Numerical investigation on the fluid elasticity effect in the impact of oblique drop onto liquid film

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ABSTRACT

In this paper, the crown formation and temporal propagation due to the oblique impact of a plane two-dimensional drop onto preexisting film in the non-Newtonian viscoelastic fluid is analyzed numerically. The finite volume method (FVM) is applied to solve the governing equations and the volume of fluid (VOF) technique is used to track the free-surface of liquid phases. Here, the well-known Oldroyd-B model is used as the constitutive equation for viscoelastic phase. However, formation and temporal evolution of the crown's shape is emphasized and the effect of elastic and surface tension forces on crown's dynamic are considered in detail. The results show that the increase in Weissenberg number, viscosity ratio and Weber number leads to increase in both the dimensionless crown height (Z^*) and spread factor (S^*), while impact angle has major effect on the control of crown's height, on the other hand, this parameter has negligible effect on spread factor in viscoelastic fluid. Moreover, by thickening of fluid film, the crown's height increase and the crown's radius decrease. As a main finding of present study, the fluid's elasticity in the presence of surface tension force can enhances the rate of the crown propagation in the impact of oblique drop onto liquid film.

KEYWORDS

Viscoelastic non-Newtonian fluid, oblique drop impact, Crown formation and propagation, Two phase flow, Volume of fluid.

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1. Introduction

In fluid mechanics and technical applications, the dynamics of crown formation due to the drop impact onto a liquid film are very interesting. Although many studies [1, 2] have deal with the Newtonian cases, the influences of the fluid's rheological properties, have not been extensively studied in the literature.

Coppola *et al.* [3] numerically investigated the effects of viscous, inertia, and surface tension forces on drop impact problem. Their simulation showed that the two-dimensional results are agreed well with axisymmetric one. Cheng and Lou [4] numerically investigated the oblique impact of drop onto liquid film in Newtonian fluid. The results showed that the crown's shape is asymmetric. Chen *et al.* [5] numerically showed that the growth of crown's dimension is strongly depend on drop's inertia and the time variation of crown's radius is similar to power law relation.

In non-Newtonian fluid, Tome *et al.* [6, 7] developed a new method for solving the governing equations. Recently, Rezaie *et al.* [8] numerically investigated the effects of non-linear viscoelastic fluid on the impact of drop onto same liquid film. The results indicated that elasticity can increase the crown dimensions.

The above literatures indicate the necessity of study of the fluid's elasticity effect on oblique drop impact onto liquid film. Therefore, the inclusion of elastic and surface tension forces in governing equations is important. The parameters related with this problem are depicted in Figure 1.

2. Mathematical formulation

The schematic illustration of present problem is shown in Figure 2. The governing equations for the incompressible viscoelastic fluid flow as follows [8]:

$$\nabla \cdot v = 0, \tag{1}$$

$$\frac{\partial(\rho v)}{\partial t} + \nabla \cdot (\rho v v) = -\nabla p + \nabla \cdot \tau + \rho g + F_s. \tag{2}$$

In this study, the Oldroyd-B model is used as follows:

$$\tau + \lambda \overset{\nabla}{\tau} = 2\eta\left(\varepsilon + \frac{\lambda \eta_s}{\eta} \overset{\nabla}{\varepsilon}\right) \tag{3}$$

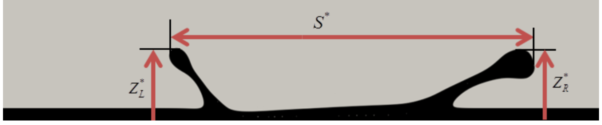

Figure 1. Schematic illustration of the crown's dimension

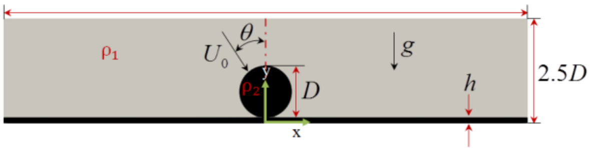

Figure 2. Schematic illustration of the problem domain

$$Re = \frac{\rho U_0 D}{\eta_0}, \quad We = \frac{\rho U_0^2 D}{\sigma}, \quad Bo = \frac{\rho g D^2}{\sigma}, \quad Wi = \lambda \dot{\gamma} = \frac{\lambda U_0}{D}, \quad \beta = \frac{\eta_p}{\eta_p + \eta_s}, \quad t^* = \frac{U_0 t}{D}, \quad H = \frac{h}{D}, \quad S^* = \frac{S}{D}, \quad Z^* = \frac{Z}{D}. \tag{4}$$

The viscoelastic drop is impacted onto quiescent fluid film with initial velocity of U_0 and angle of θ. The no-slip boundary condition is applied to bottom and side walls. The finite volume method (FVM) is applied to solve the governing equations. The OpenFOAM software is employed to discretize and solve the governing and constitutive equations.

3. Results and discussion

The results of simulations are presented for specific ranges, including the Weissenberg number (10 - 1000), Weber number (200-800), fluid film thickness (0.2-0.3), viscosity ratio (0.1-0.5) and Reynolds number (100-200), while the Bond number is kept constant at 1.6.

The accuracy of results for domain size of $2.5D \times 10D$ and grid size of 800×3200 is acceptable. The validation of the results showed that the power law relation is confirmed for growth of crown's radius. Moreover, Figure 3 reveals that the results of present solver are agree well with those of previous study.

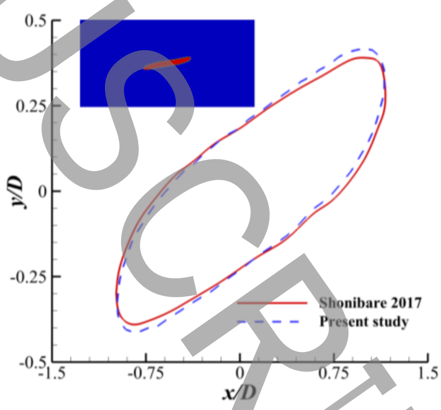

Figure 3. The comparison of drop shape between present study and Shonibare [9]

The effect of Weissenberg on crown's parameter is presented in Figure 4 for different value of impact angle. The results are indicated that the elasticity has major effect on crown's shape.

The effect of angle of impact on crown shape is shown in Figure 5. By increasing the impact angle, the right wall angle is decreased.

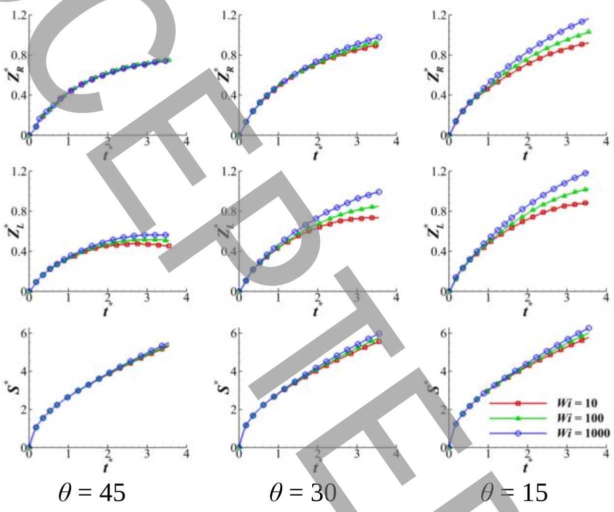

Figure 4. Time variation of crown's parameter with Weissenberg number, H = 0.2, β = 0.1, and We = 400.

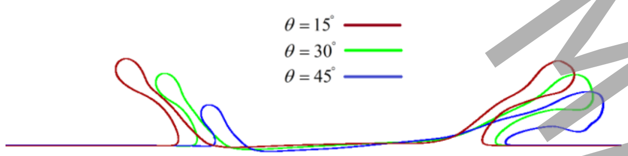

Figure 5. The crown's shape at the different impact angle.

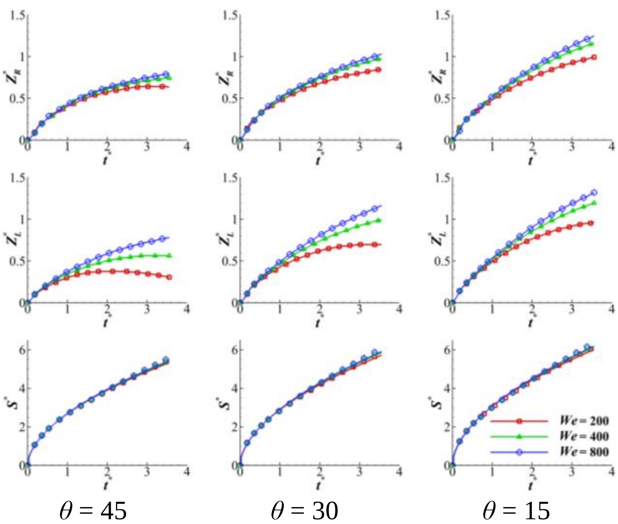

Figure 6. Time variation of crown's parameter with Weber number, H = 0.2, β = 0.1, and Wi = 1000.

The effect of Weber number on crown's parameter is depicted as in the Figure 6. The results show that the crown's height is increases as Weber number increase.

4. Conclusions

In this study, the oblique impact of drop onto liquid film in viscoelastic fluid is investigated numerically. The results of present study as follows:

- The crown's dimensions are increase by enhancement of elasticity.
- The effect of impact angle on crown's height is greater than crown's radius.
- The Weber number has significant influence on crown spread.

The results of present study help to better understanding of fluid's elasticity effect on impact problem.

5. References

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