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Intakes and Outfalls for Seawater Reverse-Osmosis Desalination Facilities

Innovations and Environmental Impacts

Springer

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Foreword

The *Greening* of Seawater Reverse Osmosis (SWRO) Systems: Focus on Intakes and Outfalls

Seawater reverse osmosis (SWRO) has emerged as the conventional seawater desalination technology, globally. While SWRO is less energy intensive than thermal processes' such as multi-stage flash (MSF) and multi-effect distillation (MED), it is still an energy intensive process (3–4 kWh/m^3). Moreover, with increasing emphasis on green technologies, the present practice of SWRO is characterized by a number of significant environmental impacts, including energy consumption, greenhouse gas (GHG) emissions, entrainment and impingement of marine organisms through intakes, and marine pollution during concentrate discharge via outfalls. SWRO is also a chemical-intensive and material-intensive process with a sizable footprint. Besides salts, SWRO brines can also contain chemicals used in pretreatment (e.g., coagulants and antiscalants) and RO cleaning agents. Periodic replacement of RO modules results in a significant solid waste problem. Thus, a challenge is realization of the *greening* of SWRO systems.

It has been estimated that further optimization of the SWRO process and its various components could potentially provide a 20 % reduction in specific energy consumption, with a concomitant reduction in GHG emissions. However, beyond this perceived limit, only emerging technologies such as forward osmosis (FO) offer the possibility of further energy reduction. SWRO pretreatment by ultrafiltration (UF), as an alternative to granular media filtration (GMF), provides an opportunity for reduced amounts of chemical coagulant (e.g., UF with in-line coagulation). New fouling resistant RO membranes can provide an opportunity for reduced use of chemical cleaning agents. Improvements in membrane fabrication have resulted in extended material life and less frequent replacement of RO modules. However, beyond these improvements, potentially major contributions to the greening of SWRO can be realized through advancements in the design and operation of SWRO intakes and outfalls, the focus of this book.

While intake choice is generally perceived as being between surface (open) and subsurface intakes, there are many subcategory options. Surface intakes can be single purpose or colocated with a power plant as well as offshore submerged, nearshore submerged, or nearshore surface intakes. Subsurface intakes can be onshore (vertical wells), including vertical beach wells or deep aquifer wells, horizontal wells, radial or collector wells, and beach infiltration galleries; or offshore wells, including horizontal drains (wells), and seabed infiltration galleries.

The use of surface, colocated, nearshore intakes is typical for water and power cogeneration plants (e.g., many in the GCC region), but these are also used by some SWRO plants (e.g., Tampa Bay USA). The use of surface, single purpose intakes is common for many larger SWRO systems. Subsurface, onshore intakes are used by small to medium capacity SWRO plants; however, subsurface, offshore intakes are under consideration for larger SWRO systems. An under-recognized attribute of subsurface intakes is that they also function as an SWRO pretreatment process, simulating a slow sand filter as a physical and biological process, without chemicals. Of particular importance is the ability of subsurface intakes to remove bacteria, algae, and biopolymers (e.g., proteins and polysaccharides), reducing both organic and biofouling of RO membranes; moreover, subsurface intakes inherently eliminate impingement and entrainment. A notable example is the Fukuoka (Japan) seabed infiltration gallery which operates before a UF pretreatment step, alone reducing the silt density index (SDI) to below three and allowing the subsequent UF to operate for long periods without backwashing. Improvements in open intake design and operation have largely focused on minimizing impingement and entrainment.

In summary, open surface intakes are generally characterized by high intake volumes (i.e., larger SWRO systems), offer a potential for colocation, are unaffected by (but also do not beneficially affect) feed water quality, and are vulnerable to impingement and entrainment. Subsurface intakes are generally used for smaller capacity SWRO systems (but seabed galleries are increasingly being considered for larger systems), are unaffected by (but can beneficially affect) water quality, and can mitigate impingement and entrainment. To drive home the importance of intakes and outfalls, it has been estimated that they account for up to 35 % of the costs of SWRO systems.

The two general categories of SWRO outfalls are surface and subsurface outfalls. The former can take the form of nearshore and offshore, with further delineation into an outfall channel, a single pipe, or a multiport diffuser. Less common are offshore and inland subsurface outfalls, taking the form of a percolation gallery, deep well injection, evaporation ponds, sewer discharge, and zero liquid discharge (ZLD), most of the latter (except for percolation galleries) being the domain of inland brackish water RO (BWRO) systems. Nearshore outfall channels are more typical for cogeneration (distillation and power) plants or colocation (SWRO plant next to power) plants. Single offshore pipes are more common for smaller SWRO plants. Multiport diffusers are more common for larger SWRO plants and are increasingly becoming the norm for such new plants. There are several types of multiport diffusers, including pipeline diffusers (nozzles arranged along a pipe) and rosette-style diffusers (several outlet risers above the seafloor with a small number of nozzles). Advancements in modeling of multi-diffuser systems allow prediction of a regulatory mixing zone. In subsurface offshore outfalls, the concentrate is slowly dissipated into the surf zone (e.g., perforated laterals placed under the ocean floor).

The *greening* of SWRO can be promoted by the use of subsurface intakes (no impingement/entrainment of organisms, pretreatment without chemicals and associated residuals); the minimization of chemical use (e.g., UF with lower or no coagulant addition); no antiscalants (scaling control by acid addition and/or limiting recovery); brine disposal through a multiport-diffuser outfall (i.e., minimize extent of mixing zone); and integration of renewable energy (e.g., solar, wind, and/or or geothermal) in design and operation (direct use or (indirect) energy compensation, reduced GHG emissions (95 % of which are associate with direct energy use)). This book will highlight the important role of two of these SWRO system components, *intakes and outfalls*.

Gary Amy
Sabine Lattemann

Preface

Freshwater supplies are dwindling as global population growth, industrialization, and agricultural expansion occur worldwide. Desalination of seawater is rapidly becoming a key aspect of global water management to balance the needs of numerous coastal countries, particularly in arid lands and industrialized counties. Seawater desalination is an energy-intensive process that has some real and perceived environmental impacts. Therefore, it is important to reduce the energy consumption of desalination, the carbon footprint, the environmental impacts, and the overall cost. Currently, the most energy efficient desalination large-scale commercial process is seawater reverse osmosis (SWRO).

It is the purpose of this book to address two important aspects of the SWRO process, design of intakes and outfalls and assessment and reduction of environmental impacts. Most of the book content is based on technical presentations made at an international workshop on desalination system intakes and outfalls sponsored and held during October 7–8, 2013 at the King Abdullah University of Science and Technology (KAUST) in Thuwal, Saudi Arabia. Additional chapters were solicited by the editors to cover various aspects of intakes and outfalls not occurring during the workshop.

The Water Desalination and Reuse Center and the Red Sea Research Center at KAUST jointly organized the workshop with generous support from KAUST's Office of Research Support. The presence of KAUST on the Red Sea, where increasing urbanization and industrialization along the coast demands additional freshwater supply, provided much of the impetus for the workshop. Saudi Arabia currently produces about 18 % of the global production of desalinated water with an expected capacity of nearly 6 million cubic meters per day in 2015. Over the long term the dependence on desalinated water in the region and much of the world will only increase. A long-term goal of this workshop and similar efforts is to reduce the energy intensity and increase water-use efficiency throughout the life cycle of desalination plants, minimizing environmental impacts to the greatest extent possible. In other words, the goal is to develop desalination plant design that promotes sustainable interaction of the human environment within our natural environment.

This book covers a considerable number of subjects that have not been published extensively in the peer-reviewed literature. The book is divided into two major sections; intakes and outfalls with some overlapping subject matter involving environmental impact assessment and reduction. The intakes section is further subdivided into surface or "open-ocean" intakes and subsurface intakes.

The overall design philosophy of intakes for SWRO plants is covered in Chap. 1. Design concepts for velocity-cap, and tunnel intake systems are covered in Chaps. 2–3. The very important issue of impingement and entrainment is covered in Chap. 4, which includes a summary of the latest U.S. environmental regulations and a summary of research. Design and impacts of passive screen intake systems are discussed in detail in Chap. 5. In recent years it has been suggested that deep intake systems could be used to obtain higher quality feed water for SWRO systems. In Chap. 6, the use of deep intakes along the Red Sea coastline of Saudi Arabia is assessed. This comprehensive study shows the variation in algae, bacteria, and various types of natural organic matter with depth in the Red Sea and how the bathymetric features of the Red Sea impact deep intake system feasibility.

Discussion of subsurface intake systems begins with Chap. 7, which provides a comprehensive planning methodology that is used to analyze the Red Sea coastal areas of Saudi Arabia and the coasts of Florida to assess technical feasibility of using various subsurface intake systems. Use of wells as intakes, the most mature subsurface intake technology, is covered in Chap. 8 with an assessment of the improvement in raw water quality that occurs between the raw seawater and after traveling through an aquifer to a production well occurring in Chap. 9. Beach and seabed gallery intake system design and innovations in their use are covered in Chaps. 10–12. Applications of seabed gallery feasibility for the Red Sea and Arabian Gulf coasts and nearshore areas of Saudi Arabia are discussed in detail in Chaps. 11 and 12. The generally new concept of using slant wells as intakes is discussed in Chap. 13. The application of coastal modeling to assess the technical feasibility of developing gallery intake systems, with an emphasis on southern California, is covered in Chap. 14. The innovations in design and operation of SWRO intake system are summarized in Chap. 15.

The second part of the book covers assessment and mitigation of environmental impacts associated with discharge of concentrate from SWRO plants and subsequent wastewater discharge. Overall, this group of papers progresses from modeling approaches for coastal discharges.

Chapter 16 provides an overall of coastal discharges and how they are managed. Chapter 17 discusses the results of laboratory modeling of various configurations of concentrate diffusers, their performance and design criteria, and applications. Chapter 18 builds from the nearfield modeling toward a tiered approach of nearfield and farfield modeling, observation, and analysis for design, placement, and implementation of new facilities. Additional evaluations and design criteria for dense brine discharges are provided in Chap. 19. Chapter 20 presents a modeling evaluation of the dispersion of heat and salt from a discharge in the Gulf of Arabia and the response of the dispersion to variations in the coastal currents. Because the

Red Sea is an enclosed basin, discharges within that basin may have impacts that can spread either along the coast or even across the axis of the basin. The model results described in Chap. 21 demonstrates the potential for that very farfield dispersion. Chapter 22 discusses the use of AUV's for farfield mapping and long-term deployments building a statistical database that can be used for comparison against numerical models where the resolution is now approaching the scale of the nearfield. Chapter 23 discusses the innovations in management of coastal discharges and evaluation of environmental impacts.

The purpose of this book is to provide the latest summary of pertinent research on intake and outfall design concepts for SWRO facilities. It should be used by design engineers, geologists, project owners, and facility operators for use as a reference and to obtain new ideas that could produce innovative designs that will reduce the energy consumption and operational costs of SWRO facilities. Also, we have provided summaries of where additional scientific and engineering research should be conducted to make improvements to intake and outfall performance.

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