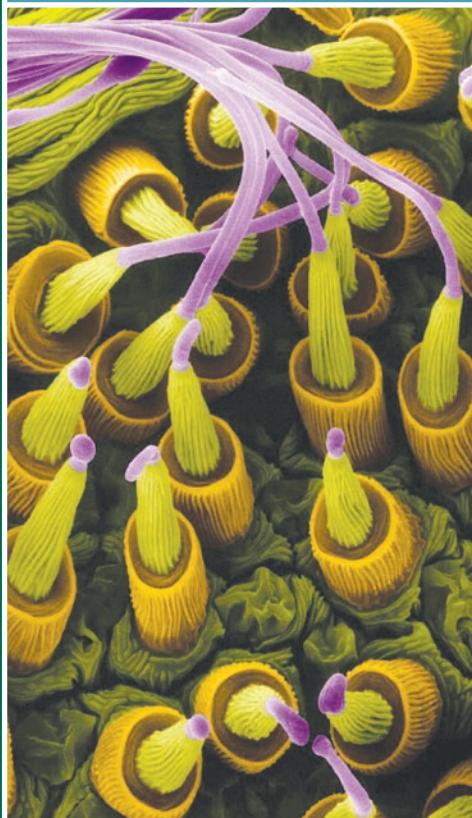


# Electrospun Nanofibres and Their Applications



Ji-Huan He, Yong Liu,  
Lu-Feng Mo, Yu-Qin Wan  
and Lan Xu

*Smithers Rapra Update*



# **Electrospun Nanofibres and Their Applications**

Ji-Huan He, Yong Liu, Lu-Feng Mo,  
Yu-Qin Wan and Lan Xu



iSmithers  
A wholly owned subsidiary of The Smithers Group

Shawbury, Shropshire, SY4 4NR, United Kingdom  
Telephone: +44 (0)1939 250383 Fax: +44 (0)1939 251118  
<http://www.rapra.net>

Published 2008

**iSmithers**

Shawbury, Shropshire, SY4 4NR, UK

©2008, iSmithers

All rights reserved. Except as permitted under current legislation no part of this publication may be photocopied, reproduced or distributed in any form or by any means or stored in a database or retrieval system, without the prior permission from the copyright holder.

A catalogue record for this book is available from the British Library.

Every effort has been made to contact copyright holders of any material reproduced within the text and the authors and publishers apologise if any have been overlooked.

Cover micrograph reproduced with permission from Dennis Kunkel  
Microscopy, Inc.

**ISBN: 978-1-84735-145-6**

Typeset by iSmithers  
Printed and bound by Lightning Source Inc.

# Contents

1.	Introduction .....	1
1.1	What is Nanotechnology?.....	1
1.2	What is Electrospinning? .....	6
1.3	What Affects Electrospinning?.....	10
1.4	Applications .....	12
1.5	Global Interest in the Field of Electrospinning .....	13
	References .....	16
2.	Mathematical Models for the Electrospinning Process.....	17
2.1	One-Dimensional Model .....	17
2.2	Spivak-Dzenis Model.....	18
2.3	Wan-Guo-Pan Model.....	19
2.4	Modified One-Dimensional Model .....	20
2.5	Modified Conservation of Charge Model .....	22
2.6	Reneker's Model.....	28
2.7	E-Infinity Theory .....	34
	References .....	39
3.	Allometric Scaling in Electrospinning .....	41
3.1	Allometric Scaling in Nature.....	42
3.2	Allometric Scaling Laws in Electrospinning .....	45
3.2.1	Relationship Between Radius $r$ of Jet and Axial Distance $z$ .....	45

3.2.2	Allometric Scaling Relationship Between Current and Voltage .....	53
3.2.3	Allometric Scaling Relationship Between Solution Flow Rate and Current.....	56
3.2.4	Effect of Concentration on Electrospun PAN Nanofibres.....	59
3.2.5	Allometric Scaling Law Between Average Polymer Molecular Weight and Electrospun Nanofibre Diameter ....	63
3.2.6	Effect of Voltage on Morphology and Diameter of Electrospun Nanofibres.....	66
3.2.7	Improving Electropinnability Using Non-ionic Surfactants.....	72
3.3	Allometric Scaling Law for Static Friction of Fibrous Materials .....	80
3.3.1	Solid–Solid Friction .....	81
3.3.2	Viscous Friction for Newtonian Flow ....	82
3.3.3	Friction for Soft Materials .....	82
3.3.4	Fibre–Fibre Friction.....	82
3.4	Allometric Scaling in Biology .....	84
	References .....	87
4.	Application of Vibration Technology to Electrospinning ...	93
4.1	Effect of Viscosity on Diameter of Electrospun Fibre.....	93
4.2	Effect of Vibration on Viscosity .....	94
4.3	Application of Vibration Technology to Polymer Electrospinning .....	95
4.4	Effect of Solution Viscosity on Mechanical Characteristics of Electrospun Fibres .....	103

## *Contents*

4.5 Carbon-Nanotube-Reinforced Polyacrylonitrile Nanofibres by Vibration Electrospinning .....	105
References .....	112
5. Magneto-Electrospinning: Control of the Instability.....	115
5.1 Critical Length of Straight Jet in Electrospinning...	116
5.2 Controlling Stability by Magnetic Field .....	119
5.3 Controlling Stability by Temperature.....	123
5.4 Siro-electrospinning .....	127
References .....	129
6. Bubble Electrospinning: Biomimic Fabrication of Electrospun Nanofibres with High Throughput.....	131
6.1 Spider Spinning.....	131
6.1.1 Intelligent Spider Fibre .....	132
6.1.2 Mathematical Model for Spider-Spun Fibres.....	134
6.2 Electrospinning of Silk Fibroin Nanofibres .....	135
6.3 Solving the Mystery of the Spider Spinning Process .....	136
6.4 Bubble Electrospinning .....	143
References .....	154
7. Controlling Numbers and Sizes of Beads in Electrospun Nanofibres .....	157
7.1 Experimental Observations.....	157
7.2 Effects of Different Solvents.....	158
7.3 Effect of Polymer Concentration.....	163
7.4 Effect of Salt Additive.....	165
References .....	167

## *Electrospun Nanofibres and Their Applications*

8.	Electrospun Nanoporous Microspheres for Nanotechnology .....	169
8.1	Electrospun Nanoporous Spheres with a Traditional Chinese Drug.....	170
8.2	Electrospinning Dilation .....	180
8.3	Single Nanoporous Fibres by Electrospinning.....	183
8.4	Microspheres with Nanoporosity .....	187
	References .....	190
9.	A Hierarchy of Motion in the Electrospinning Process and E-Infinity Nanotechnology .....	191
9.1	E-Infinity Nanotechnology.....	191
9.2	Application of E-Infinity Theory to Electrospinning.....	193
9.2.1	Hausdorff Dimension for the Hierarchy of Motion .....	194
9.2.2	Experimental Verification .....	195
9.3	Super Carbon Nanotubes: An E-Infinity Approach.....	199
	References .....	202
10.	Mechanics in Nanotextile Science.....	203
10.1	Jet Vortex Spinning and Cyclone Model .....	203
10.2	Two-Phase Flow of Yarn Motion in High-Speed Air and Micropolar Model .....	205
10.3	Mathematical Model for Yarn Motion in a Tube.....	209
10.4	Nanohydrodynamics .....	212
10.5	A New Resistance Formulation for Carbon Nanotubes and Nerve Fibres .....	218

*Contents*

10.6 Differential-Difference Model for Nanotechnology .....	220
References .....	222
11. Nonlinear Dynamics in Sirofil/SiroSpun Yarn Spinning ...	225
11.1 Convergence Point .....	227
11.2 Linear Dynamic Model.....	229
11.3 Nonlinear Dynamic Model .....	236
11.4 Stable Working Condition for Three-Strand Yarn Spinning .....	241
11.5 Nano-Sirospinning.....	246
References .....	247
Acknowledgement .....	248
Abbreviations .....	249
Index.....	251