The Effects of the Contact Angle on the Dynamics of Water Droplet Impingement

J. Hu[1], X. Huang[2], X. Xiong[1], K. T. Wan[2]

[1]University of Bridgeport, Bridgeport, CT, USA
[2]Northeastern University, Boston, MA, USA

Abstract

INTRODUCTION

The dynamic behavior of droplet impingement on a solid surface is important to many engineering applications, such as rain drops on automobile windshields, inkjet deposition and metal deposition in manufacturing processes, spray cooling of electronics, and spray coating for various applications. The droplet can spread, splash, and rebound after hitting a solid surface.

Contact angle hysteresis, a difference between the advancing contact angle and receding contact angle, is observed experimentally during the droplet spreading and recoiling process. This dynamic variation of contact angle during the spreading process might be caused by surface inhomogeneity, surface roughness, impurities on the surface and temperature variation (4). When prescribing the contact angle, the value of the angle is dependent on the sign of the contact-line speed UCL because of hysteresis (5,6). As it is normally difficult to incorporate a dynamically varying contact angle in computations, a constant contact angle has typically been used. Several works have been devoted to predict the dynamic change of contact angle during the droplet impact process in order to capture the temporal evolution of the phenomenon (5-10).

The dynamic process of droplet impingement is complex and the mechanism of droplet and surface interaction is not fully understood. This paper investigates the dynamic behavior of a droplet impinging onto a dry wax surface using a model created in COMSOL Multiphysics® software with the Phase Field method. Two different fixed contact angles as well as contact angle hysteresis are studied to see their effects on the droplet impingement process.

USE OF COMSOL MULTIPHYSICS

An axisymmetric numerical model is implemented in the commercial finite element software COMSOL Multiphysics. The geometry is shown in Fig. 1, where the water droplet is initially positioned at a certain distance above the substrate with an initial velocity. The droplet travels downward toward the substrate under the influence the gravity force and reaches the substrate at an impact velocity Vi.

Open boundary conditions are used at the top and side to simulate an infinite domain. A wetted

wall boundary condition is used for the substrate at the bottom.

The surface wettability of water on a wax surface was characterized by Sikalo and Ganic13 and Sikalo et al.14 with static advancing contact angle (θa = 105o) and static receding contact angle (θr = 95o). However, it is difficult to measure the dynamic contact angles. Therefore, contact angles are varied in the simulation to study their effects on the impingement process. Three different settings of contact angles are used: (1) fixed advancing contact angle (θa = 105o) and fixed receding contact angle (θr = 95o), and (2)-(3) fixed contact angles (θ = 95o and 100o) unaffected by motion.

CONCLUSIONS

The simulation results showed good agreement with the dynamic impingement process found in the experiment. The effect of contact angles on the impingement process was also studied. The simulation results can provide a good understanding of the dynamic impingement process and provide insights on how to control surface wettability to achieve a desired droplet spreading and rebounding process.

Reference

1. A. Gupta and R. Kumar, Droplet impingement and breakup on a dry surface, Computers and Fluids, 39, 1696-1703 (2010).

2. V. Bertola, Dynamic wetting of dilute polymer solutions: the case of impacting droplets, Advances in Colloid and Interface Science, 193-194, 1-11, 2013.

3. V. Bertola, An impact regime map for water drops impacting on heated surfaces, International J. of Heat and Mass Transfer, 85, 430-437, 2015.

4. W. Zhou, D. Loney, A. G. Fedorov, F. L Degertekin, D. W. Rosen, Impact of polyurethane droplets on a rigid surface for ink-jet printing manufacturing, 21st Solid Freeform Fabrication Symposium, 2010, Austin, TX.

5. P.D.M. Spelt, A level-set approach for simulations of flows with multiple moving contact lines with hysteresis, J. of Computational Physics, 207 (2005) 389-404.

6. Y. Sui, P.D.M. Spelt, An efficient computational model for macroscale simulations of moving contact lines, J. of Computational Physics, 242 (2013) 37-52.

7. I. Malgarinos, N. Nikolopoulos, M. Marengo, C. Antonini, M. Gavaises, VOF simulations of the contact angle dynamics during the drop spreading: standard models and a new wetting force model, Advances in Colloid and Interface Science, 212 (2014) 1-20.

8. K. Yokoi, D. Vadillo, J. Hinch, I. Hutchings, Numerical studies of the influence of the dynamic contact angle on a droplet impacting on a dry surface, Physics of Fluids, 21 072102 (2009).

9. S. Dong, On imposing dynamic contact-angle boundary conditions for wall-bounded liquid-gas flows, Comput. Mehtods Appl. Mech. Engrg., 247-248 (2012) 179-200.

10. A.A. Saha, S.K. Mitra, Effect of dynamic contact angle in a volume of fluid (VOF) model for a microfluidic capillary flow, J. of Colloid and Interface Sci., 339 (2009) 461-480.