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Simulation of the Coalescence and Subsequent Mixing of Inkjet Printed Droplets

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COMSOL CONFERENCE
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Fontys University of Applied Sciences

Expertise Centre
Thin Films & Functional Materials

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Focus on acquiring knowledge in the field of thin film technologies and functional materials and passing on this knowledge to SME's and education.

Expertise in:

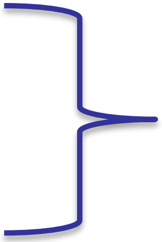
- Functional Polymers
- Applications of Functional Polymers
- Thin Film technology
- Measuring methods for the analysis of materials and thin films.

Spearheads include:

- Polymer electronics
- Structured substrates: (plastic) substrates with micro and nano structures
- Inkjet printing of polymers and nano particles
- Measurement and analysis methods.

Projectgoal

Investigate the mixing of coalescing low viscosity small droplets.

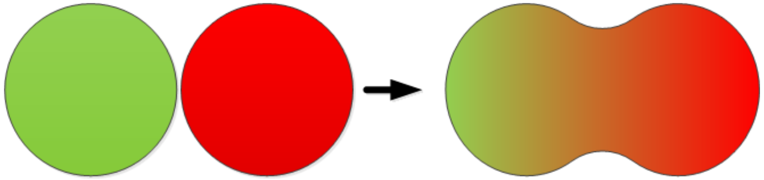


- Equally sized droplets
- Unequally sized droplets

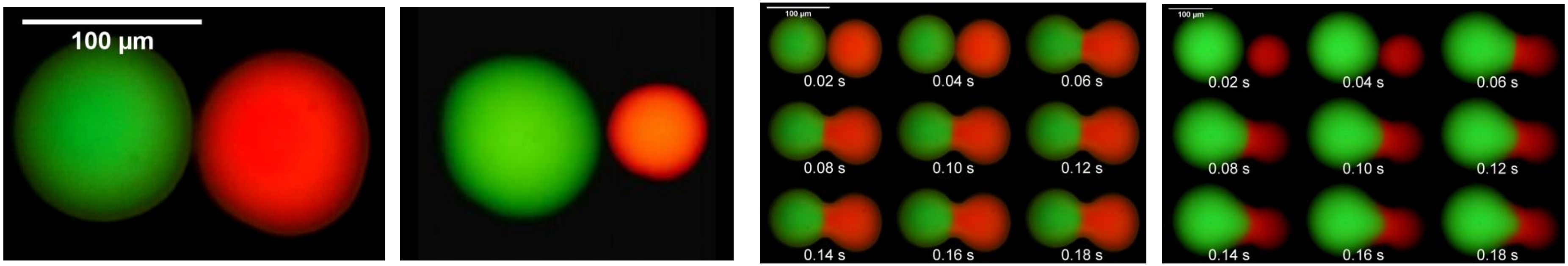
coalescence vs diffusion

Inkjet printing range

- Droplets in range of 10-80 pl,
  i.e.80-150 µm in diameter on substrate
- Viscosity <10 mPas

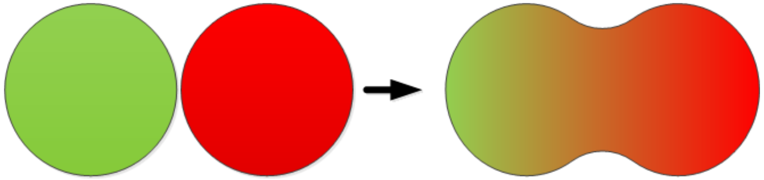


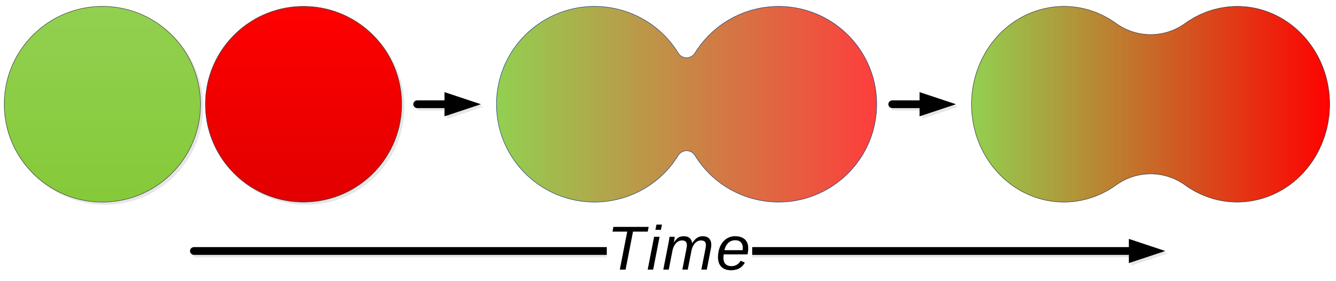
Project Challenges



Visualizing the coalescing and mixing processes in time

- Size of the droplets
- Speed of coalescence (bridge formation) for small low viscosity droplets
- Detection of flows inside droplets





Navier Stokes Equation

$$\rho\frac{\delta u}{\delta t}+\rho\left(u\cdot\nabla\right)u=-\nabla p+\eta\left(\nabla\cdot u\right)+F_g$$

Component mass balance

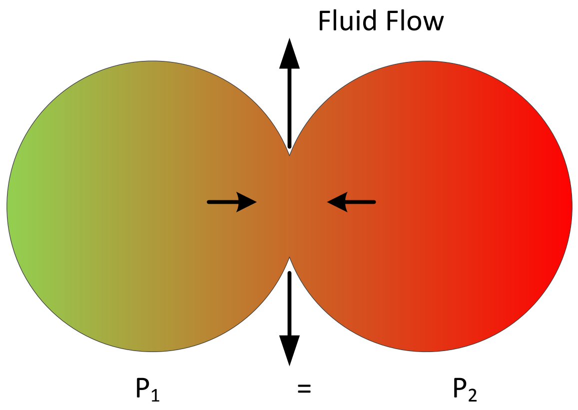
$$\frac{\delta C}{\delta t}+\left(u\cdot\nabla C\right)-D_{AB}\nabla^2 C=0$$

Surface energy induced fluid flow

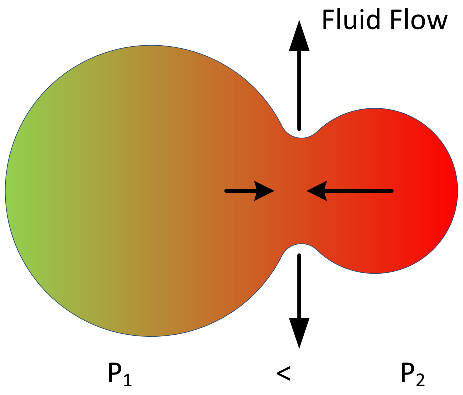
- Short lived in time
- Fastest in initial bridge formation (first milliseconds)
- Velocity determined by surface energy and internal droplet pressure

Diffusion based flow

- Induced by concentration gradient
- Long time duration
- velocity determined by diffusion coefficient D_{ab}



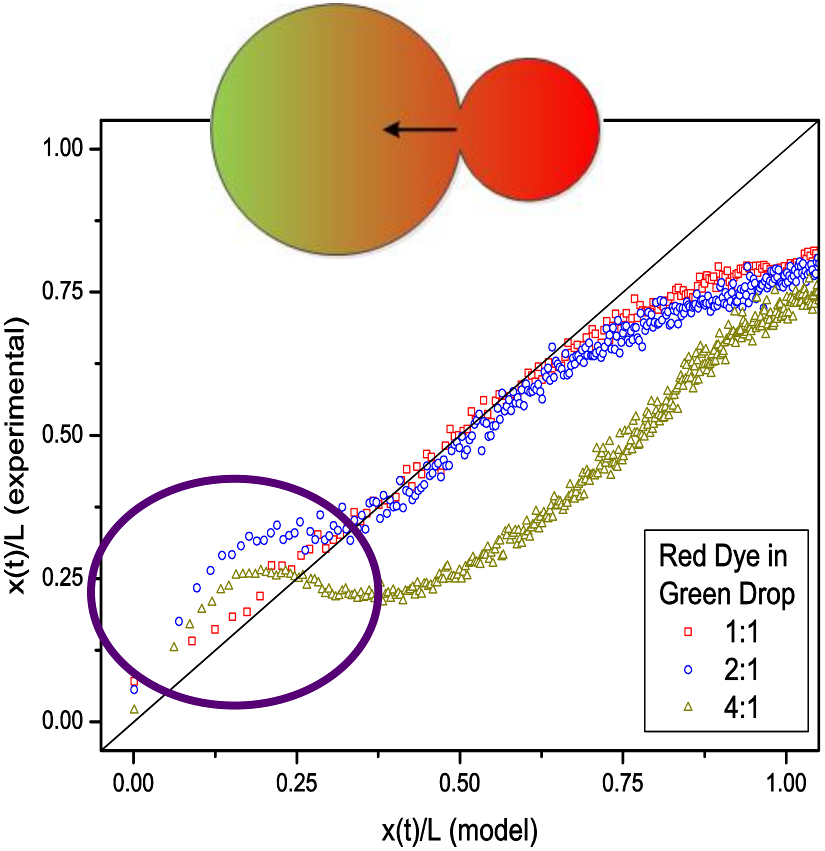
Equally sized droplets

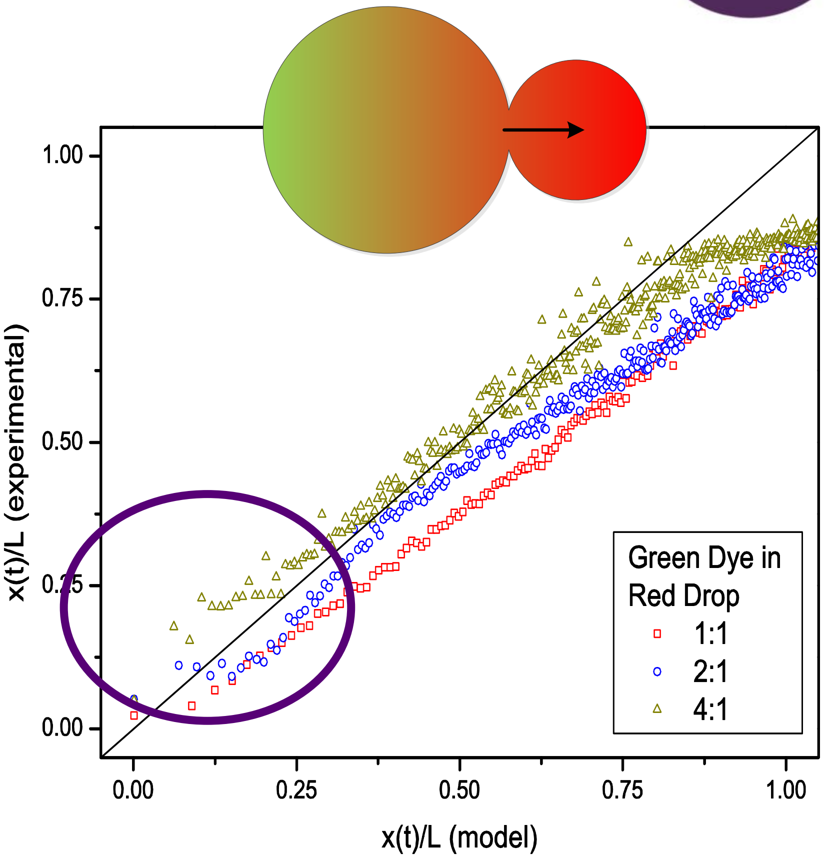


Unequally sized droplets

Experimental

Comparison diffusion volume ratios





$$Fick's\ Law: \frac{C}{C_0} = \frac{x}{2\sqrt{\pi \cdot D_{AB} \cdot t}} \exp\left(\frac{-(x)^2}{4 \cdot D_{AB} \cdot t}\right)$$

Comsol Multiphysics

- Two models:
  - Laminar Two-Phase Flow, Phase field model

    Tracking of interface between coalescing droplets
  - Transport of Diluted species model

    Tracking of concentration gradient

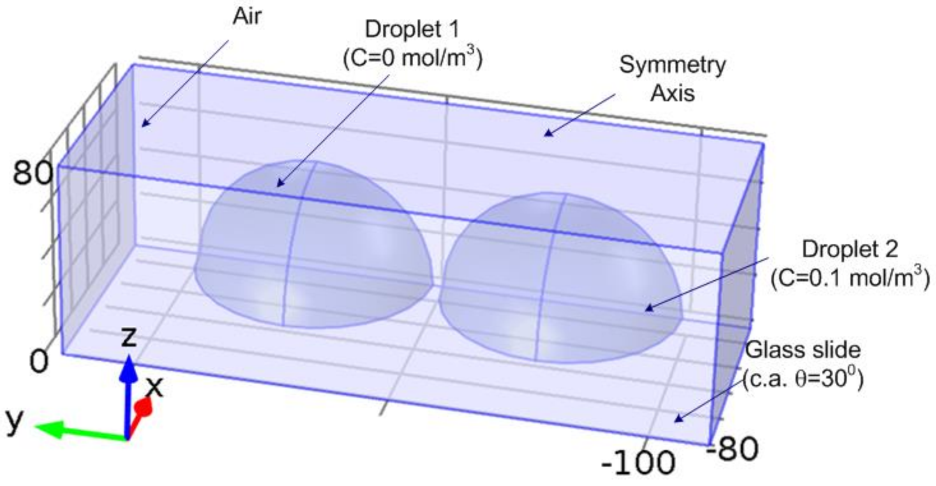


Figure 2: *Geometry for droplets with volume ratio 1:1. Small droplet is filled with 0.1 mol/m^3 dye (distances in μm)*

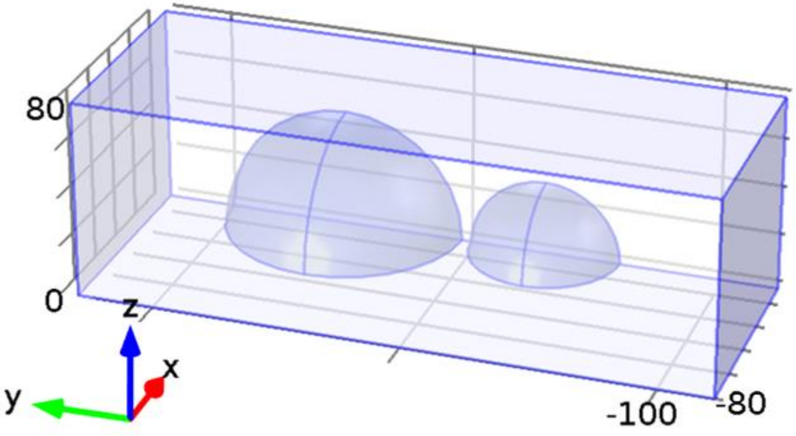
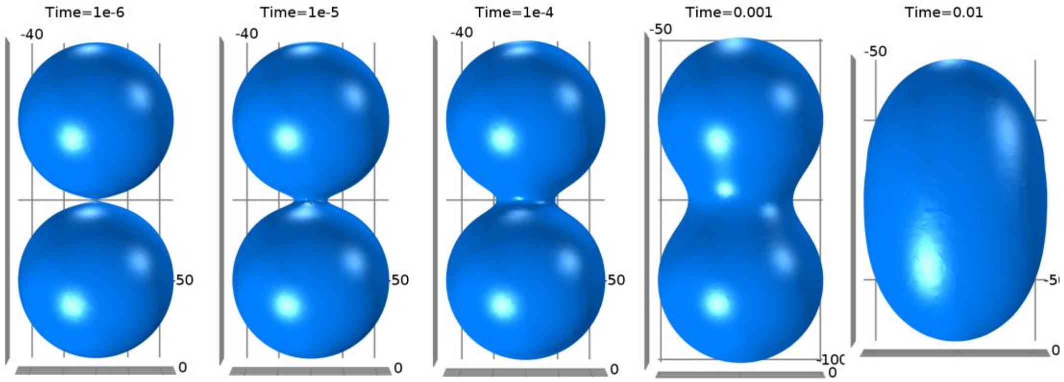


Figure 3: *Geometry for droplets with volume ratio 4:1. Small droplet is filled with 0.1 mol/m^3 dye (distances in μm)*

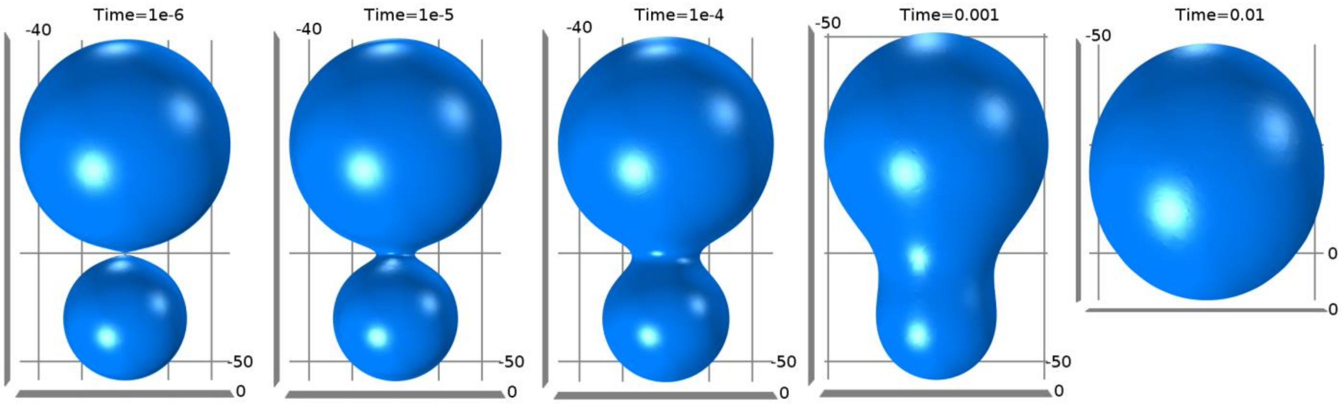
Comsol Results (1)

Tracking of interface (Laminar Two Phase flow)



1:1

4:1

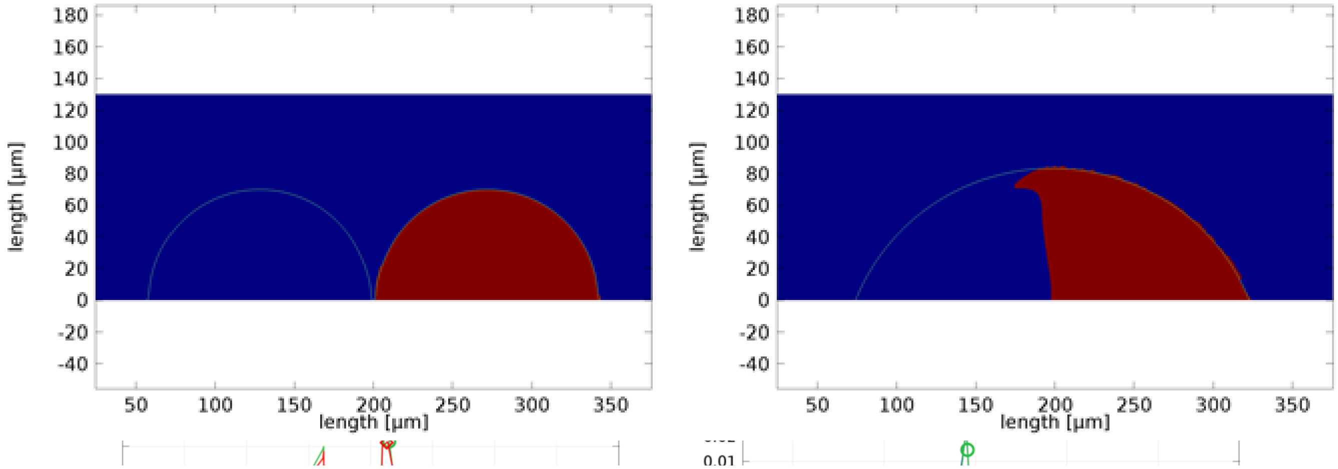


Comsol Results (2)

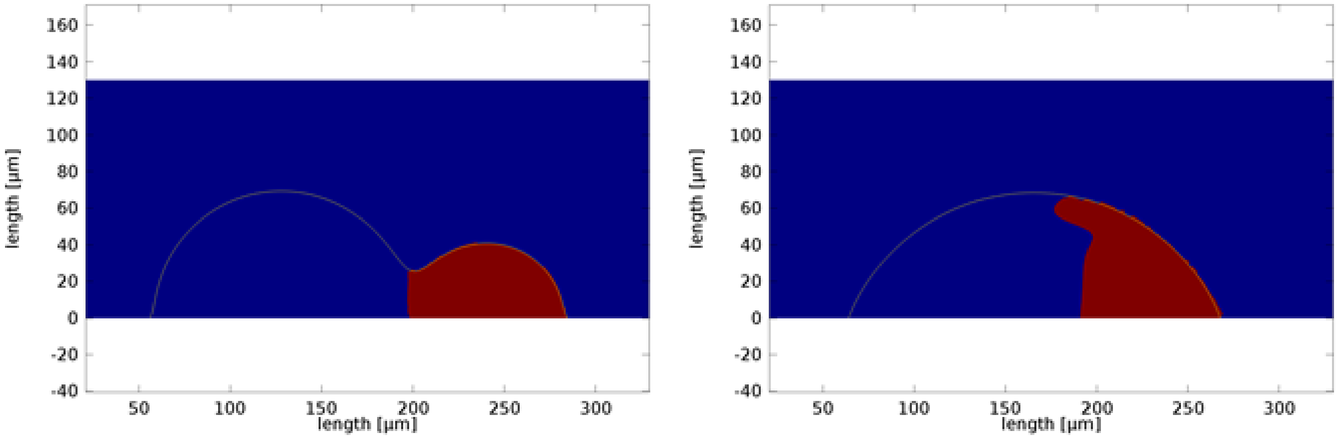
Tracking of Concentration Gradient

(Transport of Diluted species)

1:1



4:1



Conclusions

- The coalescence and subsequent mixing of small inkjet printed droplets is investigated both experimentally and by 3D-simulation in Comsol Multiphysics.

- It was found that for equivoluminal droplets, material transport over the coalescence bridge can be described by diffusion.
- For droplets of unequal volume, convective transport plays a significant role in the first 10 ms after the bridge formation. This is driven by surface tension induced flows.
- The models Laminar Flow, Phase Field and Transport of Diluted Species show a good accordance with the experimental data and theoretical theories.

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