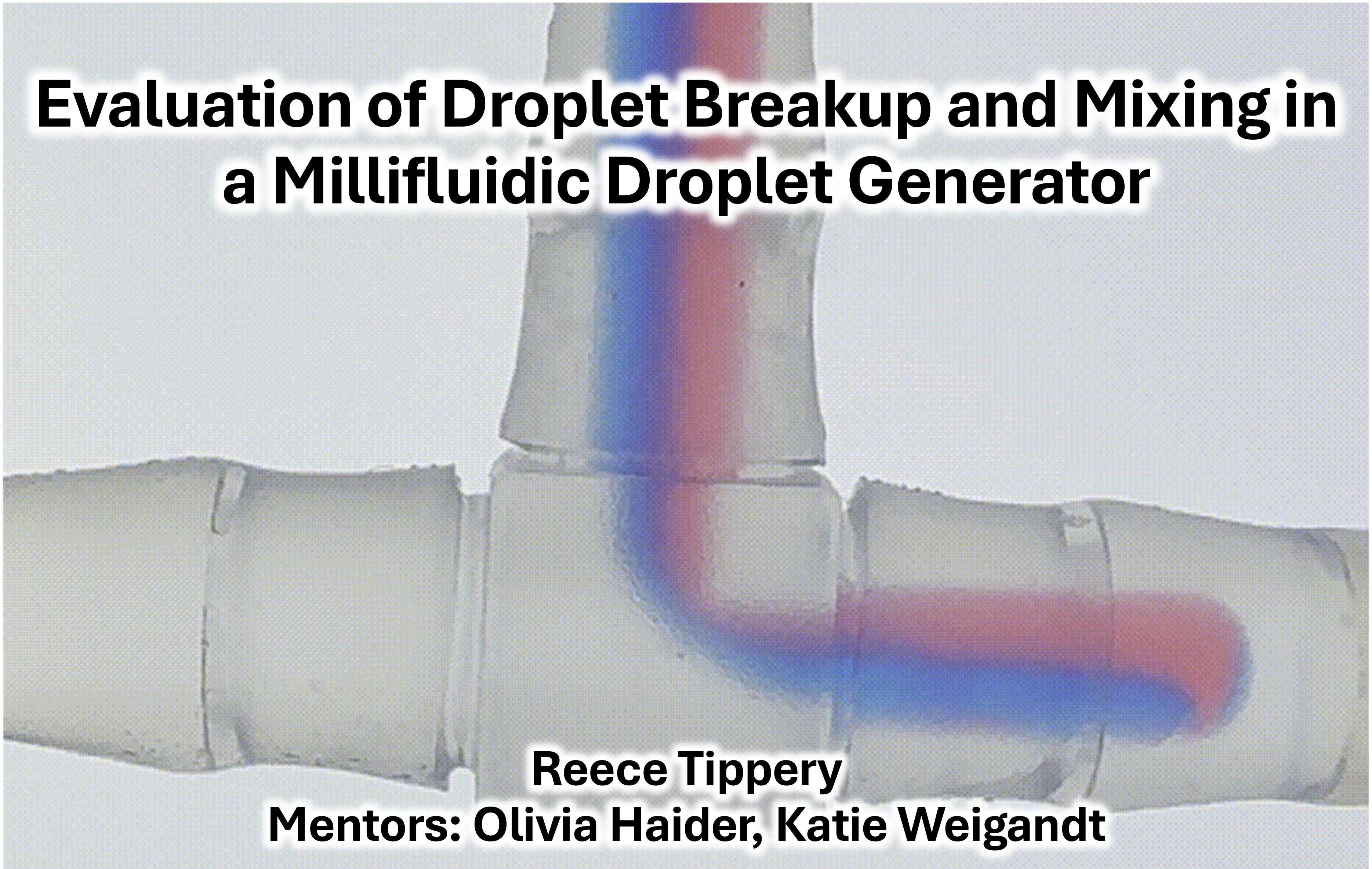
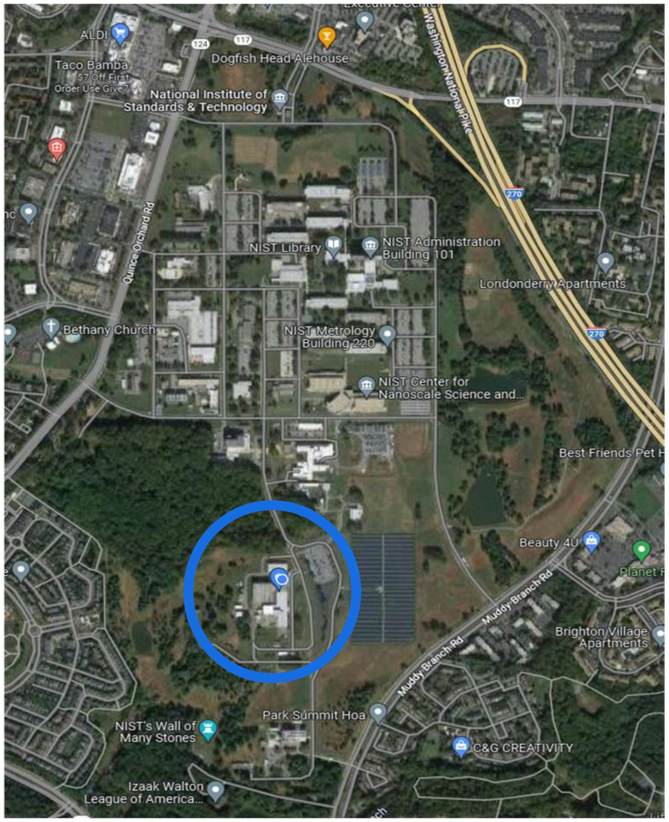


Evaluation of Droplet Breakup and Mixing in a Millifluidic Droplet Generator

Reece Tippery
Mentors: Olivia Haider, Katie Weigandt

The NIST Center for Neutron Research (NCNR) is a user facility providing access to neutron instrumentation to scientists in academia, industry, and government

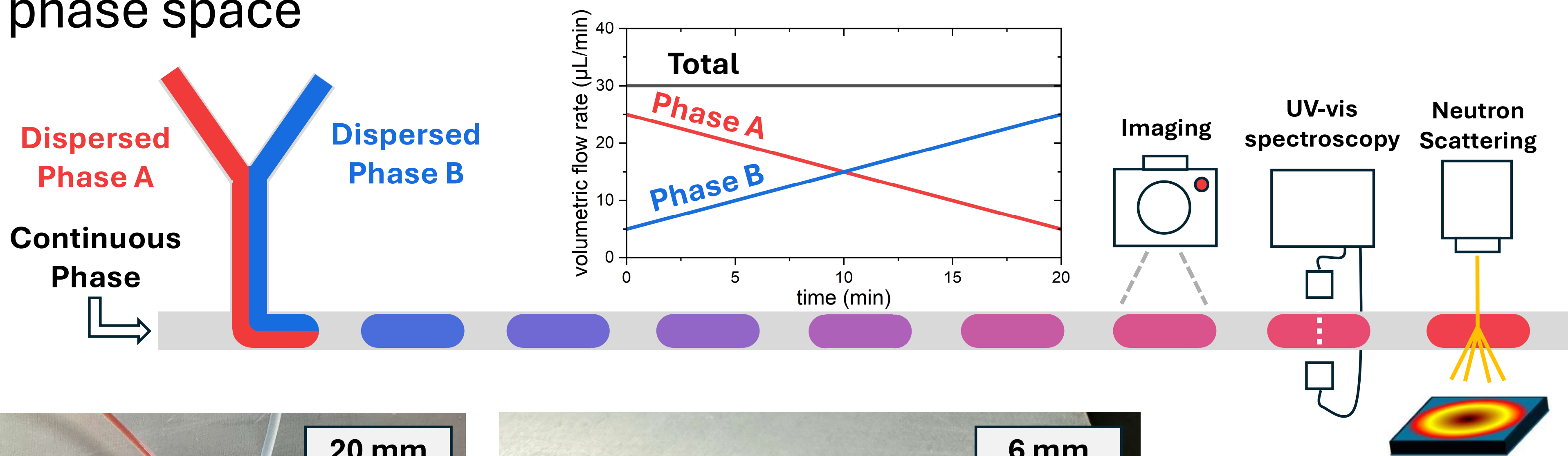


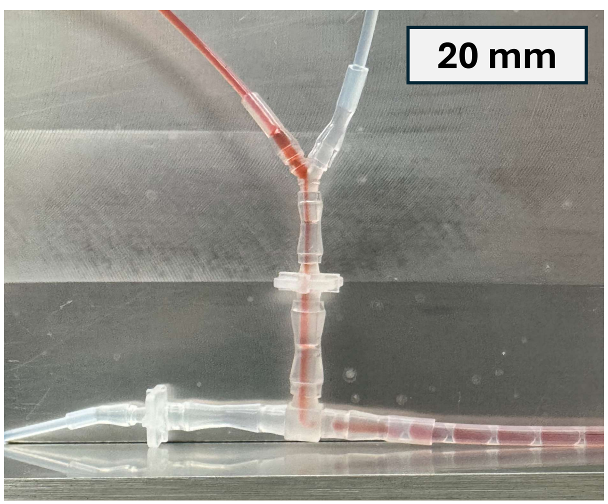
Advancement in formulation engineering is challenged by extremely large phase spaces

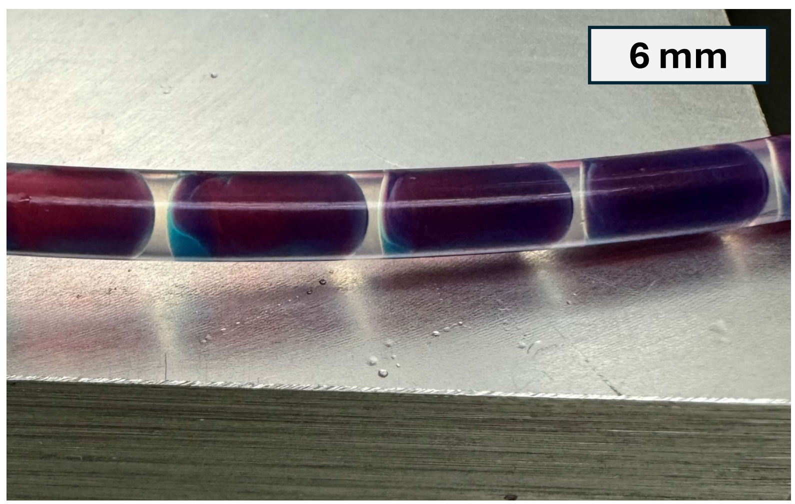
22 Ingredients Including…

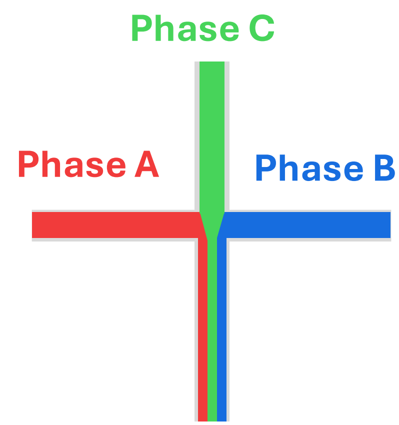
- **Solvent**
- **Surfactant**
- **Viscosity Modifier**
- **Preservative**
- **Dye**
- **Processing aids**

Millifluidic droplet generation can rapidly produce samples along a phase space

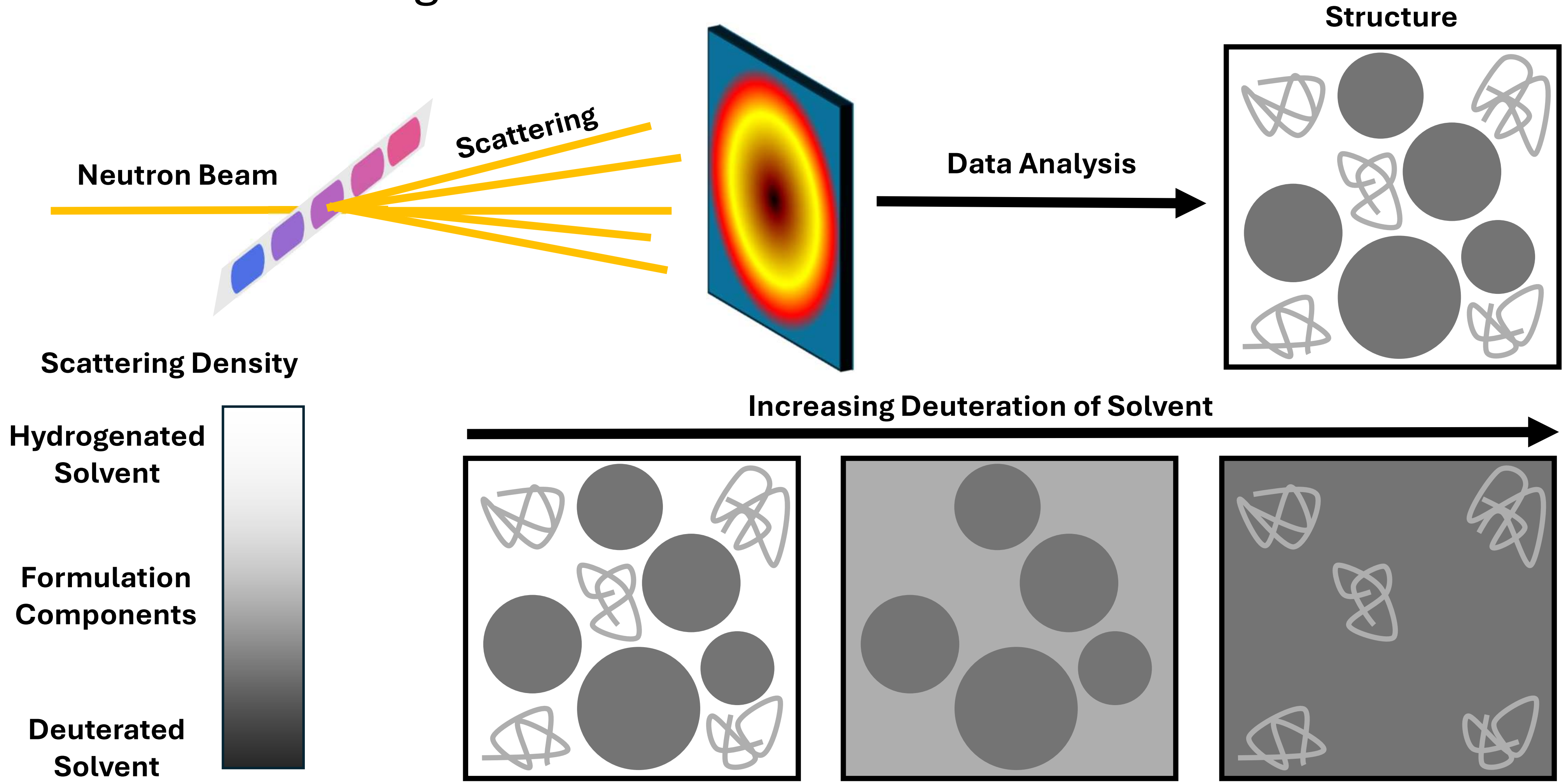




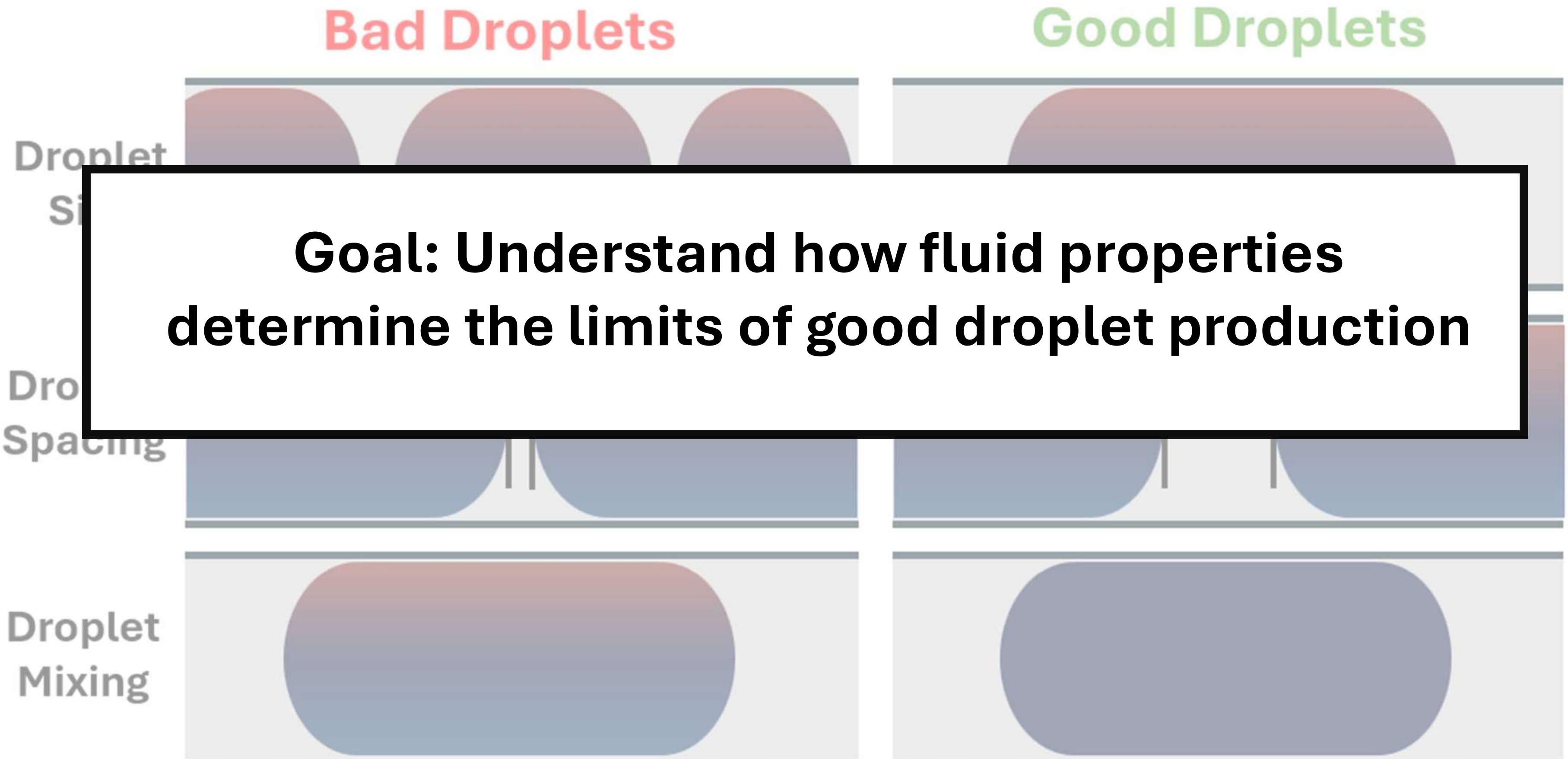




Neutrons allow for contrast matching components to isolate the effect of each ingredient



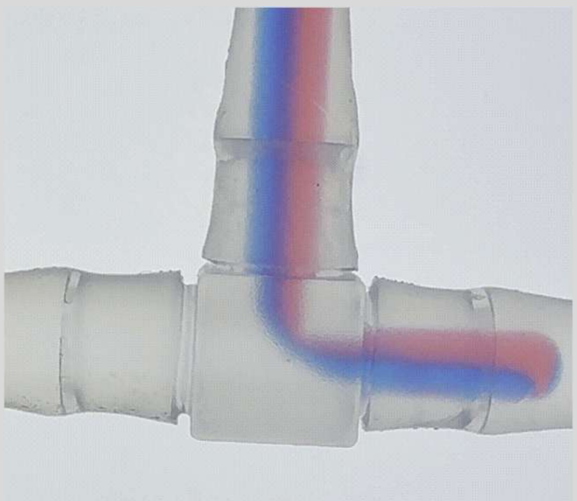
We need to understand the impact of fluid properties on droplet production



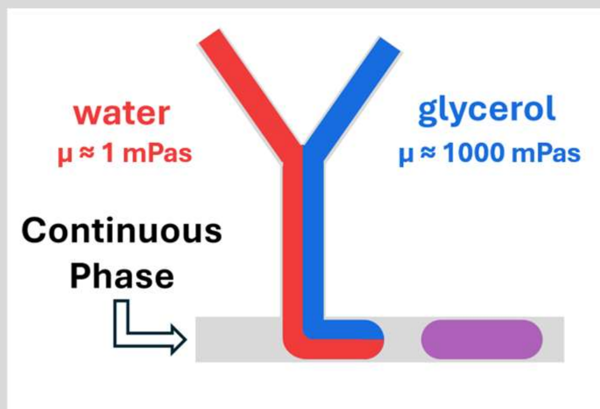
Goal: Understand how fluid properties determine the limits of good droplet production

Research Questions

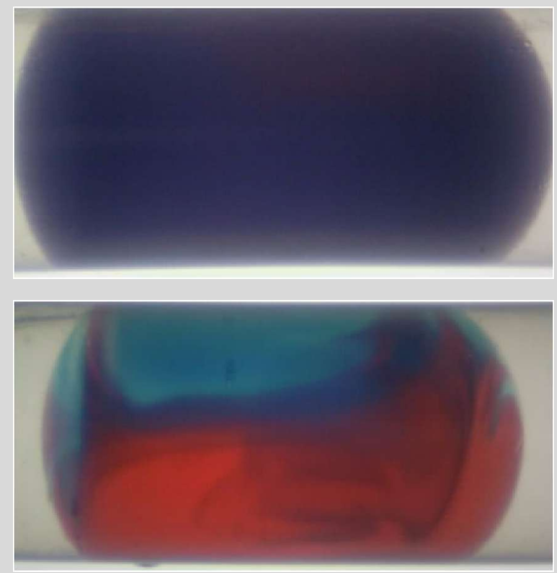
How does viscosity impact droplet breakup and the accessible operating regime?



How do differences in physical properties between dispersed phase components impact breakup?

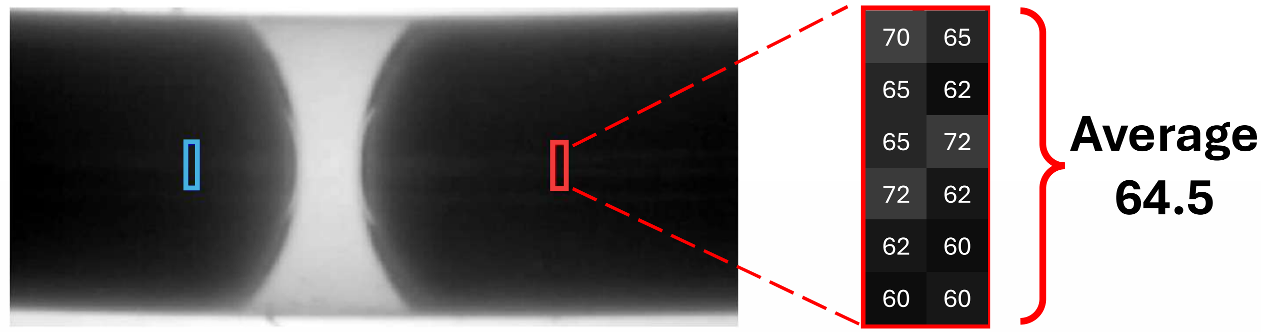


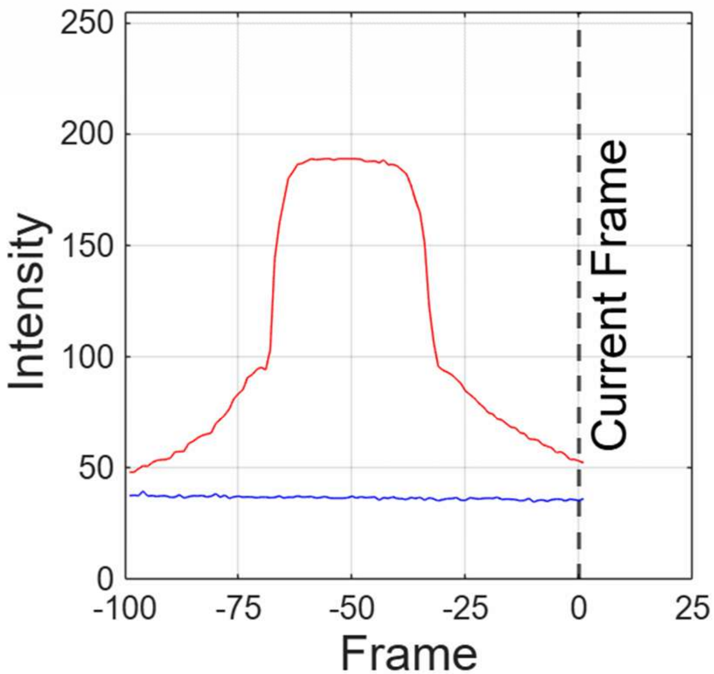
How can we evaluate and enhance the mixing of viscous droplets?

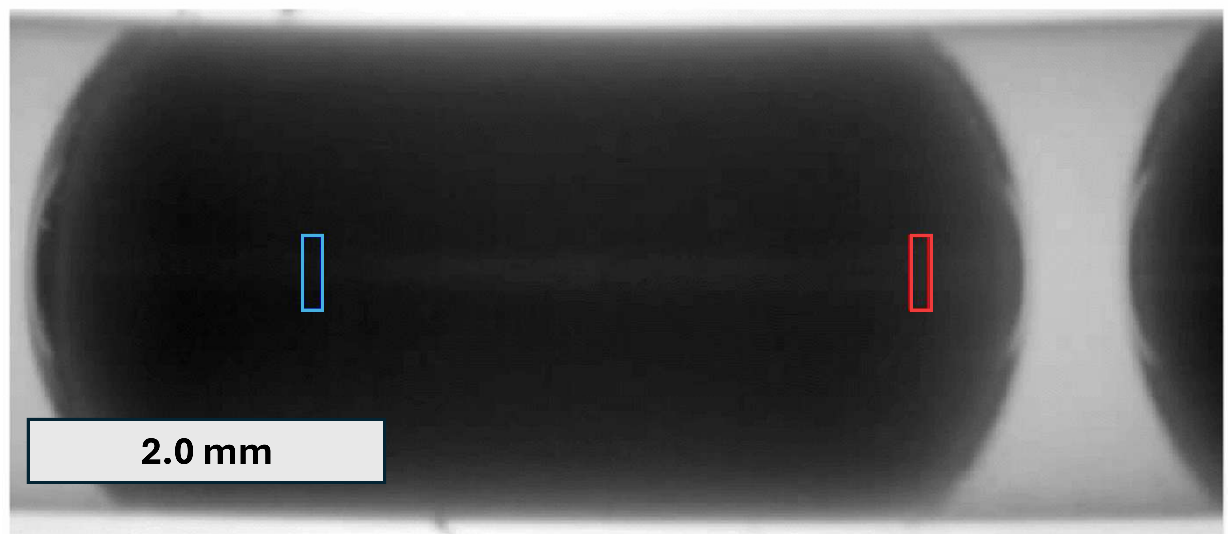


Video Analysis

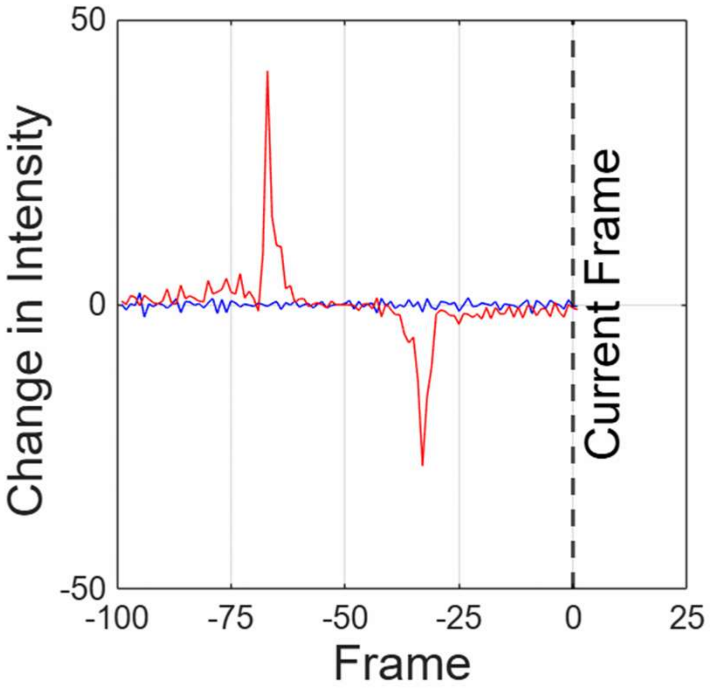
Collect signals from two small windows along the axis of the tubing

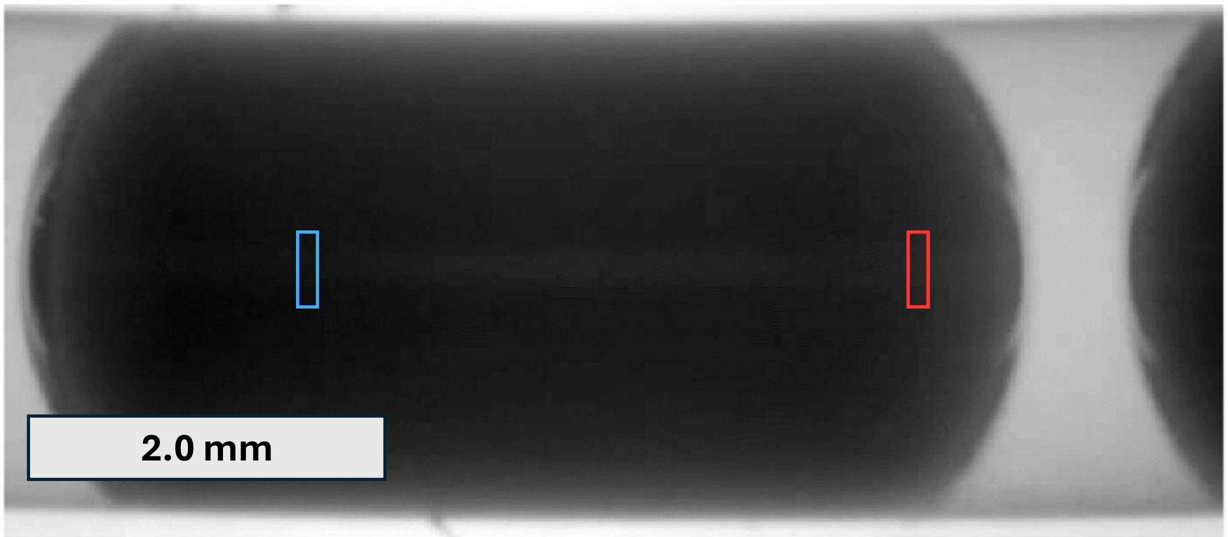






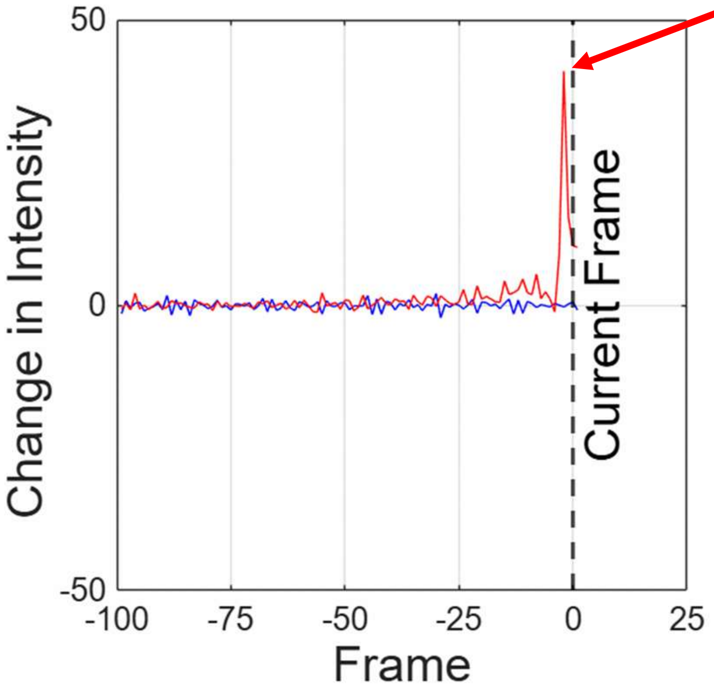
Video Analysis

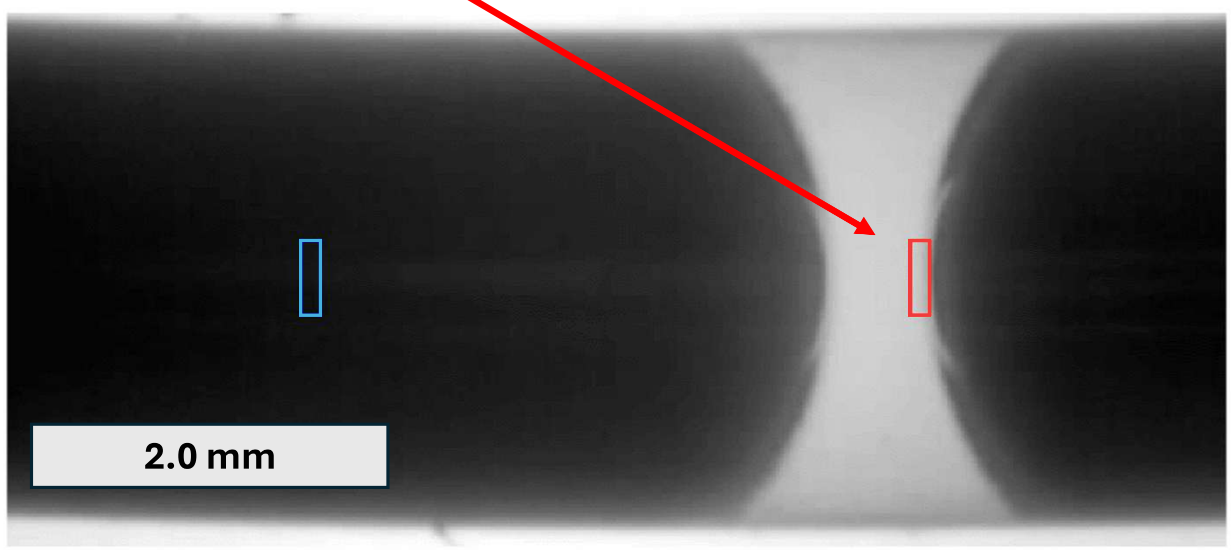




Video Analysis

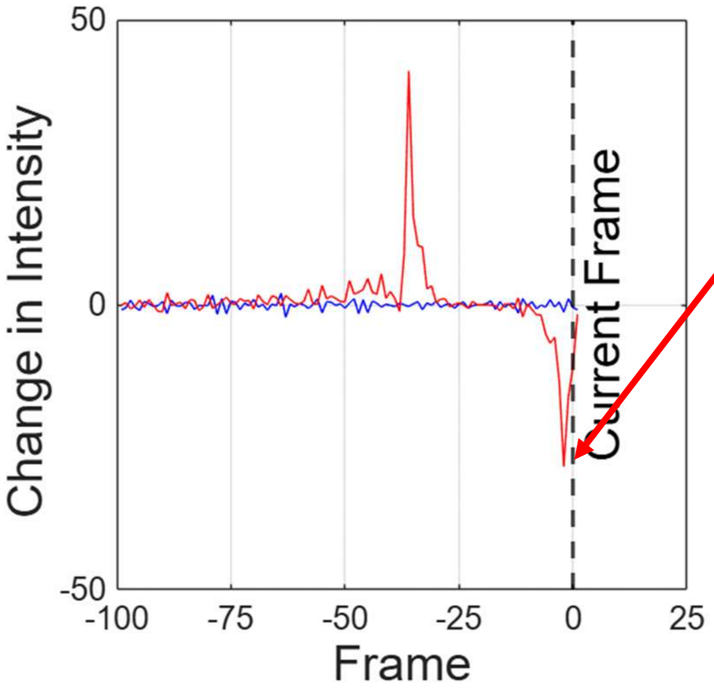
Maxima in the signal correspond
to the **end** of a drop

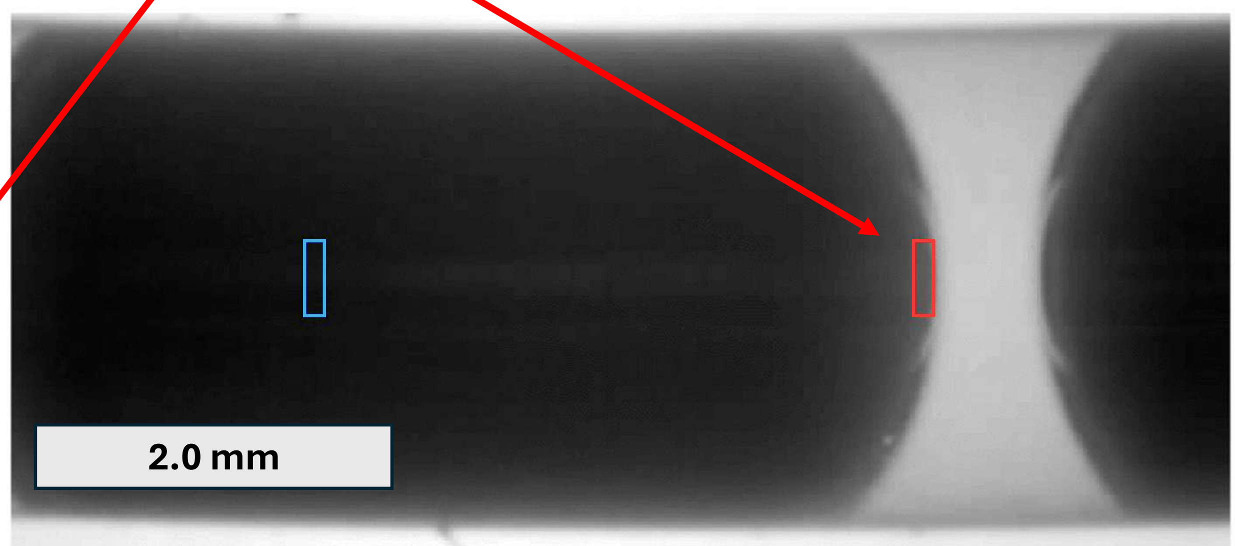




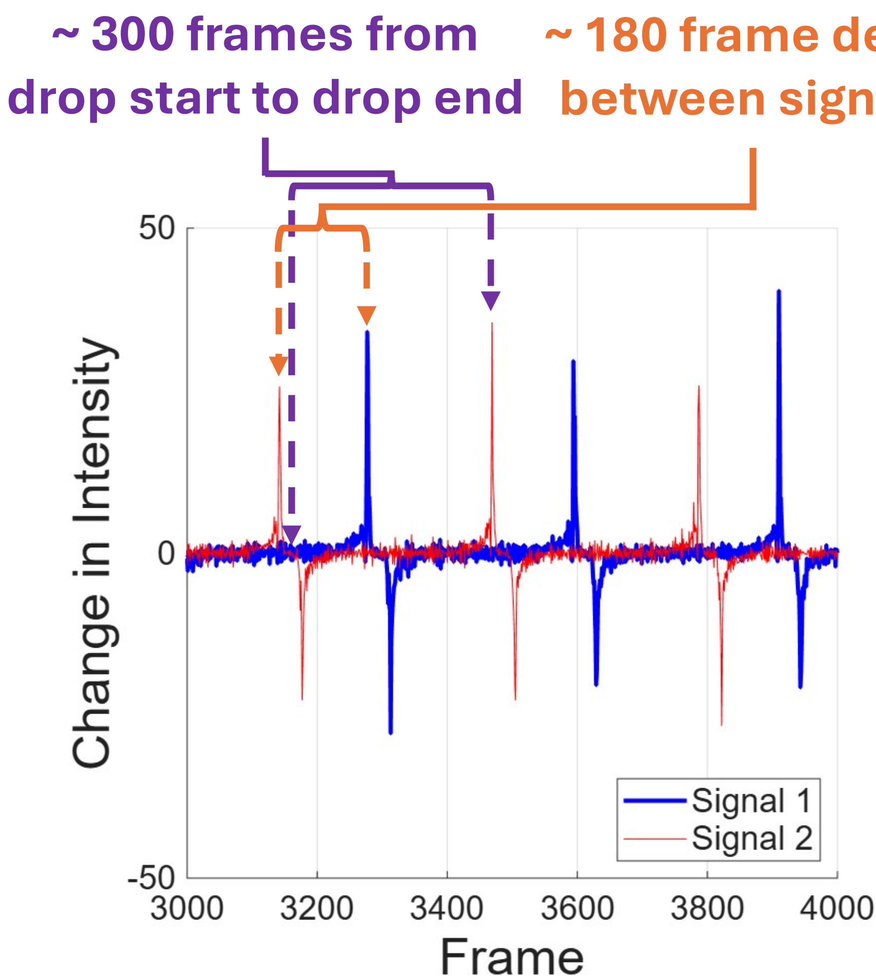
Video Analysis

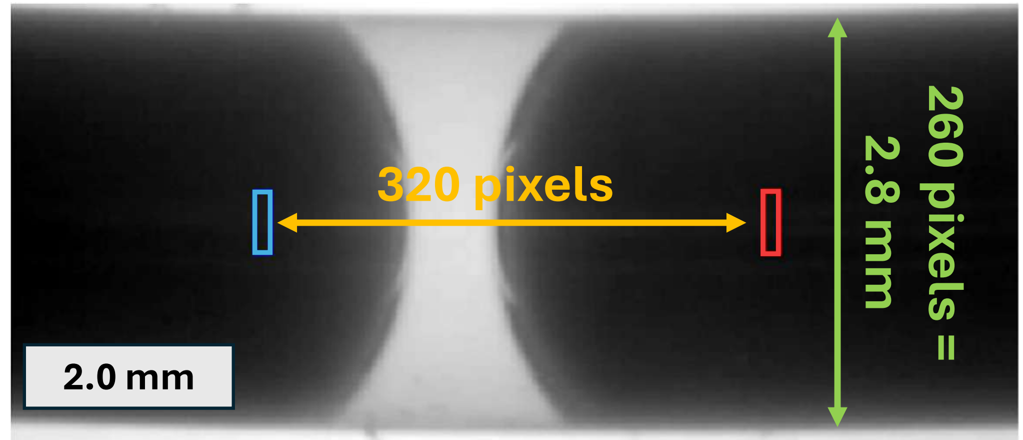
Minima in the signal correspond
to the **beginning** of a drop





Video Analysis





Drop Velocity

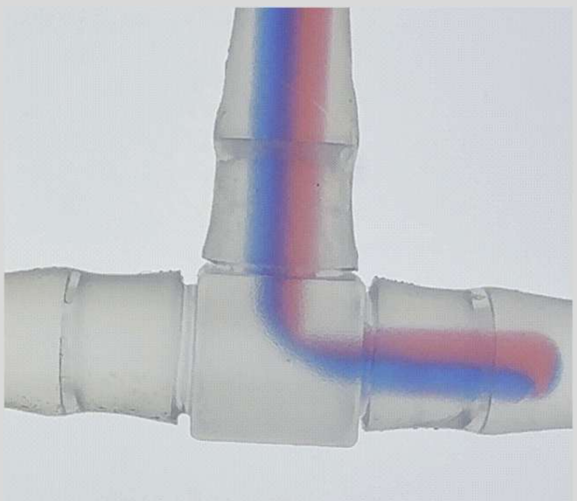
$$\frac{320\text{ pixels}}{180\text{ frames}} \times \frac{10\text{ frames}}{1\text{ second}} \times \frac{2.8\text{ mm}}{260\text{ pixels}} = \frac{0.19\text{ mm}}{\text{second}}$$

Drop Length

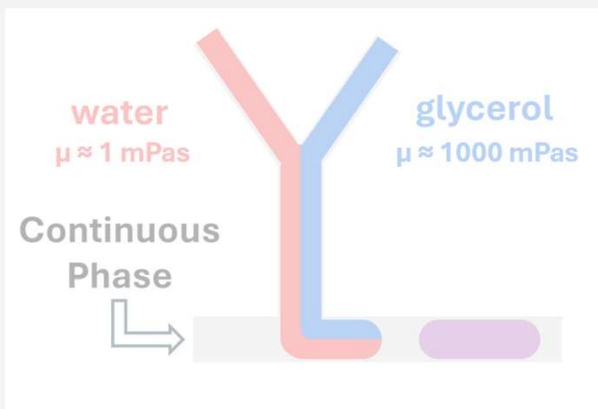
$$300\text{ frames} \times \frac{1\text{ second}}{10\text{ frames}} \times \frac{0.19\text{ mm}}{\text{second}} = 5.70\text{ mm}$$

Research Questions

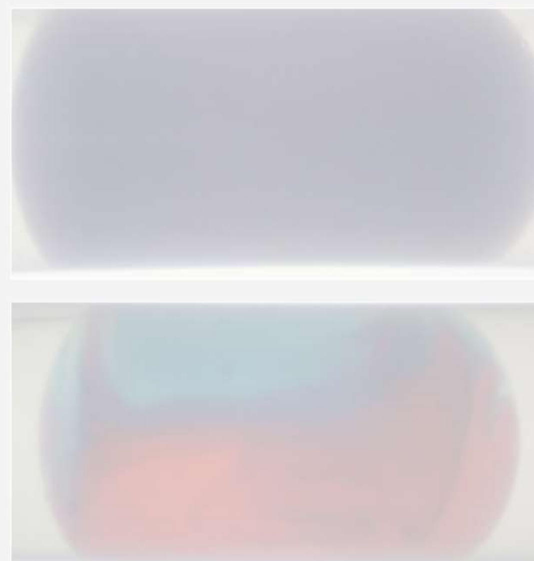
How does viscosity impact droplet breakup and the accessible operating regime?



How do differences in physical properties between dispersed phase components impact breakup?



How can we evaluate and enhance the mixing of viscous droplets?

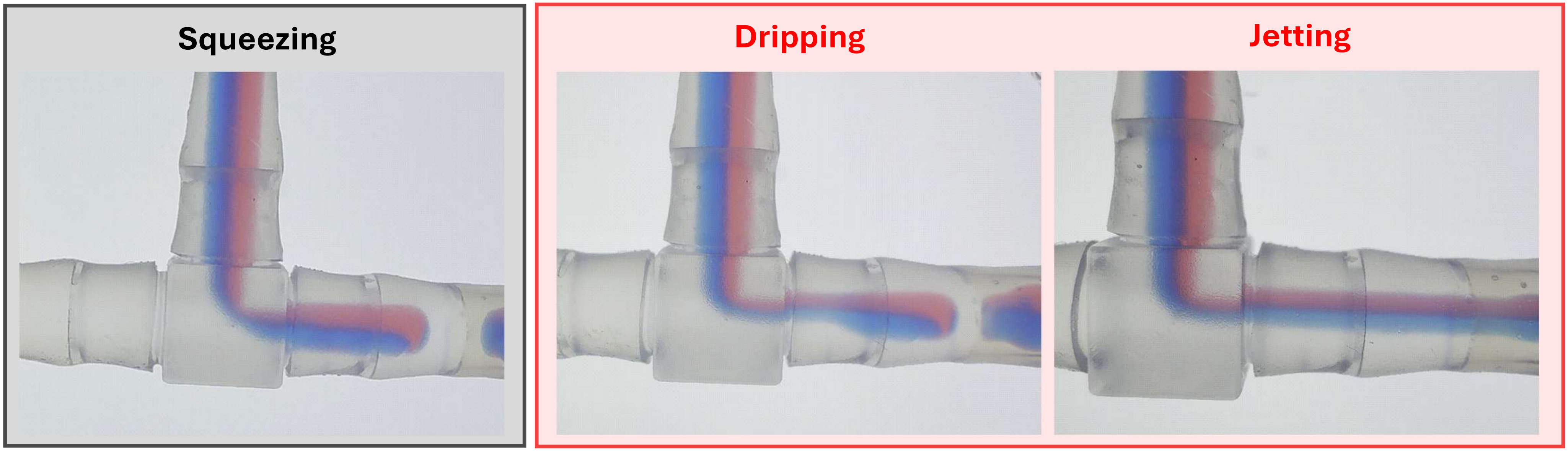


The capillary number (Ca) determines the droplet breakup regime which heavily impacts droplet quality

$$Ca = \frac{viscous\ forces}{interfacial\ tension} = \frac{\mu U}{\sigma}$$

$$Ca < 0.01\ \ Squeezing$$
$$Ca > 0.01\ Dripping/Jetting$$

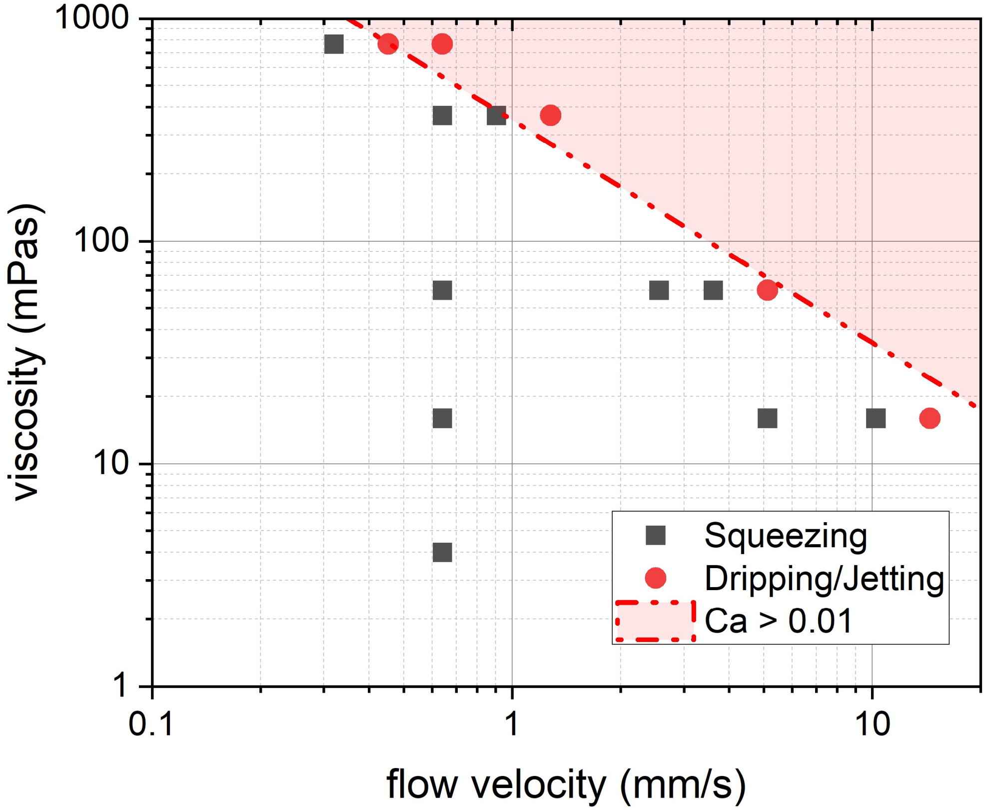
$$\mu = viscosity$$
$$U = flow\ velocity$$



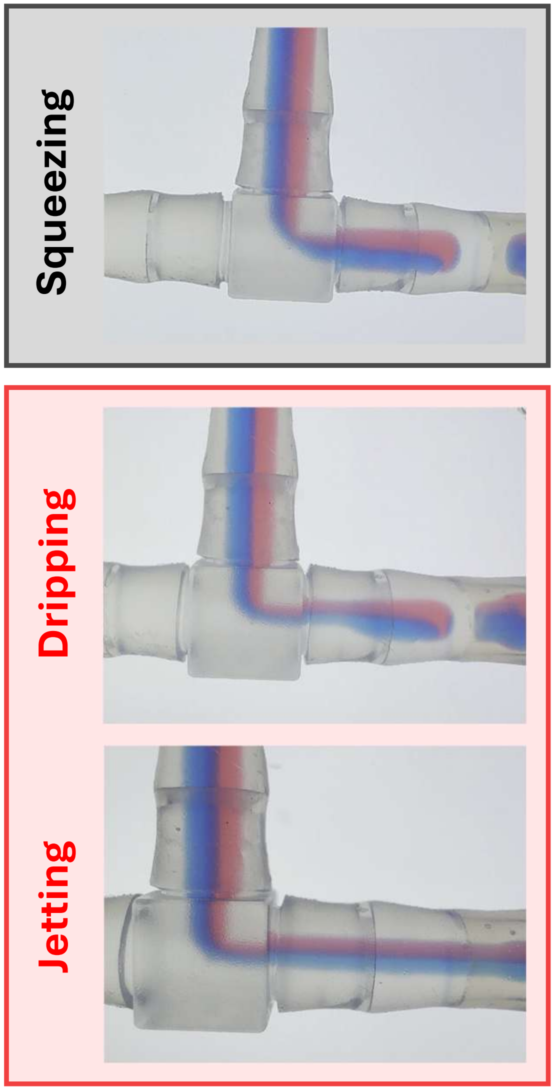
Our droplet generator follows the same trend as literature

$$Ca = \frac{viscous\ forces}{interfacial\ tension} = \frac{\mu U}{\sigma}$$

$Ca < 0.01$ *Squeezing*
$Ca > 0.01$ *Dripping/Jetting*



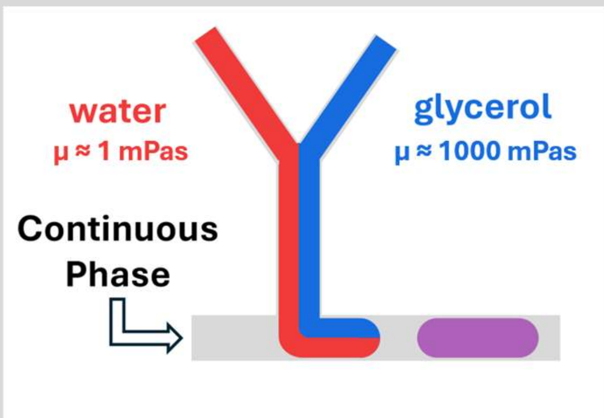
$\mu = viscosity$
$U = flow\ velocity$
$\sigma = 35\ mNm$



Research Questions

How does viscosity impact droplet breakup and the accessible operating regime?

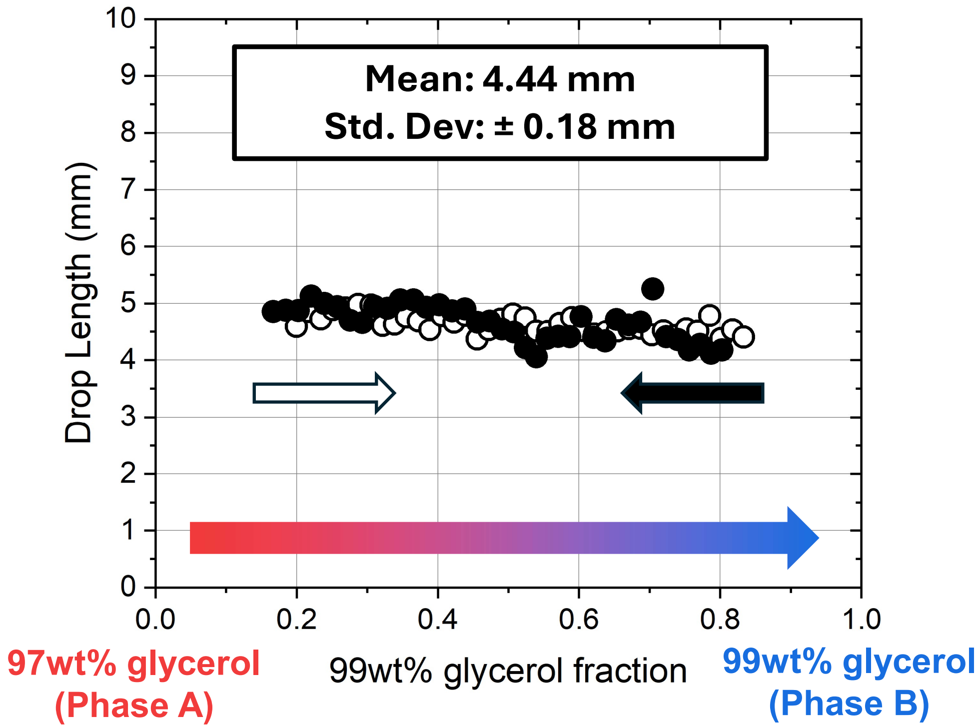
How do differences in physical properties between dispersed phase components impact breakup?



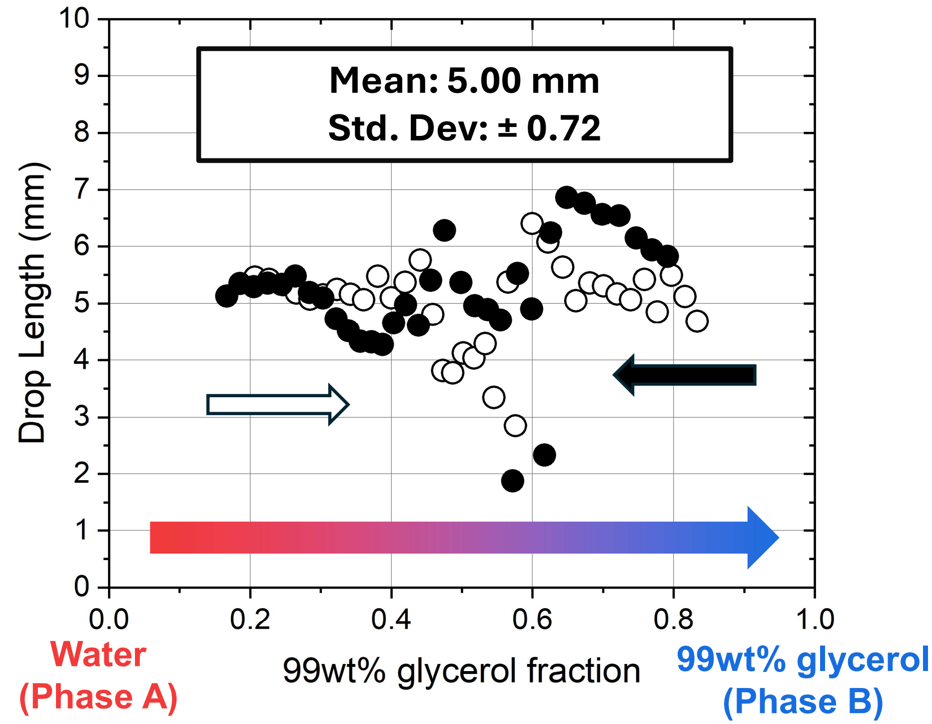
How can we evaluate and enhance the mixing of viscous droplets?

Some fluid combinations lead to inconsistent droplet production

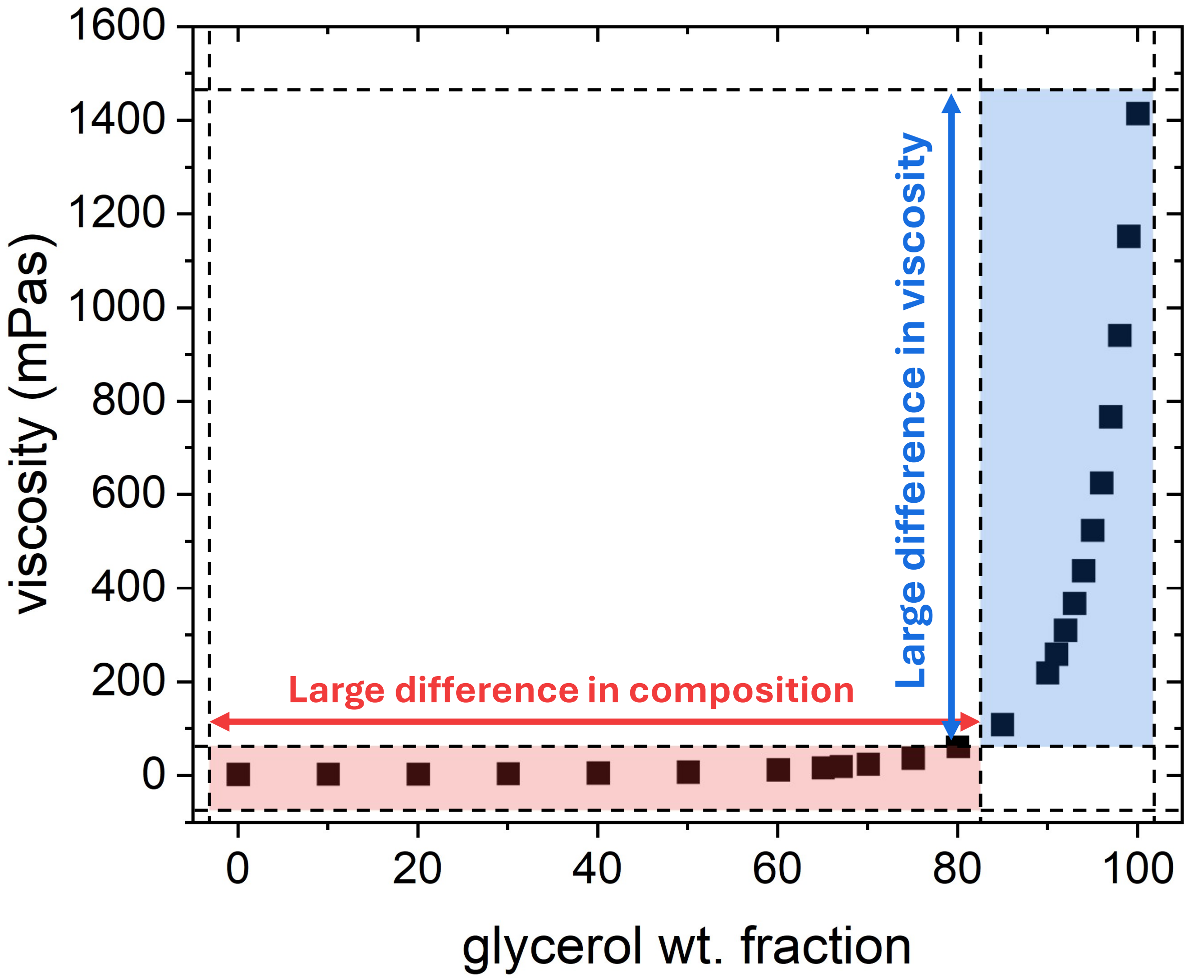
Consistent Drops (Good)



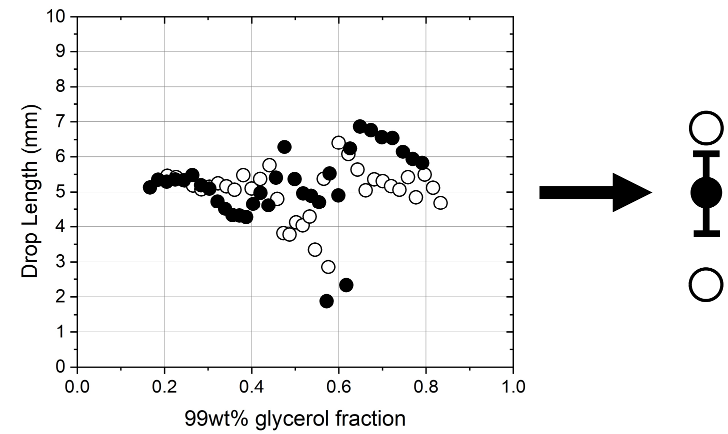
Inconsistent Drops

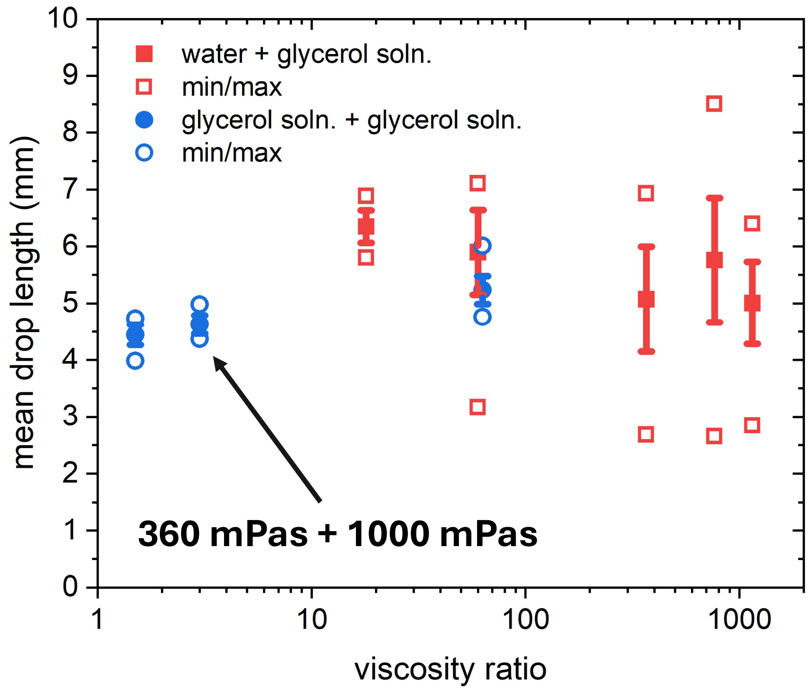


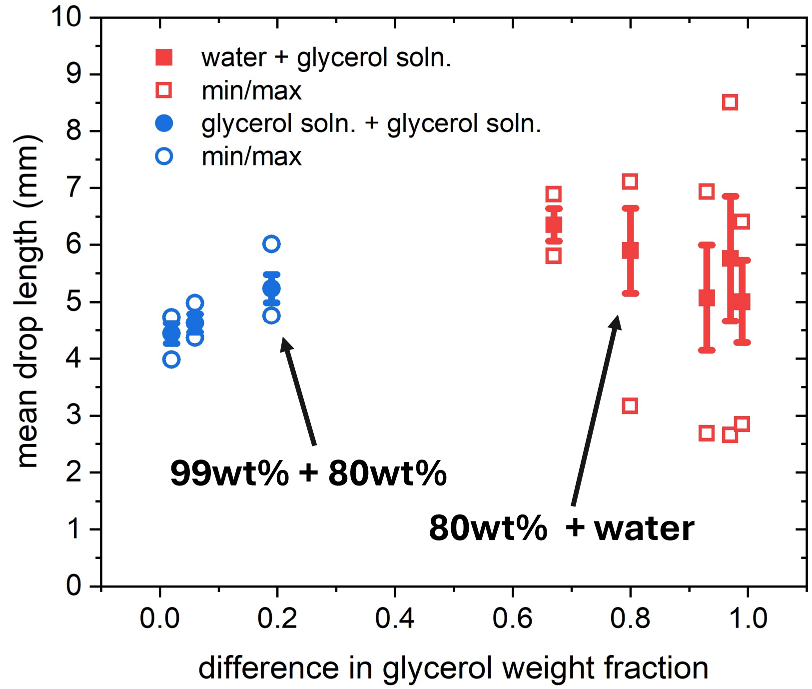
Viscosity does not follow a rule of mixtures



Difference in fluid composition may be a better predictor of breakup quality than difference in viscosity







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How does viscosity impact droplet breakup and the accessible operating regime?

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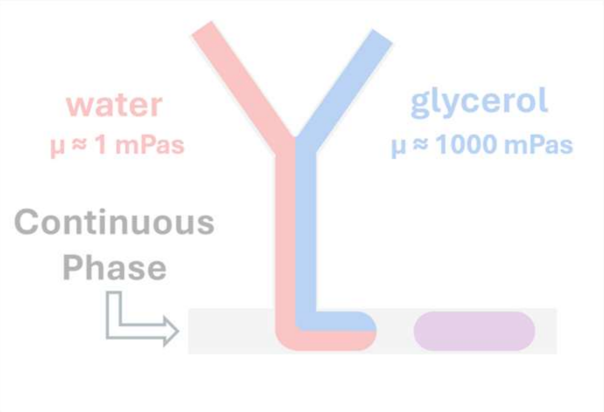

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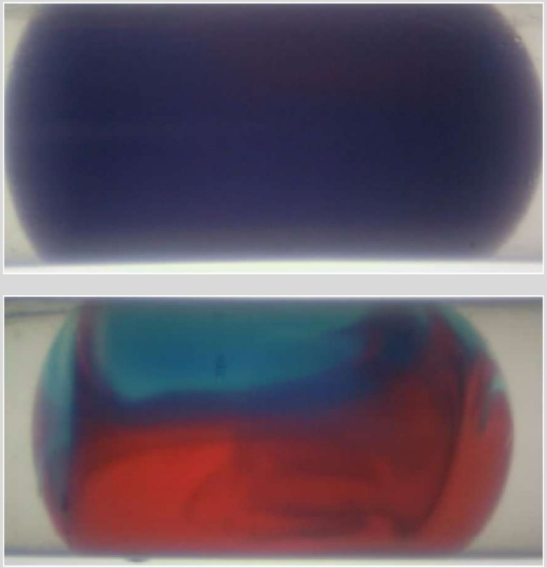
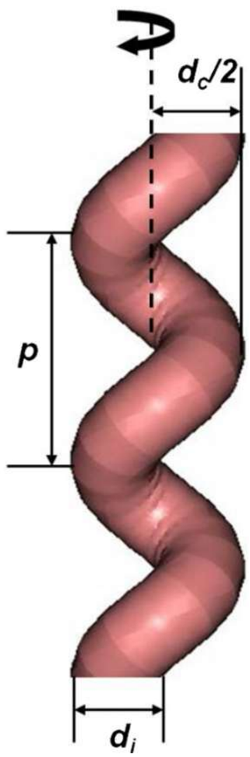


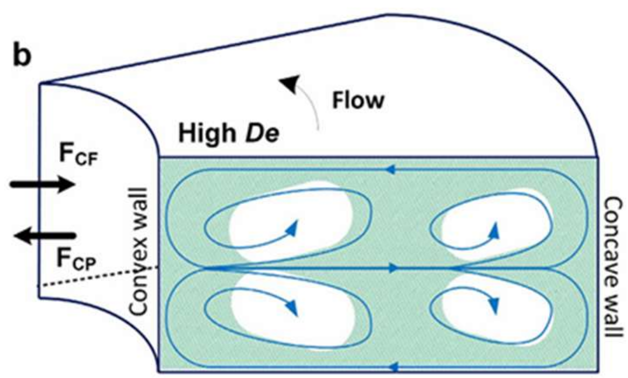
Channel curvature and mismatch in dispersed phase viscosities can enhance mixing within droplets



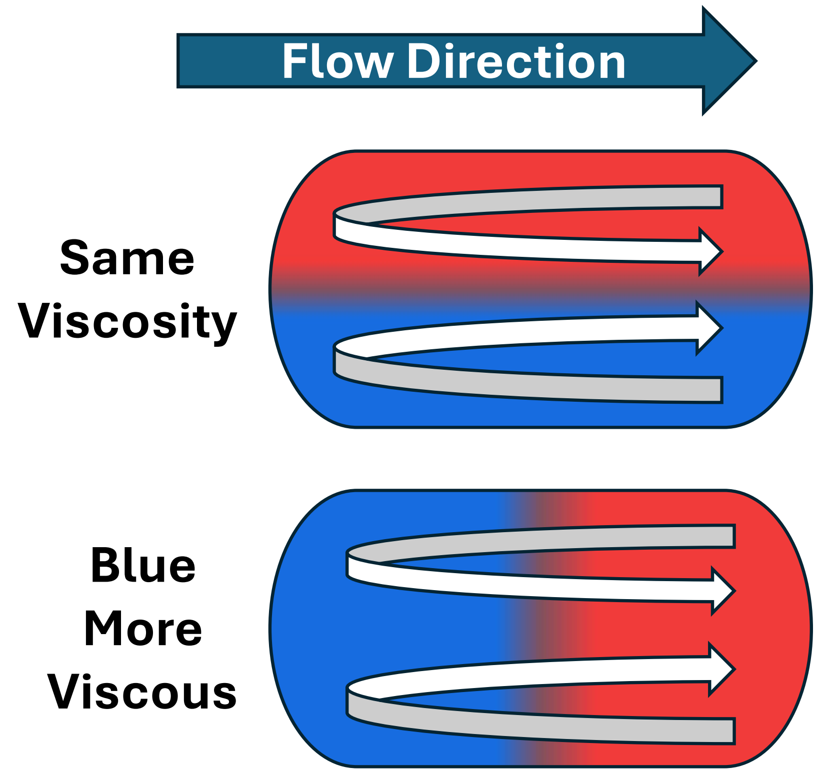
Adapted from "Geometrical influence on mixing in helical porous membranes microcontactors " Jani J. et al. Journal of Membrane Science (2011)

$$De = Re\sqrt{\frac{d_i}{d_c}}$$

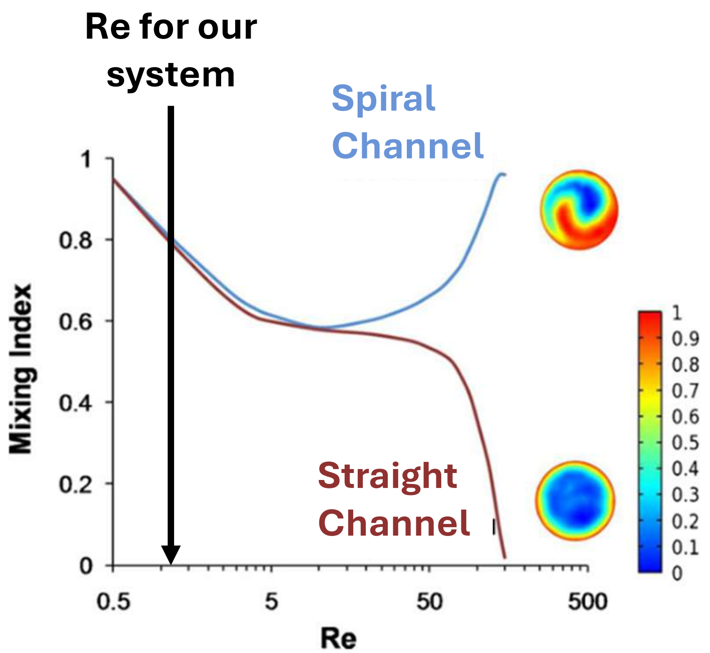
$$Re = \frac{\rho U L}{\mu}$$



"Dean Flow Dynamics in Low-Aspect Ratio Spiral Microchannels" Nivedita N. et al. Scientific Reports (2017)



Re may be too low to enhance mixing with dean flows



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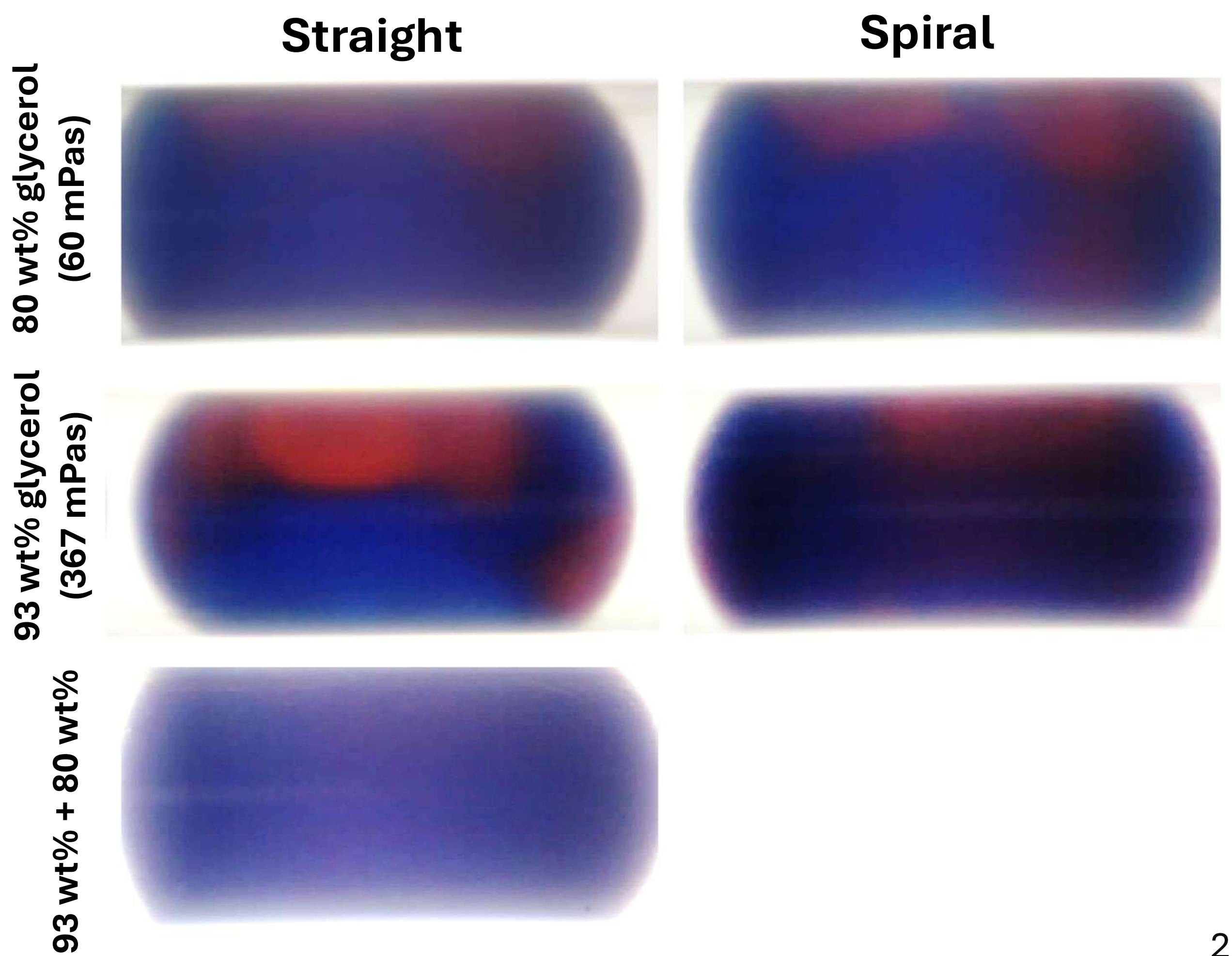
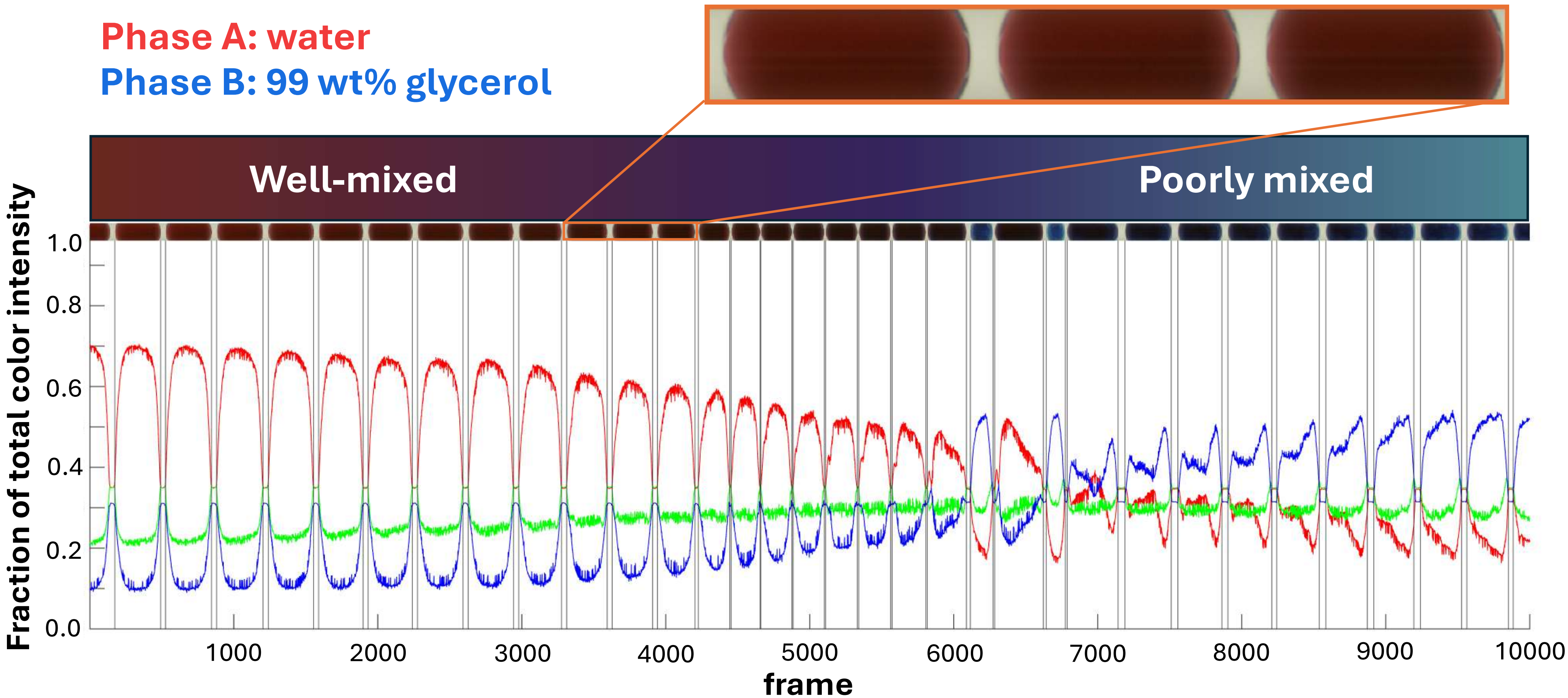
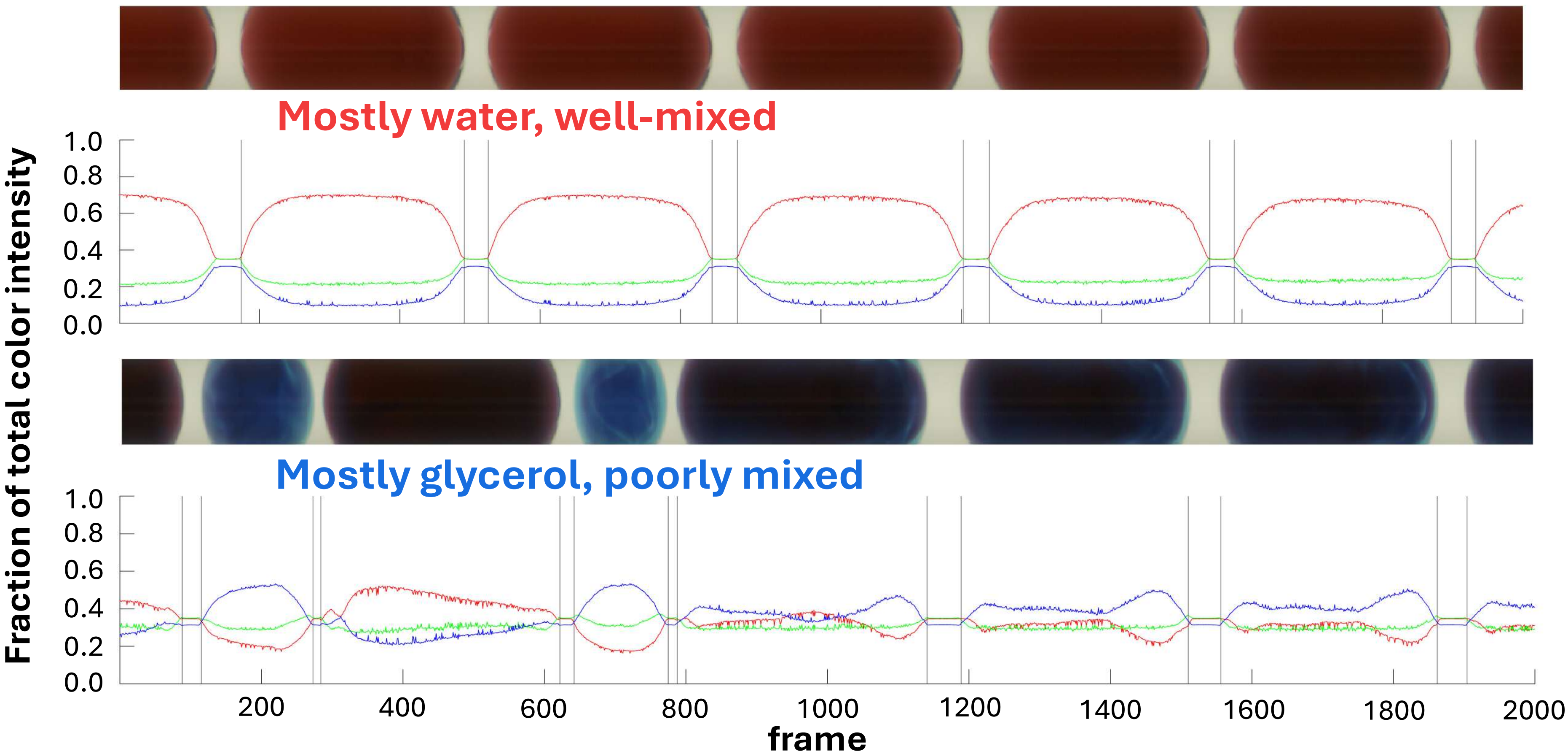


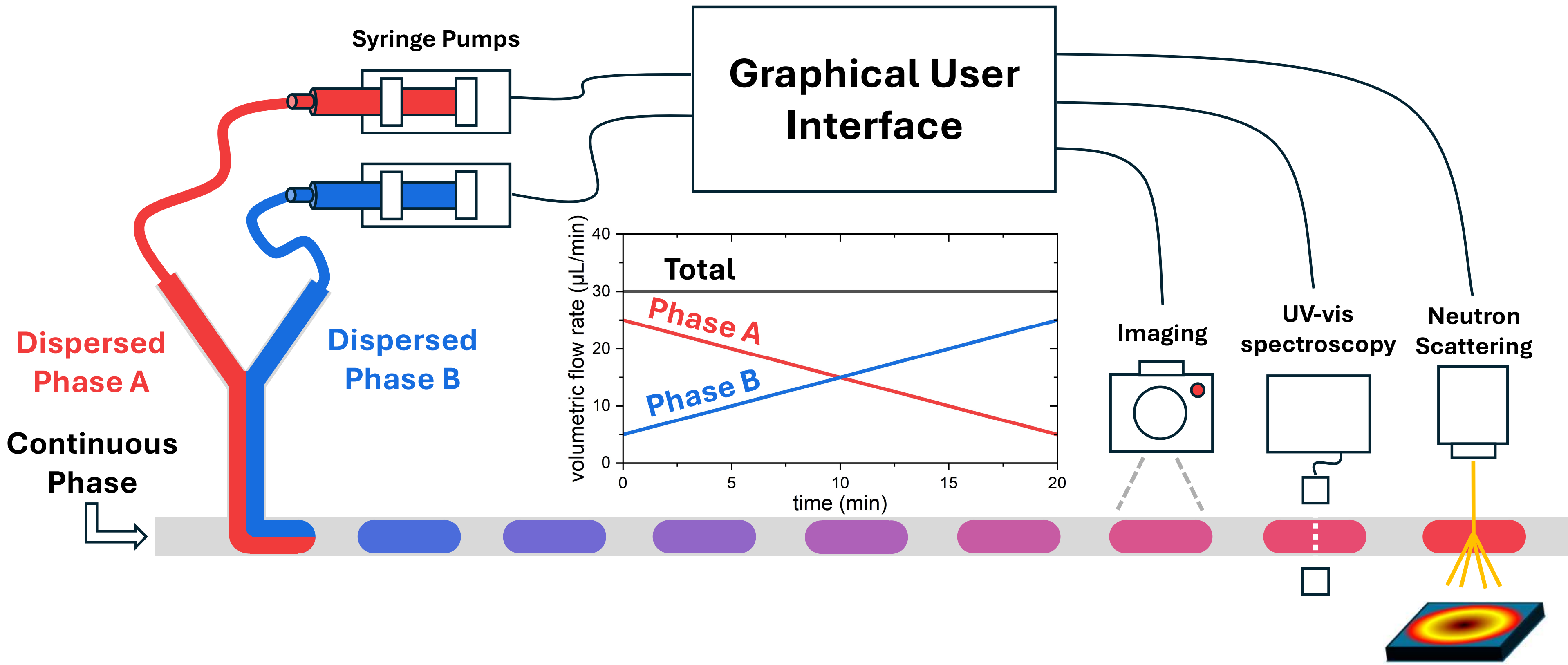
Can we extract a signal from the color data that gives an indication of mixing quality? *(Future Work)*



There is a clear difference in signal between well-mixed and unmixed drops

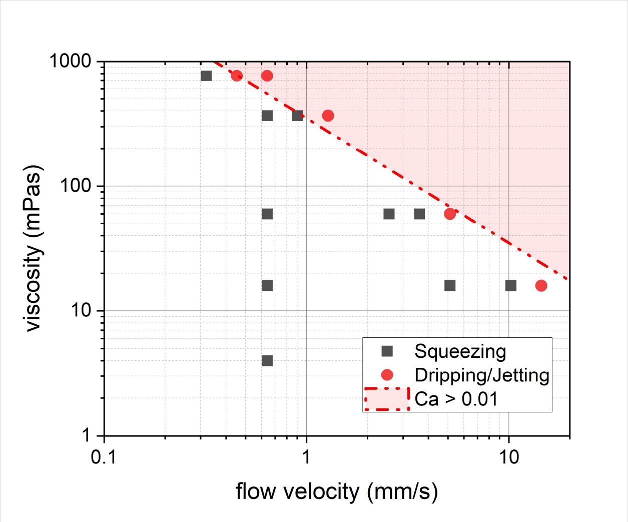


Longterm Goal: Integrating droplet production and characterization into one computer-controlled system

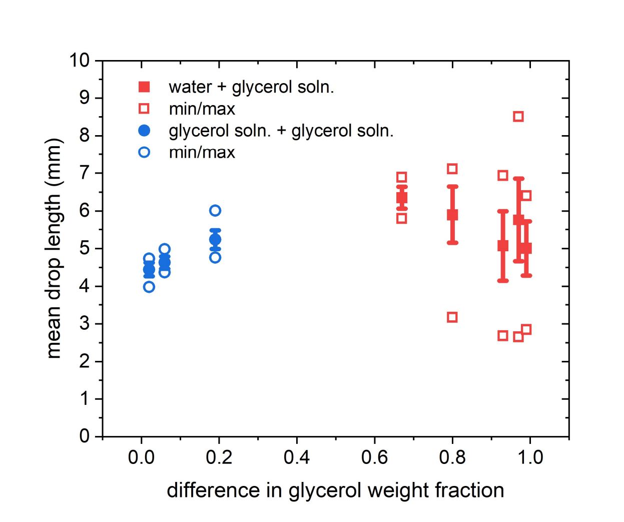


Summary

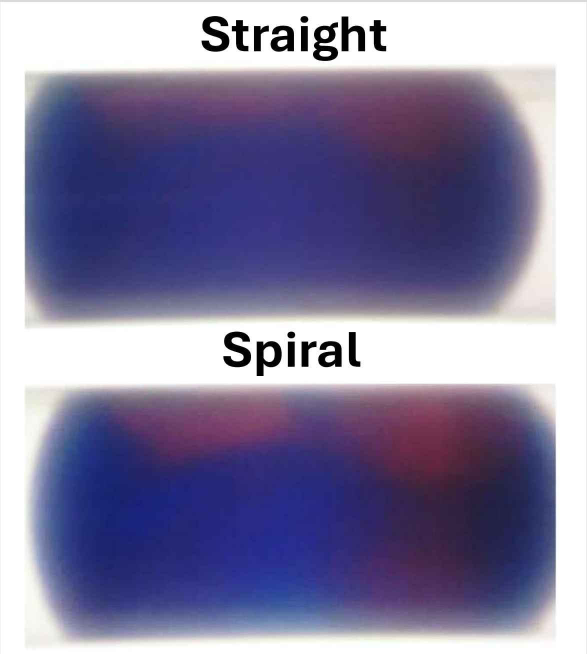
Our droplet generator follows the same breakup behavior as microfluidic devices described in literature



Large differences in dispersed phase composition produce inconsistent droplets



Spiral channels do not enhance mixing at low Re



Acknowledgements

Thank You!

Mentors: Olivia Haider, Katie Weigandt

SURF Leads: Cara O'Malley, Dr. Susana Marujo, Dr. Julie Borchers, Dr. Kelsi Rehmann

NCNR Staff

NSF CHRNS CENTER FOR HIGH RESOLUTION NEUTRON SCATTERING NIST

NIST National Institute of Standards and Technology U.S. Department of Commerce

NIST Center for Neutron Research

SURF NIST

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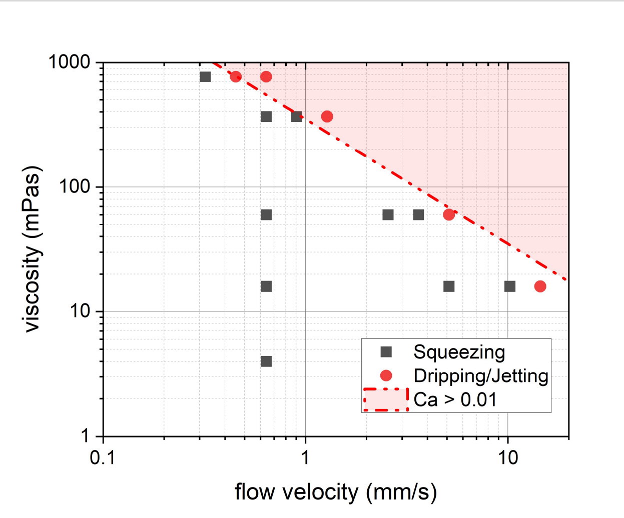

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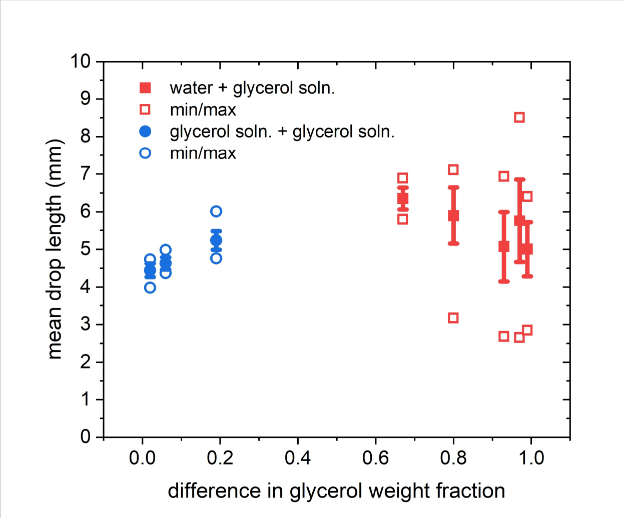

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