MRI measurement of fluid mechanical properties in granular flow

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Introduction: The transport and processing of granular materials pose longstanding industrial challenges due to their complex mechanical behavior. While numerous studies have explored the kinematics of granular flow and suspensions, these investigations are mainly limited to transparent boundaries or free surfaces. The interior flow remains poorly understood, largely due to the opacity of granular media to light. Non-invasive imaging techniques like X-ray CT and MRI [1-4] have been employed to probe these flows, but previous studies often suffered from limited field of view or insufficient spatial resolution.
This study aims to advance the use of MRI for capturing 2D and 3D spatially resolved flow fields of granular media in both canonical (e.g., Couette cell) and complex geometries (e.g., flow around obstacles and in screw feeders). These configurations have seen limited investigation, and we anticipate that MRI will yield new insights into the mechanics of granular materials and enable rigorous testing of continuum models, particularly regarding the coupling between density and velocity fields. The data may also contribute to the development of models for cohesive granular media, which remain poorly understood.

Methods:
Experiments are conducted at the MRI Flow Lab at the University of Rostock, a DFG-funded core facility equipped with a 3T whole-body MRI system (Magnetom Trio, Siemens). The lab has previously validated high-accuracy flow imaging methods using gradient-recalled echo (GRE)[5] and single-point imaging (SPI)[6], focusing on minimizing displacement artifacts and higher-order gradient moment effects, which are key sources of error in velocity-encoded MRI.
One of the main challenges in MRI of granular flows is the short T2* relaxation time of natural granular materials such as oilseeds. Although spin echo (SE) sequences are commonly used in granular media studies, their long encoding times and higher-order gradient artifacts limit their accuracy for fluid mechanics. This study, therefore, employs GRE and SPI sequences and optimizes experimental design to match their requirements.

Results and Conclusion: The project is currently in the commissioning phase, focusing on validating both the imaging sequences and the custom-designed granular media. A significant innovation is the development of gel-water beads coated with a polymer shell that supports GRE imaging without requiring ultra-short echo times. In addition to much longer T2*, these particles offer better-controlled experimental boundary conditions than natural granular materials, which typically have variable geometry and uncontrolled surface properties. Manufacturing these particles was challenging since over 10,000 such particles are needed for meaningful granular flow experiments. The successful fabrication of this MRI-optimized granular material marks a key milestone.
Initial experiments are being carried out in a large-scale Couette setup containing approximately 30,000 particles, previously studied using optical methods and numerical simulations. These MRI measurements provide spatially resolved velocity data, paving the way for a deeper understanding of granular flow mechanics in realistic conditions.

References: [1] Losert, Phys. Rev. Lett. (2000). [2] Meuth, Nature (2000) [3] Baker, Nat. Commun. (2018). [4] Clarke, Particuology (2023). [5] Romig, Magn. Reson. Imag. (2025). [5] Bruschewski, Magn. Reson. Med. (2019).