MODELING AND SIMULATION OF TAYLOR CONE AND JETTING FROM LIQUID DROPLETS

By

Asmaa Mohammed Elkady

A thesis submitted to the

Faculty of Engineering at Cairo University

In partial Fulfillment of

MASTER OF SCIENCE

In

Chemical Engineering

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Title of Thesis :
MODELING AND SIMULATION OF TAYLOR CONE AND JETTING FROM LIQUID DROPLETS

Key Words:
Taylor cone; liquid droplet; Electrospinning; momentum balance; applied voltage

Summary :
Liquid droplets are deformed when subjected to an electric field and acquires stable shapes. These shapes are a result of force balance between surface tension force, viscous force and electrostatic force. The droplet shape is turned into a conical shape, which is well known by “Taylor cone” with a half angle of 49.3^{o}; then a fine jet comes from the cone apex. This phenomenon is widely studied and is strongly related to the electrospinning process which is recognized as an efficient technique to produce nanofibers. Variety of materials is used for electrospinning; most of them are polymers, composites, semiconductors or ceramics. Most of electrospinning experiments were done in research laboratories. The main objective of the research is to simulate the Taylor cone formation and jetting process as a part of electrospinning process using COMSOL® Multiphysics program. Three materials are used in this simulation; glycerol, distilled water and NaCl solution.

Acknowledgements

First and foremost, I would like to express my profound gratitude, and thanks to my supervisor, Dr. Ahmed S. Eissa for his continuous support, invaluable advice, and constant guidance throughout the duration of this work. I would also like to thank Prof. Tarek M. Mostafa for his valuable suggestions and constructive comments that were very beneficial in my completion of this work. In particular, I would like to give a special thanks to Prof. Mai M. Fouad for her great support and kind help.

I also wish to express my appreciation to my M.Sc. committee (Prof. Hammam A. El-Abd and Prof. Salwa R. Mostafa) for their valuable comments.

Finally, my deepest gratitude goes to all the members of my family and to my friends for their life- long love, care and support.

Dedication

I dedicate this thesis to my great mother

You have successfully made me the person I am becoming

This work is also dedicated to my husband, Ashraf

I am truly thankful for having you in my life

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Abstract

Liquid droplets are deformed when subjected to an electric field and acquires stable shapes. These shapes are a result of force balance between surface tension force, viscous force and electrostatic force. This is occurs when liquid droplet is held at a capillary tube by its surface tension, this capillary tube is raised to high potential and a grounded plate is placed in an appropriate distance from the capillary. The droplet remains stable until the potential difference between the droplet and the plate exceeds the critical value. If the electric potential is raised above this critical value the droplet shape is turned into a conical shape. This conical shape is well known by “Taylor cone” with a half angle of 49.3^o; then a fine jet comes from the cone apex. This phenomenon is widely studied and is strongly related to the electrospinning process which is recognized as an efficient technique to produce nanofibers.

Electrospinning process involves two stages. During the first stage, at which the Taylor cone forms, the jet emerges from the needle tip and steadily stretches downstream by electrostatic forces. In the second stage, the polymer jet becomes sufficiently thin and bending instability occurs, then the thinned fiber spirals violently. Variety of materials is used for electrospinning; most of them are polymers, composites, semiconductors or ceramics. Most of electrospinning experiments were done in research laboratories. Many studies, theories and experiments were done in order to have a clear explanation for the first stage in electrospinning process. For this stage, Hohman et.al. presented a slender body theory for electrospinning of Newtonian fluids. Spivak and Dzenis introduced a power law viscosity model. Renker et. al. modeled the viscoelasticity of the jet by a linear Maxwell equation. The first stage of electrospinning process is important because cone formation and jetting are the basis for the analysis of the second stage of jet instability. Also first stage sets up the conditions for the second stage of electrospinning process.

Electrospinning is a complex process to be studied. This complexity is due to the coupling of electrostatic forces and momentum forces. Although electrospinning process is a century old technology and an important subject for recent intensive researches, there is no clear understanding of the behavior of the electrospun jet and parameters affecting the whole process. Moreover, the results gathered from experimental researches contain significant inconsistencies. Very little researches examined the effect of electrical parameters on the electrospun jet, such as the polarity of electrode, fluid conductivity and fluid permittivity. Furthermore, no researches were concerned with optimization of the electrospinning process. So, a comprehensive investigation is needed for optimization of electrospinning process and finds the favorable parameters and conditions for this process. The cone- Jet models become in the forefront of 1990’s researches that are concerned with droplets dynamics with the rapid development of Nano technology in either experimental researches or theoretical studies. Theoretical studies are limited to gross simplification of the actual problem because of the complication which accompanied the analysis of the coupled fluid