The trajectory and break-up of a particle laden liquid jet in the centrifugal field

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Abstract

The instability of a particle laden spiralling dilated liquid jet is investigated by means of linear stability analysis. The trajectory and the contour of the unperturbed jet serves as a basic solution for the determination of the drop size. Extensive experimental studies on the resulting drop size are in good agreement with the mathematical model.

Introduction

The generation of narrow distributed droplets is a relevant process for many applications. Rotating atomizers operated in the jetting regime are suitable devices for this purpose in spite of high throughputs. Thus, the break-up and stability of pure liquid jets ejected from a rotating atomizer have been adressed by many authors [1, 2, 3].
We present a physical-mathematical model to determine the drop size of a particle laden viscous liquid jet in the centrifugal field. Extensive experimental studies on the break-up length and the drop size are included.

Trajectory of a viscous liquid jet

The spiralling trajectory around a rotating atomizer as well as the contracted contour of the unperturbed jet serve as a basic solution for the stability analysis. A 1-dimensional model has been derived balancing force and mass in axial and radial jet coordinates. The drag coefficient for a cylinder in angular flow was determined by a direct numerical simulation using a finite volume method. The resulting equation of motion is a 2nd order ordinary differential equation with only one boundary condition namely the axial velocity of the jet at the nozzle orifice. We extend the "backward-shooting" method [5] to account for the centrifugal field and use an approximate solution for the 2nd boundary condition. The influence of the particulate phase on the stationary solution is considered by a suitable strain dependent viscosity model.

Stability analysis

The analysis of a particle laden liquid jet is based on impulse and mass balance in the Eulerian formulation. Hence, each phase is treated as a continuum. The solid and the liquid phase are coupled through interaction terms in the impulse equations as in Piesche et al. [4]. The ambient gas is treated as potential flow.
Operating with linear stability analysis, we obtain stability criteria for infinitesimal disturbances. These disturbances are oscillations of the jets surface that are growing or damped depending on the wave characteristics, the liquid, solid and gas properties and the unperturbed contour of the jet. Distinction is made between temporal and spatial analysis of such disturbances. In temporal analysis, a spatially constant wave grows or decays in time, in spatial analysis a temporally constant wave grows or decays in space. Since the growth rate for a specific wave number changes along the jet because of the contraction of the stationary contour, the growth must be integrated over the residence time in temporal analysis. The critical wave number shows the largest integral growth. In spatial analysis the growth must be integrated over the break-up length and the largest growth indicates the critical angular frequency.

Experiments

Jet stability is also investigated experimentally. The curvature and contour of a jet ejected from a cylindrical nozzle in a rotating cup and the resulting drops are analysed using a high speed camera and a back light panel consisting of a LED-array. Image analysis is capable to calculate the break-up length and the drop sizes.
The material properties viscosity and surface tension of the liquid, particle size, concentration and density of the solid phase, as well as the axial and angular velocity and the diameter of the rotary atomizer and the nozzle are varied.

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Results and Discussion

Figure 1 shows a comparison between a) the experimental observation and b) the numerical simulation of a liquid jet emitted from a rotating nozzle. The agreement of the numerical solution and the experimental observation is excellent.

In Figure 2 the experimental and numerical result of the drop diameter d_D scaled by the nozzle diameter d_0 are plotted as a function of the angular frequency ω. The drop sizes decrease with increasing ω for both numerics and experiment. The results of the spatial analysis are closer to the experimental findings, approving the thesis that the initial perturbation is a temporally constant wave growing in space.

Based on the experimental results, the similarity relations of Weber [6] for the break-up length as well as the initial amplitude of the disturbance are extended to account for particle laden dilated viscous jets. These relations serve as starting conditions for the numerical simulations.

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a) b)

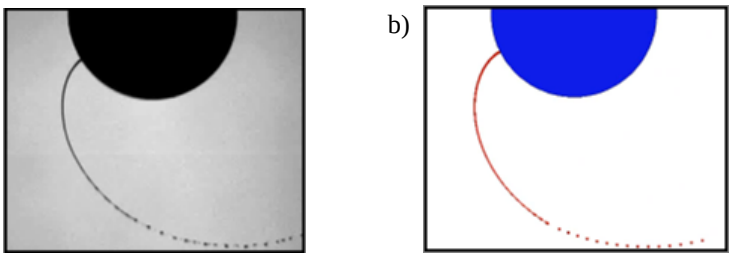

Figure 1. a) Experimental observation vs. b) Numerical simulation

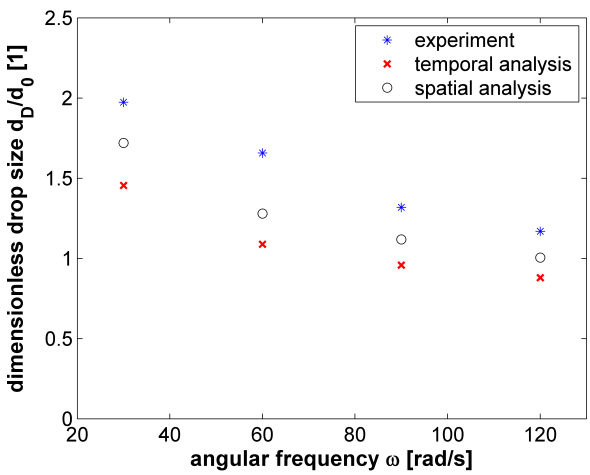

Figure 2. Dimensionless drop size dependent on angular frequency: numerical result and experimental observation