Erk Research Capabilities: Advanced Rheo-Physical Measurements

Brief statement: Prof. Erk's laboratory in the School of Materials Engineering at Purdue University is equipped with a range of commercial and custom-built instruments for the measurement of bulk and interfacial rheological behavior of soft materials and complex fluids. A Rame Hart goniometer is equipped with an in-line mechanical oscillating pump and automatic fluid dispensing system, allowing for oscillating pendant drop tensiometry to be performed on fluid-fluid interfaces. Two Anton Paar and one TA Instruments stress-controlled rheometers (Anton Paar MCR 302 and 702; TA Instruments AR-G2) are used to perform measurements of a sample's rheological response to imposed shear deformation over a wide range of applied torque (10 nN-m to 200 mN-m), shear rates (0.01-1,000 s^{-1}), frequencies (10^{-7} to 628 rad/s), temperatures (5C-200C) and environments (e.g., closed vs. open, laminar vs. turbulent). A variety of fixtures are available for use with low viscosity liquids (double- and single-gap concentric cylinders), medium-viscosity solutions (parallel plate and cone-plate fixtures), and high-viscosity pastes (sandblasted and serrated parallel plate and vane fixtures). Two custom-built flow visualization systems are used to determine the velocity profile across the thickness of the sample during rheometry tests, allowing for the "rheo-physical" behavior to be fully captured for transparent samples (using optical particle-tracking velocimetry) as well as opaque samples (using ultrasound-based velocimetry).

Rationale: Accurate knowledge of a material's flow behavior is essential to fully understand the impacts of processing on soft materials and complex fluids widely used within the chemical and agricultural sciences, including biomass suspensions and slurries. As these materials typically have a strong viscous response to applied stress, traditional mechanical characterization techniques – elastic tension and compression tests – are typically not possible. Instead, to successfully probe the dynamics of these complex viscoelastic materials, a combination of rheological and physical measurements are required in order to accurately quantify the material's response to applied forces. Such *"rheo-physical"* measurements can be accomplished by simultaneously measuring the local velocities across the thickness of a sample as it is being deformed in a shear rheometer. Rheometers are commonly used to quantify the viscosity and viscoelastic response of fluids by measuring the torque required to deform samples at a fixed shear rate (for rotational experiments) or fixed strain amplitude (for oscillatory experiments). Unfortunately, commercial rheometers are not equipped to perform the sophisticated flow visualization that is required for rheo-physical measurements. In the absence of flow visualization capabilities, rheological responses due to nonuniform behavior of the material (including shear banding, wall slip, fluid fracture, etc.) will not be accurately analyzed, resulting in the measurement of an apparent behavior that will be an under- or over-approximation of the material's true rheological response.

Detailed statement: Prof. Erk's laboratory within the School of Materials Engineering at Purdue University contains custom-built equipment that is capable of performing rheophysical measurements (rheometry + flow-visualization) on both transparent and opaque materials. For investigating transparent materials, a commercial Anton Paar MCR 302 (rotational rheometer) is coupled with a particle-tracking based flow visualization apparatus, constructed in collaboration with Dr. Y. Thomas Hu at Halliburton and based on his original design for velocimetry measurements in a transparent Couette rheometer cell.[1] In this apparatus, a sheet of laser light illuminates inert tracer particles suspended in a sample (contained in a quartz concentric cylinder geometry), and the motion of these particles is optically tracked with millisecond temporal resolution and microscale spatial resolution using an appropriately positioned high resolution camera. By performing local velocimetry simultaneously with a desired rheometry test, the occurrence of shear-induced instabilities such as the formation of shear bands or fracture planes can be directly detected during the experiments, which is currently beyond the capability of commercial rheometers. Erk and her research team have extensive experience performing these *in situ* particle velocimetry rheometry measurements of soft materials and relating instability onset to the observed rheological response and ultimately the sample's molecular structure.[2–5] For opaque materials, Erk and her team are now in the process of finalizing the construction of an ultrasound-based system for use with non-transparent (opaque) samples, with sponsorship from The Procter and Gamble Company, Anton Paar, and support from Prof. Sébastien Manneville at Ecole Normale Supérieure de Lyon (France), a world-expert in ultrasonic speckle velocimetry.[6,7] In this apparatus, an ultrasonic pulser-receiver is positioned near the wall of a custom-machined Plexiglas cup (containing the sample and inner rotating bob), fully immersed in a circulating water bath. Similar to particle-tracking systems, ms and micron resolutions are possible, and in some cases, the sample's microstructure may scatter ultrasound efficiently enough so that seeding the sample with inert tracer particles is not required. For example, recent work by Erk and Manneville quantified the extent of wall slip and shear banding in concentrated aqueous suspensions of magnesium oxide particles without the use of tracer particles.[8] Figure 1 shows schematics of both rheophysical systems at Purdue.

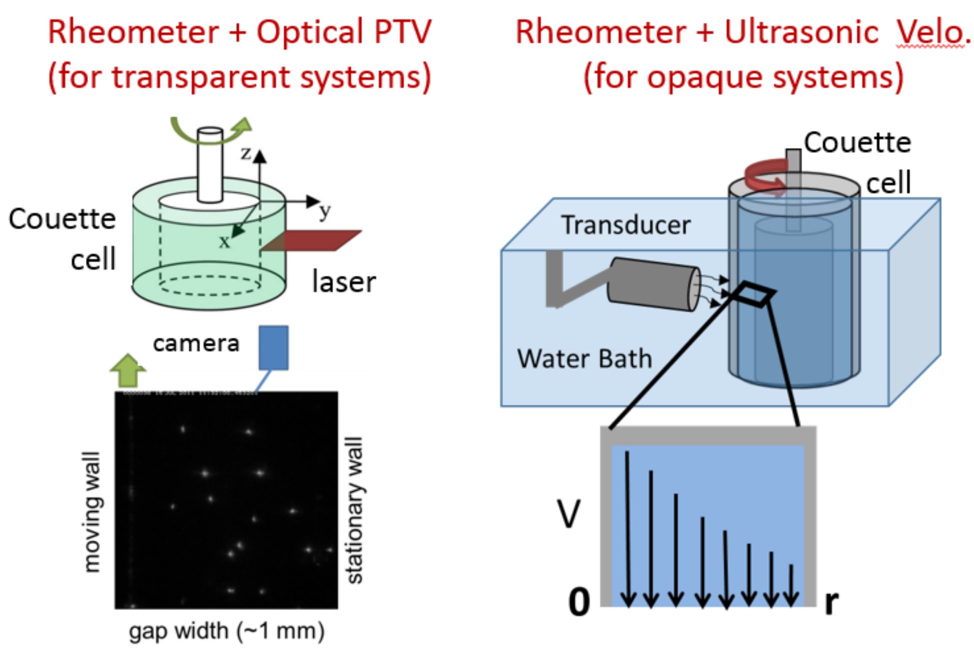

Figure 1: Schematics illustrating the advanced rheo-physical capabilities available at Purdue University for the investigation of non-Newtonian and viscoelastic soft materials and complex fluids.

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References

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