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Handbook of Lignin

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With 363 Figures and 96 Tables

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In the Name of Allah, the Most Gracious, the Most Merciful
I dedicate this Handbook of Lignin*, my first editorial endeavor, to my beloved father (Dr. Meraj, Consultant Radiologist).*

He served as both my mentor and guide, and his invaluable support and guidance were instrumental in facilitating my success.
May Allah accept this humble effort and grant my father eternal peace and happiness in the hereafter.

Your daughter,
Dr. Aatikah Meraj

Preface

This handbook provides a comprehensive and up-to-date understanding of lignin and its dynamic role in modern science and industry. Lignin, a complex and abundant plant polymer, has been widely researched for its diverse applications in areas such as biofuels, composite materials, and carbon fibers. Despite its immense potential, there is still a great deal of unexplored research on lignin. With growing global emphasis on sustainability, lignin has emerged as a promising renewable resource for energy and as a valuable raw material for chemicals and advanced materials. This handbook provides a comprehensive overview of lignin, encompassing its structure, extraction methods, and characterization techniques, functionalization, surface modification, and properties of lignin-based materials. The functionalization of lignin covers different chemical and physical modification techniques, including oxidation, esterification, and grafting. It also discusses the different functional groups of lignin and their modification to enhance specific material properties. Furthermore, the surface modification of lignin-based materials is explored through the use of nanotechnology and other advanced techniques to enhance their functionality and performance. It also explores how the surface properties of lignin-based materials can be modified to enhance their functionality and performance. It also discusses the potential applications of lignin-based materials in various industries, such as the automotive, packaging, and construction industries. Latest research and developments in the field of lignin-based materials, along with an in-depth understanding of their potential applications in various industries including automotive, packaging, and construction, are also covered.

Overall, this handbook is intended for researchers, students, and professionals in chemistry, materials science, biology, and environmental science who are interested in the dynamic field of lignin and its diverse applications in various fields.

We extend our sincere gratitude to all the qualified researchers, scholars, and experts who contributed their valuable work. The chapters compile cutting-edge research findings on lignin and its applications in various fields. We have compiled contributions from eminent authors on lignin and related research from countries including Spain, Iran, Iraq, Portugal, Australia, India, Malaysia, Saudi Arabia,

Indonesia, Egypt, Morocco, Brazil, France, China, Sweden, Ireland, Pakistan, South Korea, and Bangladesh, resulting in a globally informed and richly contextualized resource.

Al Ain, United Arab Emirates — Mohammad Jawaid
Al Kharj, Saudi Arabia — Akil Ahmed
Dhahran, Saudi Arabia — Aatikah Meraj
October 2025

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About the Editors

Dr. Mohammad Jawaid is currently working as Distinguished Professor at Chemical and Petroleum Engineering Department, United Arab Emirates University, UAE. He has more than 25 years of experience in teaching, research, and industries. His areas of research interests include hybrid composites, lignocellulosic reinforced/filled polymer composites, advance materials: graphene/nanoclay/fire retardant, modification and treatment of lignocellulosic fibers and solid wood, biopolymers and biopolymers for packaging applications, nanocomposites and nanocellulose fibers, and polymer blends. So far, he has published 100 books, more than 100 book chapters, more than 500 peer-reviewed international journal papers, and several published review papers under top 25 hot articles in ScienceDirect during 2013–2020. He also obtained 6 Patents and 6 Copyrights/Industrial design. H-index and citations in Scopus are 103 and 44,525, and in Google scholar, H-index and citations are 122 and 59,693. Forty Ph.D. and 17 master's students graduated under his supervision in 2014–2024 in the fields of hybrid composites, green composites, nanocomposites, natural fiber-reinforced composites, nanocellulose, etc. He secured various research grants at university, national, and international levels on polymer composites of around USD 3 million. He also delivered plenary and invited talks in international conferences related to composites in India, Turkey, Malaysia, Thailand, the United Kingdom, France, Saudi Arabia, Egypt, China, Germany, Indonesia, Spain, the UAE, Portugal, etc. Besides that, he is also a member of technical committees of several national and international conferences

on composites and material science. He is founding Series Editor of Springer Three Book Series. He worked as guest editor of special issues of several peer-reviewed journals. Besides that, he is also reviewer of several high-impact international peer-reviewed journals of Elsevier, Springer, Wiley, Saga, ACS, RSC, Frontiers, etc. He also received several awards at national and international levels. He is also Winner of Newton-Ungku Omar Coordination Fund: UK-Malaysia Research and Innovation Bridges Competition 2015. He is also professional member of ACS, SPE, APA, MySET, etc. He is Fellow and Chartered Scientist of The Institute of Materials, Minerals & Mining (IOM3), UK. He is also Clarivate 1% Highly cited Researcher—2023.

Dr. Akil Ahmad is currently working at Prince Sattam bin Abdulaziz University, Saudi Arabia, as Assistant Professor in Chemistry and having the experience of seven years as Research Fellow, Teaching Fellow, Postdoc, and Visiting Researcher from Universiti Teknologi Malaysia, Universiti Sains Malaysia, University of KwaZulu-Natal, South Africa, and Universiti Kebangsaan Malaysia, Malaysia. He has completed Ph.D. in Analytical Chemistry (2011) with the topic "Modification of resin for their use in the separation, preconcentration and determination of metal ions" from Aligarh Muslim University (AMU), India. His research interests are in the areas of environmental pollutants and their safe removal, synthesis of nanoparticles and nano-sorbents (GO, CNT), photodegradation and antimicrobial effects, water and wastewater treatment, and adsorption and ion-exchange. He has published more than 200 research articles and chapters in journals and publishers of international repute such as *Chemical Engineering Journal*, *Science of the Total Environment*, *Applied Water Science*, *Journal of Industrial and Engineering Chemistry*, *Journal of Molecular Liquids*, etc. He has also edited more than ten books of Springer and Elsevier. He is reviewer of several high-impact international peer-reviewed journals of Elsevier, Springer, Wiley, ACS, RSC, MDPI, Frontiers, etc. He is also guest editor of many reputed journals, namely, *Adsorption Science and Technology*—Hindawi, *Polymers MDPI*, *Frontiers in Environmental Chemistry*, and

Journal of Chemistry—Hindawi. H-index and citations in Scopus are 39 and 6142, and in Google scholar, H-index and citations are 43 and 7849. He is listed as Top 2% researcher in the world by Elsevier/Stanford University 2024, 2023, 2022.

Dr. Aatikah Meraj is currently working as a Postdoctoral Fellow at the Interdisciplinary Research Center for Advanced Materials, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia. She completed her Ph.D. in Materials Science from Universiti Putra Malaysia, located in Serdang, Selangor, Malaysia. She pursued both her master's and bachelor's degrees in Organic Chemistry, Department of Chemistry, Aligarh Muslim University, Aligarh, India. Her research areas include lignin, micro- and nanocrystalline cellulose, natural deep eutectic solvents, modifications and treatments of lignocellulosic biomass, biopolymers and their derivatives, and CO_2 adsorption and packaging applications. Her research experience also encompasses biocomposites and lignin-based composites. She has published her research in high-impact journals, including Q1 and Q2 Quartiles, such as *Industrial Crops and Products*, *Journal of Polymers and the Environment*, *Biomass Conversion and Biorefinery*, and *Scientific Reports*. She was awarded the Graduate on Time (GOT) recognition by Universiti Putra Malaysia in 2024. She has also received a research grant (GP-IPS, UPM) during her research. She has presented her research at international conferences and national conferences, and workshops, and has published book chapters with Elsevier and Springer Nature on topics including lignin-based adsorbents, nanocellulose composites, and biopolymer processing. She has also edited books for Springer Nature. She is proficient in various analytical techniques, including TEM, FESEM/SEM, FTIR, UV/Vis, XRD, DSC, TGA/DTG, and PSA. She also has hands-on experience with planetary ball milling (PM 100). She has also completed coursework in entrepreneurship, focusing on innovation and innovation methodology.

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