Modeling 3D Printing for Nanoemulsion Hydrogels

Cormak Weeks, Wentao Tang, and Lilian Hsiao

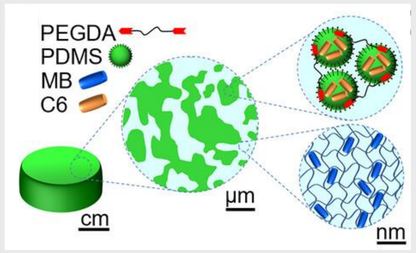
NC STATE UNIVERSITY
Department of Chemical and Biomolecular Engineering

CMI

Motivation

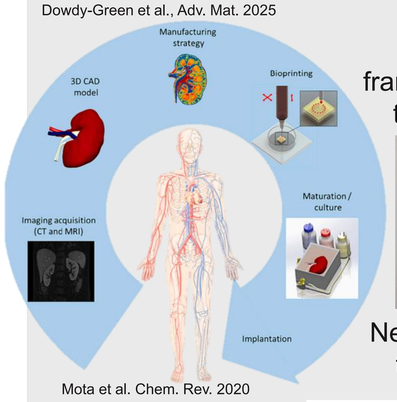
3D printing offers a potential avenue for personalized medications, but its clinical use and point of care is limited by the lack of descriptive models for complex material flow.

Introduction



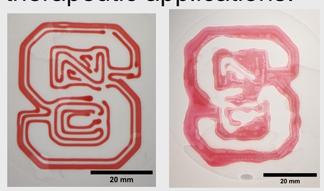
Dowdy-Green et al., Adv. Mat. 2025

Nanoemulsion hydrogels enable tunable and controlled delivery of immiscible active ingredients.



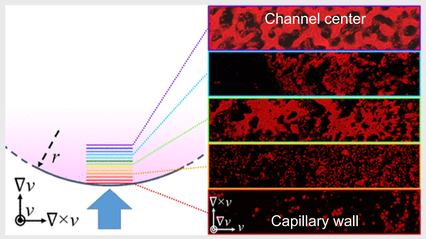
Mota et al. Chem. Rev. 2020

3D printing provides a framework for patient specific therapeutic applications.



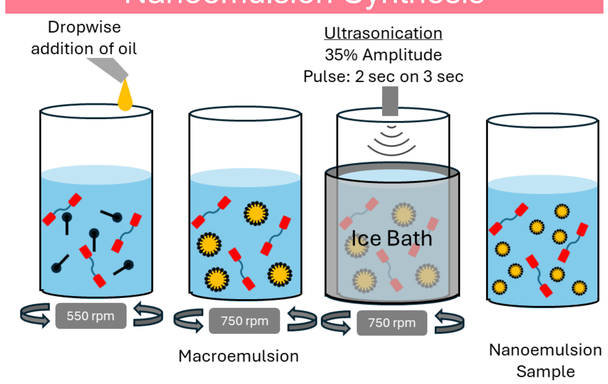
Need to improve quality for therapeutic application

Variations in bioink flow and microstructure leads to inconsistencies that are not predicted by current models.



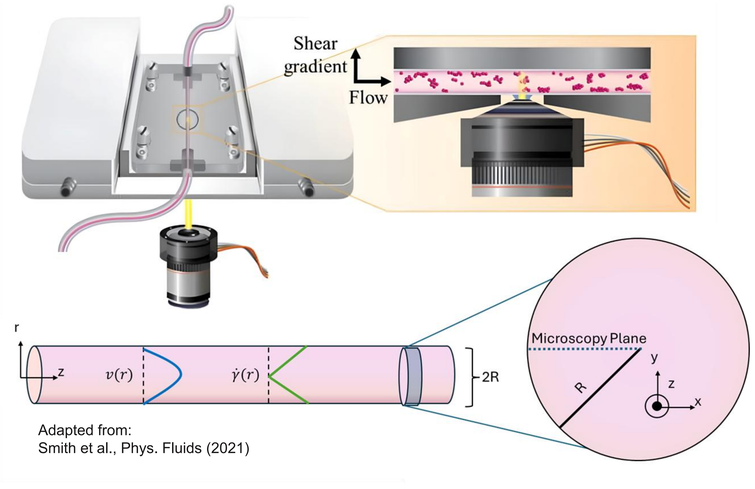
Smith et al., Langmuir 2021

Nanoemulsion Synthesis

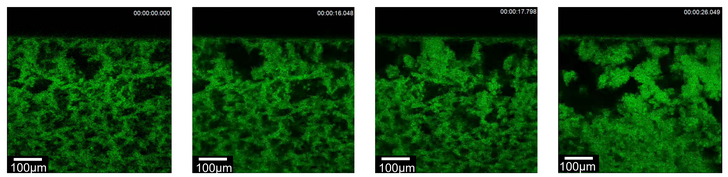


Components
- Sodium Dodecyl Sulfate (SDS)-Emulsifier
- Polydimethylsiloxane 5cSt-Oil phase (0.2 V/V)
- Poly(Ethylene Glycol) Diacrylate-Polymerizing Agent

Microscopy Imaging

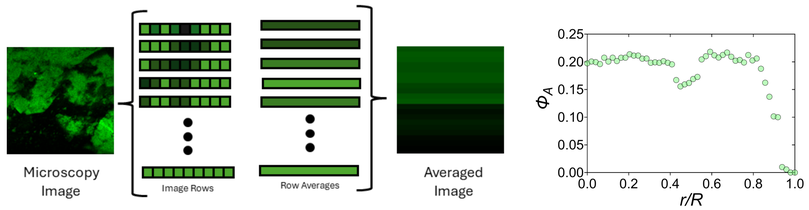


Adapted from:
Smith et al., Phys. Fluids (2021)



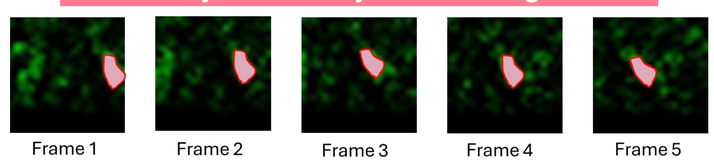
Confocal microscopy allows for the imaging of microstructural and flow type developments

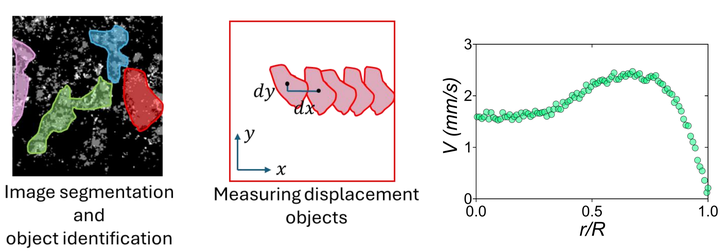
Concentration Tracking



Line averaging allows for radial concentration measurements within the channel

Dynamic Object Tracking





Object tracking allows for the local measurements of the flow through the capillary

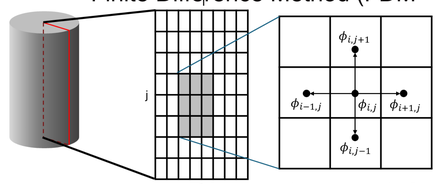
Modeling Capillary Flow

Taylor's flow for cylinders:

$$\frac{\partial \phi}{\partial t} - V(r)\frac{\partial \phi}{\partial z} = D_{eff}\frac{\partial^2 \phi}{\partial r^2} + \frac{D_{eff}}{r}\frac{\partial \phi}{\partial r} + D_{eff}\frac{\partial^2 \phi}{\partial z^2}$$

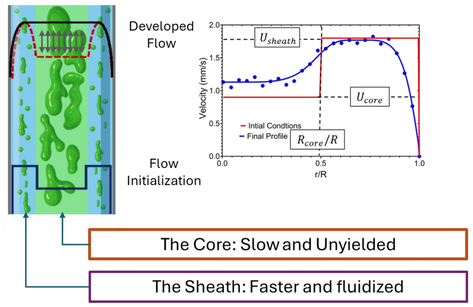
Where:
- V – Velocity Profile
- D_{eff} – Effective Dispersion Coefficent

Numerical method:
Finite Difference Method (FDM

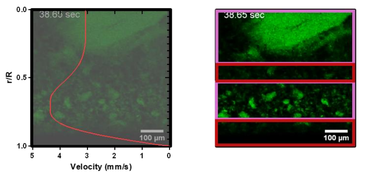


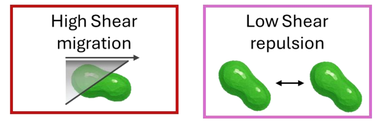
Advective model

Core Sheath Flow



Dispersive model

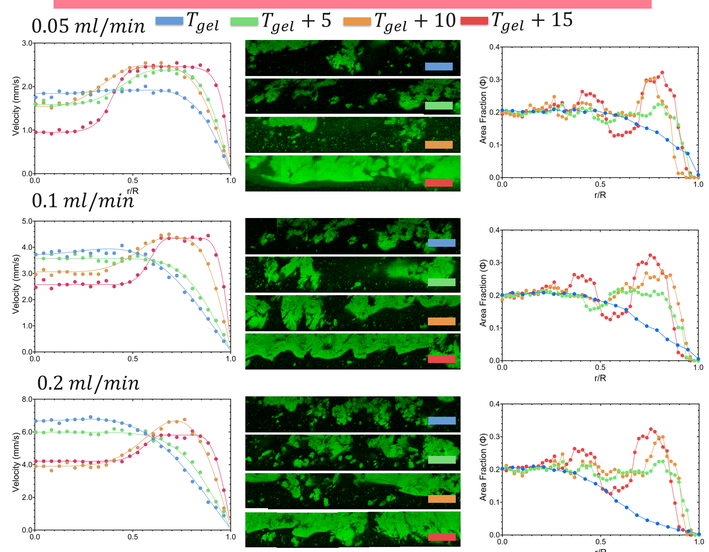




$$D_{eff} = D_0 - D_1\,\dot{\gamma}$$

Modelling allows for the prediction of flow and dispersion development within the capillary

Conclusion



- This study provides a robust framework for understanding and optimizing material behavior in capillary flow
- Provides information about dispersions of particles during extrusion
- These insights support improved design and control of 3D printed systems for customized drug delivery.

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NIH