THE EFFECT OF INTERFACIAL FORCES ON 2-PHASE MICROFLUIDICS

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ABSTRACT

We present the influence of both the solid-liquid interfacial force (surface wettability) and liquid-liquid interfacial force (added surfactants) on water-oil two-phase flow in microfluidic devices. Experimental results show that, in contrast to macroscale experiments, the surface wettability crucially determines the emulsion type created in the microchannels: O/W in hydrophilic channel and W/O in hydrophobic channel. Surfactants, however, determines the flow pattern, changing from droplet-based to stratified flow by decreasing σ_{wo}.

KEYWORDS: Microfluidics, Interfacial Force, Emulsion Type, Flow Pattern

INTRODUCTION

On the macroscale, emulsions are made simply by mixing water and oil with emulsifiers, for instance surfactants. The emulsion type (oil in water-O/W or water in oil-W/O) is mainly determined by the liquid-liquid interfacial forces, namely the respective affinity of the surfactant molecules for the water and oil phases which is called the HLB (Hydrophilic-Lipophilic-Balance) value [1]. However, when device dimensions shrink to the micrometer scale, the surface-to-volume ratio greatly increases, and as a consequence the influence of solid-liquid interfacial forces becomes dominant in determining the emulsion type [2]. Here we report on the effects of the manipulation of the solid-liquid interfacial force by a simple surface coating method and of the liquid-liquid interfacial properties by using different surfactants in the fluid(s).

THEORY

It is well known that, when one liquid(water) droplet contacts another immiscible fluid(oil) and a solid, a contact angle (θ) sets up on the solid surface (Fig. 1).

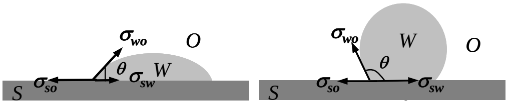

Figure 1. Contact angles set up on solid substrates. Water and oil on a hydrophilic surface (left) and a hydrophobic surface (right). W, O and S indicate water, oil and solid, respectively.

The liquid interface curves due to the differences among interfacial forces. The force balance is described by Young's equation: $\cos\theta=(\sigma_{so}-\sigma_{sw})/\sigma_{wo}$ where σ_{so}, σ_{sw}, and σ_{wo} (N/m) indicate solid-oil, solid-water and water-oil interfacial forces, respectively. The contact angle is proportional to (σ_{so}-σ_{sw}) which can be described as the relative affinity of solid for the two fluids. As a result, the surface wettability

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becomes important at the microscale [2, 3]. On the other hand, σ_{wo} influences the capillary number which determines two-phase flow patterns [4]. The manipulation of interfacial tensions is therefore critical for two-phase flow in microfluidic devices.

EXPERIMENTAL

The structure of the head-on flow device used is shown in Fig. 2.

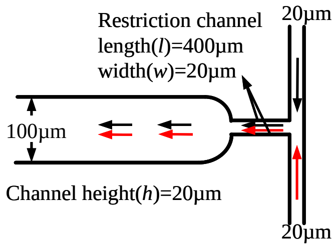


Figure 2. Schematic of the microfluidic device.

The devices were fabricated using standard photolithography [5]. Channel walls were native hydrophilic Si/Pyrex or hydrophobized by 1H, 1H, 2H, 2H - perfluorodecyltrichlorosilane. The water phase (white) was made fluorescent by dissolving fluorescein sodium salt (0.01M) in DI water and the oil phase (black) was hexadecane. Test chips were fit in a chip holder and connected to gas-tight syringes driven by a syringe pump. The flow was visualized by an inverted microscope and recorded using a CCD camera.

RESULTS

The solution components and water-oil interfacial tensions are listed in Table 1.

Table 1. The solution components and their σ_{ow} (N/m).

Water / σ_{ow} / Oil	(1-0) DI water +0.01M Fluorescein	(1-1) (1-0) +2wt% Tween80	(1-2) (1-0) +0.01M SDS
(2-0) Hexadecane	$\sim 10^{-2}$	$\sim 10^{-2}$	$\sim 10^{-2}$
(2-1) Hexadecane +2wt% Span80	$\sim 10^{-2}$	$\sim 10^{-2}$	$<10^{-4}$

In macroscale experiments, surfactants determine the emulsion type (Table 2). In hydrophilic microchannels the emulsion type is O/W since water phase preferentially flows along the hydrophilic channel walls as continuous phase and oil disperses in it as a dispersed phase (Table 3). On the contrary, W/O flow can be easily obtained in hydrophobic mircrchannels (Table 4). The flow pattern changes from droplet-based to stratified flows, at the same flow rate(Q), when the water-oil interfacial force changes from 10^{-2}N/m to 10^{-4}N/m by applying different surfactants.

Table 2. Emulsion types at the macroscale.

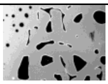
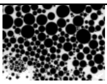
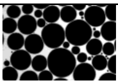
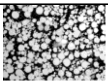
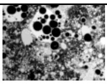
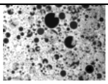
Water / Oil	(1-0)	(1-1)	(1-2)
(2-0)	 unstable	 O/W	 O/W
(2-1)	 W/O	 O/W & W/O	 Double-emulsion

Table 3. O/W emulsions created in hydrophilic microchannels, Q=0.10μL/min.

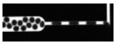
Water / Oil	(1-0)	(1-1)	(1-2)
(2-0)			
(2-1)			

Table 4. W/O emulsions created in hydrophobic microchannels, Q=0.10μL/min.

Water / Oil	(1-0)	(1-1)	(1-2)
(2-0)			
(2-1)			

CONCLUSIONS

In contrast to the macroscale, at the microscale, the surface wettability (solid-liquid interfacial tension) crucially determines the emulsion type created in the microchannels. Surfactants (liquid-liquid interfacial tension) play a secondary role by influencing the flow pattern. This study might be able to guide users to chose or modify materials when make a microfluidic device, and to select right surfactants to make stable droplets in it.

ACKNOWLEDGEMENTS

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