Effects of Contact Angle on the Dynamics of Water Droplet Impingement

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Outline

- **Introduction**
- **Mathematical Models**
  - Contact angle models
  - Fluid flow
  - Free surface tracking
- **Results and Discussion**
  - Droplet impingement process
  - Study of contact angle
- **Conclusions**

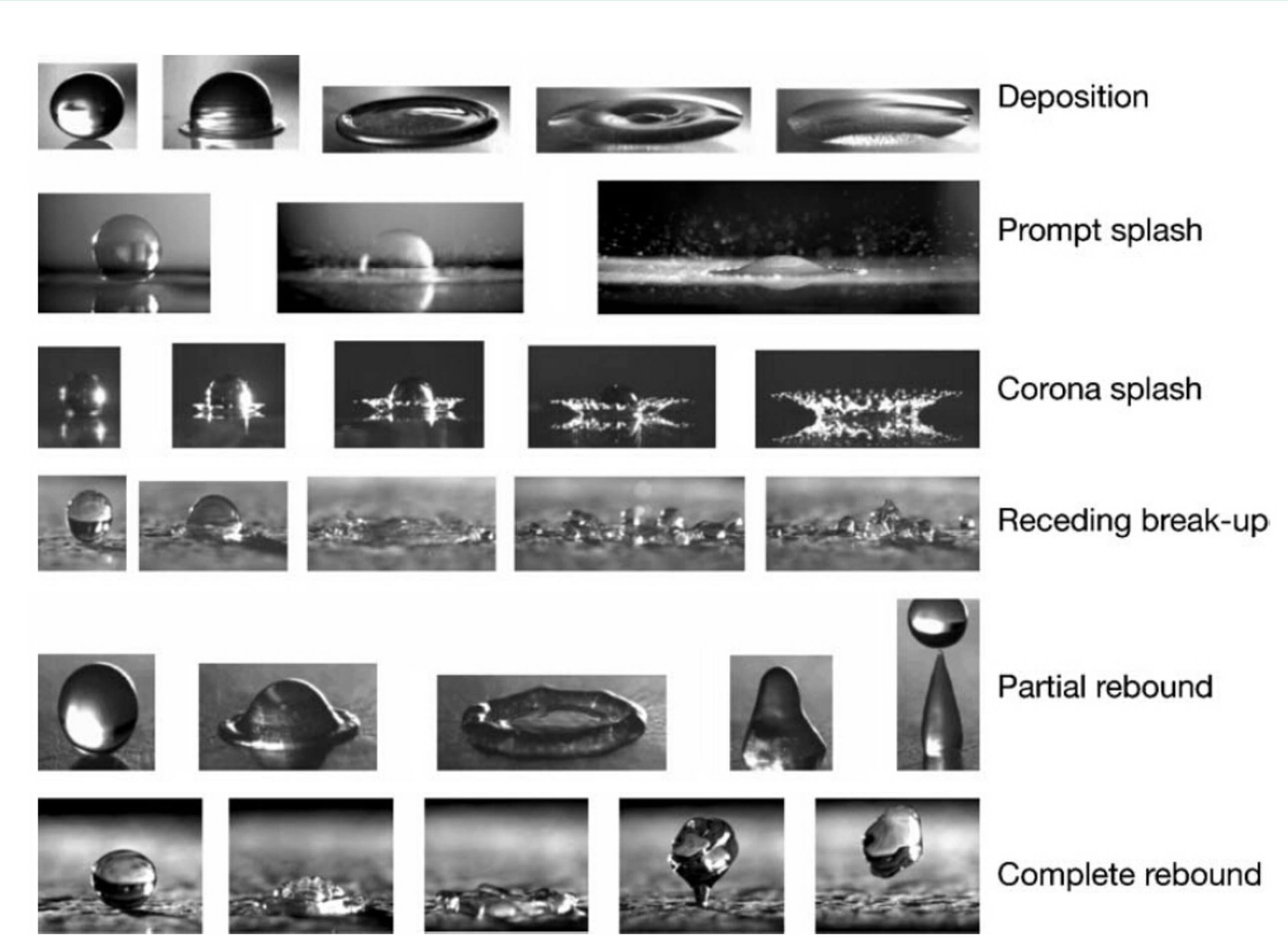
Droplet Impingement Dynamics Applications

- Inkjet printing
- Spray cooling of turbines and electronics
- Spray coating and painting
- Solder-drop deposition
- Laser deposition
- Rain drop

Droplet Impingement Dynamics Influencing Parameters

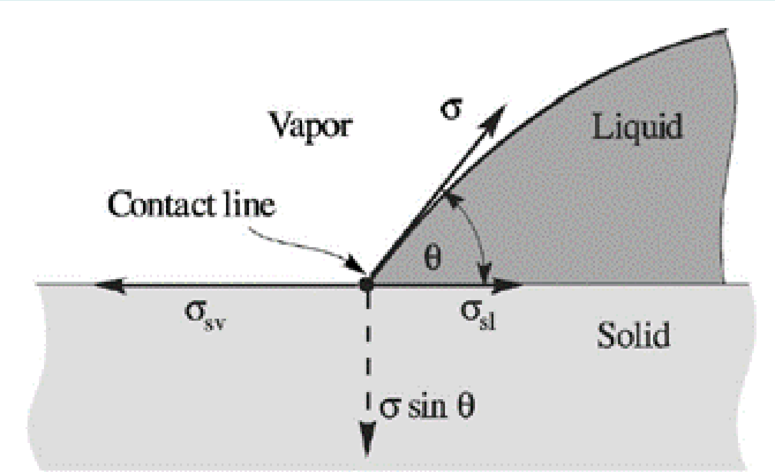
- Droplet properties
- Droplet size
- Impact velocity
- Attack angle
- Surface wettability
- Surrounding pressure

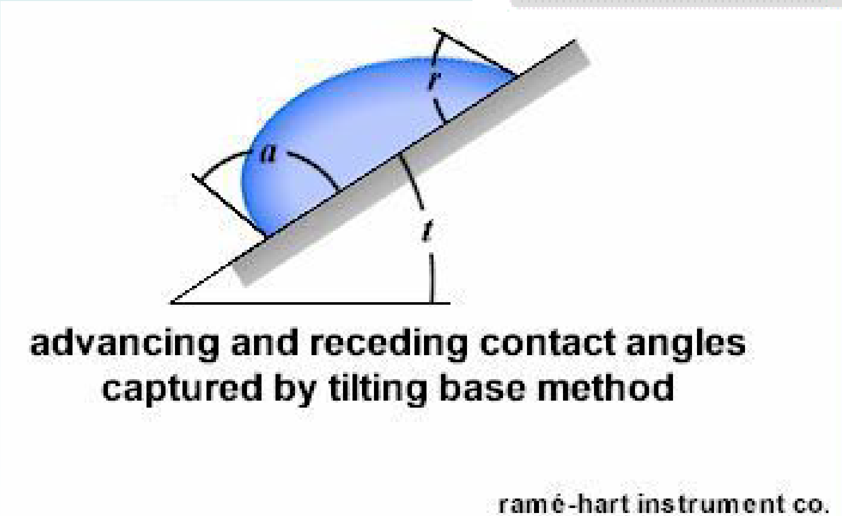
Liquid Droplet Impacting on a Dry Surface

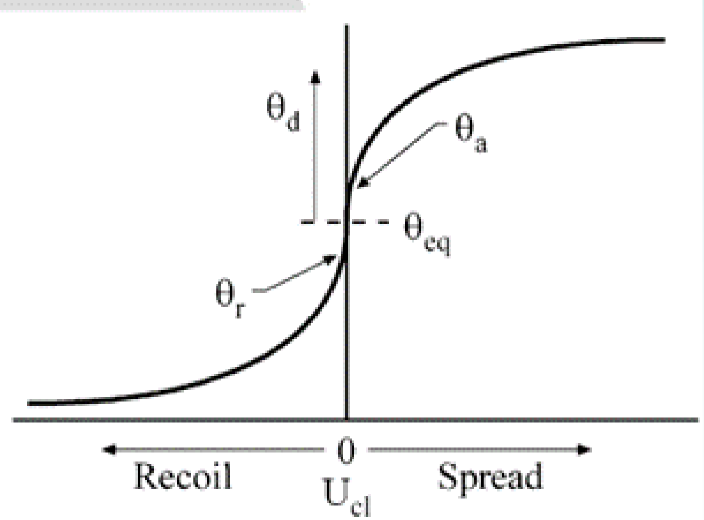


Rioboo et al., 2001

Contact Angle







Static advancing and receding contact angles, θ_a and θ_r

Static advancing, receding, and dynamic contact angles, θ_a, θ_r, and θ_d

Kistler's law for dynamic contact angle (DCA)

$$\theta_d = f_H\left[Ca + f_H^{-1}(\theta_e)\right]$$

$$f_H = \arccos\left\{1 - 2\tanh\left[5.16\left(\frac{x}{1+1.31x^{0.99}}\right)^{0.706}\right]\right\}$$

$$Ca = \frac{\mu U_{cl}}{\sigma}$$

Quasi-dynamic contact angle

$$\theta_d = \begin{cases} \theta_a & \text{if} \quad U_{cl} \geq 0 \\ \theta_r & \text{if} \quad U_{cl} < 0 \end{cases}$$

Mathematical Model - Governing Equations

- Navier-Stokes equations for fluid flow:

$$\nabla \mathbf{u} = 0$$

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}\nabla\mathbf{u}\right) = \nabla\left[-p\mathbf{I} + \mu\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right] + \rho\mathbf{g} + \mathbf{F}_{st}$$

- Phase field method for tracking interface

$$\frac{\partial \phi}{\partial t} + \mathbf{u}\nabla\phi = \nabla \cdot \frac{\gamma\lambda}{\varepsilon^2}\nabla\psi$$

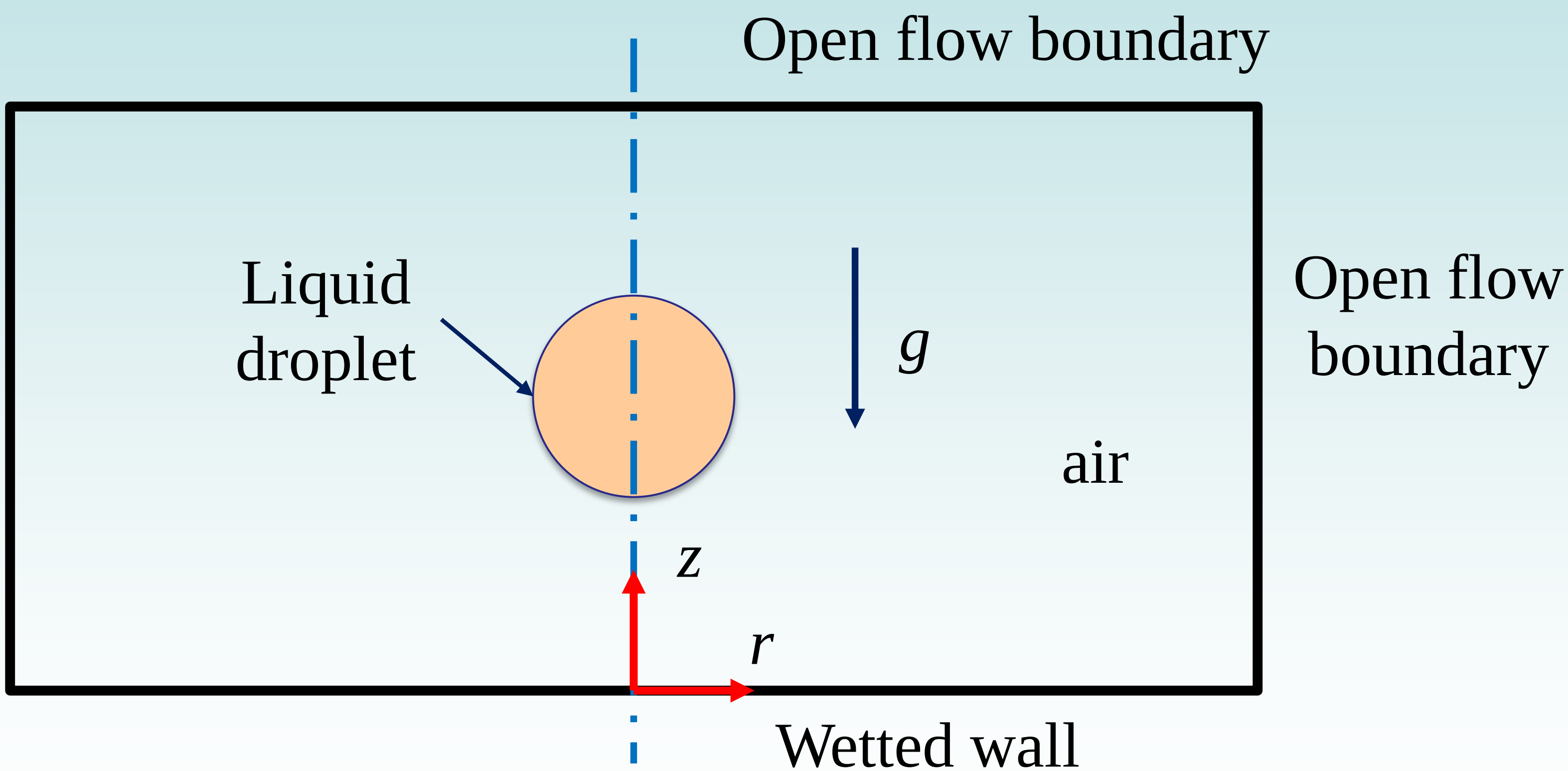
$$\psi = -\nabla \cdot \varepsilon^2 \nabla\phi - (\phi^2 - 1)\phi$$

$$\mathbf{F}_{st} = G\nabla\phi$$

where

$$\gamma = \chi\varepsilon^2 \qquad \sigma = \frac{2\sqrt{2}\lambda}{3\varepsilon} \qquad G = \frac{\lambda}{\varepsilon^2}\psi$$

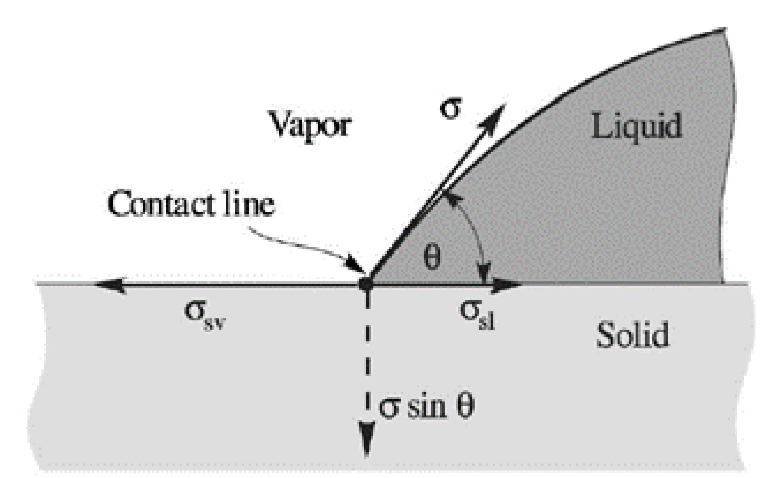
Mathematical Model-Computational Domain and Boundary Conditions



Wetted wall boundary

$$\mathbf{n}\cdot\varepsilon^2\nabla\phi=\varepsilon^2\cos(\theta_w)\left|\nabla\phi\right|$$

$$\mathbf{n}\cdot\frac{\sigma\lambda}{\varepsilon^2}\nabla\psi=0$$



Contact Angle Model	Value
SCA	95°, 100°, 105°
Quasi-DCA	95° to 105°
DCA	Kistler's model

Numerical Model of Water Droplet Impingement

Fluid Properties and Simulation Conditions

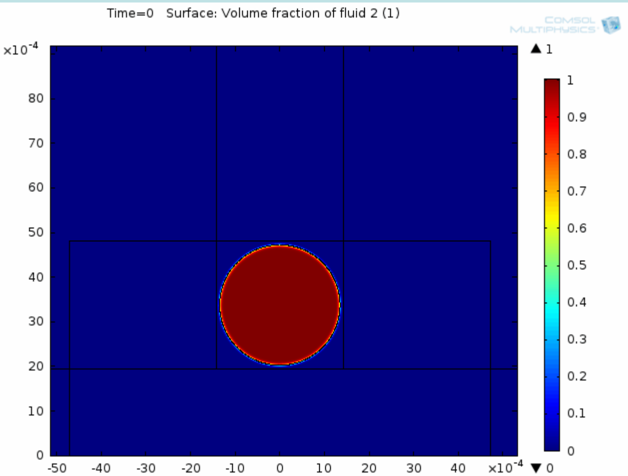
	Density	Viscosity	Surface tension	Droplet size	Impact velocity
	ρ, kg/m^3	μ, Pa·s	σ, N/m	D_0 (mm)	V_i (m/s)
Water	998	0.001	0.073	2.7	1.17
Air	1.204	1.814×10^{-5}			

Reynolds number ($Re = \rho u D/\mu$): 3100

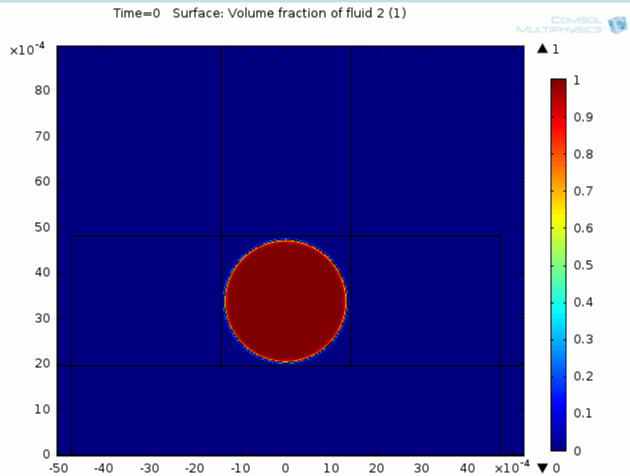
Weber number ($We = \rho u^2 D/\sigma$) : 50

Ohnesorge number ($Oh = (We)^{1/2}/Re$) : 0.0023

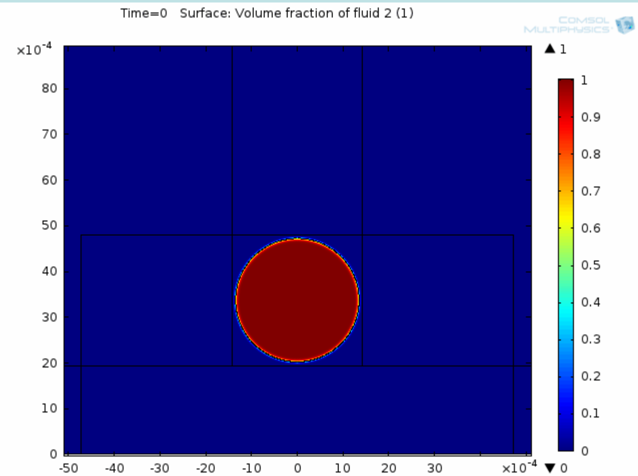
Results: Constant Static Contact Angles



95 degree

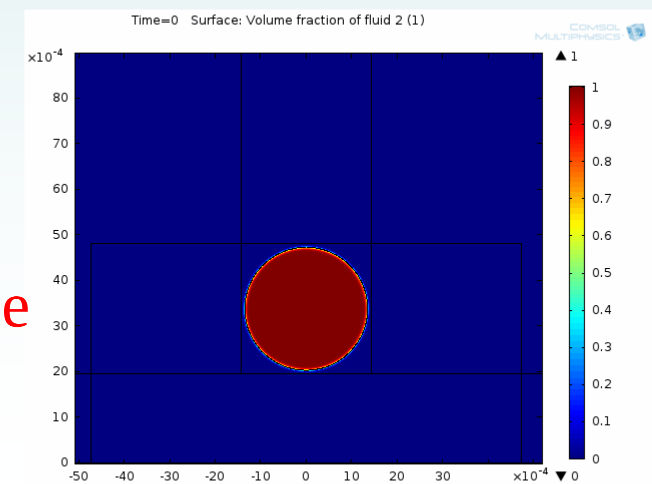


100 degree

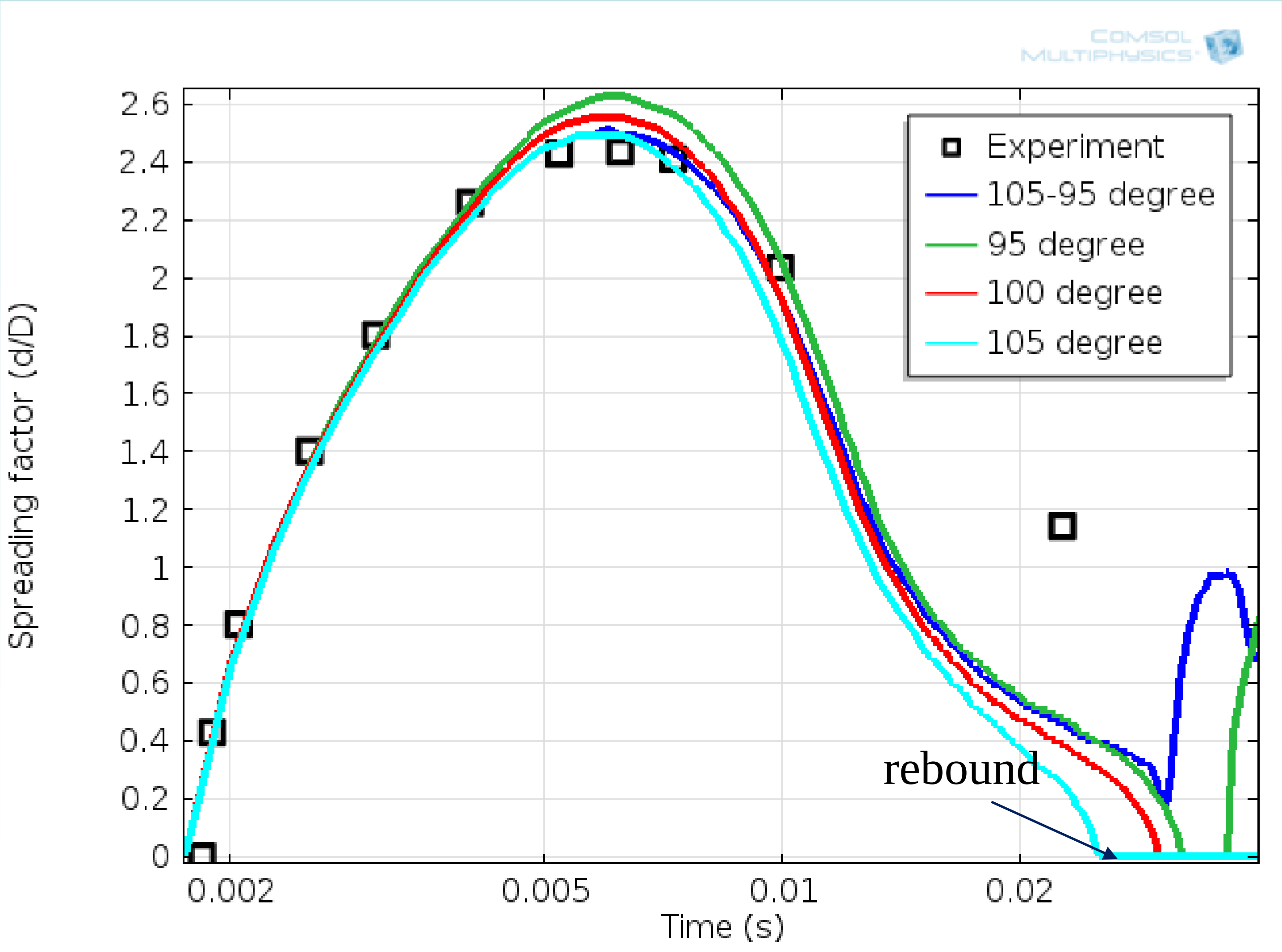


105 degree

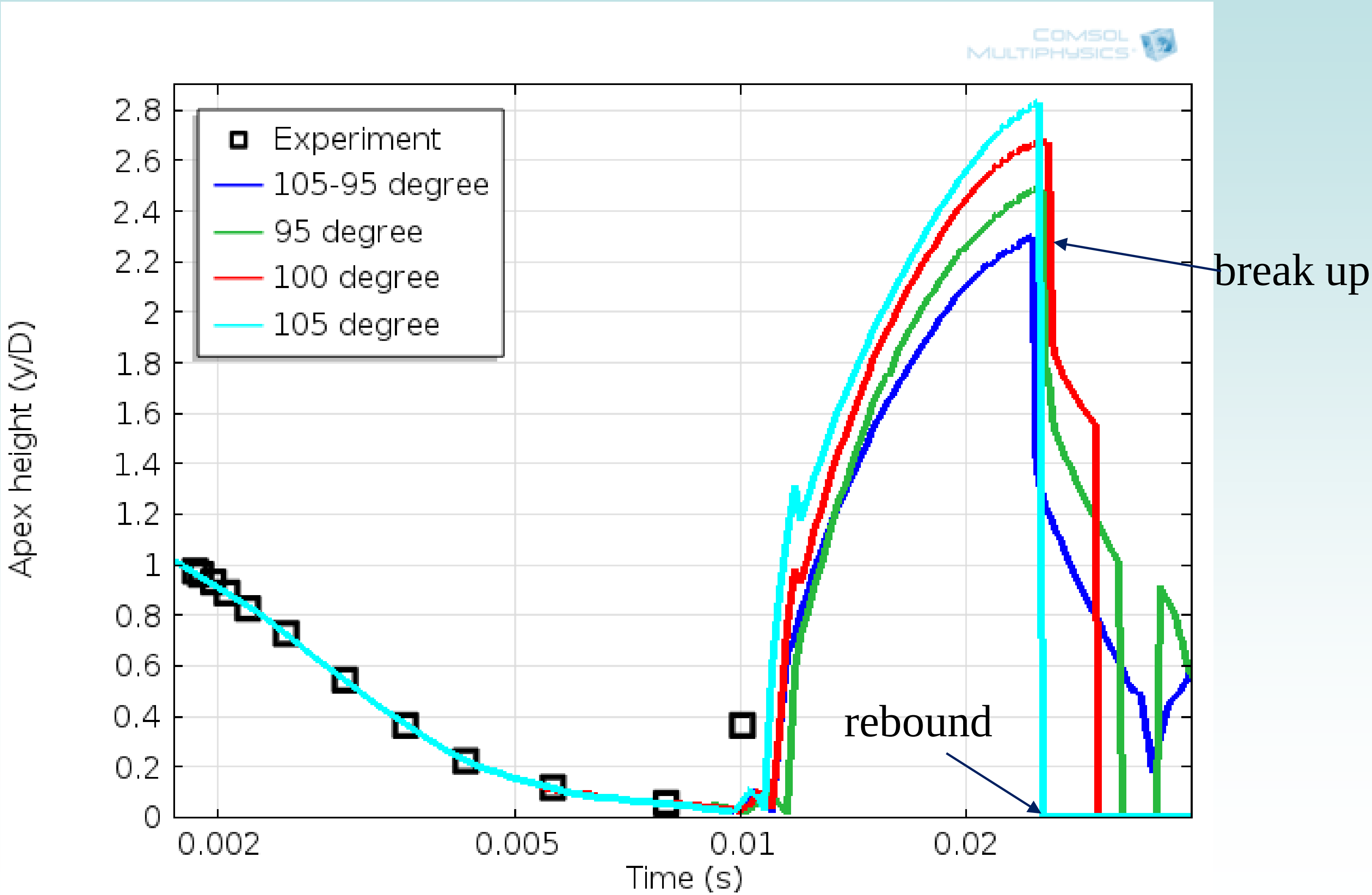
Quasi-DCA model:105-95 degree



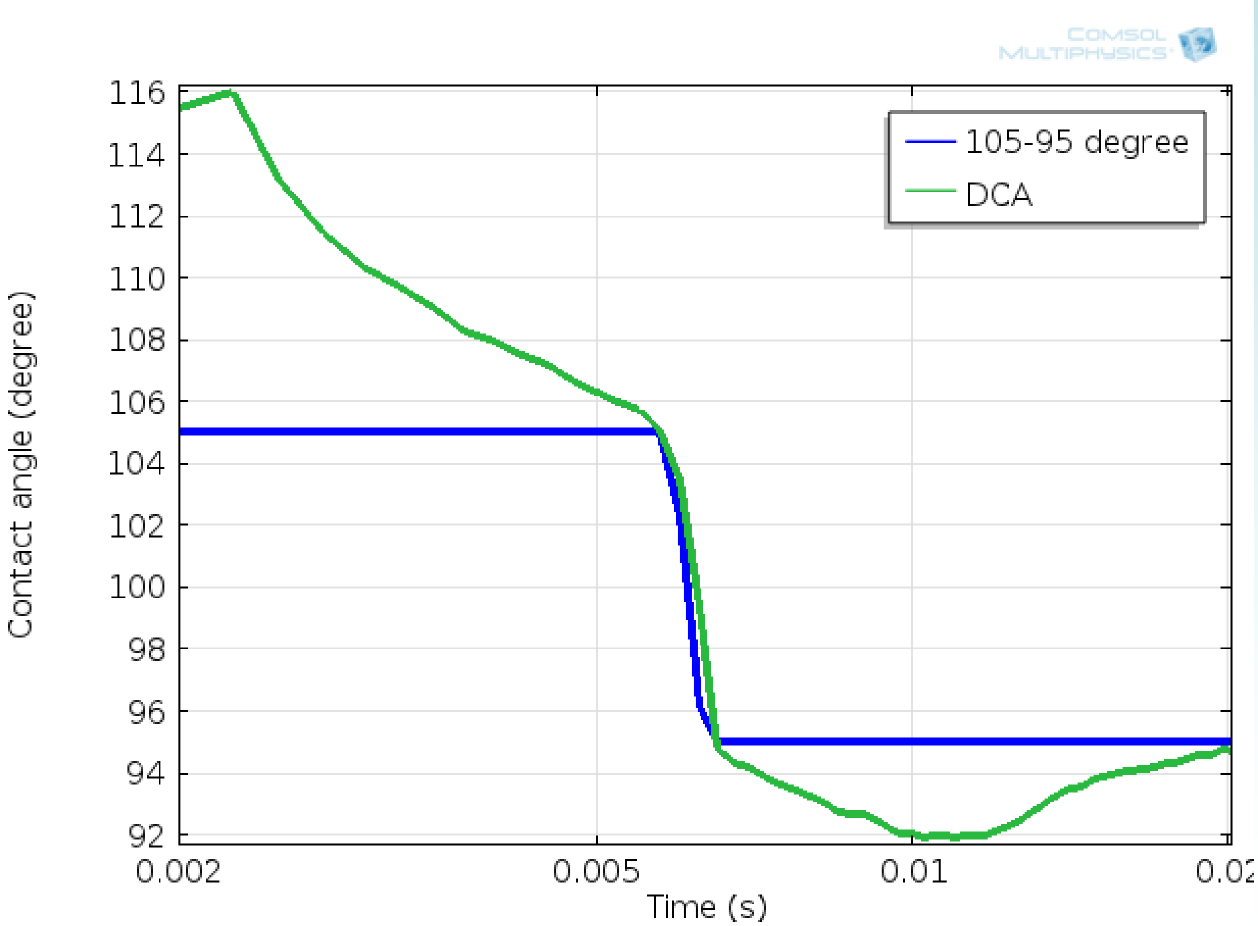
Results: Constant Static Contact Angles



Results: Constant Static Contact Angles



Results: Quasi-Dynamic Contact Angle and Dynamic Contact Angle



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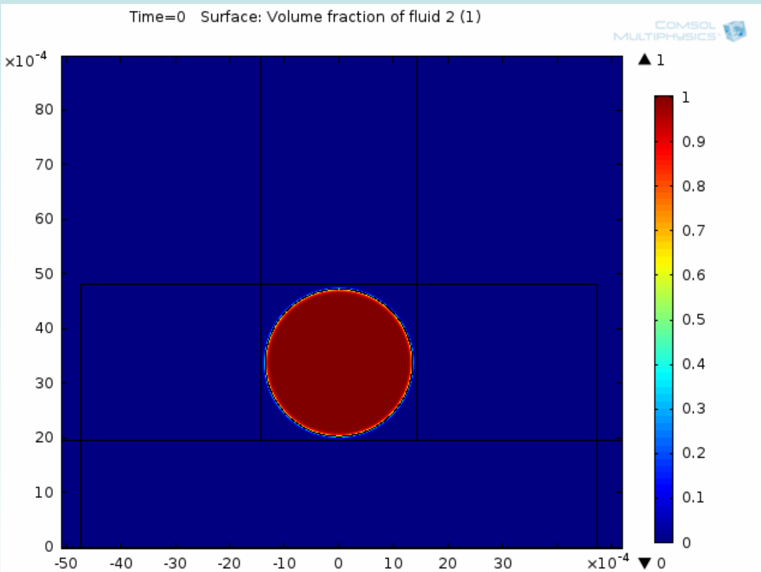
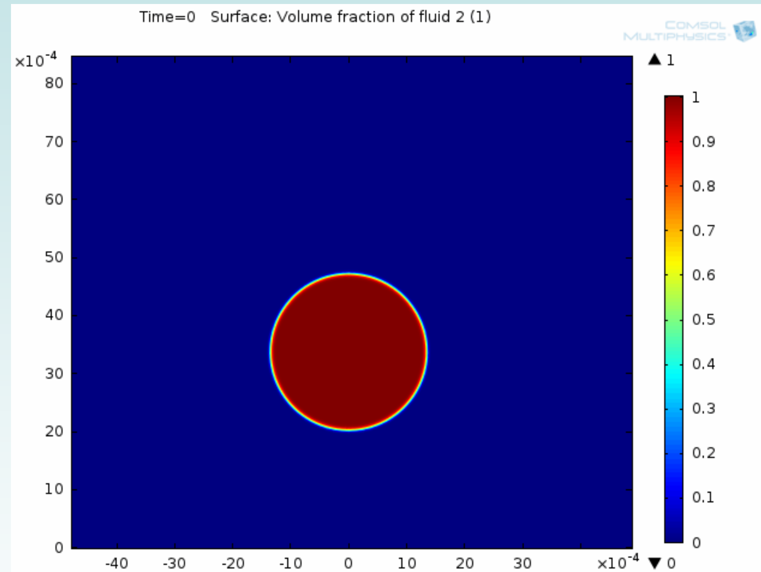
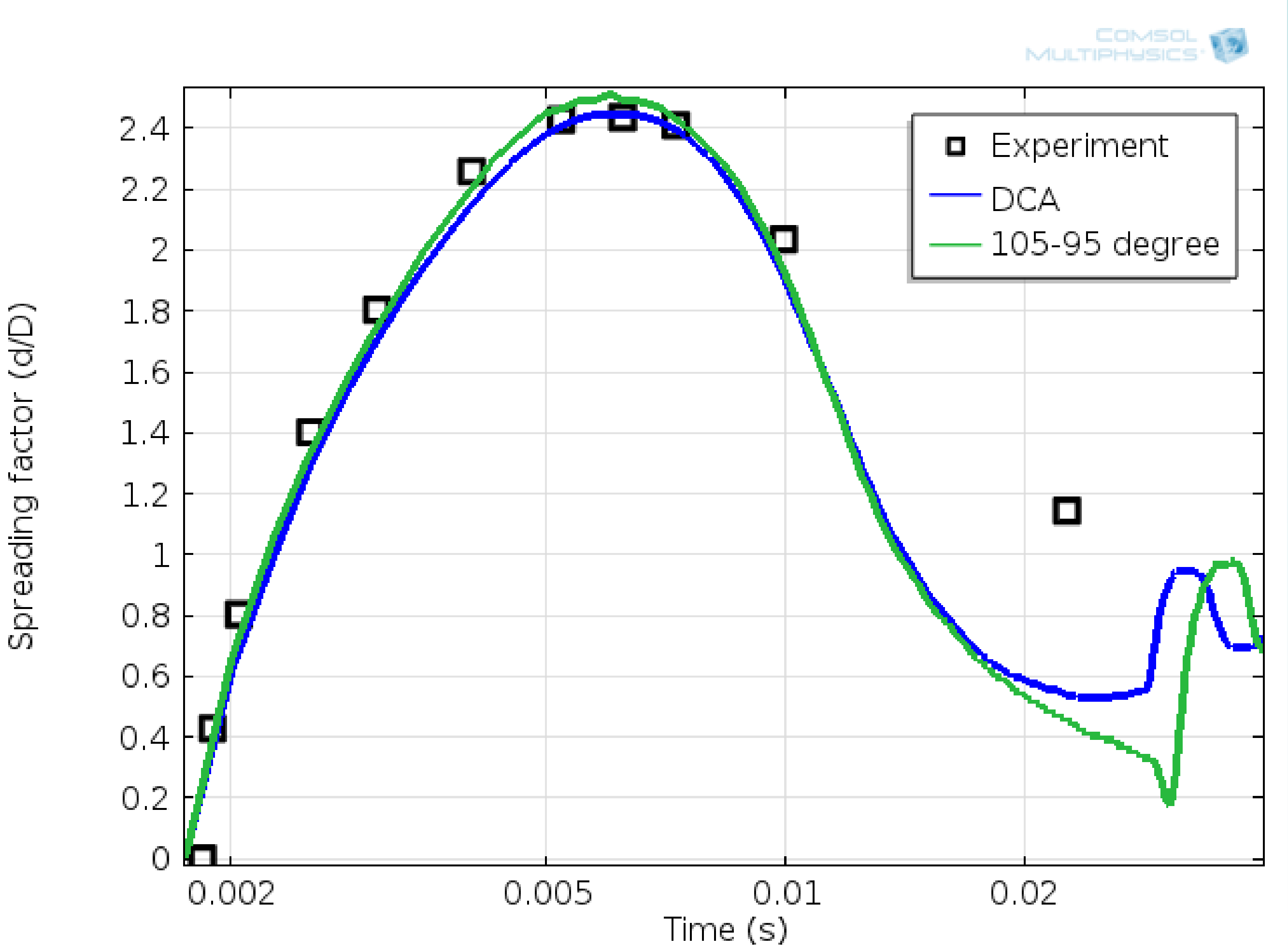


105-95 degree



DCA

Results: Quasi-Dynamic Contact Angle and Dynamic Contact Angle



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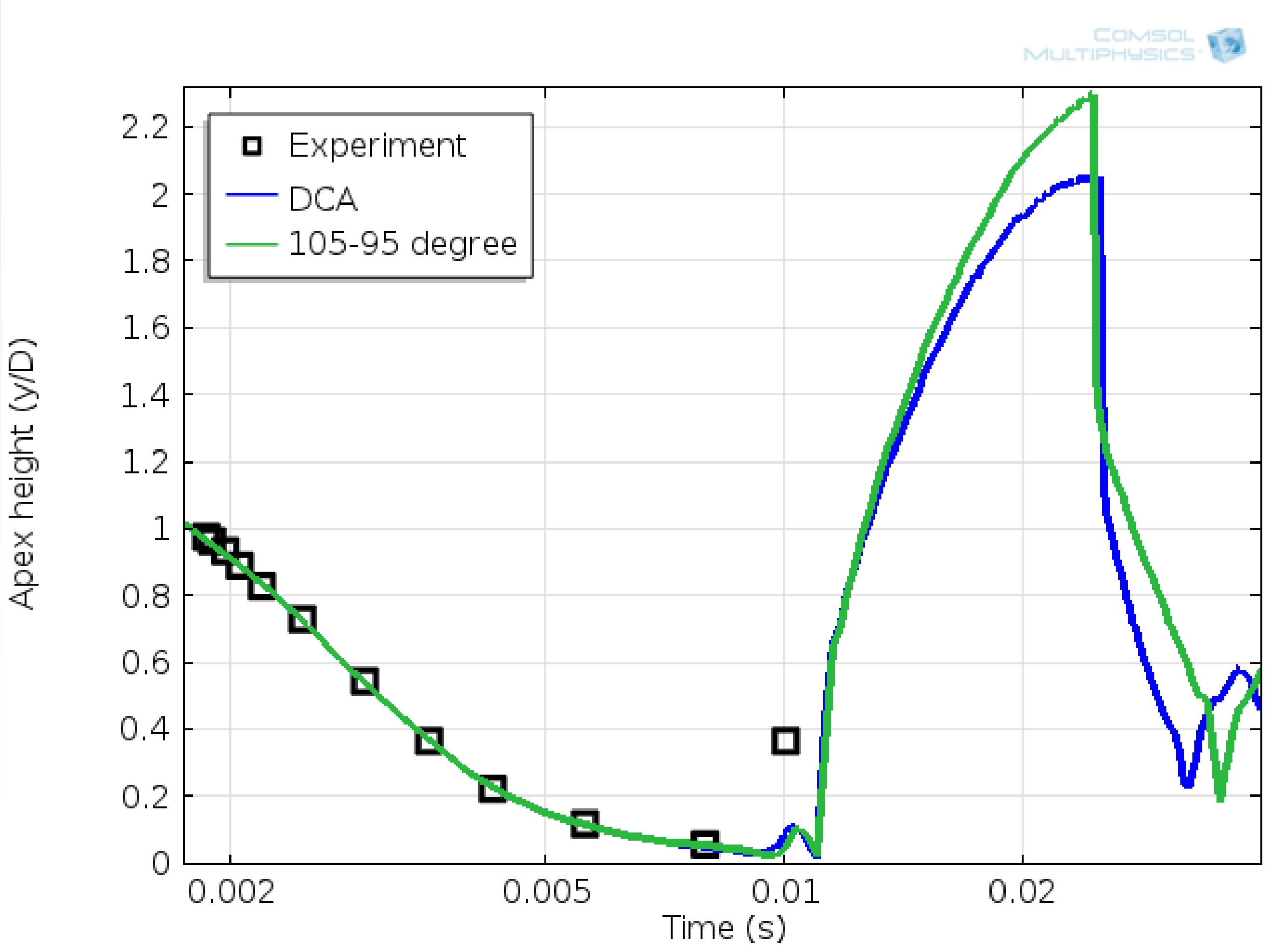
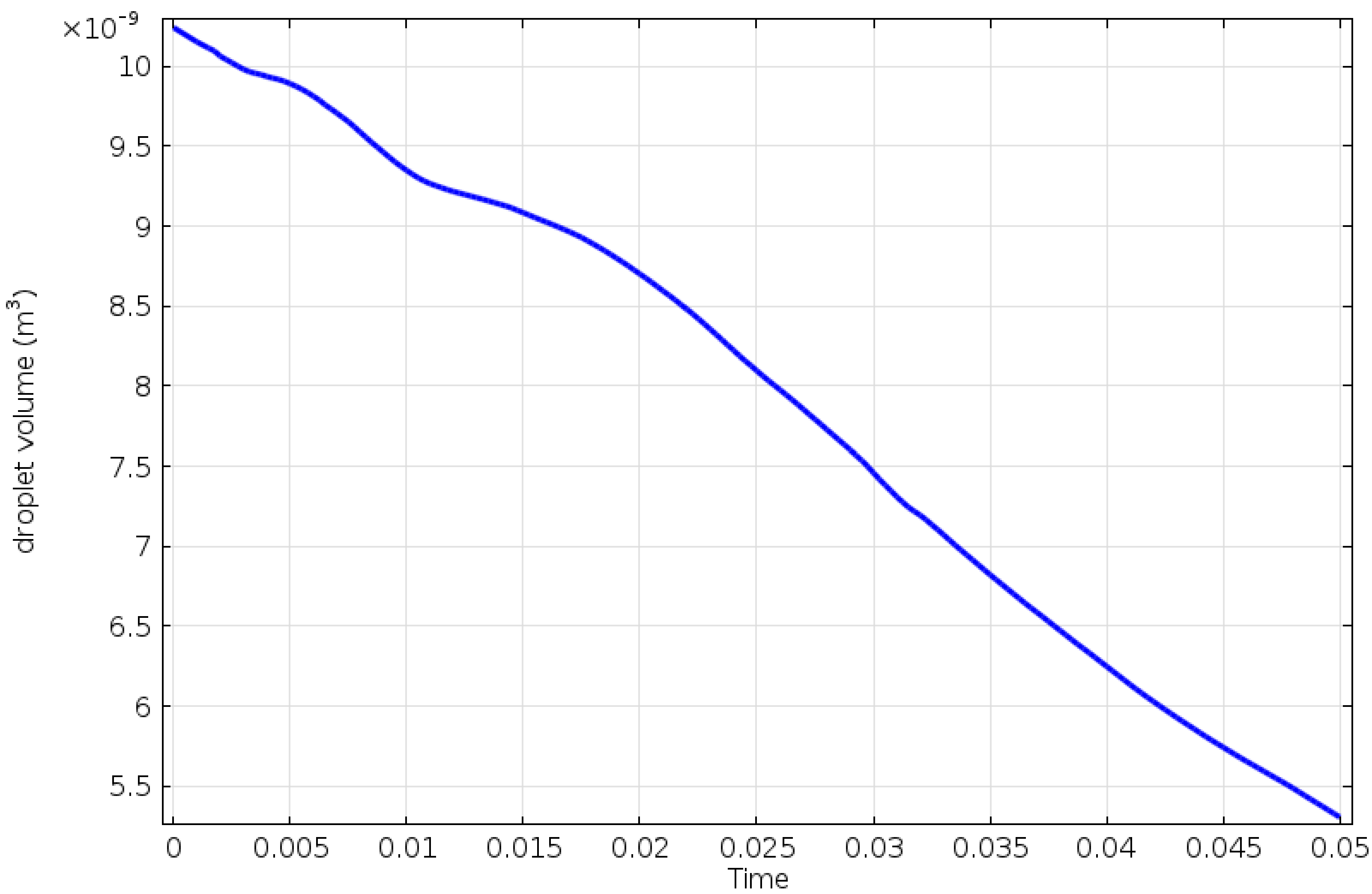


Results and Discussions

Substantial mass loss



Conclusions

- The dynamic process of water impinging onto a wax surface was simulated with the Phase Field Method in COMSOL.
- The dynamic process of impingement was presented.
- The droplet spreading factor and apex height were found to agree with the experimental results in the early spreading stage, but discrepancy were found in the receding stage.
- The effect of the contact angle on the droplet impingement process was studied using three contact angle models

Thank You