Physics of Liquid Interfaces

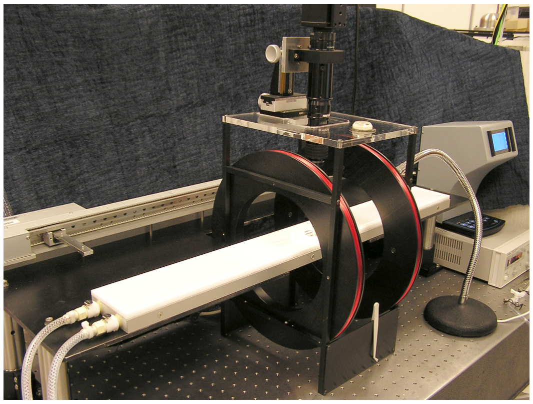

Figure 1: Interfacial stress rheometer (ISR)

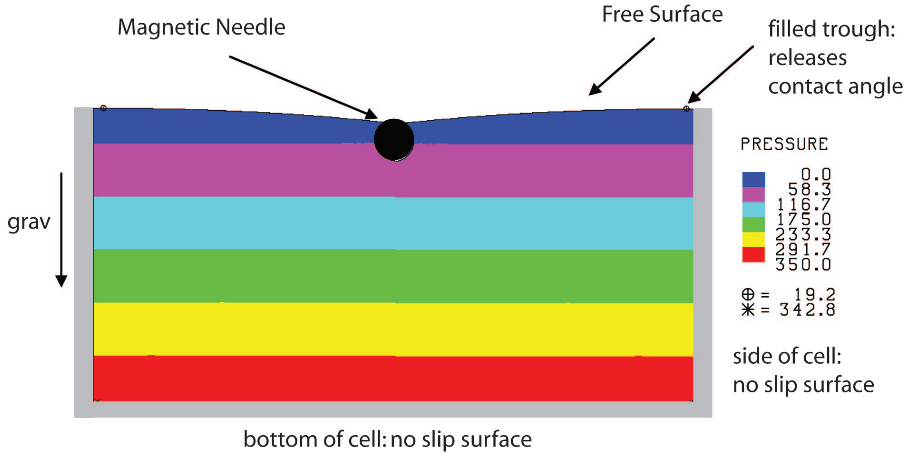

Figure 2: Finite element model of the floating needle in the ISR. Fluid is allowed to determine its own location based on the surface tension, contact angle, and weight of the needle, resulting in the slightly curved shape of the interface.

Sandia leads in both interfacial measurements and modeling

Flow of liquid through a pipe or air past a fin involves processes dominated by viscosity or inertia. However, as applications shrink to microscopic sizes there is a huge increase in the ratio of surface area to volume, and other phenomena such as surface tension, surface viscosity, and diffusion can begin to predominate. In addition to microfluidics, many macroscopic applications with large surface areas, such as foams and emulsions, have properties that are strongly influenced by interfacial phenomena. Interfacial properties are distinct from bulk properties on either side of the boundary, are not well understood, and are difficult to predict. Furthermore, although one can almost always assume that a bulk liquid under ordinary conditions is incompressible, an interface can stretch, and the dilatational terms in the momentum equation can no longer be ignored.

Sandia is at the cutting edge of both fluid interfacial property measurements and modeling. The interfacial stress rheometer (ISR, Fig. 1) uses a Langmuir trough to prepare monolayers of insoluble surfactant with a desired surface density at an air-liquid interface [1]. A Teflon-coated magnetized needle is freely suspended at the interface due to surface tension forces. A periodic magnetic field is applied to the needle, and, from the amplitude and phase shift of the periodic needle displacement, the viscoelastic properties of the interface are measured. Since the needle's response is affected by both the interface and the underlying liquid subphase, a key issue is to separate out the bulk rheological response of the system from the surface rheological response; this is done via a numerical model. The curvature of the interface can be determined through finite element modeling (Fig. 2).

A surface dilatational rheometer (SDR, Fig. 3) is used to measure the mechanical resistance to surface deformations resulting from changes in surface area [2]. Similar to a pendant drop tensiometer, where surface tension is measured by fitting the shape of a hanging drop to a solution to the Laplace equation of capillarity, the SDR uses the pendant drop technique to measure changes in surface

For more information:
Technical Contact:
Lisa Mondy
505-844-1755
lamondy@sandia.gov

Science Matters Contact:
Alan Burns, Ph.D
505-844-9642
aburns@sandia.gov

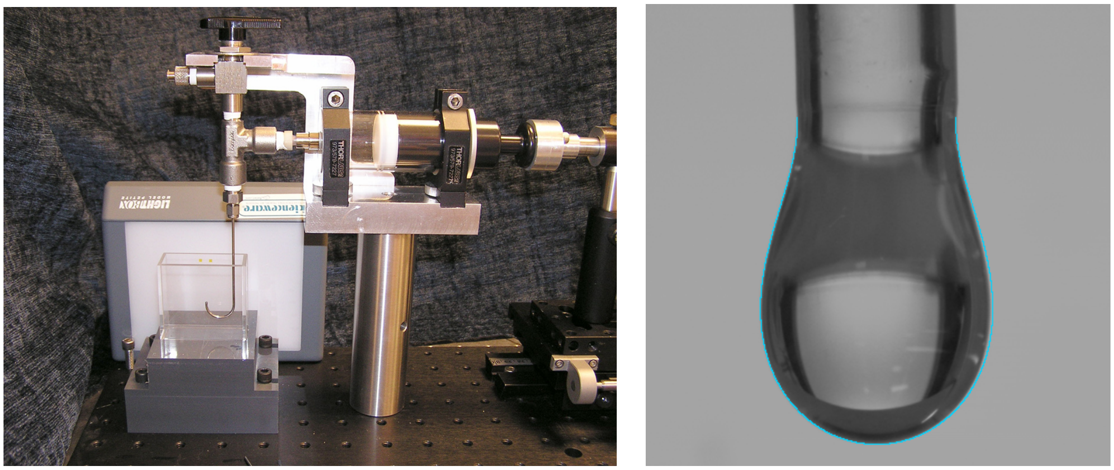

Figure 3: Left: Surface Dilatational Rheometer (SDR). Right: related pendant drop imaging used to determine surface tension.

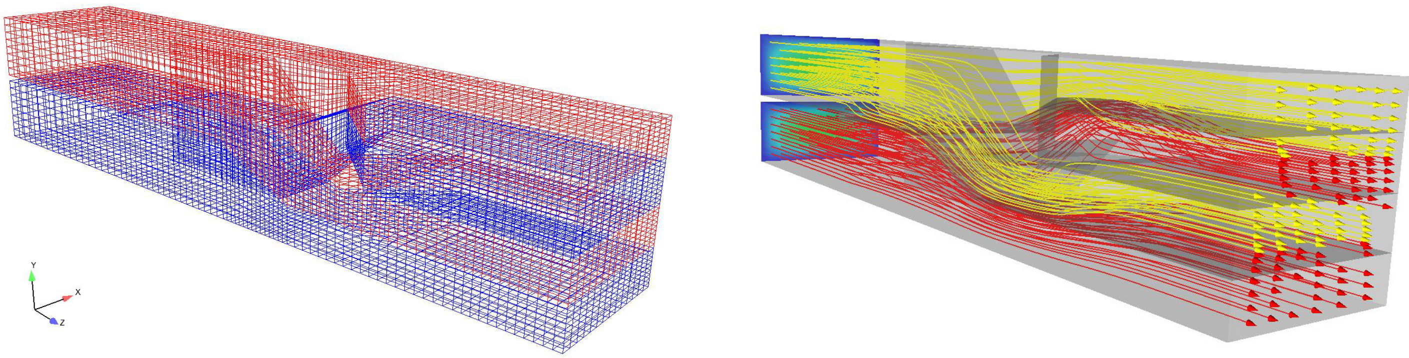

Figure 4: Finite element mesh (left) and calculated particle paths (right) of a coextruder where two initial layers are multiplied to four.

tension of an oscillating droplet. A time-dependent surface area is generated by varying the drop volume, and the resulting changes in surface tension are analyzed to measure an effective surface dilatational modulus.

Experimental discovery is key to the ongoing development of surface rheological models included in Sandia's engineering codes. Hence, it is also the key to the ability to describe the physical behavior of systems in advanced manufacturing techniques -- processes such as creating polymer membranes by reaction at a liquid interface in a microfluidic device [3] or coextrusion to form a composite of fine polymer layers [4] (Fig. 4). In addition, interfacial physics controls the stability of a foam or emulsion and, therefore, impacts the formulation and production of a wide variety of consumer products from whipped cream to pharmaceuticals. It also impacts the optimization of electronic encapsulation processes for our nuclear weapons and de-foaming strategies for eliminating particle-stabilized foams in processing nuclear wastes.

References:

1. S. Reynaert, C.F. Brooks, P. Moldenaers, J. Vermant, G.G. Fuller, *Journal of Rheology* **52**, 261-285 (2008).

2. E. M. Freer, T. Svitova, and C. J. Radke, *J. Petroleum Sci. Eng*. **39**, 137-158 (2003).

3. J. Atencia and D. Beebe, *Nature* **437**, 648-654 (2005).

4. R. R. Rao, R. Collins, R. Mrozek, J. Lenhart, R. Schunk, M. Hopkins, P. Notz, and L. Mondy, "Finite Element Analysis of Multilayer Coextrusion," Proceedings of the 24th Meeting of the Polymer Processing Society, Salerno, Italy, June 15-19, 2008.

Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2008-5080P

National Nuclear Security Administration

08/2008