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

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Abstract
Granular materials play a vital role in agriculture, industry, and medicine and exhibit complex movement properties. These solids and jams 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 Fe₃O₄ 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.

PMMA 44 μm Fe₃O₄ 100 nm cap

Experimental Setup
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
Symmetrical Magnetic Field Orientation

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

Asymmetrical Magnetic Field Orientation

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

Slopes:

- Symmetrical: 0.0109 s²⁻¹
- Asymmetrical: 0.00994 s⁻¹
- No Actuation: 0.00226 s⁻¹

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

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 material presents a unique opportunity to combat some truly complicated problems because of the properties of their movement and ability to navigate on a microm level.

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