15. Brazil Nut Effect

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Problem

When a granular mixture is shaken the larger particles may end up above the smaller ones. Investigate and explain this phenomenon. Under what conditions can the opposite distribution be obtained?

Overview

- Experiments
  - setup
  - dependencies
  - results
- Simulation
  - model
  - results
- Qualititave Explanations for segregation mechanisms

Experimental Setup

dies ist ein Foto / Video des Aufbaus

Dependencies

- Segregation and its direction depending on
  - size, density, material, filling height of particles
  - size, material, form of container
  - used acceleration: sinusoidal, taps, …
  - environmental conditions: air pressure, humidity

$\Rightarrow$ Restriction to certain parameters necessary

Results

- Very low amplitude $\longrightarrow$ nothing happens
- Increasing amplitude $\longrightarrow$ large particles rise slowly
- Eventually segregation
- Increasing amplitude $\longrightarrow$ convective cells

Simulation - Model

- Spherical particles
- Different radius and mass
- Rectangular / cuboidal / cylindrical box of infinite height
- At each timestep
  - forces acting upon each particle are evaluated
  - Newtonian equations of motion are solved numerically

Acting Forces

- Gravitation
- Collision forces
  - Collisions occur if distance between center points $\vec{x}_i$ and $\vec{x}_j$ of spheres is smaller than the sum of their radii R_i and R_j:

$$|\vec{x}_i - \vec{x}_j| < R_i + R_j$$

  - Resulting force on colliding particles

$$\vec{F}_{ij} = F_{\mathrm{N}}\vec{n}_{ij} + F_{\mathrm{S}}\vec{t}_{ij}$$

Forces in Normal Direction

$$F_{\mathrm{N}} = \underbrace{k\left(R_i + R_j - |\vec{x}_i - \vec{x}_j|\right)^{1.5}}_{\text{elastic restoration force}} - \underbrace{\gamma_{\mathrm{N}}\, m_{\mathrm{eff}}^{1.5}\, \vec{v}_{\mathrm{rel}}\, \vec{n}_{ij}}_{\text{dissipation force}}$$

where

k	Coefficient of proportionality
γ_{N}	Normal friction coefficient
m_{eff}	$= \frac{m_i m_j}{m_i + m_j}$

Forces in Tangential Direction

$$F_{\mathrm{S}} = \underbrace{-\gamma_{\mathrm{S}}\, m_{\mathrm{eff}}^{1.5}\, \vec{v}_{\mathrm{rel}}\, \vec{t}_{ij}}_{\text{elastic dissipation force}} - \underbrace{\mu F_{\mathrm{N}}}_{\text{Coulomb friction}}$$

where

γ_{S}	Shear friction coefficient
μ	Coulomb friction coefficient
m_{eff}	$= \frac{m_i m_j}{m_i + m_j}$

Simulation Results

- Brazil Nut Effect
- Depending on
  - frequency
  - amplitude
  - radii
  - masses

Percolation

- Shaking opens voids between particles
- Small particles can fill small voids under larger particles
- Large particles need large voids $\longrightarrow$ improbable
- Control parameter for percolation to occur: volume (diameter) ratio of species A and B

Convection

- Vibrating plate $\longrightarrow$ particles gain energy
- Collsions with other paricles and walls $\longrightarrow$ energy loss
- Mean kinetic energy decreases from bottom to top
- Mean kinetic energy low at walls
- Analogy to Rayleigh-Benard-convection

$\Rightarrow$ convection

Segregation by Convection

- Conditions: high container, walls
- All particles rise in center
- Particles sink in narrow stream near wall
- Large particles cannot sink

$\Rightarrow$ Segregation

Thermal Segregation

- Large particles loose less energy in collisions than small particles
- Large particle faster
- Mean free volume for large particle increases
- Density around large particles decreases
- Large particles rise

$\Rightarrow$ Segregation

Reverse Brazil Nut Effect

- Thermal segregation is due to the large particles loosing less energy per collision
  $\longrightarrow$ excavated particles$\longrightarrow$ loose equally much or more energy
  $\longrightarrow$ sink
- Particles fluidify if threshold acceleration is reached
  $\longrightarrow$ large dense particles sink because of gravitation

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