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The Effects of Different Surface Wettabilities on Droplet-Dry Substrate Impact Outcomes

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Presentation Outline

- Motivation
- Prior Research
- Research Goals
- Methods
- Validation
- Results
- Discussion
- Conclusion
- Acknowledgements
- Questions and Answers

Motivation

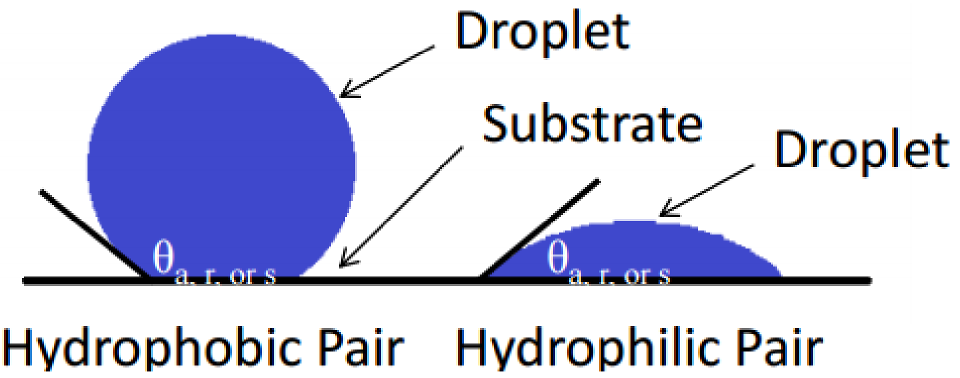
- Evaporation of toxic chemicals results in fumes in the air
- This is common in workplaces (1)
- Droplets can see evaporation while in the air (2)
- And naturally, a source of droplets is from splashing
- An example is from coolants used during machining
- If an approach to predicting secondary droplet behavior can be found, it can be possible to design out this hazard

Prior Research

Substrate	Liquid	Droplet
Roughness	Surface tension	Diameter
Angle	Viscosity	Velocity
Temperature	Density	Impact Angle
Geometry	Temperature	
Wettability	non-Newtonian rheology	
Elasticity	surfactant additives	
Charge		

(3),(4),(5),(6)

Quick Review of Wettability



-θ_a – contact angle as droplet is spreading

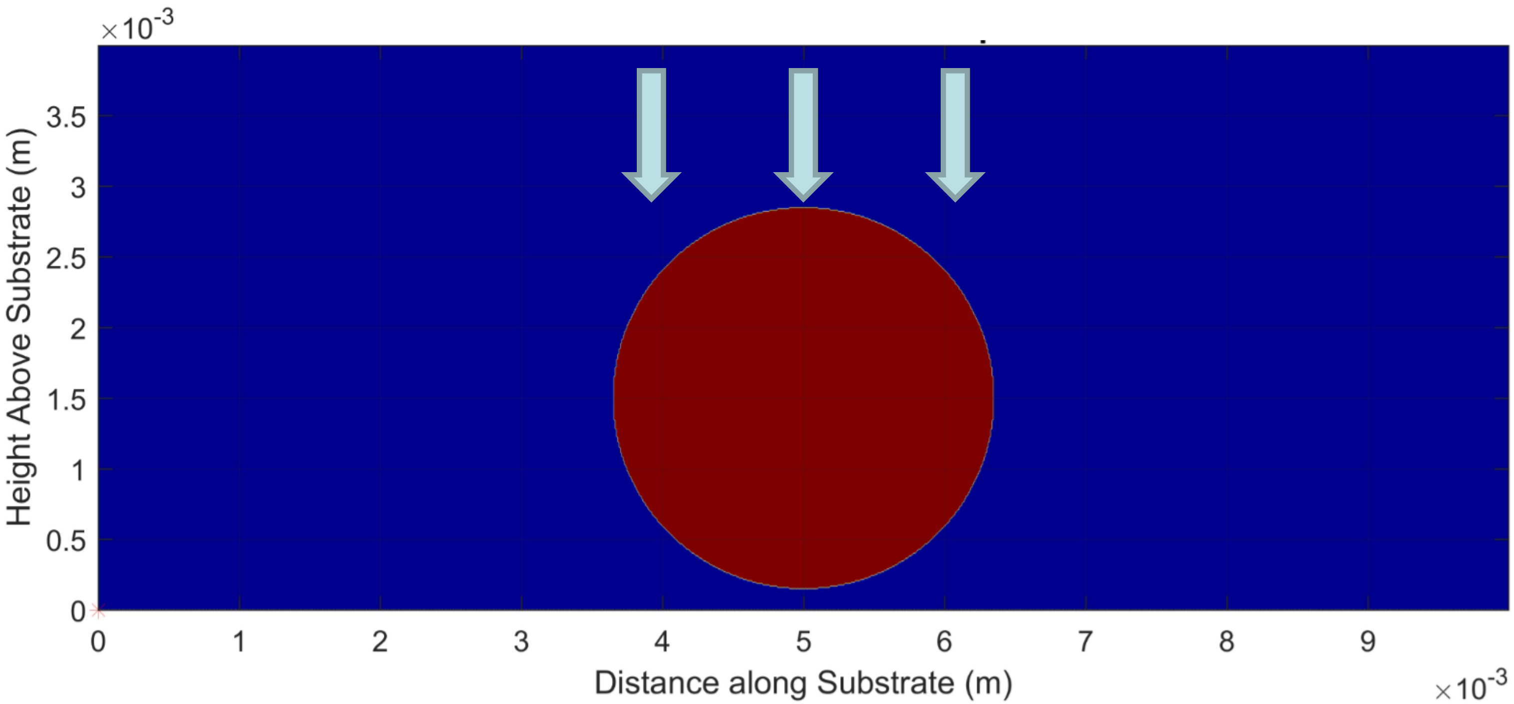
-θ_r – contact angle as droplet is receding

-θ_s – static contact angle

Goals

- As contact angle changes
  - Create a CFD simulation to investigate
    - secondary droplet production
    - secondary droplet behavior
- Determine criteria to
  - Predict the generation of secondary droplets
  - predict secondary droplet behavior

Physical Conditions



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OpenFOAM Processing (1)

- CFD using OpenFoam v3.0.1 (7)
  - OpenFOAM is an open source CFD suite
  - Runs on Linux based OS (or Bash on Windows 10)
  - Tool kit used is interFoam
    - Employs volume of fluid (VOF) with alpha solving incompressible Navier-Stokes
    - $\rho\left(\frac{D\boldsymbol{V}}{Dt}\right) = \rho\boldsymbol{g} - \nabla p + \mu\nabla^2\boldsymbol{V}$ (9)
    - Shown to have reliable results for We>>1 (8)
    - isothermal

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OpenFOAM Processing (2)

- InterFoam
  - Required Inputs
    - Kinematic viscosity (both phases)
    - Density (both phases)
  - Notes on Contact Angle
    - Requires a contact angle between primary phase and surface
    - Can be either just static angle, or can be the dynamic angles
    - Static contact angles tended to produce results which are unreliable

OpenFOAM Processing (3)

- Settings
  - PIMPLE
    - Combined algorithm of pressure-implicit split operator (PISO) and semi-implicit-linked equations (SIMPLE)
  - GAMG
    - Geometric-algebraic multigrid with diagonal incomplete-LU (DILU) preconditioner and Gauss-Seidel method for smoothing
  - Conducted a mesh convergence study
    - 11449 cells per square millimeter
  - Automatically adjustable time step
    - CFL < 0.1 determined

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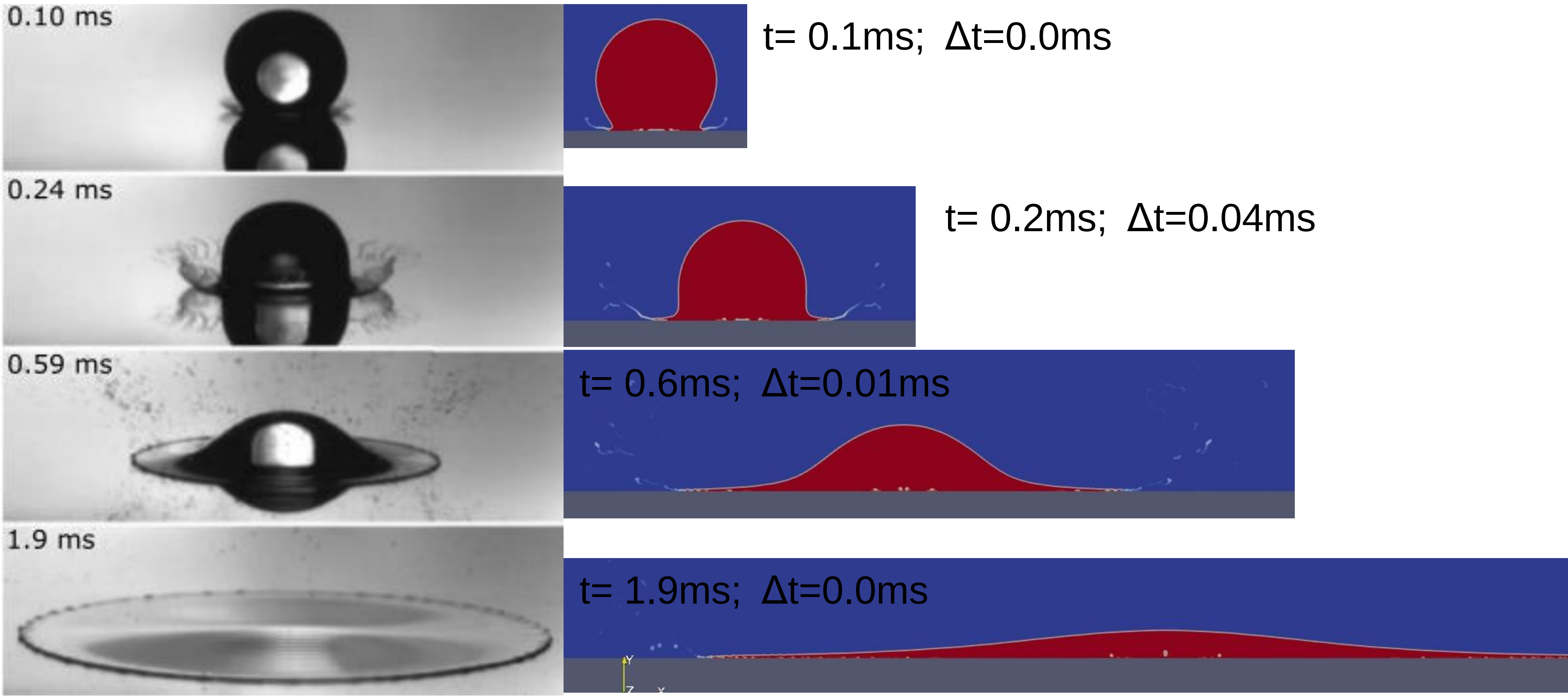
Validation

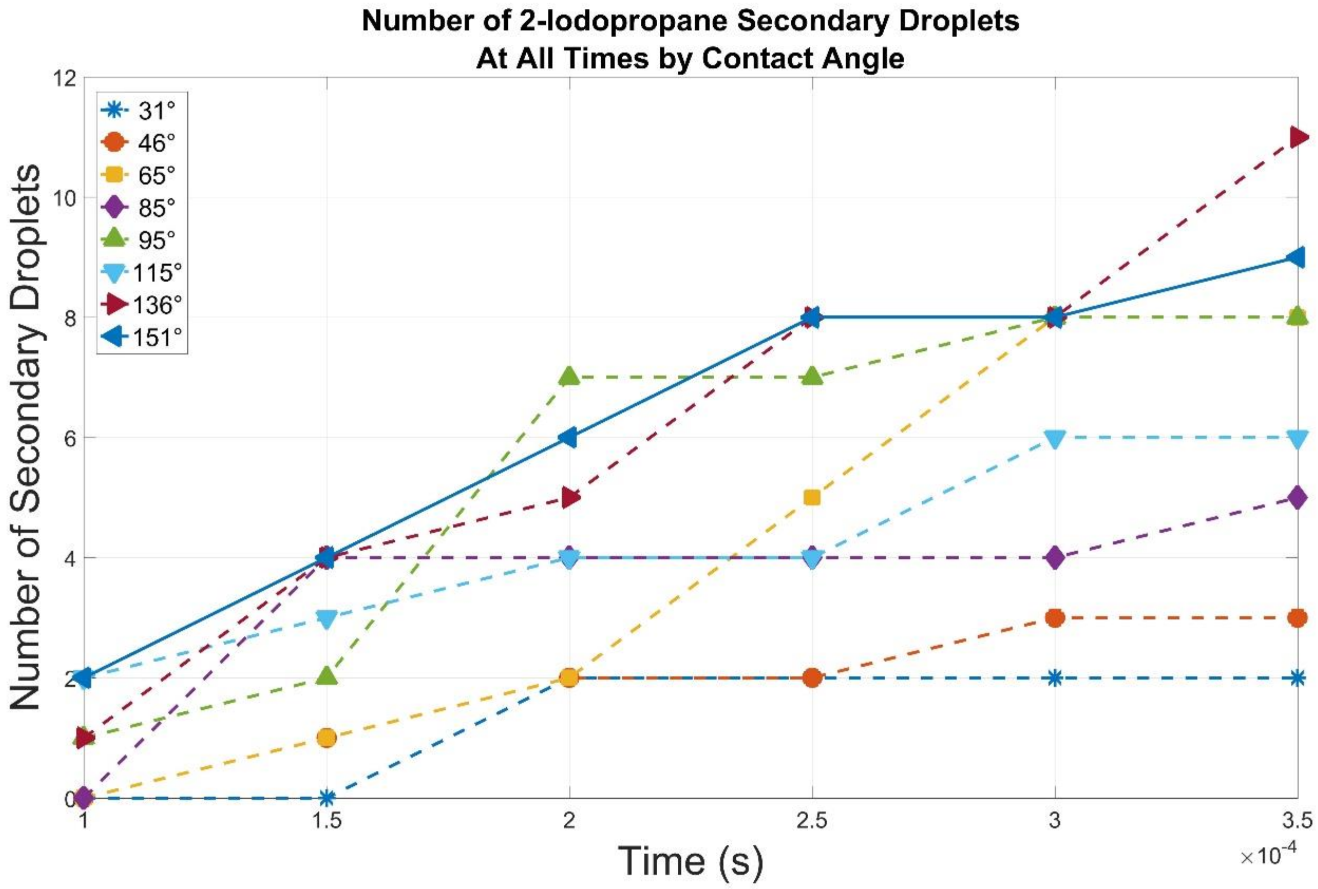


(9)

Matlab Post-Processing

- Data taken from OpenFOAM to Matlab in .raw format
- ‘centroids’ function used to find secondary droplet centers
  - Needs a logical value grid, so the data was exaggerated to have values at just 1 or 0 depending upon if its initial volume fraction was above or below 0.03, respectively
- Various secondary droplet properties then extracted or calculated
  - Velocity, position, diameter, cross sectional area

Results: Number of Droplets



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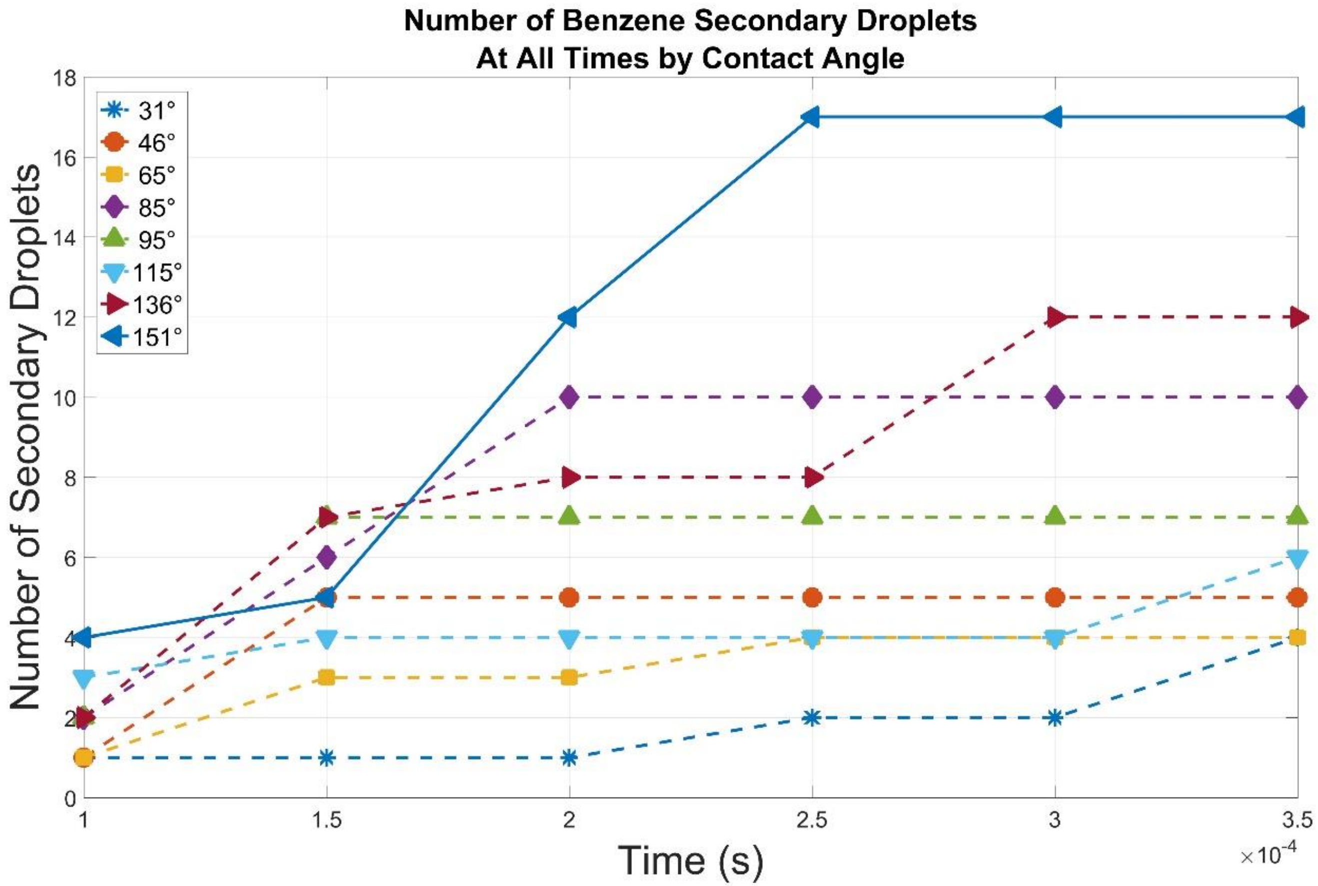
Results: Number of Droplets



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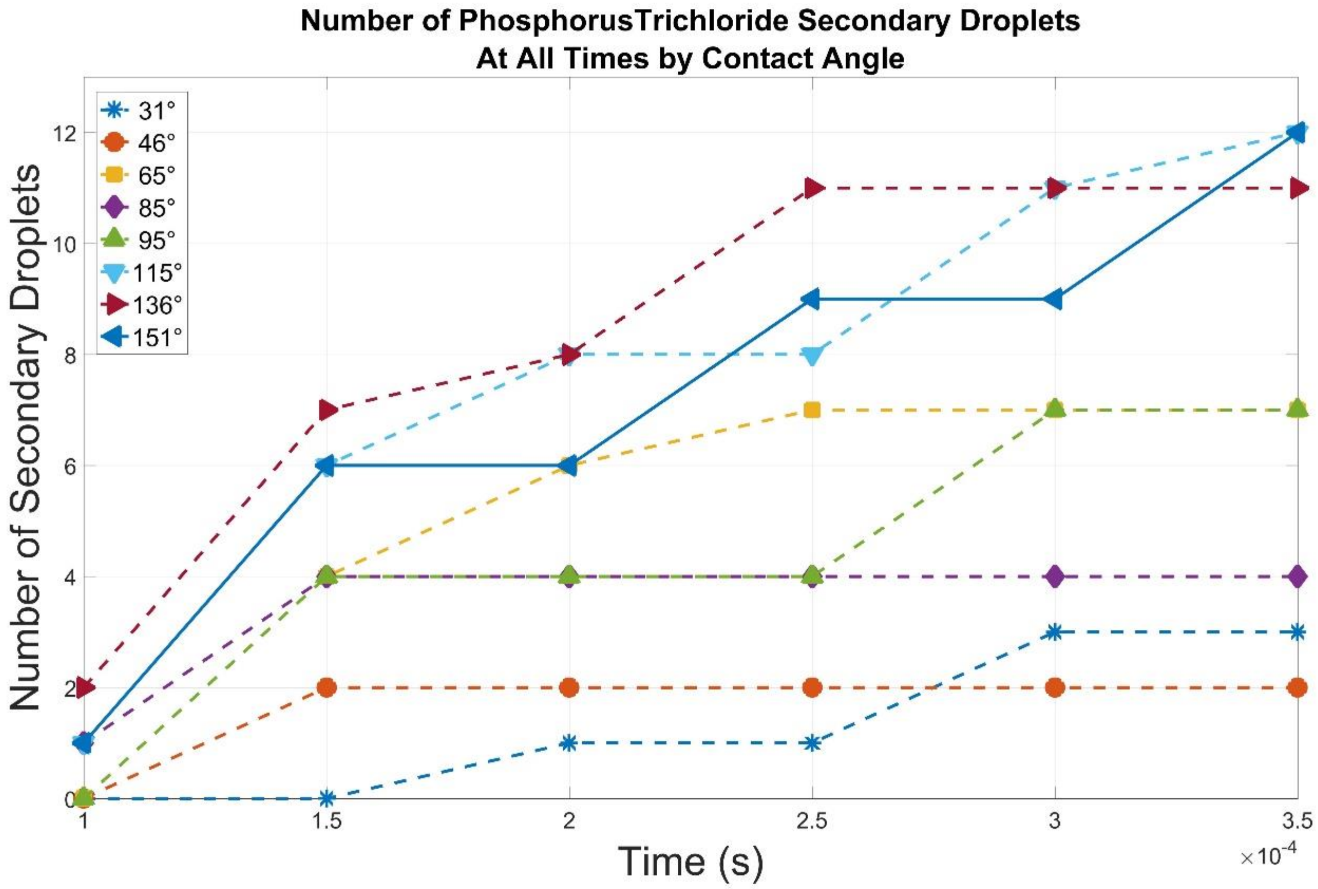
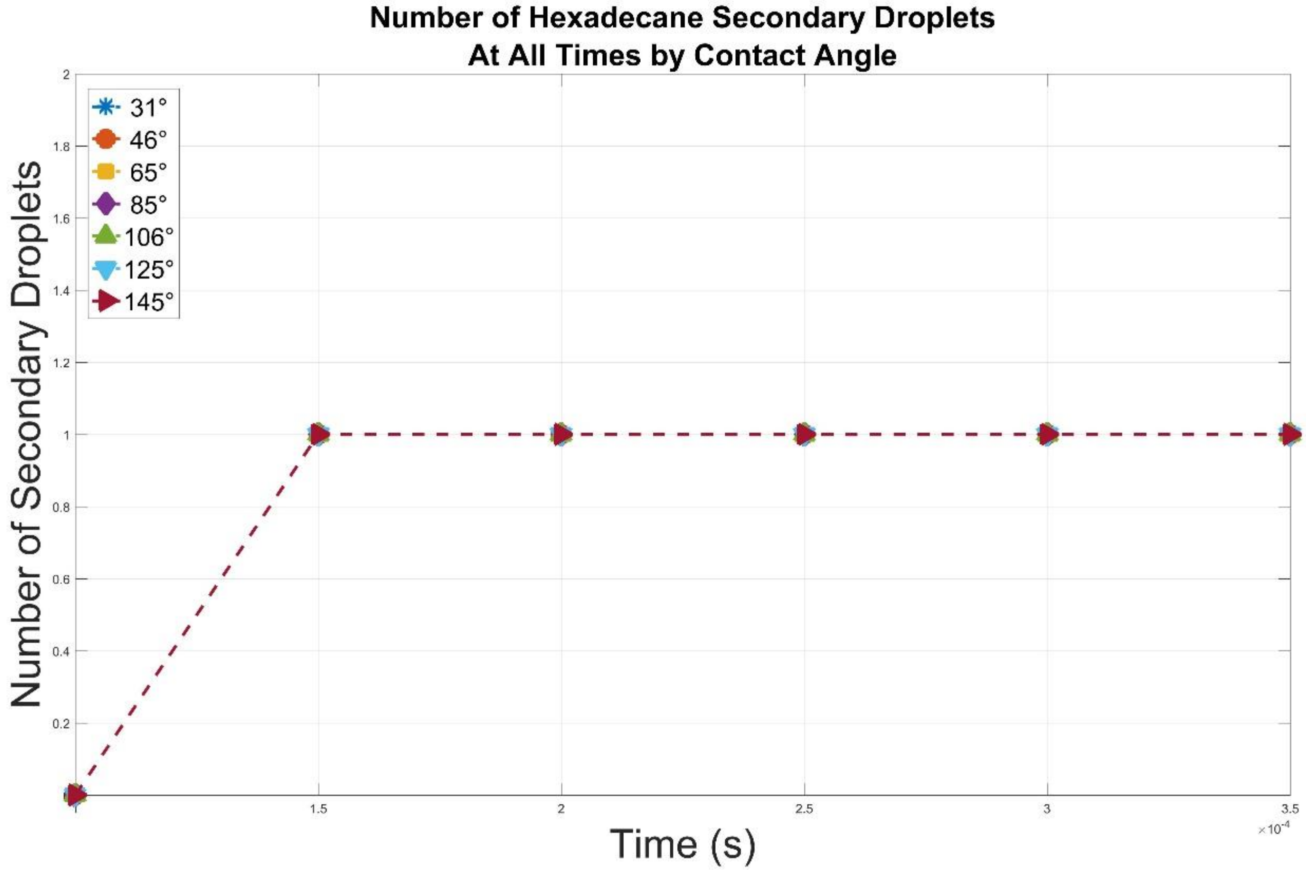
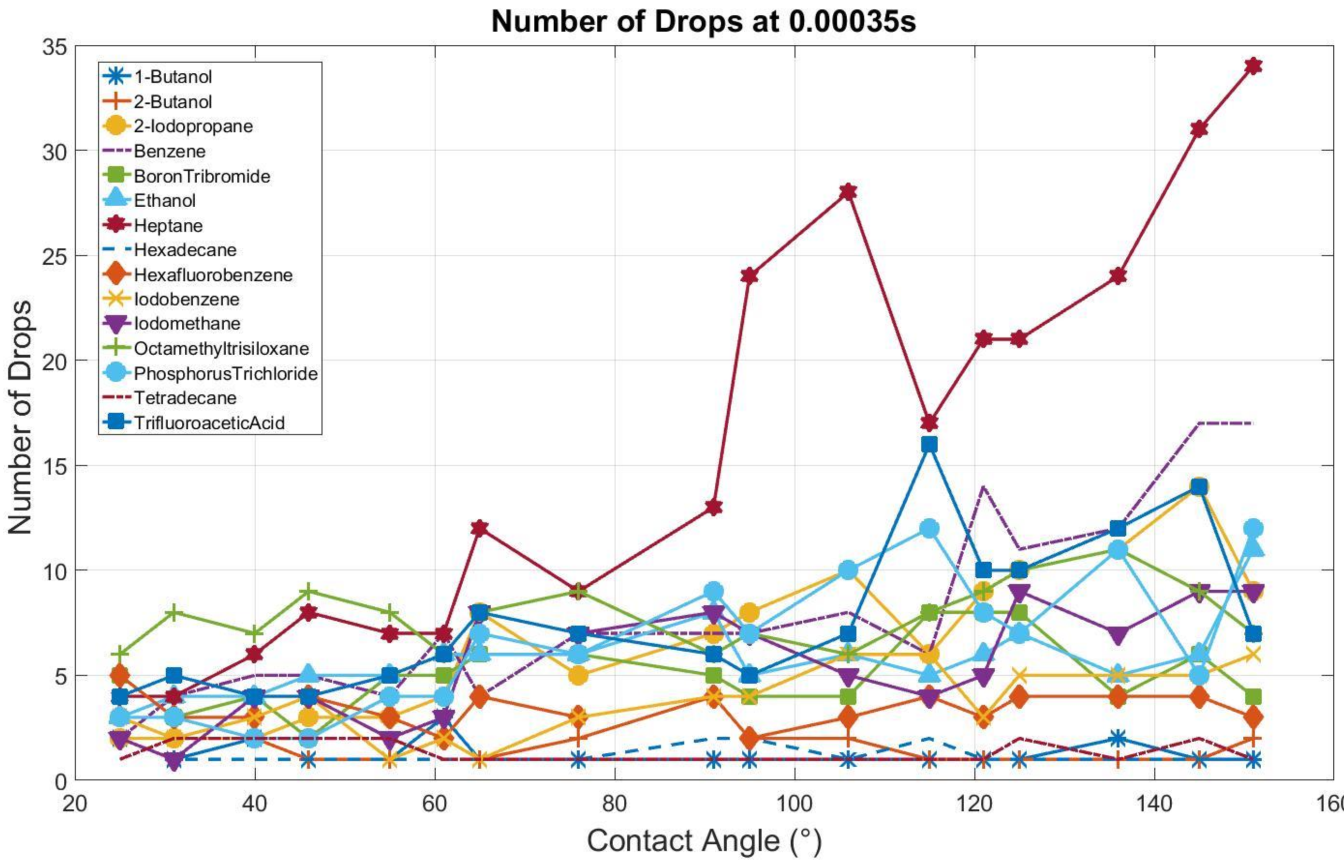
Results: Number of Droplets



Results: Number of Droplets



Results: Number of Droplets



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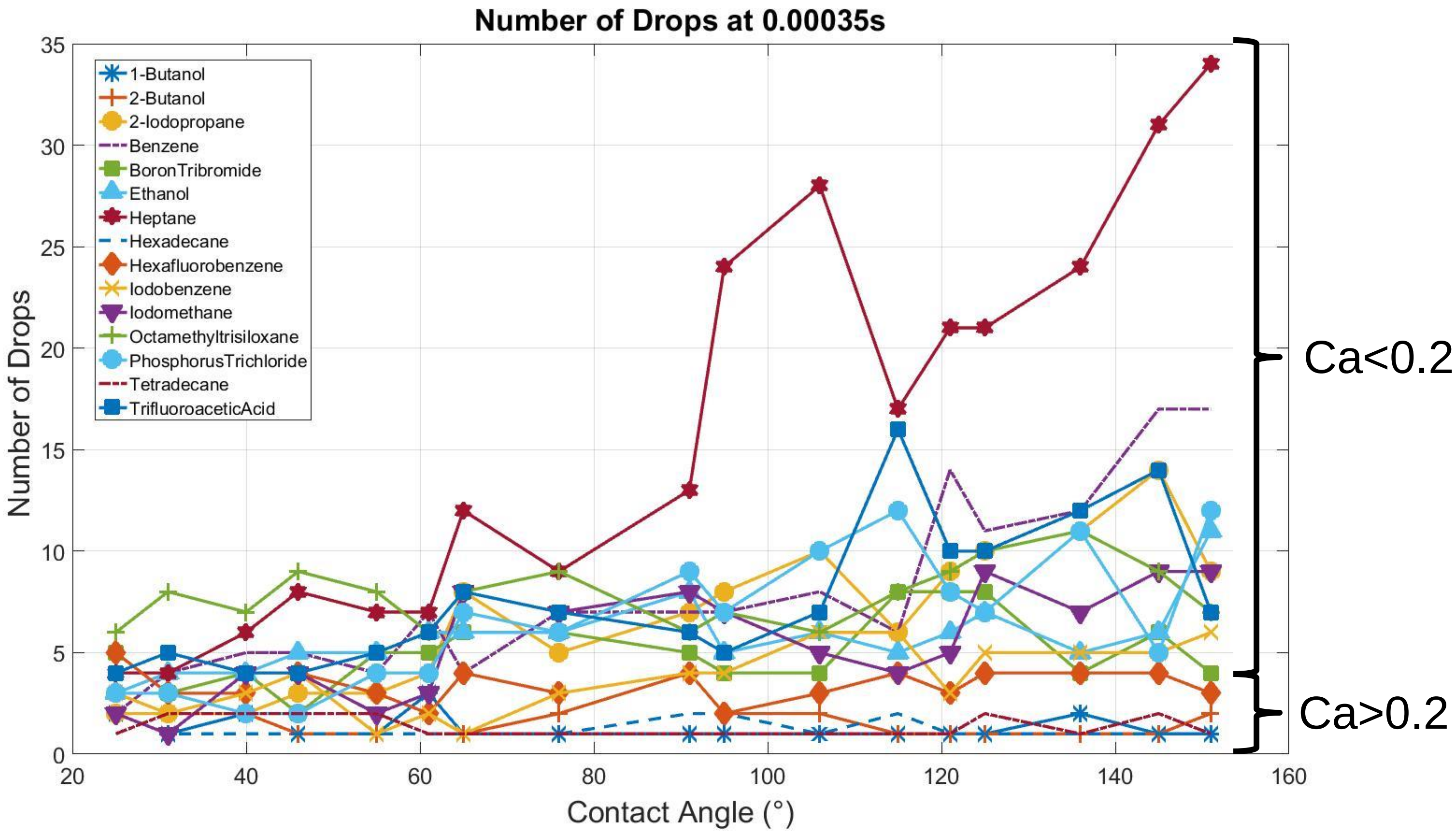
Discussion: Number of Droplets



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Discussion

- Why when Ca is smaller more droplets occur is difficult to say, implies stronger surface tension effects
- Yokoi ran limited simulations with water, suggested the contact line velocity decreases with increasing contact angle (10)
- Liquid would pass over to this and then become prompt splash
- Does not explain 1-butanol, hexadecane, or tetradecane

Conclusions

- OpenFOAM is capable of running diverse droplet impact simulations
- Simulations suggest increases in contact angle increase numbers of secondary droplets
- Some chemicals do not behave this way though, possibly due to inertial forces overcoming the contact line velocity

Future Work

- Look at chemicals within groups for change in behavior
- Determine which dimensionless numbers best predict behavior
- Change properties to change dimensionless numbers
  - See if the pattern is the same
- Change physical properties and try to predict what will happen

Acknowledgments

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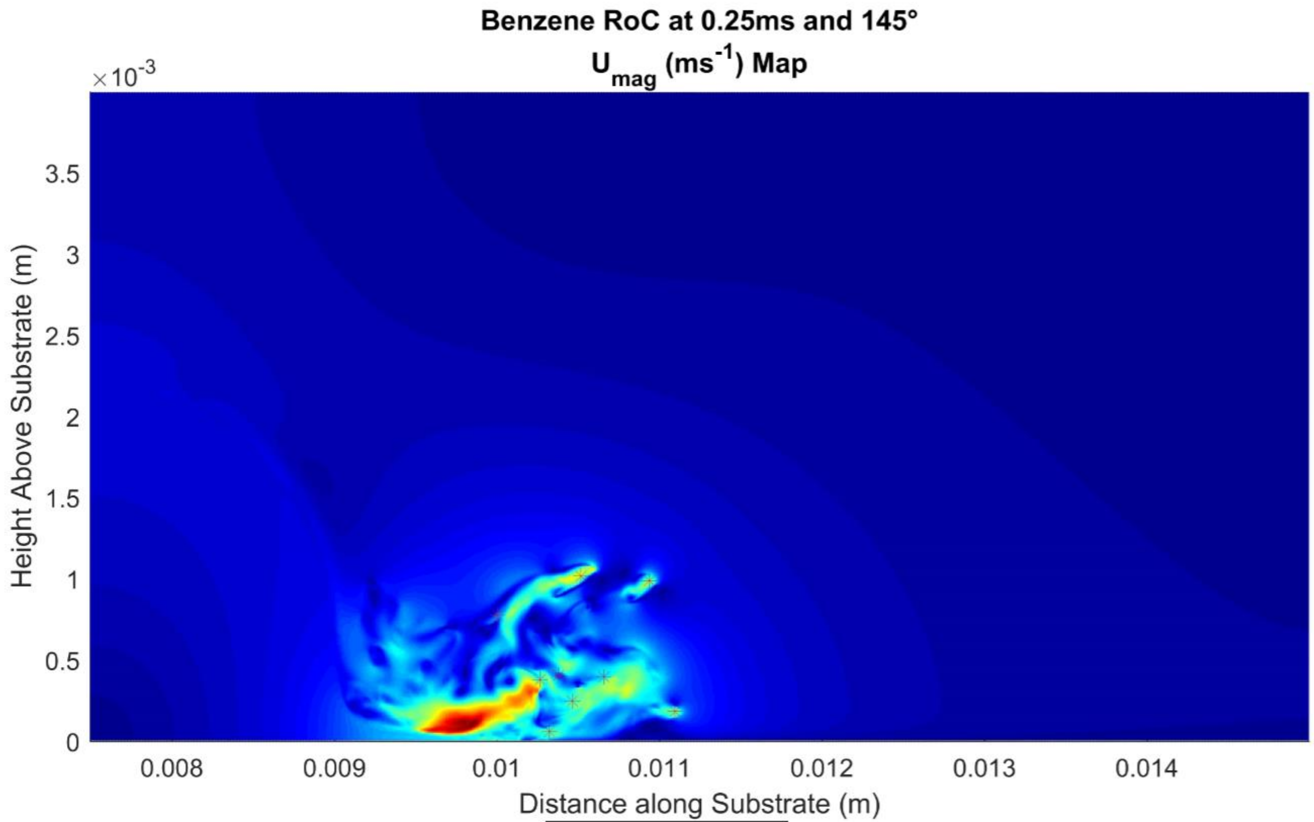
Questions



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