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Formation and Break-up of Pendant Drops in a Viscous Liquid

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Abstract

The present study is concerned with the formation and detachment of polymer solutions pendant drops initially attached to immersed needles in Newtonian mineral oil. Drop formation, pinch-off and detachment is studied in two cases: (i) one single needle placed vertically and (ii) two needles placed horizontally opposite to each other. In the second case, the interface meniscus presents an elongated shape near the two needles and oscillations of this interface are observed. These areassociated with the drop detachment.

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*Keywords:*Pendant drop; pinch – off; detachment; interface meniscus.

1. Introduction

Formation of drops at the tip of nozzles is important in a variety of engineering applications, like separation, extraction, dispersion, spraying [1]. Additionally, injection is important in practical medical applications, medical diagnostics or DNA sampling[2]. Coalescence phenomenon of colliding jets has received little attention, even though it has a significant impact on mixing processes, specifically in the domain of the liquid – liquid interaction and the interfacial dynamics applications. Studies of opposed jets (two needle placed horizontally at 180˚)is important in industrial and chemical processes, mixing and transfer processes, reaction injection molding, confined impingingjets reactors, coal gasification [3], control of mixing and transfer processesbetween threads of

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Nomenclature

ρ_{oil}	oil density $[kg/m^3]$
η_{oil}	oilviscosity $[Pas]$
ρ	density of tested liquid $[kg/m^3]$
η_0	viscosity of tested liquid $[Pas]$
σ	interfacial tension $[N/m]$
λ	relaxation time $[s]$
d	needle inner diameter $[m]$
Q	imposed flow rate $[ml/min]$
v_0	reference velocity $[m/s]$
a	horizontal distance between the two opposed needles $[mm]$
g	gravitational acceleration $[m/s^2]$
t_0	reference time $[s]$
p_0	reference pressure $[Pa]$
b	distance measured from the needle tip to the center of the detached drop $[mm]$

immiscible liquids [2] or applications for extensional rheology (opposed jets devices for measuring extensional properties, like extensional viscosity) [4].

The study focused on the experiments prior to jetting, at low flow rate regimes, low Reynolds and Capillary numbers. Interfacial tension effects were considered, equally important as the viscous and the elastic effects. Weakly elastic polymer solutions were used as samples, in order to emphasize the elastic effects.

First part of the paper is concerned with one single drop dripping from a needle placed vertically (case I). The second part presents coalescence of two opposed volumes of liquid (case II) and the detachment of the resulting coalescent liquid mass for low Reynolds and Capillary numbers.

2. Theoretical Aspects

At low flow rates (low Reynolds numbers), a liquid emerged from a nozzle breaks into uniform size drops with constant frequency [5]. In the case of a drop of Newtonian liquid formed at one neddle's tip, the non-dimensional Navier – Stokes system for incompressible isothermal liquids [5] with reference parameters $(\tilde{v}, \tilde{t}, \tilde{g}, \tilde{p})$ is:

$$\nabla \cdot \tilde{\boldsymbol{v}} = 0 \tag{1}$$

$$Re\left[\frac{\partial \tilde{v}}{\partial \tilde{t}} + (\tilde{\boldsymbol{v}} \cdot \nabla)\tilde{\boldsymbol{v}}\right] = \frac{Bo}{Ca}\tilde{\boldsymbol{g}} - \nabla \tilde{p} + \Delta \tilde{\boldsymbol{v}} \tag{2}$$

Non-dimensional parameters that characterize the phenomenon are: Reynolds number – ratio of inertia to viscous forces($\boldsymbol{Re}$), Capillary number – viscous forces to interfacial tension ($\boldsymbol{Ca}$)and Bond number – gravity to interfacial tension($\boldsymbol{Bo}$), together with the viscosities and the densities ratios:

$$Re = \frac{\rho v_0 d}{\eta}, Ca = \frac{\eta v_0}{\sigma}, Bo = \frac{(\rho - \rho_{oil}) d^2 g}{\sigma}, \frac{\eta_{oil}}{\eta}, \frac{\rho_{oil}}{\rho} \tag{3}$$

For non-Newtonian liquids, Weissenberg number – ratio of elastic to viscous forces ($\boldsymbol{Wi}$) is convenient for further experimental characterization:

$$Wi = \frac{2\lambda v}{d} \tag{4}$$