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Osmosis in a bi-disperse compartmentalized granular material in low-gravity environment

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Introduction

Granular gases have the particularity of being composed of dissipative particles, that is to say, which lose kinetic energy when they collide. This intrinsic property can be highlighted with the help of low gravity. Indeed, by removing gravity, a set of grains which have each received an initial kinetic energy will naturally "cool down", and the total kinetic energy will decay following Haff's law (Haff 1983), and this, whatever the shape of the particles (Maaß et al. 2008, Grasselli et al. 2009, Harth et al. 2018, Yu et al. 2020).
To keep a diluted set of grains in a gaseous state, it is essential to provide them some energy. Generally, the whole system is vibrated in order to provide the energy in a mechanical way. In this way, the total energy of the system can be kept constant and the system can reach an out-of-equilibrium steady state.
Mainly depending on the filling conditions, a granular gas state, or a phase separation between a dense aggregate (called "cluster") bathing in a less dense granular gas can be observed (Falcon et al. 1999, Opsomer et al. 2012). Using the VIP-Gran instrument, specially designed to study granular media in a low-gravity environment (Aumaître et al. 2018), the onset of the gas-cluster transition has been studied (Noirhomme et al. 2018).
Note that the mechanism for nucleation of the denser phase has recently been identified as arising from minimization of the power dissipated in the system (Noirhomme et al. 2021).
On the other hand, mixing several sizes of beads, always under microgravity conditions, can also give rise to convection or segregation phenomena (Opsomer et al. 2017).

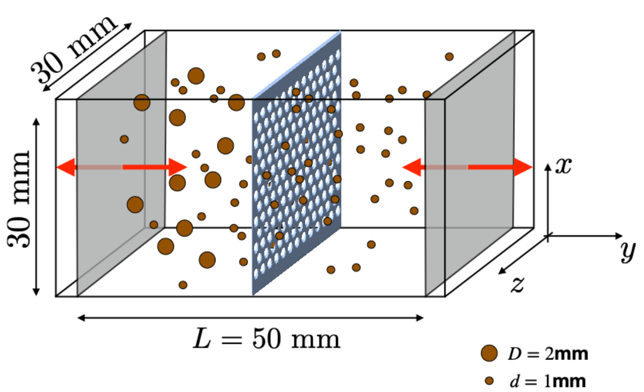

Figure 1: Sketch of the VIP-Gran 3D cell for the study of granular gases in microgravity conditions. In order to create a granular osmosis, a binary mixture of small and large spheres are placed in the cell with a wall permeable only to small grains. The large particles are all located on the left side of the wall. Vibrating pistons are displayed in red.

Experiments and simulations

Here, using the VIP-Gran instrument, we study the possibility of creating granular "osmosis" using a binary mixture of bronze spherical beads (a "solute" and a "solvent" made up of large and small particles, respectively) and a mobile wall pierced with holes whose the diameter avoids the solute to pass through it. The diameters of the particles are D=2mm for the large ones and d=1mm for the small ones, while the diameter of the holes is d_h=1.2mm. Figure 1 gives an overview of the experiment. We place 50 large particles on the left of the wall and Ns small ones on the right, with Ns=[100; 800; 1000]. We performed experiments during the Parabolic Flight Campaign 67 (PFC 67) of the European Space Agency (ESA), in the frame of the SpaceGrains project (SpaceGrains2022) and reproduced the experiment numerically.

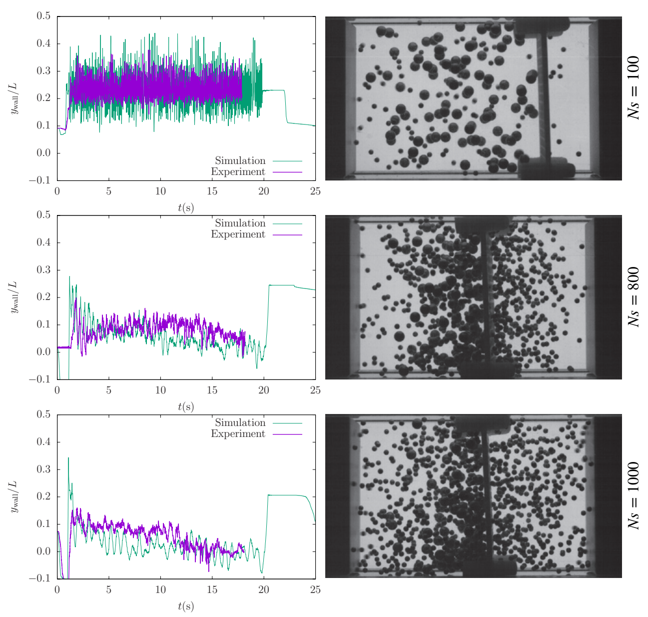

Figure 2: Left: time evolution of the normalized position of the wall y_{wall}/L measured during the parabolic flight campaign 67 (purple) and in the numerical simulations reproducing the latter (green). Right: snapshots of the corresponding experiments. The simulations take into account the g-jitter remaining in the aircraft as well as the friction of the mobile wall on the glass walls of the cell. 20s is the duration of the low-gravity phase.

Results

The first results obtained show that the position of the mobile wall, as well as the number of particles to the right of the latter, depends directly on the filling conditions of the

particles preferentially move on the side of the large ones, exactly as would be the case in a classic osmosis experiment (Marbach 2019). This being so, one could believe that it is a volume effect since the large particles exert pressure on the wall, pushing it close to the right piston. In order to remove this possible volume effect, we carried out a numerical study in which the semi-permeable wall is attached to the center of the cell. Surprisingly, the result is identical to that obtained for the mobile wall: granular osmosis, i.e. a greater number of small particles in the compartment where the large ones are, can be created under certain conditions.
Finally, the average volume occupied by each small grain remains preserved when the volumes of the left and right compartments and the numbers of particles in them are different depending on whether the wall is fixed or mobile. This volume per particle is modeled thanks to the theory of minimization of the power dissipated in the system.

Conclusions

In this work, we studied experimentally and numerically the possibility of creating a granular osmosis in low gravity thanks to the VIP-Gran instrument in which we have placed a binary mixture of particles as well as a wall permeable only to small particles. We discovered with surprise that the mobile character or not of the semipermeable wall was not relevant for the phenomenon of granular osmosis. The key parameter is the available volume per small particle minimizing the power dissipated in the system.

Acknowledgements

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