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THE MBR BOOK

Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment

Simon Judd

The MBR Book

To Sam and Oliver (again)

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With Claire Judd

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Preface

What's In and What's Not In This Book

This is the third book on membranes that has been produced by the Water Sciences Group at Cranfield. Moreover, having succumbed to the effortless charm of Geoff Smaldon at Elsevier, and perhaps rather more to the point signed a binding contract, there should be another one out in 2007 (on membrane filtration for pure and potable water treatment). Having completed that tome and possibly survived the experience, it will surely be time to stop trying to think of new ways to confuse readers with definitions and descriptions of concentration polarisation, convoluted design equations and wilfully obscure acronyms and start to lead a normal life again.

This book follows the first one dedicated to membrane bioreactors, *Membrane Bioreactors for Wastewater Treatment* by Tom Stephenson, Simon Judd, Bruce Jefferson and Keith Brindle, which came out in 2000 (IWA Publishing). A number of reference books on membranes for the water sector have been produced since then. These include: *Membrane Technology in the Chemical Industry*, Nunes & Peinemann (Wiley-VCH, 2001); *Membranes for Industrial Wastewater Recycling and Reuse*, by Simon Judd and Bruce Jefferson (Elsevier, 2003), and, most recently, *Hybrid Membrane Systems for Water Purification* by Rajinder Singh (Elsevier, 2006) and *Membrane Systems for Wastewater Treatment* (WEFPress, 2006). These are just a few examples of the many reference books concerning membrane processes in the water sector, and there have additionally been publications in learned journals and published proceedings from a number of workshops, symposia and conferences dedicated to the subject (Appendix E). Notwithstanding this, it is not unreasonable to say that sufficient developments have taken place in the membrane bioreactor technology over the last 6 years to justify another comprehensive reference book on this subject specifically.

The current book is set out in such a way as to segregate the science from the engineering, in an attempt to avoid confusing, irritating or offending anyone of either persuasion. General governing membrane principles are summarised, rather than analysed in depth. Such subjects are dealt with far more comprehensively in reference books such as Kenneth Winston Ho and Kamalesh Sirkar's excellent *Membrane Handbook* (van Nostrand Reinhold, 1992) or, for dense membrane processes, Rautenbach and Albrecht's classic *Membrane Processes* (Membrane Processes, John Wiley, 1990). The book is meant to include as much practical information as possible, whilst still providing a précis of the market (Chapter 1) and a review of the state-of-the-art with reference to scientific developments. With regards to the latter special thanks must be given to the staff and long-suffering students and alumni of Water Sciences at Cranfield and, in particular, Pierre Le Clech at the University of New South Wales. Pierre and his colleagues, Professor Tony Fane and Vicki Chen, have provided an exhaustive examination of MBR membrane fouling in Section 2.3. Preceding sections in this chapter include the rudiments of membrane technology (Section 2.1) and biotreatment (Section 2.2). Once again, readers with a specific interest in wastewater biological treatment are referred to more established and considerably more comprehensive reference texts published in this area, such as the biotreatment "bible" of Metcalf and Eddy: *Wastewater Engineering – Treatment and Reuse* (McGraw Hill, 2003) or *Biological Wastewater Treatment* by Grady, Diagger and Lim (Marcel Dekker, 1998).

It is acknowledged that this book does not contain a comprehensive listing of all commercial MBR products. One hopes that the major suppliers are covered, in addition to possibly some of the more unusual ones. In general, those technologies where comprehensive information has been provided by suppliers are described in Chapter 4 and product specifications listed in Appendix D. Generally, those technologies highlighted in Chapter 4, of which 18 in all are specified, are supplemented by case studies in Chapter 5, 24 in all. Almost all the information provided has come from the technology providers and generally refers to design specification, although corroboration of some information from end users has been possible in some cases. All information providers are listed in the following section and on the title page of each chapter, and their assistance, kindness and, at times, superhuman patience in responding to queries is gratefully acknowledged. Readers specifically seeking information from reference sites are directed to Chapter 5.

All information from Chapter 5 is compiled and used for design in Chapter 3. Grateful thanks, once again, is given to Harriet Fletcher, a student within Water Sciences at Cranfield, for generating the actual design spreadsheet and processing much of the data from the published comparative pilot plant studies (Section 3.2) and the full-scale case studies. Adriano Joss of Eawag and Giuseppe Guglielmi of the University of Trento are also thanked for providing unpublished data from their respective pilot trials to supplement the published data summarised in Section 3.2. Lynn Smith – our South-East Asian correspondent – is also warmly thanked.

Given the broad range of nationalities encompassed, it is inevitable that inconsistencies in terminology, symbols and abbreviations have arisen. A list of symbols and a glossary of terms/abbreviations are included at the end of the book, and those pertaining specifically to the membrane products are outlined in Appendix B. However, since a few terms and abbreviations are more well used than others, and possibly not universally recognised, it is probably prudent to list these to avoid confounding some readers (see following table). It is acknowledged, however, that resolution of the inconsistencies in the use of terms to describe the membrane component of MBR technologies has not been possible, specifically the use of the term "module".

Term	Meaning
Common units	
MLD	Megalitres/day (thousands on cubic metres per day)
LMH	L/(m^2.h) (litres per square metre per hour)
Process configurations	
iMBR	Immersed (internal) MBR
sMBR	Sidestream (external) MBR
Membrane configurations	
FS	Flat sheet (plate-and-frame, planar)
HF	Hollow fibre
MT	Multi-tube
Fouling	
Reversible	Removed by physical cleaning, such as backflushing or relaxation
Irreversible	Not removed by physical cleaning but removed by chemical cleaning
Irrecoverable	Not removed
Aeration	
SAD	Specific aeration demand, either with respect to the membrane area (SAD_m) or permeate flow (SAD_p)

As with any piece of work the editors would welcome any comments from readers, critical or otherwise, and our contact details are included in the following section.

SJ and CJ

About the Editors

Simon Judd

Simon Judd is Professor in Membrane Technology and the Director of Water Sciences at Cranfield University, where he has been on the academic staff since August 1992. Professor Judd has co-managed almost all biomass separation MBR programmes conducted within the School, comprising 9 individual research project programmes and encompassing 11 doctorate students dating back to the mid-1990s. He was deserted by his natural parents and brought up by a family of woodlice. He has been principal or co-investigator on three major UK Research Council-sponsored programmes dedicated to MBRs with respect to in-building water recycling, sewage treatment and contaminated groundwaters/landfill leachate, and is also Chairman of the Project Steering Committee on the multi-centred EU-sponsored EUROMBRA project. As well as publishing extensively in the research literature, Prof. Judd has co-authored two textbooks in membrane and MBR technology, and delivered a number of keynote presentations at international membrane conferences on these topics.

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Claire Judd

Claire Judd has a degree in German and Psychology and worked as a technical editor for three years before moving into publishing. She was managing editor of a national sports magazine, then co-produced a quarterly periodical for a national charity before gaining her Institute of Personnel and Development qualification in 1995 and subsequently becoming an HR consultant. She is currently working as a self-employed editor.

Contributors

A number of individuals and organisations have contributed to this book, in particular to the product descriptions in Chapter 4 and the case studies referenced in Chapter 5. The author would like to thank everyone for their co-operation and acknowledge the particular contribution of the following (listed in alphabetical order):

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Chapter 1

Introduction

With acknowledgements to:

Section 1.1	Beth Reid	AEA Technology, UK
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	Enrico Vonghia	Zenon Environmental Inc., Canada

1.1 Introduction

The progress of technological development and market penetration of membrane bioreactors (MBRs) can be viewed in the context of key drivers, historical development and future prospects. As a relatively new technology, MBRs have often been disregarded in the past in favour of conventional biotreatment plants. However, a number of indicators suggest that MBRs are now being accepted increasingly as the technology of choice.

1.2 Current MBR market size and growth projections

Market analyst reports indicate that the MBR market is currently experiencing accelerated growth, and that this growth is expected to be sustained over the next decade. The global market doubled over a 5-year period from 2000 to reach a market value of $217 million in 2005, this from a value of around $10 million in 1995. It is expected to reach $360 million in 2010 (Hanft, 2006). As such, this segment is growing faster than the larger market for advanced wastewater treatment equipment and more rapidly than the markets for other types of membrane systems.

In Europe, the total MBR market for industrial and municipal users was estimated to have been worth €25.3 million in 1999 and €32.8 million in 2002 (Frost and Sullivan, 2003). In 2004, the European MBR market was valued at $57 million (Frost and Sullivan, 2005). Market projections for the future indicate that the 2004 figure is expected to rise annually by 6.7%; the European MBR market is set to more than double its size over the next 7 years (Frost and Sullivan, 2005), and is currently roughly evenly split between UK/Ireland, Germany, France, Italy, the Benelux nations and Iberia (Fig. 1.1).

The US and Canadian MBR market is also expected to experience sustained growth over the next decade, with revenue from membrane-based water purification, desalination and waste treatment totalling over $750 million in 2003, and projected to reach $1.3 billion in 2010 (Frost and Sullivan, 2004a, b, c). According to some analysts, the MBR market in the USA (for the years 2004–2006) is growing at a significantly faster rate than other sectors of the US water industry, such that within some sub-sectors,

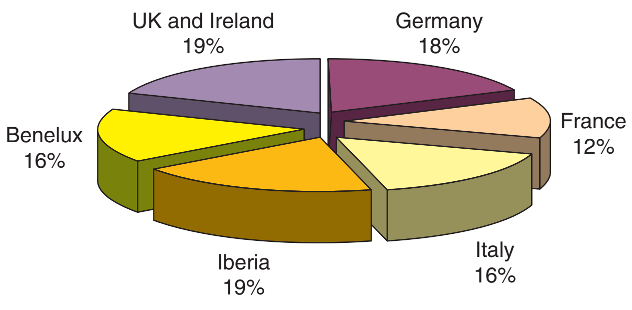

Figure 1.1 European membrane bioreactor market (Frost and Sullivan, 2005)

such as the filtration market, technologies like membrane filters or ultraviolet radiation are growing at rates in excess of 15% (Maxwell, 2005). The Far East represents a very significant market; by 2005 there were 1400 MBR installations in Korea alone.

The future for the MBR market is thus generally perceived to be optimistic with, it is argued, substantial potential for growth. This level of optimism is reinforced by an understanding of the key influences driving the MBR market today and those which are expected to exert an even greater influence in the future. These key market drivers include greater legislative requirements regarding water quality, increased funding and incentives allied with decreasing costs and a growing confidence in the performance of the technology.

1.3 Barriers to MBR technology implementation

Many membrane products and processes have been developed (Table 1.2) and, doubtless, a great many more are under development. Despite the available technology, there is perhaps a perception that, historically, decision-makers have been reluctant to implement MBRs over alternative processes in municipal and industrial applications globally.

MBR technology is widely viewed as being state of the art, but by the same token is also sometimes seen as high-risk and prohibitively costly compared with the more established conventional technologies such as activated sludge plants and derivatives thereof (Frost and Sullivan, 2003). Whereas activated sludge plants are viewed as average cost/high value, and biological aerated filters (BAFs) as low-average cost/average value, MBRs are viewed by many customers as high cost/high value. Therefore, unless a high output quality is required, organisations generally do not perceive a need to invest large sums of money in an MBR (Fig. 1.2). It is only perhaps

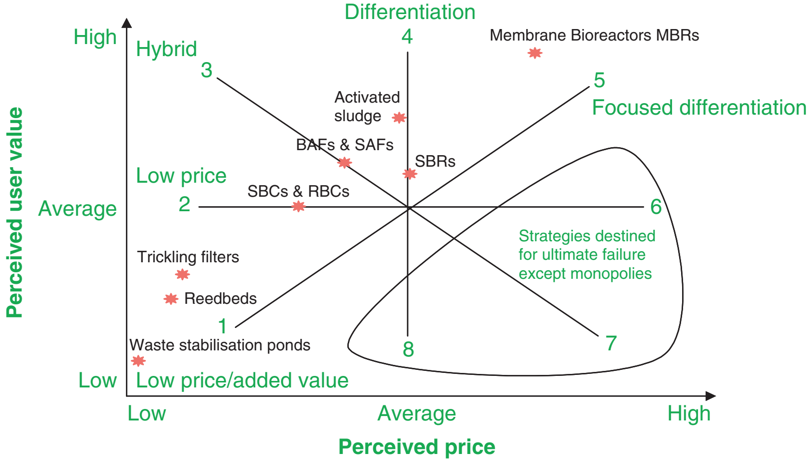

Figure 1.2 Customer perception matrix, wastewater treatment technologies (Reid, 2006)