Flow of elongated particles out of a silo with rotating bottom

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There are several interesting procedures to avoid clogging or to enhance the particle flow rate in silo discharge processes. One possibility is introducing an additional source of external shear to the system, that is, imposing the rotation of the bottom wall. Very recently, this system was investigated experimentally [1] and numerically [2], exploring the flow of spherical particles in a cylindrical flat bottom silo, but with the bottom wall rotating around the axis of the cylinder. Examining small orifice sizes $D < 5d$, both the experimental and numerical approaches similarly found that the external shear induces that the flow rate proportionally increases with the frequency of the rotation of the bottom wall f. For large orifices $D/d > 5$, however, the flow rate depended non-monotonically on f. Starting from the static case, first the discharge rate decreased (down to 5%), and then it increased when further increasing the rotational frequency. The authors of the experimental work [1] hypothesized that in the latter case the flow field transitions from funnel flow to mass flow gradually as the rotation frequency is increased. This assumption was based on the fact that the surface of the column in the silo changed from a usual V shape to a heap when the rotation was applied. Later the discrete element modeling (DEM) and the coarse-graining post-processing analysis of the numerical data confirmed this idea [2].

In general granular materials, such as stones and pills have non-spherical shapes. Thus, another interesting question is what would be the response of this system using non-spherical particles. Last year, this was experimentally examined [3], and we found that in the large orifice regime the introduction of the rotational shear greatly reduces the flow rate by about 50% and by further increasing the rotation speed the flow rate increases only slightly. Moreover, we also take advantage of DEM simulations and modeled spherocylinder particles to mimic the behavior of the wooden rods. The analysis allows us to get insight into the dynamics of this process (Fig. 1). Our results agree very well with the experimental finding [3] that the flow rate drops significantly by introducing even a slow rotation which then increases moderately by faster rotation. Complementary, we used a coarse-graining technique, and computed all relevant macroscopic fields including the macroscopic density, momentum, and the stress tensor fields. It allows us to analyze thoroughly the spatial profiles of the macroscopic fields, which shed light on the micromechanic details of the flow process.

Fig. 1. Visualization of the numerical setup of the flat bottom, cylindrical silo with rotating bottom. Elongated particles are mimicked by spherocylinders.

[1] K. To, Y. Yen, Y.K. Mo and J.R. Huang, *Granular flow from silos with rotating orifice*, Physical Review E, **100**, 012906 (2019).

[2] D. Hernández-Delfin, T. Pongó, K. To, T. Börzsönyi, and R.C. Hidalgo, *Particle flow rate in silos under rotational shear*, Physical Review E, **102**, 042902 (2020).

[3] K. To, Y.K. Mo, T. Pongó, and T. Börzsönyi, *Discharge of elongated grains from silo with rotating bottom*, Physical Review E, **103**, 062905 (2021).