The Active Sands of Time: Flow of Granular Microrollers through Funnels

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Abstract

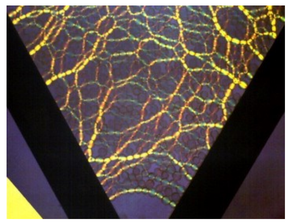

Fig. 1 Jammed granular material force networks in a 2D hopper[1]

Granular materials play a vital role in agriculture, industry, and medicine and exhibit complex movement properties. They are solids and jam up in funnels, yet behave as a fluid when moving at high speeds and exhibit distinct velocity profiles. This work explores the area of "active granular media" where magnetically responsive microroller particles rotate in response to an oscillating field, intersecting granular material and microrobotics. These polymer particles have evaporated Fe_2O_3 on half of their surface, known as Janus particles, creating a north and south pole in the metal. This allows them to be moved magnetically, individually and collectively. This work observes the flow of these functionalized 44 μm polymer particles in funnels and how they mix and disperse within a fluid under various magnetic fields to further explore their viability for navigating complex systems.

Fig. 2 Janus particles that roll when forced by a rotating magnet[2].

Experimental Setup

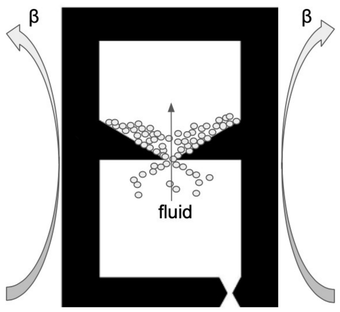

Fig. 3 Constant mixing allows fluid to easily replace displaced volume in the top of the funnel, allowing for constant flow.

Microrollers were suspended in ethanol in a 1.5mm thick funnel. A magnetic field rotates clockwise on the left side of the funnel and counterclockwise on the right side. The microrollers rotate the opposite direction of the fields they are influenced by, moving towards the orifice and constantly mixing the system.

30° Angled Funnel

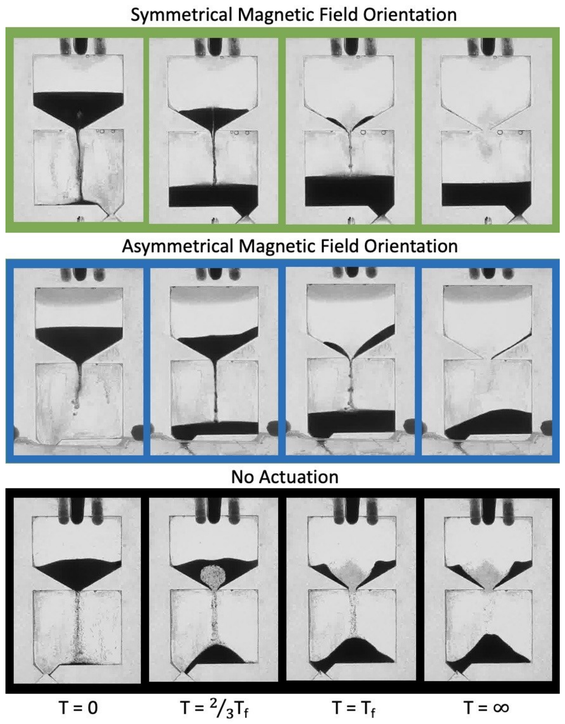

Fig. 4 Freeze frames at various times and conditions in a 30° angled funnel. Symmetrical Magnetic Field Orientation (green) consisted of a magnetic field rotating outward on each side, rotating the microrollers towards the orifice. Asymmetrical Magnetic Field Orientation (blue) consisted of a single magnetic field on the left side only. No Actuation (black) displays the particles under no magnetic manipulation.

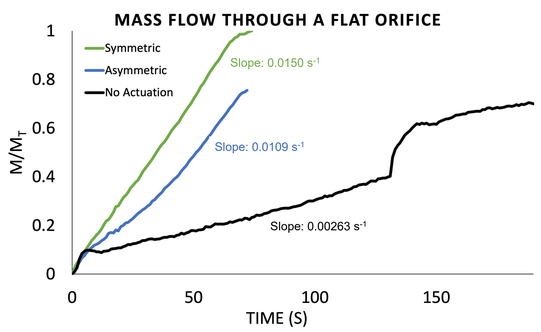

Fig. 6 Accumulation of microrollers in the bottom of the angled funnel over time in respect to total particle volume.

Squared Funnel

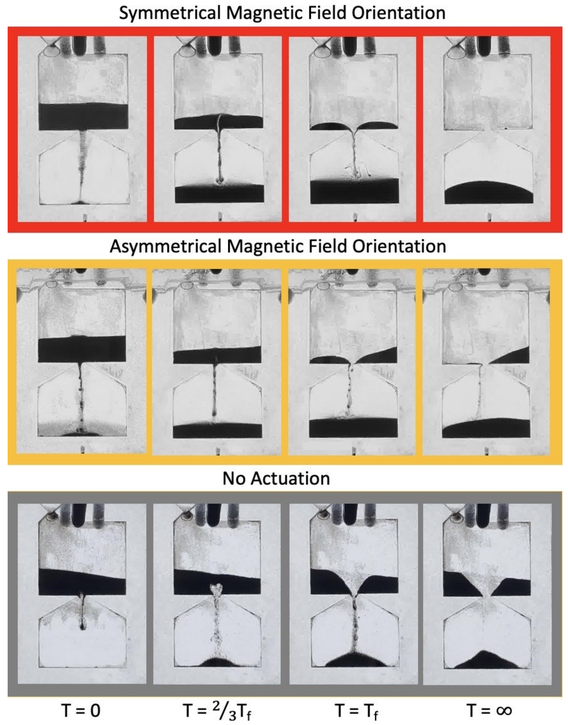

Fig. 5 Freeze frames at various times and conditions in a square funnel. Symmetrical Magnetic Field Orientation (red) consisted of a magnetic field rotating outward on each side, rotating the microrollers towards the orifice. Asymmetrical Magnetic Field Orientation (yellow) consisted of a single magnetic field on the left side only. No Actuation (grey) displays the particles under no magnetic manipulation.

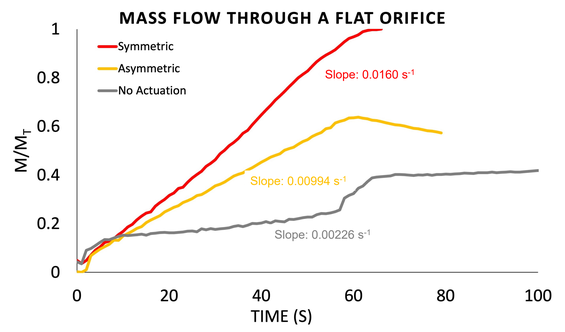

Fig. 7 Accumulation of microrollers in the bottom of the square funnel over time in respect to total particle volume.

Final Time

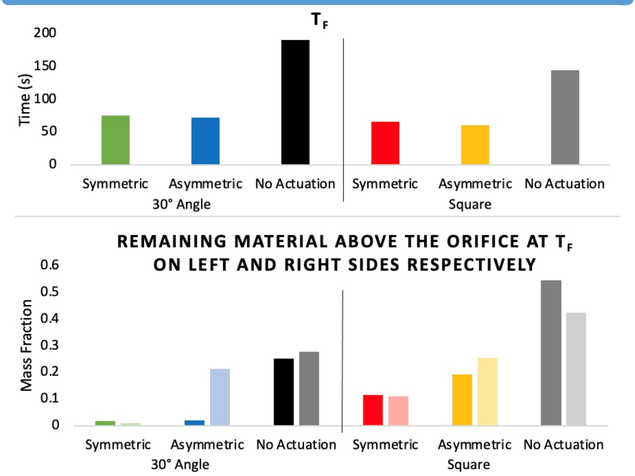

Fig. 8 (top) Final time plotted for each set of conditions. T_f is the maximum particle volume in the bottom of the funnel. Post T_f the material begins to settle. (bottom) Material remaining in the top half of the funnel at T_f on the right and left sides of the orifice, displayed respectively with respect to the total amount of material.

Summary

The symmetrically manipulated material moved through the funnel the fastest and in greatest amounts, displaying a consistent rate of movement, contrasting the irregular rate of the unmanipulated material. The fluidization of the particles in the ethanol allowed for mixing, shifting and prevented clumping and blockages. Active granular media presents a unique opportunity to combat some truly complicated problems because of the properties of their movement and ability to navigate on a micron level.

Acknowledgements

1. Behringer, R. P. Jamming in Granular Materials. *Comptes Rendus. Physique* **2015**, *16*, 10–25.
2. Wilson-Whitford, S., Gao, J., Roffin, M.C., Buckley, W.E., Gilchrist, J.F., Microrollers flow uphill as granular media, *Nature Communications*, **2023**, *14*, 5829.
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