Modeling of Straight Jet Dynamics in Electrospinning Process

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Abstract

Electrospinning is a process where high voltage is applied to produce polymer fibers of nanoscale diameter. Various polymers have been used for this process in molten form or as a solution with an appropriate solvent such as glycerol. The melt solidifies while the solvent evaporates to produce fibers. The fibers produced have properties such as high surface to volume ratio and a molecular structure which is relatively defect-free. The resultant fiber properties are considered favorable in applications requiring high degree of surface area or high mechanical strength, such as catalysis, filtration, biomedical applications, composites, adsorption, textile etc. One of the major challenges in electrospinning is to determine the radius of synthesized polymer fiber.
This work is concerned with estimation of size of polymer fiber under different operating conditions. The whole process of electrospinning can be categorized into two stages: (a) Stretching of the straight jet. (b) Spiraling of the unstable jet. We have modeled straight jet dynamics for fiber stretching under the influence of external electric field using momentum equations, charge conservation equations and viscosity models.
We have implemented the model for a straight jet polymer dynamics using COMSOL Multiphysics®. We have solved the highly coupled (i) momentum equation, (ii) charge conservation and (iii) stress components from the viscosity models using the coefficient form PDE interface of COMSOL Multiphysics. We have used the parametric solver to evaluate the radius of the fiber under different operating conditions. The model was validated against experimental results for a Newtonian fluid as shown in figure 1. The model was further extended to non-Newtonian and viscoelastic fluids. The Giesekus and Oldroyd-B viscoelastic models were used for viscoelastic fluids and effects of different parameters on fiber diameter was studied. The model was further extended to incorporate the non-Newtonian effects (thinning, thickening) of the solvent being used and compared as shown in figure 2.
The COMSOL Multiphysics model presented in this work can be used to determine the size of fibers synthesized using different types of polymers and polymer solvents. It can also predict the effect of the strength of electric field and flow rate of polymer melt. Therefore, the model can be used to optimize the properties of polymer fiber.

Reference

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Figures used in the abstract

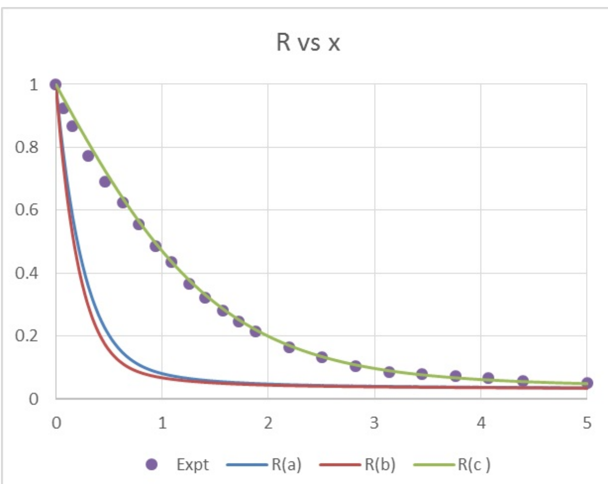

Figure 1: Validation for Newtonian fluid (Glycerol) model against experimental data[1].

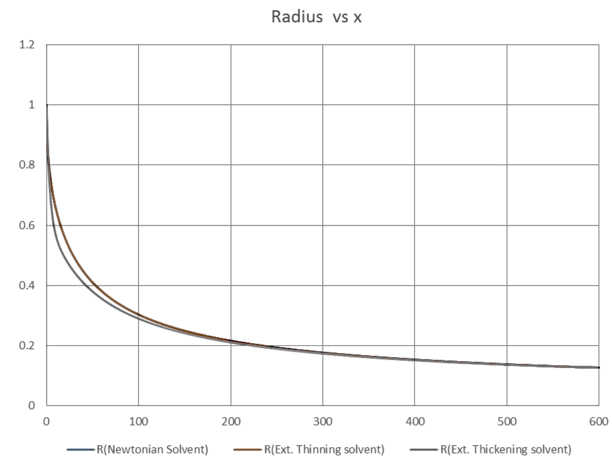

Figure 2: Comparison of different liquids used as solvents.