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Temperature effect on droplet formation characteristics for microchannel oil-in-water emulsification

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1. Introduction

Microchannel emulsification is a promising and advanced technique for producing monodisperse emulsions by forcing a dispersed phase through an MC array into a continuous phase. Temperature is an important operating parameter affecting emulsification, since the viscosity of the two phases and their interfacial tension are greatly temperature dependent. The aim of this study is to systematically characterize the effect of temperature on the dynamic behavior of droplet generation by MC emulsification.

2. Materials and Methods

1 wt% sodium dodecil sulphate (SDS) dissolved in Milli-Q water was used as the continuous phase. The disperse phase used was refined soybean oil. The dimensions of the the silicon MC plate (MS104) used was 15x15x0.5 mm and a hole with a dimaeter of 1 mm was fabricated at the center of the plate. Temperature of the MC module was controlled at every temperature in the range of 10 ºC to 70 ºC. The MC module was initially filled with the continuous phase, and then droplet generation via MCs was conducted. During the operation of MC emulsification, the applied pressure was regulated by changing the height of the chamber.

Contact angle of the dispersed phase was determined with a novel technique using parallel MCs fabricated on a silicon chip. The 15x15-mm^2 MSX11 chip consisted of four MC arrays, each having 25 channels (depth: 5 µm, width: 20 µm, length: 2,000 µm). As schematically illustrated in Fig. 1, the contact angle of the dispersed phase to the MC wall was determined from images of an oil-water interface located in the MCs. Each contact angle was manually measure with graphic editing program.

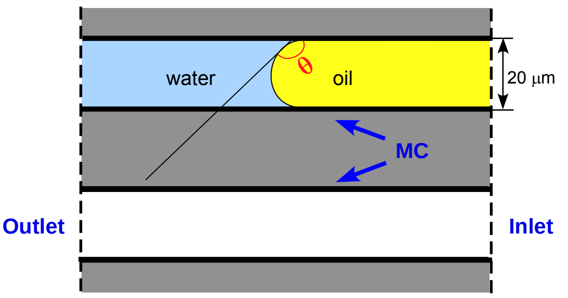

Fig. 1 Schematic of contact angle measurement inside MCs.

3. Results and Discussion

The typical optical micrograph of droplet generation via an MC array at 40 ºC is depicted in Fig. 2a. When the applied pressure of the dispersed phase reached 2.3 kPa, uniform droplets were periodically generated from MCs. Figure 2b shows the average droplet diameter (d_{av}) of the generated oil droplets linearly decreased with the increase of the operating temperature. Uniform oil droplets with d_{av} of 32 µm to 38 µm and coefficients of variation of below 5% were generated in a temperature range applied in this study.

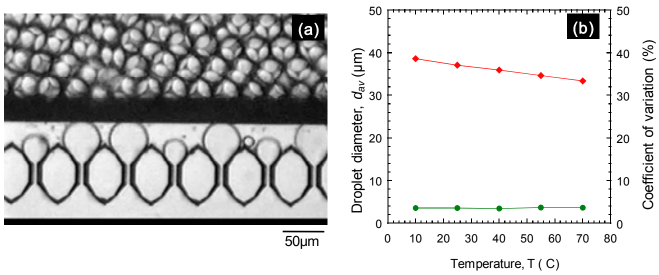

Fig. 2 (a) Typical optical micrograph of droplet generation via an MC array at 40 ºC. (b) Effect of temperature on the average droplet diameter and coefficient of variation of the oil droplets.

As shown in Fig. 3a, the contact angle of the dispersed phase decreased linearly with increasing temperature. Stable generation of uniform droplets can be achieved when the dispersed phase touched to the MC surface had a high contact angle value, i.e., the MC wall was not wetted by the dispersed phase. Contact angle values found in this study demonstrated the high ability to prevent wetting of the dispersed phase to the MC surface.

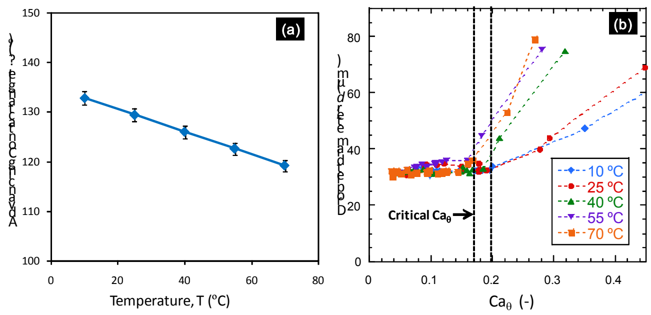

Fig. 3 (a) Variation of the contact angle with temperature (b) Effect of modified Capillary number plot of MC emulsification.

Figure 3b shows the relationship between a modified number (Ca_θ), defined as $Ca/|\cos\theta|$ where Ca is Capillary number, and the droplet diameter. We found that critical Ca_θ values ranged vary narrowly, indicating that the flow state of the dispersed phase during MC emulsification can be explained using the modified Capillary number.

4. Conclusions

Droplet diameter can be tuned by temperature; the higher the temperature, the smaller de d_{av}.

It was found a critical Ca_θ of a very narrow range over which the trend in the droplet diameter dramatically change.

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