Breakup of Finite Size Liquid Filaments Involving Substrate Effects

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Abstract

The breakup of viscous filaments has, and is being studied experimentally, theoretically, and numerically. In this study, we focus on the breakup of finite size liquid filaments on substrates, using direct numerical simulations. Although there are many parameters involved when determining whether a liquid filament breaks up, we illustrate the effects of three parameters: Ohnesorge number ($\mathrm{Oh} = \frac{\mu}{\sqrt{\rho \sigma R_0}}$), the ratio of the viscous forces to inertial and surface tension surfaces, the liquid filament aspect ratio (L_o), and a measure of the fluid slip on the substrate, i.e. slip length (λ).

Through these parameters, we are able to determine whether a liquid filament breaks up into one or multiple droplets or collapse into a single droplet on the substrate. We compare our results with the results for free standing liquid filaments. We show that the presence of the substrate promotes breakup of the filament. We also discuss the effect of the degree of slip on the break up. We comprehensively explore the parameter domain regions when including the slip effects.

Gerris Flow Solver

Gerris is an open source software used to carry out simulations of our numerical experiments [1]. It is a program that solves partial differential equations describing a fluid flow. Gerris (gfs.sf.net) solves fully nonlinear two-phase Navier-Stokes equations

$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla p + \nabla \cdot (\mu(\nabla \mathbf{u} + \nabla \mathbf{u}^T)) + \sigma \kappa \delta_S \mathbf{n}$$

$$\nabla \cdot \mathbf{u} = 0$$

using a volume-of-fluid (VOF) method, where it is assumed that the fluid flow can be modeled as an isothermal Newtonian, $\mathbf{u} = (u, v, w)$ is the velocity field, p is the pressure, κ is the curvature of the fluid-vapor interface, δ_S is the delta function at the interface, and $\mathbf{n}$ denotes the normal vector of the liquid interface. A contact angle of 90° is imposed during the simulations. The simulations were carried out on the NJIT HPC cluster, Stheno [2].

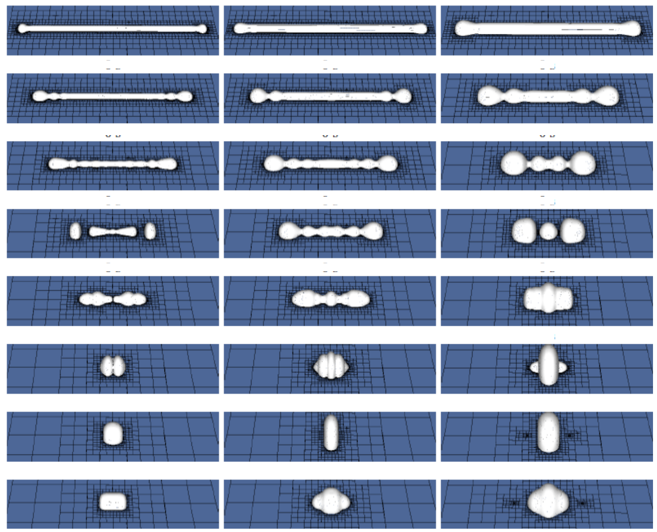
References:

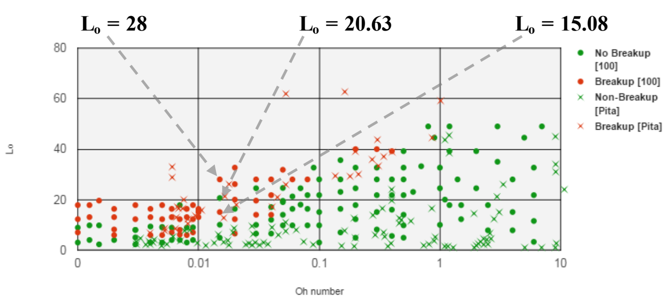
[1] Gerris (Free Software GNU GPL license). (http://gfs.sourceforge.net)

[2] Stheno, AFS (Andrew File System) NJIT ARCS (New Jersey Institute of Technology - IST Academic and Research Computing Systems). (https://wiki.hpc.arcs.njit.edu)

[3] A. A. Castrejón-Pita, J. R. Castrejón-Pita, and I. M. Hutchings. "Breakup of liquid filaments." Physical Review Letters 108 (7), 074506, 2012.

Simulation Results



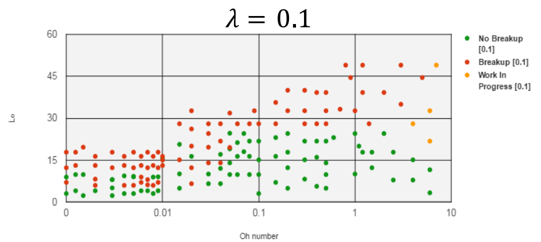


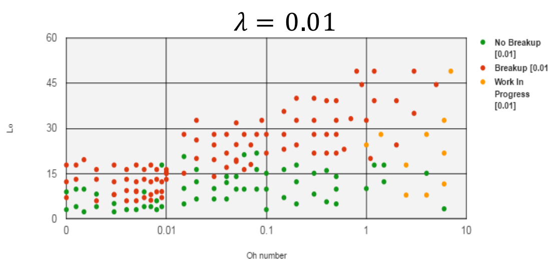
The framework of our study consists of analyzing numerical simulations to properly predict and examine the effects of the Oh number and the filament aspect ratio, as well as the effect of the substrate slip. What we show below is the behavior of a liquid filament when fixing slip length to infinity and for Oh = 0.015.

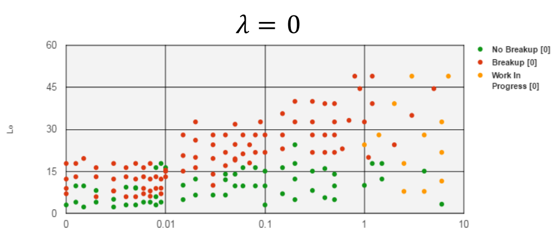
We then analyze our data and compare our numerical results with the experimental results of Pita et al. [3]. We see remarkably similar behavior between our numerical results with the experimental results of Pita et al. [3], also showing that the filament with Oh number greater than 1 never breaks up regardless of the filament aspect ratio.

Results

We then investigate the effect of slip length on the liquid filament breakup. The results we obtain from various slip values, λ, are shown below.







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