Frictional interactions in viscous suspensions:

Abrupt shear thickening and flow-induced jamming

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Particles suspended in a Newtonian fluid raise the viscosity, and there is generally also a shear rate dependence of the suspension rheology. In particular, pronounced shear thickening is one of the phenomena observed at large solid volume fraction. In recent work [1, 2], we have considered through a simulation study the minimum set of components to reproduce experimentally observed shear thickening behaviors, including the extremely abrupt or "discontinuous shear thickening" (DST). We have found frictional contact forces to be of essential importance.

The viscosity divergence at a maximum packing volume fraction has been a well known behavior in suspension rheology, as is reflected in many empirical laws for the viscosity (e.g. Krieger-Dougherty). This divergence can be identified with the jamming transition, as it is known in granular physics. Friction can affect this divergence, and in particular the maximum packing fraction is reduced if particles are frictional. It turns out that shear thickening is a direct consequence of this shift: as the shear rate increases, friction is increasingly mobilized as more contacts form, leading to a transition from a mostly frictionless to a mostly frictional rheology. This result is significant because the emphasis has shifted from lubrication hydrodynamics and detailed microscopic interactions to geometry and steric constraints close to the jamming transition. An overview of the results of the frictional-viscous model of sheared suspensions and its predictions will be given. The same basic mechanism explains shear thickening in both non-Brownian and Brownian (colloidal) suspensions. We will consider the model in comparison with other simulations and with experimental data reported in the literature. Recent work has shown that an S-shaped curve which accesses points that a rate-controlled flow missed can be access when the flow is stress controlled, and this can be driven to jamming conditions.

1] Ryohei Seto, Romain Mari, Jeffrey F. Morris, and Morton M. Denn. Discontinuous shear thickening of frictional hard-sphere suspensions.Phys. Rev. Lett., **111**:218301, 2013.

[2] Romain Mari, Ryohei Seto, Jeffrey F. Morris, and Morton M. Denn. Shear thickening, frictionless and frictional rheologies. J. Rheol. **58**, 1693. 2014.