Drop size control

How the sizes of droplets influence the dynamics of the system, in particular the effective temperature of the active bath and the diffusivity of the inner droplet, is an important question in this project. Using the capillary microfluidic device, we are able to vary continuously and seamlessly the flow rates of each phase to achieve precise control of drop sizes. However, it is challenging to control the size of one droplet (inner/outer) independently, because each flow rate affects the sizes of both droplets. As you can see in Fig. 1, when keeping both inner and outer flow rates constant and only varying the middle phase flow rate Q_m, the sizes of both droplets change. It is most evident when contrasting the cases where $Q_m = 700$ μl/h and $Q_m = 200$ μl/h, where the shell shrinks as desired, but the inner droplet gets larger undesirably.

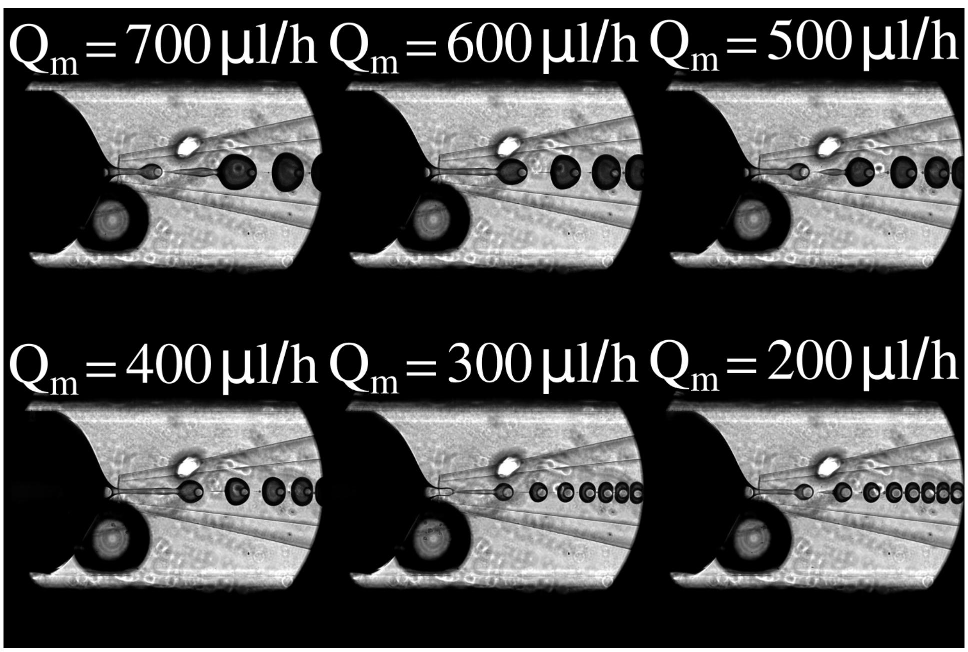

FIG. 1. Vary middle phase (bacterial suspension) flow rate Q_m from 700 to 200 μl/h, while keeping outer and inner phase flow rates constant at $Q_o = 1500$ μl/h and $Q_i = 42$ μl/h.

The results in Utada et al. [1] explains part of my observation. Their results suggest that when fixing the sum of the middle and inner phase flow rates, as well as the ratio between the two, the sizes of both droplets only depend on the outer flow rate. Figure 2 illustrates the results of Utada et al., where R is the size of droplets, Q_o is the outer phase flow rate and $Q_{sum} = Q_i + Q_m$ is the sum of the inner and middle flow rates. As a hypothesis, if we keep Q_{sum} constant and vary the ratio between Q_i and Q_m, we can keep the outer droplet constant size and explore the influence of the inner droplet size. A similar idea is that, if we keep $Q_o + Q_m$ and Q_i constant, and vary the ratio between Q_o and Q_m, the inner droplet size might be kept constant.

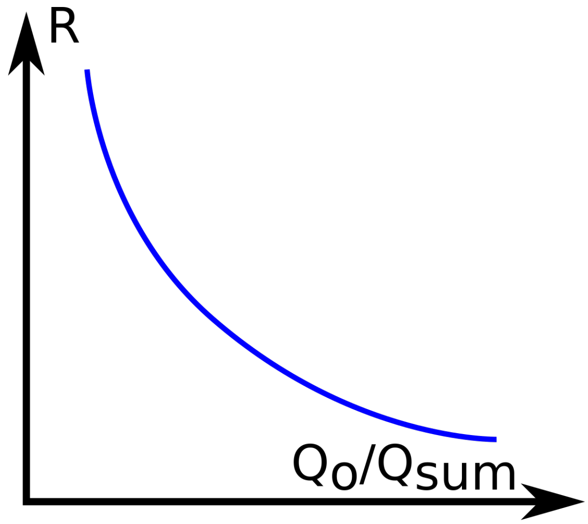

FIG. 2. Double emulsion radius R (only the outer droplet) depends on the ratio between outer phase flow rate Q_o and the sum of inner and middle phase flow rates Q_{sum}. This is reproduced from Fig. 3 in [1].

These two hypotheses remain are tested in my experiment (07132021). First, I fixed the sum of middle and inner flow rates at $Q_m + Q_i = 400$ μl/h. The outer flow rate was also fixed, at $Q_o = 1000$ μl/h. During the test, I varied the ratio between Q_m and Q_i from 0.6 to 7. And I expected that the inner droplet radii r to decrease with increasing ratio, while the outer droplet radii R remain unchanged. Figure 3 shows the droplet sizes as a function of flow rate ratio Q_m/Q_i. The empty markers denote the outer droplet radii R and the solid markers denote the inner droplet radii r. As I increase the ratio between Q_m and Q_i, r decreases as expected. However, R increases with Q_m/Q_i, contradicting my hypothesis.

Similarly, I fixed the sum of outer and middle flow rates at $Q_o + Q_m = 1700$ μl/h. The inner flow rate was also fixed, at $Q_i = 100$ μl/h. Q_o/Q_m was varied from 3.25 to 7.5. It is hypothesized that the inner droplet size remains constant, while the outer droplet size decreases with increasing Q_o/Q_m. Figure 4 shows the droplet sizes as a function of flow rate ratio Q_o/Q_m. As I increase Q_o/Q_m, r remains constant (approximately) while R decreases,

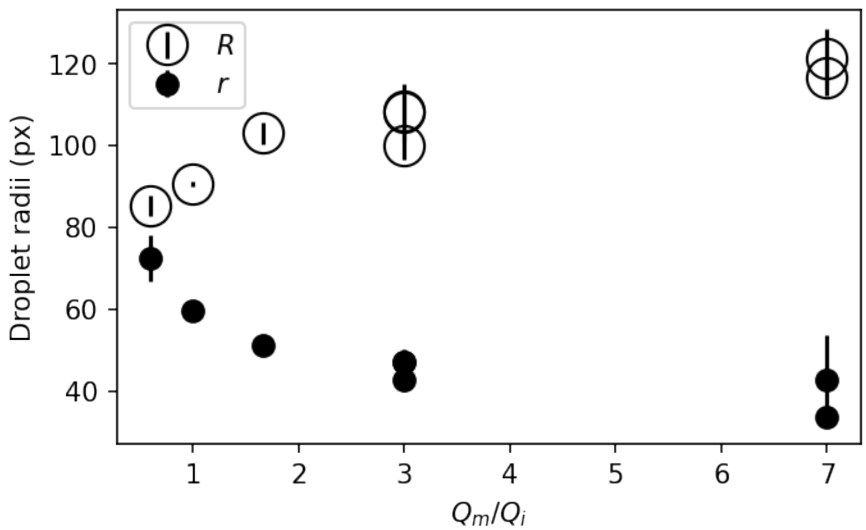

FIG. 3. Double emulsion sizes as a function of the ratio between Q_m and Q_i. The outer flow rate Q_o and the sum of middle and inner flow rates are kept constant.

in consistency with my hypothesis.

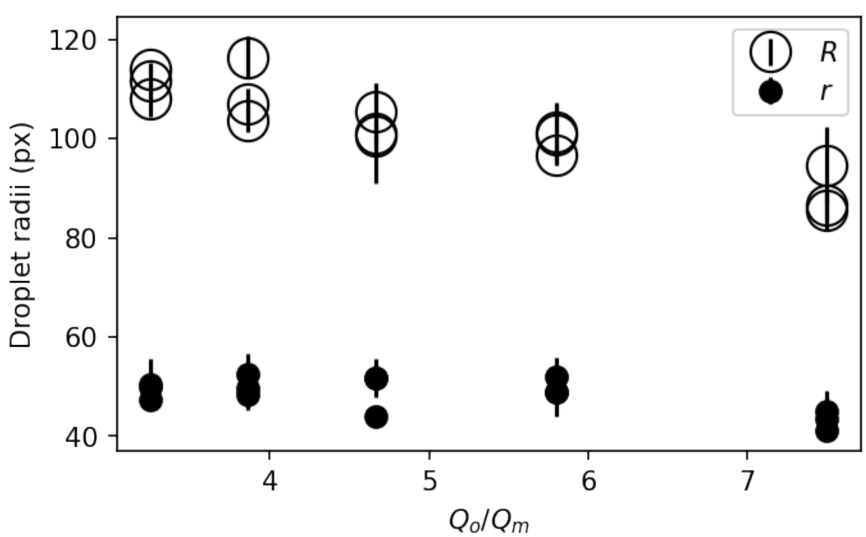

FIG. 4. Double emulsion sizes as a function of the ratio between Q_o and Q_m. The inner flow rate Q_i and the sum of outer and middle flow rates are kept constant.

Why constant $Q_m + Q_i$ does not make outer droplet size constant?

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[1] A. S. Utada, E. Lorenceau, D. R. Link, P. D. Kaplan, H. A. Stone, and D. A. Weitz, Science **308**, 537 (2005).