

Supplementary Information for “Flow of a microgel through a constrained geometry” by Yang Li, Eugenia Kumacheva and Arun Ramachandran.

S1. Preparation of agarose microgels and characterization of the polydispersity of the microgels

The shape of microgels (Fig. S2) was characterized by their roundness defined as

$$R = 4\pi * A/P^2,$$

where A and P are the projected area and perimeter of the microgel, respectively. In our work, the microgels had a well-defined round shape with $R \approx 1$.

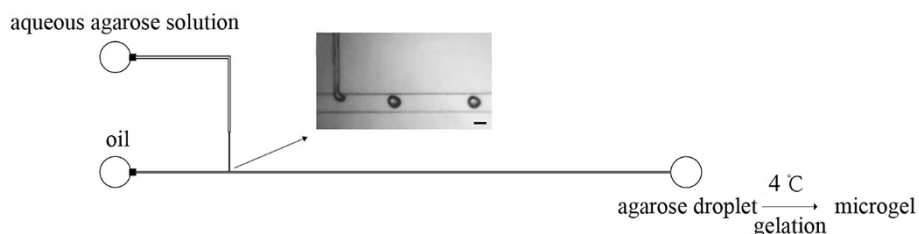


FIGURE S1 Schematic of the MF device for the generation of agarose microgels ($C_{ag} = 2$ wt.%). Inlet optical microscopy image show agarose droplets forming at the T-junction of the device. The height of the device is $150 \mu\text{m}$. Scale bar is $50 \mu\text{m}$. Collected agarose droplets are cooled for 30 minutes before the microgels are transferred into aqueous phase.

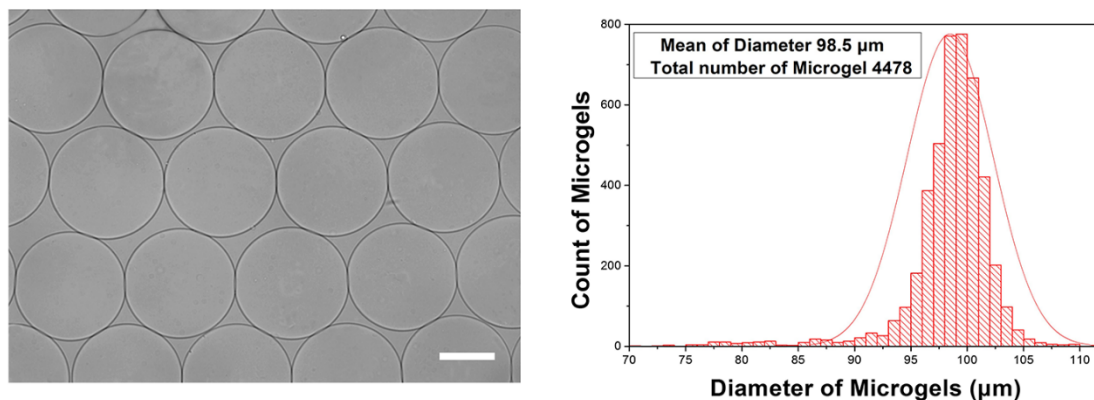


FIGURE S2 Optical microscopy images (A) and size distribution (B) of agarose microgels transferred in water. $C_{ag} = 2$ wt.%. To obtain size distribution, 4478 microgels were counted.

Scale bar is 50 μm .

S2. Fabrication of PDMS microchannels with a circular cross-section

The circular cross-section was obtained by using a nitrogen-gas-template modification process following described elsewhere (1). Original microchannel with square cross-section was fabricated by the soft lithography method. Fluidic ports were drilled by a cork borer to make a 17 gauge inlet. A patterned PDMS sheet was sealed onto a flat PDMS sheet after 90 s plasma treatment at 550 mTorr in air. Then the microchannel was filled in with a solution of silicone oligomer in hexanes, before a stream of N_2 passing along the channel. The microchannel with circular cross-section was finally obtained by polymerization of PDMS and evaporation of hexanes upon heating. By tuning the pressure of N_2 stream, the area of circular cross-section can be controlled (see Fig. S3.)

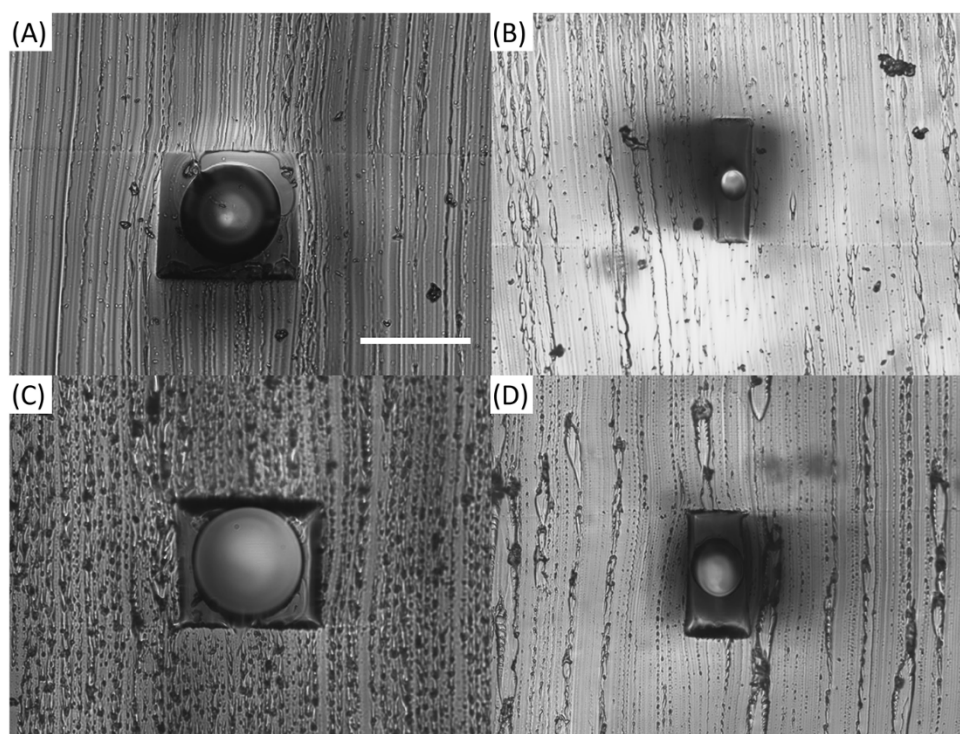


FIGURE S3 Bright field images of the cross-sectional area of the microchannels (A, C) and constrictions (B, D) produced at $C_{\text{PDMS}} = 50\%$ at P_{N_2} of 6 psi (A, B) and 12 psi (C, D). Scale bar is 100 μm and applies to all figures.

S3. Entrance study of the microgel into the constriction

Movie S1. Time lapse video of the passage of a microgel into the constriction upon step increases in the pressure drop

Movie named "Step-by-stepMotionOfTheMicrogel.avi". In states from 1 to 8, the microgel ($D_0 = 94 \mu\text{m}$) moved downstream step-by-step according to the applied pressure drop shown in Fig. 2. The microgel reached a certain steady position along the microchannel under a certain pressure drop. The pressure drop in state 9 pushed the microgel through the constriction. The entire video is 10 minutes. $\Delta t = 60 \text{ s}$.

Movie S2. Verification of absence of leakage of water from around a trapped microgel

Movie named "ProofOfAbsenceOfLeakage.avi". Two microgels ($C_{\text{ag}} = 2 \text{ wt.}\%$) were introduced one after another under constant pressure drop (1.2 kPa), and the movement of the second microgel (the microgel on the left) in the channel-at-large stopped as soon as the first microgel (the microgel on the right) was trapped in the tapering section of the microchannel. Any further movement of the second microgel in the channel-at-large was possible only when the first microgel moved, and the two motions are in perfect concert. If there were leakage of fluid about/through the first (trapped) microgel, the second microgel would have been displaced by the flow. This shows that leakage flux across the trapped microgel is negligible. $D = 110 \mu\text{m}$, $d = 45 \mu\text{m}$, $\alpha = 15^\circ$.

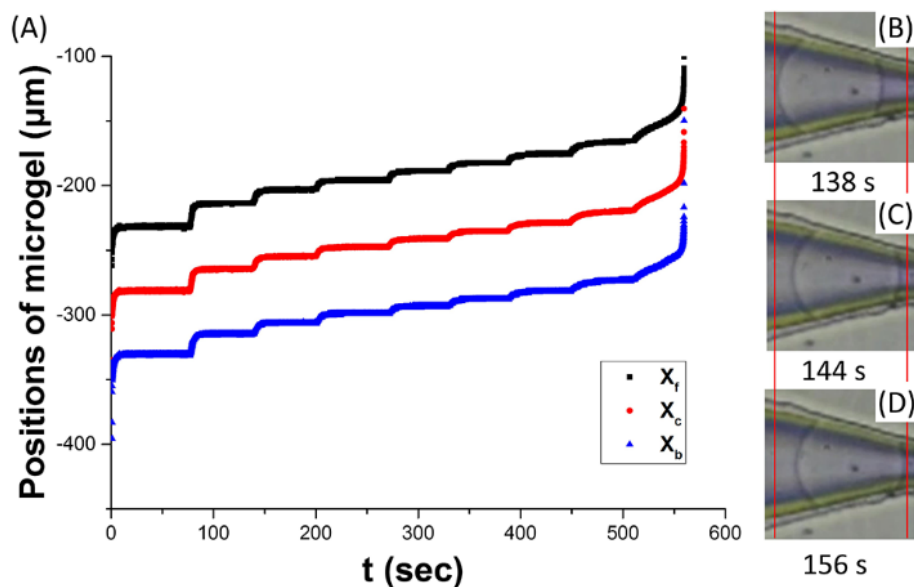


FIGURE S4 (A) Effect of the pressure drop across the microgel on the position of the front edge (black), center (red), and back edge (blue) of the microgel in the device. $\Delta t = 60$ s, $D_0 = 94$ μm . (B)-(D) shows the shape of the microgel at the starting position (138 s), at the intermediate position (144 s) and at the equilibrium position (156 s) of the microgel in the microchannel when the pressure drop was increased from 110 Pa to 350 Pa at 138 s. The two red lines indicate the back edge at 138 s and the front edge at 156 s, respectively.

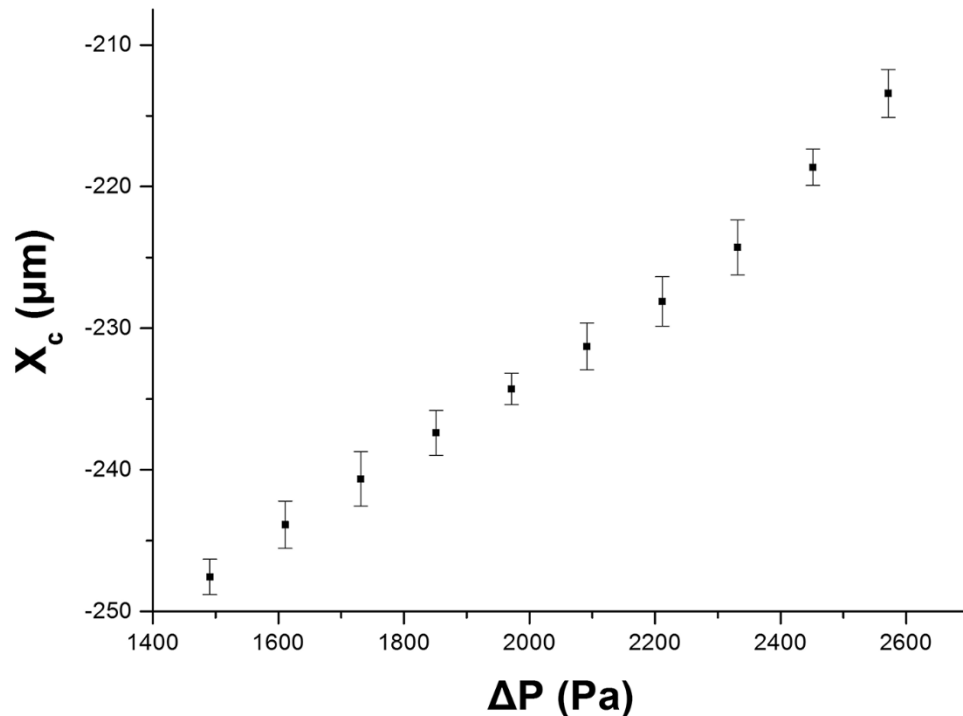


FIGURE S5 Reproducibility of effect of pressure drop onto the position of ten microgels ($D_0 = 99 \pm 1.0$ μm). $\Delta t = 60$ s, $D = 110$ μm , $d = 42$ μm , $\alpha = 15^\circ$.

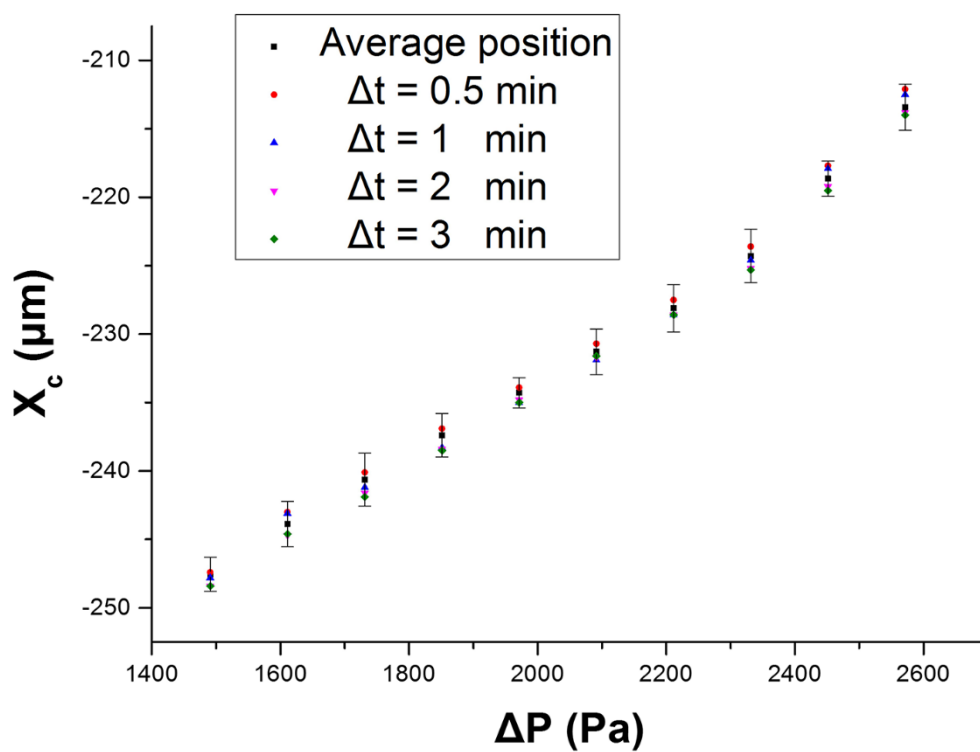


FIGURE S6 Effect of microgel maintaining time (Δt) over the position of four microgels ($D_0 = 99 \pm 1.0 \mu\text{m}$) during the progression of the microgel into the constriction. Four maintaining time was chose (from 0.5 minute to 3 minute), and the position of the microgels is found to be always within the average position obtained in Fig. S5.

S4. Volume change of the microgel during its progression into the constriction



$$\text{State 1: } V = V_1 + V_2 + V_3 = \frac{\pi}{6}h_1(3r_1^2+h_1^2) + \frac{\pi}{3}H(r_1^2+r_1r_3+r_3^2) + \frac{\pi}{6}h_3(3r_3^2+h_3^2)$$

$$\text{State 2: } V = V_1 + V_2 + V_3 + V_4 = \frac{\pi}{6}h_1(3r_1^2+h_1^2) + \frac{\pi}{3}H(r_1^2+\frac{1}{2}r_1d+\frac{1}{4}d^2) + \frac{\pi}{4}d^2L_3 + \frac{\pi}{6}h_4(\frac{3}{4}d^2+h_4^2)$$

FIGURE S8 Calculation of volume change of the microgel during its progression into the constriction. In state 1, a microgel consists of three parts (part 1 and 3 are spherical caps, and part 2 is a circular truncated cone); in state 2, a microgel consists of four parts (part 1 and 4 are spherical caps, part 2 is a circular truncated cone, and part 3 is a cylinder). The volume of a microgel in each position can be calculated either by equation of state 1 or that of state 2, based on the captured images during the progression of the microgel into the constriction. r_1 , r_3 in state 1, and r_1 , r_4 in state 2 represents the radius of the base of the according spherical cap. h_1 , h_3 in state 1, and h_1 , h_4 in state 2 represents the height of the according spherical cap. H in state 1 and 2 represents the height of the circular truncated cone (part 2). L_3 and d ($42 \mu\text{m}$) in state 2 represents the length and the diameter of the cylinder (part 3), respectively.

S5. Relaxation of a microgel upon its release from the constriction

Movie S3. Video showing the relaxation of a microgel upon its release from the constriction:

The movie is titled "RelaxationOfTheMicrogel.avi". After confinement in the constriction ($d = 45 \mu\text{m}$) for 20 min, a microgel ($D_0 = 86 \mu\text{m}$) was released into the channel-at-large (width = $300 \mu\text{m}$, height = $130 \mu\text{m}$), respectively. Images with the microgel in the center were cropped from the original video and assembled into the video by MATLAB. The video is 19.4 seconds long.

SUPPORTING REFERENCES

1. Fiddes, L. K., N. Raz, S. Sriganapalan, E. Tumarkin, C. A. Simmons, A. R. Wheeler, and E. Kumacheva. 2010. A circular cross-section PDMS microfluidics system for replication of cardiovascular flow conditions. *Biomaterials*. 31: 3459-3464.