Engineering single and double droplets for flow cytometry

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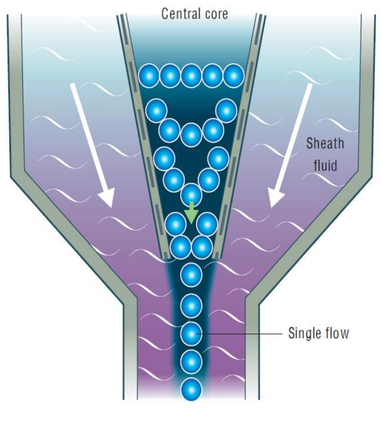
Motivation: Cell encapsulation and flow cytometry

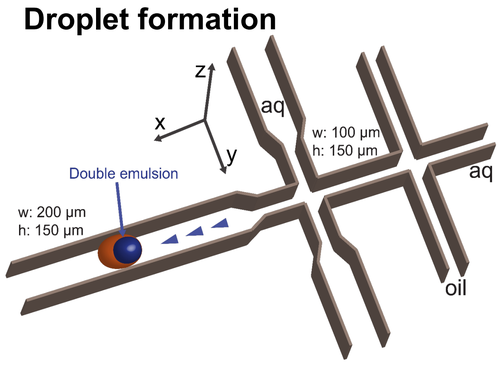


Flow cytometry [1]

- Cell encapsulation applications require a low shear droplet environment
- Single microdroplets typically not compatible with flow cytometry because carrier fluid is oil.
- Double emulsions could provide a milder environment and protect fragile cells being damaged by harsh shear conditions.
- Internal flows and deformation of compound droplets are studied to assess cell viability and suitability for flow cytometry applications such as fluorescence activated cell sorting (FACS)

Experimental Methods

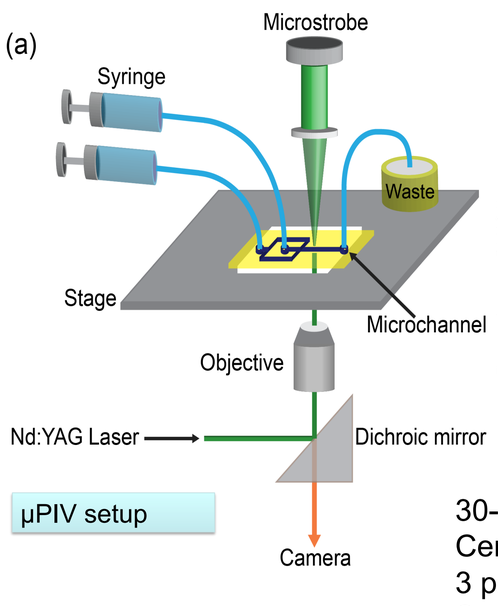
Droplet formation



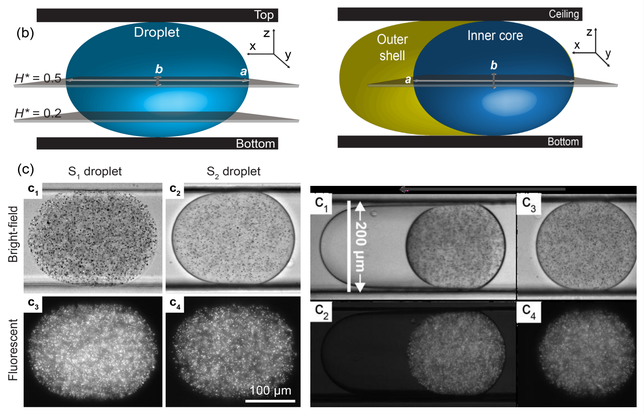
Single droplets: refractive index matching liquids as well as fluorinated oil HFE7500 (297730-93-9, 3M, 0.77cSt), Pico-Surf™ 1 (PS-1).

Double emulsions: deionised water, 1.5 wt% PS-1 surfactant in HFE7500, and water with 0.5 wt% sodium dodecyl sulphate (SDS) surfactant

Micro Particle Image Velocimetry (μPIV)



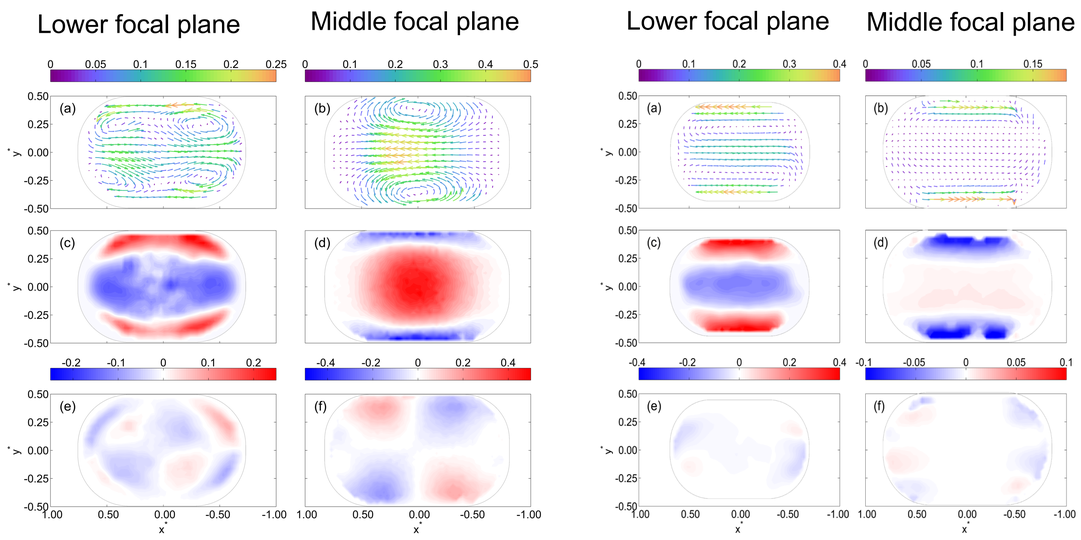
μPIV setup



Sample Images

30-50 image pairs acquired
Centroid location to estimate droplet velocity
3 pass correlation used to obtain velocity field
Spatial resolution: 6.4 um

Flow topology in single droplets

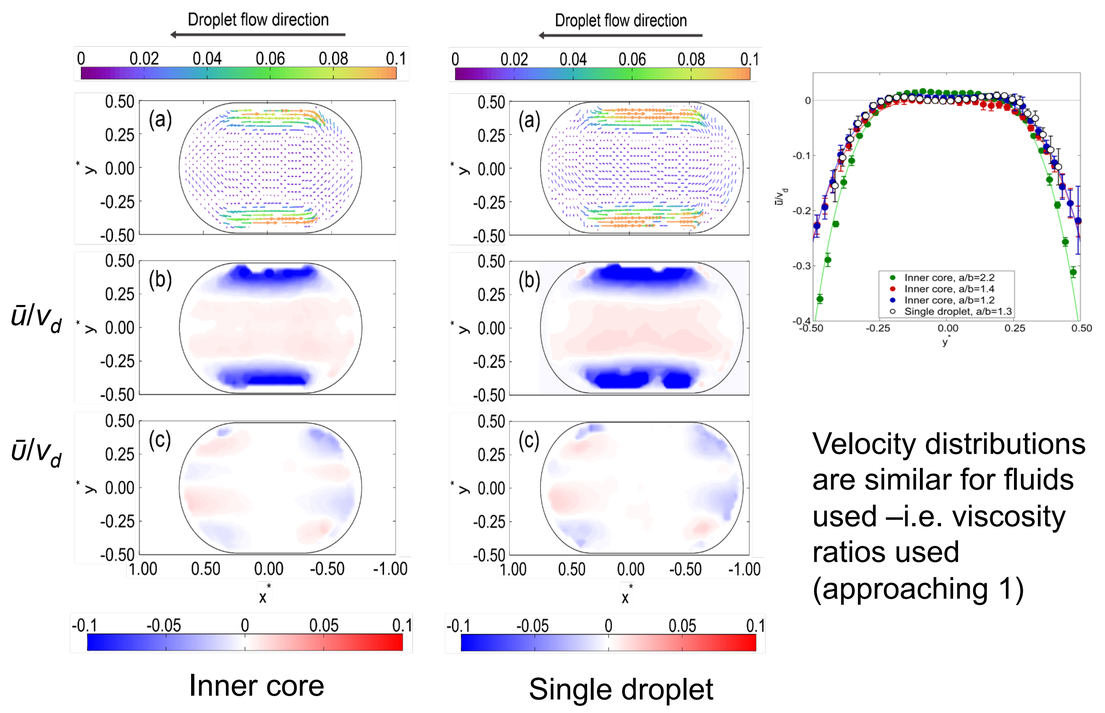


Silicon oil and water/glycerol mixture **(λ=0.12)**
Typical recirculating patterns seen.

HFE7500 **(λ=0.8)**
Higher velocity along the oil-water interface and low velocity in the bulk volume.

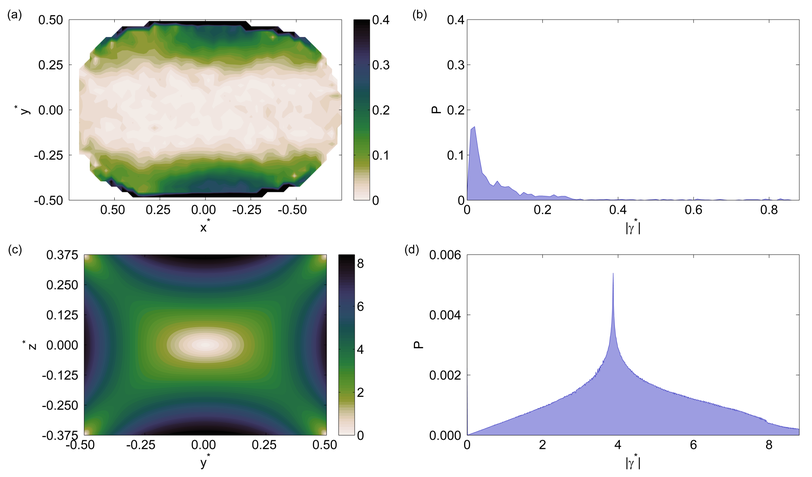
Inner-outer viscosity ratio plays a key role in determining topology

Flow patterns in w/o & w/o/w droplets



Velocity distributions are similar for fluids used –i.e. viscosity ratios used (approaching 1)

Shear stress distribution



inner core a/b=1.4

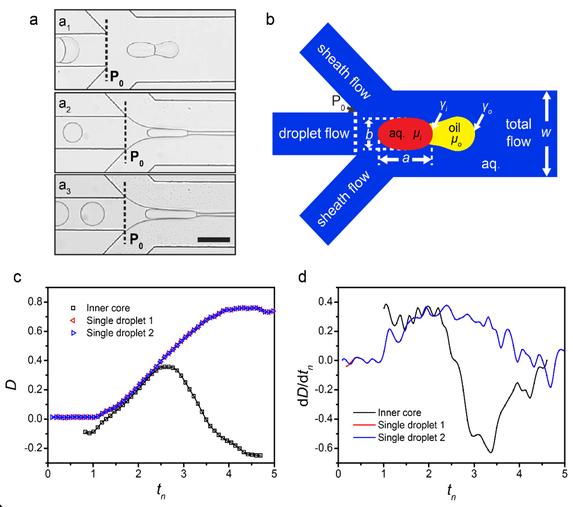
y-z plane of microchannel- Values normalised With nominal shear, v_c/w

Contours and frequency distribution of shear rate magnitude $|\gamma^*|$.

Droplets result in **a narrow distribution of shear** rate magnitude values compared to the microfluidic channel flow with a **mean value which is an order of magnitude lower.**

Droplet deformation under sheath flow conditions

Droplet deformation was studied in a hydrodynamic focusing setup designed using COMSOL. Deformation index (D) quantified from images of deforming droplets.



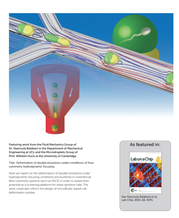
- w/o **single droplets deform more** than w/o/w double emulsions under certain aqueous sheath flow focusing
- deformed single droplets cannot recover their non-deformed morphologies as they remain in confinement longer,
- **double emulsions recover their non-deformed morphology rapidly** downstream of the sheath focusing point.

Conclusions and Outlook

- Viscosity ratio alters typical droplet flow pattern
- Increasing viscosity ratio from 0.12 to 0.80 eliminates recirculation patterns
- Role of viscosity more prominent than interfacial tension
- Double emulsions:
  - exhibit low shear stresses ensuring cell viability
  - deform less under sheath flow conditions
  - hence, good candidates for cell screening applications

[1] http://www.assay-protocol.com/cell-biology/flow-cytometry

This work is a collaboration between the Fluid Mechanics Group of Dr. Stavroula Balabani in the Department of Mechanical Engineering at UCL and the Microdroplets Group of Prof. Wilhelm Huck at the University of Cambridge, now at Radboud Univesrity. Part of the work appeared in LabChip cover.



Ma et (2015) Deformation of double emulsions under sheath flow focusing, **Lab Chip,** 15(22):4291-30; Ma et al (2015) The microenvironment of double emulsions in rectangular microchannel. **Lab Chip**, 15(10):2327-34; Ma et al (2014) On the flow topology inside droplets formed in rectangular microchannels, **Lab Chip**, 14, 3611-3620.