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Simulation of the Liquid Spraying Process in the Dripping Mode by Using the Level-Set Method

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ABSTRACT: In this study, liquid spraying process and drop formation in the dripping mode is simulated using a sharp interface method and effect of important parameters on this process such as Weber number, Ohnesorge number, and the Bond number is investigated. The level-set method is used for interface tracking. Discontinuities at the interface are imposed using the ghost fluid method. It is observed that by increasing the Weber number (from 0.0027 to 0.1875), the length of the outlet liquid is increased by about 7 percent and the liquid breakup time is decreased by about 52 percent. Also, at higher Weber numbers, the liquid return toward the nozzle after droplet detachment is less. Increasing the Ohnesorge number (from 0.0002 to 0.189) increases the length of the outlet liquid about 21 percent and breakup time about 151 percent. Also, at higher Ohnesorge numbers, the liquid return toward the nozzle is higher. Increasing the Bond number (from 7 to 39) leads to the reduction of the length of the outlet liquid and breakup time about 26 and 91 percent, respectively. At higher Bond numbers, the liquid return toward nozzle is less. Another considerable result is the reduction of the size of formed droplets by enhancement of Bond number.

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1- Introduction

The liquid breakup process into small droplets appears in many engineering applications such as liquid-liquid extraction process. Shibata et al. [1] simulated the breakup of the outlet liquid from a nozzle by using the Moving Particle Semi-implicit (MPS) method. They obtained the size distribution of the formed droplets and concluded that the breakup length of the jet is proportional to the Weber and Froude numbers. Homma et al. [2] studied the breakup of a laminar jet in a liquid-liquid system by using the front tracking method. They showed that increasing the Weber number, decreases the liquid breakup time. Che et al. [3] simulated the drop formation process by using a smeared out level-set approach. They studied the pressure oscillation inside the droplet. They reported that the droplet pressure changes are due to the changes in the droplet diameter during the drop formation process. Chakraborty et al. [4] studied outlet liquid from an orifice by using a combination of the level-set and volume of fluid methods. They considered the effect of the Weber number on the drop formation process in the dripping mode and found that increasing the Weber number increases the breakup length of the outlet liquid.

In the previous studies, interface mainly has been modeled by using a smeared approach. Also, to the best knowledge of the authors, there is no comprehensive study about the effect of the important parameters on the drop formation process. In this research, the liquid spraying process in the dripping mode is simulated by using a sharp interface approach and the effect of different parameters on this process is studied.

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2- Methodology

In this study, the governing equations are the laminar incompressible continuity and momentum equations.

During solving these equations, the appropriate jump conditions must be applied at the interface. Applying the momentum equations at the interface leads to the following jump conditions:

$$\left[\begin{pmatrix}\mathbf{n}\\ \mathbf{t}\end{pmatrix}\left(p\mathbf{I}-(\boldsymbol{\tau})\mathbf{n}^{T}\right)\right]_{\Gamma}=\begin{pmatrix}\gamma\kappa\\ 0\end{pmatrix} \quad (1)$$

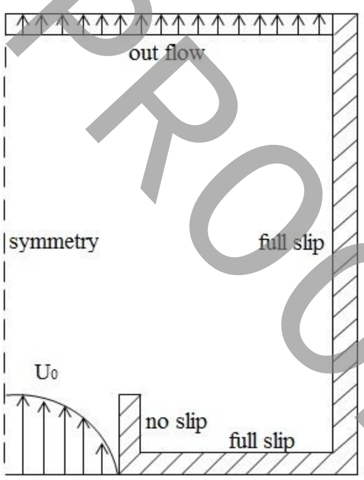

Fig. 1. The computational domain and boundary conditions

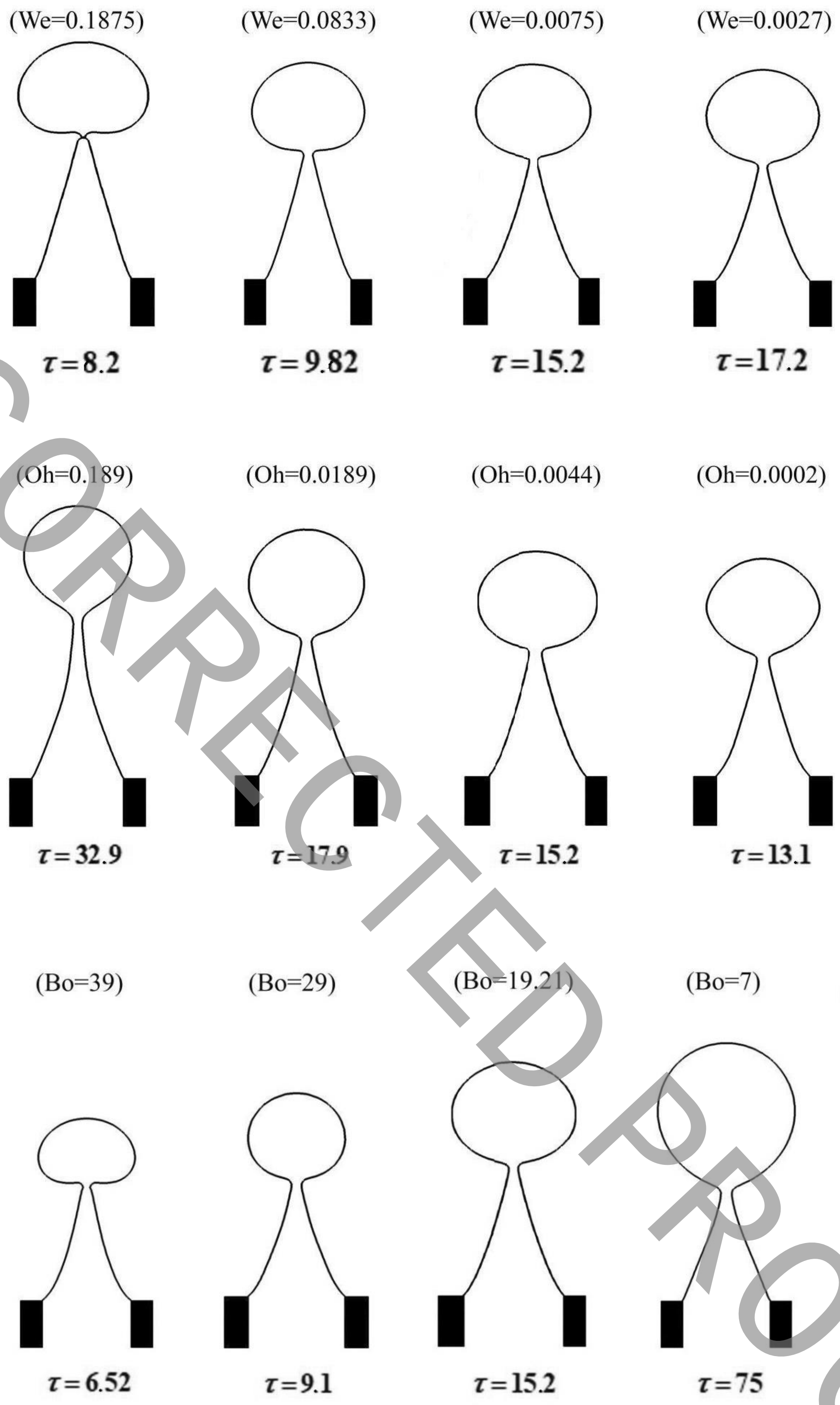

Fig. 2. The effect of the important parameters on the drop formation process

where γ and κ are surface tension and curvature, respectively. $\boldsymbol{n}$ and $\boldsymbol{t}$ represent unit normal and tangent vectors at the interface. p , τ and $\boldsymbol{I}$ are pressure, viscous stress tensor and identity tensor, respectively. Also, $[\ ]_{\Gamma}$ stands for the jump in a quantity at the interface.

In this study, the ghost fluid method is used to impose the jump conditions at the interface [5]. By using this approach, discontinuities of different quantities are preserved at the interface. The level-set method is used to track the interface [6]. The governing equations are discretized on a staggered grid by using the finite difference approach. The Weighted Essentially Non-Oscillatory (WENO) scheme [5] and central approximation are used to discretize the convective and central terms, respectively. Also, the Total Variation Diminishing (TVD) Runge-Kutta method [5] is used to discretize the temporal terms. The projection method is employed to solve the flow equations [5].

3- Results and Discussion

In this research, outlet liquid from a nozzle in the dripping mode is simulated. Fig. 1 shows the computational domain and boundary conditions. The nozzle inlet velocity is considered as the fully-developed velocity profile inside a tube. The liquid inside the nozzle is Kerosene and the outside liquid is water. The nozzle diameter is 0.0094m.

Fig. 2 represents the effect of the Weber, Ohnesorge and Bond numbers on the drop formation process. It is observed that by increasing the Weber number, the length of the outlet liquid is increased about and the liquid breakup time is decreased. Also, at higher Weber numbers, the liquid return toward the nozzle after droplet detachment is less.

Increasing the Ohnesorge number increases the length of the outlet liquid and breakup time. Also, at higher Ohnesorge numbers, the liquid return toward the nozzle is higher.

Increasing the Bond number leads to the reduction of the length of the outlet liquid and breakup time, respectively. Also, at higher Bond numbers, the liquid return toward nozzle is less. Another considerable result is the reduction of the size of formed droplets by enhancement of the Bond number.

4- Conclusions

In this research, the outlet liquid from a nozzle was simulated in the dripping mode. The level-set method along with the ghost fluid method was used to model the interface in a sharp manner. By increasing the Weber number, the length of the outlet liquid is increased about and the liquid breakup time is decreased. Increasing the Ohnesorge number increases the length of the outlet liquid and breakup time. Increasing the Bond number leads to the reduction of the length of the outlet liquid and breakup time, respectively. Also, the size of the formed droplets is reduced by enhancement of the Bond number.

References

[1] K. Shibata, S. Koshizuka, Y. Oka, Numerical analysis of jet breakup behavior using particle method, Journal of Nuclear Science and Technology, 41(7) (2004) 715-722.

[2] S. Homma, J. Koga, S. Matsumoto, M. Song, G. Tryggvason, Breakup mode of an axisymmetric liquid jet injected into another immiscible liquid, Chemical Engineering Science, 61(12) (2006) 3986-3996.

[3] Z. Che, T.N. Wong, N.-T. Nguyen, Y.F. Yap, J. Chai, Numerical investigation of upstream pressure fluctuation during growth and breakup of pendant drops, Chemical Engineering Science, 66(21) (2011) 5293-5300.

[4] I. Chakraborty, M. Rubio-Rubio, A. Sevilla, J. Gordillo, Numerical simulation of axisymmetric drop formation using a coupled level set and volume of fluid method, International Journal of Multiphase Flow, 84 (2016) 54-65.

[5] M. Kang, R.P. Fedkiw, X.-D. Liu, A boundary condition capturing method for multiphase incompressible flow, Journal of Scientific Computing, 15(3) (2000) 323-360.

[6] P. Pournaderi, A. Pishevar, A numerical investigation of droplet impact on a heated wall in the film boiling regime, Heat and Mass Transfer, 48(9) (2012) 1525-1538.