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Discontinuous Shear Thickening and Dilatancy: Frictional Effects in Viscous Suspensions

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Shear thickening in concentrated suspensions has been well-known for quite a long time, yet a firm consensus on the basis for very abrupt or "discontinuous" shear thickening (DST) seen in suspensions of large solid fraction, ϕ, has not been reached. This work addresses the DST phenomenon, and proposes a simulation method based in the Stokesian Dynamics algorithm to explore the role of various forces between the particles, including hydrodynamic, conservative potential, and frictional interactions. This work shows that allowance for friction between spherical particles suspended in a viscous liquid causes a significant reduction in the jamming solid fraction of the mixture, $\phi_{\max}$, taken as the maximum fraction at which the suspension will flow. A consequence of this is a shifting of the singularity in the effective viscosity, η, to smaller $\phi_{\max}$, and the frictional suspension has a larger viscosity than does the frictionless suspension of the same solid fraction, as is clear from the standard empirical modeling of $\eta(\phi) = (1 - \phi/\phi_{\max})^{-\alpha}$, $\alpha \approx 2$. When a counterbalancing repulsive force between the particles, representative for example of charge-induced repulsion, is incorporated in the dynamics, the mixture undergoes a transition from frictionless to frictional interactions, and from low to high effective viscosity, at a critical shear rate. Comparison with experimental data shows remarkable agreement in the features of DST captured by the method. The basic algorithm and results of both rate-controlled and stress-controlled simulations will be presented. Like the shear stress, the magnitude of the normal stress exerted by the suspended particles also increases abruptly at the critical shear rate, consistent with the long-standing notion that dilatancy and shear-thickening are synonymous. We will show that considering all shear thickening materials as dilatant is a misconception, but demonstrate the validity of the connection of dilatancy with DST in concentrated suspensions.