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Numerical Simulation of Dynamic Behavior of Two Falling Adjacent Droplets Using Lattice Boltzmann Method

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ABSTRACT

In the present study, falling of a single droplet and two adjacent droplets under gravity force, in the vertical channel with side walls and for different situations of wall effects are simulated, using the inter molecular potential model of lattice Boltzmann method. Dynamic behavior of falling droplet is simulated. The simulation results are shown in the falling droplet with initial lateral position on the centerline (vertical axis of symmetry) of channel, the droplet has been moved down straight along the centerline with no lateral motion. For the falling movement of the droplet near wall, due to various effects on droplet, it has been diverted from its initial vertical axis. If Eotvos number is not very low oscillatory trajectory is created and the droplet oscillates between the wall and the vertical axis of symmetry. By increasing Eotvos number the oscillatory amplitude increases. When two droplets are initially settled at the vertical axis of symmetry with one droplet above the other, the trailing droplet accelerates into the wake of the leading droplet and its drag reduce and finally merges with it into a new droplet with a larger size. Finally, it is shown when two droplets are initially settled on the different horizontal and vertical directions and one droplet above the other, interesting phenomena such as asymmetric collision and stretch of the above droplet are observed.

KEYWORDS:

Falling Droplet, Lattice Boltzmann Method, Eotvos Number

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1- Introduction

Investigation of droplet dynamics is one of the important and challenging phenomena in the simulation of two-phase flow. Design of variety of devices, from liquid rocket motors to blood pumping machines, requires detailed knowledge of droplet dynamics in a multiphase flow.

The breakup mechanism of liquid droplets can be found in many industrial appliances such as paint sprays, and ink-jet printers.

In recent years, the lattice Boltzmann method (LBM) has emerged as a suitable computational method for simulation of multiphase flow.

For example, Gupta and kumar[1] simulated the bubble dynamic behavior under gravity and buoyancy forces using lattice Boltzmann method. As well as in their works the interactions between adjacent multiple bubbles are investigated.

In this study, falling two adjacent droplets under gravity force, in the vertical channel with side walls for different situations of wall effects and for different initial position of the droplets are simulated, using the intermolecular potential model [2,3] of lattice Boltzmann method.

2- Methodology

According to intermolecular potential model [2] of the lattice Boltzmann method, the distribution function of each component is governed by

$$f_i^\sigma(\boldsymbol{x}+\boldsymbol{c}_i\delta_t, t+\delta_t) - f_i^\sigma(\boldsymbol{x},t) = -\frac{1}{\tau^\sigma}\left(f_i^\sigma(\boldsymbol{x},t) - f_i^{\sigma(eq)}(n^\sigma, \boldsymbol{u}_{eq}^\sigma)\right) \tag{1}$$

Where $f_i^\sigma(x,t)$ is the number density distribution function of component σ with velocity c_i at position x and time t. τ^σ is the relaxation time of component σ and $f_i^{\sigma(eq)}$ is the equilibrium distribution function that obtained as follows

$$f_i^{\sigma(eq)} = \omega_i n^\sigma\left[1+3\boldsymbol{c}_i.\boldsymbol{u}_{eq}^\sigma+\frac{9}{2}(\boldsymbol{c}_i.\boldsymbol{u}_{eq}^\sigma)^2-\frac{3}{2}(\boldsymbol{u}_{eq}^\sigma)^2\right] \tag{2}$$

In the above equation ω_i indicative the weighing factors for different directions of lattice. The fluid–fluid interaction force acting on each component can be obtained by

$$\boldsymbol{F}_f^\sigma = -\psi^\sigma(\boldsymbol{x})\sum_{\bar\sigma} G_{\sigma\bar\sigma}\sum_i \omega_i\psi^{\bar\sigma}(\boldsymbol{x}+\boldsymbol{c}_i.\delta_t)\boldsymbol{c}_i \tag{3}$$

Where ψ^σ denotes the interaction potential of fluid component σ and $G_{\sigma\bar\sigma}$ is the interaction strength between two components. The macroscopic variables of fluids are obtained

$$\begin{aligned}\rho(\boldsymbol{x},t) &= \sum_\sigma m^\sigma\sum_i f_i^\sigma(\boldsymbol{x},t)\\ \rho(\boldsymbol{x},t)\boldsymbol{U}(\boldsymbol{x},t) &= \sum_\sigma m^\sigma\sum_i \boldsymbol{c}_i f_i^\sigma(\boldsymbol{x},t)+\frac{1}{2}\sum_\sigma \boldsymbol{F}^\sigma(\boldsymbol{x},t)\\ p(\boldsymbol{x},t) &= C_s^2\sum_\sigma n^\sigma+\frac{C_s^2}{2}\sum_{\sigma\bar\sigma} G_{\sigma\bar\sigma}\psi^\sigma(n^\sigma)\psi^{\bar\sigma}(n^{\bar\sigma})\end{aligned} \tag{4}$$

That in these equations C_s^2=(1/3)

3- Results

In this section The main results of paper are presented. In all simulations the kinematic viscosity ratio are (v_d / v_c) =1 density ratio between two fluids are $\frac{m^{(d)}}{m^{(c)}} = \frac{n^{(d)}}{n^{(c)}} = 1$ ("d" denotes the droplet phase and "c" denotes the continues phase). Total parameters are in the lattice units. The domain of falling droplets is two-dimensional and divided into 280×840 (width × height) lattice nodes. A particle distribution function bounce back schemes used at the side walls of channel to obtain no-slip velocity conditions. The main dimensionless parameters for investigation of droplets dynamic are:

Eotvos number $Eo = \frac{g(\rho_d)D^2}{\sigma}$

Ohnesorge number $Oh = \frac{\mu}{(\rho D\sigma)^{\frac{1}{2}}}$

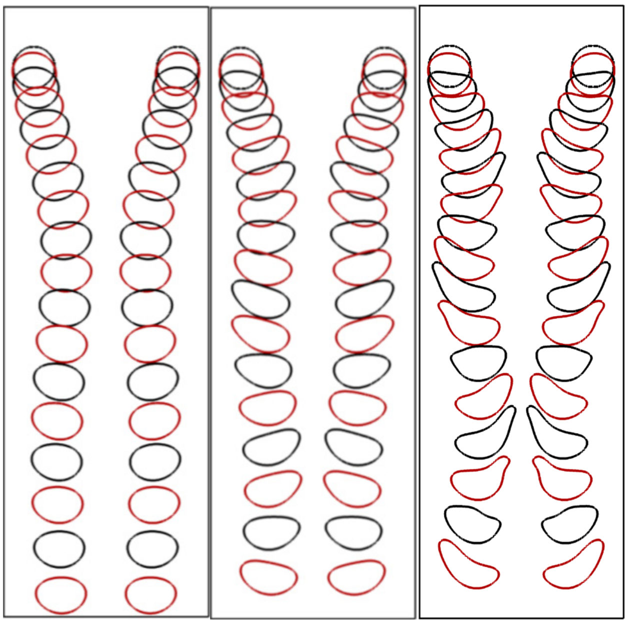
Dimension less time $t^* = \frac{t}{\left(\frac{D}{g}\right)^{\frac{1}{2}}}$

Where D is the initial diameter of droplet, μ is the kinematic viscosity and g is the gravity acceleration.

3-1- Falling two adjacent droplets by different initial lateral positions

Figure 1 illustrates the effect of the inter-droplet repulsion by settling two droplets near the sidewalls symmetrically in the computational regions with same initial horizontal position.

Figure 1 (a-c), show that the walls tend to push the two droplets together, while their mutual repulsion keeps them apart. It is expected that at the low Eotvos number (*Eo*= 3), two droplets move down along a steady straight line near the centerline of channel. For the low Eotvos number case with small inertial effects, the deformation is smaller than from the higher Eotvos number (6=*Eo*). For the larger Eotvos number (*Eo*=6), Due to the large deformation and high inertia the two droplets exhibit oscillatory motion. If Eotvos number increases to 12 due to the higher gravity force and inertial effects, the droplets are greatly deformed. Since the inertia is strong (*Eo*=12), the pressure difference and rotation force and also inter-droplet repulsion push the droplets near the centerline back to the wall, and the wall repulsion to the centerline again. The cycle is repeated because the viscous damping is not large, and it can be seen the oscillatory trajectory. Larger Eotvos number leads to larger oscillatory amplitude.



a) Eo=3 b) Eo=12 c) Eo=23

Figure 1. Falling two adjacent droplets by different initial lateral positions from near the side walls (*Oh*=0.072 , t_0^*=0 , Δt^*=1)

3-2- Falling of two identical droplets from centerline of channel with different horizontal line

In this case, the leading droplet experiences much more deformation than the trailing droplet. In fact, the leading droplet seems to freely rise in the surrounding fluid and the wake it generates considerably affects the dynamics of the lower droplet. The wake of the leading droplet leads to drag forces and consequently deformation of trailing droplet reduced. As time goes on, the trailing droplet falls in the wake region of the lower droplet, and the distance between the two droplets decreases rapidly, leading to collision and coalescence. The resulting coalesced droplet is two times larger than the initial droplets. Results reveal that at Ohnesorge number of 0.07, two droplets after several time steps collision together and finally coalescence. The new droplet has a larger size than the old one, and it deforms more than the old one due to the reduced effect of surface tension and viscosity. By increasing Eotvos number from 3 to 23, effect of gravity force is increases against to the surface tension and leads to larger deformation of two droplet during the falling.

4- Conclusions

Generally in the phenomenon of falling droplets, by increasing Eotvos number, deformation of the droplet with initial lateral position near the wall has an oscillatory trajectory around the vertical center line of channel with increasing amplitude as time progressing due to the increasing inertia. Also by increasing Eotvos number, effect of gravity force will be stronger and therefore, the amplitude of oscillatory trajectory will be increased. For two droplets initially settled symmetrically at the same horizontal location. The walls tend to push the droplets together, their mutual repulsion keeps them apart, and it can be seen the oscillatory trajectory for two droplets. By increasing Eotvos number, deformation of droplets during the falling will be increased. When droplets are settled initially at the centerline with one droplet above another one, the leading one forms a low-pressure region after the droplet, which will accelerate the trailing one. The trailing one with a higher velocity finally coalesces with the leading one to form a larger droplet.

5- References

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