# Level-set simulation of impingement and spreading of micro-sized non-Newtonian droplet on solid surface

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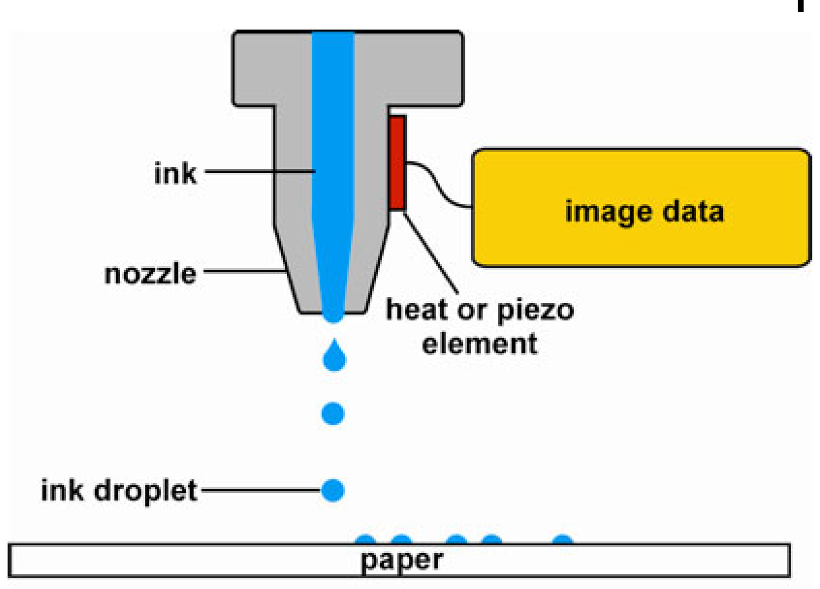
## Introduction:

The impingement and spreading of a micro-sized droplet on a solid substrate are the critical processes that determine the size and location of the features to be deposited. Extensive studies have been devoted to spreading dynamics of Newtonian fluids. However, numerous polymer solutions and particulate suspensions exhibit non-Newtonian characteristics. In the present work, we propose a Level-set simulation of non-Newtonian micro-sized droplet impacting on solid surface.




http://www.dp3project.org

**Figure 1**. Drop-on-demand inkjet.

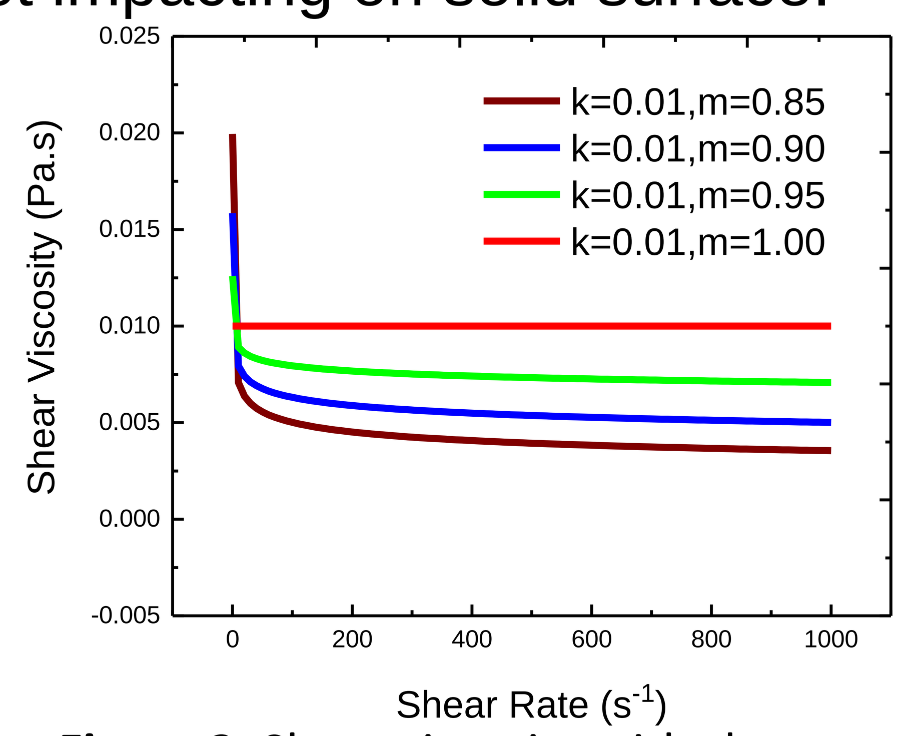



**Figure 2**. Shear viscosity with shear rate of liquids with different power law index *m*.

## Computational Method:

The interfaces are tracked by the Level-set method. The incompressible liquid−air flow of mass and momentum are represented by the Navier−Stokes equations. To implement the shear thinning non-Newtonian fluid properties, the truncated Power-law viscosity model has been adopted in the present computational model.

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

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

$$F_{st} = \nabla\cdot((\sigma(\mathbf{I} - \mathbf{n}\mathbf{n}^T))\delta)$$

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

$$\eta(\dot{\gamma}) = k\dot{\gamma}^{m-1},\ \left[\dot{\gamma} = \max\left(\sqrt{\mathbf{D}:\mathbf{D}}, \dot{\gamma}_{\min}\right)\right],$$

$$\mathbf{D} = \frac{1}{2}\left[\nabla\mathbf{u} + (\nabla\mathbf{u})^T\right], \dot{\gamma}_{\min} = 0.01s^{-1}$$

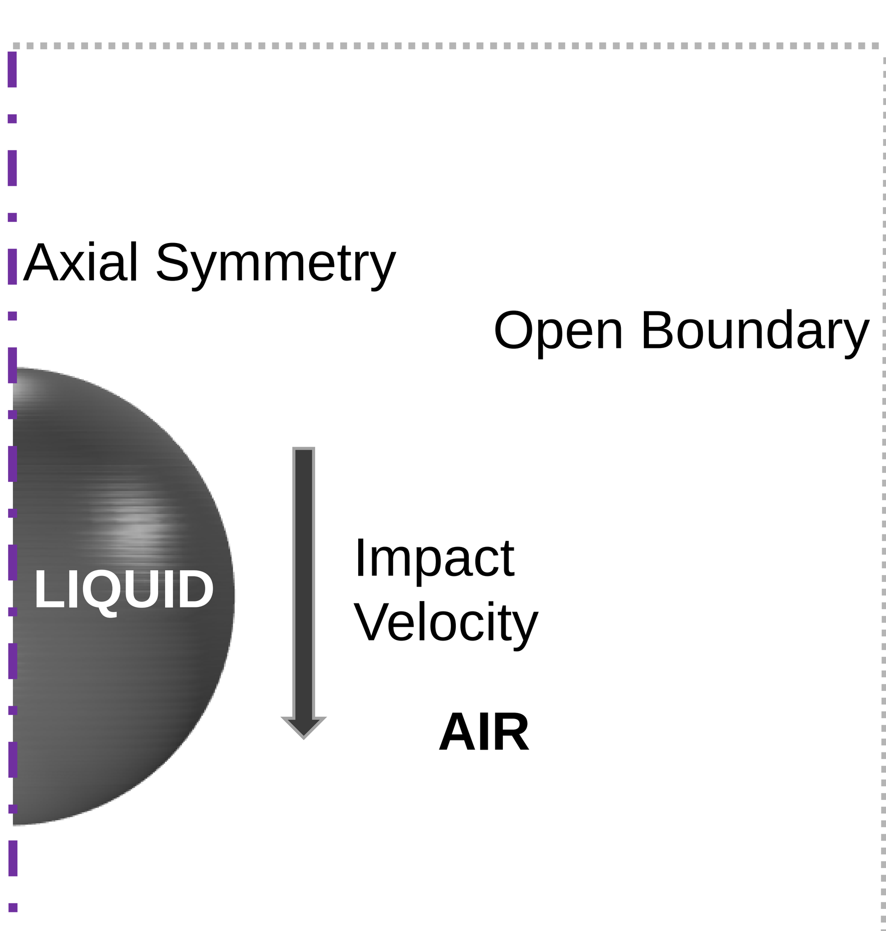
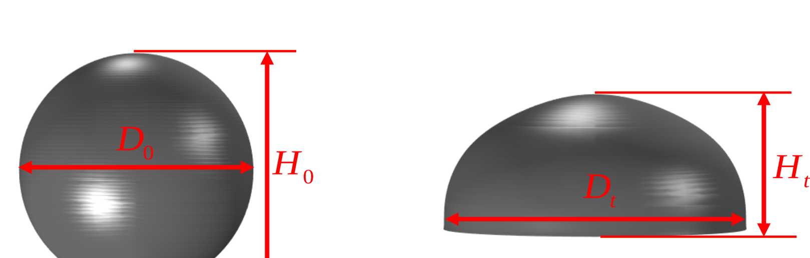



**Figure 3**. Computation domain for axisymmetric simulation.



Spreading Factor: $D^* = \frac{D_t}{D_0}$

Dimensionless Height: $H^* = \frac{H_t}{H_0}$

**Figure 4**. Definition of dimensionless Parameters.

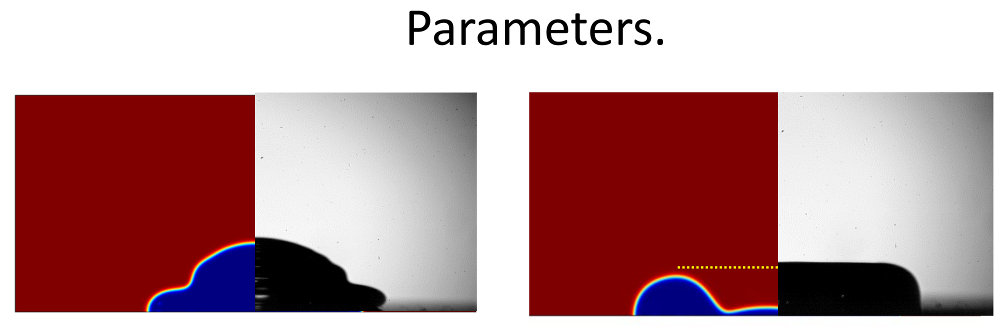



**Figure 5**. Visualization of a water droplet impact on surface: the left half is simulation, the right half is experiment (We=15).

## Simulation Results:

| Variables | Value | Units |
|---|---|---|
| Density | 1000 | kg/m³ |
| Droplet Diameter | 55 | um |
| Surface Tension | 72.8 | mN/m |
| Impact Velocity | 2.45 | m/s |
| Weber Number | 4.53 | 1 |
| Contact Angle | 55 | degree |

**Table 1**. Droplet and surface properties.

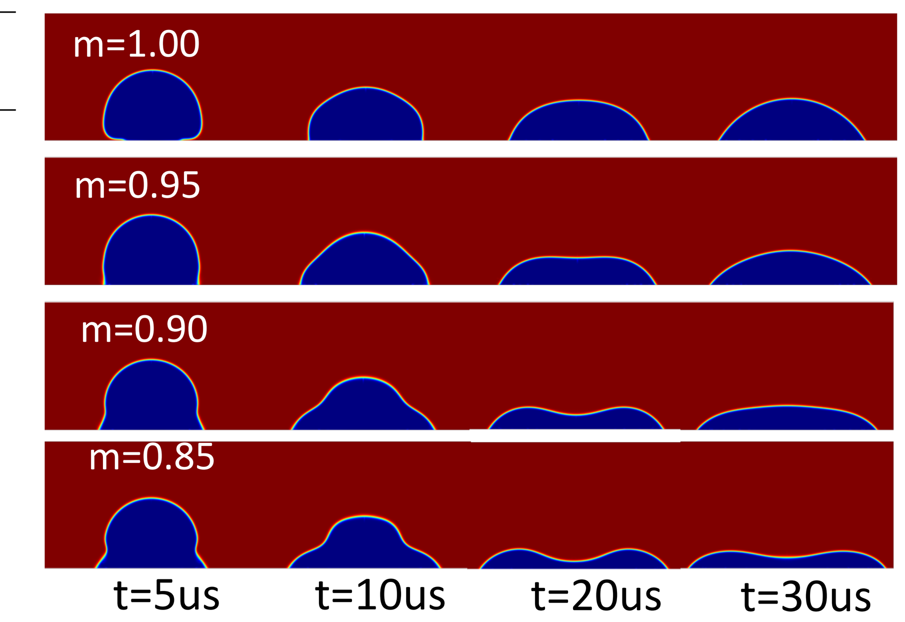



**Figure 6**. Spreading processes of droplet on solid surface.

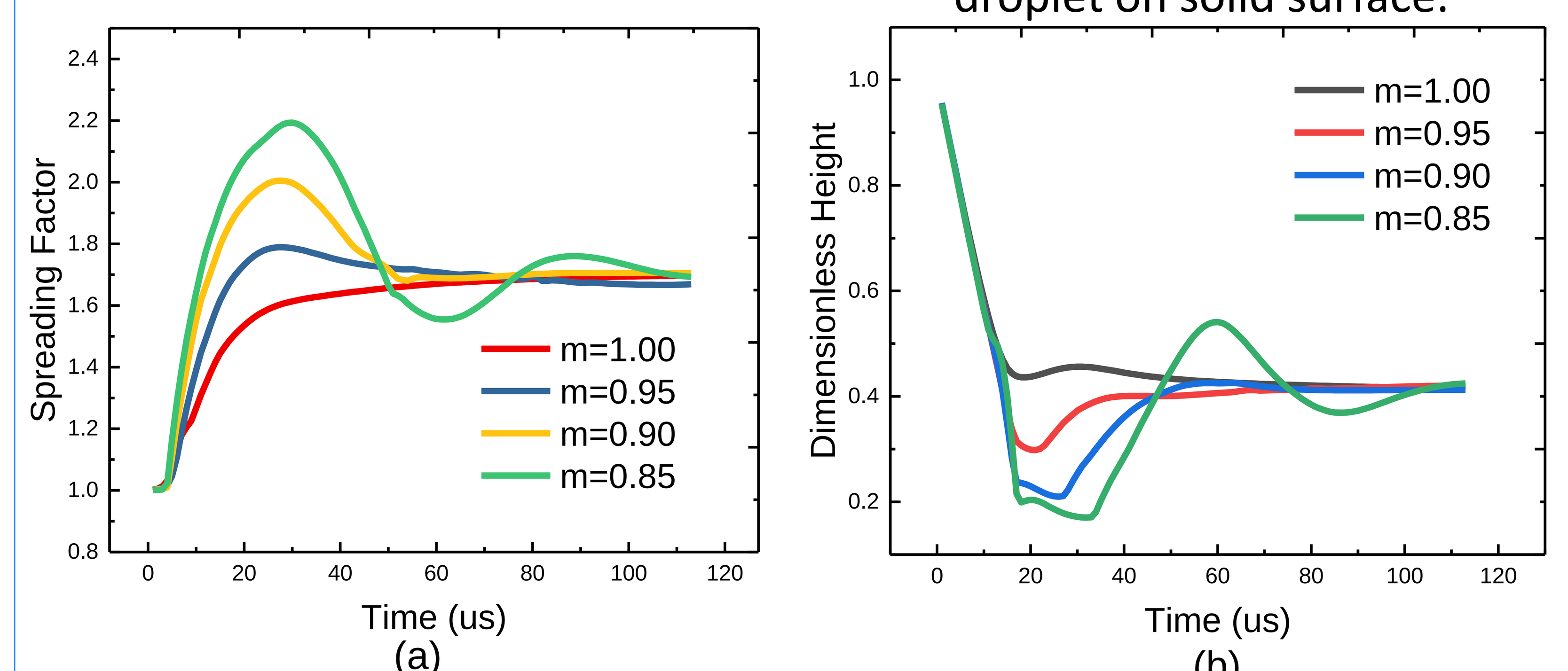



**Figure 7**. Droplets with various power law index *m* impact on surface: evolution of the spreading factor (a) and dimensionless height (b) with time.

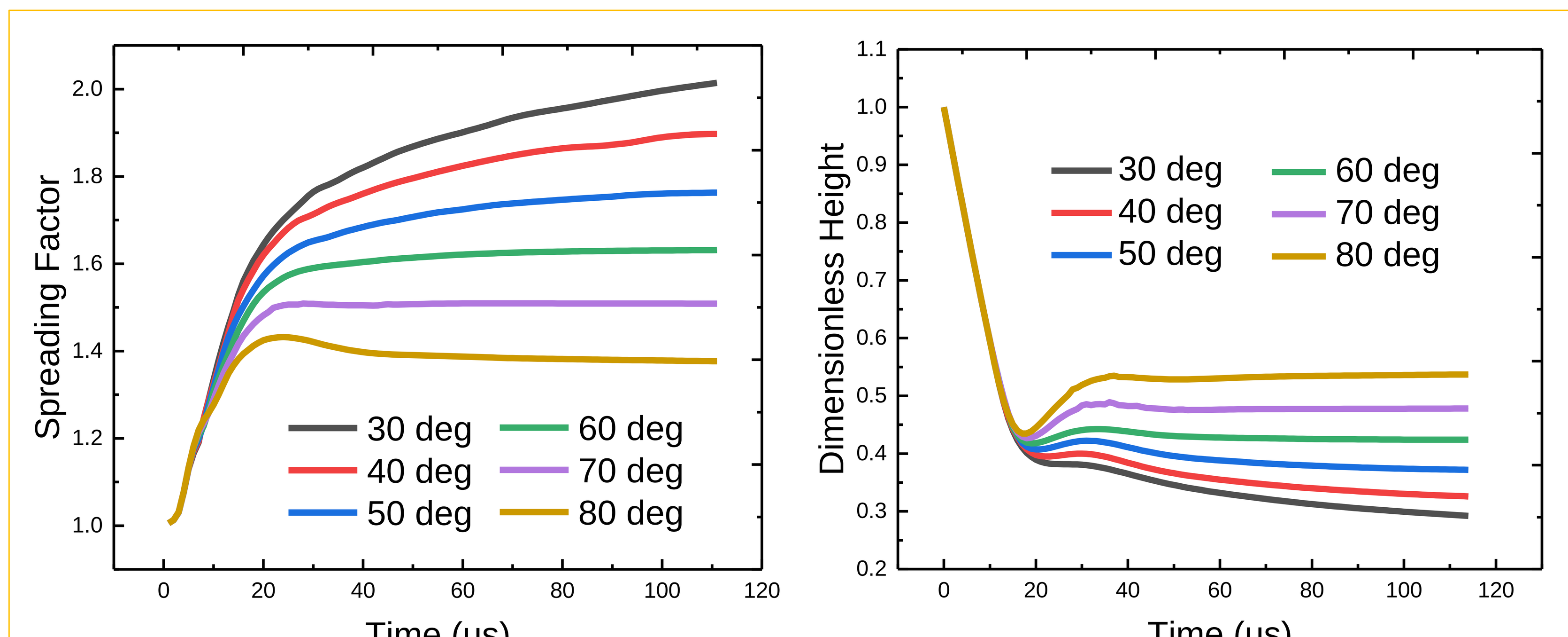



**Figure 8**. Effects of surface wettability: evolution of the spreading factor (a) and dimensionless height (b) with time (k=0.01, m=1; We=4.53).

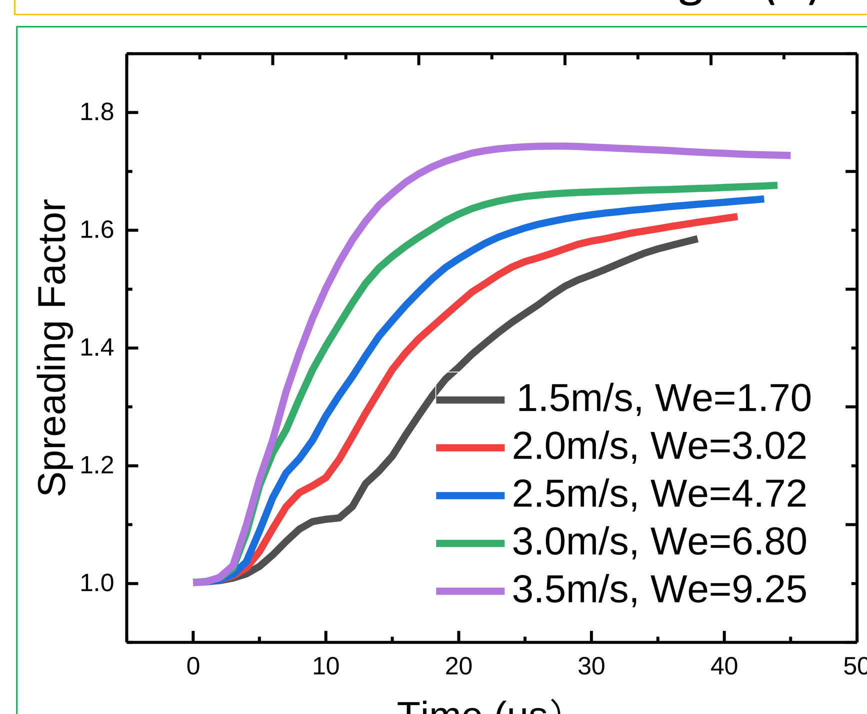



**Figure 9**. Effects of inertial force (k=0.01, m=1; Contact Angle=55 deg).

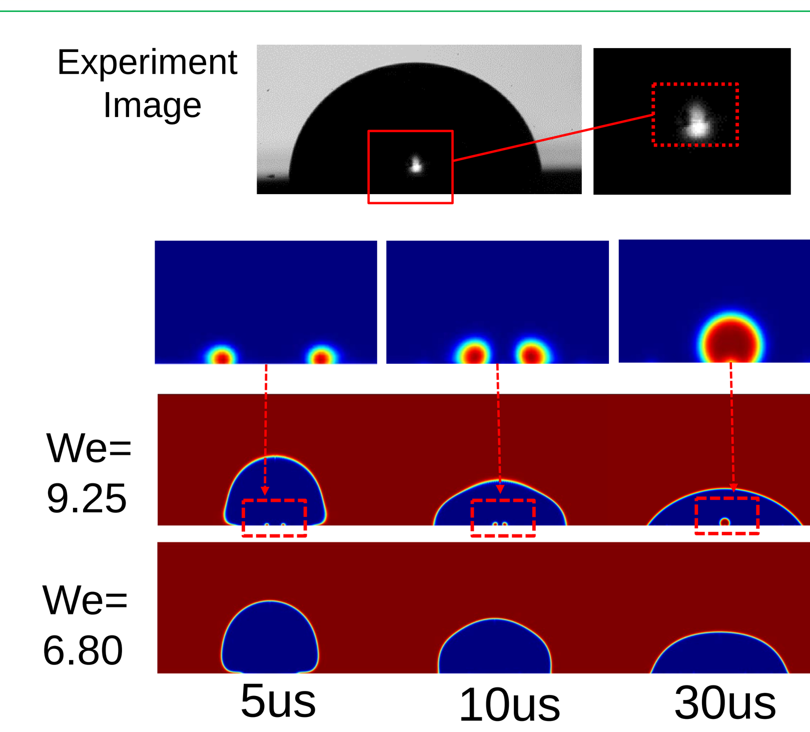



**Figure 10**. Air Bubble Entrapment.

## Conclusions:

The impingement and spreading of a micro-sized droplet with different rheological properties on a solid surface were modeled numerically based on Level-set method through finite element method. Numerical results based on various surface wettability and inertial force were also compared.

## Reference:

1. Liu, H.L., Um, M.K., Hwang, W.R., A scaling rule for the flow mobility of a power-law fluid through unidirectional fibrous porous media. Journal of Non-Newtonian Fluid Mechanics 224, 40–50, 2015
2. Olsson, E., Kreiss, G., A conservative level set method for two phase flow. Journal of Computational Physics 210, 225–246, 2005

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