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Granular Flows – How Size Matters

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Introduction

Granular flows are extremely important for the chemical industry [1]. To understand the impact of particle size on the mean as well as on the fluctuating flow field in granular flows is critical. However, the effect of different particle sizes has not been systematically investigated yet for a wide range of flows.

Here, we demonstrate how to use a specialized simulation technique [2, 3] as well as a sophisticated flow measurement system to obtain a deep insight into dry and wet granular flow.

Objectives

- To measure time-resolved granular flow fields by means of Particle Image Velocimetry (PIV).
- To simulate particle motion by means of the Discrete Elemente Method (DEM).
- To apply this technique to a mixer and a granular Hele-Shaw cell.

Experiments

- The heart of our experimental system is a 1.4 Megapixel high-speed camera system. Using sophisticated image analysis software [4], it is possible to extract the instantaneous granular flow field with a frame rate greater than 500 Hz.
- Experiments involving a stirred granular bed are performed in a vacuum-tight and temperature controlled glass container (Figure 1).
- The results (Figure 2) clearly indicate a transition from a smooth flow field in case of 0.5 mm glass beads to a more erratic behavior for the larger beads. This is due to a "roll-and-lock" effect that is caused by the gaps between big particles.

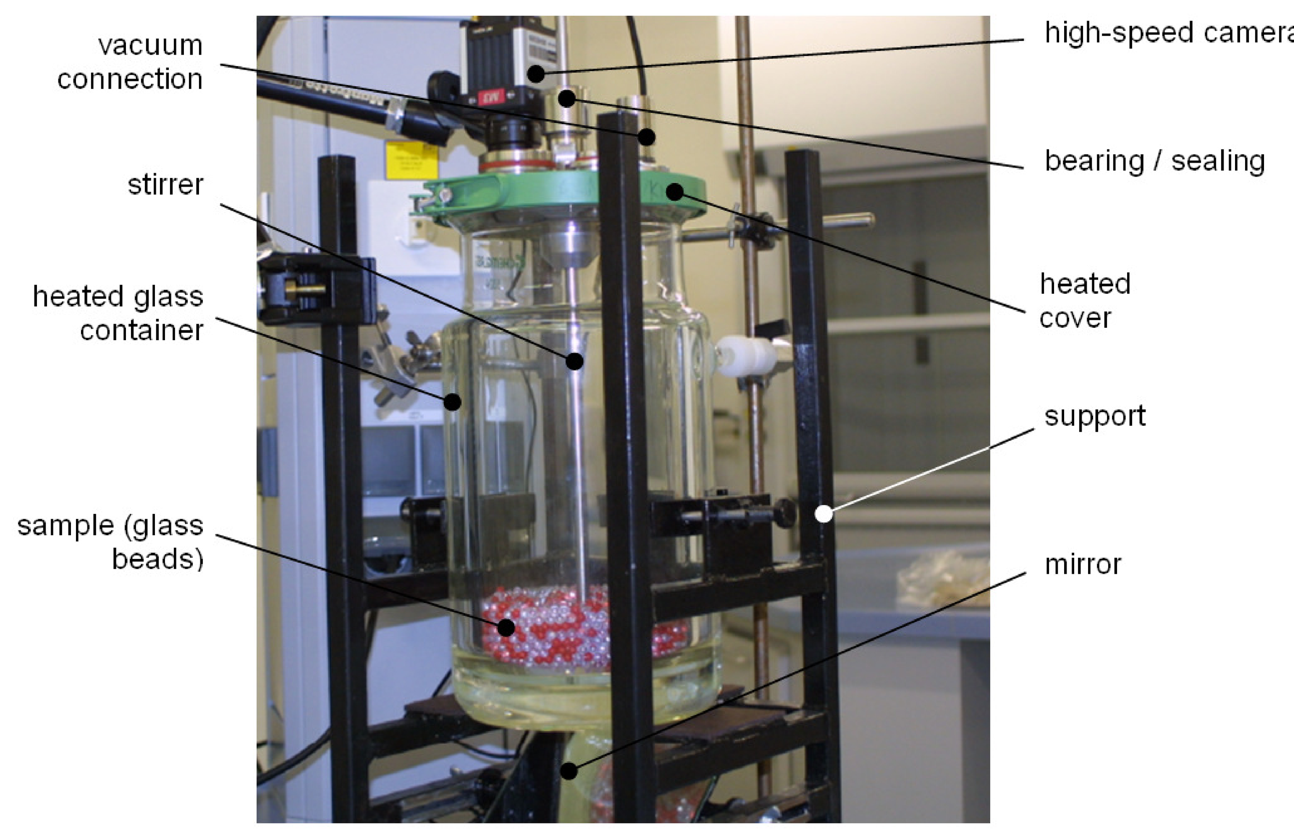


Figure 1: Experimental mixer setup with camera, stirrer and temperature-controlled glass container.

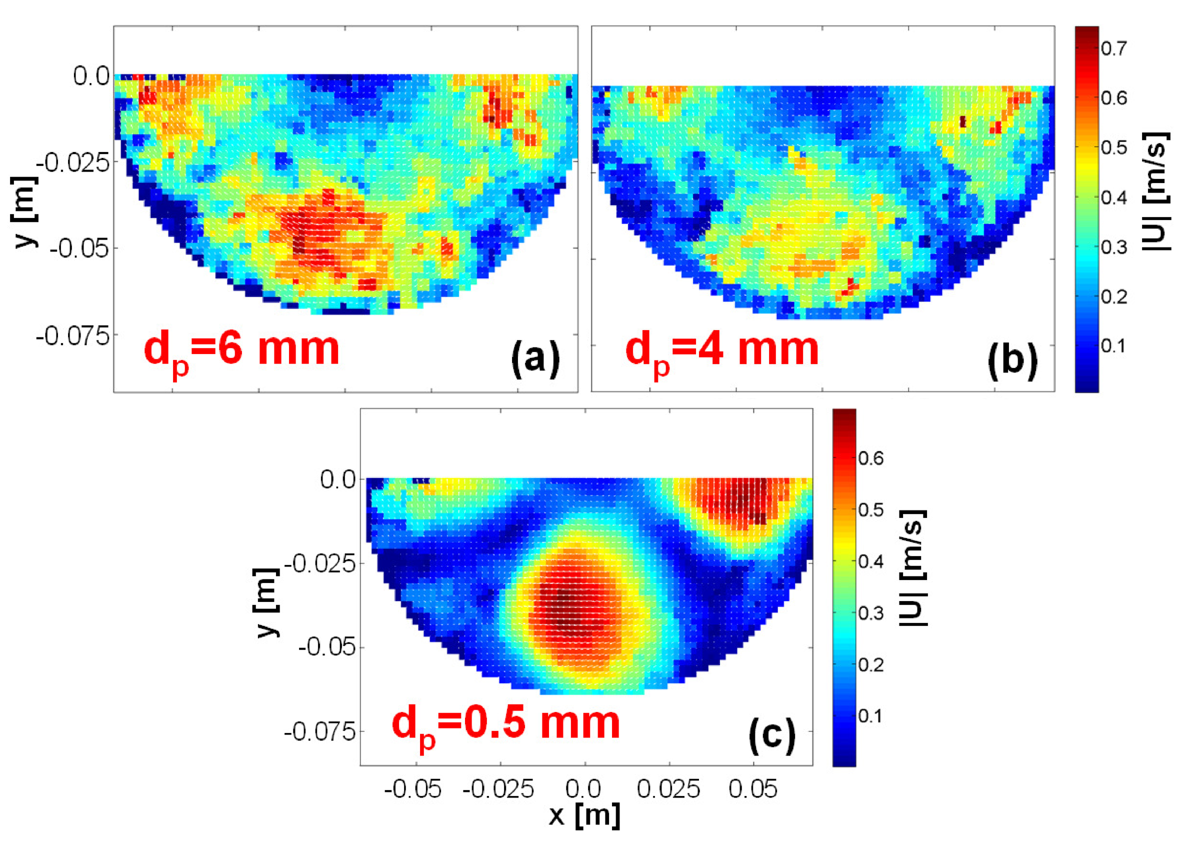


Figure 2: Flow field of stirred granular matter for different particle sizes (60 rpm, glass beads)

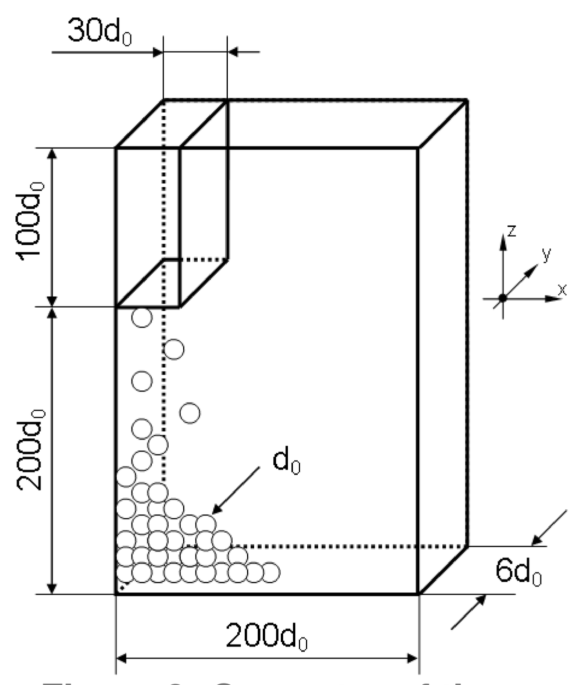
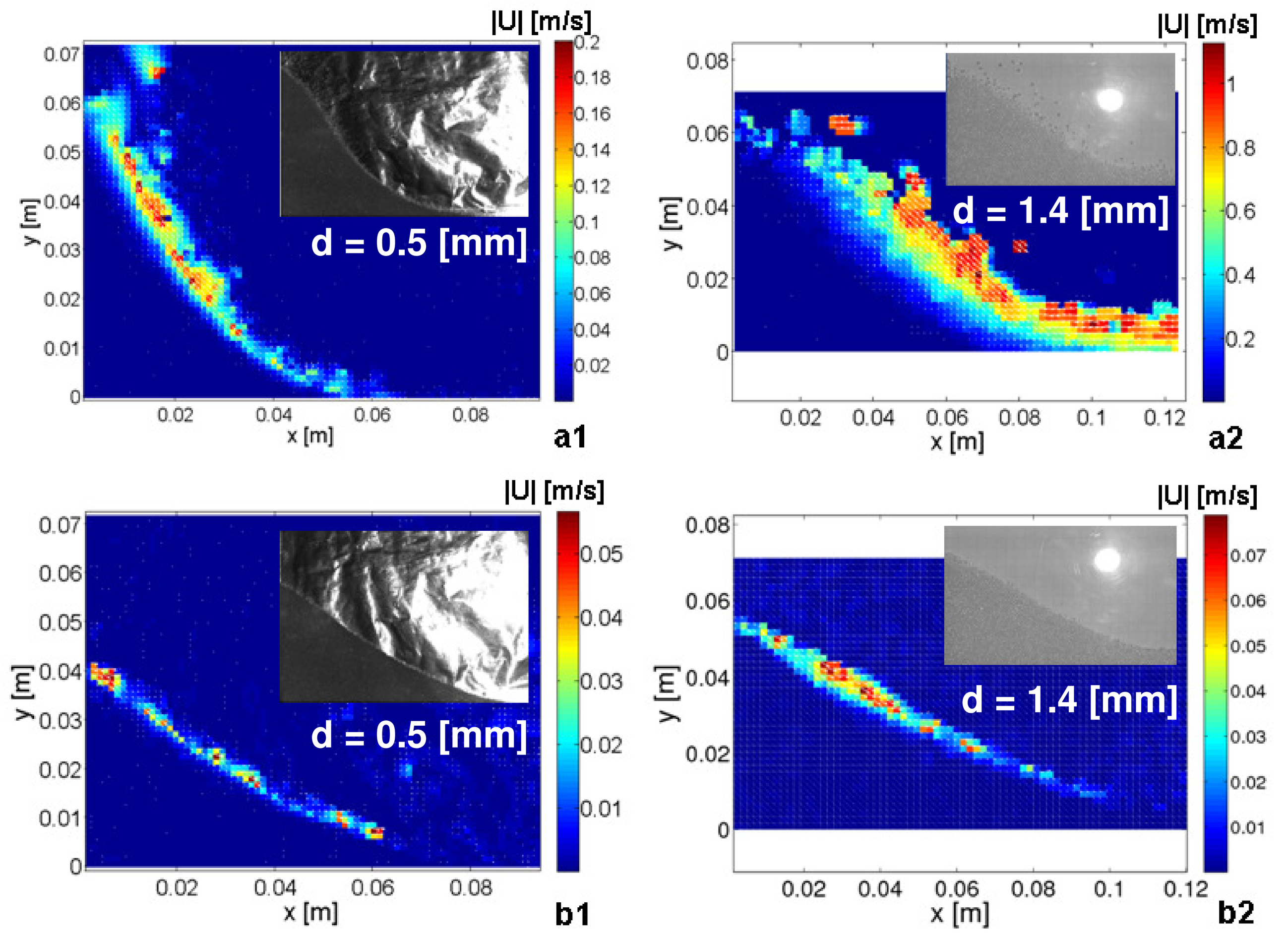


Figure 3: Geometry of the Hele-Shaw cell

- Experiments involving a pseudo-2D granular flow, i.e., a Hele-Shaw cell are performed in a plexi-glass container (Figure 3).
- Glass beads have been reproducibly discharged into these cells and the shape of the resulting pile as well as the flow field has been measured.
- Similar to the mixer case, bigger particles lead to higher peak velocities (Figure 4).



Bed Angle α:
- a1: 50°
- b1: 30°
- a2: 40°
- b2: 28°

Maximal Velocity $|U_{max}|$:
- a1: 0.2 [m/s]
- b1: 0.06 [m/s]
- a2: 1.1 [m/s]
- b2: 0.08 [m/s]

Figure 4: Velocity field of particles with different sizes in a Hele-Shaw cell (glass beads, the inserts are the raw images used for the PIV analysis)
a1: 0.5 [mm]-Phase 2, a2: 1.4 [mm]-Phase 2, b1: 0.5 [mm]-Phase 3. b2: 1.4 [mm]-Phase 3.
Phase 2: Pictures were taken at the moment the last glass bead hit the pile.
Phase 3: Pictures were taken when there was no longer a change of the angle of repose.

Simulations

We use the DEM to simulate flow and mixing of granular matter. This method is based on Newton's equation of motion and tracks each individual particle in the granular bed.

$$m_i \frac{d\vec{v}_i}{dt} = \vec{F}_{b,i} + \sum_{j\neq i}^{k} \vec{F}_{c,ij} + \sum_{j\neq i}^{k} \vec{F}_{coh,ij}$$

$$I_i \frac{d\dot{\vec{\theta}}_i}{dt} = \vec{M}_{total,i}$$

b……. body forces
c……. contact forces
coh…. cohesion forces
i……. particle index
j……. contact index

Our simulations for the flow in the Hele-Shaw cell agree very well with the experimental data presented. Thus, we can predict the significantly thicker shear layer on top of the pile in case of larger particles (see Figure 5). Also, the predicted angles of repose agree exceptionally well with experimental data.

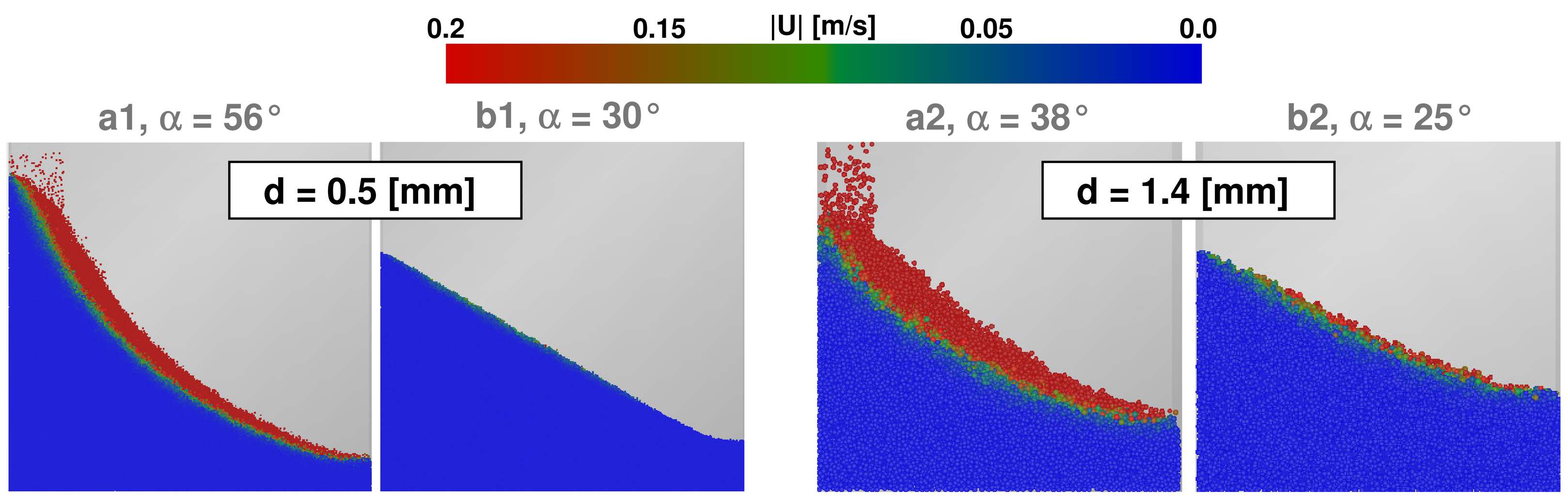


Figure 5: Predicted shape and velocity distribution in the granular pile
(movies are available at http://ippt.tugraz.at/index.php?lang=_de&node=&scheme=50102)

References

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