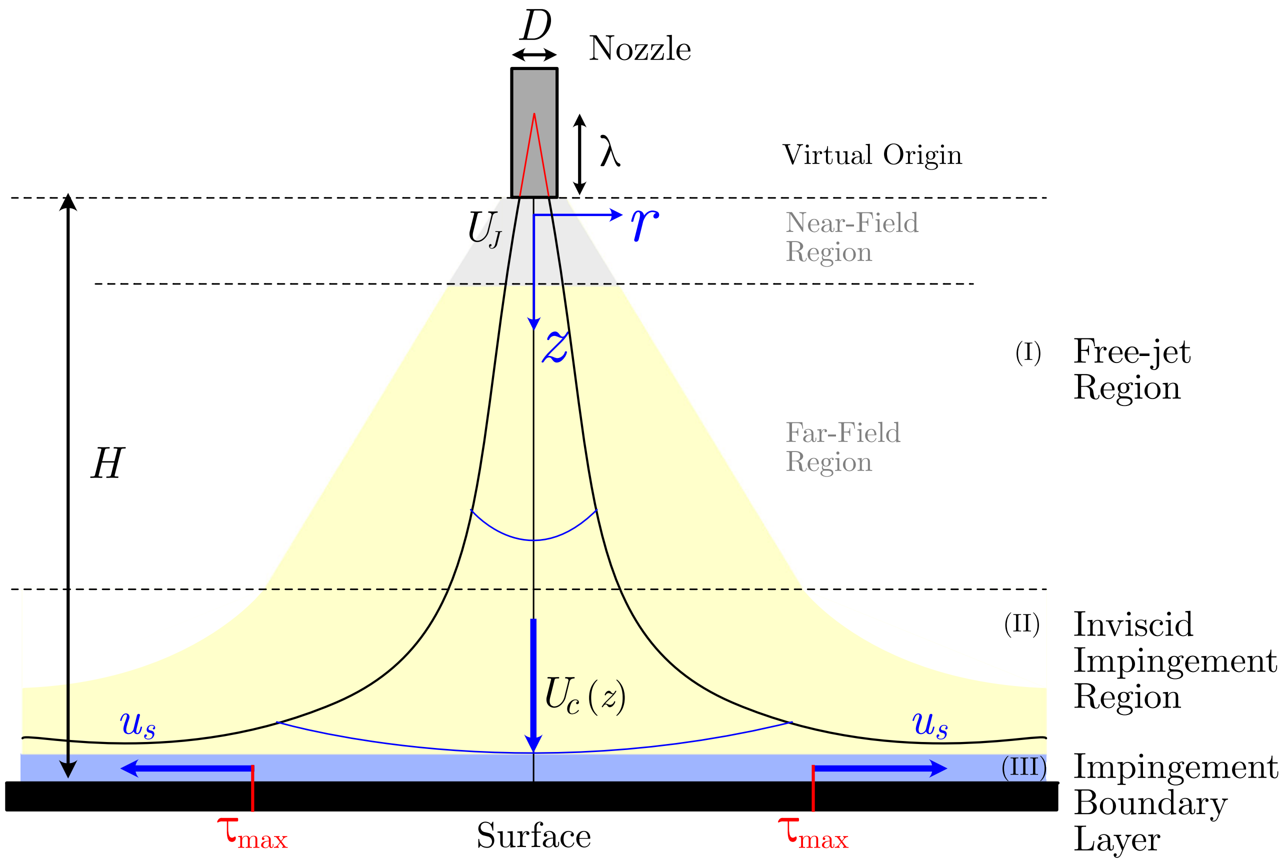
Impinging Turbulent Jet



Axisymmetric turbulent jet:

After the jet has reached a self-similar state, its time-averaged velocity only depends on the *z* and *r* coordinates.

A normally impinging axisymmetric turbulent jet:

Phares *et al.* (2000)
Badr *et al.* (2016)

Dimensionless Height: $h^+ = \left(\frac{H}{D} + \frac{\lambda}{D}\right)$

Centerline Velocity: $U_c = \kappa\, U_J \left(\frac{H}{D} + \frac{\lambda}{D}\right)^{-1}$

Max. Surface Velocity: $\max\ u_s \simeq U_c = \kappa\, U_J \left(\frac{H}{D} + \frac{\lambda}{D}\right)^{-1}$

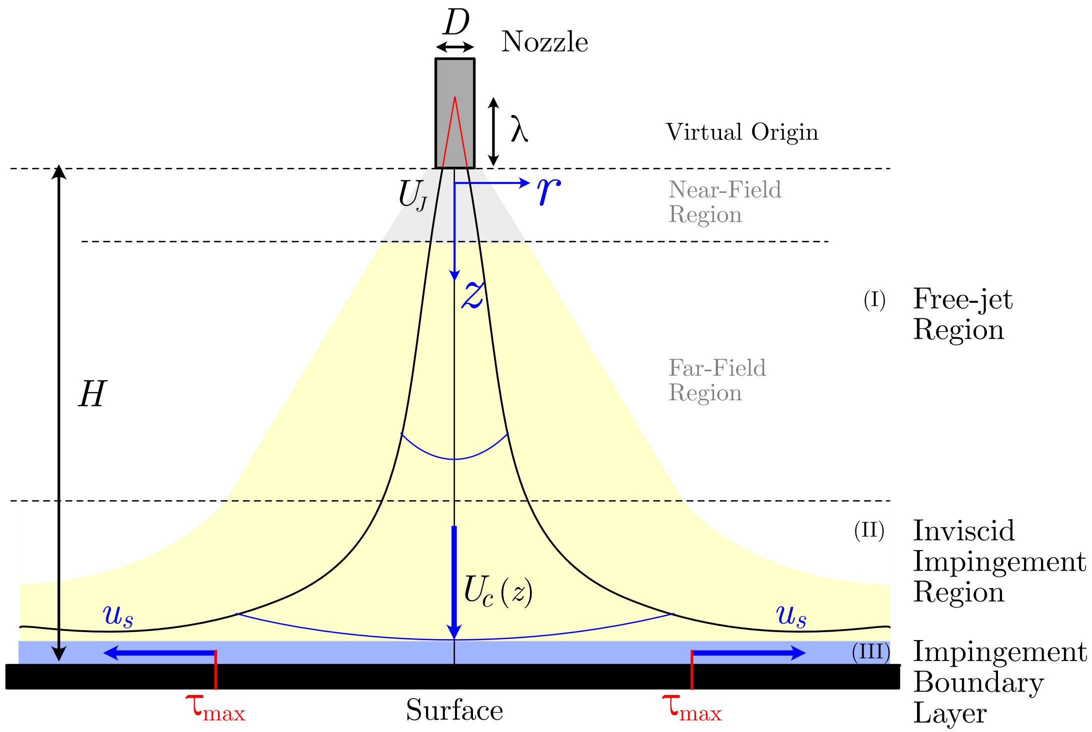
Max. Surface Shear: $\max\ \tau = \kappa_2\, U_J^2\, Re_J^{1/2} \left(\frac{H}{D} + \frac{\lambda}{D}\right)^{-1}$

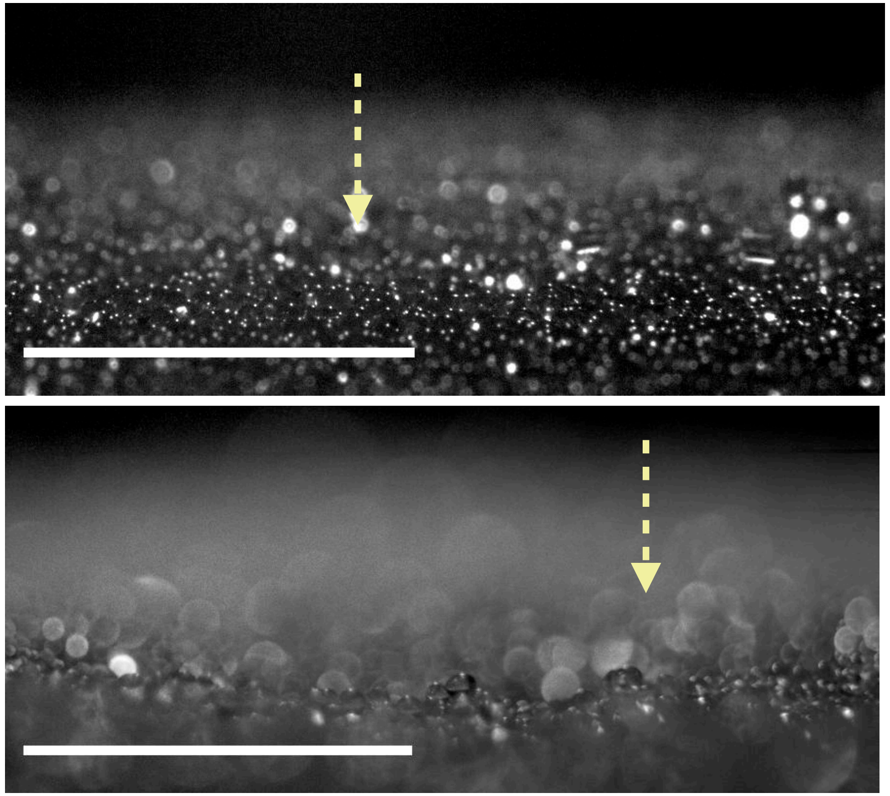
Location of max surface velocity $\simeq$ location of max surface shear stress

λ Virtual origin

κ, κ_2 Numerical prefactors that depends on the structure of the jet

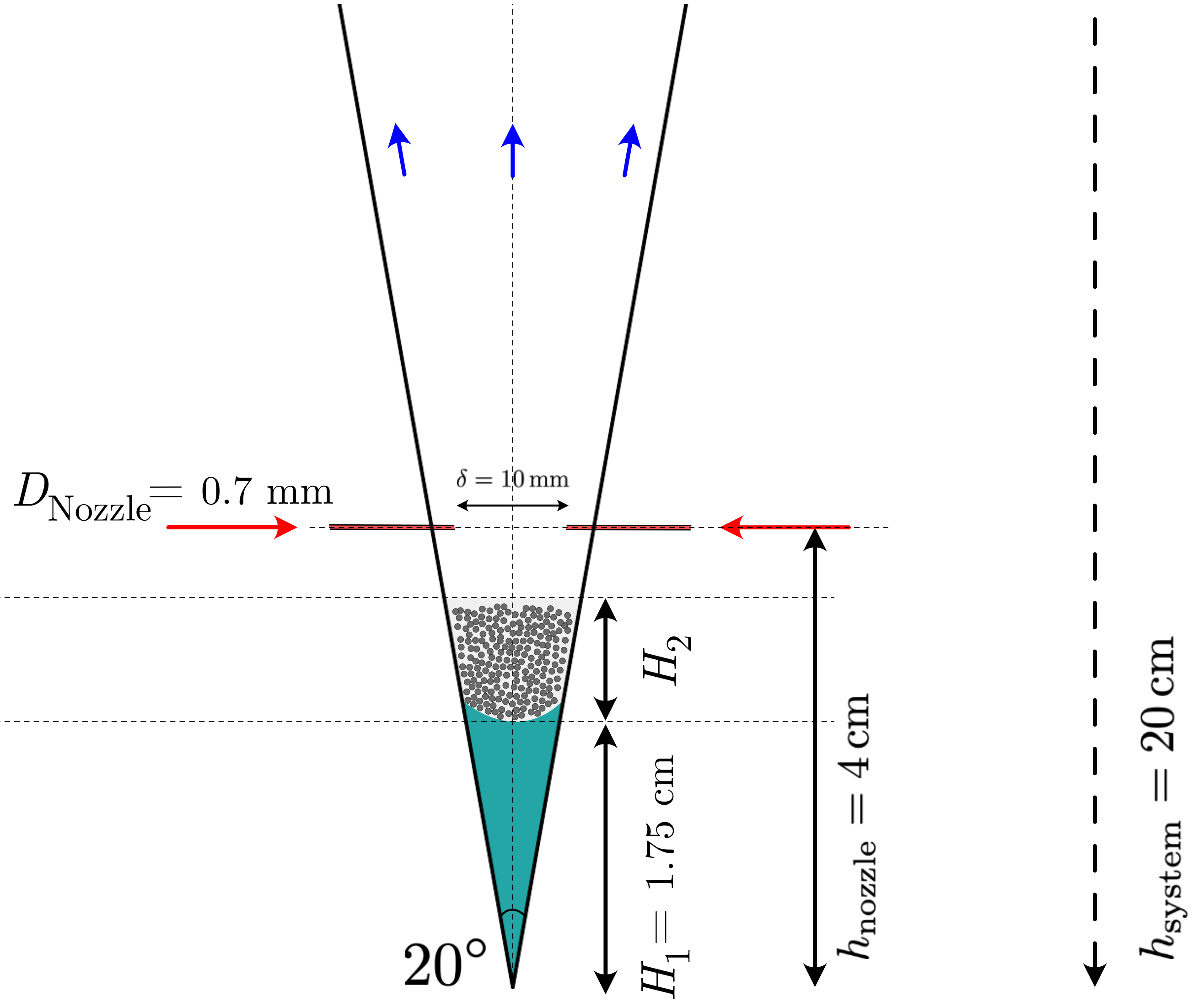
Impinging Turbulent Jet

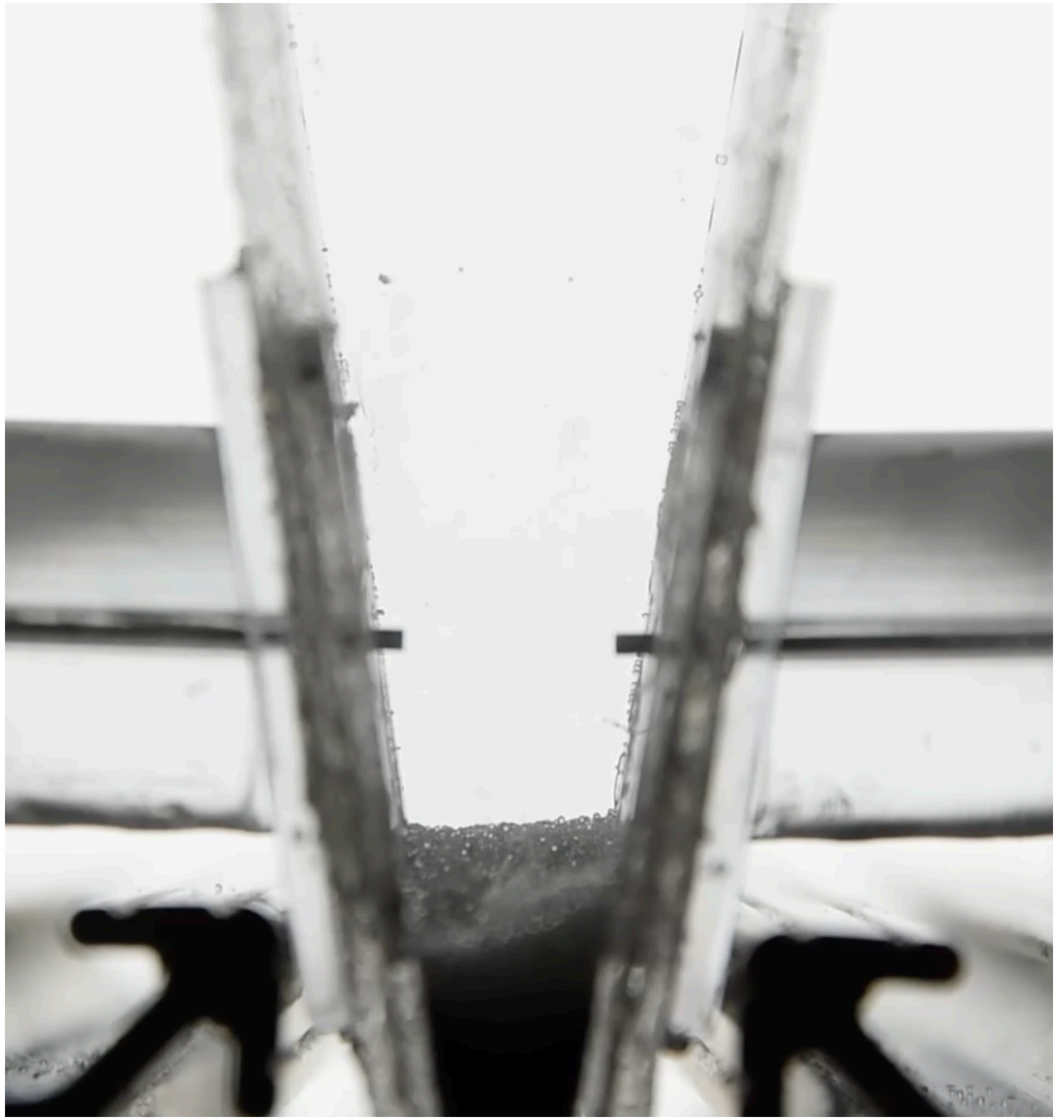




Sharma *et al.*, **Erosion of cohesive grains by an impinging turbulent jet**, Physical Review Fluids, 7(7), 074303 (2022).

Towards Higher Shear: Impinging Turbulent Jet



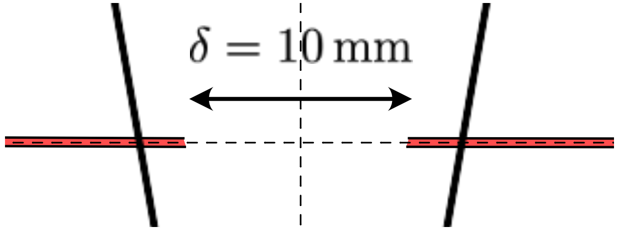


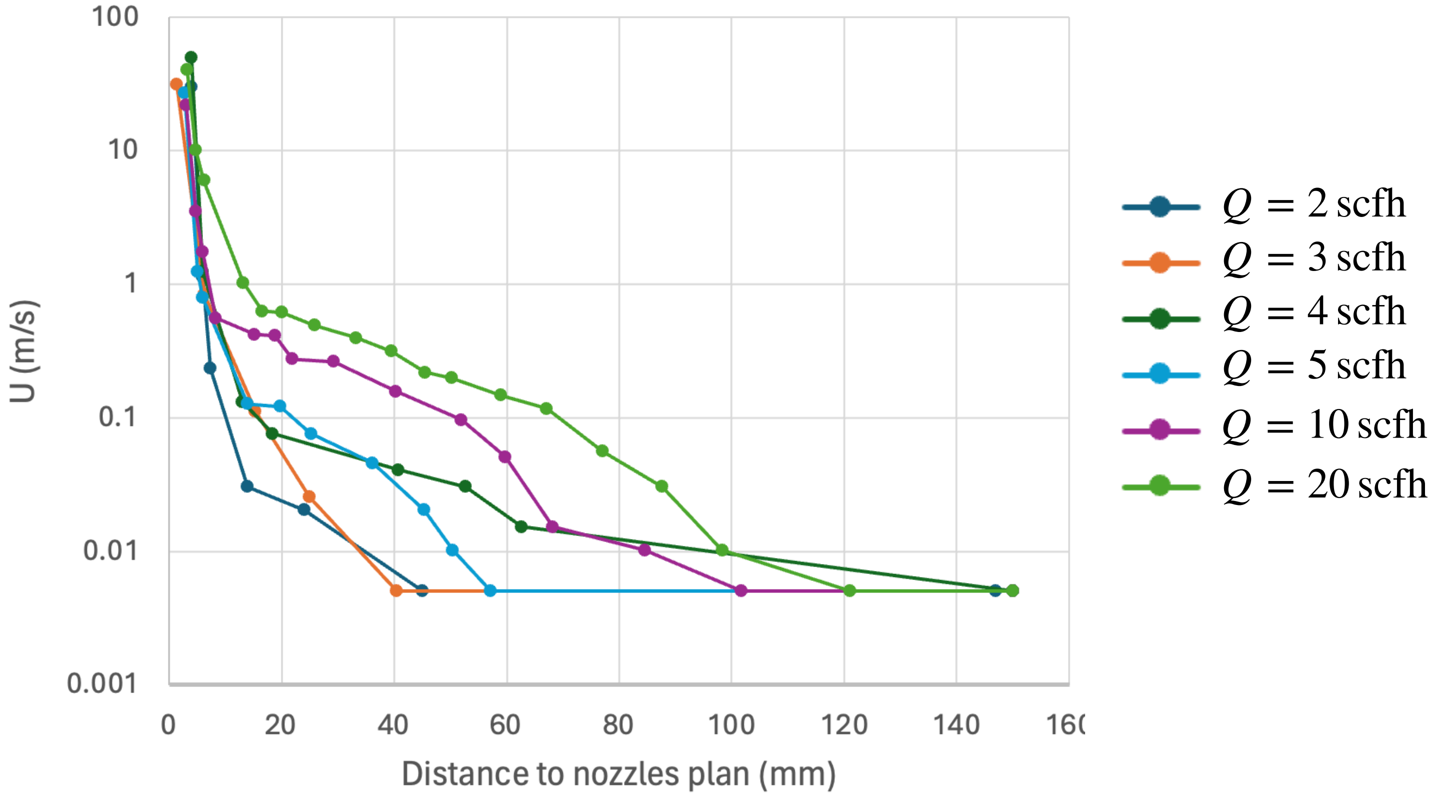
Impinging Turbulent Jet: Estimation of the Velocity and Shear

Flow rate: $5\,\mathrm{scfh} \leq Q \leq 25\,\mathrm{scfh}$ ($4 \times 10^{-5}\,\mathrm{m^3/s} \leq Q \leq 2.5 \times 10^{-4}\,\mathrm{m^3/s}$)

Nozzle diameter: $d = 0.7\,\mathrm{mm}$

Velocity at the outlet: $100\,\mathrm{m/s} \lesssim U_\mathrm{J} \lesssim 300\,\mathrm{m/s}$





$$\tau_{\max} \sim 40 \rho_a U_\mathrm{J}^2 \,\mathrm{Re}_\mathrm{J}^{-1/2} \left(\frac{H}{D}\right)^{-2}$$

$$\tau_{\max} \sim [30\,\mathrm{Pa}, 200\,\mathrm{Pa}]$$

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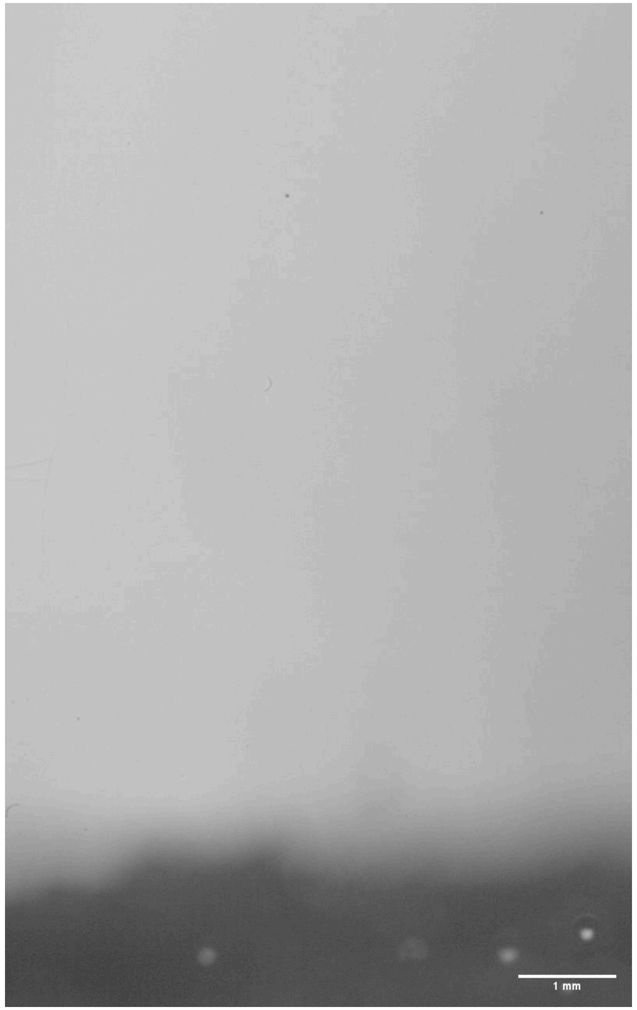
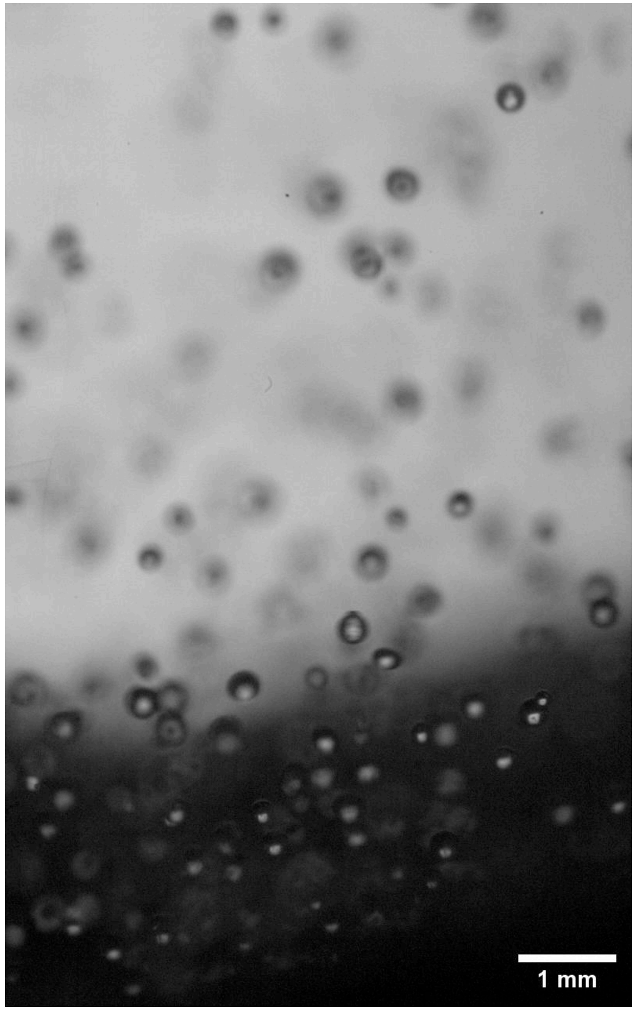
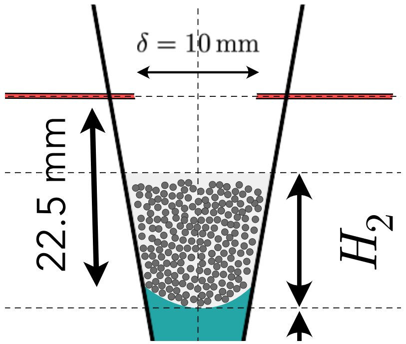
OBSERVATIONS: H_2=15MM

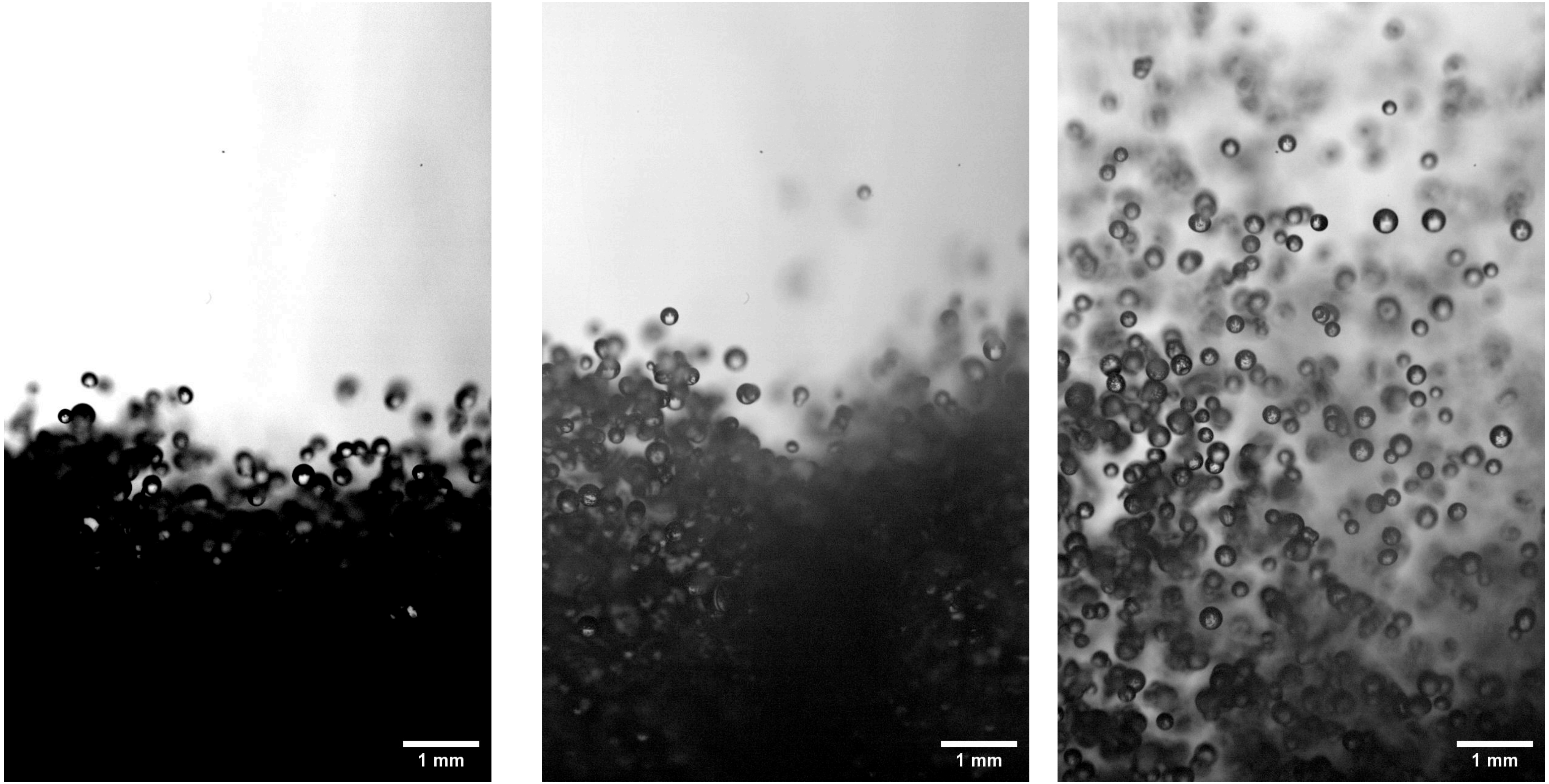


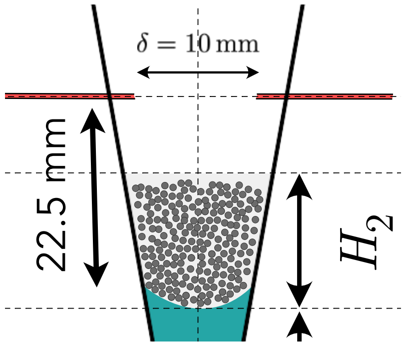




Slow down 100 times

OBSERVATIONS: H_2=24.5 MM

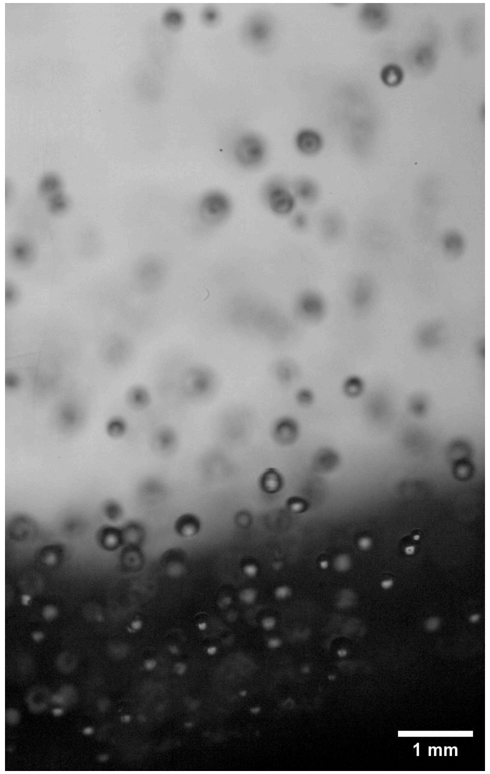




Slow down 300 times

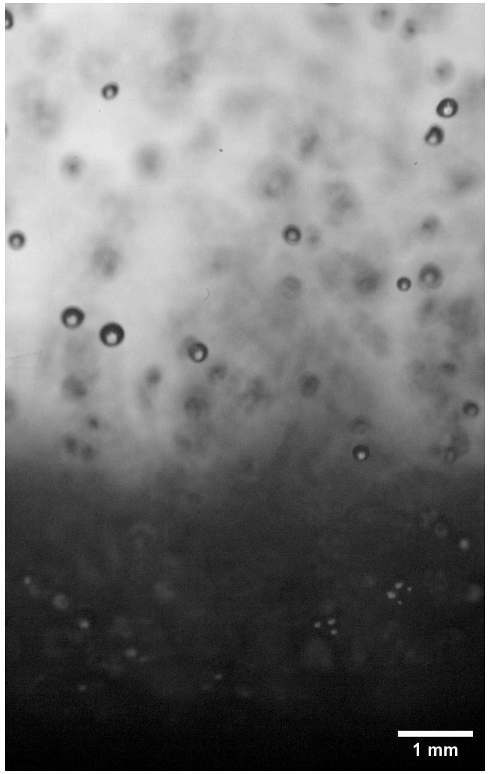
Position of the turbulent jet

$\delta H = 9.8\,\mathrm{mm}$

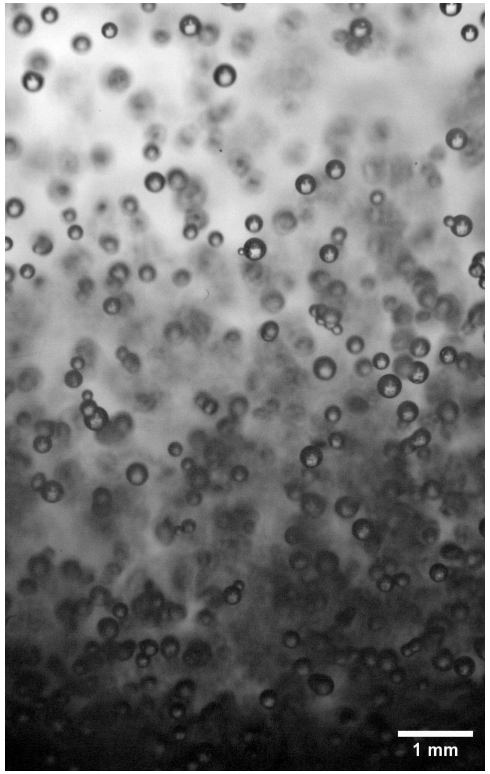


Slow down 100 times

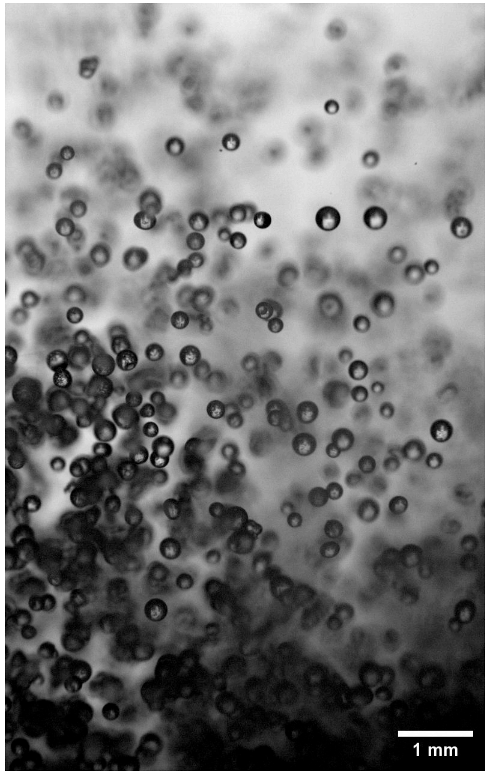
$\delta H = 7.5\,\mathrm{mm}$



$\delta H = 1.5\,\mathrm{mm}$



$\delta H = -2\,\mathrm{mm}$



Slow down 300 times

CONCLUSIONS & NEXT STEPS

Designed a new setup with a much stronger **localized shear** brought by a turbulent jet

First tests performed with **200 microns** glass beads and estimates of the flow velocity

Adding wet grains and powders **(calcium carbonate)**: time evolution and final size of aggregates

Control of **humidity and temperature** in the incoming turbulent jet

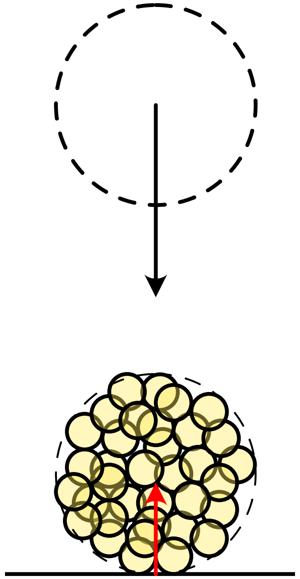
Ram Sharma

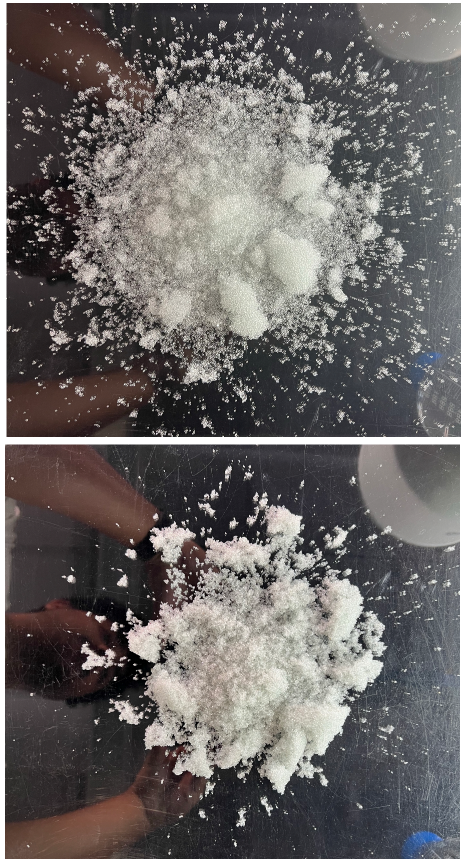
Sreeram Rajesh

In parallel: improve our fundamental knowledge of cohesive grains and multiphase processes

More on Cohesive Grains and Multiphase Processes

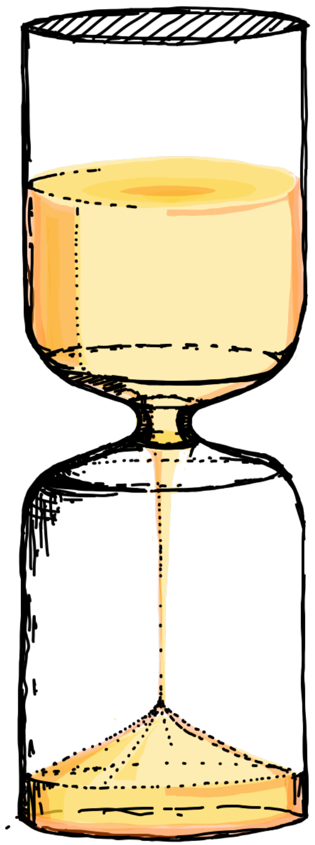
Fragmentation of aggregates

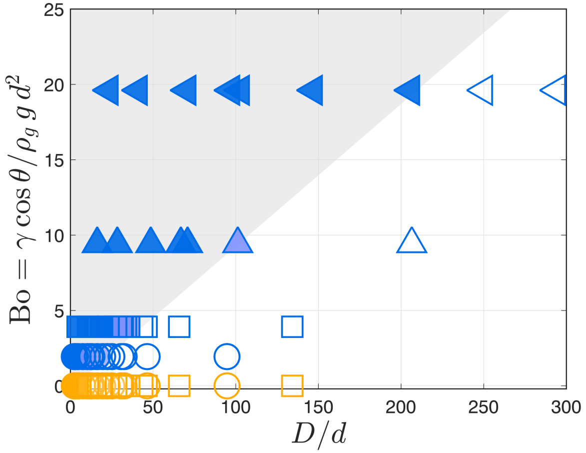


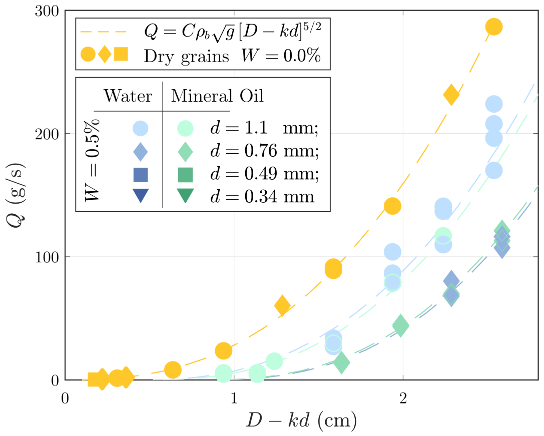


Model agglomerate:
- size (D)
- grain size (d)
- cohesion
- initial height (H)

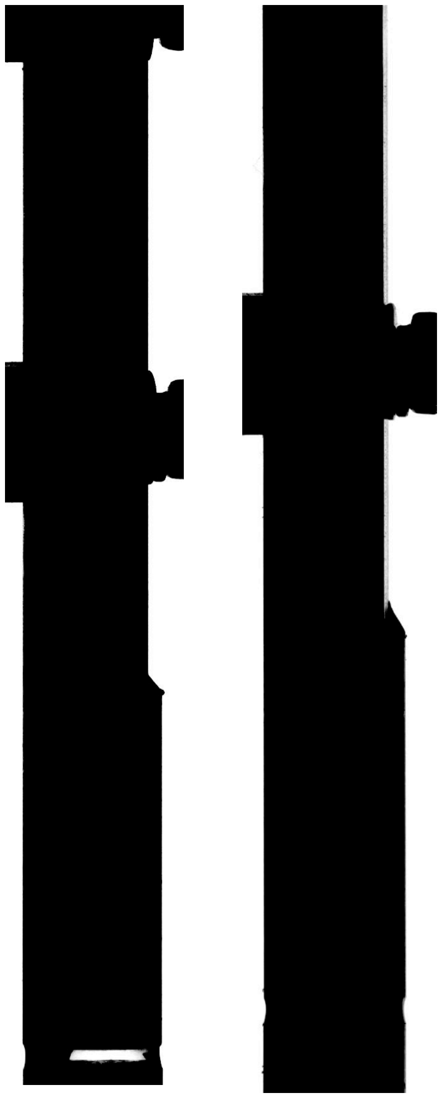
Beverloo's law and clogging for cohesive grains







Atomization of suspensions



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