Oral presentation | Multi-phase flow

Multi-phase flow-II

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[2-D-02] Application of lattice Boltzmann method to simulate droplet coalescence phenomenon under shear flow

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Application of lattice Boltzmann method to simulate droplet coalescence phenomenon under shear flow

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1 Introduction

Predicting the coalescence conditions of droplets is crucial in various application scenarios. In shear flow, emulsions that consist of drops of one fluid dispersed in another are subject to complex flow fields, causing droplets to undergo deformation and collision, resulting in coalescence and separation. These phenomena are influenced by dimensionless parameters such as droplet size distribution, Cahn number Cn, Reynolds number Re and capillary number Ca. However, in practical engineering applications, droplet coalescence is not confined to isolated pairs; instead, multiple droplet pairs coexist in space. Therefore, when simulating coalescence phenomenon of observation pair, it is important to consider the influence of surrounding droplets.

We employ the Single Relaxation Time Lattice Boltzmann Method (SRT-LBM) combined with the Cahn-Hilliard model to calculate the impact of concentration on droplet coalescence under shear flow. In investigating the influence of droplet concentration, the analysis is conducted along three directions: the x-direction, y-direction, and z-direction. we focus on on examining the effects of concentration in the x and y directions. The current findings of our study indicate that as the concentration in the x-direction(ψ_x) increases, coalescence becomes more challenging, while an increase in concentration in the y-direction(ψ_y) makes coalescence easier.

2 Problem Statement

In order to understand the influence of the surrounding droplet pair, we follow the setting of Shardt *et al.* [1] of initial condition and have imposed periodic boundary conditions in the streamwise direction (x-direction) and symmetric boundary conditions in the spanwise direction (y-direction). This setup aims to simulate the behavior of other droplet pairs in the vicinity of the observation pair. We represent concentration as a distance from the surrounding droplet pair. By adjusting the domain of the observation pair, we can vary the concentration in streamwise and spanwise.

$$(\Psi_x, \Psi_y, \Psi_z) = \left(\frac{4R}{b_x}, \frac{2R}{b_y}, \frac{2R}{H}\right), \tag{1}$$

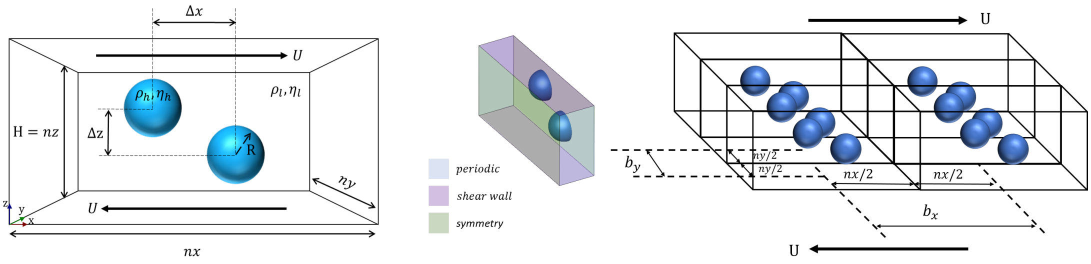

Figure 1: schematic of droplet concentration

3 Preliminary results

Within a certain range, each Reynolds number Re corresponds to a critical capillary number Ca_c such that when the capillary number Ca is greater than the critical value, droplets separate without coalescence, and when the capillary number is less than the critical value, droplets coalesce into a single spherical entity as shown in Figure 2.

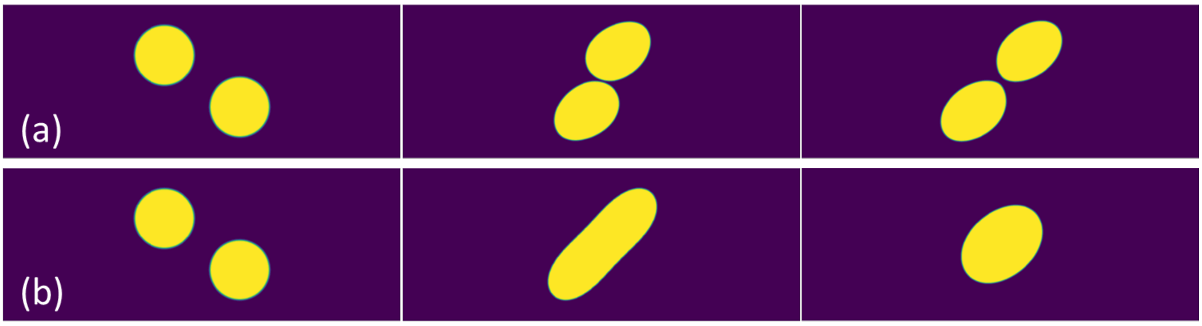

Figure 2: The behavior of droplet pair under Re=1 and (a)Ca=0.09 (b)Ca=0.08

The (a) and (b) of figure 3 illustrate the coalescence angle and time when the concentration in the y-direction is fixed, and in the x-direction is varied. When ψ_x is less than 0.4, there is no significant change in both coalescence time and angle with decreasing concentration in the x-direction. However, when ψ_x is greater than 0.4, there is a delay in coalescence time and an increase in coalescence angle, indicating that an increase in x-direction concentration makes coalescence more challenging. While the (c) and (d) also illustrate the angle and time but under the concentration in the x-direction is fixed, and y-direction is varied. When ψ_y is less than 0.3, there is no significant change in both coalescence time and angle with decreasing concentration in the y-direction. As ψ_y surpasses 0.3, it becomes evident that there is an advance in the coalescence time and a decrease in the coalescence angle. This indicates that a higher concentration of droplets in the y-direction enhances the likelihood of droplet coalescence.

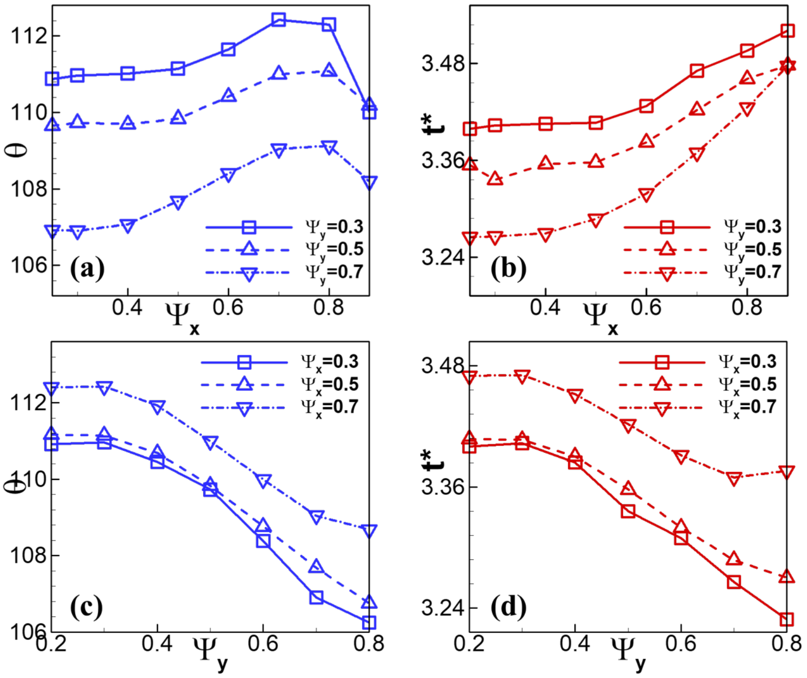

Figure 3: Droplet angle at the instant of contact at (a)fixed Ψ_y and varied ψ_x (b)fixed Ψ_x and varied ψ_y

Comparing the high concentration result in the x-direction (c) with the control group (b) in Figure 4 reveals that an increase in ψ_x results in a reduction of the coalescence region under certain Reynolds numbers. This suggests that the overall conditions for coalescence become more stringent as ψ_x increases. In contrast, when comparing the result of high concentration in the y-direction (a) with the control group (b), high ψ_y expands the coalescence region, facilitating the coalescence of two droplets.

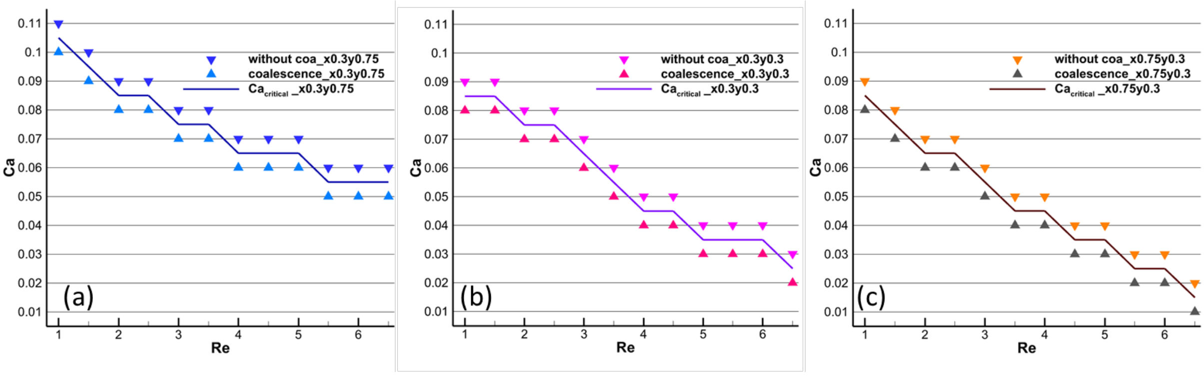

Figure 4: The solid lines show the Ca_c in in three types of concentration (a)$\psi_x = 0.3, \psi_y = 0.75$ (b)$\psi_x = 0.3, \psi_y = 0.3$ (c)$\psi_x = 0.75, \psi_y = 0.3$

References

[1] Orest Shardt, JJ Derksen, and Sushanta K Mitra. Simulations of droplet coalescence in simple shear flow. *Langmuir*, 29(21):6201–6212, 2013.