69b Observations of Tipstreaming in a Flow Focusing Microfluidic Device

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Recent microfluidic methods of generating highly monodisperse droplets offer precise control over the size and size distribution; however the drop size is typically restricted to the size of the device. Flow focusing methods offer the ability to generate droplets whose size is significantly smaller than the device size. In this paper, we consider a specific phenomenon, called tipstreaming, that we observe within a flow focusing microfluidic experiment, which yields micron and sub-micron droplets. Tipstreaming is a mode of drop breakup in which daughter drops are ejected from the pointed ends of parent drops. Although first observed by G.I. Taylor in 1934, relatively little is known about this phenomenon. Prior work concerning tipstreaming has relied upon measurements using drops in four-roll mill or Couette flow devices. Observations based upon drops whose interfaces contain a finite amount of surfactant show oscillatory behavior and then a complete cessation of tipstreaming due to surfactant depletion. Despite the knowledge that surfactants are necessary to achieve tipstreaming, a comprehensive study of the phenomenon using well-characterized surfactants has yet to be accomplished.

In this paper, we present the results of experiments performed using two-phase flow in a microfluidic flow-focusing device to produce tipstreaming. In our experiments, oil acts as the continuous phase and water as the dispersed phase. We dissolve surfactants into one of the phases and observe tipstreaming as a function of surfactant concentration and capillary number. Simultaneously, we have used pendant bubble and microtensiometry methods to characterize the surfactant kinetic rate constants in detail. In contrast with traditional flow devices, drop formation in our device occurs from a protruding ‘finger' of dispersed phase liquid. Flow rates of the liquid phases can be used to control the supply of surfactant convected to the interface, depending on which phase the surfactant is soluble in. Our observations indicate that tipstreaming occurs only in a specific range of capillary numbers, between approximately $Ca \sim 0.2$ to 0.6. This limited range is consistent with other observations reported in the literature. Additionally we observe that as the capillary number increases within this range, the thread size decreases, leading to smaller daughter drops. Furthermore the interface shape becomes increasingly cusp-like as the capillary number increases. Tipstreaming within our device is oscillatory, and we relate the observed timescales to a balance between convection and dynamics of surfactant transport to the interface. We do not observe cessation of tipstreaming since we continuously supply the interface with surfactant via convection. Ultimately, we aim to exploit a fundamental understanding of the tipstreaming process to generate highly monodisperse micron and submicron droplets and particles.