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Shear thickening in suspensions: the lubricated-to-frictional contact scenario[1]

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Suspensions of solid particles in viscous liquids can vary from low-viscosity liquids to wet granular materials or soft solids depending on the solids loading and the forces acting between particles. When the particles are very concentrated, these mixtures are "dense suspensions." Dense suspensions often exhibit shear thickening, an increase in apparent viscosity as the shear rate is increased. In its most extreme form, order of magnitude increases in viscosity over such a narrow range in shear rate occur that the term discontinuous shear thickening (DST) is applied. DST is particularly striking as it occurs in the relatively simple case of nearly hard spheres in a Newtonian liquid, and is found to take place for submicron particles in colloidal dispersions to much larger particle corn starch dispersions. We focus on simulations of a recently developed "lubricated-to-frictional" rheology in which the interplay of viscous lubrication, repulsive surface forces, and contact friction between particle surfaces provides a scenario to explain DST. Our simulation method brings together elements of the discrete-element method from granular flow with a simplified Stokesian Dynamics, and can rationalize not only the abrupt change in properties with imposed shear rate (or shear stress), but also the magnitude of the change. The large change in properties is associated with the breakdown of lubricating films between particles, with activation of Coulomb friction between particles. The rate dependence is caused by the shearing forces driving particles to contact, overwhelming conservative repulsive forces between surfaces; the repulsive forces are representative of colloidal stabilization by surface charge or steric effects, e.g. due to adsorbed polymer. The results of simulation are compared to developments by other groups, including a number of experimental studies and a theory incorporating the same basic elements as the simulation. The comparison to experiments of the predictions of the lubricated-to-frictional rheology is generally good, but discrepancies demand some perspective on the strong simplifying assumptions in the model. Since contact is difficult to both establish and to characterize for surfaces between particles of micron scale or smaller, what is happening in the very close "contacts" is not clear, and how changes at this scale give rise to the large-scale force organization is yet to be established. The insight to the elements needed for the abrupt flow induced transition seen in DST thus suggests a need for consideration of both the microscopic physics of contact and the statistical physics governing the macroscopic properties.

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