Simulation of the Coalescence and Subsequent Mixing of Inkjet Printed Droplets

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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

Spearheads include:
- Polymer electronics
- Structured substrates: (plastic) substrates with micro and nano structures
- Inkjet printing of polymers and nano particles
- Measurement and analysis methods.
Investigate the mixing of coalescing low viscosity small droplets.

• Equally sized droplets
  coalescence vs diffusion

• Unequally sized droplets

Inkjet printing range

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

\[ \rho \frac{\partial u}{\partial t} + \rho (u \cdot \nabla) u = -\nabla p + \eta (\nabla \cdot u) + F_g \]

Component mass balance

\[ \frac{\partial C}{\partial t} + (u \cdot \nabla) C - D_{AB} \nabla^2 C = 0 \]

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 \( D_{ab} \)

Fluid Flow

Equally sized droplets
\[ P_1 = P_2 \]

Unequally sized droplets
\[ P_1 < P_2 \]
Experimental Comparison diffusion volume ratios

Fick's Law: \[ \frac{C}{C_0} = \frac{x}{2\sqrt{\pi \cdot D_{AB} \cdot t}} \exp \left( \frac{-x^2}{4 \cdot D_{AB} \cdot t} \right) \]
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/m³ dye (distances in µm)

**Figure 3:** Geometry for droplets with volume ratio 4:1. Small droplet is filled with 0.1 mol/m³ dye (distances in µm)
Tracking of interface (Laminar Two Phase flow)

Comsol Results (1)
Tracking of Concentration Gradient
(Transport of Diluted species)

Comsol Results (2)
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.