MEMBRANE TECHNOLOGY AND APPLICATIONS

Second edition

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PREFACE

My introduction to membranes was as a graduate student in 1963. At that time membrane permeation was a sub-study of materials science. What is now called membrane technology did not exist, nor did any large industrial applications of membranes. Since then, sales of membranes and membrane equipment have increased more than 100-fold and several tens of millions of square meters of membrane are produced each year—a membrane industry has been created.

This membrane industry is very fragmented. Industrial applications are divided into six main sub-groups: reverse osmosis, ultrafiltration, microfiltration, gas separation, pervaporation, and electrodialysis. Medical applications are divided into three more: artificial kidneys, blood oxygenators, and controlled release pharmaceuticals. Few companies are involved in more than one sub-group of the industry. Because of these divisions it is difficult to obtain an overview of membrane science and technology; this book is an attempt to give such an overview.

The book starts with a series of general chapters on membrane preparation, transport theory, and concentration polarization. Thereafter, each major membrane application is treated in a single 20-to 40-page chapter. In a book of this size it is impossible to describe every membrane process in detail, but the major processes are covered. However, medical applications were short-changed somewhat and some applications—fuel cell and battery separators and membrane sensors, for example—are not covered at all.

Each application chapter starts with a short historical background to acknowledge the developers of the technology. I am conscious that my views of what was important in the past differ from those of many of my academic colleagues. In this book I have given more credit than is usual to the engineers who actually made the processes work.

Readers of the Theory section (Chapter 3) and elsewhere in the book will see that membrane permeation is described using simple phenomenological equations, most commonly, Fick's law. There is no mention of irreversible thermodynamics. The irreversible thermodynamic approach to permeation was very fashionable when I began to work with membranes in the 1960s. This approach has the appearance of rigor but hides the physical reality of even simple processes behind a fog of tough equations. As a student and young researcher, I struggled with irreversible thermodynamics for more than 15 years before finally giving up in the 1970s. I have lived happily ever after.

Finally, a few words on units. Because a great deal of modern membrane technology originated in the United States, the U.S. engineering units—gallons, cubic feet, and pounds per square inch—are widely used in the membrane industry. Unlike the creators of the Pascal, I am not a worshipper of mindless uniformity. Metric units are used when appropriate, but U.S. engineering units are used when they are the industry standard.

ACKNOWLEDGMENTS FOR THE FIRST EDITION

As a school boy I once received a mark of ½ out of a possible 20 in an end-of-term spelling test. My spelling is still weak, and the only punctuation I every really mastered was the period. This made the preparation of a polished final book draft from my yellow notepads a major undertaking. This effort was headed by Tessa Ennals and Cindi Wieselman. Cindi typed and retyped the manuscript with amazing speed, through its numerous revisions, without complaint. Tessa corrected my English, clarified my language, unsplit my infinitives and added every semicolon found in this book. She also chased down a source for all of the illustrations used and worked with David Lehmann, our graphics artist, to prepare the figures. It is a pleasure to acknowledge my debt to these

people. This book would have been far weaker without the many hours they spent working on it. I also received help from other friends and colleagues at MTR. Hans Wijmans read, corrected and made numerous suggestions on the theoretical section of the book (Chapter 3). Ingo Pinnau also provided data, references and many valuable suggestions in the area of membrane preparation and membrane material sciences. I am also grateful to Kenji Matsumoto, who read the section on Reverse Osmosis and made corrections, and to Heiner Strathmann, who did the same for Electrodialysis. The assistance of Marcia Patten, who proofed the manuscript, and Vivian Tran, who checked many of the references, is also appreciated.

ACKNOWLEDGMENTS FOR THE SECOND EDITION

Eighteen months after the first edition of this book appeared, it was out of print. Fortunately, John Wiley and Sons agreed to publish a second edition, and I have taken the opportunity to update and revise a number of sections. Tessa Ennals, long-time editor at Membrane Technology and Research, postponed her retirement to help me finish the new edition. Tessa has the standards of an earlier time, and here, as in the past, she gave the task nothing but her best effort. I am indebted to her, and wish her a long and happy retirement. Marcia Patten, Eric Peterson, David Lehmann, Cindy Dunnegan and Janet Farrant assisted Tessa by typing new sections, revising and adding figures, and checking references, as well as helping with proofing the manuscript. I am grateful to all of these colleagues for their help.