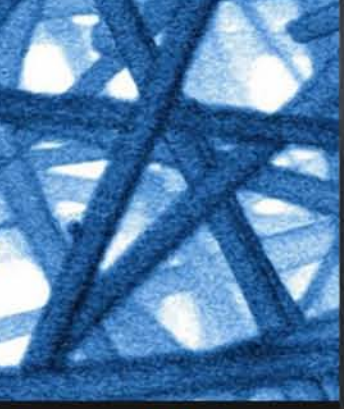

Electrospinning of Nanofibers in Textiles

A.K. Haghi, PhD

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Contents

List of Abbreviations

AFM	Atomic force microscopy
CV	Coefficient of variation
dB	Decibels
DMF	Dimethylformamide
EOS	Equivalent opening size
FCCD	Face-centered central composite design
MAT	Medial axis transformation
MFD	Mean fiber diameter
ODF	Orientation distribution function
PAN	Polyacrylonitrile
PDLA	Poly D, L-lactide
PEOT/PBT	Polyethylene oxide terephthalate/polybutylene terephthalate
POA	Percent open area
PPSN	Polypropylene spun-bond nonwoven
PSD	Pore-opening size distribution
PVA	Polyvinyl alcohol
PVdF	Polyvinylidene fluoride
RMSE	Root mean square errors
RSM	Response surface methodology
SE	Shielding effectiveness
SEM	Scanning electron microscopy
SF	Silk fibroin
StdFD	Standard deviation of fiber diameter
TEM	Transmission electron microscopy

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Preface

Nanotechnology, refers to a field whose theme is the control of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller, and involves developing materials or devices within that size. Nanotechnology is extremely diverse, ranging from novel extensions of conventional device physics, to completely new approaches based upon molecular self-assembly, to developing new materials with dimensions on the nanoscale, even to speculation on whether we can directly control matter on the atomic scale. There has been much debate on the future of implications of nanotechnology. Nanotechnology has the potential to create many new materials and devices with wide-ranging applications, such as in medicine, electronics, and energy production. On the other hand, nanotechnology raises many of the same issues as with any introduction of new technology, including concerns about the toxicity and environmental impact of nanomaterials, and their potential effects on global economics, as well as speculation about various doomsday scenarios. These concerns have led to a debate among advocacy groups and governments on whether special regulation of nanotechnology is warranted.

Nanotechnology is now used in precision engineering, new materials development as well as in electronics; electromechanical systems as well as mainstream biomedical applications in areas such as gene therapy, drug delivery and novel drug discovery techniques.

Nanofibers are defined as fibers with diameters on the order of 100 nanometers. They can be produced by interfacial polymerization and electrospinning. Nanofibers are included in garments, insulation and in energy storage. They are also used in medical applications, which include drug and gene delivery, artificial blood vessels, artificial organs and medical facemasks. Electrospinning is the cheapest and the most straightforward way to produce nanomaterials. Electrospun nanofibres are very important for the scientific and economic revival of developing countries. It is now possible to produce a low-cost, high-value, high-strength fibre from a biodegradable and renewable waste product for easing environmental concerns. Electrospun nanofibres can be used in many applications. This book presents new research in this dynamic field and covers all aspects of electrospinning as used to produce nanofibres.

— A. K. Haghi

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Chapter 1

Electrospun Nanofibers: An Introduction

INTRODUCTION

An emerging technology of manufacturing of thin natural fibers is based on the principle of electrospinning process. In conventional fiber spinning, the mechanical force is applied to the end of a jet. Whereas in the electrospinning process the electric body force act on element of charged fluid. Electrospinning has emerged as a specialized processing technique for the formation of sub-micron fibers (typically between 100 nm and 1 μm in diameter), with high specific surface areas. Due to their high specific surface area, high porosity, and small pore size, the unique fibers have been suggested for wide range of applications. Electrospinning of natural fibers offers unique capabilities for producing novel natural nanofibers and fabrics with controllable pore structure. Current research effort has focused in understanding the electrospinning of natural fibers in which the influence of different governing parameters are discussed.

A schematic diagram to interpret electrospinning of polymer nanofibers is shown in Fig. 1.1. There are basically three components to fulfill the process: a high voltage supplier, a capillary tube with a pipette or needle of small diameter, and a metal collecting screen.

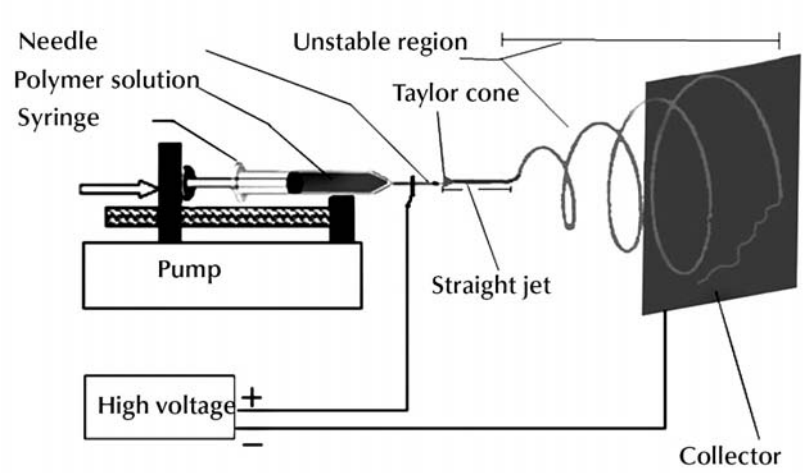

Figure 1.1. Electrospinning setup.

The morphological structure can be slightly changed by changing the solution flow rate as shown in Fig. 1.2. At the flow rate of 0.3 ml/h, a few of big beads were observed

on fibers. The flow rate could affect electrospinning process. A shift in the mass-balance resulted in sustained but unstable jet and fibers with big beads were formed.

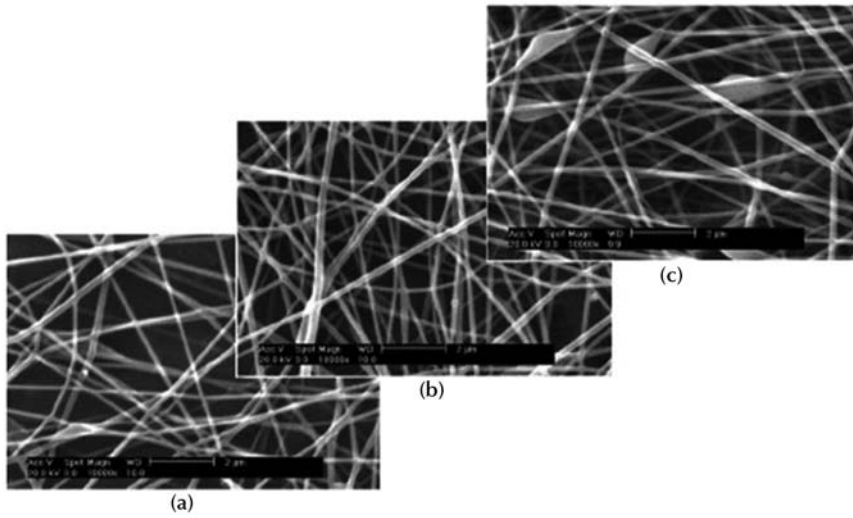

Figure 1.2. Effect of flow rate of 7% PVA water solution on fiber morphology (DH = 98%, voltage = 8 kV, tip–target distance = 15 cm). Flow rate: (a) 0.1 ml/h; (b) 0.2 ml/h; (c) 0.3 ml/h. Original magnification 10 k.

Typically, electrospinning has two stages. In the first, the polymer jet issues from a nozzle and thins steadily and smoothly downstream. In the second stage, the thin thread becomes unstable to a non-axisymmetric instability and spirals violently in large loops. The jet is governed by four steady-state equations representing the conservation of mass and electric charges, the linear momentum balance, and Coulomb's law for the E field. Mass conservation requires that

$$\pi R^2 \upsilon = Q \tag{1}$$

where Q is a constant volume flow rate. Charge conservation may be expressed by

$$\pi R^2 KE + 2\pi R \upsilon \sigma = I \tag{2}$$

where E is the z component of the electric field, K is the conductivity of the liquid, and I is the constant current in the jet. The momentum equation is formulated by Fig. 1.3:

$$\frac{d}{dz}(\pi R^2 \rho \upsilon^2) = \pi R^2 \rho g + \frac{d}{dz}[\pi R(-P + \tau_{ZZ})] + \frac{\gamma}{R}.2\pi RR' + 2\pi R(t_t^e - t_n^e R'), \tag{3}$$

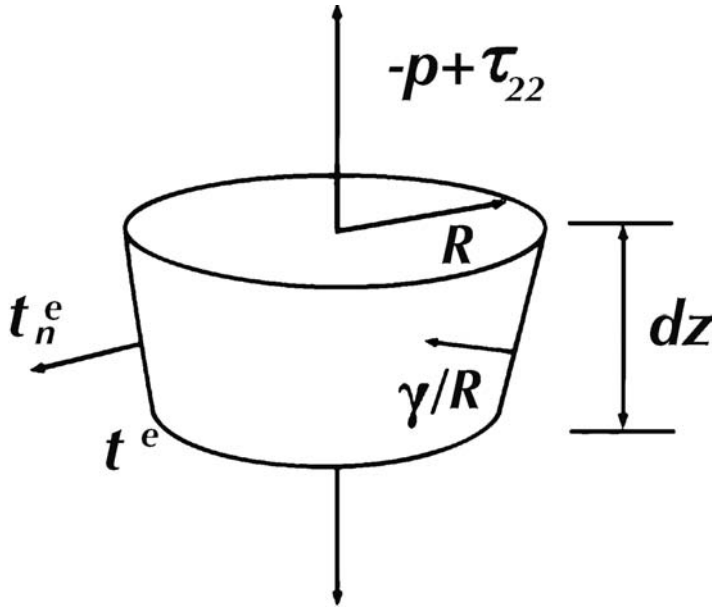

Figure 1.3. Momentum balance on a short section of the jet.

where τ_{zz} is the axial viscous normal stress, p is the pressure, γ is the surface tension, and t_t^e and t_n^e are the tangential and normal tractions on the surface of the jet due to electricity. The prime indicates derivative with respect to z, and R' is the slope of the jet surface. The ambient pressure has been set to zero. The electrostatic tractions are determined by the surface charge density and the electric field:

$$t_n^e = \left\| \frac{\varepsilon}{2}(E_n^2 - E_t^2) \right\| \approx \frac{\sigma^2}{2\bar{\varepsilon}} - \frac{\varepsilon' - \varepsilon}{2} E^2 , \tag{4}$$

$$t_t^e = \sigma E_t \approx \sigma E , \tag{5}$$

where ε and $\bar{\varepsilon}$ are dielectric constants of the jet and the ambient air, respectively, E_n and E_t are normal and tangential components of the electric field at the surface, and $\|*\|$ indicates the jump of a quantity across the surface of the jet. We have used the jump conditions for E_n and E_t: $\| \varepsilon E_n \| = \bar{\varepsilon}\bar{E} - \varepsilon E_n = \sigma$, $\|E_t\| = \bar{E}_t - E_t = 0$, and assumed that $\varepsilon E_n << \bar{\varepsilon}\bar{E}$ and $E_t \approx E$. The overbar indicates quantities in the surrounding air. The pressure $p(z)$ is determined by the radial momentum balance, and applying the normal force balance at the jet surface leads to: