<u>Chapter 8 Questions</u>

1. Reversible shear thickening is predicted and evident even for semi-dilute dispersions-explain the mechanism.

2. Explain how the critical stress for shear thickening depends on the particle size, stabilization forces, and volume fraction.

3. What are hydroclusters and how are they detected?

4. Explain the differences and similarities between dilatancy and shear thickening.

5. Give an example of how to reduce shear thickening for a given process.

Chapter 8 Answers

1. Shear thickening is due to the shear-induced formation of density fluctuations under flow, known as "hydroclusters". The reversible clustering of particles leads to strong lubrication forces that dissipate more energy. Two particles in shear flow at high Peclet number will, on average, spend more time in close proximity due to the strong lubrication forces, and thus, dissipate more energy, leading to shear thickening.

2. The critical stress for shear thickening arises as a balance between the dominant stabilizing force(s) acting at short range and the lubrication hydrodynamics. As such, the dependence on particle size depends on the nature of the stabilizing forces: for Brownian hard spheres the critical shear stress scales as a^{-3} whereas for electrostatically stabilized dispersions, it scales as a^{-2}. The critical stress will depend on the strength of the stabilizing forces and so the parameters that characterize those forces enter into the expression for the critical stress. To leading order, the critical stress is independent on volume fraction with the exception being hard spheres, where the Brownian forces are dependent on the volume fraction.

3. Hydroclusters are groupings of particles that are in close proximity (i.e., transient density fluctuations) that are evident in simulations as instantaneous clusters of particles, and in scattering experiments and direct visualization experiments as local clustering of particles. Note that the particles move in and out of these clusters with time and the clusters grow and disappear as fluctuations in the shear field, i.e. they are not permanent. The important feature of hydroclusters is that there is a significant increase in energy dissipation that gives rise to an increase in viscosity (i.e., shear thickening) as the lubrication hydrodynamic stresses acting between particles in close proximity can be very large.

4. Dilatancy is the expansion in volume observed for non-Brownian suspensions and some colloidal dispersions at high volume fraction and shear rate. This is accompanied by positive first normal stress differences and often leads to sample ejection from the rheometer. When confined, dilatancy leads to shear thickening. Shear thickening, on the other hand, arises due to hydrocluster formation and does not require dilatancy. Such shear thickening suspensions do not exhibit dilatancy and have negative first and second normal stress differences.

5. For example, polymer could be grafted to the surface of the particle to impart steric stability. For moderate grafting densities, where the grafted brush is in good solvent and imparts steric repulsion between particles but still allows solvent to flow through the brush, this can delay shear thickening to much higher shear rates than for the bare particle dispersion. The calculation of this effect can be estimated given the nature of the brush and the degree of hydrodynamic resistance afforded by the brush. Note that the addition of polymer will in general have other consequences on the suspension's

rheology (such as increasing the effective volume fraction and hence, the zero shear viscosity) and this should be considered in formulation.