Numerical Simulation of the Bouncing Behavior of Non-Newtonian Droplets Impacting on Hydrophobic Surfaces

Nuo Zheng, Hailong Liu*, Honglei Wu, Junfeng Wang and Changfeng Li
School of Energy and Power Engineering, Jiangsu University, Zhenjiang, Jiangsu Province, China

Introduction:

The droplet impact on a solid wall is common and important phenomenon in numerous applications, it is widely used in industrial and agricultural production. And different industrial applications require droplets to exhibit different spreading behavior. Many studies have pointed out that the shear viscosity of droplets with shear-thinning property dynamically changes during the spreading process and directly affects droplet behavior. Therefore, we present numerical simulation of shear-thinning droplets impacting on hydrophobic surfaces based on level-set method and dynamic contact angle model.

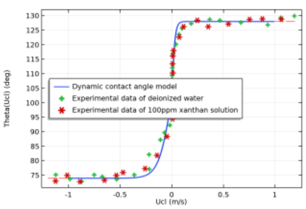


Figure 1. Comparison of dynamic contact angle model and experimental data

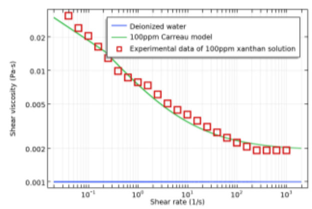
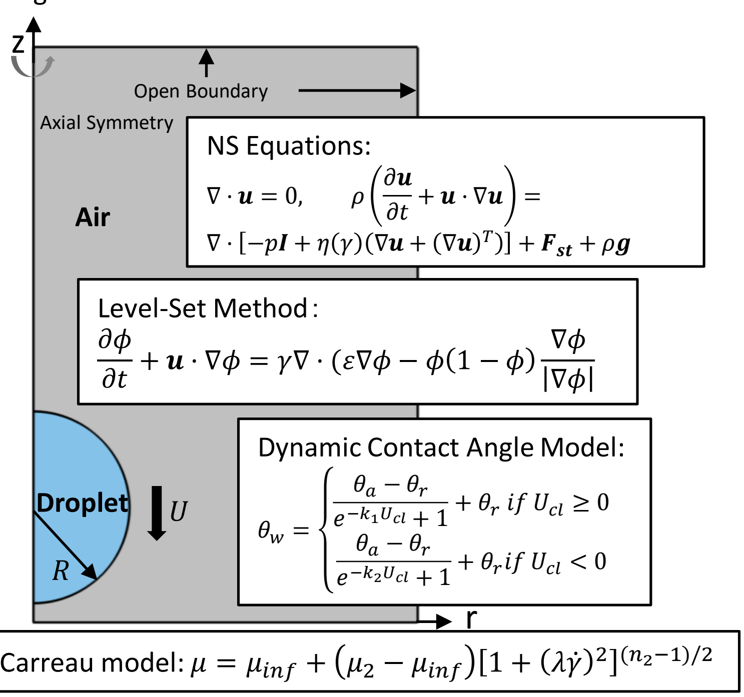


Figure 2. Comparison of carreau model and experimental data

Computational Method:

A numerical model based on the level-set method was developed by the finite element simulation software COMSOL Multiphysics. The carreau model is used to represent the dynamically changing viscosity of non-Newtonian fluid during droplet spreading stage. And the dynamic contact angle function is derived from the sigmoid function.



NS Equations:

$$\nabla \cdot \boldsymbol{u} = 0, \qquad \rho\left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{u}\right) = \nabla \cdot [-p\boldsymbol{I} + \eta(\gamma)(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T)] + \boldsymbol{F}_{st} + \rho \boldsymbol{g}$$

Level-Set Method:

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

Dynamic Contact Angle Model:

$$\theta_w = \begin{cases} \dfrac{\theta_a - \theta_r}{e^{-k_1 U_{cl}} + 1} + \theta_r \; if \; U_{cl} \geq 0 \\ \dfrac{\theta_a - \theta_r}{e^{-k_2 U_{cl}} + 1} + \theta_r if \; U_{cl} < 0 \end{cases}$$

Carreau model: $\mu = \mu_{inf} + (\mu_2 - \mu_{inf})[1 + (\lambda \dot{\gamma})^2]^{(n_2-1)/2}$

Figure 3. Computation domain: boundary conditions and numerical formulation

Results:

Variables	Value	Units	Variables	Value	Units
Density	1000	Kg/m3	Weber Number	30.7	1
Droplet Dimeter	2.38	mm	Advancing Angle	128	degree
Surface Tension	73	mN/m	Receding Angle	74	degree

Table 1. Droplet and surface properties

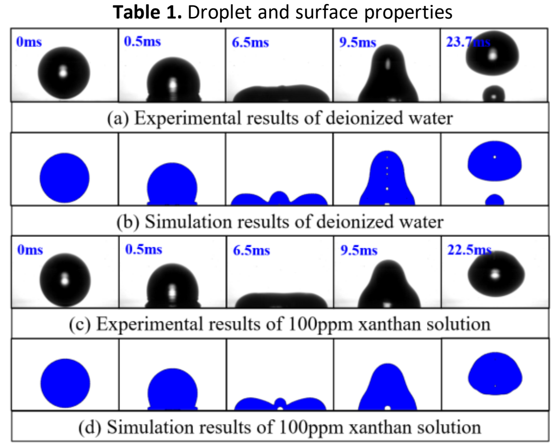


Figure 4. Image sequence of droplets impacting on hydrophobic surfaces

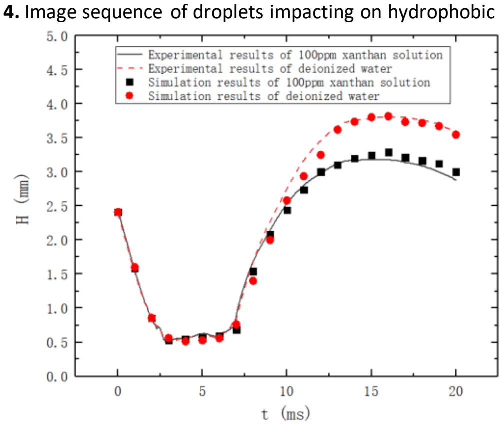


Figure 5. Temporal evolution of droplets height H for deionized water and 100ppm xanthan solution (experimental results and simulation results)

Conclusions:

Numerical simulations of the bouncing behavior of Newtonian and non-Newtonian fluid droplets impacting on hydrophobic surfaces were performed based on the level set method and dynamic contact angle model. Comparison with the experimental data shows that not only the height curves of the droplets matched well, but also the different bouncing behavior of the droplets after impacting on hydrophobic surfaces were well simulated. This verifies the accuracy of this numerical model.

Reference:

1. Liu, H. L. et al. Spreading behaviors of high-viscous nanofluid droplets impact on solid surfaces. Korea-Australia Rheology Journal 31 (2019).
2. Yokoi, K., Vadillo, D., Hinch, J. & Hutchings, I. Numerical studies of the influence of the dynamic contact angle on a droplet impacting on a dry surface. Physics of Fluids 21, 072102 (2009).

江蘇大學
JIANGSU UNIVERSITY