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Seawater Desalination: Trends and Technologies

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1. Introduction

Figure 1 below provides information on our planet's available water resources which do not allow too many alternatives.

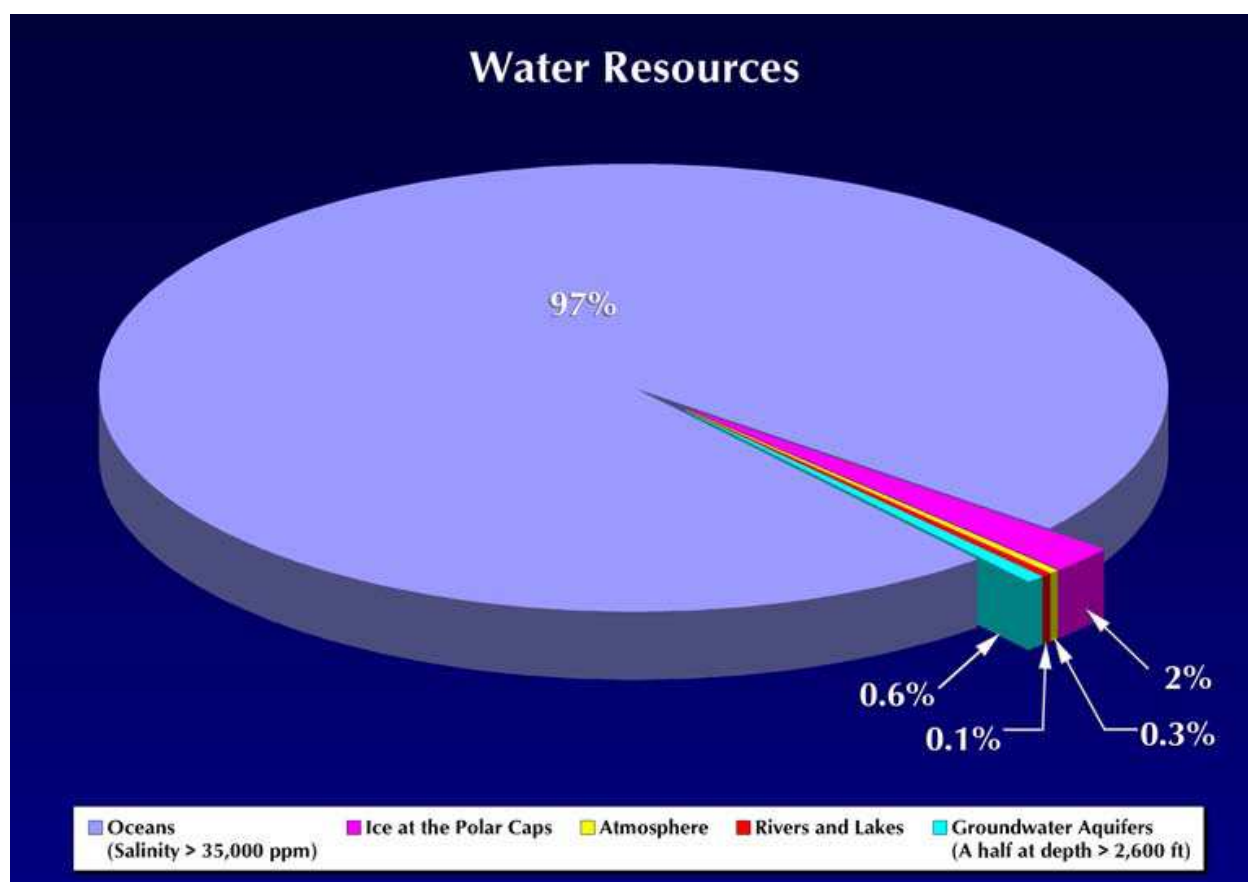


Fig. 1. Water Resources on the Earth

With 97% of available water represented by salty water with the Salinity Level > 35 g/l, the largest possible source of alternative water supply requires and will require desalination. The conventional water treatment technologies have been known and widely used for centuries, and some, like media filtration, were applied thousands of years ago, while

membranes were introduced to water treatment just in the second half of the 20th Century. Development of the first high pressure membrane, Reverse Osmosis (RO) was claimed at University of California in Los Angeles (UCLA) in 1962, and commercialized by the early 1970s.. The low pressure membranes, Microfiltration (MF) and Ultrafiltration (UF) were commercialized for drinking water treatment just about one decade ago. Because they provide significant technical benefits and have become cost-competitive, membrane technologies are rapidly displacing and replacing traditional processes verified by the centuries.

The oldest desalination methods are based on evaporating water and collecting the condensate. The best known commercially applied thermal technologies are:

- **Multi Stage Flash (MSF)**
- **Multi Effect Distillation (MED)**
- **Vapor Compression (VC)**

While MSF, MED, and VC use thermal power to separate water from the brine, **Electrodialysis Reversal (EDR)** uses high voltage current to remove Cations and Anions from the stream.

The newest commercial technology for Desalination is based on membrane treatment. **Reverse Osmosis (RO)** and **Brackish Water Reverse Osmosis (BWRO)** or **Sea Water Reverse Osmosis (SWRO)**, are the fastest growing desalination techniques with the greatest number of installations around the globe. Desalination by RO is beginning to dominate the current and future desalination markets. As seen in the chart below, the number of membrane desalination installations is close to 80% of all desalination facilities.

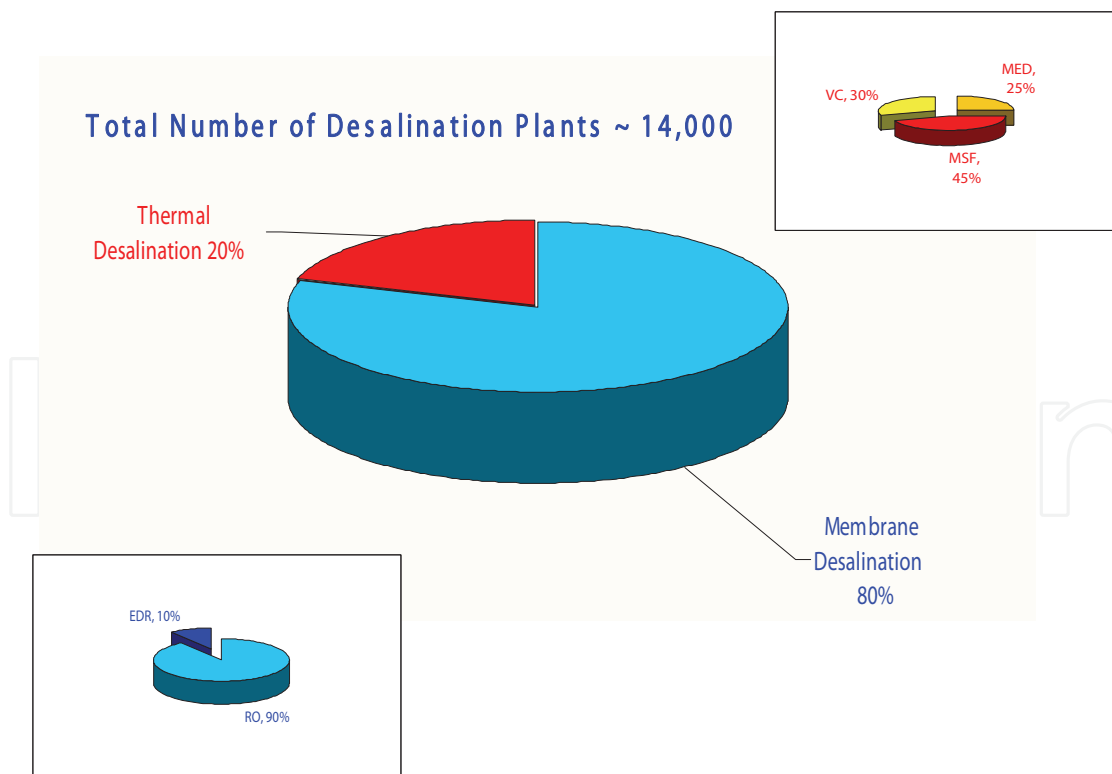


Fig. 2. Number of desalination plants worldwide. RO - Reverse Osmosis, EDR - Electro Dialysis Reversal, MSF - Multi Stage Flash, MED - Multi Effect Distillation, VC - Vapor Compression

The first RO desalination membranes were developed in the first half of the 20th Century. Desalination by RO entered the commercial market in the early 1970s when the membrane manufacturing process became efficient enough to produce desalted water that was competitive to thermal processes, and when the technological process for RO desalination was well established.

While leading in the number of installations, desalination by RO still provides only a comparable capacity to the thermal processes:

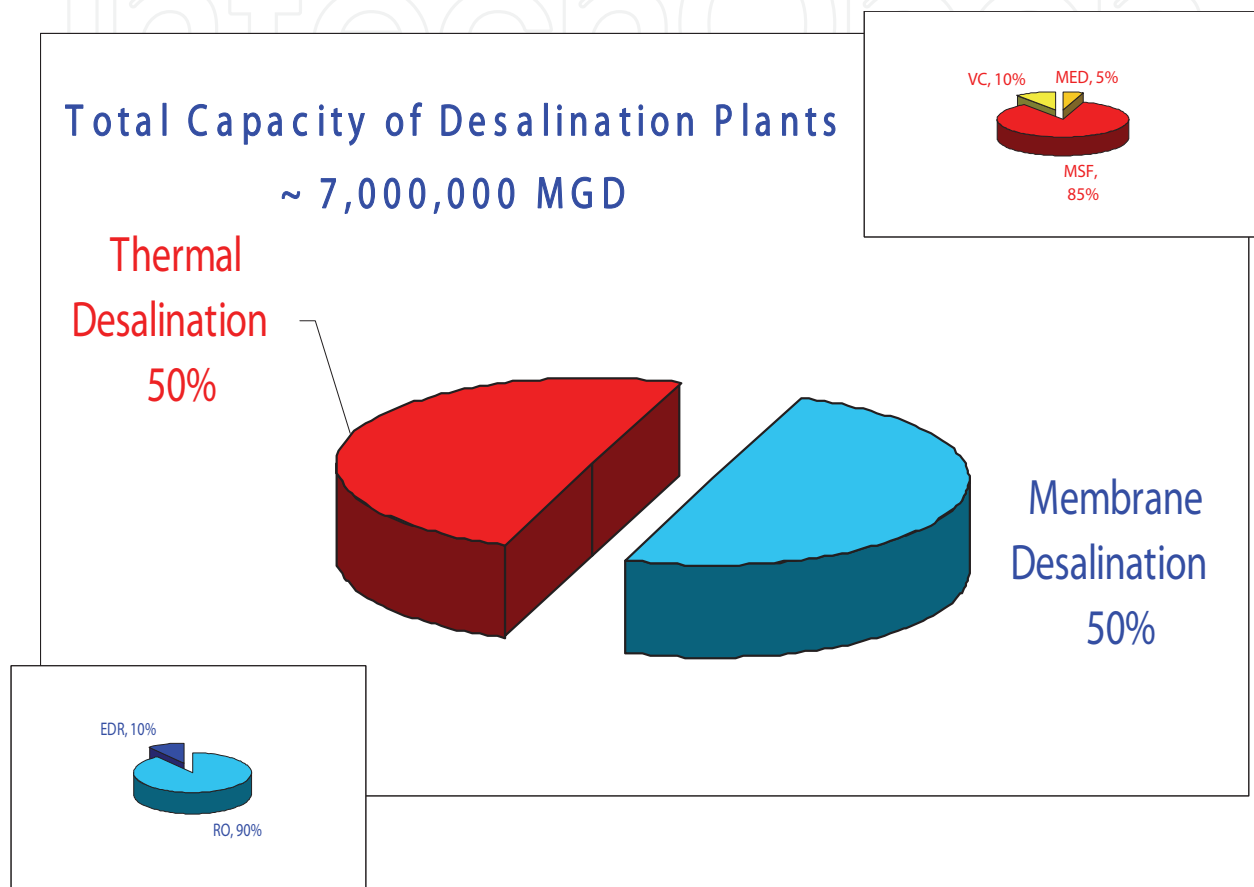


Fig. 3. Desalination Capacity Worldwide. RO - Reverse Osmosis, EDR - Electro Dialysis Reversal, MSF - Multi Stage Flash, MED - Multi Effect Distillation, VC - Vapor Compression

The lack of correlation between the number of installations and overall capacities can be explained by the development of membrane desalination. Thermal processes have been on the market for more than five decades and most of them provide relatively high capacities. However, this ratio is expected to change significantly because most of the desalination systems currently designed, constructed, and considered for construction are based on membrane technology. For example, the largest membrane desalination plant in the U.S. is the Tampa Bay SWRO, with a capacity of 25 MGD / 95,000 m³/day (and provision for up to 35 MGD / 130,000 m³/day expansion). The plant went into the operation in 2003. The newly considered Carlsbad desalination plant capacity 50 MGD / 190,000 m³/day is planning to use SWRO membrane technology. A much larger membrane desalination facility was commissioned in May 2005 in Israel, the Ashkelon SWRO, with a capacity of 44

MGD / 166,000 m³/day, which was expanded to 88 MGD / 330,000 m³/day at the end of 2005.

When different technologies were evaluated for these large desalination facilities, SWRO provided the most cost-effective solution for all considerations: capital expenditures, O&M, and cost per 1,000 gallons of treated water based on 20 – 30 years of operation.

As positive results, such as cost-effectiveness, emerge from large SWRO facilities in operation, they will provide more security and confidence in building SWRO plants with larger capacities.

2. Membrane technologies

Membranes are becoming a common commodity in water treatment, with four major membrane categories that depend on the membrane pore sizes in commercial use at the present time:

- Microfiltration (MF) - screens particles from 0.1 to 0.5 microns
- Ultrafiltration (UF) - screens particles from 0.005 to 0.05 microns
- Nanofiltration (NF) - screens particles from 0.0005 to 0.001 microns
- Reverse Osmosis (RO) - ranging molecular size down to 10 MWCO

The appropriate membrane treatment process for the removal of different constituents from water can be traced in the chart below. All four membrane categories are commonly used in water treatment to achieve the goals of Drinking Water Guidelines and Standards, as well as

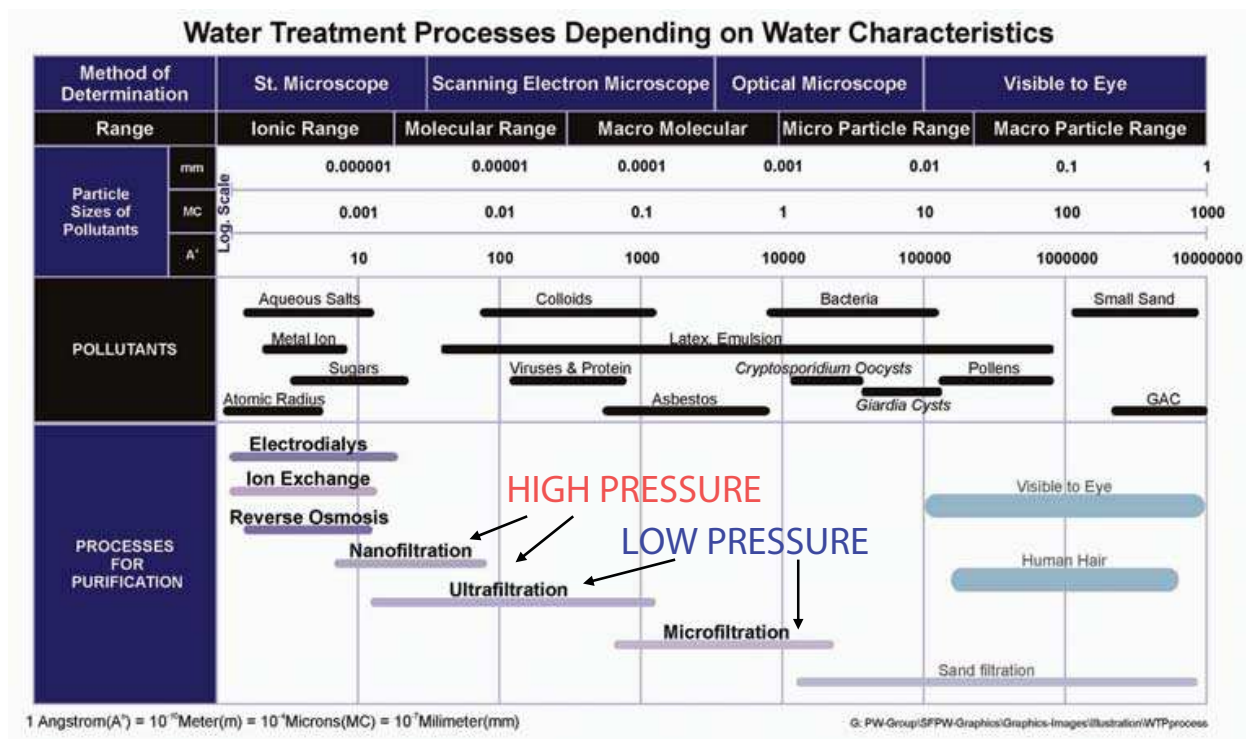


Fig. 4. Water Treatment Spectrum

to produce desalted and/or Ultra Pure Water (UPW) for different industrial and other needs, such as power plants make-up water, electronic ships manufacturing, food industry, pharmaceutical, medical, and others.

Water impurities depending on size and hydraulic properties:

- Suspended Solids (expressed as TSS, TVSS, Turbidity)
- Colloids (expressed as SDI)
- Dissolved Solids (expressed as TDS, TVDS)

Nature of water impurities:

- Mineral nature (non organic)
- Organic nature

Membrane Shape Type:

- Spiral Wound
- Hollow Fiber
- Flat Sheet

Membrane Type depending on driven pressure:

- Pressure Driven (MF, UF, NF and RO)
- Immersed, Vacuum Driven (MF only)

The first commercial use of membrane technology was desalination by RO, the process known decades ago and commercialized in the early 1960s.

3. Energy recovery

Implementation of efficient Energy Recovery Turbines (ERT) into the RO desalination technologies boosted growth of RO plants worldwide. There are three major types of ERT:

- Pelton Wheel
- Francis type
- Reversal pump

Recent developments in RO energy conservation brought the following technologies into the market:

- Double Work Exchanger Energy Recovery DWEER
- Hydraulic turbo-charger
- Pressure/Work Exchanger and others

From the ERT, the most popular and reliable was the first type, Pelton Wheel ERT, which can save up to 30% and higher of the energy consumed by high pressure RO pumps, represents the highest O&M expenditure for RO plant operation. Of the latest developments, DWEER and other systems can save up to 90-95% of the brine energy. For example, for high salinity water with the RO recovery of 40%, the overall energy savings can be as high as 50% or more of the energy for the entire plant operation.

4. Desalination statistics

Table 1 provides more detailed information and figures on the global production of desalinated water, by process and plant capacity.

Desalting process	Percentage	Capacity ($\times 10^6$ m ³ /day)	Capacity (10 ⁶ gal/day)	No. of plants
<i>Unit capacity</i>				
<i>100-60 000 m³/day</i>				
Multistage flash	44.4	10.02	2,204	1,244
Reverse osmosis	39.1	8.83	1,943	7,851
Multiple effect	4.1	0.92	202	682
Electrodialysis Reversal	5.6	1.27	279	1,470
Vapor compression	4.3	0.97	213	903
Membrane softening	2.0	0.45	99	101
Hybrid	0.2	0.05	11	62
Others	0.3	0.06	13	120
	100.0	22.57	4,965	12,433
<i>Unit capacity</i>				
<i>500-60 000 m³/day</i>				
Multistage flash	46.8	10.00	2,200	1,033
Reverse osmosis	37.9	8.10	1,782	3,835
Multiple effect	3.8	0.81	178	653
Electrodialysis Reversal	4.7	1.00	220	230
Vapor compression	4.2	0.90	198	486
Membrane softening	2.1	0.45	99	64
Hybrid	0.2	0.04	9	27
Others	0.23	0.05	11	11
EDI	0.05	0.01	2	97
	100.0	21.36	4,699	6,436
<i>Unit capacity</i>				
<i>4000-60 000 m³/day¹</i>				
Multistage flash	64.0	9.27	2,039	496
Reverse osmosis	25.7	3.72	818	613
Multiple effect	3.6	0.52	114	48
Electrodialysis Reversal	2.1	0.31	68	60
Vapor compression	1.9	0.28	62	42
Membrane softening	2	0.36	79	50
Hybrid	0	0.02	4	2
Others	0	0.00	0	0
	100.0	14.48	3,186	1,311

Table 1. Summary of worldwide desalination capacity to 1998, split by plant type and process capacity range. Source: 1998 IDA Worldwide Desalting Plants. Inventory Report No. 15. Wangnick Consulting GmbH.

Today, the desalination capacity of membranes using RO reaches close to 3,500,000 MGD / 14 000 000 000 m³/day total capacity, which is half of the entire desalination capacity worldwide. Membrane desalination is the fastest growing technology, and is expected to become the prevalent desalination technology for the 21st century.

Microfiltration and ultrafiltration technologies became commercial in the late 1980s -1990s. The major issues in membrane developments are:

- Increase membrane flux
- Decrease trans-membrane pressure
- Increase particles and salt rejection
- Extend membrane lifetime
- Improve operational process including back-wash technique and CIP cleaning

To address these issues, improve membrane performance, and bring membrane applications to a new level, the following membrane characteristics and parameters are subjects for current and future research and development:

- Improving pore shape, uniformity, and distribution
- Upgrading hydrophilic properties
- Increasing overall porosity or pore density of membranes
- Developing more sophisticated and cost-effective membrane materials
- Improving the membrane manufacturing process

During the past 10 to 20 years, the availability, efficiency, and reliability of membrane systems have increased significantly, while the capital and operational costs of these

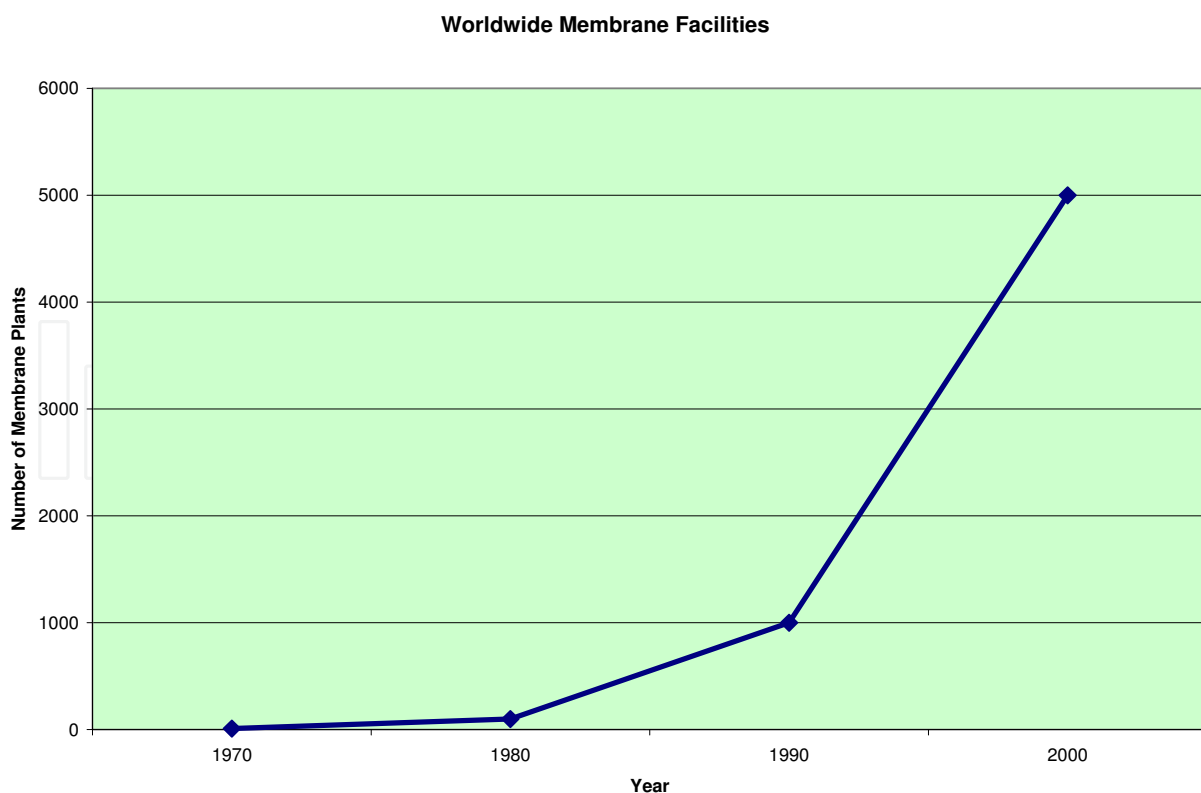


Fig. 5. Worldwide Membrane Facilities (not including Desalination)

systems have dropped considerably. These developments have resulted in worldwide exponential growth of membrane treatment plants. The latest AMTA information on the number of membrane plants worldwide (not including desalination systems) is provided in the following chart.

As a result of the growing membrane industry, membrane prices have trended lower during the last decade. Some membrane manufacturers supply membranes to membrane system integrators, while some suppliers also act as membrane integrators as well. When manufacturers are deciding whether or not to be system integrators, they evaluate many criteria, including competition with the professional system integrator companies. Since high pressure membranes such as RO and NF are no longer on the market, most of the RO/NF membrane manufacturers do not act as system integrators. Moreover, the industry has reached a consensus on the standard sizes for RO and NF membranes. The most widely used RO/NF elements are 2.5", 4" and 8" in diameter and 40" and 60" long. Currently, RO elements are sized 16", 17.5", 18 and 18.5" diameter in the commercialization process to increase the amount of active membrane area provided by each element.

The low pressure MF/UF membranes are a relatively new technology, and no industrial standard has yet been currently established. As the low pressure market grows, the low pressure membranes will likely develop their own across-the-industry standard in order to optimize MF/UF plant designs and reduce project costs. As a result of the current situation, most of the MF/UF membrane manufacturers are also acting as system integrators.

When comparing open sea intakes to beach wells, the latter have preference:

- Less turbidity and solids in the feed and less pre-treatment is required
- Less chemical consumption by pretreatment
- Less seasonal and daily fluctuation of water quality and temperature, which allows better and more reliable facility operation

For large SWROs, the well intakes are rarely considered as a water source, and open intakes are the most appropriate solution. When an open intake is considered, the most common pre-treatment may include a clarifier followed by media filters, two-stage media filters in series, or other pre-treatment based on the feed water quality, local project conditions, and project economics. As described above, conventional technologies can provide sufficient pre-treatment when they are very sensitive to the water parameter fluctuations.

The best prototype may be low pressure MF/UF membrane pre-treatment, which provides an absolute barrier to the particles regardless of the system load, operational conditions, or the fluctuations and changes. The integrated membrane systems containing pre-treatment by microfiltration or ultrafiltration have been successfully piloted around the world and have found a significant number of applications in different industries. Some small municipal plants are currently designed with membrane pre-treatment, and it is believed that in the near future, more and larger municipal SWROs will be designed and built with membrane pretreatment based on microfiltration and/or ultrafiltration membranes.

5. SWRO design considerations

Figure 6 below can be a guide on the major criteria to be considered when designing SWROs:

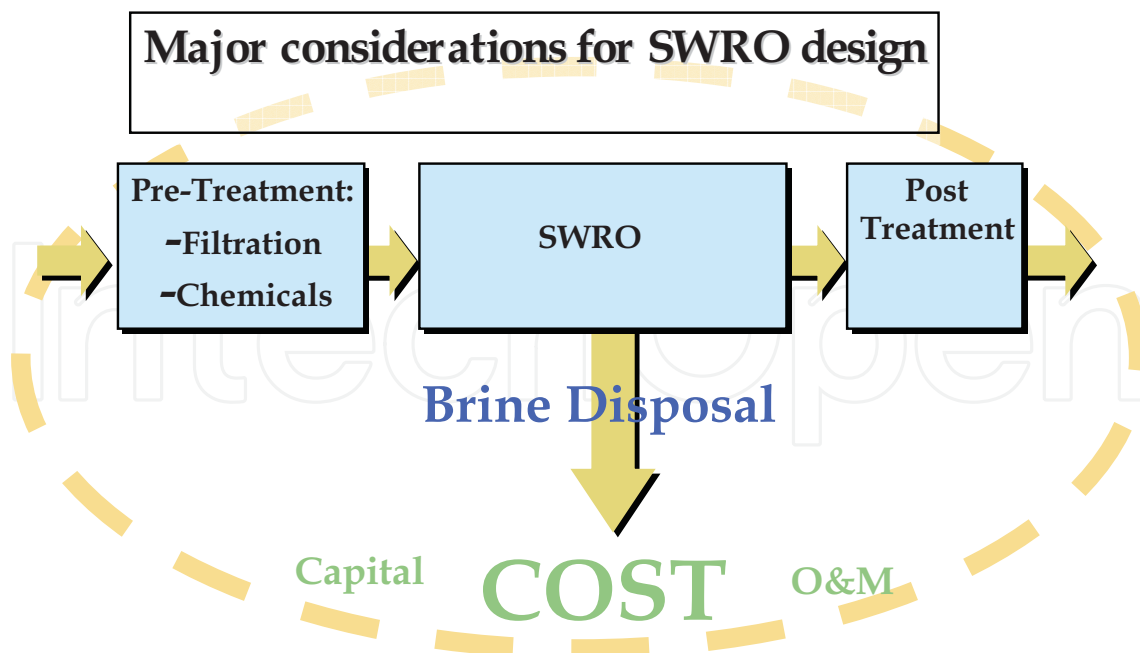


Fig. 6. Major considerations for SWRO design. The larger the SWRO, the lower the water cost and visa versa. For those who are considering SWRO, the tables below show comparable numbers for facilities of different sizes.

Parameter	Metric	US
Capacity	20,000 m ³ /day	5.3 MGD
CAPITAL TOTAL	\$ 20 M	\$ 20 M
Capital cost for 20 yrs at 6%	\$ 0.27 /m ³	\$ 1.02 / 1000 gal
Energy cost at 4 KW-H/m ³ , \$ 0.06 /KW-H	\$ 0.24 /m ³	\$ 0.91 / 1000 gal
Chemicals + Labor	\$ 0.21 /m ³	\$ 0.79 / 1000 gal
TOTAL WATER COST	\$ 0.72 /m ³	\$ 2.73 / 1000 gal

Table 2. Typical SWRO - 5 MGD (based on Eilat SWRO) (TDS = 52,000 ppm)

Parameter	Value	US
Capacity	95,000 m ³ /day (135,000 m ³ /day)	25 MGD (35 MGD)
CAPITAL TOTAL (construction 20 months)	\$ 110 M	\$ 110 M
Capital cost for 20 yrs at 6%	\$ 0.32 /m ³	\$ 1.21 / 1000 gal
Energy cost at 2.96 KW-H/m ³ , \$ 0.04 /KW-H	\$ 0.12 /m ³	\$ 0.45 / 1000 gal
Chemicals + Labor (12 people)	\$ 0.219 /m ³	\$ 0.83 / 1000 gal
TOTAL O&M COST (Fixed \$ 8.5M/yr for 30 yrs)	\$ 0.659 /m ³	\$ 2.49 / 1000 gal

Table 3. The largest SWRO in the U.S., Tampa Bay SWRO (TDS = 26,000 ppm), 25 MGD, expansion to 35 MGD

Parameter	Metric	US
Capacity	165,000 m ³ /day (330,000 m ³ /day)	44 MGD (88 MGD)
CAPITAL TOTAL	\$ 212 M	\$ 212 M
Capital cost for 20 yrs at 6%	\$ 0.17 /m ³	\$ 0.64 / 1000 gal
Energy cost at 4 KW-H/m ³ , \$ 0.06 /KW-H	\$ 0.24 /m ³	\$ 0.91 / 1000 gal
Chemicals + Labor	\$ 0.117 /m ³	\$ 0.44 / 1000 gal
TOTAL WATER COST	\$ 0.527 /m ³	\$ 1.99 / 1000 gal

Table 4. Largest SWRO in the world– Ashkelon, Israel 44 MGD (expansion to 88 MGD by 2005)

6. Summary

Membranes are becoming a commodity in the desalination and in the water treatment field, finding more applications and replacing traditional conventional technologies. Used in combination with different technologies, membranes may address removal of mineral and organic compounds in the water including volatile types such as endocrine disruptors (EDCs) (42 found in the U.S.), pharmaceutically-active compounds (PhACs), and personal care products (PCPs).

The major reasons membrane desalination is emerging as the dominant technology are:

- Absolute barrier for treatment/removal
- Product water is not affected by the feed water hydraulic and contaminant overloads, spikes, and fluctuations
- Less or no chemicals required
- Smaller footprint/layout
- Single step process
- Modular expandability (for future expansions)
- Less volume of discharged wastes (including sludge and chemicals)
- Simplicity of operation, process automation

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The book comprises 14 chapters covering all the issues related to water desalination. These chapters emphasize the relationship between problems encountered with the use of feed water, the processes developed to address them, the operation of the required plants and solutions actually implemented. This compendium will assist designers, engineers and investigators to select the process and plant configuration that are most appropriate for the particular feed water to be used, for the geographic region considered, as well as for the characteristics required of the treated water produced. This survey offers a comprehensive, hierarchical and logical assessment of the entire desalination industry. It starts with the worldwide scarcity of water and energy, continues with the thermal - and membrane-based processes and, finally, presents the design and operation of large and small desalination plants. As such, it covers all the scientific, technological and economical aspects of this critical industry, not disregarding its environmental and social points of view. One of InTech's books has received widespread praise across a number of key publications. Desalination, Trends and Technologies (Ed. Schorr, M. 2011) has been reviewed in Corrosion Engineering, Science & Technology – the official magazine for the Institute of Materials, Minerals & Mining, and Taylor & Francis's Desalination Publications. Praised for its “multi-faceted content [which] contributes to enrich it,” and described as “an essential companion...[that] enables the reader to gain a deeper understanding of the desalination industry,” this book is testament to the quality improvements we have been striving towards over the last twelve months.

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