Experimental and computational studies of generation of highly uniform droplets via asymmetric microchannels

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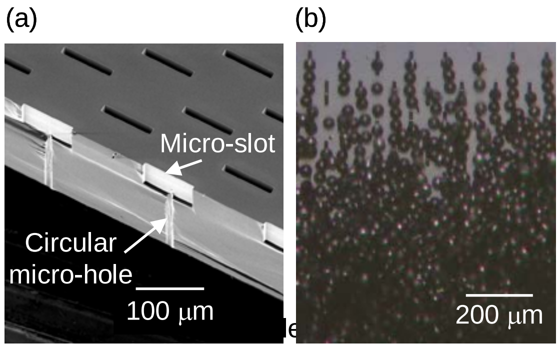
Microchannel (MC) emulsification is a promising technique for producing highly uniform droplets with a relative standard deviation of less than 5% using unique MC array plates [1]. We recently developed a new MC emulsification plate consisting of numerous microfabricated asymmetric through holes for large-scale production of uniform droplets [2]; however, the productivity of uniform droplets using asymmetric MC array plates has not yet been investigated. In this study, we present the generation of highly uniform droplets using an asymmetric MC array plate at a high production scale. We also conducted three-dimensional simulations of droplet generation via an asymmetric MC using CFD (computational fluid dynamics).

A silicon asymmetric MC array plate with a 24×24-mm size used in this study consists of 11,558 asymmetric MCs. Asymmetric MCs in a WMS2-2 plate (Fig. 1a) consisted of a micro-slot (10×70-μm size and 30-μm depth) and a circular micro-hole (10-μm diameter and 120-μm depth). Refined soybean oil was used as the to-be-dispersed phase, and Milli-Q water solutions containing sodium dodecyl sulfate (SDS) or polyoxyethylene (20) sorbitan monolaurate (Tween20) were used as the continuous phase. Droplet generation was conducted by injecting the to-be-dispersed phase via asymmetric MCs into the compartment over the outlets of asymmetric MCs, which is filled with continuous phase. A CFD code (CFD-ACE+ version 2004) with a finite volume code was used to calculate droplet generation via an asymmetric MC constructed in a computational domain. All the walls in the computational domain were set to be not wetted by the to-be-dispersed phase.

As shown in Fig. 1b, asymmetric MCs in the WMS 2-2 plate stably produced uniform oil droplets with an average diameter of 32.0 μm at a high flow rate of the to-be-dispersed phase, Q_d, of 10.0 mL/h and an estimated droplet production rate of about 8.6×10^8 h^{-1}. This Q_d value exceeded the previous MC emulsification plates by at least two orders of magnitude. The visualized CFD calculation results demonstrate that oil droplets with diameters of about 30 μm are stably generated via an asymmetric MC without applying a forced cross-flow of the continuous phase. The numerical CFD calculation results for the resultant droplet diameter and droplet generation rate agreed excellently with the results obtained from droplet generation experiments using a refined soybean oil-in-water of 2.0 wt% Tween 20 system and a WMS1-3 plate (slit: 10×70-μm size and 30-μm depth, channel: 10-μm diameter and 70-μm depth).



asymmetric MCs in a WMS2-2 plate. (b) Typical optical micrograph of production of uniform soybean oil droplets dispersed in a Milli-Q water solution of 1.0 wt% SDS via asymmetric MCs (WMS2-2).

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References

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