Characterizing the effects of shear on drying wet powders

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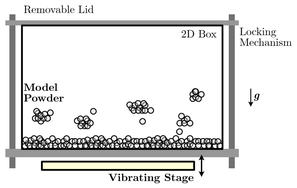
Objective — Characterize how shear can affect the state of agglomeration of products undergoing drying

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.

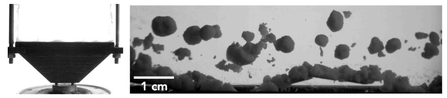
Updates — Experimental approaches to model shear provided to the grains. Mechanical agitation was the primary source of shear considered in year 1. This year, focus has been on using airflow to provide the shear to the product, more closely resembling drying.

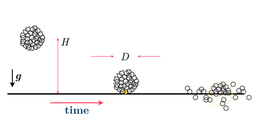
Shear provided by mechanical agitation & collisions:

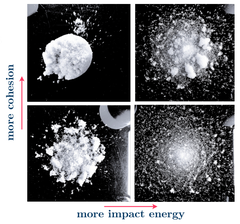


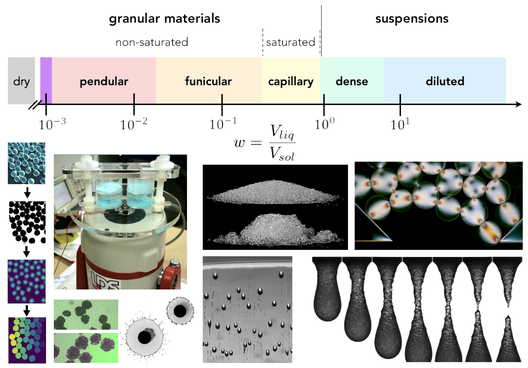
Recap: This setup gave results was more complicated than expected. Continuous fragmentation and coalescence of agglomerates observed, and such processes are not well linked to particle- or bond-scale models. At the suggestion of IFPRI members from last AGM, this approach simplified and the focus of the project moving to airflows instead.

Over time, disintegration observed rather than drying. A disintegration is a result of continuous fragmentation events at impact. A new experiment studying the fragmentation statistics using controlled collisions of agglomerates and surfaces, to develop a first-order model of such mechanical interactions.

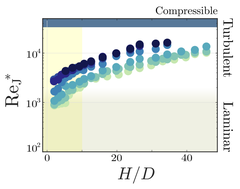








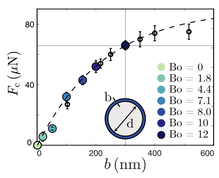
Model erosion using idealized cohesion and airflow

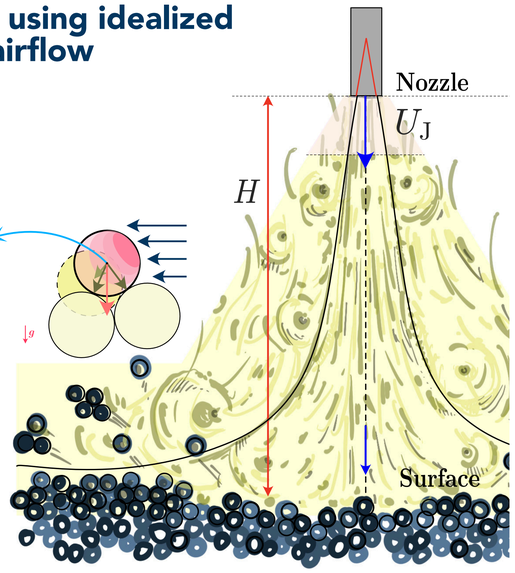


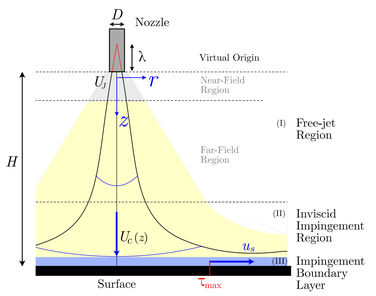
$$\mathrm{Sh}_{J,c} = \frac{F_J}{F_W + F_{c,tot}}$$

An estimate for total cohesion

$$F_{c,tot} = \alpha F_c$$







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

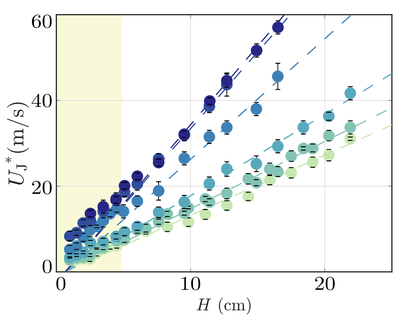
Centerline Velocity: $U_c = \kappa U_J \left(\frac{H}{D} + \frac{\lambda}{D}\right)^{-1}$

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 — location of max surface shear stress

λ Virtual origin — κ, κ_2 Numerical prefactors that depend on the structure of the jet



Effects of cohesion on resisting the onset of erosion are captured by a bond number, $\mathrm{Bo} = \frac{F_C}{F_W}$

$$\mathrm{Sh}_{J,c} = \frac{\mathrm{Sh}_J}{1 + \alpha\,\mathrm{Bo}}$$

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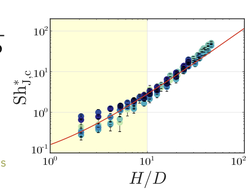
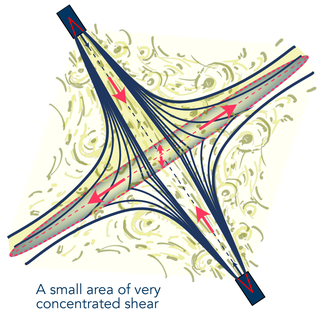
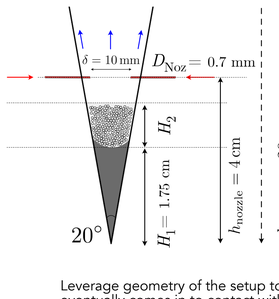
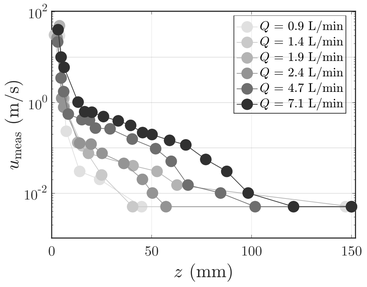


Impinging turbulent jets of air

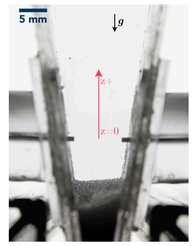


A small area of very concentrated shear





Leverage geometry of the setup to ensure that all product eventually comes in to contact with region of known and large shear. Walls made steep to avoid sedimentation, particularly for cohesive grains.



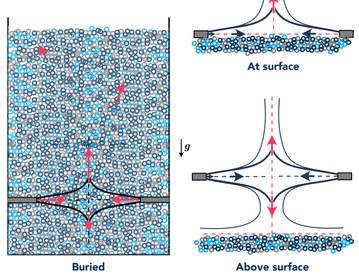
Controlling flow rate, Q, allows us to control the local velocity (and shear) within the device

$U_J = Q/A_{Noz} = [100,300]$ m/s

$Re_J = \rho_a U_J D/\mu_{air} \approx 50{,}000 - 150{,}000$

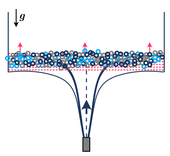
$\tau_{max} \sim 40\,\rho_a U_J^2\,\mathrm{Re}_J^{-1/2} \left(\frac{H}{D}\right)^{-2} \approx 30 - 200\mathrm{Pa}$

$\tau_{max} \sim \rho_a u_{meas}^2 \approx 0.5 - 3\,\mathrm{kPa}\,(\mathrm{over-estimate})$



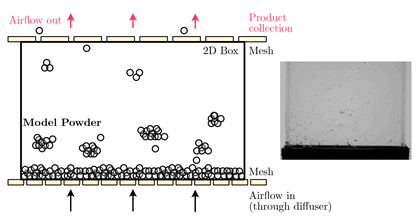
Now studying the evolution of agglomerate sizes when a mass of grains is placed in such a flow. Setup designed so the area of large shear can be tested for being buried within the granular bed, roughly at the surface and also above. In all cases, the provided airflow can be modified to control how much the product far from the interacting jets is affected. Next step to quantify the association of peak shear and agglomerate size distributions.

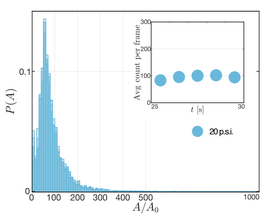
Airflow through bed ($a \gg g$)

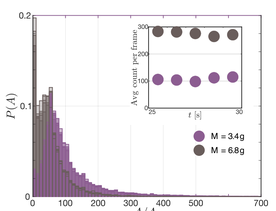


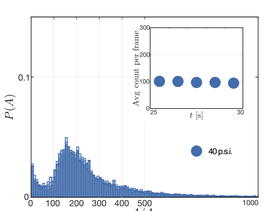
Some statistics of agglomerate sizes were studied for the case when the applied airflow is placed below a granular bed. The force due to the airflow is much larger than the weight of the particle, causing agglomerates to be airborne, as they undergo drying. The quazi-2D box is then placed in front of a light panel and imaged.

For a given airflow and cohesive powder, average statistics converge for a few different trials after some initial transience. Shown here for sphere of d=70um, made wet by 1%[v] of water. Agglomerate sizes are shown relative to the size of an individual grain.







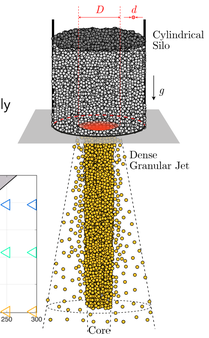


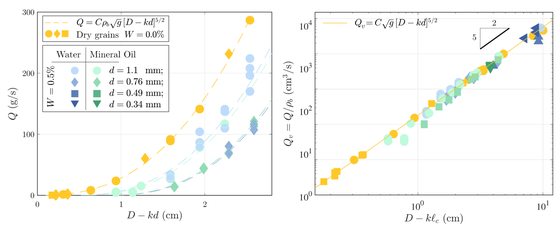
Cohesive silo flows

Alongside studying the effects of shear on drying powders, our lab is currently studying the effects of cohesion on model silo flows.

As expected, the effects of cohesion are most strongly felt in the ability of such systems to spontaneously clog. Much larger apertures can frequently clog with cohesive grains, and this is studied for controlled cohesion.

Effects on flow rate (Beverloo's law) can be captured by considering a length dependent on cohesion replacing the grain diameter. For large enough openings, effects of cohesion are small.





New input flow: direct flow measurement and temperature control at input. Flow and humidity measure in system.

More close details of stresses within the system: Using tracer particles and flow measure to determine a set of conditions where all particles are made to go through the area of large shear.

Measurements: Once these parameters are brought under control, we will study the evolution of agglomerate sizes undergoing agitation at the interaction of the jets.

Final size distributions: of brittle agglomerates once moisture has been removed.

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