ADVANCED MEMBRANE TECHNOLOGY AND APPLICATIONS

Edited By

Norman N. Li, Anthony G. Fane,
W. S. Winston Ho, and T. Matsuura

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PREFACE

Since the last membrane book I published with the New York Academy of Sciences, I have attended several quite large membrane conferences including the one that I organized in the beautiful city of Irsee, Germany. I was struck by the fact that there had been very good progress made in the broad field of membranes science and technology. Also, membranes seem to be coming to the center of the water treatment and desalination technologies. Many parts of the world now are in critical need of clear water. Membrane technology is gaining increasing importance in treating and reusing wastewater and in producing potable water from seawater. It appears there is a timely need for a book that comprehensively reviews the up-to-date membrane technology and its many applications.

To undertake the task of publishing this book, I invited three of my colleagues, Tony Fan, Winston Ho, and Takeshi Matsuura to help, thus a team of four editors. Together we invited 35 chapters to cover membrane applications from gas to water separations. These chapters are now divided into six categories—membranes and applications in water and wastewater, membranes and applications in biotechnology and biomedical engineering, gas separations, membrane contactors and reactors, environmental and energy applications, and membrane materials and characterization. These six categories indeed cover a very broad field of applications.

I believe three somewhat unique features can be said about these chapters. One is that the percentage of contributors from industry is high. This is, of course, a relative comparison, in general, with the other published membrane books. As we know, most of the authors of the chapters in a membrane book are from academia, whereas many of the contributors from this book are from some of the major international membrane manufacturing companies. The other feature is that the chapters, in general, are more into applications than theories. The third feature is that a very strong coverage of water treatment and purification is presented for the reason mentioned above.

We are truly gratified to the strong response to contributing chapters. As a matter of fact, we still have quite many chapters that have been promised but have not been finished. This prompted me to consider publishing a second book in the near future. Meanwhile, we are indeed very pleased to have this book published and wish to thank all the reviewers and chapter contributors.

Norman N. Li

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ABOUT THE EDITORS

Dr. Norman N. Li has about 40 years of working experience in the chemical and petroleum industries. He was a senior scientist with Exxon Research and Engineering Co, Director of Separation Science and Technology at UOP Co. and Director of Research and Technology at AlliedSignal Co. (now part of Honeywell). Since 1995, he is the president of NL Chemical Technology, Inc., which focuses on the development of membrane technologies. Dr. Li has more than 100 technical publications, 44 U.S. patents, and 13 books edited, all in the field of separation science and technology. He received the prestigious Award of Separation Science and Technology from the American Chemical Society, the Founders Award, Alpha Chi Sigma Award for Chemical Engineering Research, and the Award in Chemical Engineering Practice from the American Institute of Chemical Engineers and the Perkin Medal from the Society of Chemical Industry. The American Institute of Chemical Engineers held special symposia on membranes in his honor at its national meetings in 1995 and 2000. Dr. Li served as the president of the North American Membrane Society and the chair of the International Congress on Membranes and Membrane Processes (ICOM) in 1990. He is a member of the National Academy of Engineering, United States.

Dr. Tony Fane is a chemical engineer with a Ph.D. from Imperial College, London. He has been working on membranes since 1973 when he joined the University of New South Wales, in Sydney, Australia. His current interests are in membranes applied to environmental applications and the water cycle, with a focus on the sustainability aspects of membrane technology. He is a former director of the UNESCO Centre for Membrane Science and Technology at UNSW and recently Temasek Professor at Nanyang Technological University, Singapore. He is currently director of the Singapore Membrane Technology Centre at NTU. He is on the editorial board of the *Journal of Membrane Science and Desalination*. He is a fellow of the Australian Academy of Technological Sciences and Engineering, a recipient of the Centenary Medal in 2002 for services to Chemical Engineering and the Environment, and an honorary life member of the European Membrane Society.

Dr. W. S. Winston Ho is University Scholar Professor of Chemical and Materials Science and Engineering at the Ohio State University since 2002. Previously, he was a professor of chemical engineering at the University of Kentucky, after having more than 28 years of industrial R&D experience with Allied Chemical, Xerox, and Exxon, and serving as senior vice-president of technology at Commodore Separation Technologies. He was elected a member of the National Academy of Engineering, United States, in 2002. A New Jersey Inventor of the Year (1991), Dr. Ho holds more than 50 U.S. patents in separation processes. He is co-editor of *Membrane Handbook* and the recipient of the Professional and Scholarly Publishing Award for the most outstannding engineering work in 1993. He received the 2006 Institute Award for Excellence in Industrial Gases

Technology and the 2007 Clarence G. Gerhold Award from AIChE. He obtained his B.S. degree from National Taiwan University and his M.S. and Ph.D. degrees from the University of Illinois at Urbana–Champaign, all in chemical engineering.

Dr. Takeshi Matsuura received his B.Sc. and M.Sc. degrees from the Department of Applied Chemistry, University of Tokyo, and his doctoral degree from the Institute of Chemical Technology of the Technical University of Berlin in 1965. After working at the Department of Synthetic Chemisty of the University of Tokyo as a staff assistant and at the Department of Chemical Engineering of the University of California as a postdoc, he joined the National Research Council of Canada in 1969. He became a chair professor at the University of Ottawa in 1992. He also served as the director of the Industrial Membrane Research Institute until he retired in 2002. He is now a visiting professor at the National University of Singapore and the University Technology Malaysia, Skudai. Dr. Matsuura received the Research Award of International Desalination and Environmental Association in 1983. A symposium of membrane gas separation was held at the Eighth Annual Meeting of the North American Membrane Society, May 18–22, 1996, Ottawa, to honor him and Dr. S. Sourirajan. He received the George S. Links Award for Excellence in Research from University of Ottawa in 1998. He has published more than 300 articles in refereed journals, authored and co-authored 3 books, and edited 4 books.

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PART I

MEMBRANES AND APPLICATIONS IN WATER AND WASTEWATER