THREAD FORMATION AND TIPSTREAMING IN A MICROFLUIDIC FLOW FOCUSING DEVICE

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Microfluidic devices have recently emerged as an effective method of generating monodisperse emulsion droplets. However, in these and other methods, the drop size that can be produced is typically limited by the size of the capillary or orifice tube from which the droplet grows. In microfluidic devices, this normally means that the minimum achievable drop size is around 5 to 10 microns. The ability to reduce the drop size still further, into the submicron range, is of interest in a range of applications including drug and gene delivery, medical imaging and nanoparticle synthesis.

In this paper we present a novel microfluidic method of synthesizing micron-scale and smaller droplets. Our method utilizes surfactants at the liquid-liquid interface, combined with elongational flow in a microfluidic flow focusing device [1], to promote a phenomenon called tipstreaming. Tipstreaming occurs when a parent drop forms a highly pointed tip, and daughter drops up to two orders of magnitude smaller are ejected from that tip (see [2] and references therein). Recent numerical simulations have shown that tipstreaming occurs in a specific range of surfactant concentration and capillary number [3]. We present experiments in which we systematically vary the *surfactant concentration*, the *capillary number*, and the *flow rate ratio*. We observe that in a particular range of surfactant concentration, large drops are followed by the formation of long thin threads. As the flow rate ratio increases, the threads grow longer, eventually exhibiting sustained tipstreaming at very large flow rate ratios. This behavior occurs in a range of capillary numbers between $0.4 < \mathrm{Ca} < 1.0$ with a peak in the thread length at $Ca \sim 0.5$, consistent with conditions at which tipstreaming is observed in classic drop breakup experiments [2].

In this paper we estimate the drop diameter resulting from the breakup of the thin threads and from tipstreaming to be in the range of $d \sim 0.5 - 2$ microns. We characterize the thread length as a function of time, flow parameters, and surfactant concentration, and we interpret the observed results in terms of induced surface tension gradients and the tip radius and cone angle of the highly sharpened tip. To aid our understanding we utilize a physical model of the tipstreaming process similar to that recently presented by Krechetnikov and Homsy [4].

References

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