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Breakup of Liquid Jets

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Abstract

The present paper investigates breakup of immersed jets of water and water - glycerol solutions in a hydrophobic environment. Organic oil was used as the surrounding medium. Experimental setup allowed the investigation of jet behavior, respectively the exact moment when perturbations appear. The phenomenon of jet breakup was quantified by measuring the breakup length. Maximum breakup length, normalized with the nozzle diameter, was plotted and analyzed function of dimensionless numbers. Results showed that normalized breakup length has a linear dependence with Reynolds and Capillary, respectively.

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1. Introduction

Oil spilling pollution is one of the most important ecological problems of the century. Breakup of liquid jets is a phenomenon related to this problem. When oil is spilled in the ocean, generally it spreads at the water surface and, depending on its density and composition it might migrate into the water or form a slick at the surface [1]. This oil - water interaction leads to a process in which sea water droplets become suspended in the oil to form a water-in-oil emulsion. This physical mixing is promoted by turbulence at the sea surface and it increases the volume of pollutant between 3 and 4 times [2]. This affects drastically the evolution of the marine biosystem and it is a tremendous challenging problem for bioresearchers [3].

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In the environmental context of nowadays, understanding how pollutants are acting provides the main knowledge for finding optimal solutions to counteract their action. In this framework we are interested to see how droplets are formed when water penetrates a hydrophobic fluid, such as oil.

Along with the emulsification, other multiphase processes in which breakup of jets is of huge interest are widely encountered in nature, technology and basic science, such as medical diagnostics, DNA sampling, cosmetics, sprays, jet engine technology and combustion processes [4].

A liquid jet emerging from a nozzle will experience instability and breakup into drops. This phenomenon is known as Rayleigh instability. This instability is due to the interaction between the fluid discharging from the nozzle and the surrounding medium properties. The resulting shape of the interface can be a subject of Fourier analysis, and it can be showed that there is a certain wave length at which jet breakup occurs [4]–[6].

Until now, breakup of both Newtonian and non-Newtonian jets into droplets was extensively studied in the literature, covering mostly their evolution in the air [7]–[9]. Both theoretical and experimental aspects regarding the injection of a liquid jet in a gaseous medium were first studied by Lord Rayleigh [4], [10] .

The aim of this work was to investigate instabilities and breakup of different immersed jets into an oil phase. The influence of physical properties, such as viscosity, on the dynamics of breakup, especially the breakup length was discussed. Starting from Tomotika's work [5], a theoretical prediction for the breakup length was achieved, in good agreement with the experimental work.

Nomenclature

$\boldsymbol{\gamma}$	interfacial tension $[N/m]$
$\boldsymbol{\rho}$	density $[kg/m^3]$
$\boldsymbol{g}$	constant of gravity $[m/s^2]$
η	viscosity of water and water – glycerol $[Pas]$
$\boldsymbol{\eta_{oil}}$	viscosity of the surrounding medium $[Pas]$
$\boldsymbol{a}$	capillary length $[m]$
$\boldsymbol{D}$	needle inner diameter $[m]$
$\boldsymbol{R}$	needle inner radius $[m]$
$\boldsymbol{L}$	breakup length of the jet $[m]$
$\boldsymbol{v}$	single jet velocity $[m/s]$
$\boldsymbol{k}$	wave number $[1/m]$
$\boldsymbol{\lambda}$	wavelength $[m]$
$\boldsymbol{\omega}$	perturbation frequency (growth rate of disturbance $[1/s]$
$\boldsymbol{t}$	breakup time $[s]$

2. Materials and methods

The experiments involved in this study used organic oil as hydrophobic medium. Mixtures of water and glycerol were used for studying jet formation and breakup into oil. Pure water jet was used as reference.

By adding glycerol in water we increased the viscosity and density of the mixture.

Interfacial tension between the two phases was measured with the pendant drop method. Densities are evaluated by weighting a volume of liquid using a Hamilton microsyringe (Gastight #1725 0.25 ml) and a microscale balance (Radwag AS 82/220.R2). Viscosity was measured with a rotational rheometer (Anton Parr Physica MCR301), using a cone –plate geometry (CP 50/1°). Fluids properties are presented in Table 1, along with the capillary length, a, values. All fluids were tested at $25^{\circ}C$.

$$a = \sqrt{\frac{\gamma}{\rho g}} \tag{1}$$