Primary Breakup of Round Non-Newtonian Liquid Turbulent Jet

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Summary The dynamic atomization process of non-Newtonian liquid is investigated by the method of numerical simulation. The full transient process of the primary instability, deformation, and fragmentation of interface were simulated by solving the Navier-Stokes equations using an algorithm based on the finite volume method. The liquid-gas interface was tracked using the VOF technique. The LES model is employed to model the turbulence in the jet flow. The CSF method is used to describe the surface tension. In this paper, The distribution of dimensionless liquid core length and dimensionless breakup length were analyzed detailedly.

NUMERICAL CALCULATION

Jet flow is related to the two-phase flow. In order to get the real characteristics of the jet flow, it is essential to precisely track the free surface of two immiscible fluids. VOF method could be used to track the free surface[1,2] with the computational domain characterized by a liquid volume fraction function, which is used to determine the interface orientation. The surface tension is taken into account through the continuum surface force (CSF) model[3]. The dispersed phase is non-Newtonian liquid, and the continuous phase is air. In addition, the two phases are supposed to be incompressible and incompatible. There only exists the transfer of momentum between the two phases, and the thermal production and transmission are negligible.

Computational region and physical properties

Fig.1 shows the computational domain in this paper. The diameter of nozzle D equals 1 mm, and it is determinated as the characteristic length. Some relevant dimensionless parameters are obtained: the dimensionless potential core length (Lc/D) and the dimensionless breakup length (Lb/D). The power-law equation was used to describe the rheological behavior of non-Newtonian liquid. The parameters in this simulation are listed in Tab.1. Fig.2 shows the computational grid, which is non-uniform in order to get detailed information.

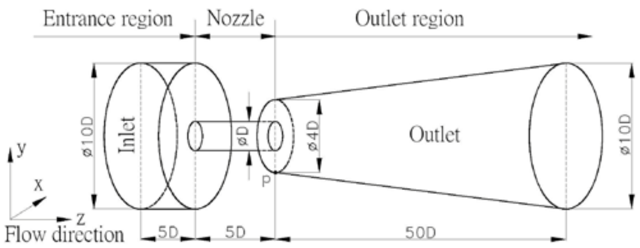

Fig.1 Geometry of computational domain

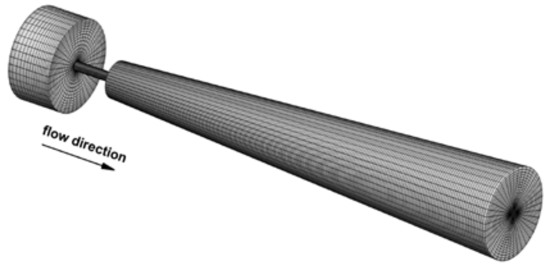

Fig.2 Computational mesh

Tab. 1 Physical properties

Phase	Viscosity/(kg·m-1·s-1)	Density/(kg·m-3)	Static surface tension/(mN·m-1)
Liquid	μ_0=0.025 μ_∞=0.005	1 126.4	70.12
Gas	0.000 018	20.2	—

RESULTS and DISCUSSION

Characteristic parameters of jet

After liquid column is jetted out of nozzle, the liquid column does not achieve atomization immediately. In the liquid column, there is a continuous liquid core. Fig.3 shows the numerical result of intact liquid core and liquid core length, Lc. F is volume fraction of liquid phase.

Fig.4 is based on numerical results. Two stages can be seen in Fig.4. First, the developed region of liquid core length (from the beginning time t_0=0～tc), where the length of liquid core mainly grows linearly, and the growth rate is approximately equal to $0.82U_0$ (U_0 is the inlet velocity which is equal to 0.5 m/s). Second, the stable region of liquid core length (tc～2.0 ms), where the length of liquid core fluctuates obviously. However, the amplitude is basically

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stable as shown in Fig.4, i.e. the range of liquid core length is basically stable. The value of liquid core length, which is obtained by averaging over amplitudes, ranges from 7.78D to 10.49D. A basically stable frequency can also be obtained in this stage. The average frequency (λc) is 0.225 ms approximately.

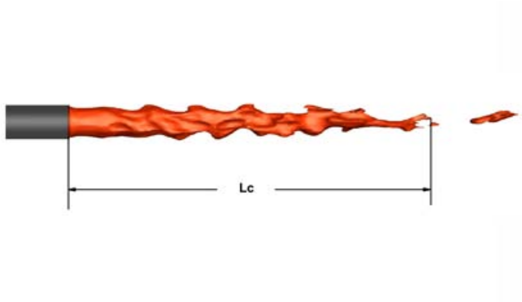

Fig.3 Instantaneous iso-surface of F=0.95 at t=1.5 ms

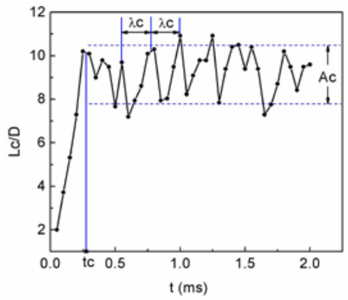

Fig.4 Dimensionless length of liquid core versus time

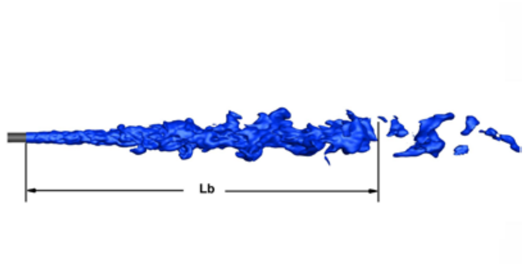

Fig.5 Instantaneous iso-surface of F=0.05 at t=1.5 ms

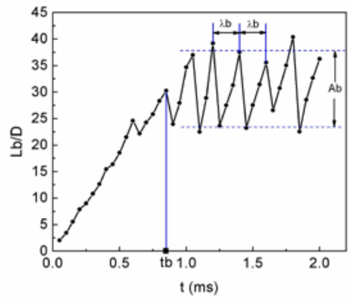

Fig.6 Dimensionless breakup length versus time

In this paper, a threshold of liquid volume fraction is artificially set as 0.05 to describe the continuous distance of spray penetration length. The numerical result of breakup length was shown in Fig.5.

The curve in Fig.6 is similar to that in Fig.4. Two stages can also be seen in Fig.6. First, the developed region of breakup length (t_0～tb), where the breakup length mainly grows linearly, and the growth rate is approximately equal to $0.71U_0$, which is significantly lower than that in Fig.4. It is understandable that the growth rate is determined by the interaction of initial power and aerodynamic drag, which firstly act on the surface of liquid column and then act on the core zone of liquid column. This factor causes the difference of two kinds of growth rates in different stages. Second, the stable region of breakup length (tb～2.0 ms), where the breakup length fluctuates obviously. However, the amplitude is basically stable as shown in Fig.6, i.e. the range of breakup length is basically stable. The value of breakup length, which is obtained by averaging amplitudes, ranges from 23.4D to 37.9D. The reason why the breakup length is larger than liquid core length is understandable. By comparing Fig.4 and Fig.6, we can see that tb>tc, which reveals that the moment when Lc reaches stable is early than that when Lb reaches stable. And a basically stable frequency can be obtained in this stage. The average frequency λb is 0.4 ms approximately.

CONCLUSIONS

The dynamic cylindrical atomization processes of non-Newtonian liquid are investigated by numerical simulation. The whole transient process is simulated by using the VOF-LES method. The relationship of Lc/D versus time is obtained. Lc/D increases linearly in the initial stage, and then it fluctuates in a stable range. The range of breakup length can be obtained by averaging over amplitudes. And a basically stable frequency can be obtained in the second stage. The distribution of Lb/D versus time has a similar form to the distribution of Lc/D.

Acknowledgements

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