2D Gravity Driven Granular Flow: Effect of Friction at the Walls on Flow Rate and Janssen Pressure

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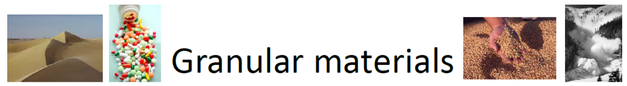
Granular materials

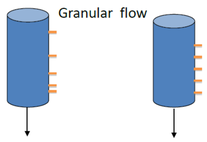


Large group of discrete macroscopic particles.

Contact forces:
Collisions and frictional forces

Energy is dissipated:
Inelastic collisions, friction

Athermal Systems:
Thermal fluctuations are irrelevant.



Liquid flow: Varying pressure head. Decreasing flow rate.

Sand flow: Constant pressure head. Constant flow rate.

Flow Rate in 2D and 3D Hopper Geometries

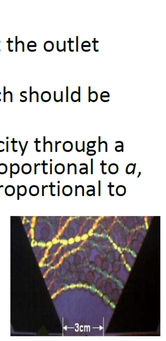
Flow rate is constant and depends on outlet size

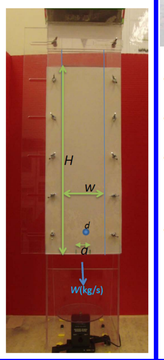
Beverloo's model:

- There is a free fall zone at the outlet limited by an arch.
- The dimensions of the arch should be proportional to a.
- Grains fall from zero velocity through a free fall zone of height proportional to a, giving velocity at outlet proportional to $a^{1/2}$.
- Flow rate proportional to

$(a^{1/2} * a^2) \sim a^{5/2}$ 3D

$(a^{1/2} * a) \sim a^{3/2}$ 2D

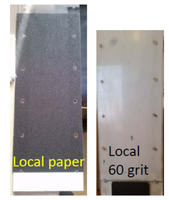




What is the role of friction?

- How does friction at the wall affect flow rate?
- Does the effect of friction change with flow rate?
- Is flow rate only dependent on local parameters at the opening? (size of opening and friction)
- Is flow rate independent of the pressure at the opening? (Leads to measurements of Janssen pressure for each setup)

Experimental Setup



- Outlet size, a, is 1.5cm, 1.8cm, 2.0cm to 5.0cm in increments of 0.5cm, 5.2cm & 5.5cm
- Width of hopper ,w, is 12cm.
- Wall roughness
  - Teflon
  - Poster paper (local and nonlocal)
  - 60 grit sandpaper (local and nonlocal)
- Using steel spheres of diameter d=2.5mm.
- Flow is quasi-2D: Distance between front and back walls is 3mm.

Measurement of Flow Rate

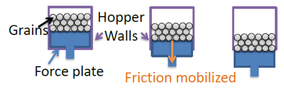
Highlight of Flow Rate Data

- Flow rate decreases with increasing friction.
- Localized friction near the opening determines the flow rate.
- Non-localized friction does not affect the flow rate.

Localized friction can be used as a "knob" to control flow rate!

Janssen Pressure

- What is Janssen pressure?
  - When filling a container with grains the pressure at the bottom plateaus to some value where the filling height ≈width of container.
- Why does it saturate to a plateau?
  - Force chains carry stress to the outer walls of the hopper.
- How is it measured?
  - In order to measure Janssen Pressure, friction must be mobilized and the measuring instrument has to be isolated from the container.



Janssen Data

Saturation pressure is determined by the placement and details of the distribution of wall friction.

Connecting Flow Rate, Friction and Janssen Saturation Pressure

- Flow rate is determined only by the local friction at the opening, not the magnitude of the pressure at the opening.
- The magnitude of the saturation pressure is different for local and nonlocal friction placements.
- The constancy of the saturation pressure is necessary for the constancy of the flow rate.

The magnitude of the saturation pressure does not determine the flow rate.

Testing Beverloo's Model

Flow rate = Aa^{Υ}

Exponent Υ

Beverloo prediction for 2D flow:

- Υ = 1.5
- Independent of friction

Our data:

Exponent varies with friction!!

Model of arch formation needs to be refined.

Data supports possibility of shallower and longer arches with higher friction.

Conclusions:

- Friction plays a more dominate role in controlling flow rate than expected.
- The details of the placement of friction on the walls is an important parameter for controlling granular flow.
- Friction changes the dynamics of arch formation.

Future Work:

Friction could change the jamming threshold.

Smith College Physics Department