Shear flow and silo flow of elongated and flat particles

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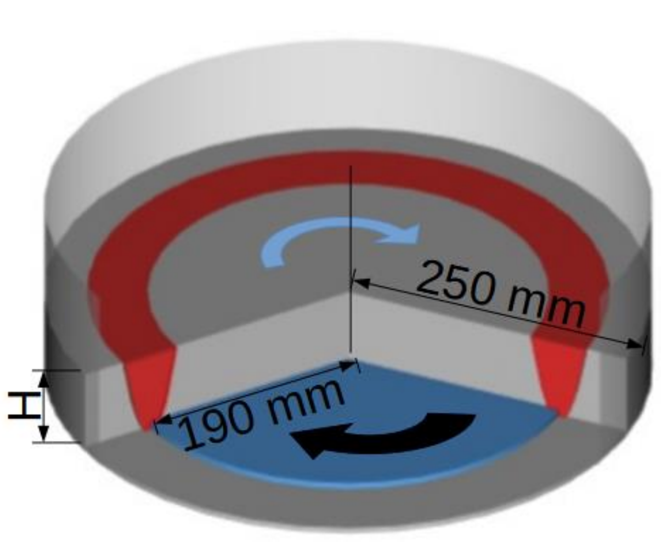
When elongated particles are flowing, we observe that orientational ordering develops: the particles align with their long axis approximately parallel to the flow.

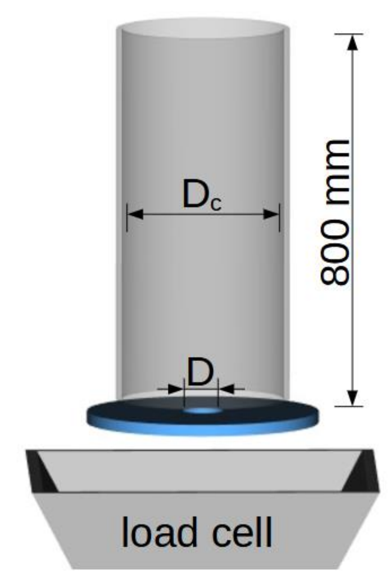
Does this lead to easier flow for such grains compared to spheres? Will we observe faster discharge rate from a silo for non-spherical particles than for spherical ones? Will the alignment of the grains lead to smaller resistance against shearing?

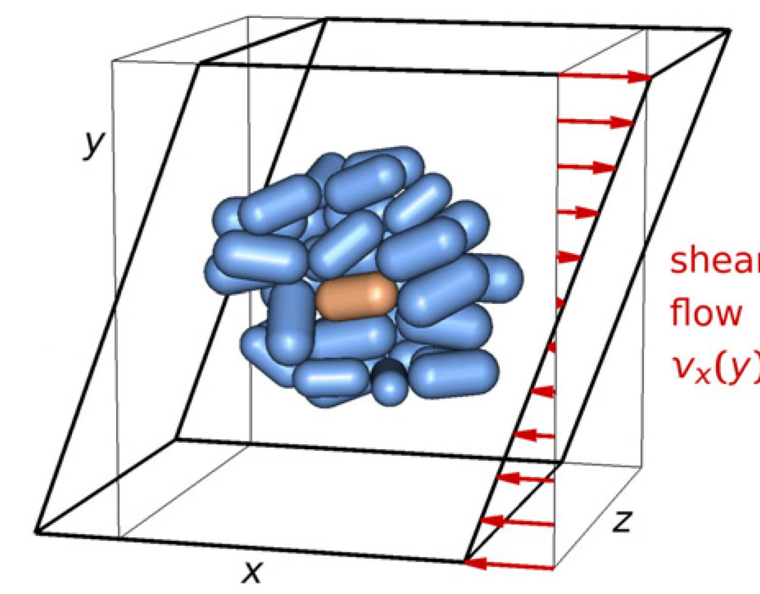
In this work we seek the answer to these questions by laboratory experiments and numerical (DEM) simulations. We perform a systematic study by changing the grain shape by using elongated and flat ellipsoids (rice-like and lentil-like shapes) and rods.

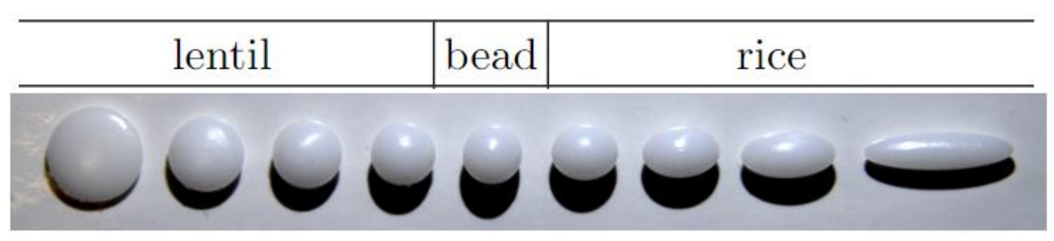
We find a non-trivial dependence for the silo discharge rate as well as for the effective friction of the granular material as a function of grain aspect ratio.

Shear experiment — **Silo experiment/simulation** — **Shear simulation**







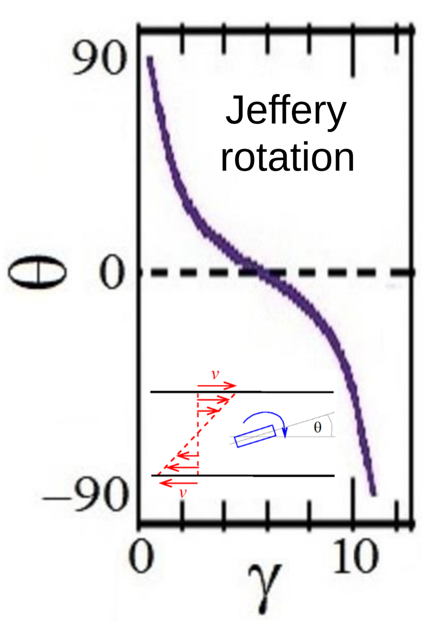


rods

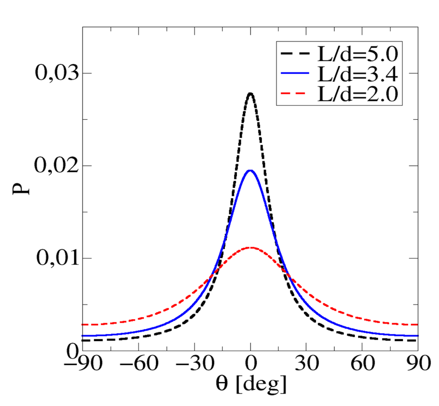
An elongated particle in a shear flow rotates with modulated speed.

Hard particle in a liquid

Orientation angle of an ellipsoid in a sheared liquid as a function of shear strain: rotation speed is modulated.

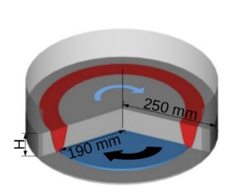


Orientation distribution: average alignment is parallel to the main flow

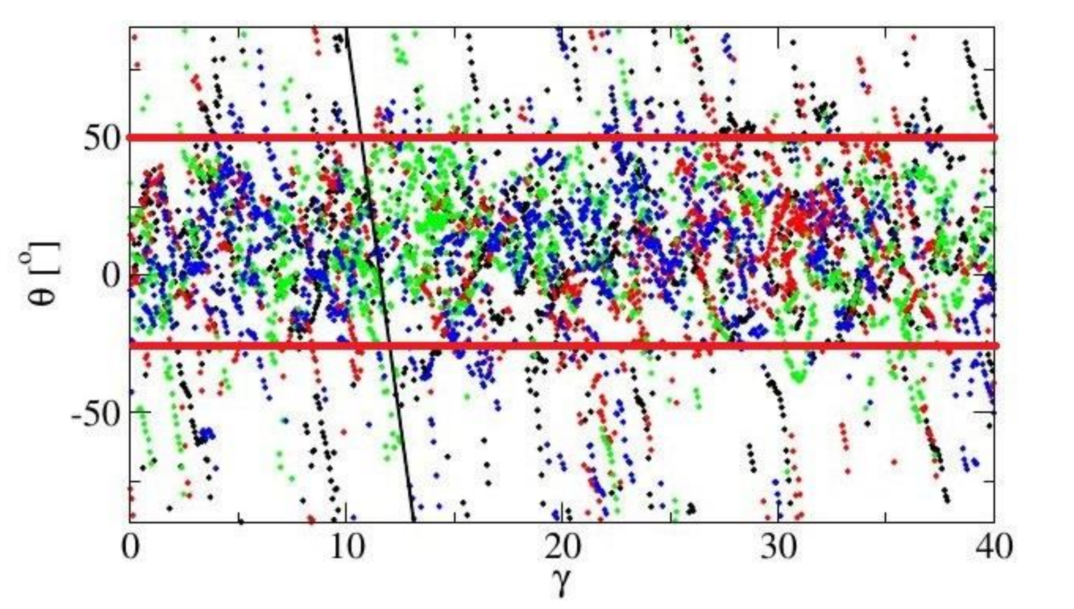


Dense granular flow (interacting grains, no liquid)

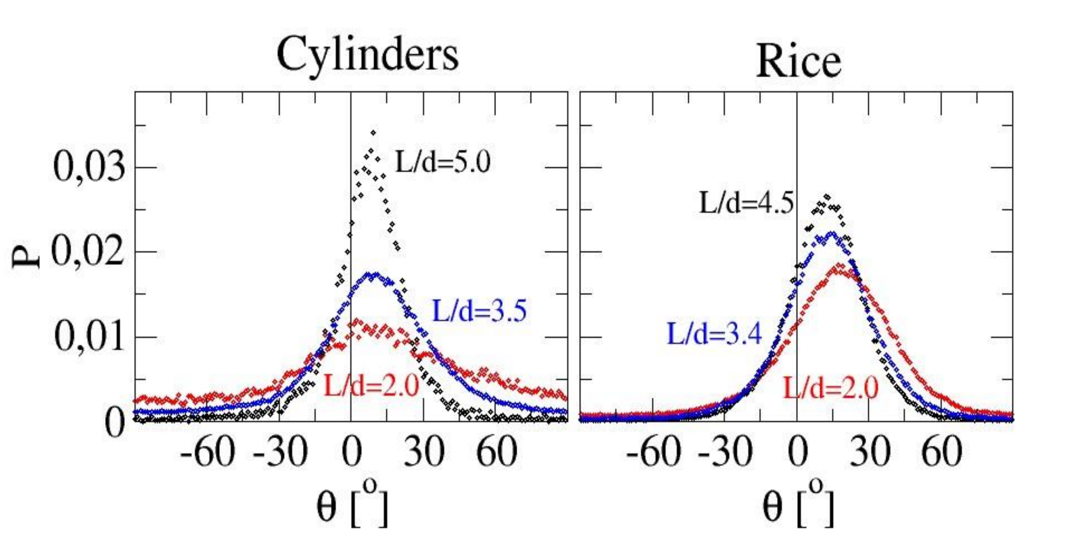
In a dense granular flow noisy rotation is observed due to collisions with neighbors.

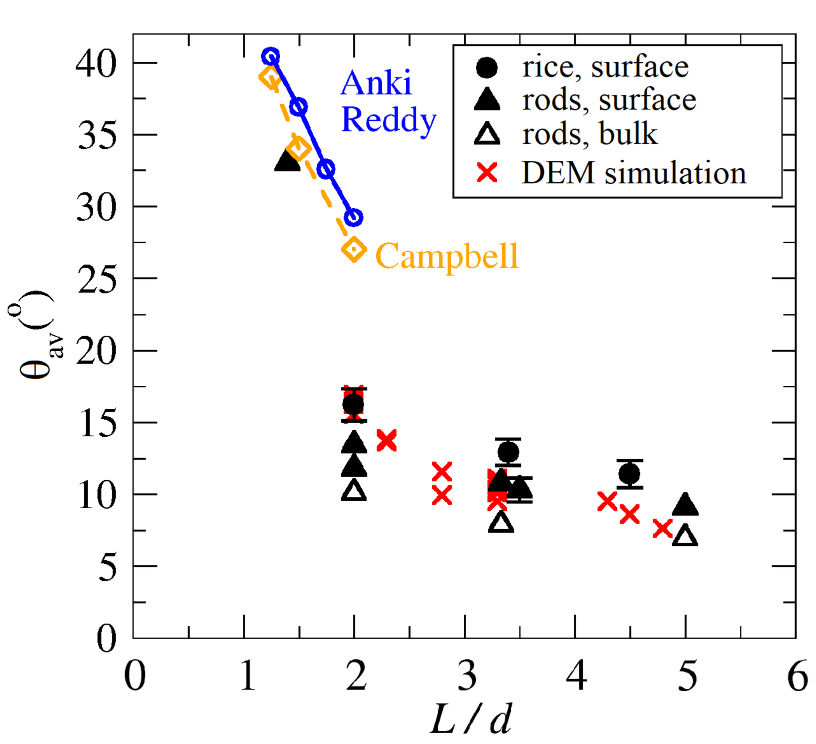


Börzsönyi et al. Phys. Rev. Lett. (2012), Phys. Rev. E (2012)

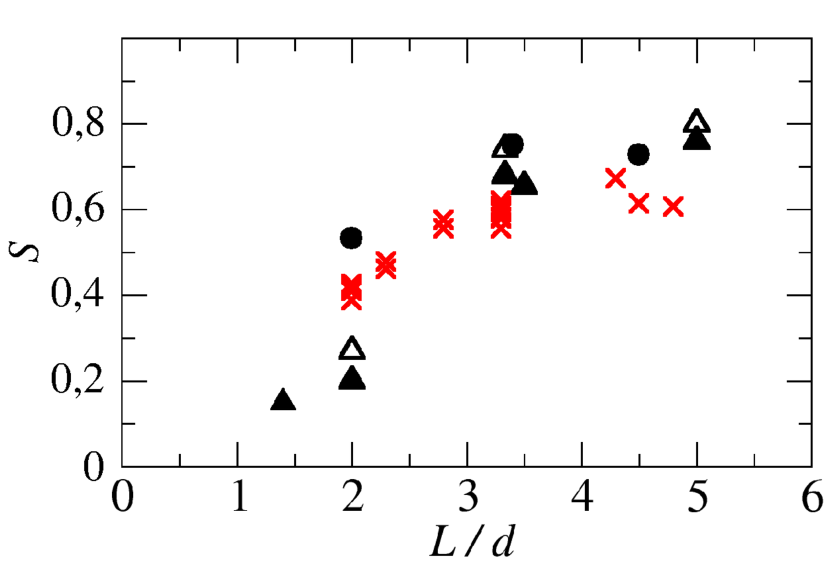


Interaction with neigbors leads to an orientation distribution with the average alignment NOT parallel to the main flow.

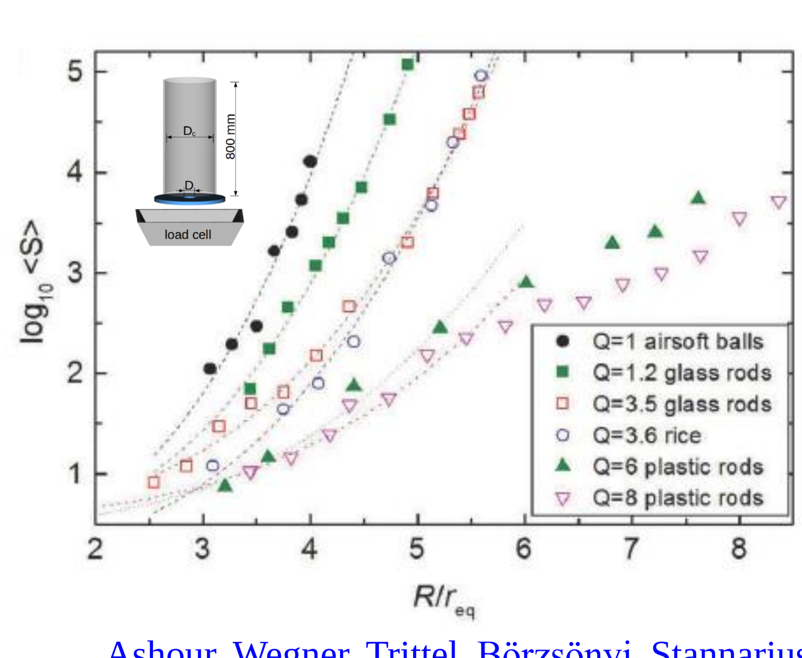


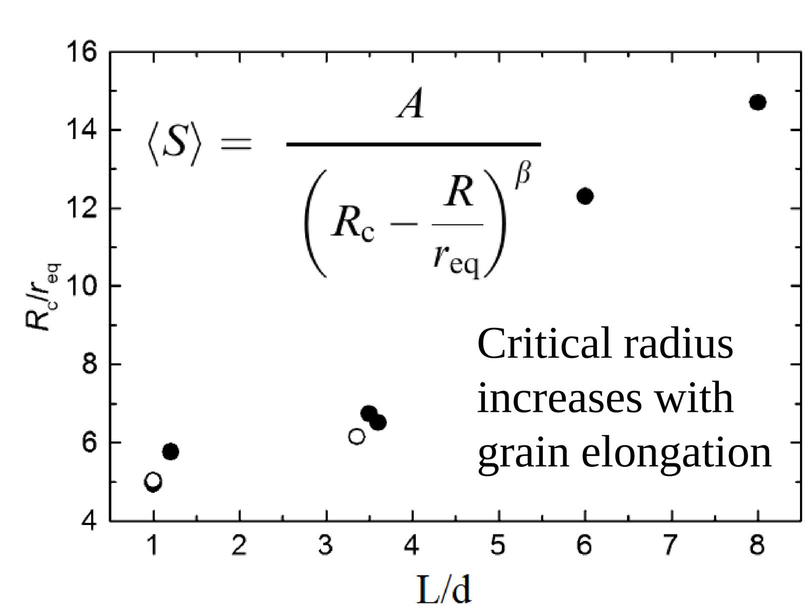


The average angle of the grains θ_{av} is decreasing, the order parameter S is increasing with aspect ratio.



Silo with small orifice: higher probability for clogging with increasing grain elongation





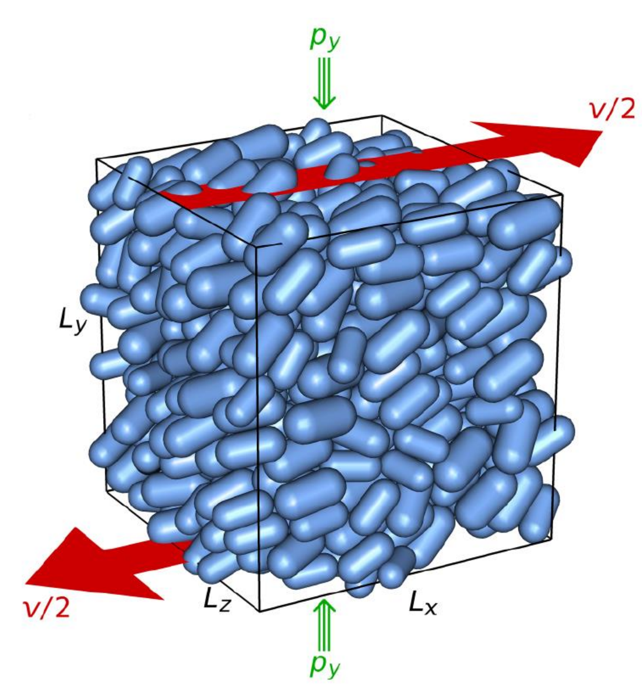
$$\langle S \rangle = \frac{A}{\left(R_c - \frac{R}{r_{eq}}\right)^{\beta}}$$

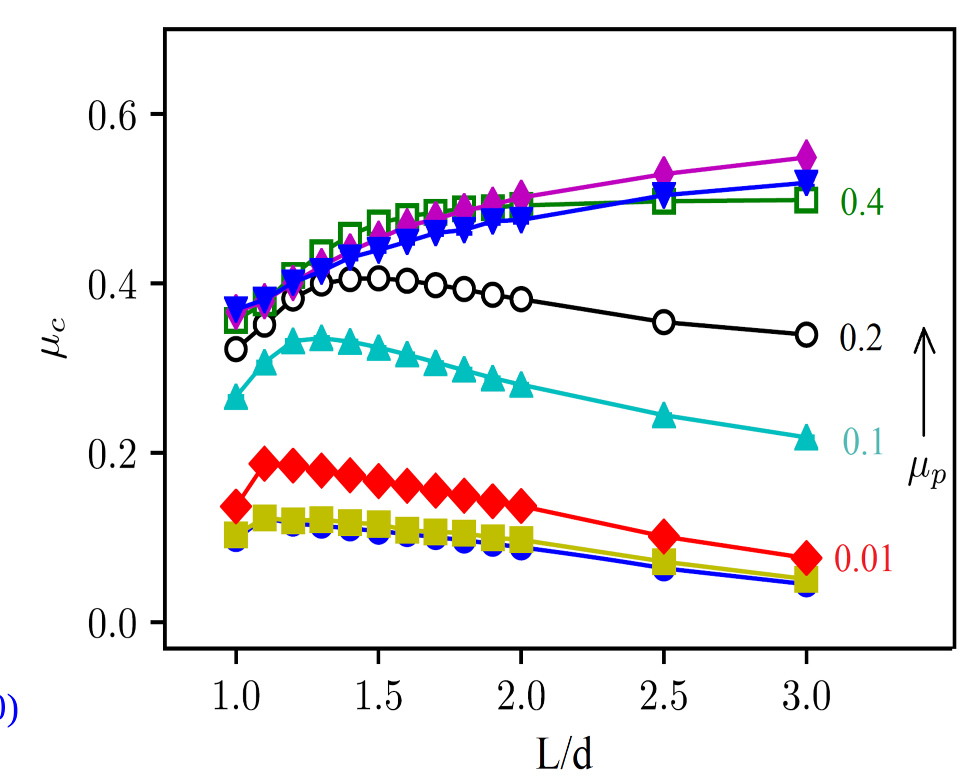
Critical radius increases with grain elongation

Ashour, Wegner, Trittel, Börzsönyi, Stannarius, Soft Matter (2017)

Effective friction as a function of grain elongation

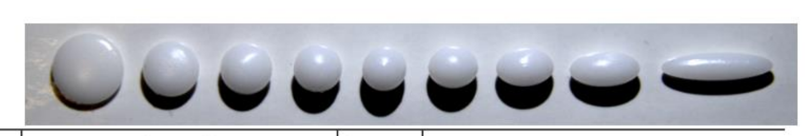
DEM simulations with constant pressure: for frictional grains ($\mu > 0.3$) we find increasing effective friction with increasing grain elongation. For low friction grains ($\mu < 0.3$) the curve is non-monotonic: slightly elongated grains have the largest effective friction.



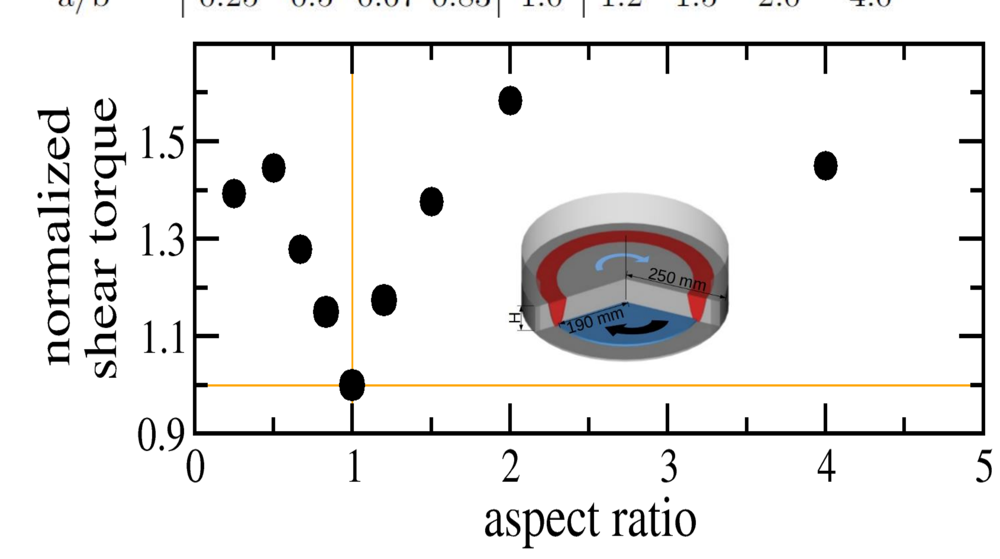


Nagy, Claudin, Börzsönyi, Somfai, New J. Phys. (2020)

In laboratory experiments with smooth plastic (POM) particles we recover the numerically predicted non-monotonic dependence of the effective friction as a function of grain elongation. We find the largest shear force for slightly elongated (or flat) ellipsoids.

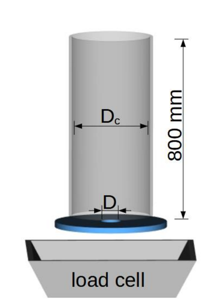


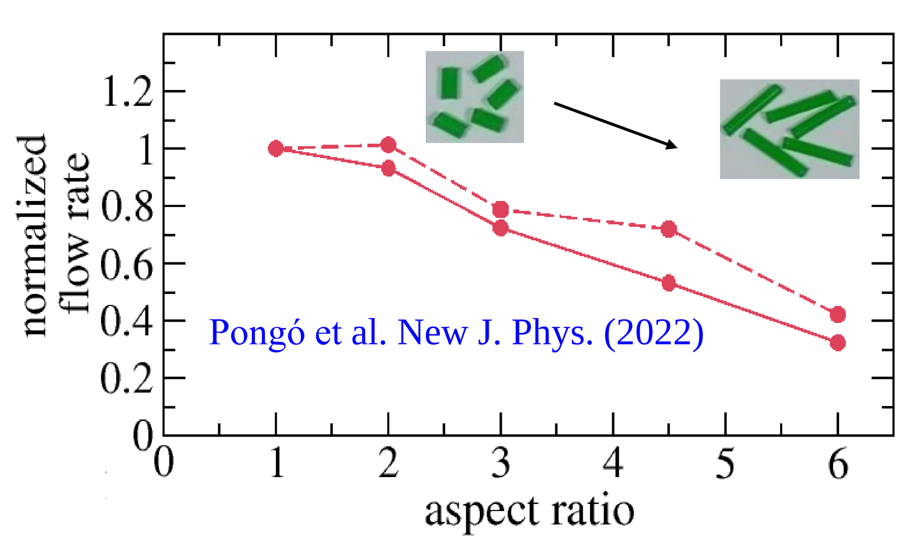
	lentil				bead	rice			
a/b	0.25	0.5	0.67	0.83	1.0	1.2	1.5	2.0	4.0



Silo flow rate as a function of grain elongation

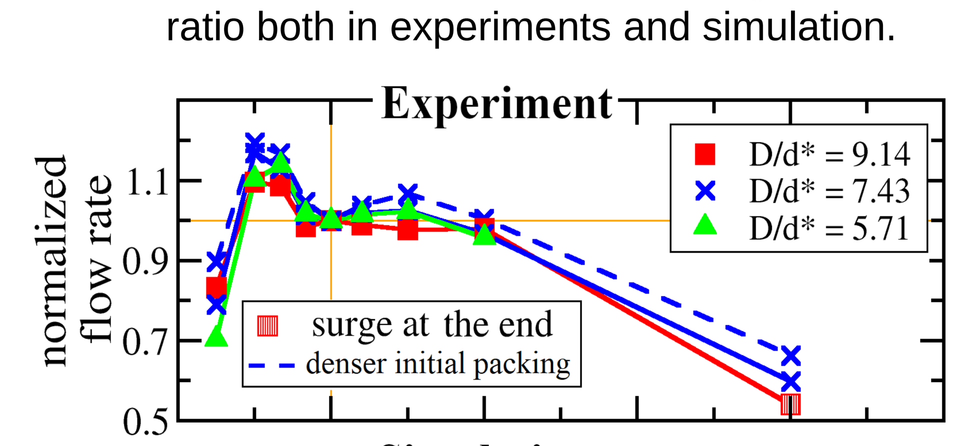
In experiments with rods we find a decreasing flow rate with increasing grain elongation.

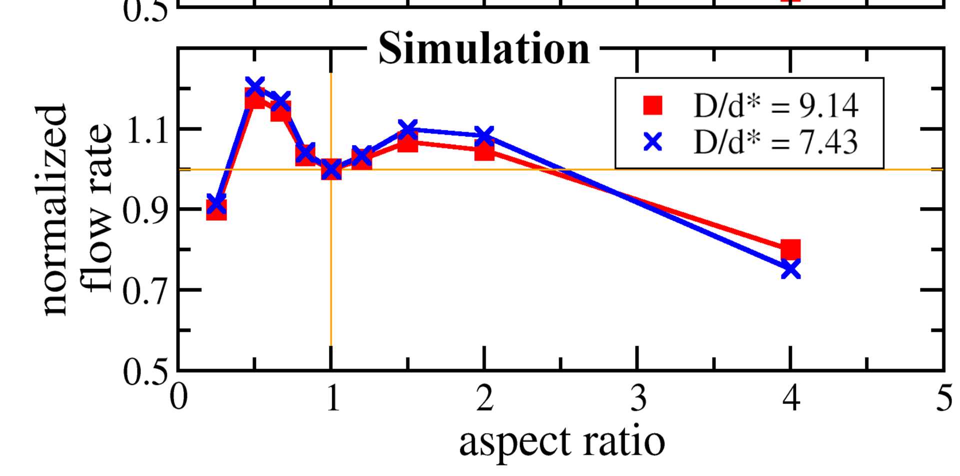




Pongó et al. New J. Phys. (2022)

For nearly spherical ellipsoids we find a non-monotonic flow rate as a function of grain aspect ratio both in experiments and simulation.





The packing fraction in the silo is non-monotonic as a function of grain aspect ratio, but the variation is less strong than the variation in the flow rate.

Thus, the faster flow rate for slightly non-spherical grains is not only because of slightly denser packing of such grains, but also because of faster grain velocity through the orifice. So the geometry of the „free-fall-arch" changes with grain shape.