CAPILLARY SUSPENSIONS: RHEOLOGICAL FEATURES AND POTENTIAL APPLICATIONS

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When a small amount (less than 1%) of a second immiscible liquid is added to the continuous phase of a suspension, the rheological properties of the mixture are dramatically altered and can change from a fluid-like to a gel-like state (see figure). The yield stress σ_y and viscosity increase by several orders of magnitude as the volume of the second fluid increases. This transition is attributed to the capillary forces of the two fluids on the solid particles, and in an analogy to wet granular materials, two distinct states are defined: the "pendular state" where the secondary fluid preferentially wets the particles and the "capillary state" where the secondary fluid wets the particles worse than the primary fluid. We have investigated a broad variety of particle/fluid mixtures including limestone, hydrophobic calcium carbonate, clean and hydrophobic glass spheres, cocoa, and PVC suspended in water, silicone oil, or diisononyl phthalate with the addition of a second immiscible fluid. We find that both the pendular and capillary states are associated with a transition in the suspension from a fluid-like (or weakly elastic) to a highly elastic gel-like state. This research investigates this general phenomenon and provides evidence that capillary forces control the observed behavior.

The transition to a gel-like state using two fluids occurs for particle volume fractions as low as $\phi = 0.10$ – well below the limit of dense packing. The measured yield stress for these gels, when normalized by the yield stress for no added secondary fluid, is independent of volume fraction. For a series of glass bead suspensions with varying particle radius R, the expected 1/R scaling of σ_y is found. Various grades of PVC with different particle size do not show this simple behavior due to variations in the particle shape, morphology, and wetting properties. We further demonstrate that the phenomenon d1scribed above may have numerous technical applications. Stable suspensions can be formed when settling would otherwise occur. A variety of suspensions with tunable rheological properties can be created and the strong network of particles aggregated due to capillary forces may be used as a template for the manufacturing of various porous materials, like lightweight ceramics, thermal insulators, or catalyst carriers.

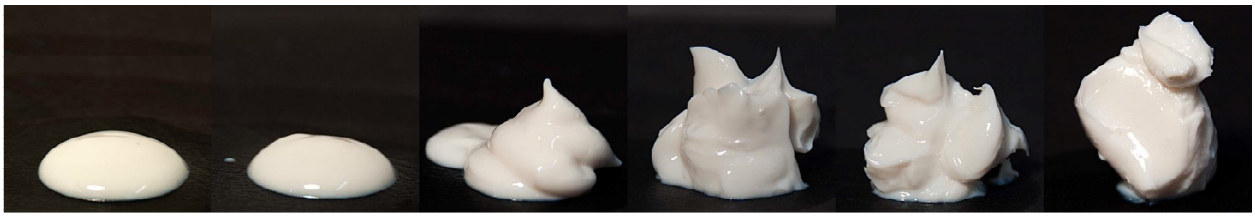

Figure: Transition from weakly elastic, fluid-like to highly elastic, gel-like state with the addition of small amounts of a second immiscible fluid as shown for hydrophobic calcium carbonate ($\phi = 0.111$) in diisononyl phthalate with less than 0.50% wt. distilled water.