Faraday Heaping

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When a container filled with small spheres (e.g. mustard seeds) is vibrated vertically with a frequency between 1 – 10 Hz, so called Faraday heaping occurs.
Explore this phenomenon.

Presentation Plan

1. Experiments

- ❖ Experimental Setup
- ❖ Air drag role

2. Mechanisms responsible for heap formation

- ❖ Internal Avalanches
- ❖ Pressure gradients
- ❖ The stability of inclined surfaces

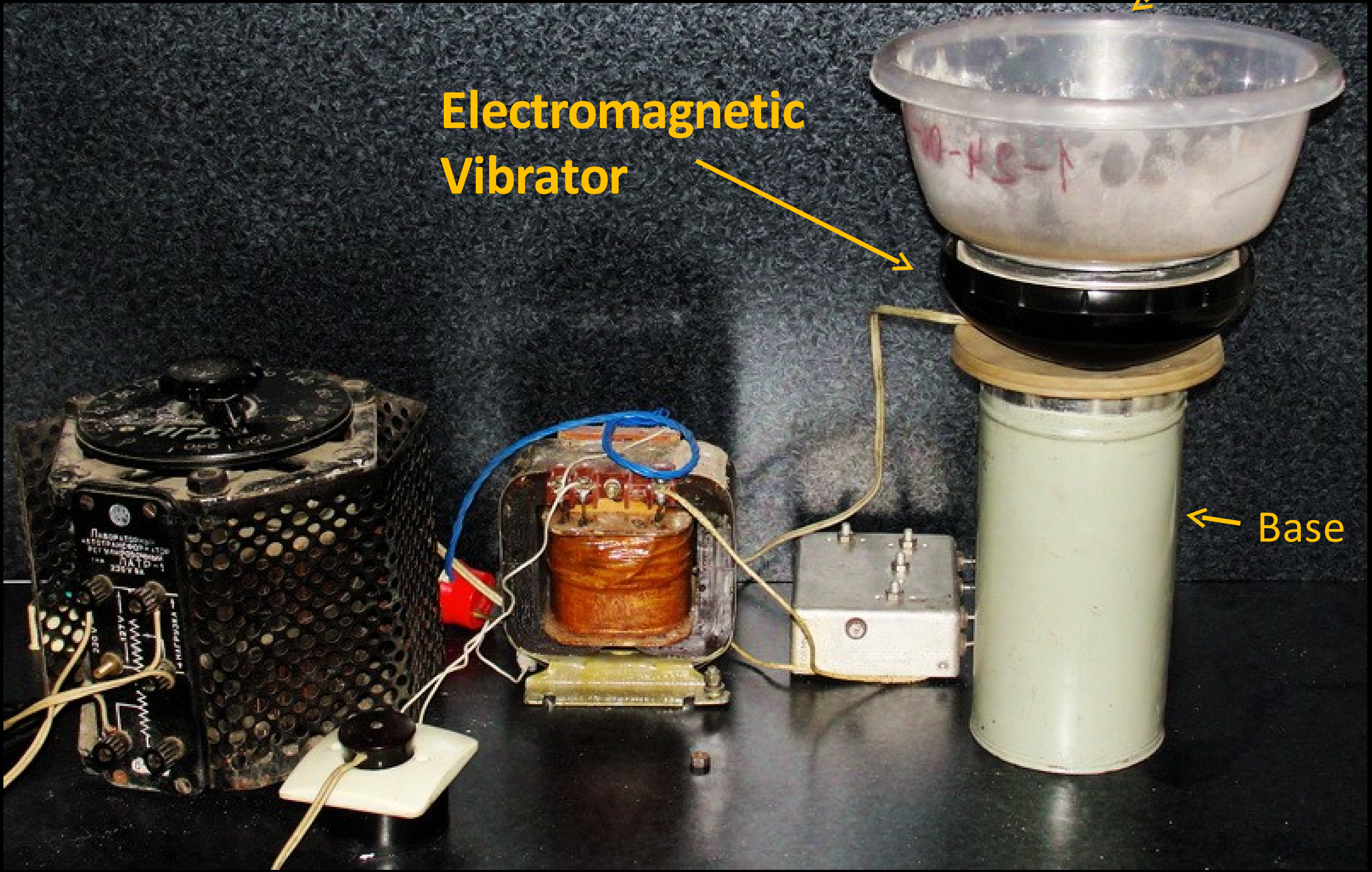
3. Other Phenomena

- ❖ Heap coarsening
- ❖ Standing Waves
- ❖ Jet Bursts

4. Conclusion

Experimental Setup

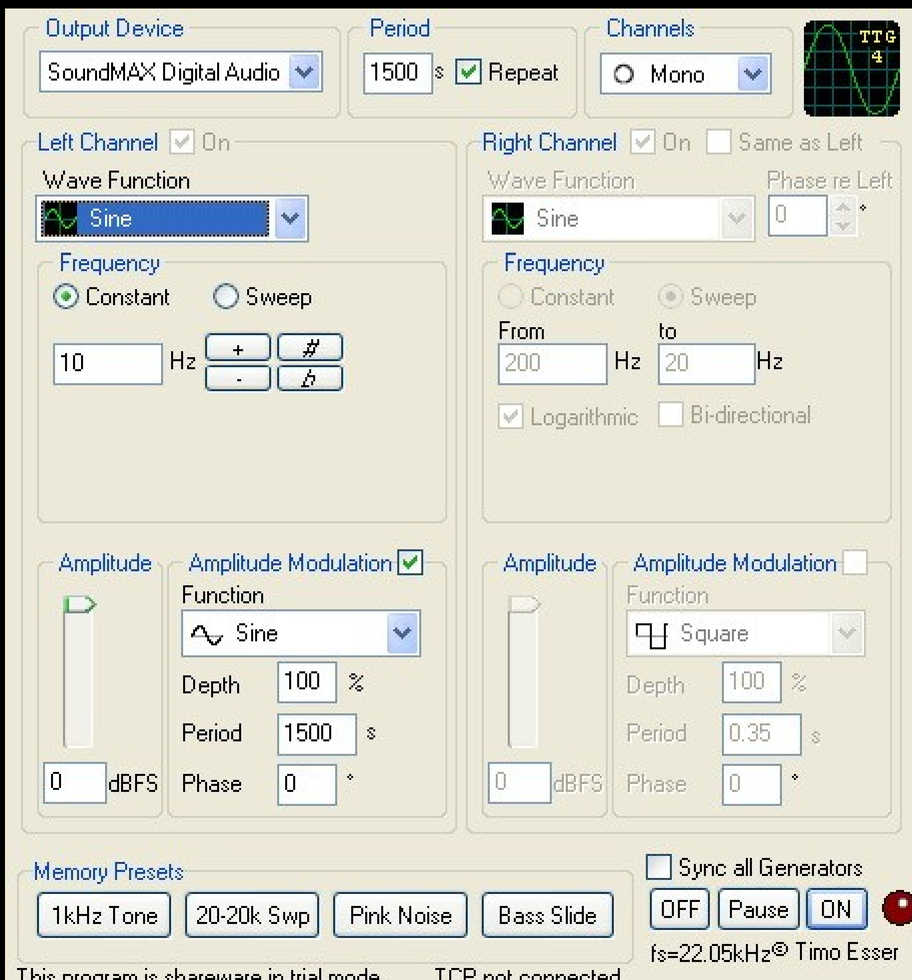
1) Electromagnetic Vibrator

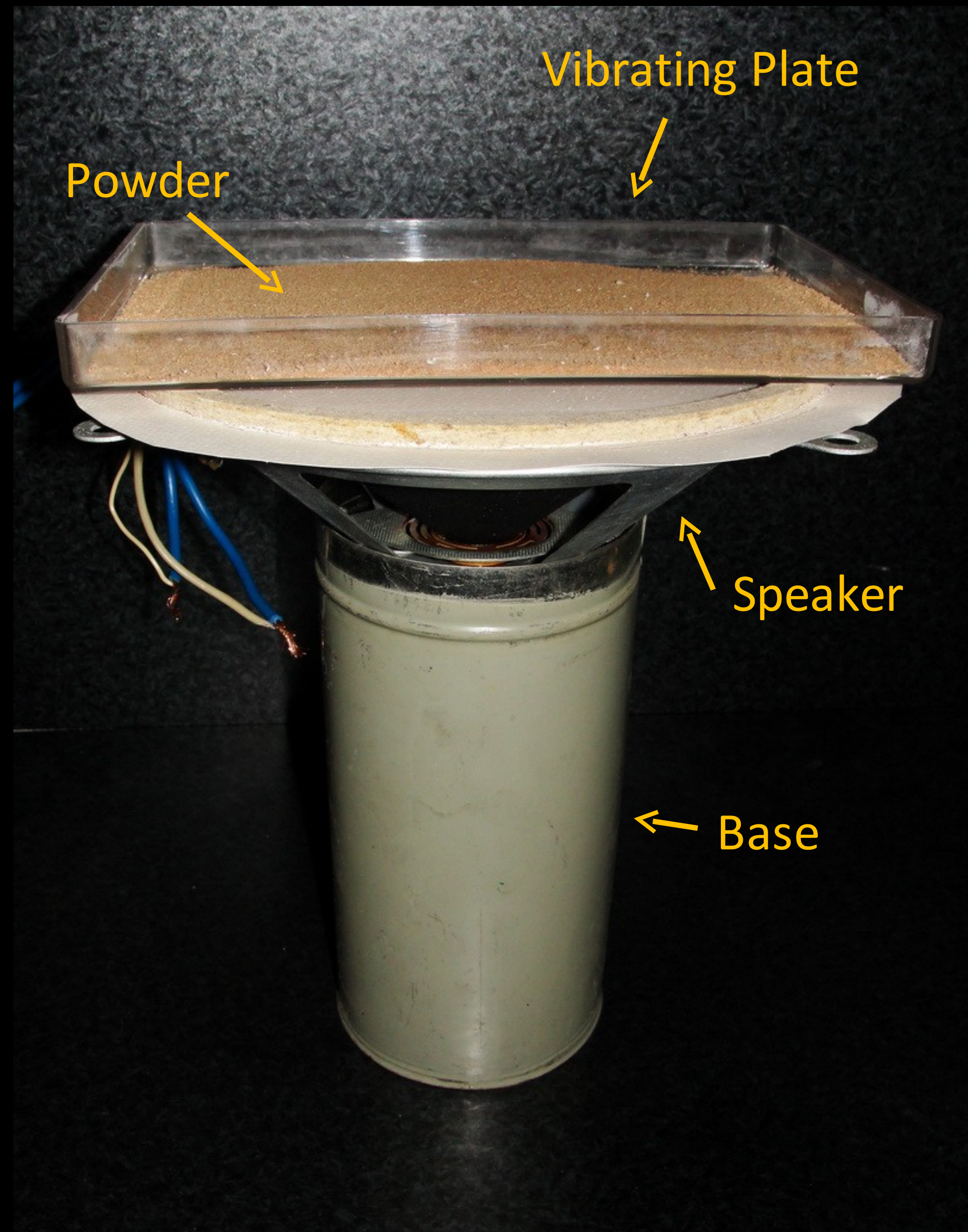


Experimental Setup

2) Sound Vibrator

Tone Generator





Experiments

Heap growing

When a box with fine dry sand is vertically vibrated or tapped, already after a few cycles, some random surface fluctuations are seen to grow into small heaps.

Cork

Experiments

Air drag role

When the air drag on the particles can be neglected, no heaping is observed.

For small but heavy spheres also no heaping occurs

Video

Heaping Conditions

The external control parameters :

A - vibration amplitude

f - vibration frequency,

$N = \frac{H}{D}$, where H - height of the layer ;

D - the particle size

1

Dimensionless acceleration of the plate :

$$\Gamma = \frac{4\pi^2 f^2 A}{g}$$

2

Ratio of Air drag and Gravitational forces:

$$\mathfrak{B} = \frac{F_{drag}}{F_{grav}} = \frac{3\pi\eta D v}{\rho\pi g D^3/6} = \frac{18\eta v}{\rho g D^2}$$

η - fluid viscosity

v - air velocity relatively to particle

Free fall velocity of solid sphere:

$$v_{ff} = \frac{D^2}{18\eta}\rho g$$

3

Particle-fluid interaction should be taken into account when

$$\mathfrak{B} \gtrsim 1$$

Conditions necessary for Faraday Heaping :

$\Gamma > 1$; $v \gtrsim v_{ff}$

4

For 0.4 mm cork particles in air: $v_{ff} \approx 0.8$ *m/sec*

For 0.4 mm shot rolls in air: $v_{ff} \approx 10$ *m/sec*

For 5mm amplitude *sin* oscillations:

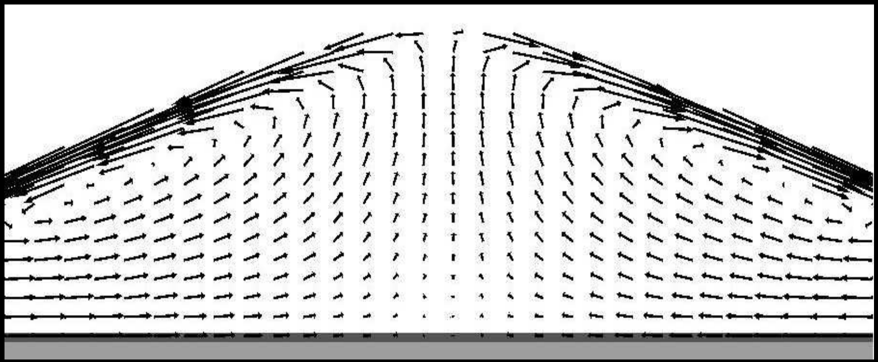
$v \approx 0{,}03(m)\cdot f$; $\Gamma = 10^{-2}\left(sec^2\right)\cdot f^2$

For cork Heaping : $f \gtrsim 10\ Hz$

5

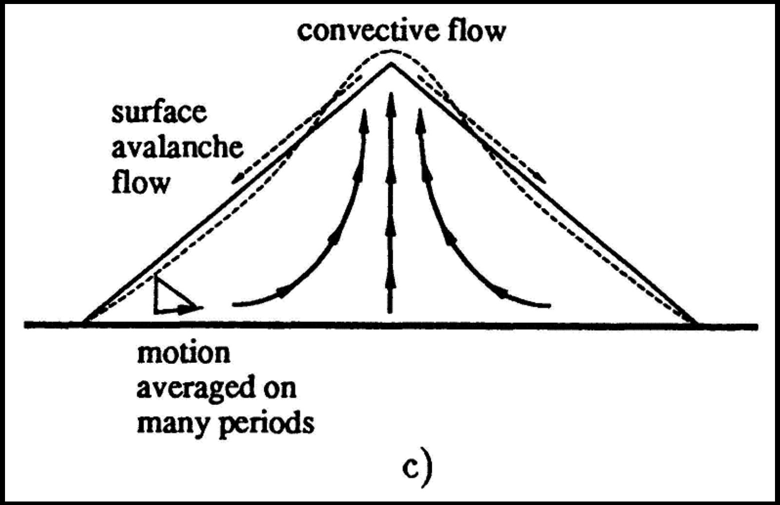
Mechanisms of Heaping

There can be several factors which can force the heaps keep a stable shape



3. Horizontal pressure gradients [1]
4. Internal Avalanches [2]
5. Stability of inclined surfaces compared to horizontal [3]

“Dynamical equilibrium” within the heap:
Outward avalanche in the upper surface layers is balanced by a collective inward motion of the particles in the interior of the heap.

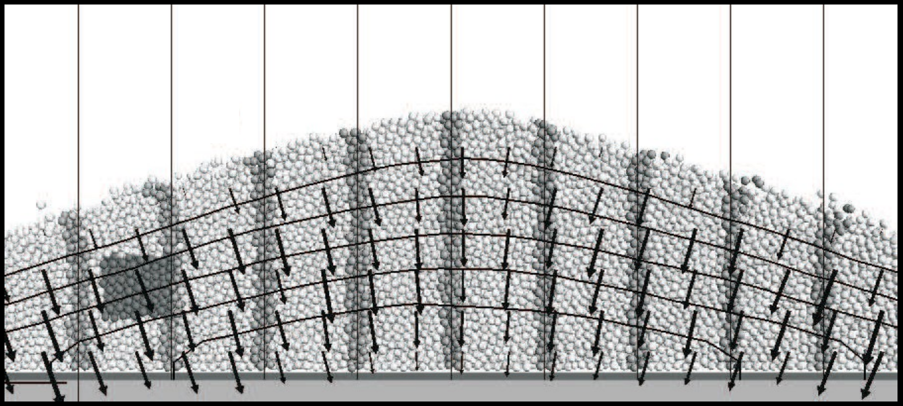


Heap Formation

STAGE 1

The bottomplate and bed are moving upwards together.

STAGE 2



- Plate begins to slow its moveup velocity with acceleration ***>g***
  (effective gravity becomes negative) ;
- Bed is detached from the bottom;
- Gap starts to grow between bottom and bed;
- A **region of low pressure appears underneath the heap**.

* Pressure above the heap is approximately constant ;
* Isobars run parallel to the surface of the heap;
* This causes air flow perpendicular to this surface.

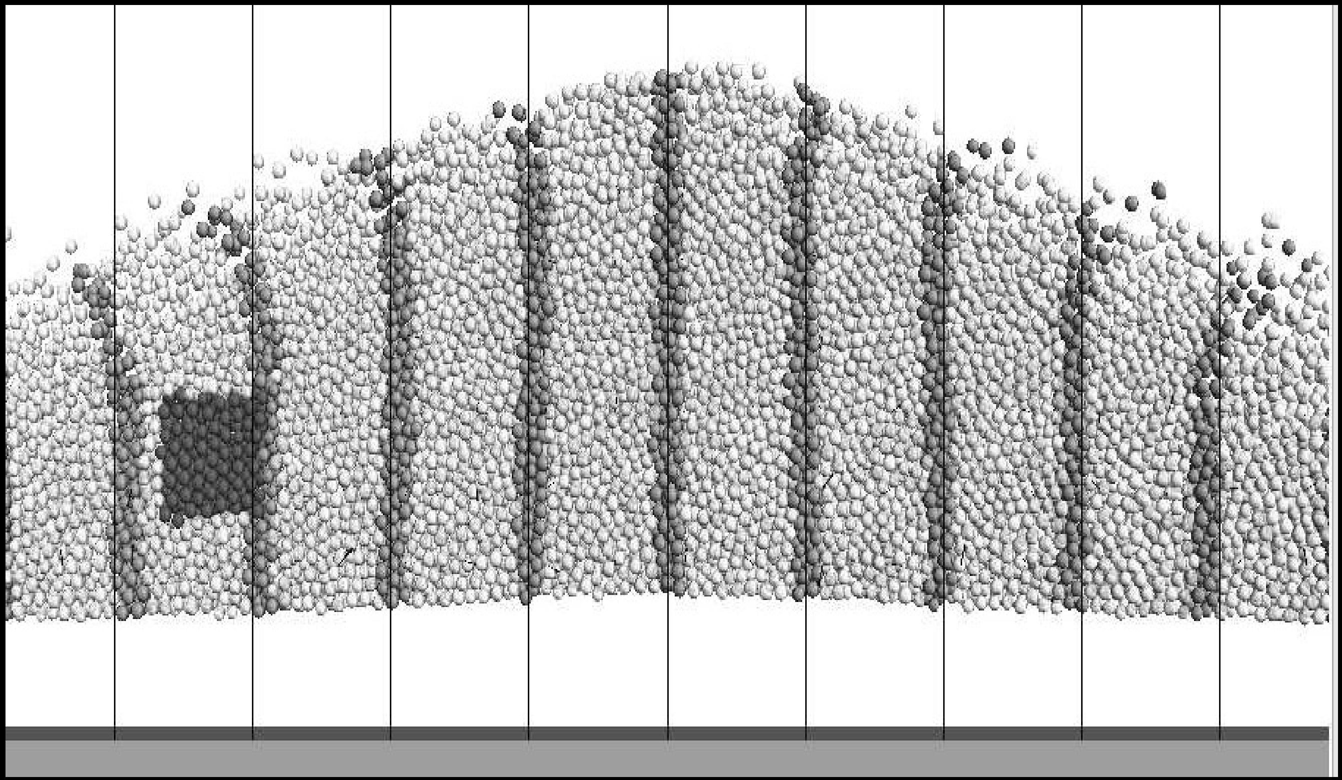
a) Horizontal component of the pressure gradient in the bed

c) Horizontal pressure gradient at the floor

* Pressure is lowest underneath the center .
* This generates a downward air flow through the heap with an inward component.
* **The air drag thus accelerates the particles down and inwards.**

Heap Formation

STAGE 3



- Bottom-plate moves downwards and the heap is in free flight.
- Bed itself becomes slightly curved .
- Air flow through the layer fluidizes the grain layer.

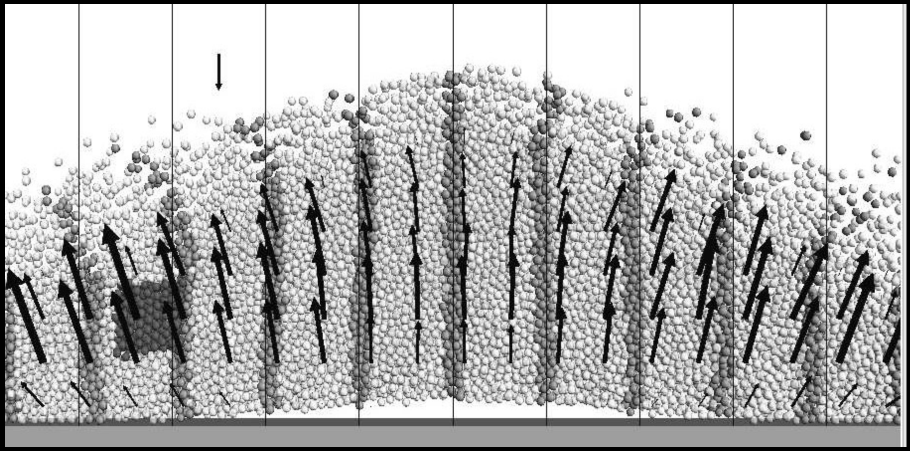
Heap Formation

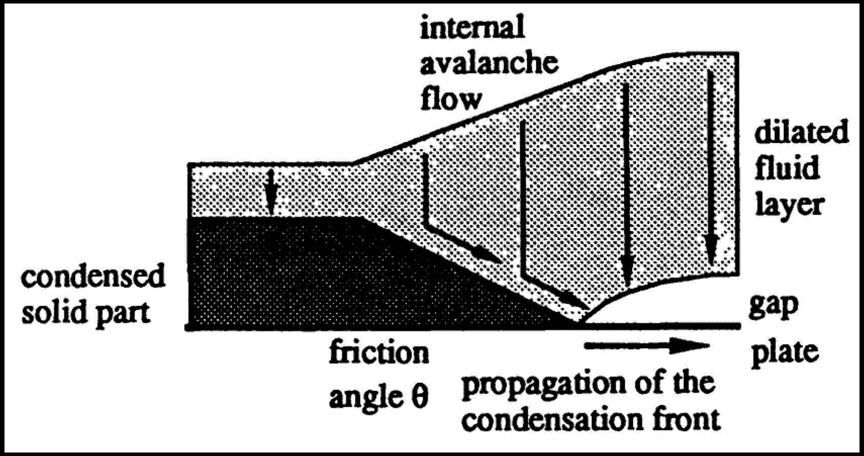
STAGE 4

Bottom-plate slows its moving downward and the bed catches it up.

Here several mechanisms begin to work.

- Bed is coming down again, and the sides have already reached the bottom.
- Large up- and outward drag force due to the increased air pressure below the bed.
- However, the **collision with the bottom will rapidly compactify the heap at sides**, so that the particles get locked.





Heap side collides earlier.
It condensates and deflects the falling particles creating an avalanche flow inside the heap.

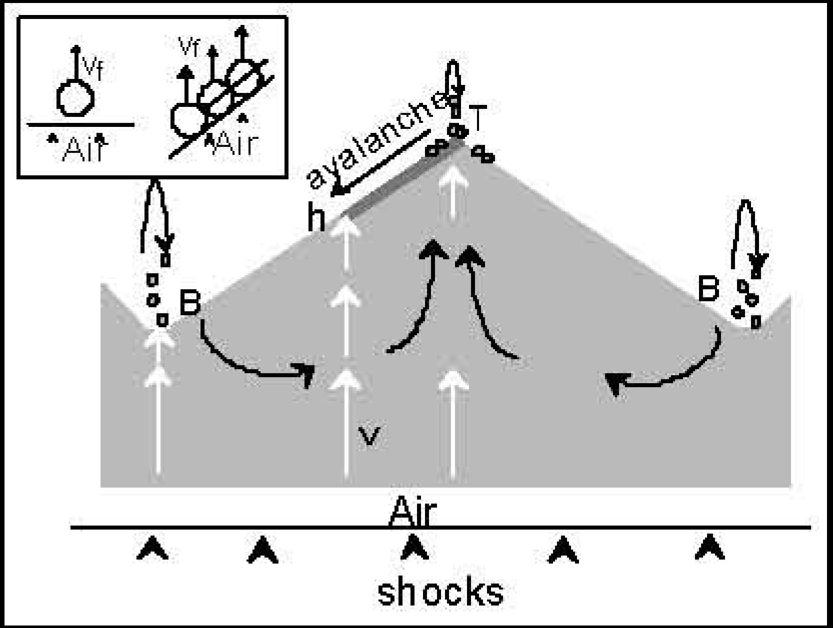
The averaged motion :
- Horizontal flow from the thinner parts of heap
- Upward flow at the thicker part of heap

Heap Formation

STAGE 4 cont'd

One more mechanism working at this stage:

- Inclined surface is more stable state than a horizontal flat surface with respect to air blow from below
- On sides of the hill, particle feels additional weight of the above lying particles involved in the avalanche layer .
- Additional mass opposes the blowing up from the sides



Darcy's law: $$v_h = K\frac{\Delta P}{h}$$

h – layer thickness
K – porous layer permeability
ΔP - pressure difference
v_h - air flow velocity out of layer

Particle will be blown off if $v_h > v_{ff}$

From this condition taking into account additional weight of avalanched particles [2]

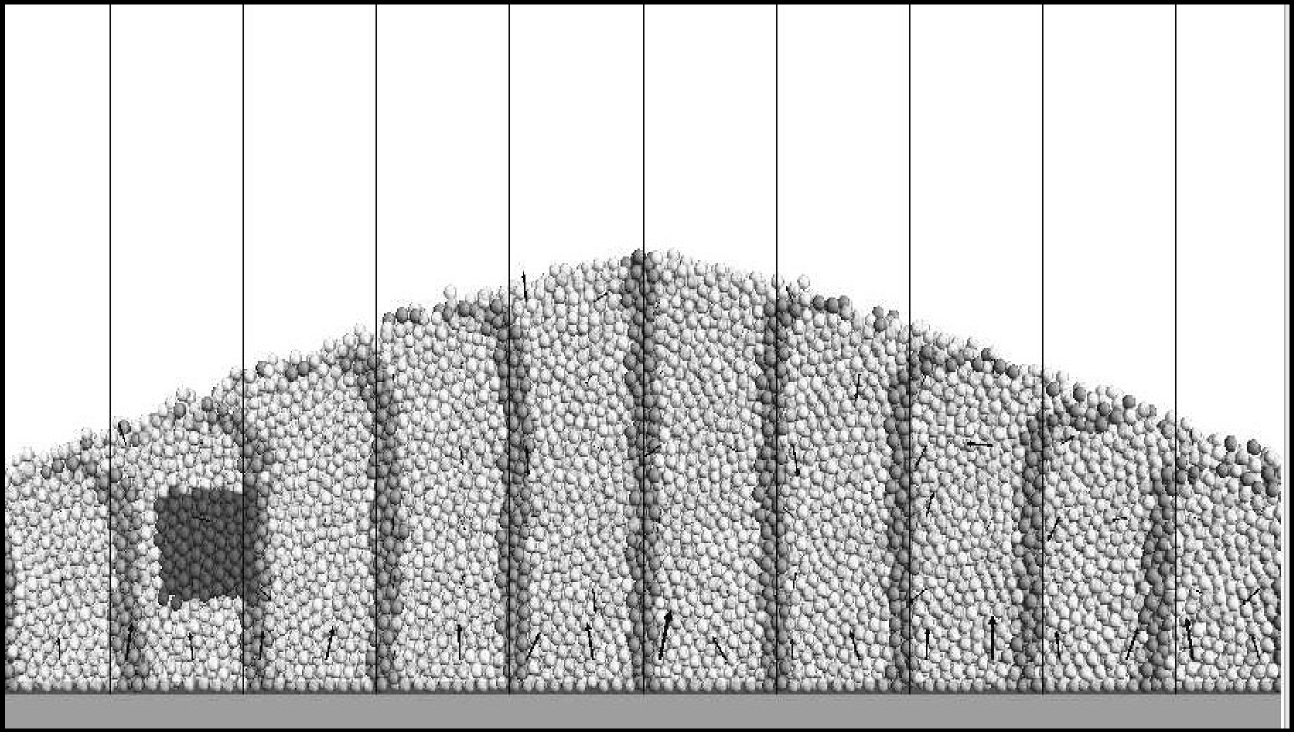
$$K\frac{\Delta P}{h_{critical}} \cong v_{ff}\left(h_{Top} - h_{Critical}\right) n\, Sin\theta / D$$

n - number of avalanching sheets
θ - avalanche angle

Heap Formation

STAGE 5

The heap is in rest except for a thin layer of particles that avalanches down its slopes.



This avalanche compensates the surplus of particles at the heap’s center created during the previous stages, and thereby completes the circulation pattern

Heap Coarsening

Two-stage coarsening process:
b)A fast initial stage where several small heaps are formed
c)A slow second stage where the heaps merge and combine into larger heaps;

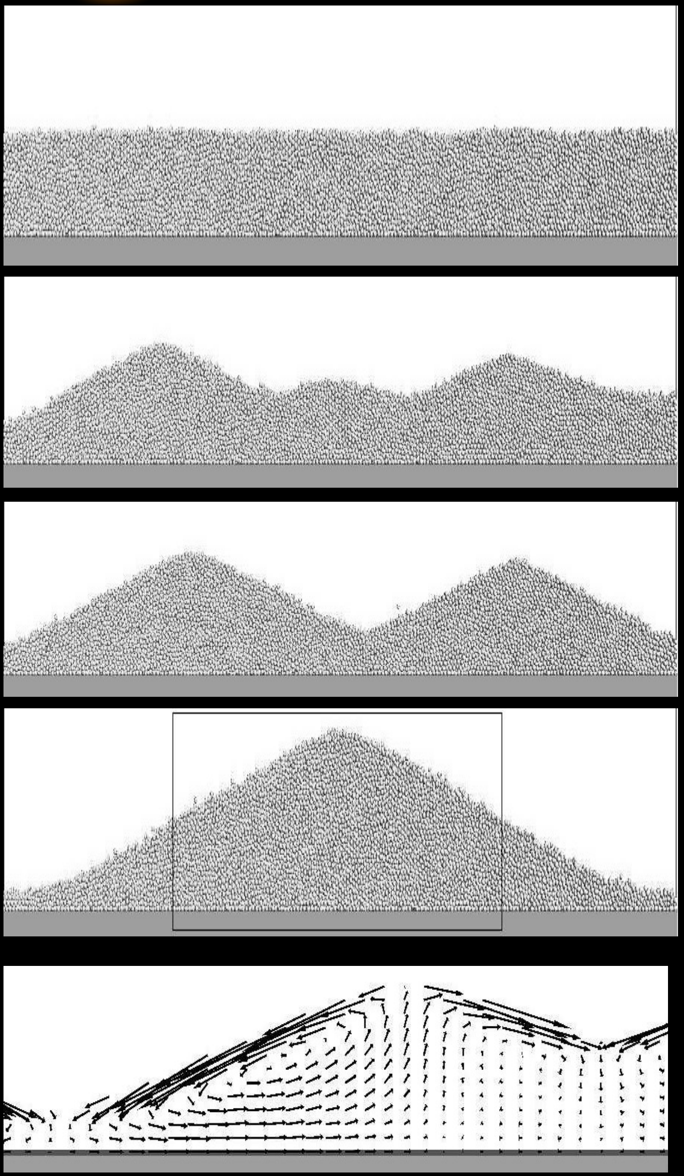
At last these heaps merge into one single heap.

Merging slows down considerably with a decreasing number of heaps.

Stage (*a*). Heaps are formed as discussed above

Stage (*b*). Asymmetry of heap slopes.

The inward motion inside the left (longer) part of the selected heap is much larger than in the right (neighbor to other heap) part.
Inward drag force is stronger in longer slope.



Cork

Coarsening of heaps takes place primarily because heaps move towards each other.

Vibration Amplitude and Acceleration

The heap angle slowly decreases with increasing acceleration.

- Inward motion increases at high accelerations.
- Avalanching strongly increases with impact velocity.

A limit is reached when:

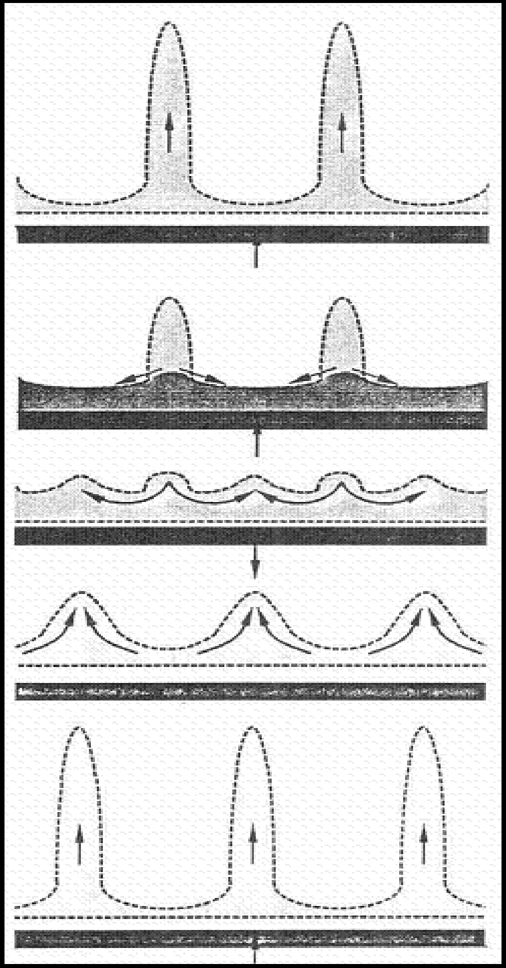
- The impact of the bed on the plate becomes too strong
- The outward motion due to avalanching becomes larger than the inward motion due to the air drag.

That is why the heaping phenomenon breaks down at large shaking strengths.

Standing Waves

There is a resonance condition for the development of the waves: the two relevant time scales are the external forcing period and the characteristic avalanche time.

This wavy regime is at half the excitation frequency



Flour Jets

Flour jets may occur due to "cumulative effect" - energy concentration in some small volume and its orientation in some definite direction.

Two possible mechanisms of creation of this effect:

1. Analog of the small stone into the water
2. Small air bubble being compressed and then exploding.

Video

Conclusions

1. **Air drag plays a crucial role for Faraday heaping.**

2. **Main mechanisms responsible for heap formation are:**

- ❖ Pressure gradients
- ❖ Internal Avalanches
- ❖ The stability of inclined surfaces compared to horizontal

3. **Heap coarsening occurs due to asymmetry of heap slopes, when heaps occasionally approach each other.**

4. **At distinct frequencies standing waves appear.**

5. **At some conditions "Jet burst" phenomenon was observed.**

6. Special demonstration (1min 12') video

Thank you for Attention!

References

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1 H.J. Van Gerner. Ph.D. Thesis. 2009
2 Duran J., Phys. Rev. Lett., 84, 5126, (2000)
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4 Laroche C., Douady S. and Fauve S., J. Phys. suppl. 3, Tome 50, 187(1989).