Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 54(1) (2022) 3-6
DOI: 10.22060/mej.2021.19488.7036

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 are analyzed numerically. The finite volume method is applied to solve the governing equations and the volume of fluid 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 the viscoelastic phase. However, the formation and temporal evolution of the crown's shape is emphasized and the effects of elastic and surface tension forces on the crown's dynamic are considered in detail. The results show that the increase in Weissenberg number, viscosity ratio, and Weber number leads to an increase in both the dimensionless crown height (Z*) and spread factor (S*), while impact angle has a major effect on the control of the crown's height, on the other hand, this parameter has a 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 the main finding of the present study, the fluid's elasticity in the presence of surface tension force can enhance the rate of the crown propagation in the impact of an oblique drop onto liquid film.

Review History:

Received: Jan. 12, 2021
Revised: Oct. 07, 2021
Accepted: Oct. 09, 2021
Available Online: Oct. 28, 2021

Keywords:

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

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 dealt 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 the drop impact problem. Their simulation showed that the two-dimensional results are agreed well with the axisymmetric one. Cheng and Lou [4] numerically investigated the oblique impact of a drop onto liquid film in a Newtonian fluid. The results showed that the crown's shape is asymmetric. Chen et al. [5] numerically showed that the growth of the crown's dimension is strongly dependent on the drop's inertia and the time variation of the crown's radius is similar to the 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 a drop onto the same liquid film. The results indicated that elasticity can increase the crown dimensions.

The above literature indicates the necessity of the 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 to this problem are depicted in Fig. 1.

2- Mathematical Formulation

The schematic illustration of the present problem is shown in Fig. 2. The governing equations for the incompressible viscoelastic fluid flow are 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:

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

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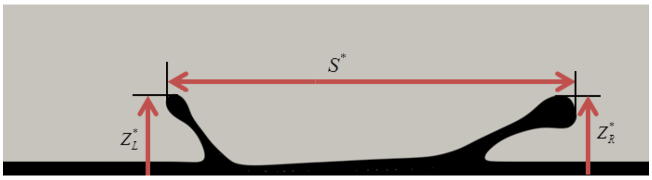


Fig. 1.Schematic illustration of the crown's dimension

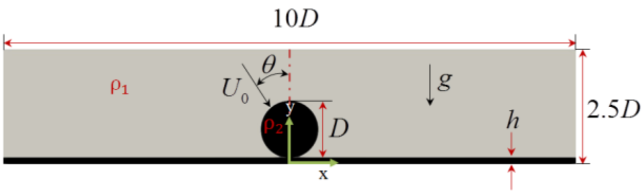


Fig. 2. Schematic illustration of the problem domain

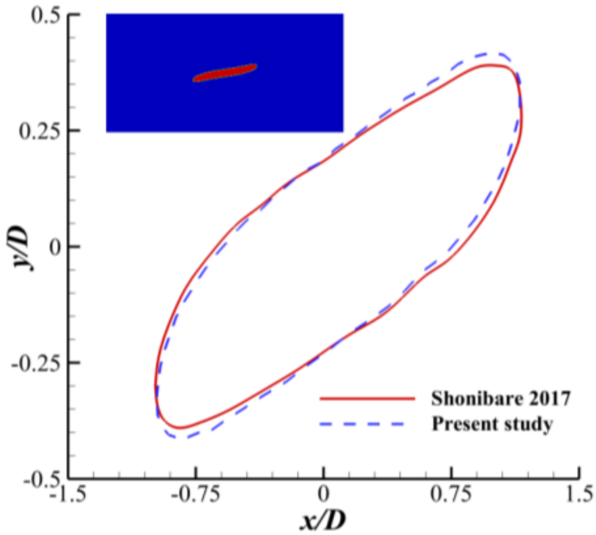


Fig. 3. The comparison of drop shape between the present study and Shonibare [9]

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

The viscoelastic drop is impacted onto quiescent fluid film with an initial velocity of U0 and angle of θ. The no-slip boundary condition is applied to the bottom and sidewalls. 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×10D and grid size of 800×3200 is acceptable. The validation of the results showed that the power-law relation is confirmed for the growth of the crown's radius. Moreover, Fig. 3 reveals that the results of the present solver are agreed well with those of the previous study.

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

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

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

4- Conclusions

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

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

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

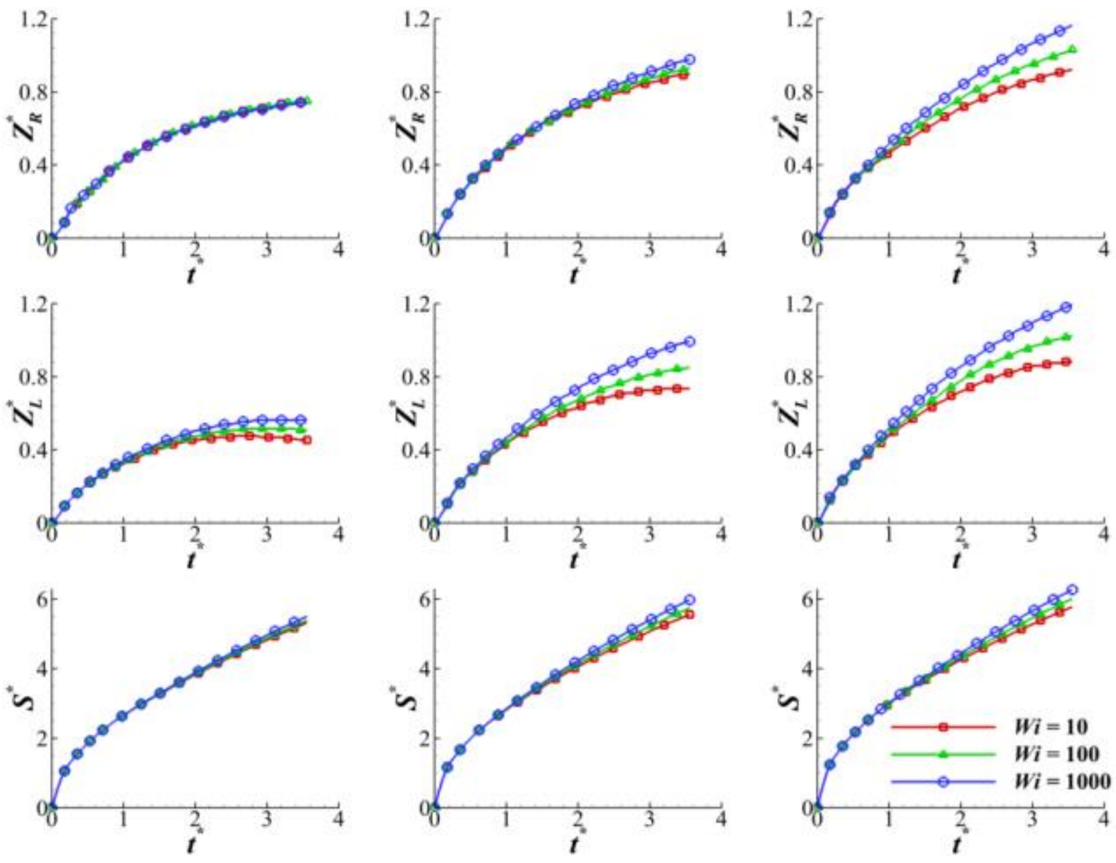


Fig. 4. Time variation of crown's parameter with Weissenberg number, H = 0.2, β = 0.1, and We = 400.

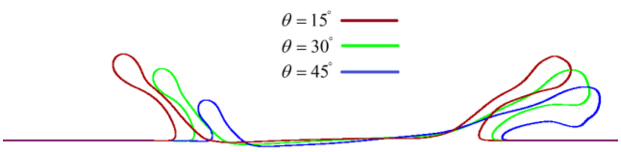


Fig. 5. The crown's shape at different impact angles.

References

[1] M. Rieber, A. Frohn, A numerical study on the mechanism of splashing, International Journal of Heat and Fluid Flow, 20(5) (1999) 455-461.

[2] S.L. Manzello, J.C. Yang, An experimental study of a water droplet impinging on a liquid surface, Experiments in Fluids, 32(5) (2002) 580-589.

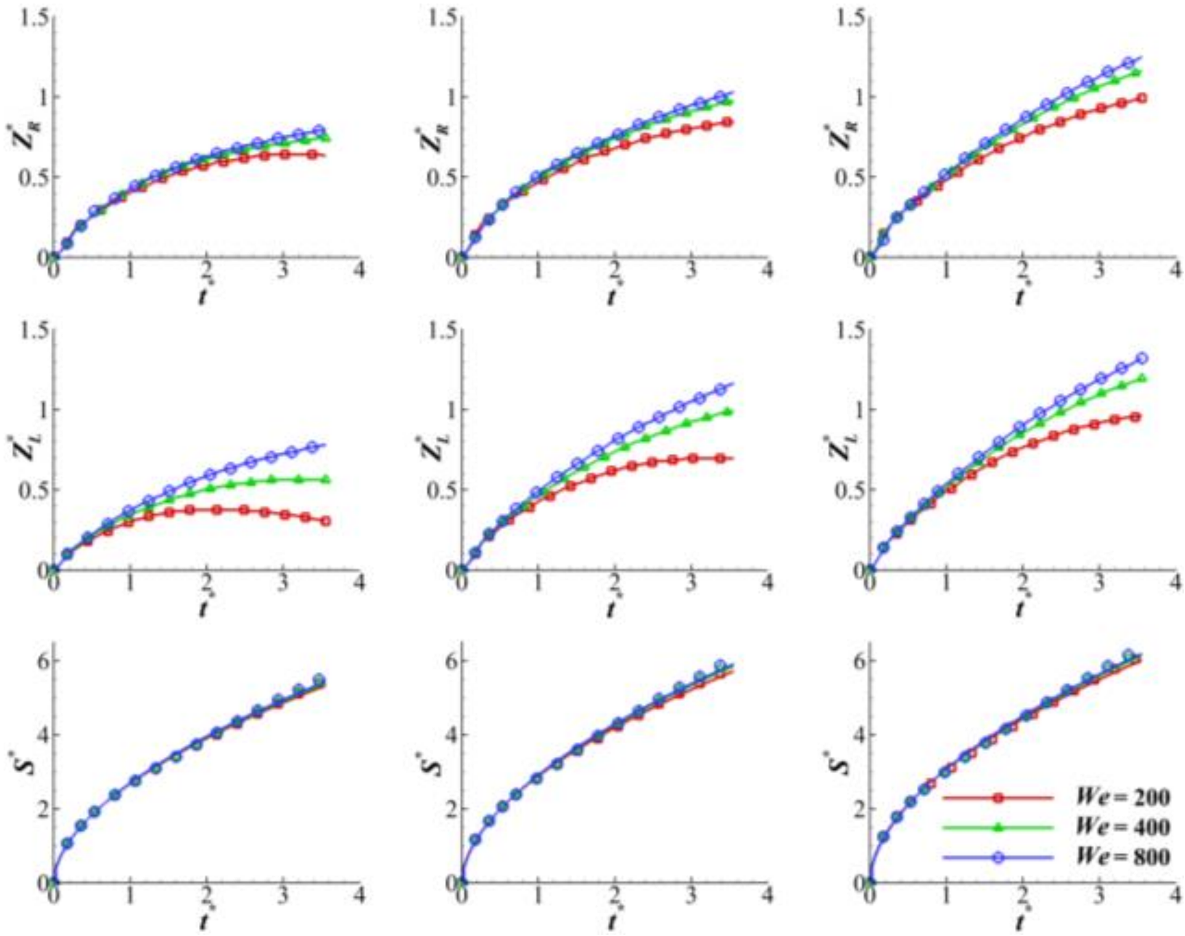
[3] G. Coppola, G. Rocco, L. de Luca, Insights on the impact of a plane drop on a thin liquid film, Physics of Fluids, 23(2) (2011) 022105.

[4] M. Cheng, J. Lou, A numerical study on splash of oblique drop impact on wet walls, Computers & Fluids, 115 (2015) 11-24.

[5] Z. Chen, C. Shu, Y. Wang, L.M. Yang, Oblique drop impact on thin film: Splashing dynamics at moderate impingement angles, Physics of Fluids, 32(3) (2020) 033303.

[6] M.F. Tomé, L. Grossi, A. Castelo, J.A. Cuminato, S. McKee, K. Walters, Die-swell, splashing drop and a numerical technique for solving the Oldroyd B model for axisymmetric free surface flows, Journal of Non-Newtonian Fluid Mechanics, 141(2) (2007) 148-166.

[7] M.F. Tomé, S. McKee, K. Walters, A computational study of some rheological influences on the "splashing experiment", Journal of Non-Newtonian Fluid



$\theta = 45$ $\theta = 30$ $\theta = 15$

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

Mechanics, 165(19) (2010) 1258-1264.

[8] M.R. Rezaie, M. Norouzi, M.H. Kayhani, S.M. Taghavi, Numerical analysis of the drop impact onto a liquid film of non-linear viscoelastic fluids, Meccanica, (2021).

[9] O. Shonibare, Numerical Simulation of Viscoelastic Multiphase Flows Using an Improved Two-phase Flow Solver, (2017).

HOW TO CITE THIS ARTICLE

M. R. Rezaie, M. Norouzi , M. H. Kayhani, S. M. Taghavi , Numerical Investigation on the Fluid Elasticity Effect in the Impact of Oblique Drop onto Liquid Film, Amirkabir J. Mech Eng., 54(1) (2022) 3-6.

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