AN INVESTIGATION OF DROPLET IMPINGEMENT ON LIQUID FILM CONSIDERING THE EFFECT OF EVAPORATION OF LIQUID

Jia-Hong Guo Xiao-Yong Wang
Shanghai Institute of Applied Mathematics and Mechanics
Shanghai University, Shanghai 200072, P.R.China

INTRODUCTION

Droplet impinging upon a liquid film on the solid surface is of both academic and practical importance to many processes such as the corrosion of turbine blades, spray injection in internal combustion engines, ink-jet printing, the spray and droplet impingement cooling. In these processes, evaporation of the liquid is inevitable, and for this reason, there always exists vapour around the liquid. Therefore, it is essential to understand the underlying mechanisms of two-phase flow governing the flow phenomenon as a droplet collide onto the film when the effect of evaporation should be considered. Although some experimental and numerical results have been reported such as Josserand et al (2003), Wal Randy et al (2006) and Castanet et al (2009) on droplets impinging on the film, until now, few efforts have been made to elucidate the two phase flow mechanism for a droplet colliding onto the film considering the effect of evaporation of the liquid and then the vapour flow. In this paper, numerical simulation and experimental observation have been performed to investigate the two phase flow phenomena resulted from the impingement of a single liquid droplet on to the film considering the effect of evaporation of liquid and to probe into the roles of the vapour flow, the density ratio of liquid to vapour and the surface tension of the liquid droplet in the impact process.

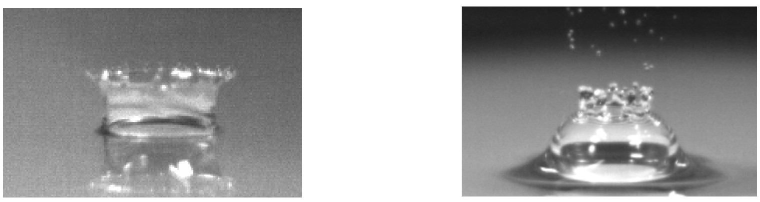
NUMERICAL METHOD AND EXPERIMENTAL SET-UP

A two-distribution function Lattice Boltzmann method by He et al(1999) and Lee et al(2005) is employed for simulating the two phase flow induced by a liquid droplet impinging onto the film of the same liquid on solid surface, which is considered here to be incompressible and laminar. One distribution function models pressure and momentum, while the other distribution function models density. The surface tension force in the intermolecular forcing terms is recast in either a stress form or a potential form by using the vector identity. The stress form of the surface tension force which can smooth the profile of the modified pressure across the phase interface and improves the stability in the case of large surface tension force is adopted for the Lattice Boltzmann equation(LBE) for pressure and momentum. The potential form, which is suited for separating phase interface, is adopted for the LBE for density. The model is suitable for solution of two-phase flow at high density and viscosity ratios of liquid to vapour and phase transition between liquid and its vapor.

The experimental set-up includes a container in which an impact platform made up of aluminum on which a thin ring with changeable thickness was stuck. The inner region of the ring is filled with liquid to produce a thin film onto which droplets impinge. The platform could be heated and the temperature of the film could be changed. The pressure in the container could also be adjusted. The set-up also includes a needle suspended at a distance from the impacted liquid film ranging between 0.05 and 1.0m and connected to a small tank. A cannula is pulled on the needle to control the diameter of the droplet detached from it. A Photran APX-RS high-speed camera (1024× 512) is used to record the droplet impact at 6,000 frames per second.

RESULT AND DISCUSSION

The characteristics of droplet impact on a liquid film are dependent on the diameter D, the impact velocity V, the viscosity of the liquid μ_l and the vapour μ_v, the density of the liquid ρ_l and the vapour ρ_v, the surface tension σ and the film thickness h. The Weber number and Reynolds number are respectively defined as $We = \rho_l D V^2 / \sigma$ and $\mathrm{Re} = \rho_l D V / \mu_l$.

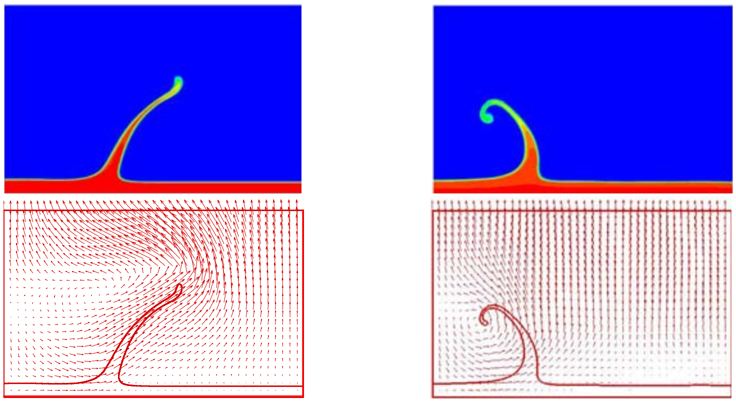


a: sparse vapour b: dense vapour

Fig.1 Comparison of flow patterns given by experiments

A series of experiments were performed for an ethanol droplet with various velocities impacting on the film of the same liquid on solid surface. Due to evaporation of the ethanol, in the container there exists ethanol vapour around the liquid. Figure 1 shows the flow patterns obtained by experiment of an ethanol droplet impacting on the film as the vapour is sparse and dense respectively. For the case of sparse vapour, a crown engenders after the droplet collides with the film, however, for the case of dense vapour a bell like splash is obtained.

Numerical simulations were conducted to investigate the two phase flow resulted from the impingement of a single liquid droplet on the film considering the effect of evaporation of liquid. The numerical results exhibit abundant flow patterns induced by the impact of a liquid droplet on the films as the liquid evaporating simultaneously. Figure 2 shows the comparison of the flow patterns and the velocity field obtained by computation with the same dynamic parameters. In Fig.2a, as ρ_l / ρ_v=1000 a crown engenders after the droplet collides with the film. Yet in Fig.2b, as ρ_l / ρ_v=10 a bell like splash is obtained. The numerical results coincide with the experimental results considerably. Therefore it is apparent that the density ratio of liquid to vapour affects remarkably the splash behaviour. The reason is due to the vapour flow induced by the droplet fall and splash in the whole impinging process and evaporation of the liquid. For the case of ρ_l / ρ_v=1000, because the vapour is much sparse, it could have almost no influence on the splash after the droplet collides with the film. For the case of ρ_l / ρ_v=10, the vapour flow holds back the expansion of the splashing lamella on its top obviously, however, the vapour flow affects the expansion of the splashing lamella on its bottom is not identifiable.



a: ρ_l / ρ_v=1000 b: ρ_l / ρ_v=10

Fig.2 The flow patterns and the velocity field resulted by impact of a droplet on film

CONCLUSIONS

Through experiments and simulations, the following conclusions are reached:

(1) The vapour flow plays an important role in flow phenomena resulted from the impingement of a single liquid droplet on to the film as liquid evaporating simultaneously.

(2) As liquid evaporating simultaneously, for the case of high density ratio of liquid to vapor a crown may engender after the droplet collides with the film. However, for the case of small density ratio of liquid to vapor a bell like splash may be observed.

(3) The Weber number, the Reynolds number, the density ratio of liquid to vapor and the thickness of the film play different roles in determining the process of droplet spread, the dimensions of the crown and the status of the splash at each time as a droplet impacts on the film.

Acknowledgement

This work was supported by the National Natural Science Foundation of China (Grant No.10872123, 11032007) and the Opening Fund of State Key Laboratory of Nonlinear Mechanics

References

[1] Josserand C. and Zaleski S., Droplet splashing on a thin liquid film, Physics of Fluids, 2003, 15(6): 1650-1657

[2] Wal Randy L. Vander, Berger Gordon M. and Mozes Steven D., Droplets splashing upon films of the same fluid of various depths, Experiments in Fluids, 2006, 40: 33–52

[3] Castanet G., Liénart T. and Lemoine F., Dynamics and temperature of droplets impacting onto a heated wall, International Journal of Heat and Mass Transfer, 2009, 52: 670-679

[4] He X., Chen S., Zhang R., A lattice Boltzmann scheme for incompressible multiphase flow and its application in simulation of Rayleigh–Taylor instability, J. Comput. Phys. 1999, 152(2): 642-663.

[5] Lee T. and Lin C. L., A stable discretization of the lattice Boltzmann equation for simulation of incompressible two-phase flows at high density ratio. Journal of Computational Physics. 2005, 206(1): 16-47