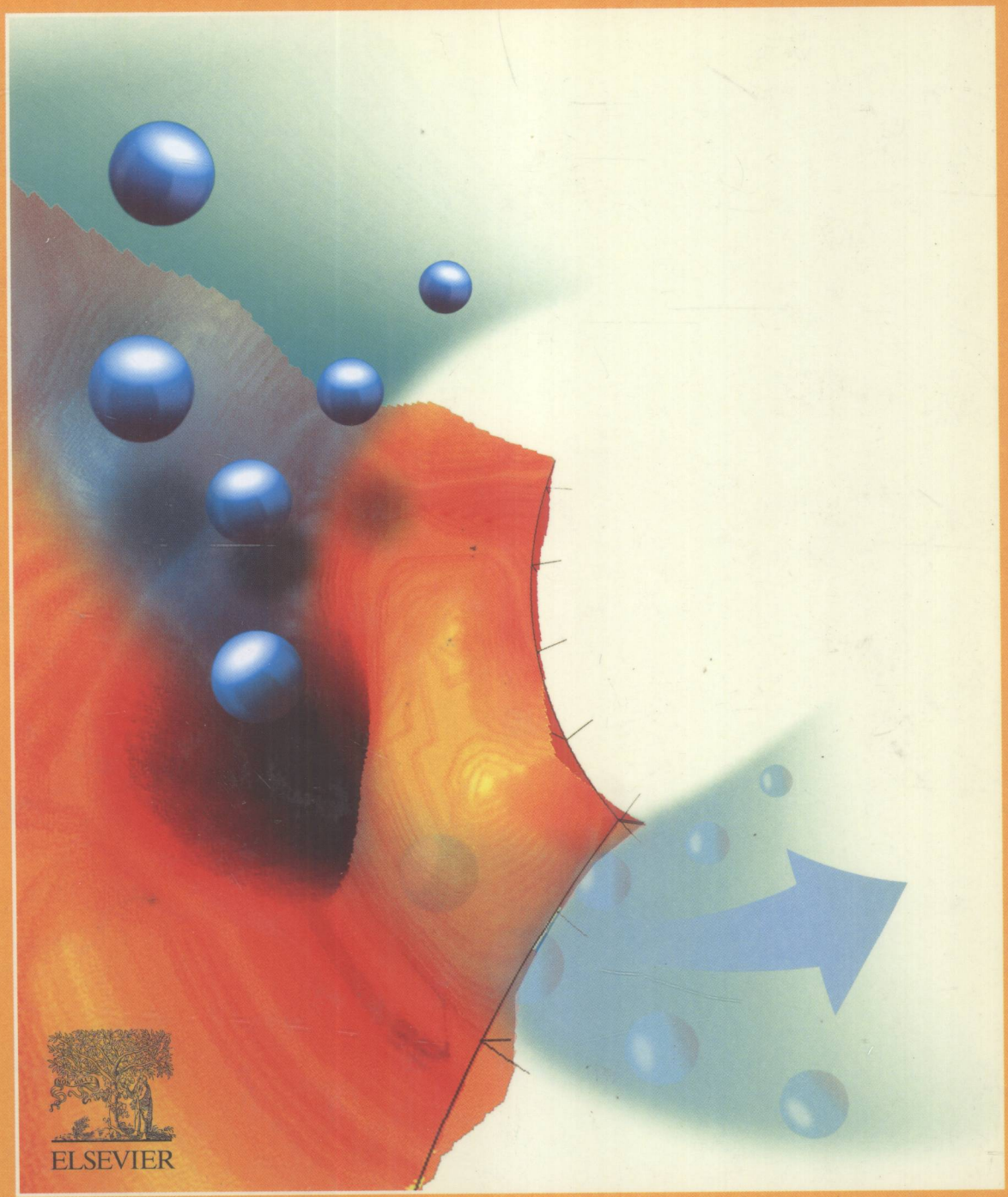
NANOFILTRATION
PRINCIPLES AND APPLICATIONS



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Nanofiltration – Principles and Applications

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Nanofiltration – Principles and Applications

Acknowledgements

In many ways editing this book has been a special experience thanks primarily to the people who were involved. The seed of an idea was planted when Joe Eckenrode (Technomic Publishing Company) approached us regarding writing a book at the Paris World Water Congress in 2000 – hunting for mad authors willing to commit to such a daunting task. Joe was satisfied with a manuscript a few weeks later, while we insisted that a book on nanofiltration – to date missing on the market – could not be done in a satisfactory way without including the experts in the field.

Through the negotiations with potential publishers and contributors, it has been a great journey with a highlighted by a contributor's dinner in the Les Caves de la Maréchale Restaurant during ICOM 2002 in Toulouse. Our publisher, Geoff Smaldon, sponsored the supposedly-small gathering of contributors, only to find out that

"contributor" in Australia means author, whereas in the UK it means editor! So thanks to Geoff's generosity, 25 of us wined and dined in true French fashion, with the added privilege of Marcel Mulder's presence. Thanks too goes to Geoff for all those fun email exchanges, and for giving in to the majority of requests from that demanding editor-in-chief and finally for funding a secret retreat to enable this book to be submitted at last.

We are indebted to the contributors (about 50 people all up!) who very patiently dealt with our requests, reviews, comments, formatting requirements, and (well, to an extent!) the deadlines. It has been a great pleasure to be in touch with you over the last two years and we are especially grateful to those who put their hand up at the last minute to fill in for those who couldn't contribute. I hope we all stay in touch and will work together on future editions.

Thank you to Richard Bowen and Chris Wright (Centre for Complex Fluids Processing, Swansea, UK) for providing the famous AFM picture of a nanofiltration pore, on which we based the front cover design as well as Alastair Williams (Mark-making Ltd) for the artistic design and stunning colours.

We appreciate the time taken and contributions made by the scientific review committee members in assisting the editors with this task;

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We hope that the readers will find the product useful and thanks (in advance) to those of you who will provide value feedback and reviews and assist in making future editions better and more complete. Inevitably some experts were not included, we apologise to those overseen and invite those to contact us for contributions for future editions.

Let's hope that nanofiltration can make valuable contributions towards making better use of our planet's resources and producing less pollution.

"I love deadlines. I especially like the whooshing sound they make as they go flying by" (anonymous).

Foreword

It was around the end of 1984. A few of us were gathered in the office of FilmTec's advertising manager to tackle a problem of terminology. What does one call a reverse osmosis process that selectively and purposely allows some ionic solutes in a feed water to permeate through? The phrase "loose RO" had been used, but it connoted the idea of leaky membranes. FilmTec had moved on to the expression "hybrid RO-UF," planning to name some products as hybrid RO-UF membranes. However, neither "loose RO" nor "hybrid" translated well into Japanese. According to FilmTec's Japanese distributor, the latter term carried objectionable overtones in Japanese.

The source of this naming problem was NS-300, a membrane discovered at North Star Research Institute. In 1976, John Cadotte combined piperazine with trimesoyl chloride, alone and blended with isophthaloyl chloride, to produce a series of thin-film-composite membranes with surprisingly high flux. These membranes also exhibited high permeability to aqueous chloride ions but high rejection of aqueous sulfate ions. The membrane was an orphan. The U.S. government's Office of Water Research and Technology, which sponsored the research, did not see any particular usefulness of the membrane for its purposes, which were primarily the development of national water resources. But FilmTec took an interest in it, with industrial applications in mind. Among these were salt whey concentration, pulp and paper effluent treatment, and preparation of sulfate-free seawater on oil platforms for secondary oil recovery operations in barium-containing oilfield strata. FilmTec had named its version of the membrane as FT40. Naming the membrane was not an issue. Naming the process was the problem!

I remember suggesting that FilmTec adopt the term "nanofiltration" for such processes. The term had at least some logical basis. First, Sourirajan and Matsuura had calculated the size of a hypothetical capillary pore in annealed cellulose acetate membranes to be about 9 Angstroms – 0.9 nm – in their development of the surface force/capillary flow model of reverse osmosis. Our "loose" membranes would correspondingly have hypothetical capillary pores slightly larger, presumably in the 1.0–1.2 nanometer range. Second, hyperfiltration was a term often used in early research on reverse osmosis membranes, and was deemed synonymous with reverse osmosis. Why not simply connect "nano" to "filtration"? Third, "nanograde" solvents were in wide use, and a term incorporating "nano" would connote goodness, purity, quality. (That's a suggestion designed to carry great influence with an advertising man!) One of the advantages of working in a small company was the ability to make instant decisions. We left that meeting with a mandate to use nanofiltration in our trade literature and publications. And two of FilmTec's "FT" membranes were immediately recast as "NF" membranes.

It didn't occur to me at the time that the term nanofiltration could be easily transliterated into foreign languages. That is, nanofiltration could be used without modification in some languages, and easily adopted into others by minor changes in spelling. Further, nanofiltration as a descriptor carried no "baggage" with it. As a new word, it referred to a particular membrane process for which it was coined, and to no other. Within a few years, other membrane scientists began using the word nanofiltration. Its widespread use today is testament to the need for just such a descriptor in the membrane lexicon.

As the body of literature on nanofiltration membranes and processes has expanded, the meaning of the term has necessarily been stretched to accommodate the wide range of features. It is appropriate that this book begins with an effort to define the term. An interesting aspect of nanofiltration membranes is the fact that so many parameters can come into play, when one tries to model and characterize the pressure-driven selectivities of such membranes. Parameters may include, for example, ionic interactions such as Donnan ion repulsion, site sharing phenomena by polyvalent ions in charged membranes, solute-membrane adsorption affinities, and stearic size interactions. Compared to modeling of nanofiltration membrane behavior, modeling the behavior of high rejection reverse osmosis membranes was a comparatively simpler task.

Standard reverse osmosis for water purification has matured in many respects, and has become in large part the domain of engineers engaged in issues of yield, consistency, quality and manufacturing efficiency. The objective is always the same – make a pure water permeate with at the lowest cost. But nanofiltration is, in my opinion, remains as a most fascinating extension of reverse osmosis technology. Nanofiltration offers to the membrane scientist a variety of membrane possibilities and a plethora of fascinating applications. Reverse osmosis is like the main course of a dinner, like a beefsteak that can be prepared in only a limited number of ways, but satisfies the hunger. Nanofiltration, on the other hand, is like the wine menu accompanying the meal – an opportunity for creativity and exploration. As you explore this book, enjoy the wonderful variety it provides on the subject of nanofiltration.

Robert J. Petersen

This book is dedicated to one of our co-authors and friends
Marcel Mulder
1951 – 2002

To see a world in a Drop of Water
And a Heaven in a Membrane
Hold Infinity in the palm of your hand
And Eternity in an hour
(after Blake)

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