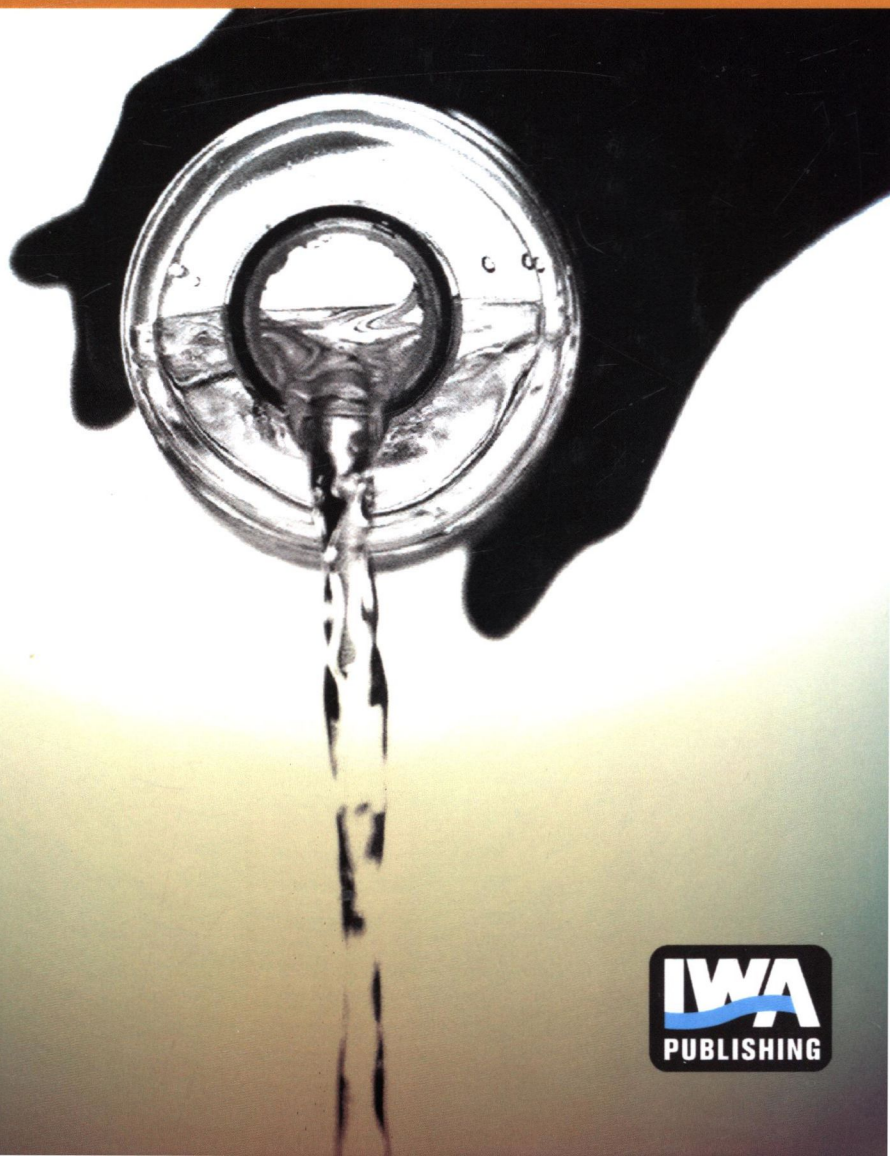


A MULTIDISCIPLINARY INTRODUCTION TO DESALINATION

ALIREZA BAZARGAN (EDITOR)



IWA
PUBLISHING

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Although more than 70% of the globe is covered with water, only a small portion is suitable for direct human use, making the scarcity of freshwater one of our planet's most serious challenges. In this context, desalination, defined as "the separation of salts from water", is one of the possible solutions for appeasing our ever-increasing thirst.

By drawing upon the expertise of a remarkable team of international authors, this book aims to provide a simple, encompassing, and "multidisciplinary" introduction to desalination. The particular forte of this publication is its inclusive yet straightforward nature. In other words, the unique assortment of reader-friendly chapters is designed to cover the topic of desalination as a whole, and strike a delicate balance between the technical and non-technical.

To this end, the book is divided into five general sections:

- ▶ The first section presents an overview of water scarcity, followed by a review of integrated water management and the alternatives to desalination. The fundamentals of desalination are also provided, including simple water chemistry;
- ▶ The second section covers conventional desalination technologies, including thermal and membrane processes. The topics of pre- and post- treatment are given due credit, as all desalination plants are more or less reliant on them;
- ▶ The third section reviews the history of how desalination technologies originated, including a review of today's R&D activities and cutting edge research. The topic of membrane manufacturing is also covered;
- ▶ Section four is concerned with energy and environmental issues, including the application of renewable and nuclear energy, energy minimization, brine management, and environmental impacts;
- ▶ Finally, section five covers the social and commercial issues, ranging from rural desalination to politics. Desalination costs and economic feasibility are discussed, as well as issues in business development and future market prospects.



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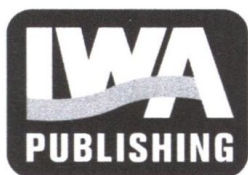
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A Multidisciplinary Introduction to Desalination

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*Dedicated to our firstborn son, Iman, who is as old as this book.
You are God's precious gift, and our greatest venture.*

Foreword I

Emilio Gabbrielli¹

¹President of the International Desalination Association (IDA)

It is always a great honor to be invited to write the Foreword to an ambitious volume like this one, but it is also a greater responsibility as it needs to set the scene for the reader, and has to be an inspiring piece. Having reflected on the task at hand, on the “what’s” and “why’s” of this book, I feel that the task of writing a foreword should not be hard at all, because desalination *is* itself inspiring. Desalination benefits mankind, and its importance in a world of increasing population can only increase. Let us see if you share my view.

Desalination is one of the oldest processes known to mankind and has been used since antiquity. Its practice based on simple evaporation followed by condensation became systematic with applications aboard ships with the advent of the trans-oceanic voyages of the Europeans in the XVI Century. In the second half of the XIX Century, several industrial manufactures appeared, and desalination units based on evaporation then started to be used on land all over the world.

Its use has kept growing since then, introducing technologies based on different principles, in particular reverse osmosis, to nearly 100 million m³/day of installed capacity at the time I write this. This is a lot of fresh water, something like 20 times the average flow rate of the river Thames.

When looking at the well-known graph of installed capacity growth over the last 40 years, it is quite easy to notice that overall installed capacity was growing at a more or less constant rate until 1995. Its growth sped up dramatically through the start of the new millennium, until 2005, when growth once again continued at a rather constant rate, but this time twice as fast as in the period pre-1995.

The increase was definitely driven by the increased scarcity of fresh water resources everywhere, but what made it possible was the dramatic decline in the unit cost of desalination by reverse osmosis from 1995 to 2005. This occurred mainly thanks to the development of energy recovery devices, which

basically cut in half the energy needed to desalinate. The cost for desalting sea water fell to an average reference figure of 1 US\$/m³ all included. This is a value in many cases competitive or cheaper than treating traditional sources of poor quality water or transferring water from increasingly distant places to quench the thirst of ever increasing urban populations.

It means that in the new millennium, desalination has become a mainstream water supply alternative, and this includes reuse. As such, it should always be routinely considered in medium/long term planning of fresh water resources. The relevance of desalination technologies has also been enhanced by climate change, because it relies on a non-traditional, always available, water source like the sea, or effluent from waste water treatment plants in the case of reuse.

Although the availability of reliable fresh water supplies is crucial to society, many of the applications of desalination being considered today would have been simply economically and environmentally non-viable just 20 years ago, when the energy for producing fresh water with reverse osmosis was still 2 to 3 times the present value.

This is why the world has to be thankful to the Middle East, Northern Africa, the Caribbean and elsewhere, which took on the higher costs of desalination and adopted desalination on a large scale from the 1970s onwards. The early adopters in these regions showed the way, and allowed the further development and dramatic decline in the cost of the technology, making it affordable to other countries.

As a matter of fact, the application of desalination in more than three quarters of the world's countries shows that it has definitely become more widely affordable. In the coming years, it will become more and more part of normal water supplies around the world, both in potable and industrial water applications, and increasingly in agricultural applications as well.

The full potential and associated benefits of desalination have yet to be fully realized because there is still a misconception that desalination technologies are too expensive and not generally affordable. This cannot be surprising, as the lowering of unit costs happened so fast, in a decade or even less. Still, the reality is that desalination and reuse technologies are here to stay as crucial water supply alternatives and potential key contributors to sustainable growth and our planet's well-being. This realization is becoming more widespread and as a result, society and government officials around the world are recognizing its value more broadly.

With this backdrop, an ambitious volume like this one could not come at a more appropriate moment, when more and more people are becoming

interested and want to refer to the principles and features of desalination technologies. At the same time, one might ask for how long this book will remain up-to-date and a useful reference for those involved in desalination technology, given the speed with which scientific developments and advancements in technology occur.

In my view, the answer is easy: for a long time. The basic principles of desalination have not changed for centuries; even osmosis was already known in the XVIII Century. In terms of large installations, it is easy to forecast that RO will remain the primary desalination technology for a long time, with MED/MSF continuing their application in co-generation applications in the Middle East.

As this book proves, these technologies are all established, well understood and reliable. However, with the thirst of the world increasing and problems of scarcity widening, research for cheaper and more effective ways to desalt water is, and will continue, to increase.

In due course, a real breakthrough will happen and a much cheaper way to desalinate water will be found, possibly with some totally new technology: all of this for the best of the world. Mankind needs it! However, before any new way becomes commercially available and useful for large applications, several years will pass, probably decades, during which time the core content of this volume will remain an up-to-date reference to the mainstream technologies.

Moreover, a successful desalination project does not rely just on the plant and its economics; it has to rely on several associated technologies and chemistry fundamentals plus a cohesive approach to the social, political and environmental aspects, all of which are duly covered within the multidisciplinary approach that Dr. Bazargan has envisaged for this book. As no deeper understanding of the present can ever be reached without the perspective of where we are coming from, it is good that the origins of desalination are also given due attention.

It is increasingly evident that desalination and reuse will play a more and more important role in securing our future. Many have said and are still saying that future wars will be fought over water and not oil. In a world of increasing belligerent actions and words, the technologies covered by this volume are definitely going in the opposite direction of peaceful co-existence. This because their ultimate goal and potential is to guarantee plentiful affordable quantities of fresh water for all from non-traditional sources like the sea, which are practically unlimited.

Foreword II

Neil Palmer^{1,2,3}

¹Water Discipline Principal, Tonkin Consulting, Adelaide, Australia

²Former Chief Executive Officer, National Centre of Excellence in Desalination, Australia

³World's most influential water leader (2015), Water & Wastewater International

Water touches everyone.

This indispensable part of each of our lives, from intimate personal use to keeping our great industries running, is rarely appreciated until it becomes scarce. But the notion of water scarcity is a conundrum when we consider water covers seventy percent of our Earth's surface.

But almost all of it is salty.

So this monumental volume *A Multidisciplinary Introduction to Desalination* provides a scholarly and comprehensive starting point to the art and science of man's attempts to make fresh water from salt water.

But wait – doesn't *all* our fresh water come from natural desalination powered by renewable energy?

On 6 June 2016, the Australian Bureau of Meteorology recorded that more than 5 mm of rain had fallen on a third of the Australian continent the previous day, some 2 million square kilometres. 10,000 gigalitres were desalinated by natural evaporation of seawater from the warmth of the sun, transported by the wind and distributed evenly over a massive land area.

To obtain perspective, this is enough to supply the 4 million people who live in Sydney for 17 years. From one day's weather. There is much, it would seem, we can learn from the principles of nature.

This book explores desalination from its earliest history and delves into politics, economics, technology and practicalities. Desalination offers hope to those parts of the world where water is scarce or unreliable. From serious development of artificial desalination in the 1950s, people are working out how to emulate nature in supplying affordable and sustainable fresh water from our abundant impaired water sources. We have seen significant improvement of desalination techniques using new materials to separate salt from water and more efficient pre-treatment and pumping systems along with new ways of using energy from the wind, the sun and nuclear power.

This book contains sufficient easily readable detail to satisfy not only the engineers and scientists who research, design and build desalination infrastructure, but also students, community leaders and policy makers.

We have come 60 years since the first seriously large thermal desalination plants were built in the Caribbean and the Middle East, and the very first reverse osmosis membranes were produced.

Given the relentless pursuit of continuous improvement, we can only wonder with a sense of anticipation what the next 60 years will bring.

Preface

In the summer of 2015, Mark de Jongh, the man who would later become my publisher, posed a simple question: would I be interested in putting together a book on desalination? It was a simple-enough question, but for a person who doesn't commit to something unless he's sure he can do it right, I needed time to think. Although I had previously published my research in reputable academic journals, and had written a hefty dissertation during my PhD, this would undoubtedly be my biggest academic undertaking to date. Now, exactly two years and hundreds of hours of hard work later, I am glad I said yes.

This book, as its name implies, is aimed at giving an overall review of the entire desalination ecosystem; this means that in addition to the technological aspect which is an inseparable part of any introductory book on desalination, it also includes topics which more often than not are missing in our understanding of the bigger picture. Hence, in the process of choosing authors and chapter topics, I have methodically tried to include an assortment of what I think is relevant. The scope of topics covered in the book will hopefully allow for any reader to obtain a well-balanced understanding of what desalination is all about. I personally believe that the contributors have provided ample rich insight which allows this volume to effectively function as a textbook, both at the undergraduate and postgraduate levels. Of course, the list of chapters is not exhaustive, and there is always more that could have been said.

In the process of writing this book, I am proud to have met and collaborated with some of the world's most renowned experts. Most notably, I would like to thank Dr. Jim Birkett, who with his blessing and contribution of a chapter, really helped propel the project to a world-class undertaking. For newcomers to the field who might not know him, Jim is considered one of the desalination industry's most respected professionals, with more than four decades of experience under his belt. Most importantly, he was the first elected President of the International Desalination Association (IDA), and later served as Treasurer and Director for many years, helping shape the entire

modern desalination industry as we know it. As others have put it, he is the desalination industry's "de facto historian".

I would also like to take this opportunity to unreservedly thank two of the industry's giants who have written forewords for the book: Emilio Gabbrielli who is the current President of the IDA as well as the Director of Overseas Business Development for Toray; and Dr. Neil Palmer, the former CEO of the National Centre of Excellence in Desalination Australia, who was designated as the most influential leader in the water industry by Water & Wastewater International in 2015, and again a top candidate in 2017. It is truly an honor for me to have my work validated by these two gentlemen.

In addition, I wish to thank all the chapter authors who have kindly contributed to this book. I am proud of each and every one of their contributions, and say to them: "I am sorry if I pushed you too hard, but I'm sure you would agree that it has all paid off."

During these two years, I have personally reviewed all chapters several times and -with the help of external reviewers- have made the necessary modifications. Some chapters have gone through extensive editing and are indistinguishable from the original submitted manuscript, while others have remained virtually unchanged. I have tried to ensure both the scientific rigor and correctness of the language. As an example, the body of water located at the heart of the Middle East is referred to as the "Persian Gulf" as advised by the United Nations and the International Hydrographic Organization; and fabricated and false names such as the "Arabian Gulf" or merely "The Gulf" have been avoided.

It should also be noted that although as editor I am responsible for the factual correctness of the material within the book, but, the responsibility of proper citations and copyright issues are outside my domain of accountability, and lie with the respective chapter authors.

The list of external reviewers who have helped peer-review the chapters are as follows:

- Adil Bushnak
Chairman and CEO of Bushnak Group, Jeddah, Saudi Arabia
- Steward Burn
Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia