Break-up of droplets in a concentrated emulsion flowing through a narrow constriction

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In this study we explore the break-up of droplets in a concentrated emulsion during its flow through a microchannel consisting of a narrow constriction. Droplet microfluidics, in which aqueous droplets possessing volumes from nanoliters to femtoliters are used as individual biochemical reactors, has enabled a wide range of high throughput screening applications such as directed evolution of enzymes, digital PCR, and screening of antibiotics. While there have been detailed studies on droplet generation, few studies have considered the throughput of the droplet interrogation process in which drops containing target molecules or cells are being reinjected into a funnel-shaped microchannel consisting of a narrow constriction. The constriction forces the drops to arrange in a single file, and ensures that drops enter the detection region one at a time.

Analysis of the behavior of a large number of drops ($N > 4000$) shows that the number of break-ups increases with increasing flow rate, entrance angle to the constriction, and size of the drops relative to the width of the constriction. As single drops do not break at the highest flow rate used in the system, break-ups arise primarily from droplet-droplet interactions. Analysis of droplet properties at a high temporal resolution of 10 microseconds makes it possible to relate droplet deformation with droplet break-up probability. Similar to previous studies on single drops, no break-up is observed below certain critical flow rates and droplet deformations. Unlike previous studies, however, not all drops undergo break-up above the critical values. Instead, the probability of droplet break-up increases with flow rate and the local deformation of the drops. Practically, these results can be used to calculate the maximum throughput of the serial interrogation process often employed in droplet microfluidics. For 40 pL-drops, the highest throughput with less than 1 % droplet break-up was measured to be approximately 7000 drops per second. In addition, the results presented are useful for understanding the behavior of concentrated emulsions in applications such as mobility control in enhanced oil recovery, and for extrapolating critical parameters such as injection rates to ensure the stability of the fluids going through small pore throats.