NUMERICAL SIMULATION OF FRAGMENTATION OF LIQUID JET IN VACUUM BASED ON LATTICE BOLTZMANN METHOD

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Summary A multi-phase fluid model for the fragmentation of liquid jet in vacuum is established based on lattice Boltzmann method. In the model, the concept of volume fraction is proposed. The interfaces between different phases are reconstructed every time step in a simplified way. In addition, the momentum transfer between different phases is taken into account. The processes of the growth and broken-up of the bubble under different cases are investigated by simulation. The numerical results are compared with the experiments results and have a good agreement.

INTRODUCTION

When a liquid jet is exposed into the vacuum environment, it will rapidly break up because of a large explosive release of pressure liquefied gasses and flash evaporation due to the sudden pressure drop. The expansion of the gasses and liquid vapour leads to the fragmentation of the liquid jet.

One difficulty in numerical simulating of the fragmentation of liquid jet in vacuum is the complexity of the development of interfaces between different phases. From the bubbles' growth and expansion, interaction to the liquid's being rupture, the interface configuration change rapidly and the scale is very small. The Lattice Boltzmann Method[1-3] (LBM) is suitable for this problem because of its microcosmic character and it has a natural capability to deal with the interfaces. The LBM has been widely used in flow with moving boundaries[4], flow in porous media[5], micro-fluid[6] and so on. In this paper, we apply the LBM to the task of simulating the fragmentation of liquid jet in vacuum where surface tension plays a key role and there must be some special disposals in the reconstruction of the interfaces.

NUMERICAL MODEL

The differential Boltzmann equation is as follows:

$$f_i^{\sigma}(x+c_i\Delta t,t+\Delta t)-f_i^{\sigma}(x,t)=-\frac{1}{\omega^{\sigma}}(f_i^{\sigma}(x,t)-f_i^{\sigma(eq)}(x,t))$$

where f_i^{σ} is the density distribution function for the i-th velocity and the σ phase. f_i^{eq} is the distribution function in equilibrium state which can be expressed by macro state values as follows in the assumption of homogenous temperature and low velocity.

$$f_i^{\sigma(eq)}=w_i\cdot[1+\frac{e_i\cdot u}{c_s^2}-\frac{u^2}{2c_s^2}+\frac{(e_i\cdot u)^2}{2c_s^4}]$$

In this case a rectangular two-dimensional nine-speed (D2Q9) is applied and c denotes lattice velocity. Then $\rho^{\sigma}=\sum_i f_i^{\sigma}$, $\rho^{\sigma}u^{\sigma}=\sum_i c_i f_i^{\sigma}$. All the values are dimensionless. And the time step dt and lattice spacing dx can be decided through the following relation:

$$(\tau-\frac{1}{2})\times\frac{1}{3}=\nu\times\frac{dt}{dx^2}$$

where τ is the relaxation time and ν is the macroscopical viscosity coefficient.

A volume fraction $\varepsilon(x,t)$ is defined for every lattice for the model of interface reconstruction in two-phase flow. The case $\varepsilon(x,t)=1$ means that the lattice is filled with fluid 1; $0<\varepsilon(x,t)<1$, the lattice is filled with fluid 1 and fluid 2; $\varepsilon(x,t)=0$, the lattice is filled with fluid 2.

When $\varepsilon(x+e_i,t)>\varepsilon(x,t)$, $d\varepsilon_i=\varepsilon(x+e_i,t)[f_I(x+e_i,t)-f_i(x,t)]$; else, $d\varepsilon_i=\varepsilon(x,t)[f_I(x+e_i,t)-f_i(x,t)]$. $d\varepsilon_i$ is the net increment of the volume fraction in each direction and I corresponds to the reverse direction of the i-th direction.

We carry out following operations to reconstruct the interfaces.

(1) If the volume fraction decrease to a negative value, assign the negative mass to the surrounding lattices according to the velocity distribution function to form a new boundary and let the volume fraction of the local lattice equal to 0 (empty lattice);

(2) If the volume fraction exceeds 1, assign the over part to the surrounding lattices according to the velocity distribution function and let the volume fraction of the local lattice equal to 1.

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Let $f_I(x,t+1)=f_I^{eq}(u,\rho)$, that is to say, the fraction transported from the empty lattice to the interface lattice equals to the distribution function in equilibrium state.

RESULTS AND DISCUSSIONS

The processes of the growth and broken-up of the bubble under different cases are investigated by simulation based on the proposed model. In the first case we assume that there's only one bubble generating in a single liquid drop. The diameters of the liquid drop and bubble are 30 and 18, respectively which are corresponding to the real liquid drop of 3mm and the bubble of 1.8mm in diameter. The process of the growth and broken-up of the bubble is shown in Fig.1. After the broken-up of the bubble, the droplets of 0.1mm are formed.

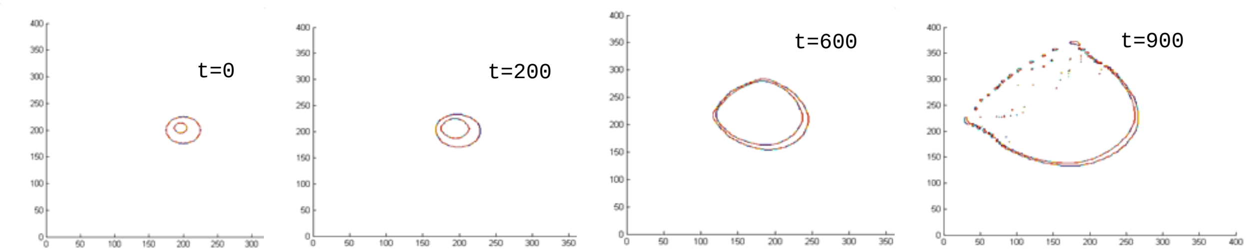

Fig.1 Single droplet with single bubble

In another case, multiple bubbles are distributed randomly in the liquid jet. The process of the growth and broken-up of the liquid jet with multiple bubbles is indicated in Fig.2. It can be seen that the process is complex. At the boundary among the bubbles and the outer boundary of the bubble, the formed droplets can be as small as 0.1mm in diameter. On the other hand, droplets of larger diameter can be formed at the outer boundary of the two contacted bubbles because the expanding velocities of the bubbles decrease under the interaction of the flows. The results show a good agreement with experiments.

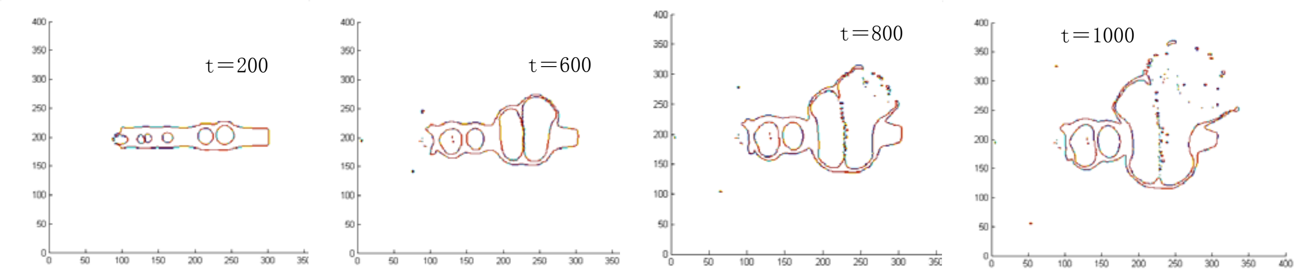

Fig.2 Liquid jet with multiple bubbles

CONCLUSIONS

In this paper, a multi-phase fluid model for the fragmentation of liquid jet in vacuum is proposed based on lattice Boltzmann method. It is applied to investigate the processes of the growth and broken-up of the bubble under different cases. The numerical results are compared with the experiments results and have a good agreement.

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