Parametric Investigation of Picoliter Droplet Interfacial Tension using a Microfluidic Device

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Abstract

The transport and detection of nanoscale objects has become an essential part of sub-cellular biochemical research and with it the use of droplets as controllable confined volumes. To fully understand and utilize the chemical environment of droplet systems, it is necessary to elucidate the physical properties of the droplet interface, namely through studying system parameters such as the interfacial tension. The interfacial tension (IFT) is an important physical factor for designing and calculating fluidic dynamics in microfluidic droplet systems. In fluid dynamics, the capillary number (Ca) represents the relative effect of viscous forces versus surface tension acting across an interface between two immiscible liquids. Using Ca, it is possible to simulate fluidic channels and better aid in design, and explain phenomenon.

Introduction

This project seeks to investigate changes in the interfacial tension as a function of the following factors: ion concentration, surfactant type, surfactant concentration, and oil type. The interfacial tension of numerous individual droplets was measured by examining the deformation and restoration dynamics of the drops through a microfluidic channel constriction. Droplet generation parameters were independently varied and results were captured using fast imaging techniques. This video data was analyzed using a mathematical model of droplet dynamics, coded with the program Labview, which calculated the interfacial tensions.

These results will attempt to further clarify the quantitative relationship among the key factors, and should provide general trends for the interfacial tension as system variances are made, allowing future research the ability to predict the effect on droplet formation when used in microfluidic devices for bio-analytical applications.

Design and Fabrication

This microfluidic approach to measure IFT observes the response of individual droplets in a carrier fluid to deformation. A microfluidic tensiometer device should; (a) produce controllably sized droplets, (b) accelerate the droplets, and (c) induce drop deformation and restoration. We designed a system to generate aqueous plugs using a T-junction with an aqueous inlet and an oil inlet. To achieve independent control of the inter droplet distance as well as the droplet velocity, they are accelerated via flow focused oil lines coming from a single inlet.

Droplet deformation occurs in a flow field generated by a microchannel constriction. We experimentally determined that a constriction width of 200 μm induces modest deformations, to which the Taylor theory applies. A thickness of about 200 μm throughout was determined to be optimal.

Silicon masters patterned with SU-8 photoresist were fabricated using photolithography as described in detail elsewhere. Briefly, in order to create channels of 200 μm thickness, it was necessary to successively spin two 100 μm layers of SU-8. These were exposed to UV through a patterned mask, and then developed using propyl glycol methyl ether acetate (PGMEA).

To form the microchannels, the pattern on the master was replicated in poly(dimethylsiloxane) (PDMS) and then sealed with oxygen plasma to a coverslip with a thin layer of spin-coated PDMS. It was necessary to coat the coverslip with PDMS because the generation of aqueous droplets required channels with four hydrophobic walls to prevent wetting by the aqueous phase of the walls of the channel.

To address the microchannels, access holes to the channels were punched with a 16-gauge needle. Polyethylene tubing (PE 100) was inserted into the access holes and then attached to a microinjector, with the aqueous and two oil inlets having their own respective injector.

Parameters Tested

The continuous phase type and its viscosity have significance on the experiment. High viscous oils generally make very stable small droplets easier than low viscosity oils. The compatibility of the oil with the sample is also important since biological samples require low mass transfer between the oil and water and vice versa to maintain droplet constant concentrations.

Surfactants are known to reduce the interfacial tension at the oil-water interface and are necessary to create stable droplets in most systems. Similarly, different types of surfactants have varying compatibilities with both the continuous and dispersed phases.

When using biological samples, the pH of the system becomes important. The ion concentration is dependent on the pH. An investigation of the affects of ion concentration on the affects of interfacial tension is thus important.

Results and Conclusions

Interfacial tension was calculated by using a custom built Labview program that would track the vertical deformation of the droplets as a function of position. By measuring the time for drop shape relaxation, the interfacial tension could be calculated.

The results demonstrate that interfacial tension correlates positively with oil viscosity, negatively with surfactant concentration, and negatively with ion concentration (Figures 1-3). The three surfactant types tested (Gran Surf 77, Tween 20, and Span 85) were found to have no correlation with the interfacial tension (not shown). It is well known that surfactant concentration correlates negatively with interfacial tension. The fact that ion concentration correlates negatively with interfacial tension was a surprising result. Intuitively, we would expect that an increase in ions would cause the water phase to be more dissimilar to the oil phase, which would cause an increase in interfacial tension.

In conclusion, we successfully developed a microfluidic device that rapidly measured interfacial tension of picoliter droplets, and have shown that surface active components indeed affect the interfacial tension. These results can be used to extrapolate interfacial tension values so as to extrapolate the optimal microfluidic chip design

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References

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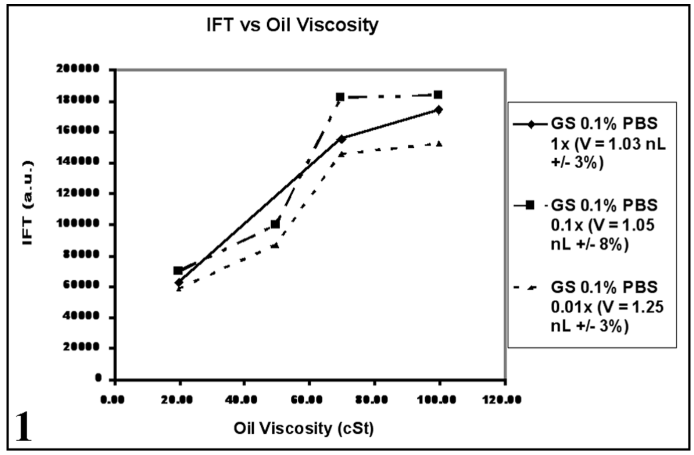

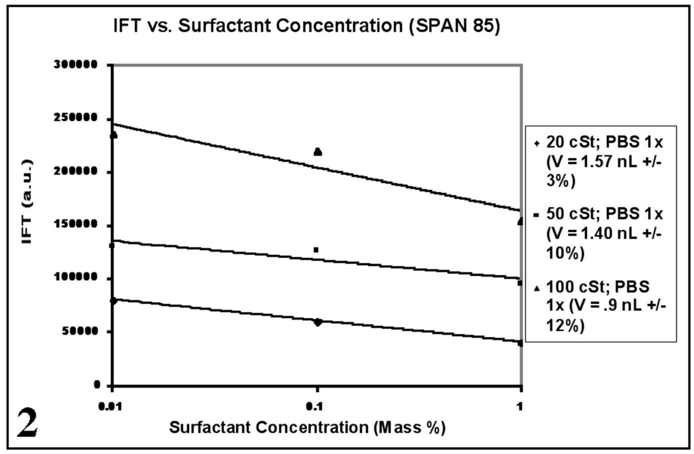

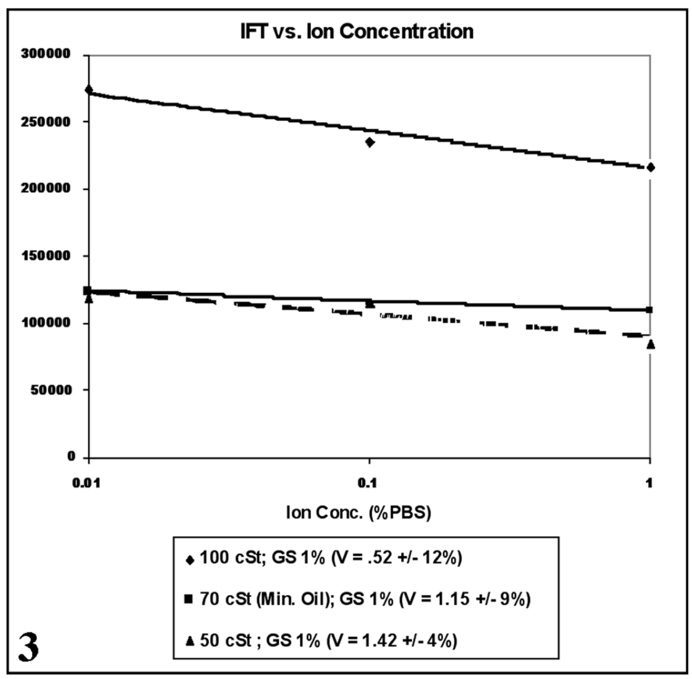

Figure 1: IFT as a function of oil viscosity at three different ion concentrations.

Figure 2: IFT as a function of surfactant concentration for three different oils.

Figure 3: IFT as a function of ion concentration for three different oils.