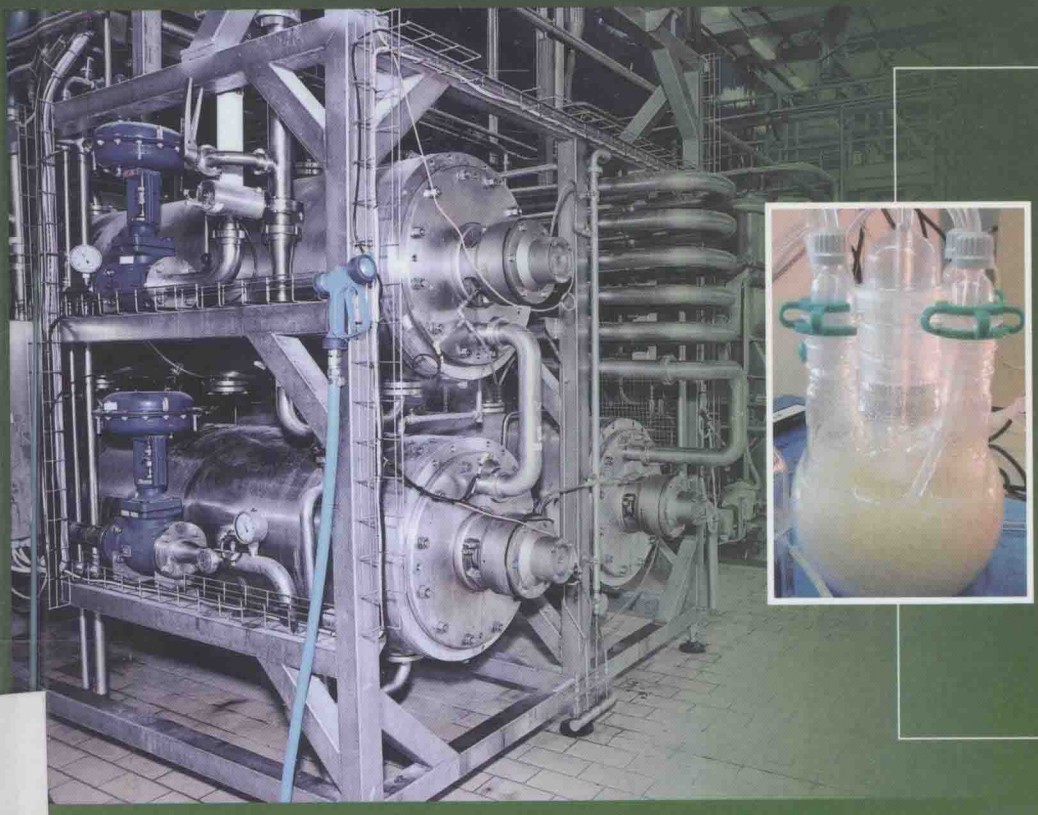
ACKMEZ MUDHOO, Editor

# BIOGAS PRODUCTION

## PRETREATMENT METHODS IN ANAEROBIC DIGESTION



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## Pretreatment Methods in Anaerobic Digestion

Edited by

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# Preface

**"The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value. Conservation means development as much as it does protection."**

Theodore Roosevelt (1858–1919)

Biomass as a natural resource contains varying amounts of cellulose, hemi-cellulose, and lignin. Currently, the second-generation bioproducts, such as bioethanol, biodiesel, methane, and biohydrogen from lignocellulosic biomass, are increasingly being produced from wastes rather than from energy crops, because the latter compete for land and water with food crops that are already in high demand. However, a major drawback to the production and maximum recovery of valuable materials from lignocellulosic biomass is the structure of lignocellulose, which has evolved to resist degradation, due to cross-linking between the polysaccharides and the lignin via ester and ether linkages.

In fact, with the standard anaerobic digestion technologies, only approximately 20–30% of the organic matter is mineralized. The main goal of any pretreatment to the anaerobic digestion processes would be to alter or remove the inherent structural and compositional impediments to hydrolysis, which is the rate-determining step, and subsequent degradation processes in order to enhance digestibility, improve the rate of enzyme hydrolysis, and increase yields of intended products. A substantial increase of biogas production can hence be obtained by applying a proper physical, chemical, thermal, mechanical, or biological pretreatment step, such as hydrothermal heating, microwave heating, ultrasonic treatment, use of (genetically-engineered) enzymes, and/or treatment (hydrolysis). The potential of the various pretreatment processes to augment the anaerobic biodegradation rate and produce more

biogas is considerable. These methods cause mechanical, physical, chemical, or biological changes in the plant biomass in order to achieve the desired products.

This book highlights the recent advances in the pretreatment and value addition of lignocellulosic wastes and other biomass forms. Mechanical, physical, and biological treatment systems are brought into perspective. The main value-added products from lignocellulosic wastes are summarized in a manner that pinpoints the most recent trends and the future directions. Physicochemical and biological treatment systems seem to be the most favored options, while biofuels, biodegradable composites, and biosorbents production paint a bright picture of the current and future bio-based products. Engineered microbes seem to tackle the problem of bioconversion of substrates better, a process which would otherwise not be optimized by conventional wild strains.

Ackmez Mudhoo

# Acknowledgements

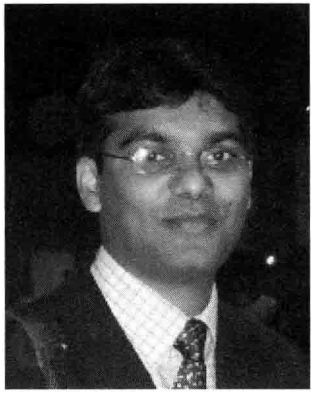
This undertaking has brought a unique opportunity to renew some old friendships and hopefully weave some new ones in the pursuit to gather and distill the expertise required for editing and compiling this book. Words of appreciation and thanks are entirely due to the contributors for the way they have graciously responded with characteristic good humor and patience to the deadlines. Their constructive criticisms and suggestions have enhanced the content of the present work. It is hoped that the final result does ample justice to their painstaking efforts deployed in preparing their respective chapter(s). Mr. Ackmez Mudhoo expresses his appreciation for the faith his parents, Mr. Azad A. Mudhoo and Mrs. Ruxana B. Mudhoo, his brother Assad, sister-in-law Teena, and lovely niece Yanna have placed in him throughout the writing and compilation of this handbook. A. Mudhoo is thankful to Prof. Konrad Morgan (Former Vice-Chancellor & Chairman of Senate of the University of Mauritius, Réduit, Mauritius), Prof. Romeela Mohee (National Research Chair in Solid Waste Management, Mauritius), Dr. Vinod K. Garg (Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India) and Professor Herbert H.P. Fang (hrechef@hkucc.hku.hk) of the Environmental Biotechnology Laboratory (http://web.hku.hk/~hrechef/) from the Department of Civil Engineering, The University of Hong Kong, Hong Kong, People's Republic of China for their presence, encouragement, and support.

Ackmez Mudhoo

# Special Contributor

**Romeela Mohee** is Professor of Chemical and Environmental Engineering. She was formerly an Academic Staff in the Department of Chemical and Environmental Engineering at the University of Mauritius (Mauritius) for more than fifteen years, and recently serviced for three years as Dean of Faculty of Engineering in the same university. With over twenty years of active research and consultancy work in solid waste management, the research of Prof Mohee is focused on waste containment, solid waste management and treatment technologies, beneficial reuse of waste materials, heat and mass transfer modeling, and environmental performance analysis through carbon footprint assessment. She earned a PhD at the University of Mauritius under the supervision of eminent professors from the University of Leeds (United Kingdom) and Clemson University (USA), and was a Fulbright Scholar. Prof Mohee delivered a pivotal role in the writing of this book. With her sense of good humour, experience and discernment, critical thinking and astuteness, she has provided a number of valuable suggestions during the peer review of the chapters. These suggestions were welcomed by the respective chapter contributors and ultimately helped in bringing the book to its present shape and size. Prof Mohee is presently the National Research Chair in Solid Waste Management in Mauritius.

# Editor



**Mr. Ackmez Mudhoo** obtained his Bachelor's degree (B.Eng. (Hons.)) in Chemical and Environmental Engineering from the University of Mauritius in 2004. He then read and earned a Master of Philosophy (M.Phil.) degree in Chemical Engineering from the University of Mauritius in 2011. His research interests encompass the bioremediation of solid wastes and wastewaters by composting, anaerobic digestion and biosorption. Ackmez has 53 international journal publications, 4 conference papers, and 6 co-edited books to his credit. Ackmez serves as peer reviewer for *Waste Management*, *International Journal of Environment and Waste Management*, and *Journal of Hazardous Materials*, and as Handling Editor for *International Journal of Environment and Waste Management* and *International Journal of Environmental Engineering*. He is presently a Lecturer in the Department of Chemical and Environmental Engineering, University of Mauritius. Ackmez is also the co-editor/co-author of *Green Chemistry for Environmental Sustainability* (Publisher: Taylor & Francis Group, LLC, Florida, Boca Raton, USA, CRC Press, 454 pages, ISBN: 978-1-4398-2473-3), *Adsorption of Reactive Red 158 dye by chemically treated Cocos nucifera L. shell*

*powder* (SpringerBriefs in Molecular Science-Green Chemistry for Sustainability Series, Springer, Dordrecht, The Netherlands, ISBN: 978-94-007-1985-9), *A Handbook of Applied Biopolymer Technology: Synthesis, Degradation & Applications* (Royal Society of Chemistry, ISBN: 978-1-8497-3151-5), and *Handbook on Applications of Ultrasound: Sonochemistry for Sustainability* (Taylor & Francis Group, LLC, ISBN: 978-1-4398-4206-5).

# List of Contributors

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**Dr. Azam Jeihanipour** received her BSc and MSc in Chemical Engineering from Isfahan University of Technology, and PhD in biotechnology from Chalmers University of Technology and University of Borås in Sweden (2007–2011). In her PhD thesis "Bioprocessing of waste textiles to biogas and bioethanol", she was mainly challenging with recalcitrant structure of cellulose and succeeded to publish more than 10 articles. She has recently moved back home to Iran and work as assistant professor on bioenergy from biomass at University of Isfahan.

**Dr. Katerina Stamatelatou** is an assistant professor in the Democritus University of Thrace (Department of Environmental Engineering). She is a chemical engineer and obtained her diploma and PhD in the Department of Chemical Engineering of University of Patras. Her field of research includes the study and development of anaerobic digestion processes, design and operation of bioreactors and bioprocess modeling. She is the coauthor of 32 research papers in peer reviewed journals, 2 chapter books and over 40 publications in proceedings of international and national conferences.

**Georgia Antonopoulou** is a Chemical engineer and has completed her PhD and M.Sc in the department of Chemical Engineering, in Patras University, in October 2006. From October 2006 and until now, she is a post doctoral researcher in Laboratory of Biochemical Engineering and Environmental Technology of Institute of Chemical Engineering and High Temperature Chemical Processes. Her research interest include the development of environmental biotechnological method for the treatment of municipal, agricultural and industrial wastes, biofuels (hydrogen and methane) and electricity production through biological processes, montelling of microbial processes and management of natural ecosystems. She has 13 publications in International refereed Journals, 3 chapter books and 28 publications in Conference Proceedings (International and national).

**Dr. Ioanna G. Ntaikou** received her B.Sc. in Biology and her PhD in Chemical Engineering from the University of Patras, Greece. She has joined FORTH/ICE-HT in 2006 as a postdoctoral researcher. Her research interests are in the field of on biochemical engineering and microbial biotechnology, with main focus on microbial fermentations for biofuels and bioplastics production, as well as modeling of microbial metabolism. She has 11 publications in International referred Journals, and 23 publications in International Conference Proceedings.

**Prof. Gerasimos Lyberatos** is currently professor in the School of Chemical Engineering, National Technical university of Athens (since July 2011) and a collaborating faculty member of the Institute of Chemical Engineering and High Temperature Chemical Processes (Foundation of Research and Technology Hellas). He obtained his B.S. at M.I.T. and his M.S. and PhD at CALTECH (USA) and served as Assistant, and Associate Professor at the University of Florida. In 1990 he joined the University of Patras as an Associate Professor and in 1993 became a Full Professor. His research interests are in Biochemical Engineering and Environmental Technologies. He has over 140 publications in International refereed Journals, and over 200 participations in International Conferences, 9 Chapters in books and two books. He has supervised 25 PhD theses and 15 M.S. theses. He has organized two International Conferences. Prof. Lyberatos is Editor of the Journal of Hazardous Materials (Elsevier), Associate Editor of Waste and Biomass Valorization (Springer) and is also heading a graduate programme on "Waste Management" in the Hellenic Open University.

**Dr. Kuan-Yeow Show** is currently serving as Professor and Head, Department of Environmental Engineering, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman, Malaysia. He is also serving as Chair, SP Setia Professor of Environmental Engineering & Green Technology and as a consultant in Singapore, Taiwan, China, Vietnam and Malaysia. He has received several professional awards including the prestigious National Technology Award in Singapore, US Patent 6793822 and International Patent WO 2003/070649. He has published over 140 technical papers in refereed journals and conferences, 70 technical reports and short-courses, 2 journal/book editorships, 1 book and 18 book chapters.

**Lai-Peng Wong** is currently serving as a lecturer while pursuing her PhD study in Department of Environmental Engineering, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman (UTAR), Malaysia. She graduated from Universiti Teknology Malaysia, Malaysia in Chemistry and obtained her Master degree from National University Singapore, Singapore in Environmental Engineering. Before joining UTAR, she was a head of department in analytical laboratory and waste water treatment plant in a textile factory. Her main research interest is on ultrasonication technology for wastewater treatment.

**Dr. Cigdem Eskicioglu** is a registered Professional Engineer and a faculty member of the School of Engineering at the University of British Columbia Okanagan. She was previously a PhD student and Postdoctoral Fellow at the University of Ottawa. Dr. Eskicioglu's research focuses on advanced biological treatment processes for bioenergy production and organic waste utilization. She is the recipient of numerous awards, including University of Ottawa's National Excellence Scholarships, Air & Waste Management Association Doctoral and City of Kelowna 2011 Mayor's Environmental Awards. She is a member of the Water Environment Federation, Canadian Association of Water Quality, and International Water Association.

**Teresa Suárez Quiñones** obtained her Master of Science in Chemistry and Biochemistry at the Agrarian University of Havanna, Cuba. She received her PhD from the Humboldt University of Berlin, Germany in Agricultural Engineering with special emphasis on prebiotic properties of mushrooms. Since 2007 she is research scientist at Leibniz Institute for Agricultural Engineering Potsdam-Bornim focusing on pretreatment methods for biomass conversion

processes. Teresa Suárez Quiñones has a strong background in the field of hydrolytic enzymes and improved techniques of analyzing phytocellular components.

**Matthias Plöchl** is the managing director of the Bioenergie Beratung Bornim GmbH (Bioenergy Consulting Service). He received his PhD from Frankfurt University in Natural Sciences with a focus in ecosystem theory. After several years at the Potsdam Institute for Climate Impact Research he went to the Leibniz Institute for Agricultural Engineering Potsdam-Bornim where he developed models and algorithms for the technology assessment of animal husbandry, irrigation and biogas production. He contributed to many national and international projects and published his results in many acknowledged journals.

**Katrin Päzolt** obtained a diploma in Geoecology from the University of Potsdam. During her work at the Helmholtz Centre for Environmental Research, she focussed on microbial interactions and microbial processes in water-unsaturated systems. Since the beginning of the year 2011 she is working within the national joint research project "BiogasEnzyme"at the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim with special emphasis on enzyme application to ligno-cellulose-rich feedstock for biomethanation process.

**Jörn Budde** is research scientist at Leibniz Institute for Agricultural Engineering Potsdam-Bornim. He holds a Diploma in mechanical engineering with special emphasis on renewable energies from Berlin University of Applied Sciences. His interests include farm-based biogas technology and automation to optimize the biogas production chain. Jörn Budde has a strong background in process design and process evaluation on anaerobic digestion in lab-, pilot- and full-scale. Currently, he finalizes his PhD thesis regarding thermobarical hydrolysis as pretreatment for less digestible biomass.

In 2010 **Robert Kausmann** finished his study Environmental and Energy-Process Engineering at the Otto-von-Guericke-University in Magdeburg. The topic of his diploma thesis was to develop a balance model for different methods for decentralized conditioning of biomass for energy recovery. Currently, he is working at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim as a PhD student within the national joint research project "BiogasEnzyme".

His primary research interests are the assessment of enzyme application at large-scale biogas plants.

**Edith Nettmann** received her PhD from the Technical University Berlin in 2009. The subject of the PhD thesis was the molecular genetic analysis of methanogens from full-scale biogas reactors. Currently, she is responsible for the sub-project microbiology in the junior research group APECS (Anaerobic Pathways to Renewable Energies and Carbon Sinks) at the Leibniz-Institute for Agricultural Engineering in Potsdam-Bornim. Edith Nettmann published the results of her PhD thesis in three journal articles and was involved in the preparation of further journal articles on this subject. The publications reflect her research interests in microbial communities involved in the anaerobic digestion process.

**Monika Heiermann** received her PhD from the Humboldt University of Berlin. Since 2000 she is a research scientist at Leibniz Institute for Agricultural Engineering Potsdam-Bornim with a strong background in process evaluation and experimental studies on anaerobic digestion in lab-scale, pilot plants and full-scale biogas plants. She participated in the European project "EU-Agro-Biogas", an initiative to improve the efficiency of the biogas production chain. Currently, she is coordinator of the national joint research project "BiogasEnzyme", financed by the Agency for Renewable Resources. Monika Heiermann is the author/co-author of several research papers and reports.

**Dr. Lise Appels** (1983) holds a M.Sc. in Environmental Engineering from the University of Antwerp and a PhD in Chemical Engineering of the KU Leuven (University of Leuven). She is currently doing research on anaerobic digestion as a postdoctoral research fellow at the Chemical Engineering Department of KU Leuven. Her work mainly focuses on the enhancement of anaerobic digestion by pretreatment methods and its mathematical modeling. She has (co-) authored 15 publications in international peer-reviewed journals and has presented more than 20 contributions at international conferences.

**Prof. Jan Van Impe** (1965) obtained a M.Sc. in Electrical and Mechanical engineering (1988, University of Gent) and a PhD in Applied Sciences (1993, KU Leuven). In that year, he started the BioTeC research team which develops a systemic approach to design, optimization and control of chemical and biochemical

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**Prof. Raf Dewil** (1979) studied Chemical Engineering at the KU Leuven (University of Leuven) and holds a PhD in Bioscience Engineering of the University of Antwerp. He is currently working as an assistant professor at the Chemical Engineering Department of the KU Leuven. His research mainly focuses on conversion methods for the valorization of biomass and organic wastes. He has (co-)authored over 40 publications in peer-reviewed international journals and about 50 presentations at international conferences. He is an associate editor with Journal of Environmental Management and a member of the editorial board of various international journals.

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