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Simulation of a 3D Flow-Focusing Capillary-Based Droplet Generator

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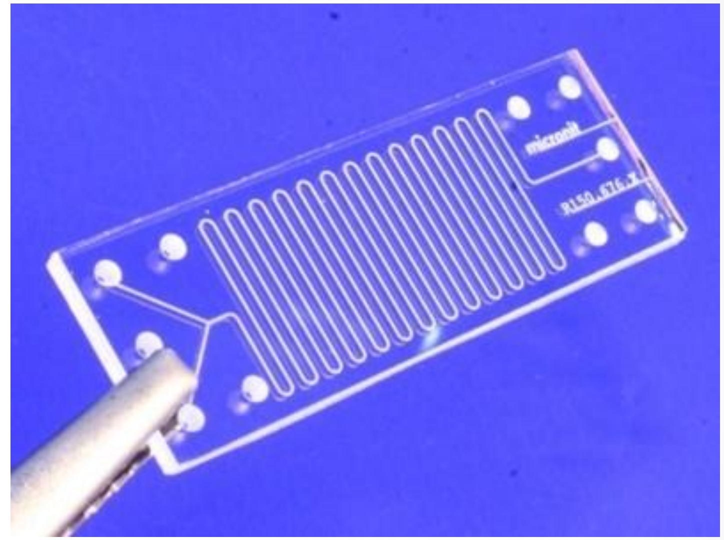
EMPIRe Laboratory

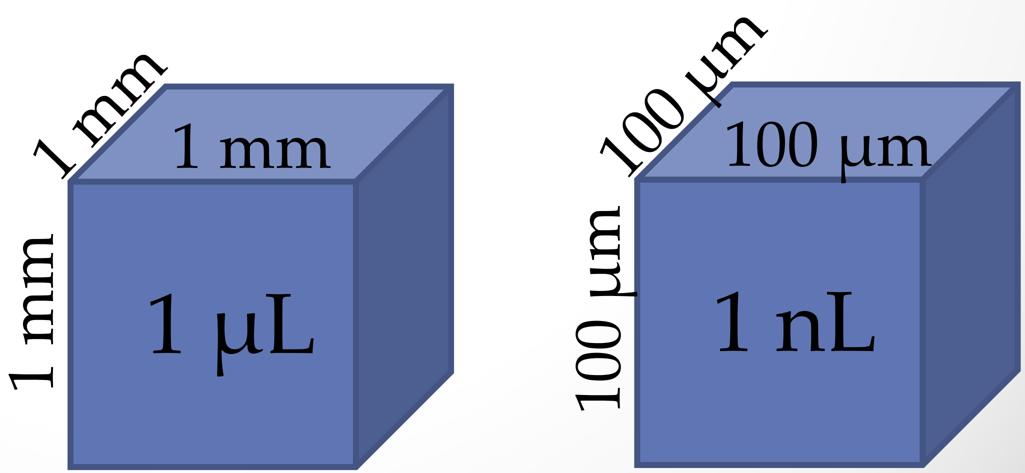
Microfluidics

Deals with:

→ Behavior
→ Control
→ Manipulation

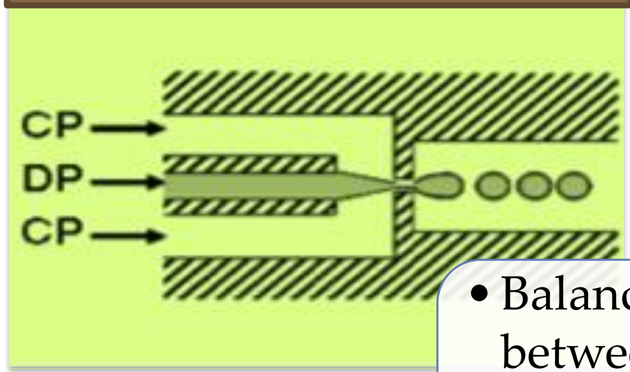
Of small volumes of fluids (µL, nL, pL)





Droplet Microfluidics

Microfluidic Droplet Generators



(Anna ,2003)

- Balance between viscous and surface tension forces.
- Discrete Volumes (Nano to Femtoliter)

- CP= Continuous Phase (medium) & DP= Disperse Phase (droplets)

Potential Applications

High reaction **parameter control**

High temperature control

Drugs Crystallization

API -*Active Pharmaceutical Ingredients*

Controlled **stoichiometries** of reagents

Hazardous Products

Azides preparation/reaction

Exploration of dangerous reagents

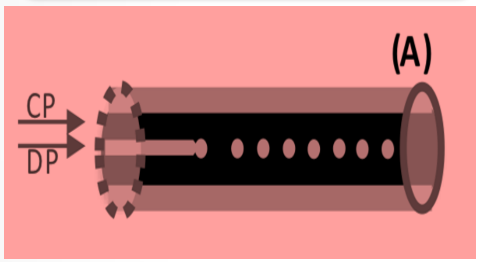
Phosgene, Acrolein, Interhalogen compounds,

Gas-Liquid Reactions

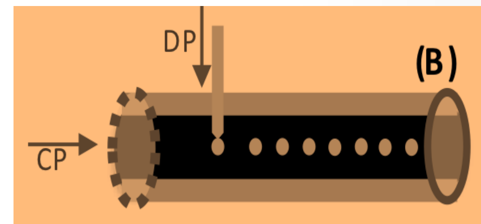
Capillary-Based Droplet Generators

Co-Flow → Capillary MFDG ← Cross-flow

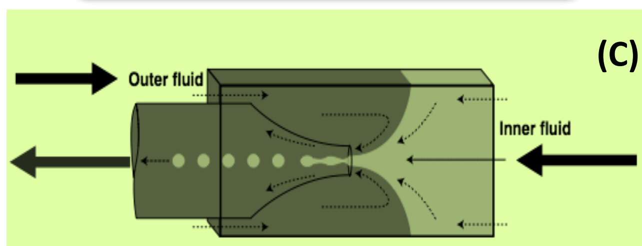
3D-Flow Focusing ↑ Capillary MFDG



(Seong, 2005)

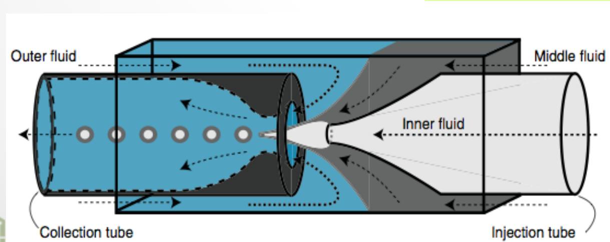


(McQuade, 2005)



(Utada ,2007)

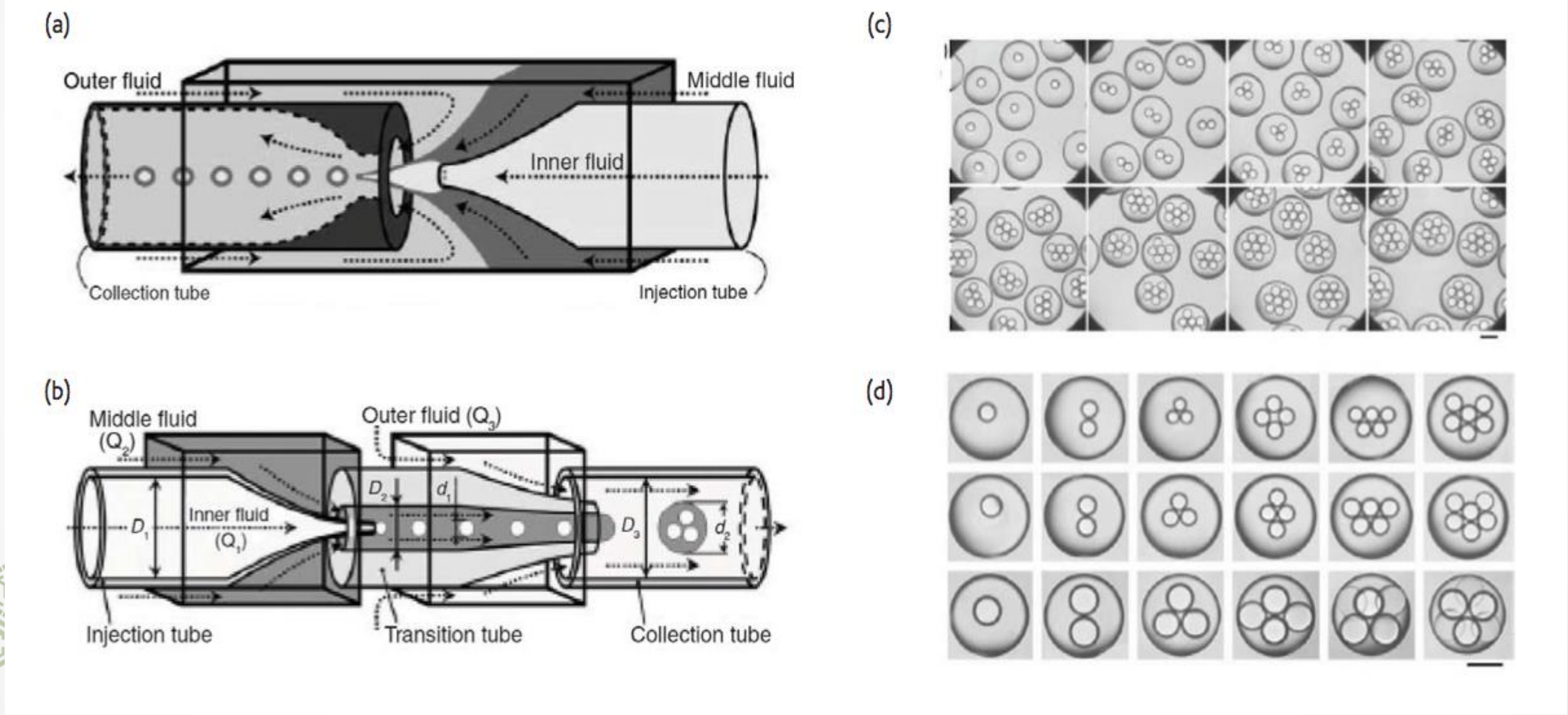
(D)



(Utada ,2007)

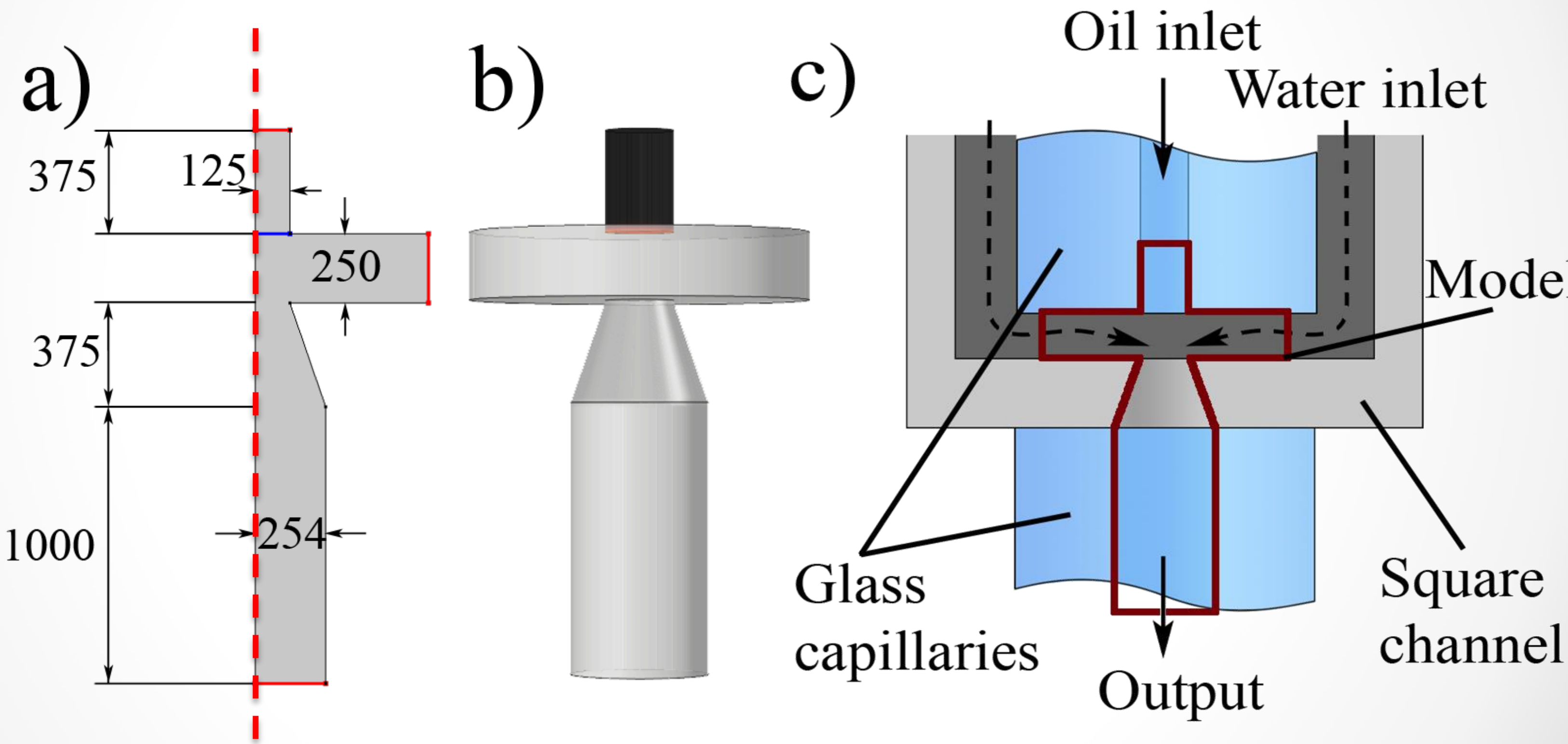
⇐ 3D Flow-Focusing & Co-flow Devices

Capillary-Based Droplet Generators



(Chu, 2007)

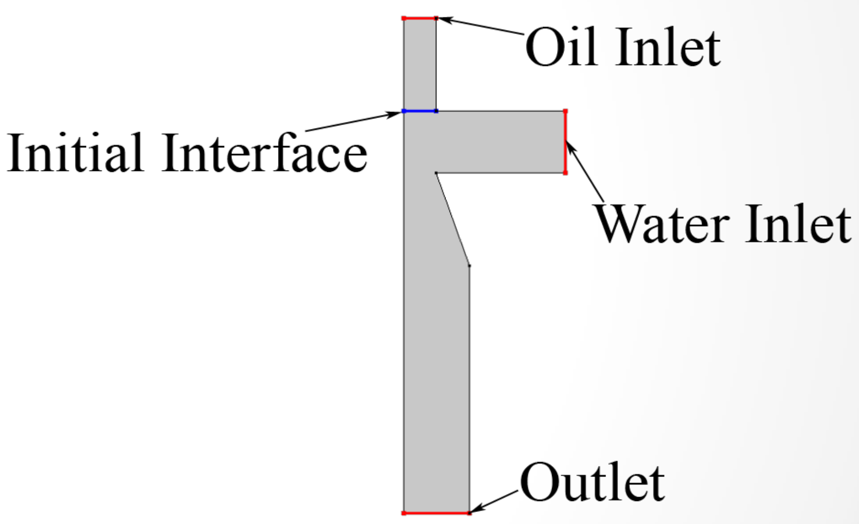
Simulated Capillary-Based Device



2D Model | Solid of Revolution | Physical Device

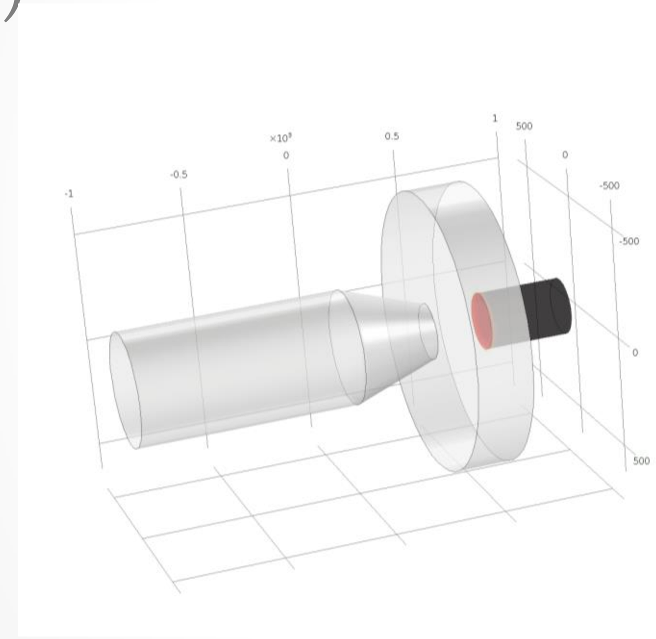
Simulation Setup

- Laminar Two-phase flow, phase field method.
- Physics Controlled Mesh
- Boundary conditions:
  - Inlets: Fixed Flow Rates for Water and Oil
  - Outlet: Zero pressure, no viscous stress
  - Initial Interface
  - 2D Axisymmetric

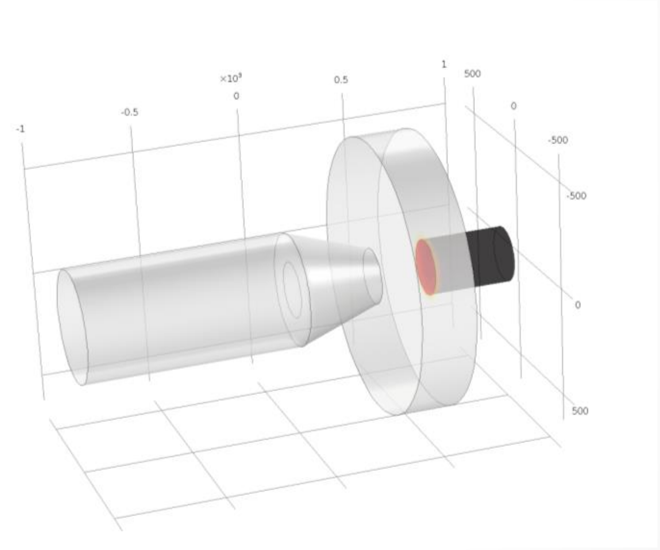


Simulation

a)



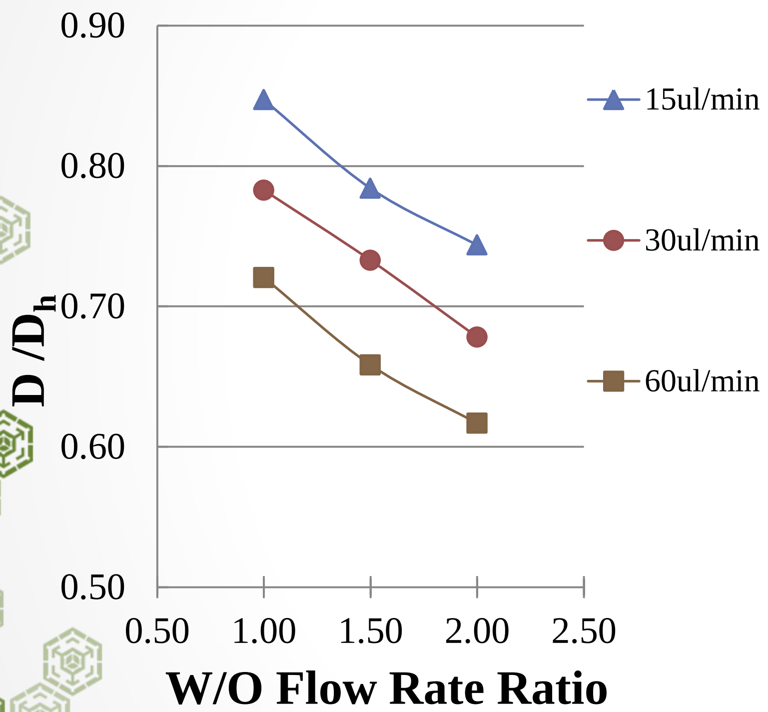
b)



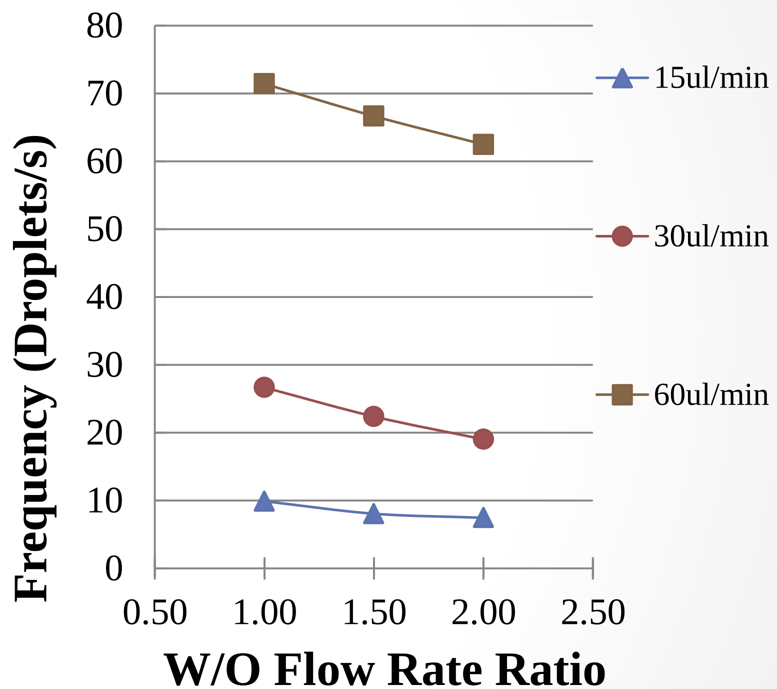
Oil Flow Rate (Red) = 15μL/min
Water Flow Rate = 15μL/min

Oil Flow Rate (Red) = 20μL/min
Water Flow Rate = 40μL/min

Characterization



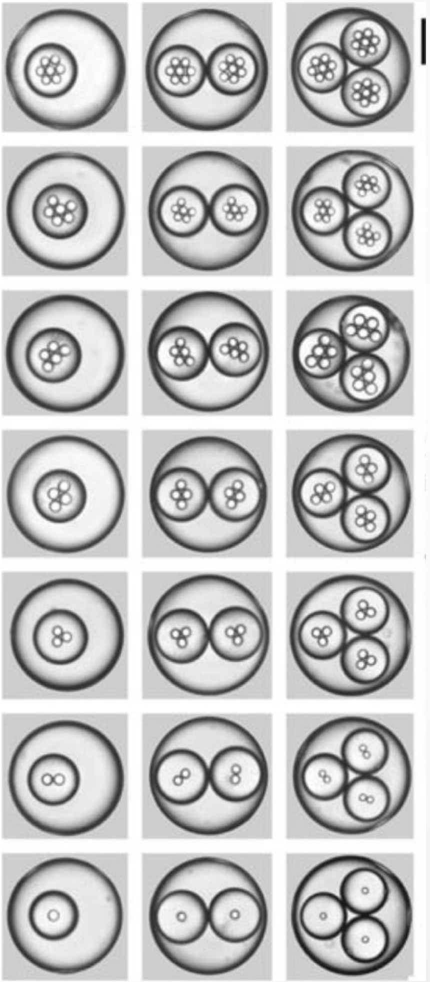
Normalized droplet diameter (D/Dh) versus flow rate ratio, at different total flow rates.



Frequency of generation (in droplets per second) versus flow rate ratio, at different total flow rates.

Future Work

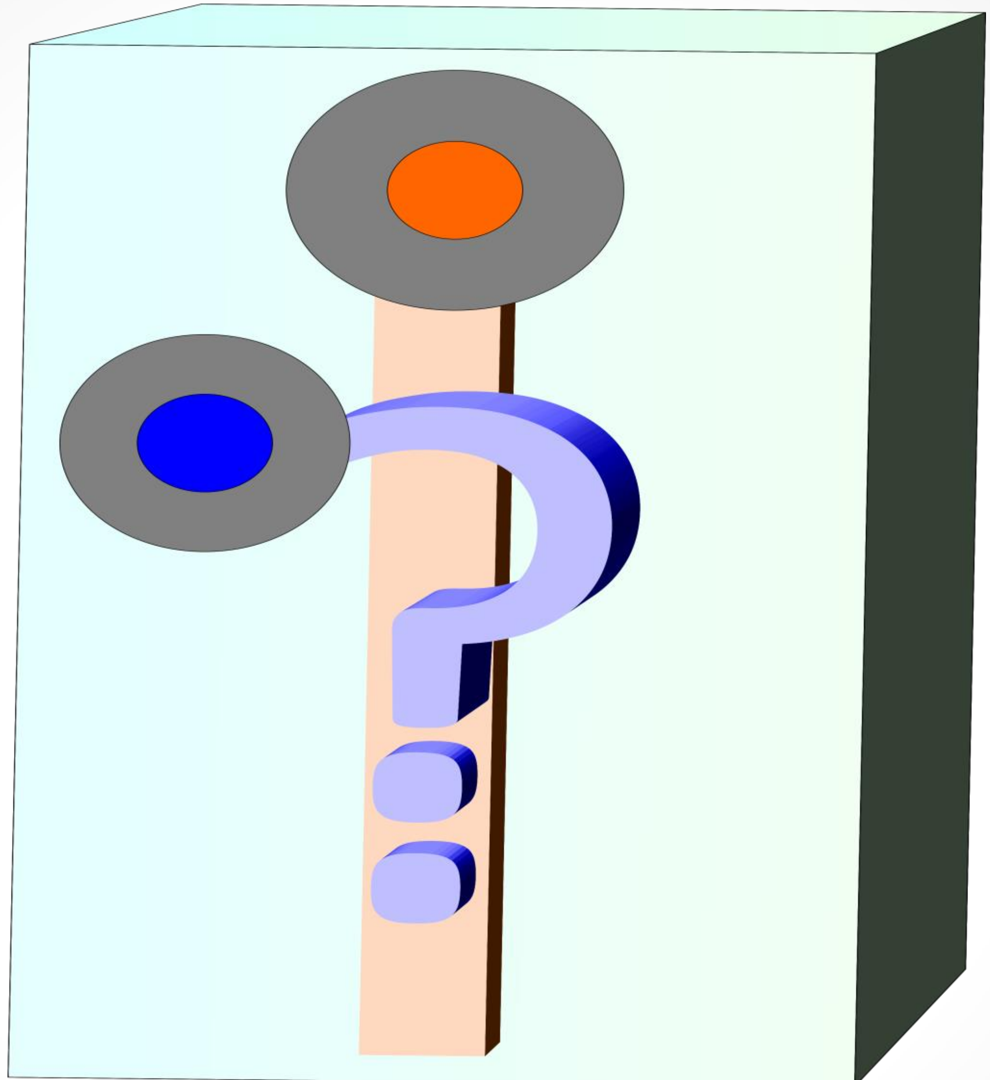
- Through this simulation one could able to design generators in **series** to produce multiple emulsions with specific parameters:
  - Size,
  - Core-shell thickness,
  - Number of Daughter Droplets,
  - Synchronization of generation



(Chu, 2007)

Conclusions

- We have successfully simulated a 3D Flow focusing device using a **2D axisymmetric** model (fast convergence <15min.)
- CFD can help to **save time** with fabrication and testing of the devices.
- This model will allow us to design **multiple droplets** with desired characteristics.
- At higher flow rates, droplet diameter decreases, and frequency of generation increases.



Thank you!

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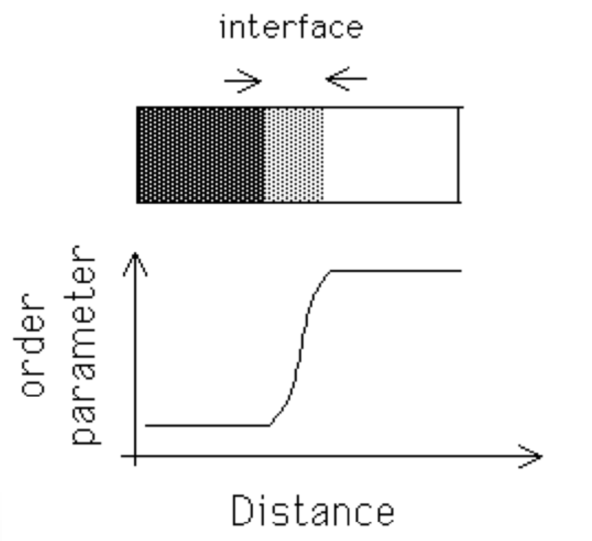
Fluid Properties

Property	Oil (DP)	Water (CP)
Density (Kg/m^3)	1000	1000
Dynamic viscosity (mPa·s)	6.71	1.95

Laminar Phase Field Method

- The multiphase flow is described by the **parameter ϕ**. One fluid element is defined as $\phi = 1$, whereas the second fluid element is $\phi = 0$. The interface between them (phase field) is the set of values $1 < \phi < 0$.



(Bhadeshia)

Motivation

- Droplet formation depends on the **liquids properties** (viscosity and interfacial tension between the phases), and **flowing rates.**(Capillary Number)
- **Unknown** expected **droplet size** and hence core-shell thickness.
- Proper **synchronization** is needed to create multiple droplets
- **Fabrication is challenging** (especially the tapered wall and assembly process)
- **Expensive cameras** are required to characterize at high generation frequencies

Interdisciplinary Field