Simulation of Droplet Impingement Dynamics by the Level Set Method

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Outline

- ❑ **Introduction**
- ❑ **Mathematical Models**
- ❑ **Results and Discussion**
  - Droplet impingement process
  - Studies of Level Set parameters
- ❑ **Conclusions**

Droplet Impingement Dynamics Applications

- Inkjet deposition
- Spray cooling of electronics
- Spray coating
- Rain drop

Droplet Impingement Dynamics Influencing Parameters

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

Droplet Impingement Dynamics Influencing Parameters

Reynolds number

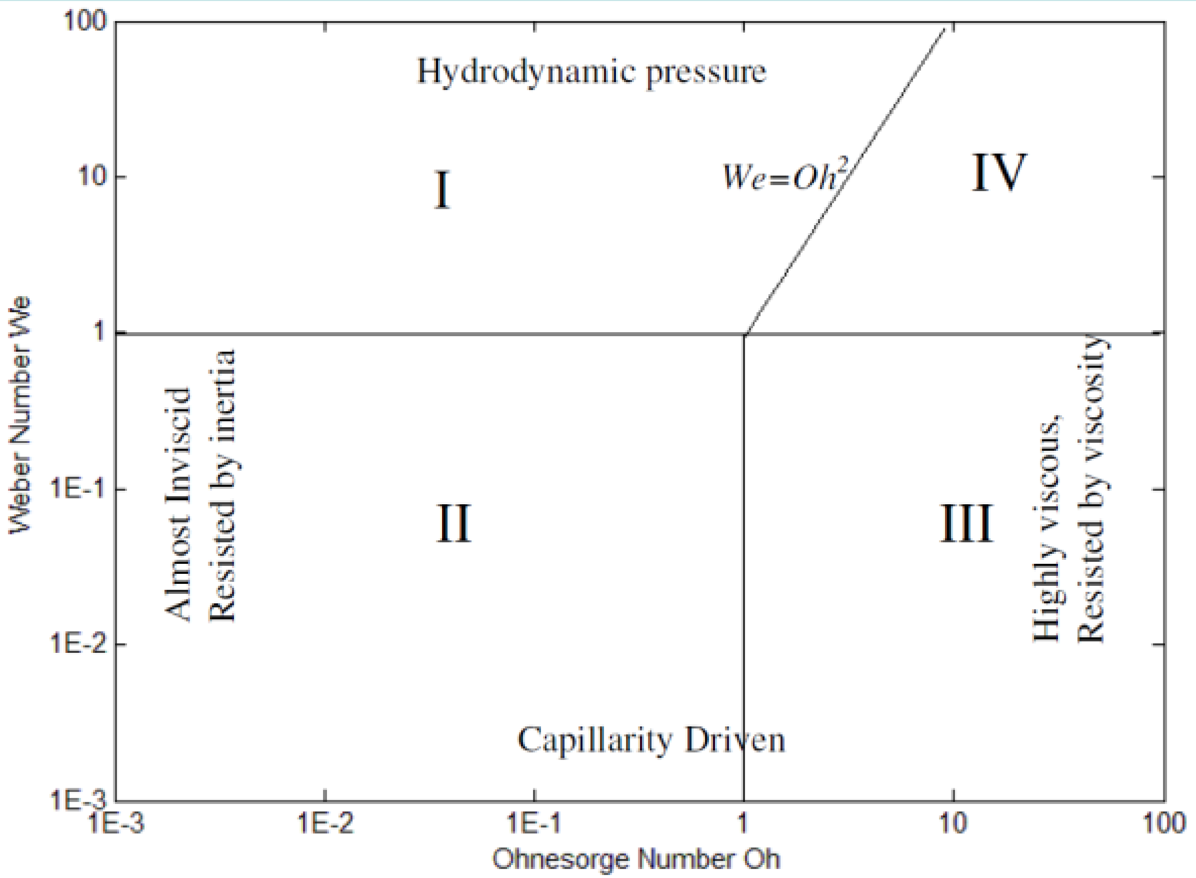
$(Re = \rho u D/\mu)$

Weber number

$(We = \rho u^2 D/\sigma)$

Ohnesorge number

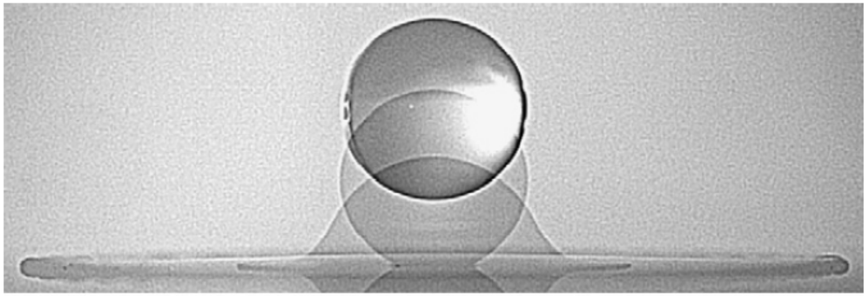
$(Oh = (We)^{1/2}/Re)$



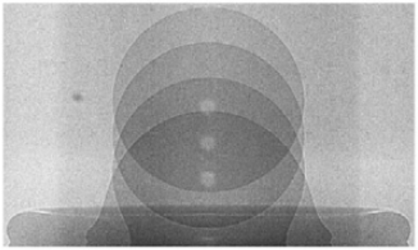
Shiaffino and Sonin

Experimental Results of Water and Glycerin Impinging onto Smooth Glass

Spreading



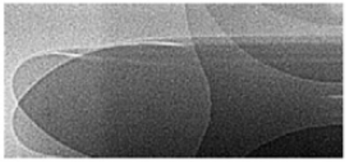
(a) water/glass: $t = 0.030, 0.350, 1.950$ ms



(b) glycerin/glass: $t = 0.100, 0.260, 2.020$ ms

Receding

(c) water/glass: $t = 0.045, 0.365, 7.085$ μs



(d) glycerin/glass: $t = 0.104, 2.024, 6.824$ ms

Impact of a water and a glycerin droplet onto glass for We = 391

Sikalo and Ganic, 2006

Numerical Model of a Glycerin Droplet Impingement

Fluid Properties and Simulation Conditions

Parameter	Symbol	Value	Unit
Density of glycerin	ρ_l	1220	kg/m^3
Dynamics viscosity of glycerin	μ_l	0.116	Pa·s
Density of air	ρ_a	1.204	kg/m^3
Dynamics viscosity of air	μ_a	1.814×10^{-5}	Pa·s
Surface tension	σ	0.063	N/m
Droplet diameter	D	2.45	mm
Impact velocity	v	1.41	m
Reynolds number	Re	36.3	
Weber number	We	93.8	
Ohnesorge number	Oh	0.267	

Mathematical Modeling of GMAW-Governing Equations

- Navier-Stokes equations for fluid flow:

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

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

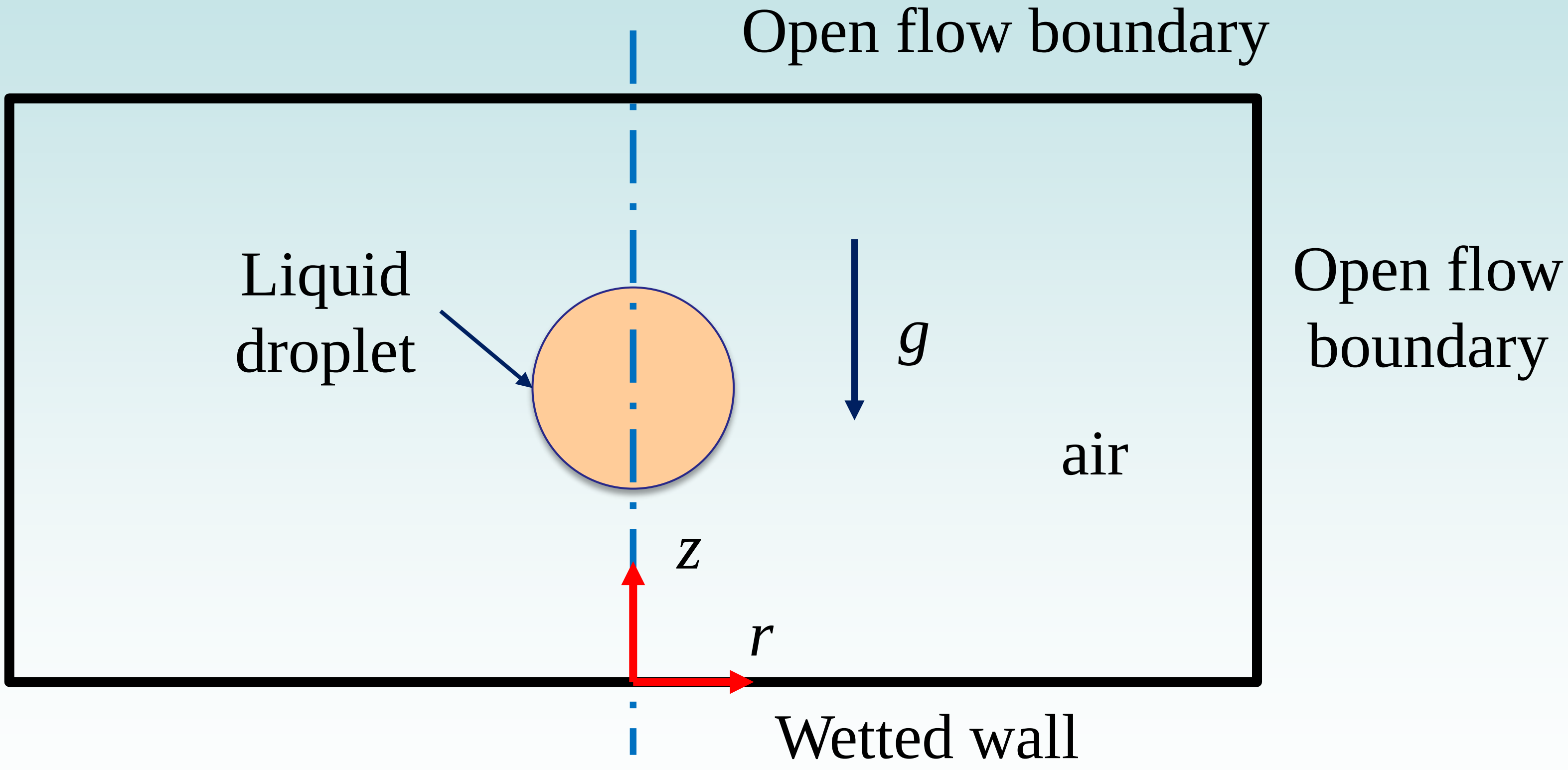
- Conservative Level Set method for interface

$$\rho\left(\frac{\partial\phi}{\partial t} + \nabla(\phi\mathbf{u})\right) = \gamma\left[\varepsilon\nabla\cdot\nabla\phi - \nabla\cdot\left(\phi(1-\phi)\frac{\nabla\phi}{|\nabla\phi|}\right)\right]$$

$$\mathbf{F}_{st} = \nabla\mathbf{T} = \nabla\cdot\left[\left(\sigma\left(\mathbf{I}-\mathbf{n}\mathbf{n}^T\right)\right)\delta\right]$$

$$\mathbf{n} = \frac{\nabla\phi}{|\nabla\phi|}$$

Mathematical Modeling of GMAW-Computational Domain and Boundary Conditions



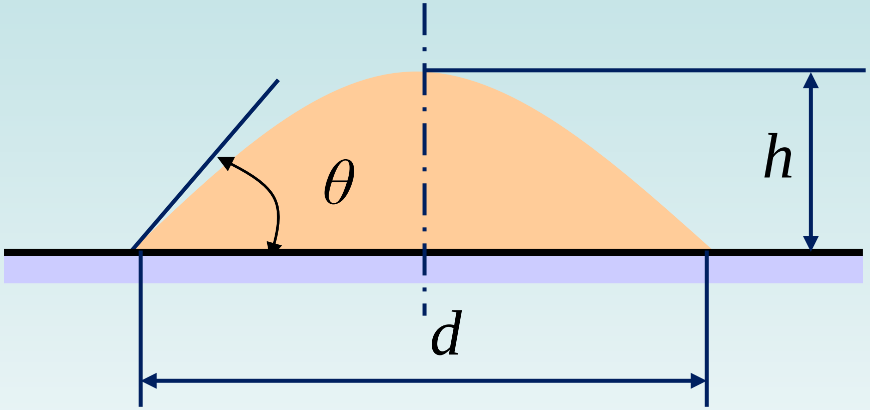
Mathematical Modeling of GMAW – Boundary Conditions

Wetted wall boundary

$$\mathbf{u}\mathbf{n}_{wall} = 0$$

$$\mathbf{F}_{fr} = -\frac{\eta}{\beta}\mathbf{u}$$

where η is the fluid viscosity and β is the slip length

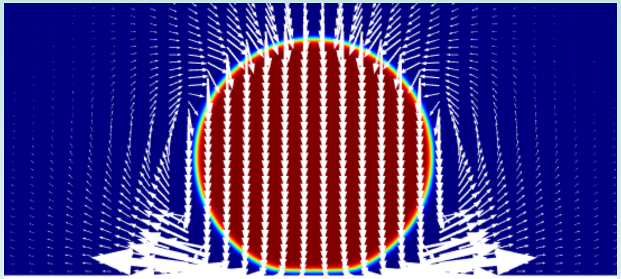


Schematic of droplet attached to a surface: θ, contact angle; h, droplet height; d, droplet wet diameter

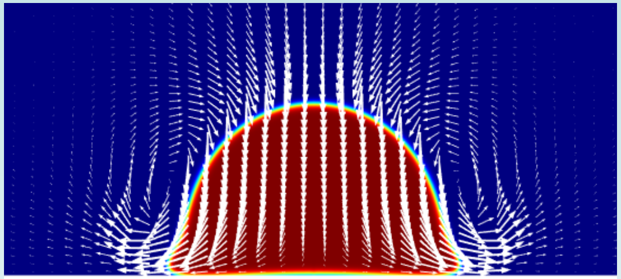
Results and Discussions

Impingement Process of Glycerin onto Wax Surface ($\theta = 94^o$)

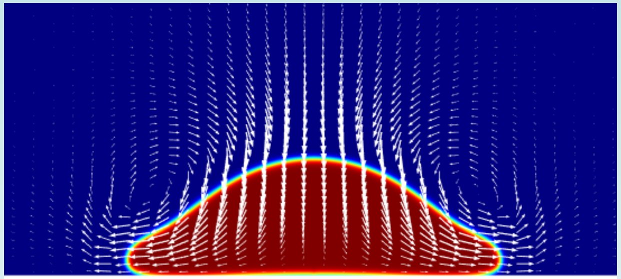
t = 0.18 ms



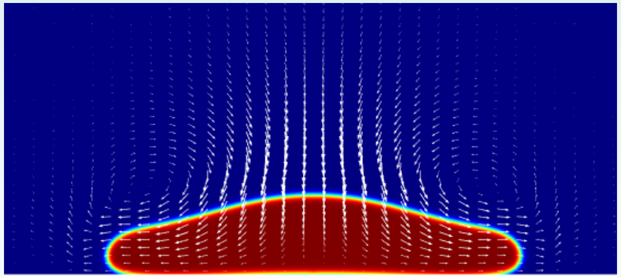
t = 0.68 ms



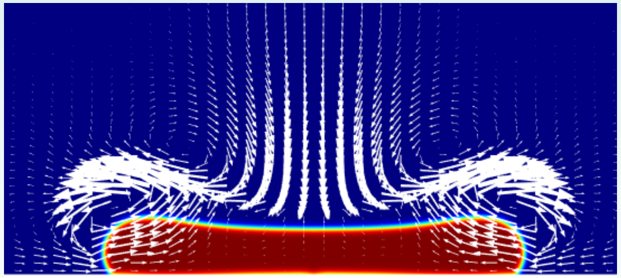
t = 1.18 ms



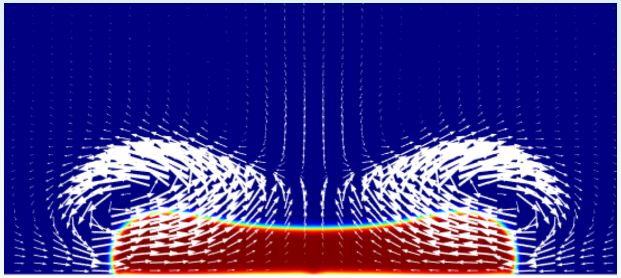
t = 1.68 ms



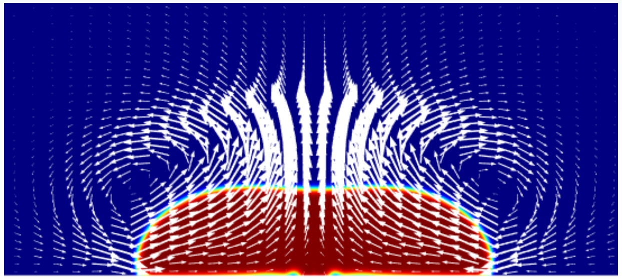
t = 3.38 ms



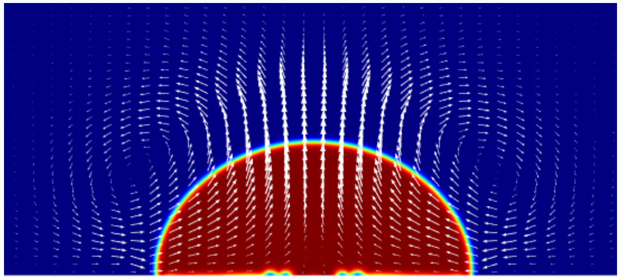
t = 4.2 ms



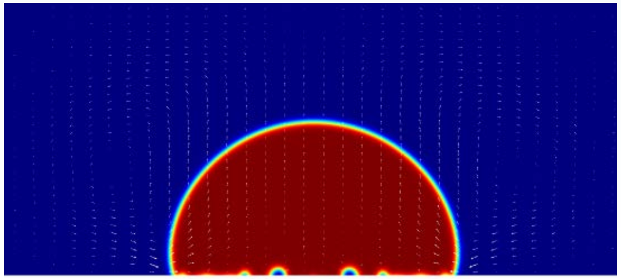
t = 7.2 ms



t = 10.2 ms

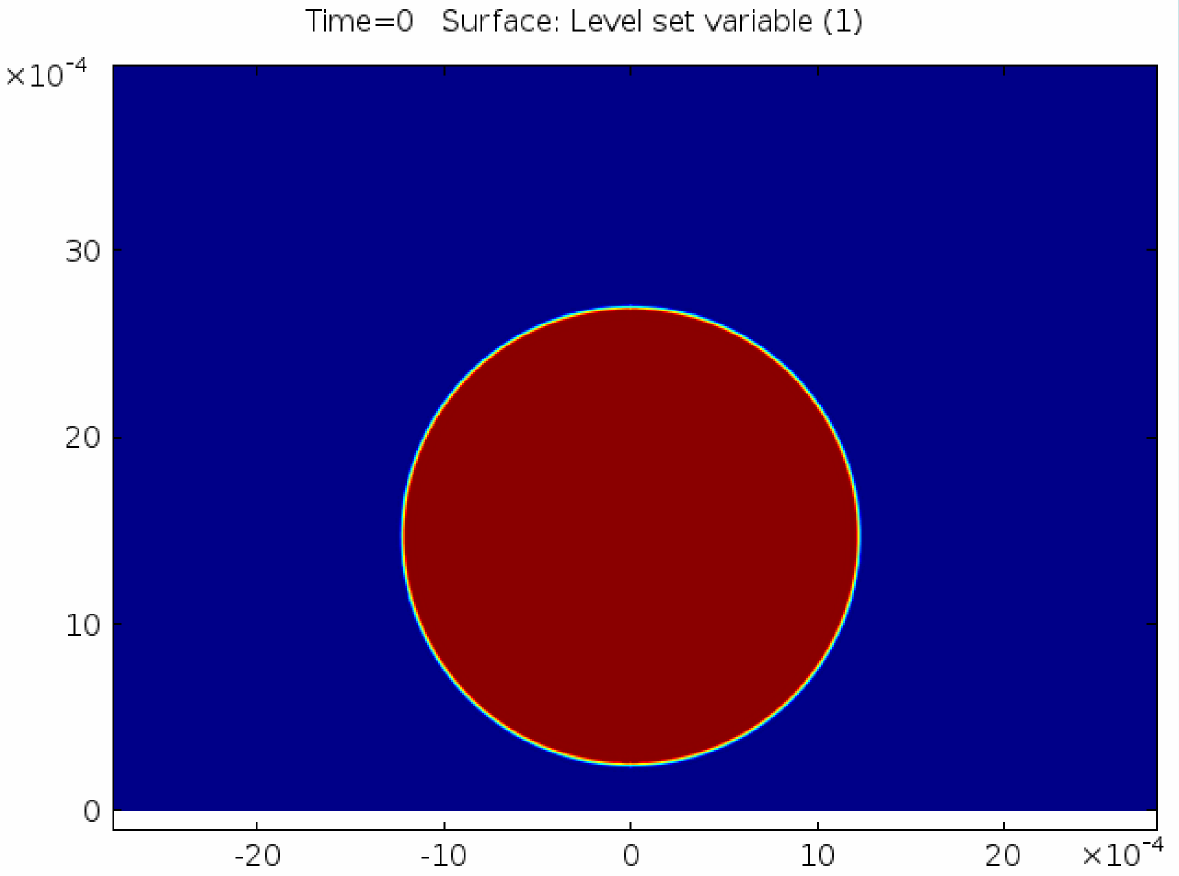


t = 20 ms



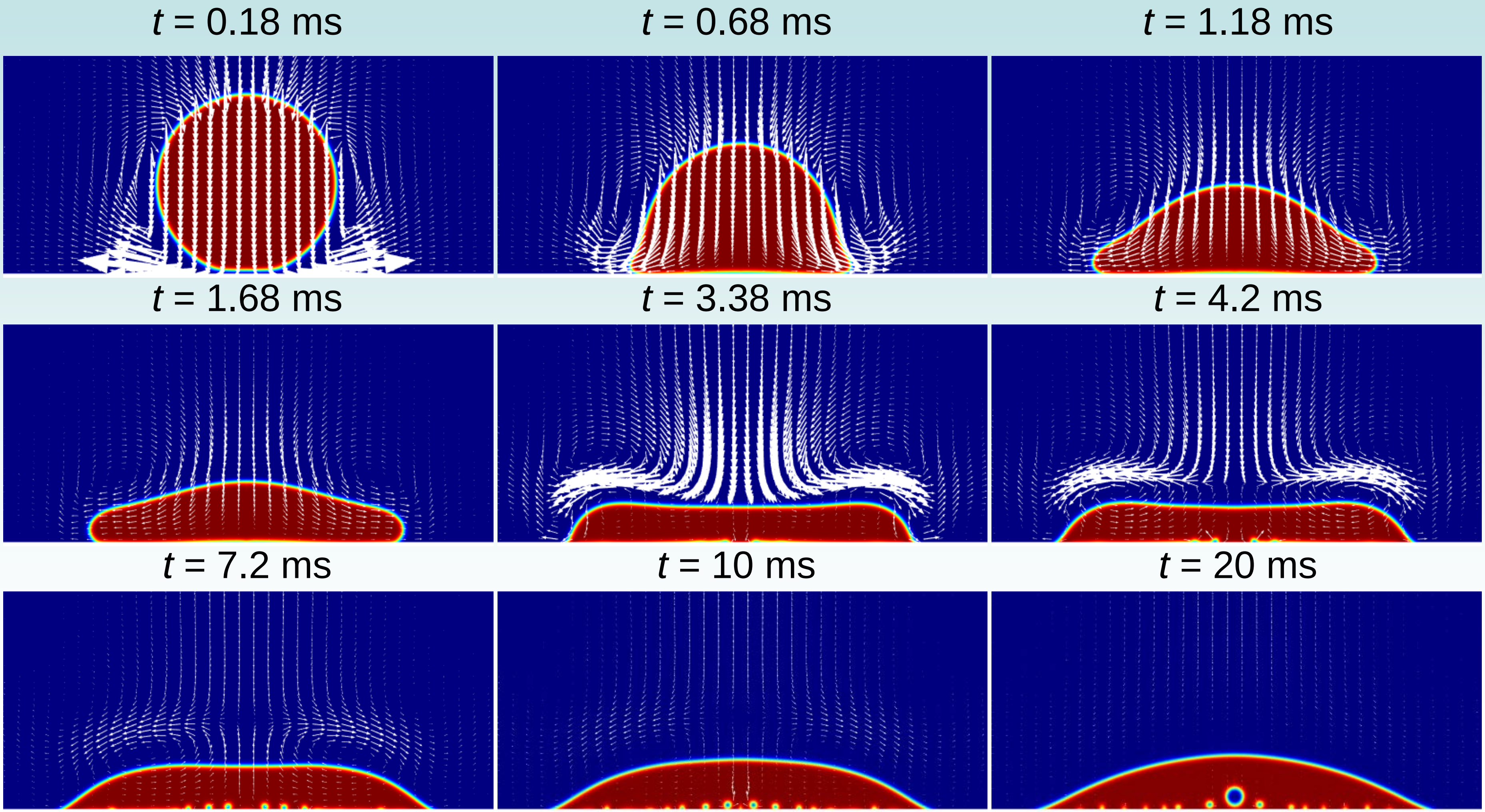
Results and Discussions

Impingement Process of Glycerin onto Wax Surface ($\theta = 15^o$)



Results and Discussions

Impingement Process of Glycerin onto Glass Surface ($\theta = 15^{o}$)



t = 0.18 ms

t = 0.68 ms

t = 1.18 ms

t = 1.68 ms

t = 3.38 ms

t = 4.2 ms

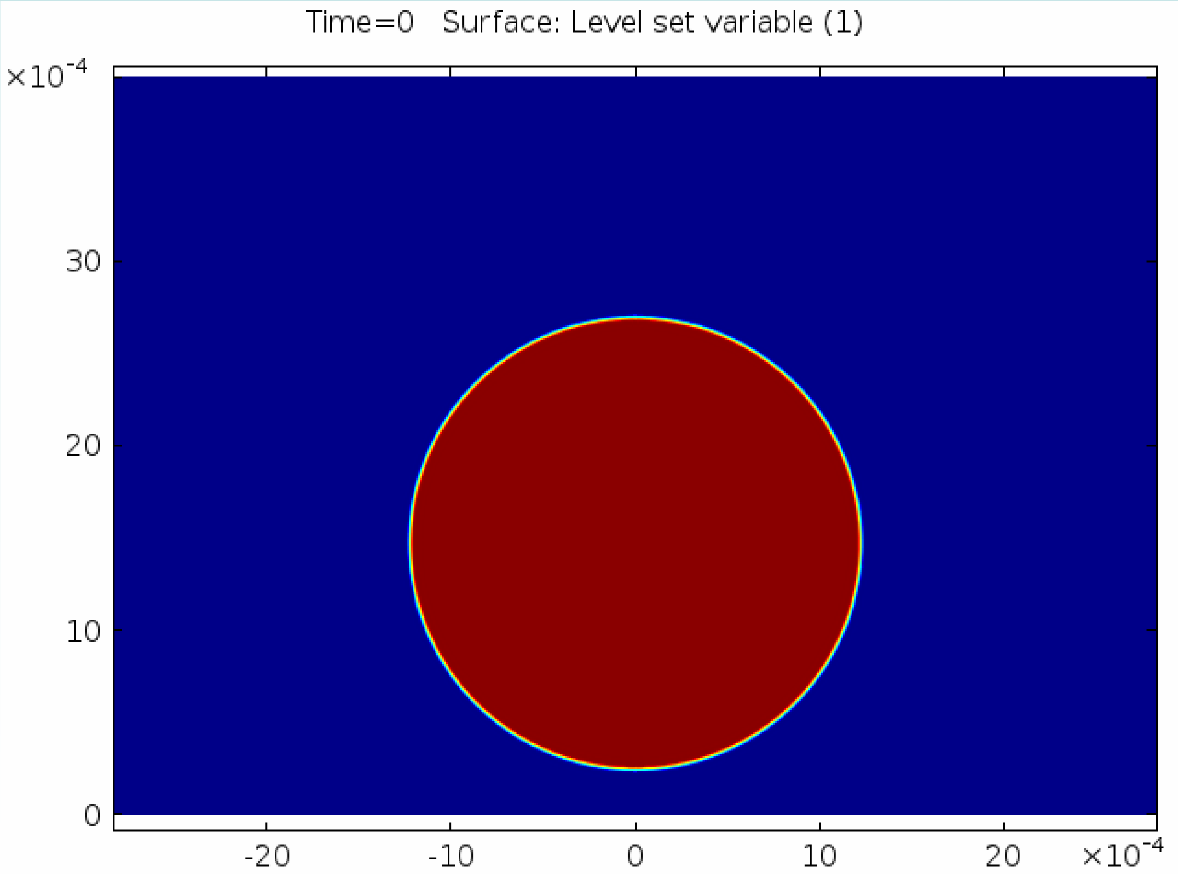
t = 7.2 ms

t = 10 ms

t = 20 ms

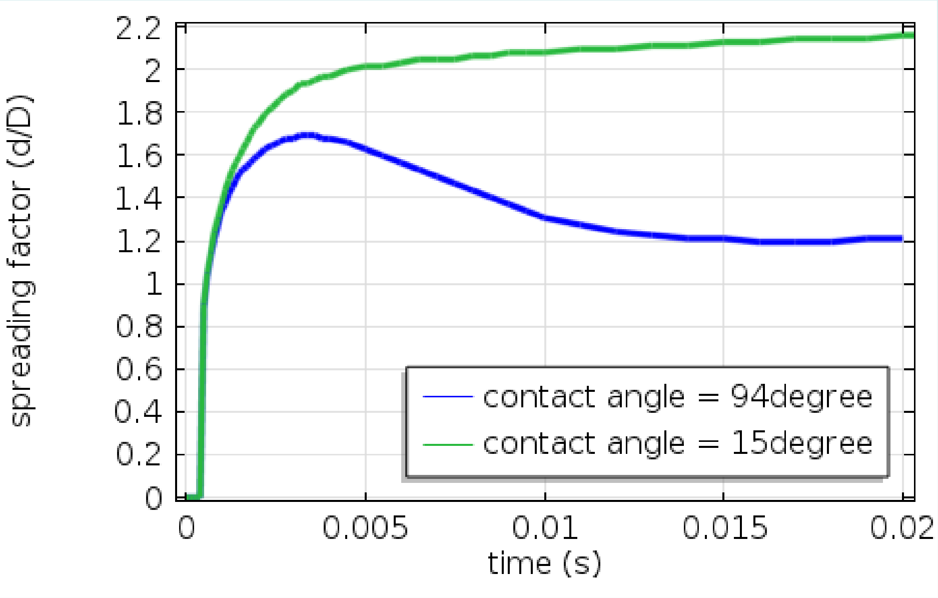
Results and Discussions

Impingement Process of Glycerin onto Wax Surface ($\theta = 94^o$)

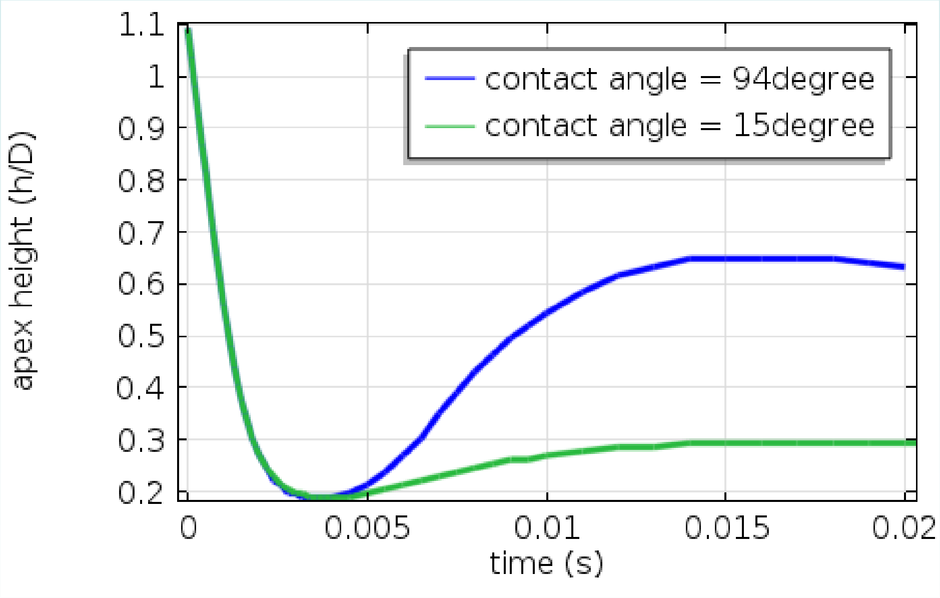


Effect of Contact Angle

Spreading Factor

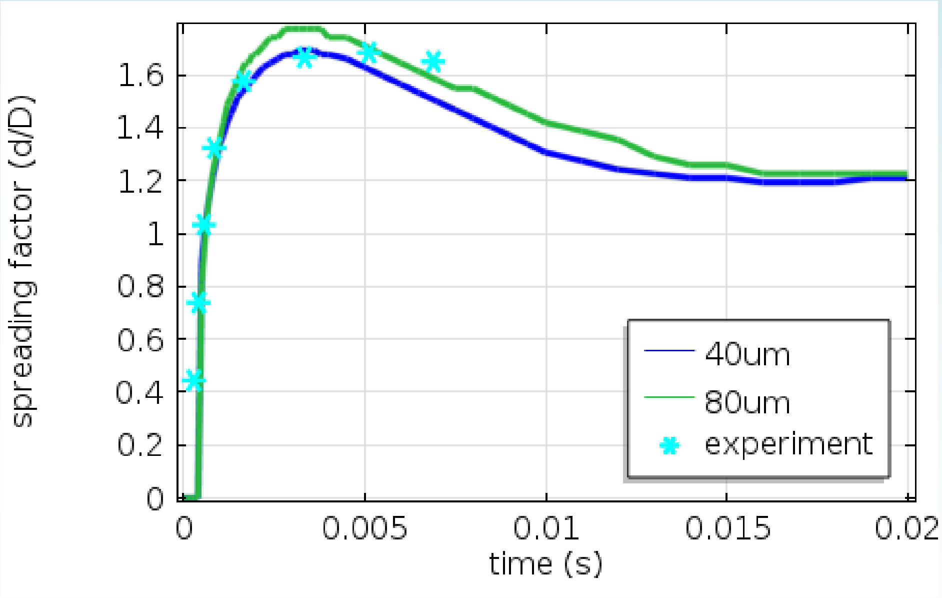


Apex Height

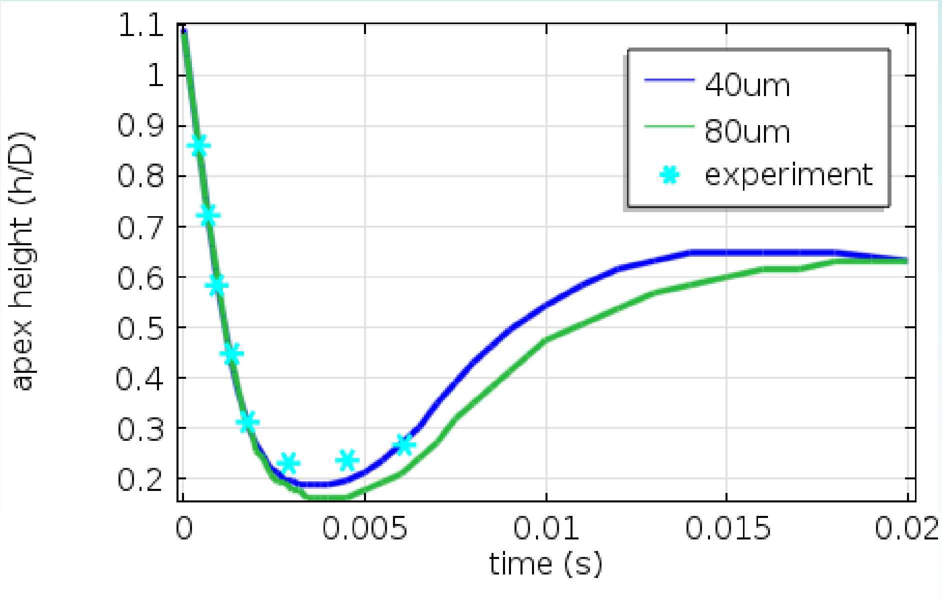


Effect of mesh and Experimental Validation

Spreading Factor



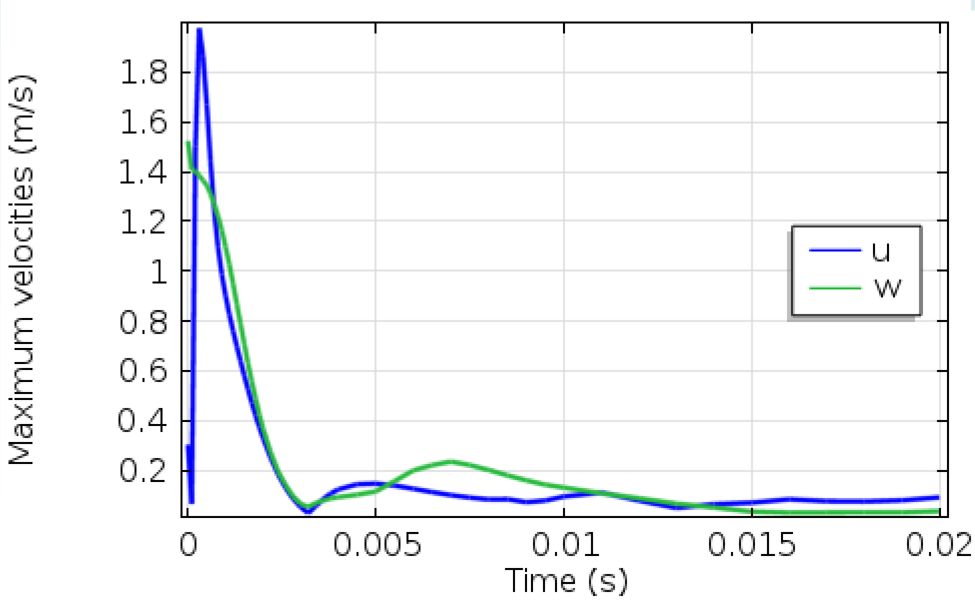
Apex Height

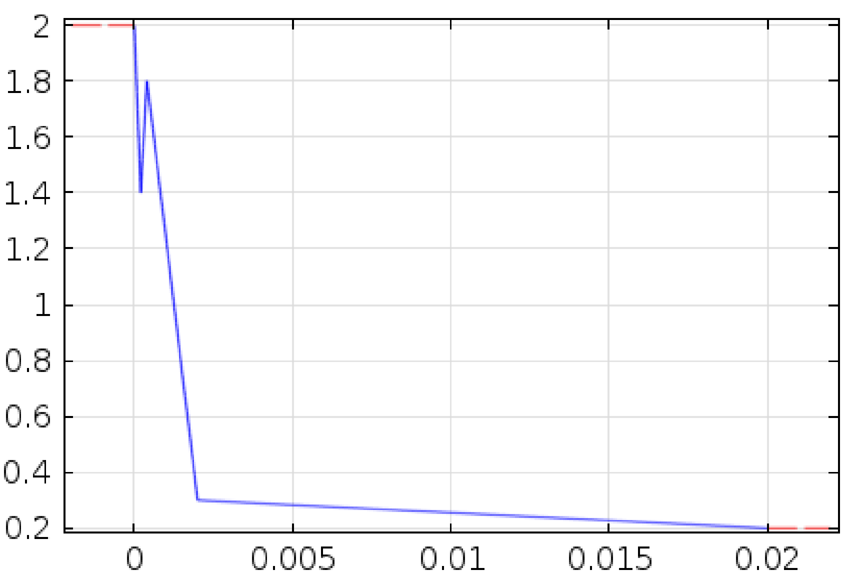


Effect of Reinitialization Parameter, γ

Maximum Velocity

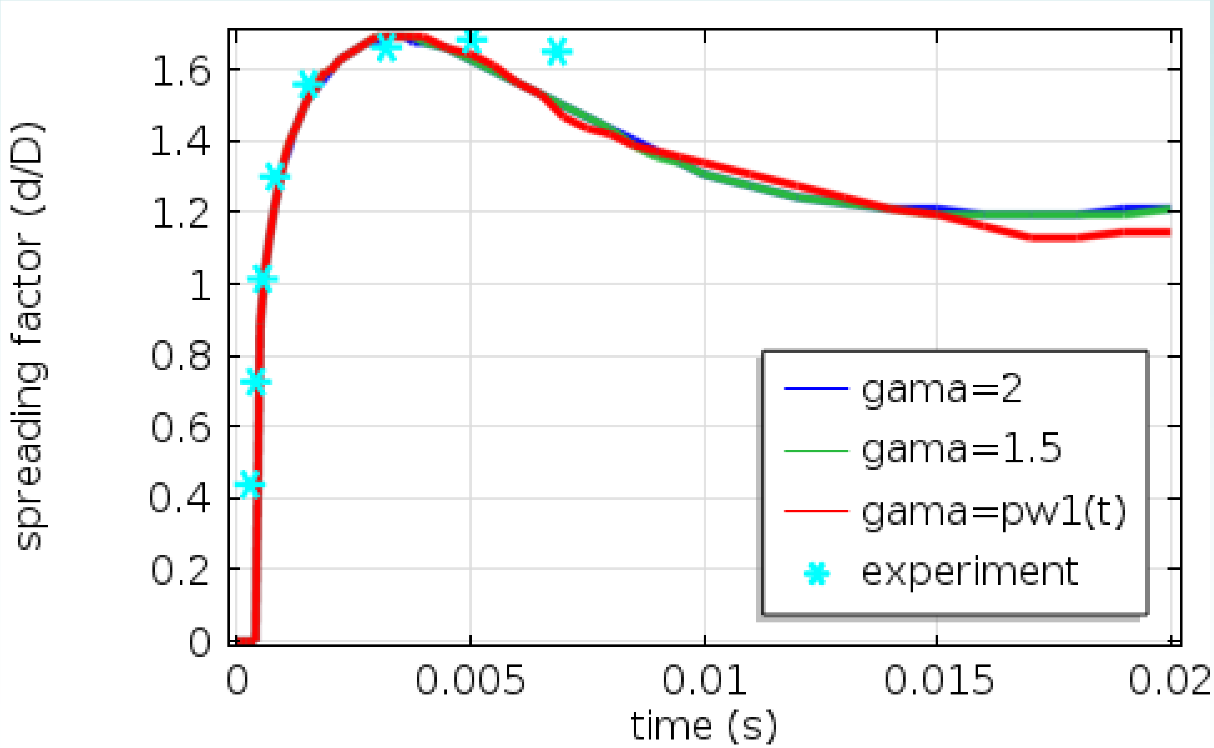
Piecewise function pw1(t) for γ



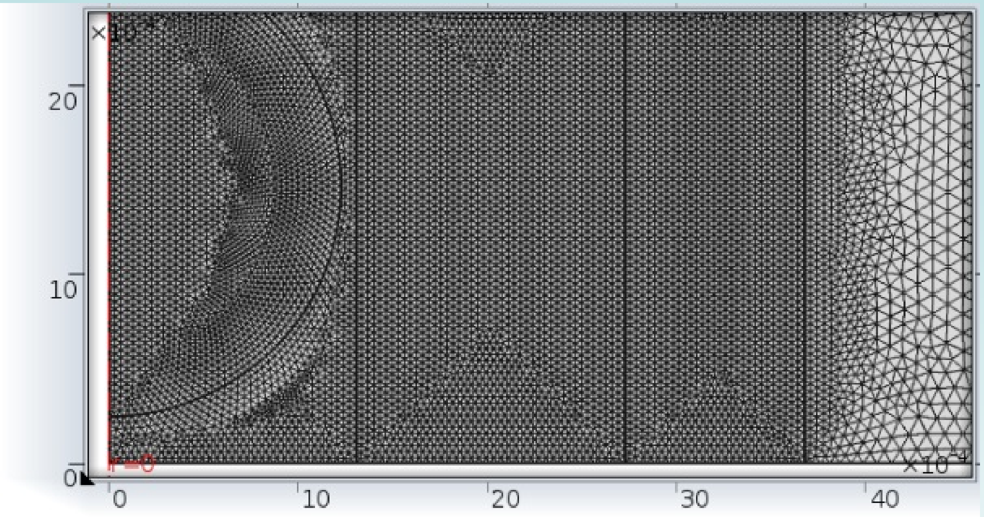


Effect of Reinitialization Parameter, γ

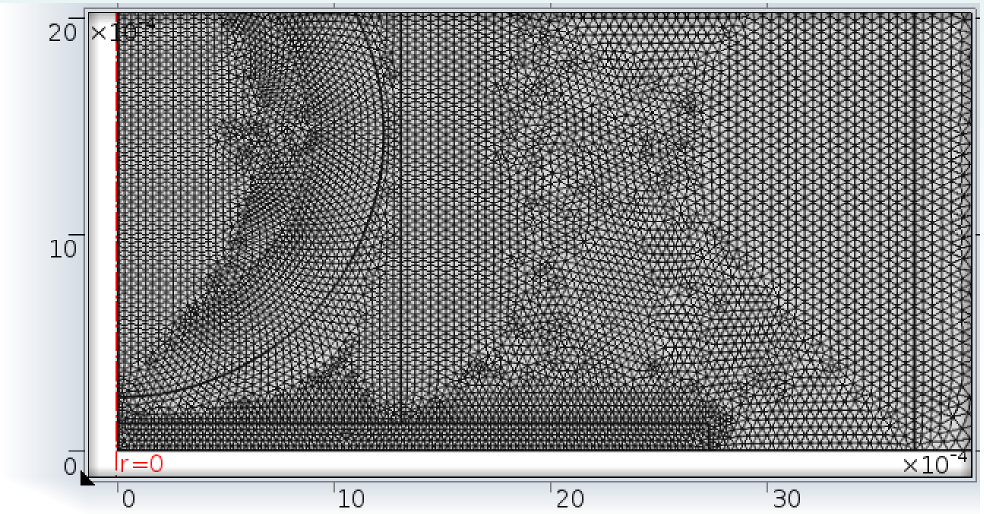
Comparison of Spreading Factors Obtained with Different Setting of γ



Effect of the Parameter Controlling Interface, ε_{ls}



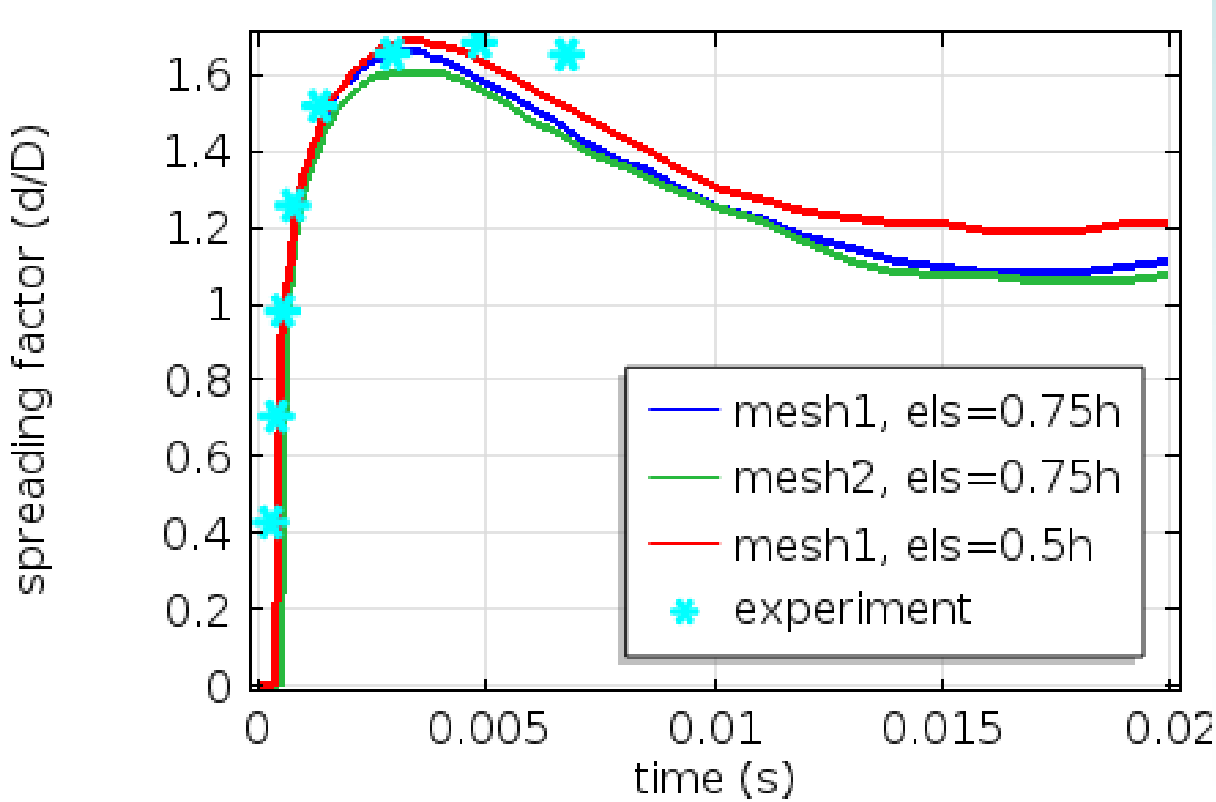
mesh1



mesh2

Effect of the Parameter Controlling Interface, ε_{ls}

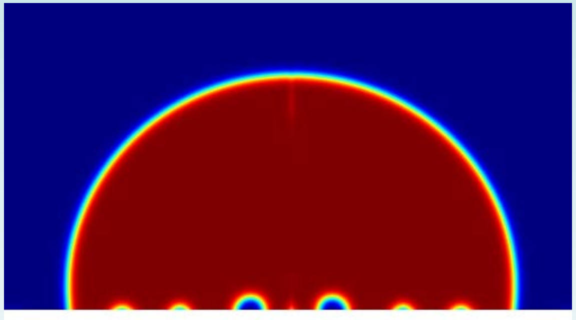
Comparison of Spreading factors Obtained with Different Meshes and ε_{ls}



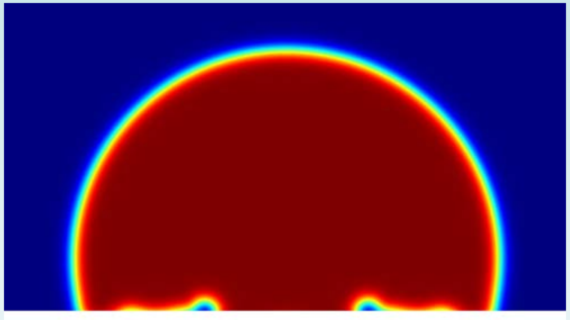
Effect of the Parameter Controlling Interface, ε_{ls}

Droplet Cross-Sectional Shape

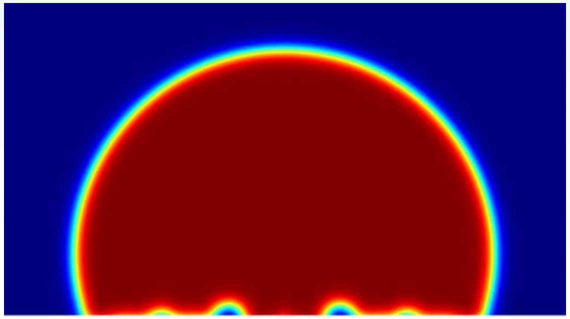
mesh1 and $\varepsilon_{ls} = 0.5h$



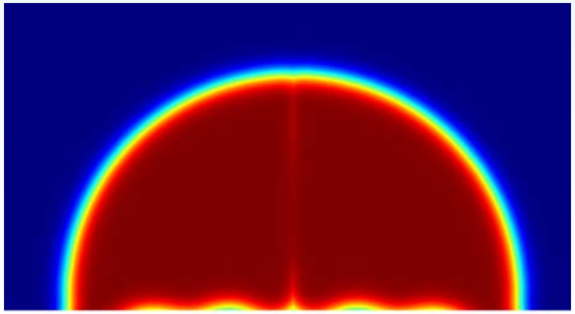
mesh1 and $\varepsilon_{ls} = 0.75h$



mesh2 and $\varepsilon_{ls} = 0.75h$

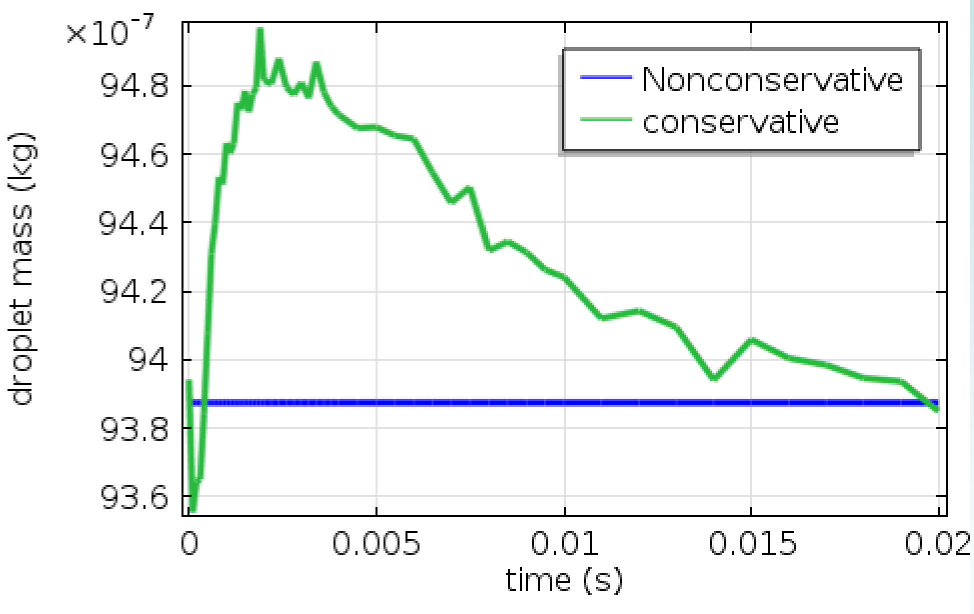


Coarse mesh and $\varepsilon_{ls} = 0.5h$

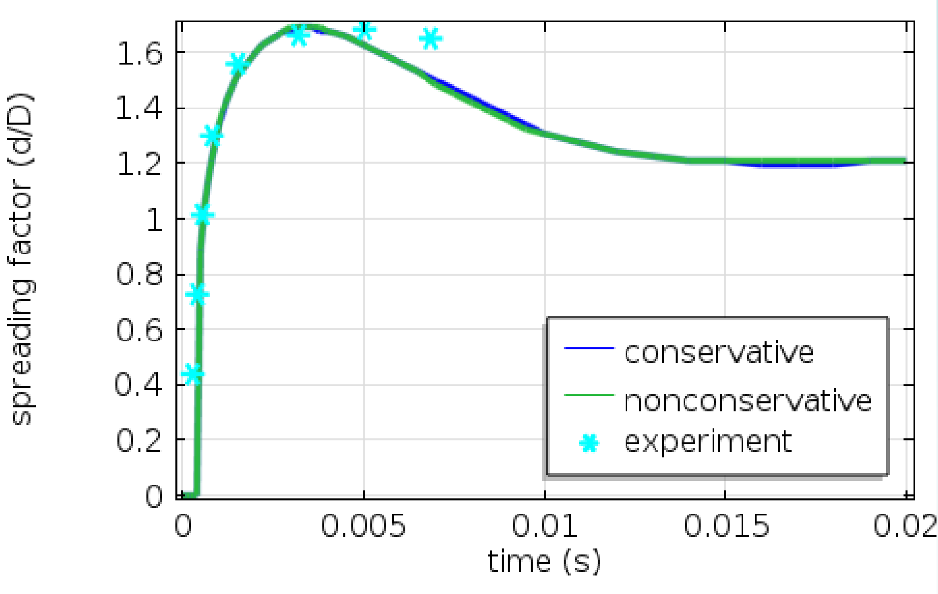


Effect of Conservative and Nonconservative Form

Doplet Mass



Spreading Factor



Conclusions

- ☐ The dynamic process of glycerin impinging onto two solid substrates with different surface wettability were simulated using the conservative Level Set method.
- ☐ The dynamic process of impingement was presented.
- ☐ The droplet spreading factor and apex height of glycerin spreading on a wax surface were validated against experimental results and good agreement were found
- ☐ Level set parameters are also studied to see their effects on the spreading factor and the porosity formation.

Thank You