CENTER FOR FLUID MECHANICS AND
THE FLUIDS, THERMAL AND CHEMICAL PROCESSES GROUP
OF THE DIVISION OF ENGINEERING SEMINAR SERIES

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EXTENSIONAL FLOWS OF VISCOELASTIC WORMLIKE MICELLE SOLUTIONS

Surfactants are surface active molecules that consist of a hydrophilic head group and a hydrophobic tail. When dissolved in water they can spontaneously form several different types of self-assembling aggregates. The size and shape of the resulting aggregate morphology depends on surfactant and counterion concentration. Under the proper conditions wormlike micelles, resembling slender rods, can entangle and impart viscoelasticity to the fluid. The behavior of wormlike micelles solutions is similar to that of polymer solutions. The primary difference being that, unlike a covalently bonded polymer backbone, micelles are in a state of thermodynamic equilibrium with the solvent and are continuously breaking and reforming under Brownian fluctuations. This leads to a broad and dynamic distribution of micelle lengths which can change under an imposed shear or extensional flow. Surfactant solutions are used extensively as rheological and surface tension modifiers in many consumer products and applications.

In this presentation, I will discuss the behaviour of a series of wormlike micelle solutions in several extensional flows and describe several newly observed flow instabilities unique to these fluids. The experiments were performed using a series of wormlike micelle solutions of cetyltrimethylammonium bromide (CTAB) and sodium salicylate (NaSal) dissolved in deionized water. In the first part of the talk, I will describe the behavior of these fluids in pure extensional flows. A filament stretching rheometer was used to follow the evolution in the tensile force and the flow induced birefringence of a wormlike micelle solution experiencing an uniaxial elongation flow. The wormlike micelle solutions demonstrate significant strain hardening and a failure of the stress-optical. At a critical stress, nearly independent of strain rate, the wormlike micelle solutions filaments were found to fail through a dramatic rupture near the axial midplane. This filament failure is not the result of elastocapillary thinning as is commonly observed in the filament stretching of weakly strain hardening polymer solutions. Instead, I believe that the filament failure stems from the local scission of individual wormlike micelle chains. The energy of wormlike micelle chain scission can be calculated and was found to be roughly 4 $k_B T$ for all the solutions tested. For the extension rates tested, this scission energy was found to be nearly independent of both the imposed extension rate and the concentration of the surfactant and the salt. In the second part of the talk, I will describe how the extensional rheology of these wormlike micelle solutions can affect the flow past a falling sphere. Experimental measurements of terminal velocity, particle image velocimetry and flow induced birefringence for a wide range of Deborah numbers will be presented. At a critical Deborah number, a new flow instability was observed resulting in dramatic fluctuations in the sedimentation velocity of the sphere are observed. I will present evidence that suggests this instability is directly related to the filament rupture observed in the pure extensional flows.

TUESDAY – OCTOBER 19, 2004
Barus & Holley, Room 190
4:00pm