High speed granular flows down inclines

Effect of restitution coefficient

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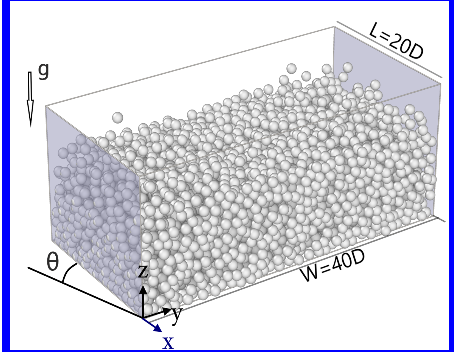
Outline

Numerical Simulation Model

Discrete Element Method [1, 2].



Granular gravity-driven flow confined between lateral frictional walls. Periodic boundary condition in the main direction of the flow.

Geometrical parameters

$W(D)$	$H(D)$	$\theta(^\circ)$
40	5	25 – 45

Mass hold up: $H = \int_0^{+\infty} \nu(z)dz$.

Mechanical parameters

	grain/grain	grain/wall
e	[0.64 – 1]	0.8
μ	0.33	0.593

μ: Friction coefficient

Role of normal restitution coefficient between grains e.

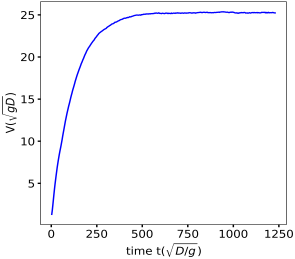
Steady states and supported regime for $e = 0.972$

Initial conditions: dropping of a loose assembly of agitated grains at a small altitude [1, 2].

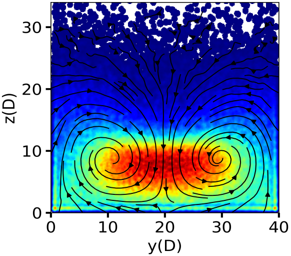
For all studied inclination angles the flows reach a steady state.

For $\theta > \theta_c \approx 27°$, the flows enter "supported regime".

Mean velocity vs time

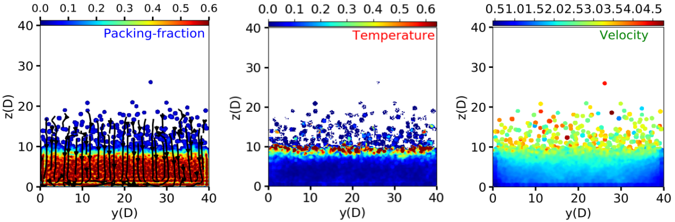


Cross-section map of the packing fraction



Time evolution towards steady state: Supported flow regime

Time evolution of the cross-section map of packing fraction, temperature and velocity for $e = 0.972, \theta = 30°$.

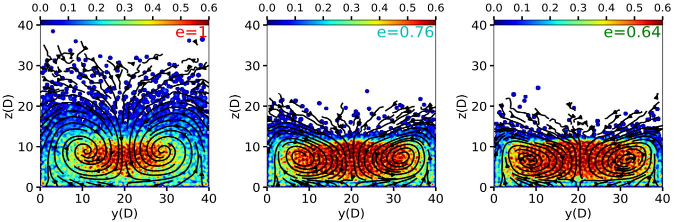


The dense and cold core is supported by a dilute and agitated (hot) gaseous phase.

The dense core moves at a fast speed like a plug.

Effect of the restitution coefficient

The cross-section map of packing fraction, $e = [1, 0.76, 0.64]$, $\theta = 30^\circ$, for steady states.

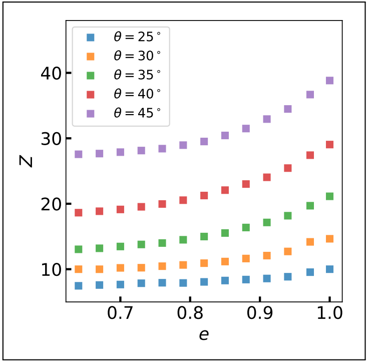


A decrease of the restitution coefficient leads to a vertical contraction of the flow together with an increase of the width of the dense core.

The dissipation favours the granular clustering instability.

Effect of restitution coefficient

Evolution of the effective height Z of the flow as a function of the restitution coefficient.



1. The effective height Z is defined as:

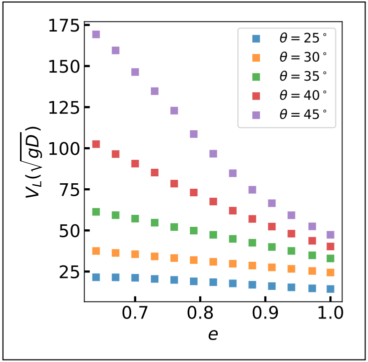
$$Z/W = (tan\theta - \mu_b)/\mu_w$$

   where μ_b and μ_w are the effective basal and side wall friction, respectively.

2. The height Z decreases with decreasing e.
3. The flow contraction is more pronounced for high inclination angle.

Effect of restitution coefficient

Variation of the mean flow velocity as a function of the restitution coefficient for various angles.



1. Surprisingly, the flow velocity increases with decreasing restitution coefficient
2. The velocity increase can be explained by the fact that the flow contracts, resulting in a decrease of the friction area at the walls.

Conclusion

When e decreases (dissipation increases):

- **The mean velocity increases.**
- **The core size increases.**
- **The effective height of the flows decreases, resulting in a reduction of the side wall friction.**
- **The critical angle θ_c for the emergence of supported regime is decreased, enlarging their domain of existence.**

Perspective

- **Toward a "universal" relation between the effective friction coefficient and a Froude number?**
  We know, that for $e = 0.972$ there is a relation between the effective friction coefficient (μ_{eff}) at the boundaries and a Froude number $Fr = V/\sqrt{Hcos(\theta)}$ where V is the sliding velocity at the boundary [3]. This relation, which seems to be valid whatever H, θ, W is monotonic: the friction increases with the Froude number. As we saw, when e decreases, the area of friction decreases, which means that the friction coefficient has to increase in order to keep the balance between the driving component of the weight and the friction, and the velocity increases. The monotonic, growing, relation between μ_{eff} and Fr seems thus to be verified whatever e.
- **Future work : is the $\mu(Fr)$ relation universal?**

References

[1] N.Brodu, R.Patrick, and R.Delannay. Shallow granular flows down flat frictional channels: Steady flows and longitudinal vortices. Phys. Rev. E, 87:022202, Feb 2013.

[2] N.Brodu, R.Delannay, V.Alexandre, and R.Patrick. New patterns in high-speed granular flows. Journal of Fluid Mechanics, pages1–11, April 2015.

[3] Y. Zhu, R. Delannay and A Valance, "High speed granular flow revisited", Submitted to Granular Matter (2020).