

# **Gels Horizons: From Science to Smart Materials**

## **Series editor**

Vijay Kumar Thakur, School of Aerospace, Transport and Manufacturing,  
Cranfield University, Cranfield, Bedfordshire, UK

This series aims at providing a comprehensive collection of works on the recent advances and developments in the domain of *Gels*, particularly as applied to the various research fields of sciences and engineering disciplines. It covers a broad range of topics related to *Gels* ranging from *Polymer Gels*, *Protein Gels*, *Self-Healing Gels*, *Colloidal Gels*, *Composites/Nanocomposites Gels*, *Organogels*, *Aerogels*, *Metallogels & Hydrogels* to *Micro/Nano gels*. The series provides timely and detailed information on advanced synthesis methods, characterization and their application in a broad range of interrelated fields such as chemistry, physics, polymer science & engineering, biomedical & biochemical engineering, chemical engineering, molecular biology, mechanical engineering and materials science & engineering.

This Series accepts both edited and authored works, including textbooks, monographs, reference works, and professional books. The books in this series will provide a deep insight into the state-of-art of *Gels* and serve researchers and professionals, practitioners, and students alike.

More information about this series at <http://www.springer.com/series/15205>

Vijay Kumar Thakur · Manju Kumari Thakur  
Editors

# Polymer Gels

Science and Fundamentals

 Springer

*Editors*

Vijay Kumar Thakur  
Faculty in Manufacturing, Enhanced  
Composites and Structures Centre,  
School of Aerospace, Transport  
and Manufacturing  
Cranfield University  
Cranfield  
UK

Manju Kumari Thakur  
Division of Chemistry  
Government Degree College Bhoranj,  
Himachal Pradesh University  
Shimla, Himachal Pradesh  
India

ISSN 2367-0061

ISSN 2367-007X (electronic)

Gels Horizons: From Science to Smart Materials

ISBN 978-981-10-6085-4

ISBN 978-981-10-6086-1 (eBook)

<https://doi.org/10.1007/978-981-10-6086-1>

Library of Congress Control Number: 2018939938

© Springer Nature Singapore Pte Ltd. 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd. The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

# Preface

A gel is described as a soft, solid- or liquid-like unique condensed material that has a three-dimensional network composed of several components such as long polymers, species of small molecules and a large amount of solvent. These 3D network condensed materials usually form through chemical, physical or supramolecular crosslinking. The weight and size of gels are more like a liquid, but they are treated like a solid. Two important characteristics of gels are phase state and their rheological properties. On the other hand, a polymer is defined a large molecule (macromolecules) composed of repeating structural units that comprise of multiple assemblies of simple structural units. In gels, the polymer network can be physically or chemically crosslinked. In case of physical gels, the network formation occurs due to various weak interactions, like the entanglement of the polymer chains, hydrogen bonds or van der Waals interactions. Such structures are usually not permanent and they dissolve over the time when immersed in their solvents. However, the polymer chains can also be crosslinked through chemical reactions, leading to strong covalent bonds. The chemically crosslinked network is much more stable and cannot be dissolved without the degradation of the polymer. Therefore, chemical gels are usually preferable in the majority of the application fields. Polymer gels comprise a great variety of different polymeric components that present innumerable industrial applications. Polymers can be naturally produced (some time referred as bio-based polymers), in which case the most representative group is polysaccharides. Natural polymers' demand is expected to grow 7.1% every year. Moreover, their low toxicity and excellent biodegradability have also attracted researchers to pay attention towards the widespread application of natural polymers. Polymer obtained from natural sources such as chitosan, alginate, dextran, starch, pectin, cellulose and lignin has shown excellent potential for biomedical and other applications in the form of microsphere, nanoparticles, crosslinked hydrogels, beads, membranes and granules. On the other hand, a wide variety of synthetic polymers capable of forming gels present different industrial applications, such as polyacrylamide and polyvinyl alcohol-based gels. Both synthetic and natural polymer-based gels find applications from health sciences such as

agents for controlled drug delivery, sustained drug delivery, targeted drug delivery and various other types of novel drug delivery systems to water purification.

Polymer gels due to their several unique characteristics have become an indispensable part of new advanced and smart materials in the twenty-first century for numerous applications including but not limited to biological, biomedical, electronic and environmental. Keeping in mind the immense advantages of polymer gel-based materials, this volume of the series is solely focused on the science and fundamental of polymer gels. It provides a comprehensive collection of works on the recent advances and developments in science and fundamentals of both synthetic and natural polymer-based gels particularly as applied to the various research fields of sciences and engineering disciplines. Some of the important topics include but not limited to: polysaccharide-based gels and their fundamentals; stimuli-responsive polymer gels; polymer gels applied to enzyme and cell immobilization; chitosan-based gels for cancer therapy; natural polymeric and gelling agents; radiation dosimetry—a different prospective of polymer gel; polymeric gels as vehicles for enhanced drug delivery across skin; transport in and through gel; graphene oxide—polymer gels; polymer gel nanocomposites; and functional gels to name a few.

In editing and organising this volume *Polymer Gels: Science and Fundamentals* of the book series *Gels Horizons: From Science to Smart Materials*, we have made our best efforts to cover the growing field of polymer gels and related technologies. It reflects the recent theoretical advances and experimental results and opens new avenues for researchers as well as readers working in the fields of polymer and functional materials. In addition, several critical issues and suggestions for future work are comprehensively discussed in this book with the hope that the book will provide a deep insight into the state of the art of *Polymer Gels*. We express our sincere thanks to all the authors, who have contributed their extensive experience through their work for the success of this book. We would also like to thank Swati Meherishi and the rest of the team at Springer for invaluable help in the organisation of the editing process.

Cranfield, UK  
Shimla, India

Vijay Kumar Thakur, Ph.D.  
Manju Kumari Thakur, M.Sc., M.Phil., Ph.D.

# Contents

<b>1</b>	<b>Polymer Hydrogel-Clay (Nano)Composites</b> . . . . .	<b>1</b>
	Piotr Kuśtrowski, Piotr Natkański, Anna Rokicińska and Ewa Witek	
<b>2</b>	<b>An Overview on Polymer Gels Applied to Enzyme and Cell Immobilization</b> . . . . .	<b>63</b>
	Gustavo Pagotto Borin, Ricardo Rodrigues de Melo, Elaine Crespim, Helia Harumi Sato and Fabiano Jares Contesini	
<b>3</b>	<b>Hemicellulose-Based Hydrogels and Their Potential Application</b> . . . . .	<b>87</b>
	Weiqing Kong, Qingqing Dai, Cundian Gao, Junli Ren, Chuanfu Liu and Runcang Sun	
<b>4</b>	<b>Updates on Stimuli-Responsive Polymers: Synthesis Approaches and Features</b> . . . . .	<b>129</b>
	Ibrahim M. El-Sherbiny, Islam A. Khalil and Isra H. Ali	
<b>5</b>	<b>Polysaccharide-Based Polymer Gels</b> . . . . .	<b>147</b>
	Tamás Fekete and Judit Borsa	
<b>6</b>	<b>Polysaccharide Containing Gels for Pharmaceutical Applications</b> . . . . .	<b>231</b>
	Catalina Natalia Cheaburu-Yilmaz, Sakine Tuncay Tanriverdi, Ozgen Ozer and Cornelia Vasile	
<b>7</b>	<b>Design of Multifunctional Nanogels with Intelligent Behavior</b> . . . . .	<b>279</b>
	G. Rimondino, C. Biglione, M. Martinelli, C. Alvarez Igarzábal and M. Strumia	
<b>8</b>	<b>Radiation Dosimetry—A Different Perspective of Polymer Gel</b> . . . . .	<b>309</b>
	Deena Titus, E. James Jebaseelan Samuel and Selvaraj Mohana Roopan	

<b>9</b>	<b>Polymeric Gels: Vehicles for Enhanced Drug Delivery Across Skin</b> .....	343
	Rachna Prasad and Veena Koul	
<b>10</b>	<b>Graphene Oxide–Polymer Gels</b> .....	377
	Abbas Dadkhah Tehrani, Mohsen Adeli, Sh. Sattari and Kh. Soleimani	
<b>11</b>	<b>Transport in and Through Gel</b> .....	413
	Masayuki Tokita	
<b>12</b>	<b>Incorporation of Filler/Additives in Polymer Gel for Advanced Application</b> .....	445
	Ida Idayu Muhamad, Eraricar Salleh, Shahrulzaman Shahrudin, Norhayatie Pa'e, Suguna Selvakumaran and Mohd. Harfiz Salehudin	



## About the Editors



**Dr. Vijay Kumar Thakur, Ph.D.** Prior to commencing in the School of Aerospace, Transport and Manufacturing at Cranfield University, Dr. Vijay Kumar Thakur was working as a Staff Scientist in the School of Mechanical and Materials Engineering at Washington State University, USA (2013–2016). Some of his other prior significant appointments include being a Research Scientist in Temasek Laboratories at Nanyang Technological University, Singapore (2009–2012) and a Visiting Research Fellow in the Department of Chemical and Materials Engineering at LHM—Taiwan. He did his post-doctoral study in Materials Science and Engineering at Iowa State University and received Ph.D. in Polymer Chemistry (2009).

In his academic career, he has published more than 100 SCI journal research articles in the field of chemical sciences/materials science and holds one US patent. He has also published 33 books and 35 chapters on the advanced state-of-the-art of polymer science/materials science/nanotechnology with numerous publishers. His research interests include the synthesis and processing of bio-based polymers, composites, nanostructured materials, hydrogels, polymer micro/nanocomposites, nanoelectronic materials, novel high dielectric constant materials, engineering nanomaterials, electrochromic materials, green synthesis of nanomaterials and surface functionalization of polymers/nanomaterials. Application aspects range from automotive to aerospace, energy storage, water purification and biomedical fields.

He is an editorial board member of several international journals, as well as a member of scientific bodies around the globe. Some of his significant appointments include Associate Editor for *Materials Express* (SCI); Advisory Editor for *SpringerPlus* (SCI); Editor for *Energies* (SCI); Editor for *Cogent Chemistry* (SCI); Associate Editor for *Current Smart Materials*; Associate Editor for *Current Applied Polymer Science*; Regional Editor for *Recent Patents on Materials Science* (Scopus); and Regional Editor for *Current Biochemical Engineering* (CAS). He also serves on the Editorial Advisory Board of *Polymers for Advanced Technologies* (SCI) and is on the Editorial Board of *Journal of Macromolecular Science, Part A: Pure and Applied Chemistry* (SCI), *International Journal of Industrial Chemistry* (SCI), *Biointerface Research in Applied Chemistry* (SCI) and *Advances in Natural Sciences: Nanoscience and Nanotechnology* (SCI). e-mail: [Vijay.Kumar@cranfield.ac.uk](mailto:Vijay.Kumar@cranfield.ac.uk)



**Dr. Manju Kumar Thakur, M.Sc., M.Phil., Ph.D.** has been working as an Assistant Professor of Chemistry at the Division of Chemistry, Government Degree College, Sarkaghat, Himachal Pradesh University, Shimla, India, since June 2010. She received her B.Sc. in Chemistry, Botany and Zoology; M.Sc., M. Phil. in Organic Chemistry; and Ph.D. in Polymer Chemistry from the Chemistry Department at Himachal Pradesh University, Shimla, India. She has rich experience in the fields of organic chemistry, biopolymers, composites/nanocomposites, hydrogels, applications of hydrogels in the removal of toxic heavy metal ions, drug delivery, etc. She has published more than 30 research papers in several international journals, co-authored five books and also published 25 chapters in the field of polymeric materials. e-mail: [chauhanmanjuchem@gmail.com](mailto:chauhanmanjuchem@gmail.com)