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Doctoral Defense
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Roberts 319

RheoNMR as a technique to study shear-induced transitions in nanocolloidal suspensions

Abstract:
Complex fluids like ketchup, toothpaste, and yogurt exhibit shear-rate dependent material properties, such as viscosity, and can be challenging to measure and study. Nanocrystalline cellulose (NCC) and Laponite® are two complex fluids composed of nanoscale rods and discs, respectively. Due to their nanoscale constituents which can form mesoscale structures, both fluids exhibit complicated flow behavior. This behavior depends on variables like concentration, shear rate, time, ionic species concentration, and others. NCC and Laponite® find use in applications ranging from tissue engineering to electric sensors, and it is necessary to understand their flow behavior to properly design industrial products and processes.

Standard rheometry techniques complemented with RheoNMR velocimetry and relaxometry have been leveraged to measure the flow of NCC and Laponite® aqueous suspensions. While standard rheometry provides bulk flow information which is readily comparable to known fluid flow models, RheoNMR velocimetry and relaxometry offer insight into the mesoscale flow behavior. In this work, RheoNMR has been used to generate velocity profiles with spatial resolution on the order of tens of microns and temporal resolution on the order of seconds. With this data we have observed short time-scale velocity fluctuations in a 5% w/v liquid crystal NCC suspension which have previously only been modeled for rod-like liquid crystal polymers. In addition, we have observed concentration, shear, and time-dependent complex fluid flow behavior, e.g. yield stress, stick-slip and shear banding, for both NCC and Laponite®. Additional experiments on NCC with added NaCl have revealed a dependence of flow behavior on ionic concentration which correlates to solid to liquid phase transitions, including viscoelastic liquid, gel and glass-type behavior. NMR relaxometry experiments of highly concentrated NCC suspensions (>/= 30% w/v) undergoing hydration show magnetization signal changes that indicate a dependence of water distribution on ionic concentration, as well as a dependence on hydration time.

This data provides information about mesoscale flow behavior not attainable with traditional rheometry and offers insight into the structural changes of NCC and Laponite® during shear. Such information can be used to inform fluid models, product design, and manufacturing processes that enable a broader application of these fluids for consumer use.