REVERSE OSMOSIS MEMBRANES

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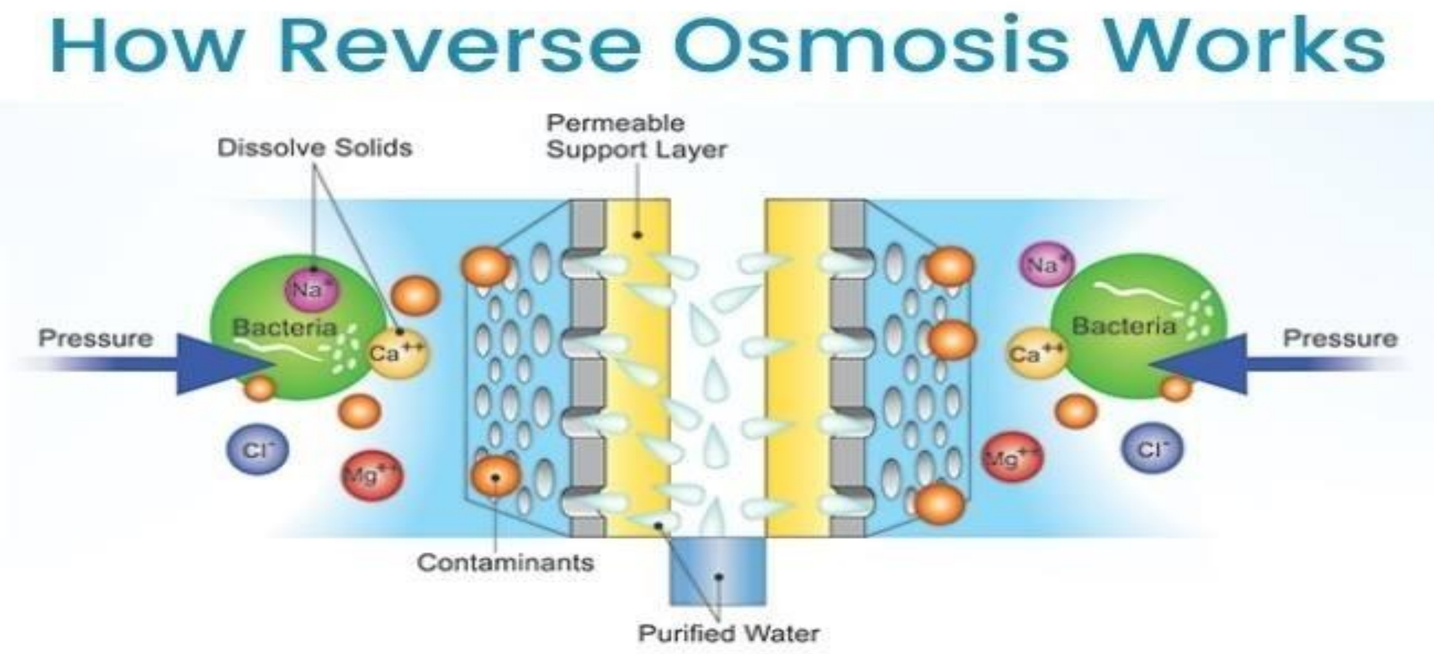
RO TECHNOLOGY

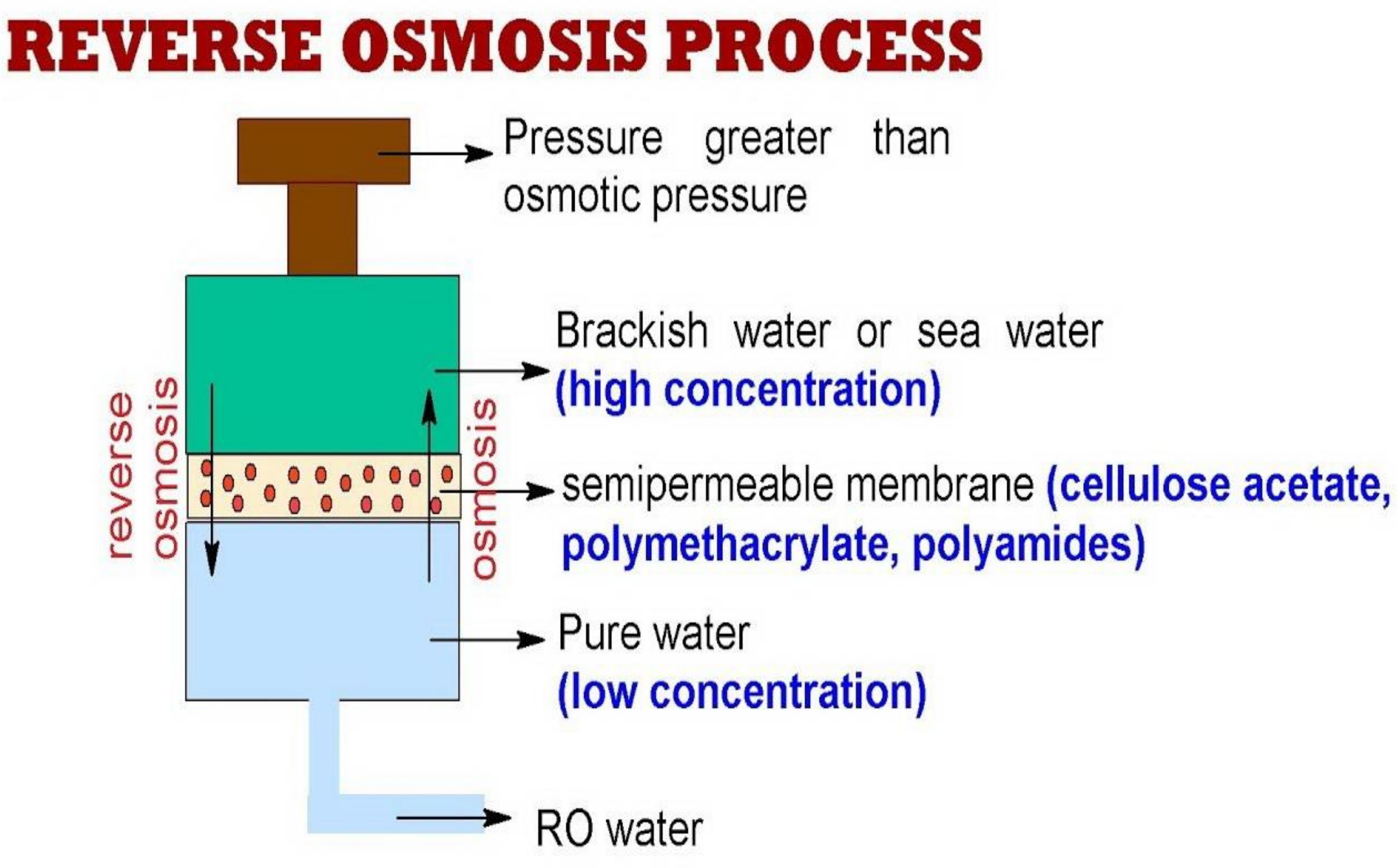
1. INTRODUCTION

A process of osmosis through semipermeable membranes was first observed in 1748 by Jean-Antoine Nollet. For the following 200 years, osmosis was only a phenomenon observed in the laboratory. In 1950, the University of California at Los Angeles first investigated desalination of seawater using semipermeable membranes. Researchers from both University of California at Los Angeles and the University of Florida successfully produced fresh water from seawater in the mid-1950s, but the flux was too low to be commercially viable[1] until the discovery at University of California at Los Angeles by Sidney Loeb and Srinivasa Sourirajan[2] at the National Research Council of Canada, Ottawa, of techniques for making asymmetric membranes characterized by an effectively thin "skin" layer supported atop a highly porous and much thicker substrate region of the membrane. John Cadotte, of FilmTec Corporation, discovered that membranes with particularly high flux and low salt passage could be made by interfacial polymerization of m-phenylene diamine and trimesoyl chloride. Cadotte's patent on this process[3] was the subject of litigation and has since expired. Almost all commercial reverse-osmosis membrane is now made by this method. By 2019, there were approximately 16,000 desalination plants operating around the world, producing around 95 million cubic metres per day (25 billion US gallons per day) of desalinated water for human use. Around half of this capacity was in the Middle East and North Africa region.



2. OVERVIEW OF RO APPLICATION:

Reverse Osmosis (RO) is a separation technique that is suitable for a wide range of applications, especially when salt and/or dissolved solids need to be removed from a solution. Accordingly, RO can be used for seawater and brackish water desalination, to produce both water for industrial application, and drinking water. It can also be applied for the production of ultrapure water (e.g. semiconductor, pharmaceutical industries) and boiler feed water. In addition, RO membrane systems are used for wastewater and water reuse treatments. RO is currently considered one of the most economic and effective process for water desalination. Accordingly, it is often the appropriate technique to treat solutions having salt concentrations from 100 to over 50,000 mg/ liter. Solutions with salinity from surface water to sea water, and even brines, can be treated by RO membrane.



Cross flow is the configuration applied for membrane separation using RO membrane. As shown in Figure 1.1 the feed water stream flows tangentially to the membrane surface. A fraction of the water in this feed stream passes through the membrane, whereas the majority of the feed flow travels along the surface. Thus, two streams are collected:

- permeate, almost pure water containing low concentration of ions
- concentrate, having high concentration of small particles and dissolved ions Figure 1.1

In operation, the RO membrane system is continuously supplied with feedwater which produces a constant water movement from feed to concentrate. When in cross-flow operation, there is little accumulation of the rejected solutes and fouling or scaling can be minimized.

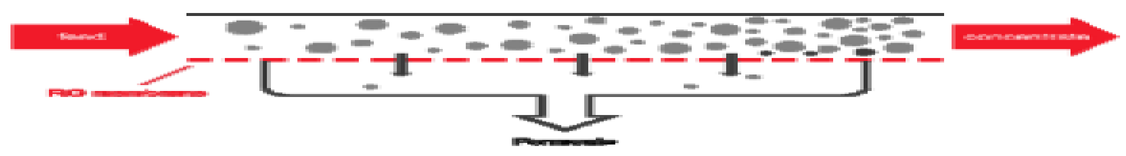
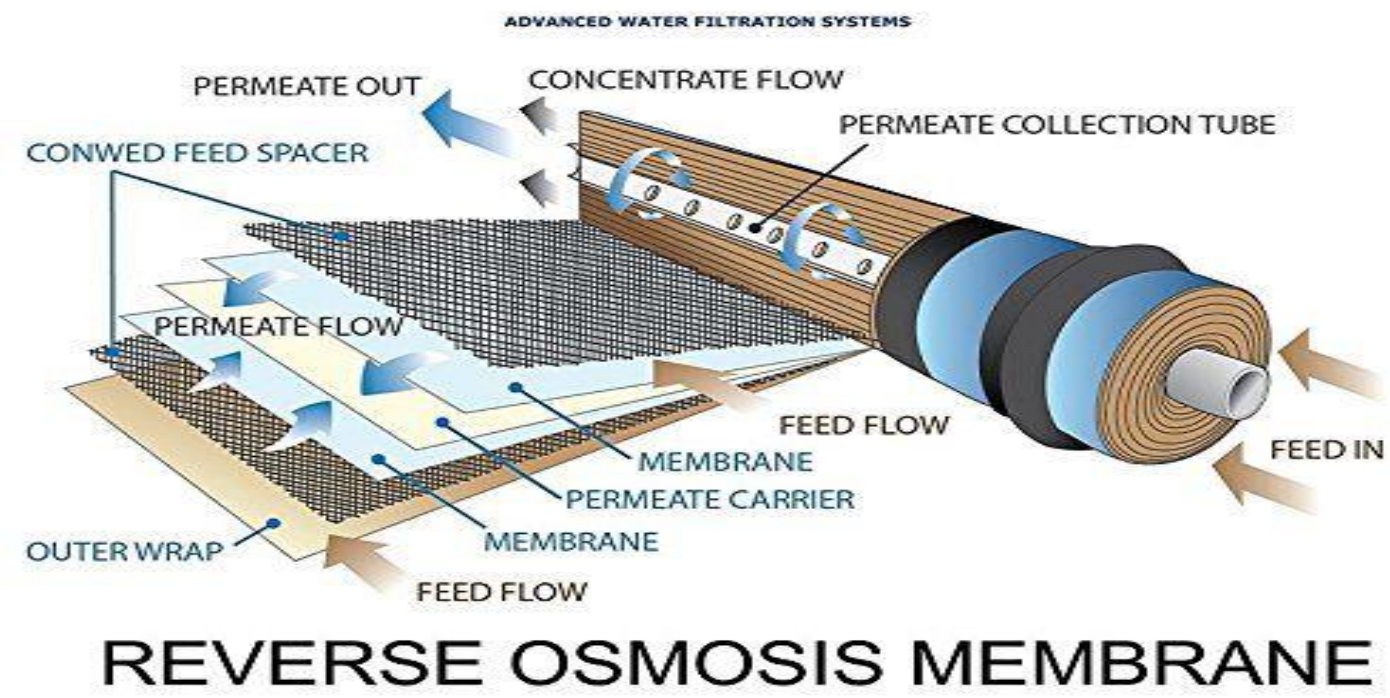


Figure 1.1: Schematic flow of RO membrane

Figure 1.1 Schematic flow of RO membrane

3. RO MEMBRANE DESCRIPTION

Reverse osmosis (RO) membranes play a key role in wastewater treatment units as they are used to remove salts and other pollutants effectively, Historically, RO technology started with cellulose acetate (CA) membranes.



RO membranes can be supplied in both flat sheet and HFF (Hollow Fine Fiber) structural formats. The flat sheet RO membrane is composed of three layers. As shown in Figure 1.2, there is a nonwoven polyester support layer, a polysulfone layer, and on top the polyamide barrier layer. The barrier layer is formed by the polyamide of which the molecular structure is shown in Figure 1.2. and 1.3

The RO membrane market is essentially based on thin-film composite (TFC) polyamide membranes, generally consisting of a polyester web used as a support (120–150 μm thick), a microporous interlayer usually made of polysulphonic polymer (40–50 μm), and a top ultrathin barrier layer with selectivity properties and low resistance to mass transfer of permeate (~0.2 μm).

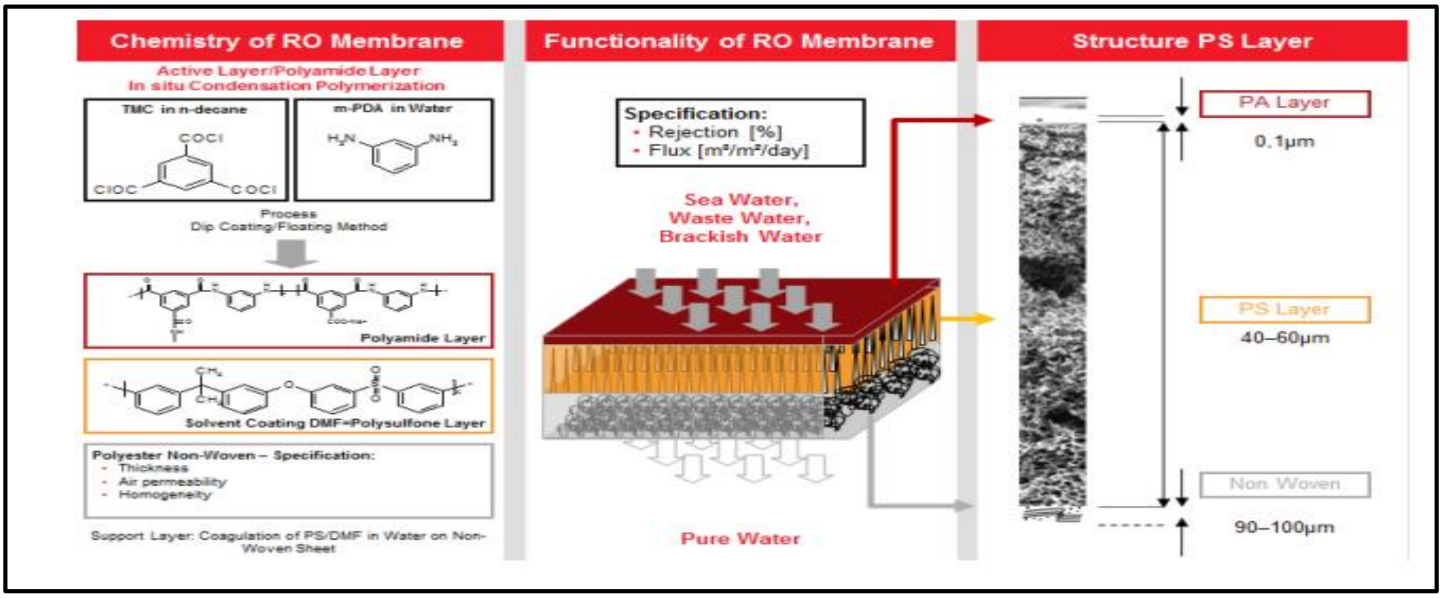


Figure 1.2

The selective layer, which is generally able to provide salt rejection higher than 99.5% to NaCl, is commonly made of 1,3-phenylenediamine (also known as 1,3-benzenediamine) and tri-acid chloride of benzene (Figure 1). Although they are characterized by higher resistance to chlorine (extensively used as a disinfectant to prevent bacterial growth on membranes), asymmetric CA or triacetate hollow-fibre modules are much less frequently installed in RO plants because of their lower rejection ability.

Although they are characterized by higher resistance to chlorine (extensively used as a disinfectant to prevent bacterial growth on membranes), asymmetric CA or triacetate hollow-fibre modules are much less frequently installed in RO plants because of their lower rejection ability. Among the unresolved challenges, the boron rejection of any commercially available membrane is still insufficient (~93%) to meet WHO water drinking standards by one-pass RO process.

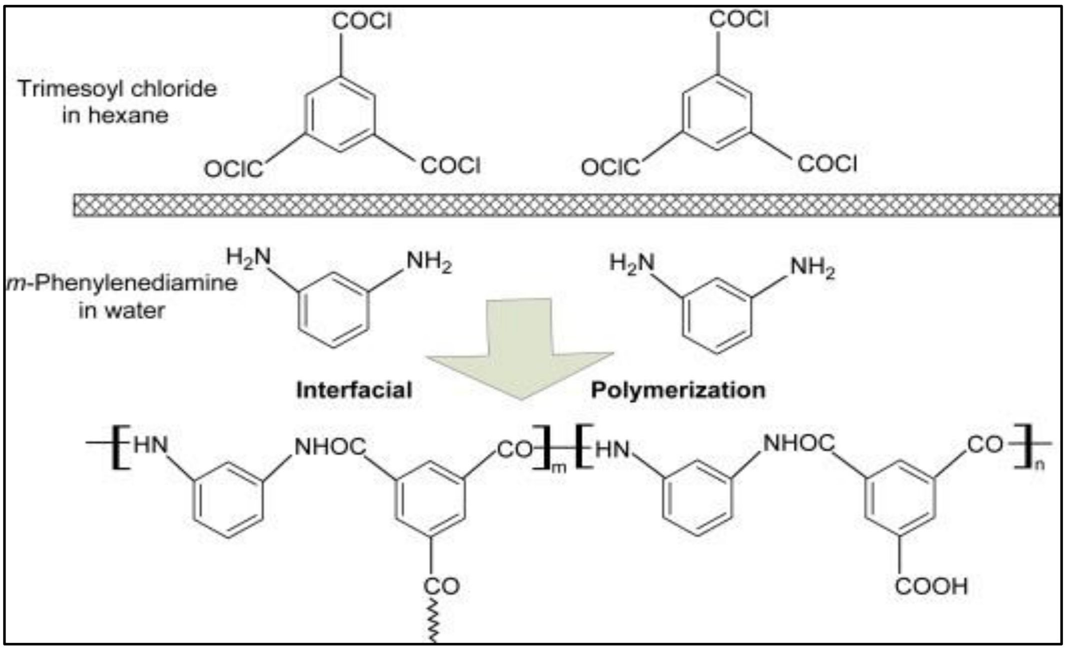


Figure 1.3 sample scheme of interfacial polymerization for the preparation of the top layer of a thin film composit , fully aromatic polyamide membrane.

With few exceptions, RO membranes are prepared in the flat-sheet form and are assembled in spiral-wound module (SWM) configuration with a high specific membrane surface area (the packing density is about 500–800 m^2/m^3) and low replacement cost (Pearce, 2007). Figure 1.4

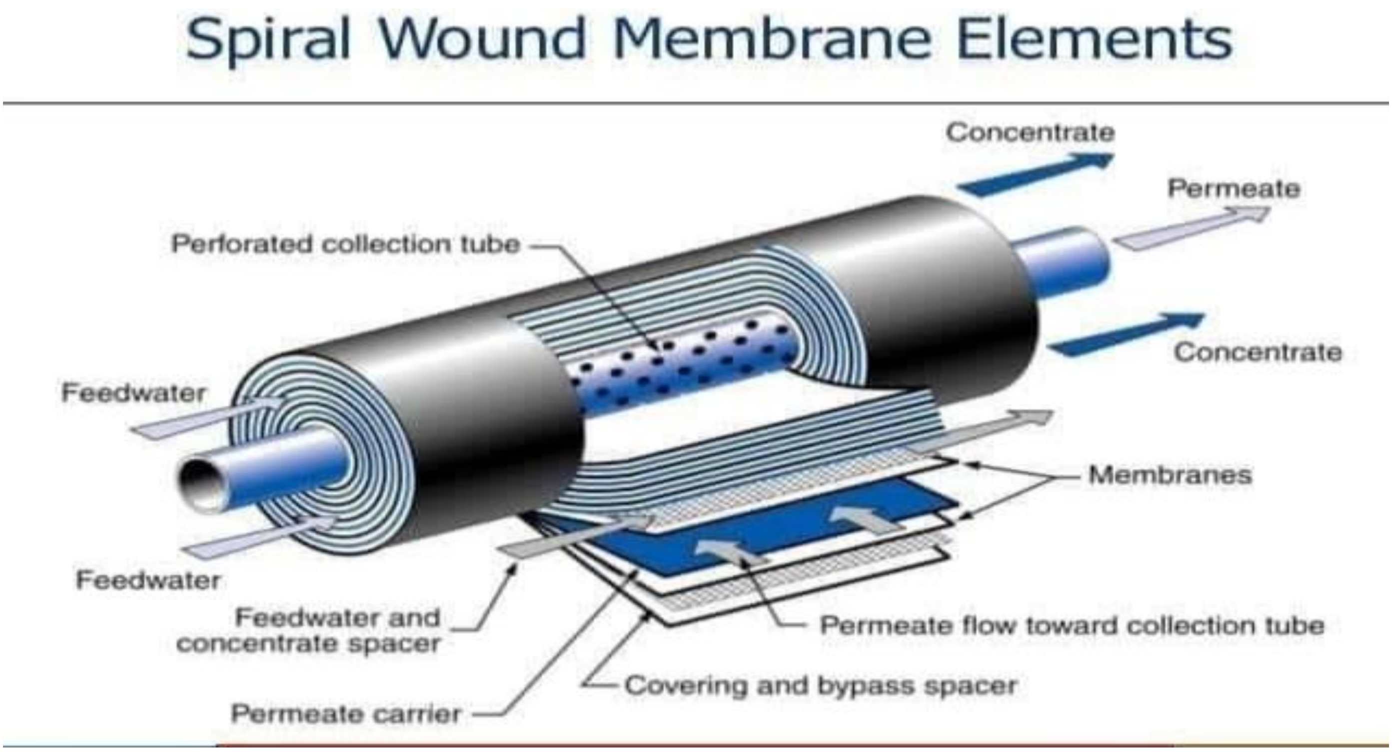


Figure 1.4

In SWM, two rectangular flat-sheet membranes are placed back to back and sealed on three sides to form an envelope. One or multiple envelopes are wound around a collector tube connected to the fourth side, which remains open. Feed water enters tangentially in the module and the permeate goes through the membrane and flows perpendicularly in the collector tube, while the retentate leaves the module at the opposite end.

Advances in membrane desalination (innovation in membrane materials, optimization of module fluid dynamics, and improvement in process design, pretreatment, and energy recovery systems) resulted in progressive enhancement of membrane rejection and a decrease in overall energy consumption, as illustrated in Figure 2.

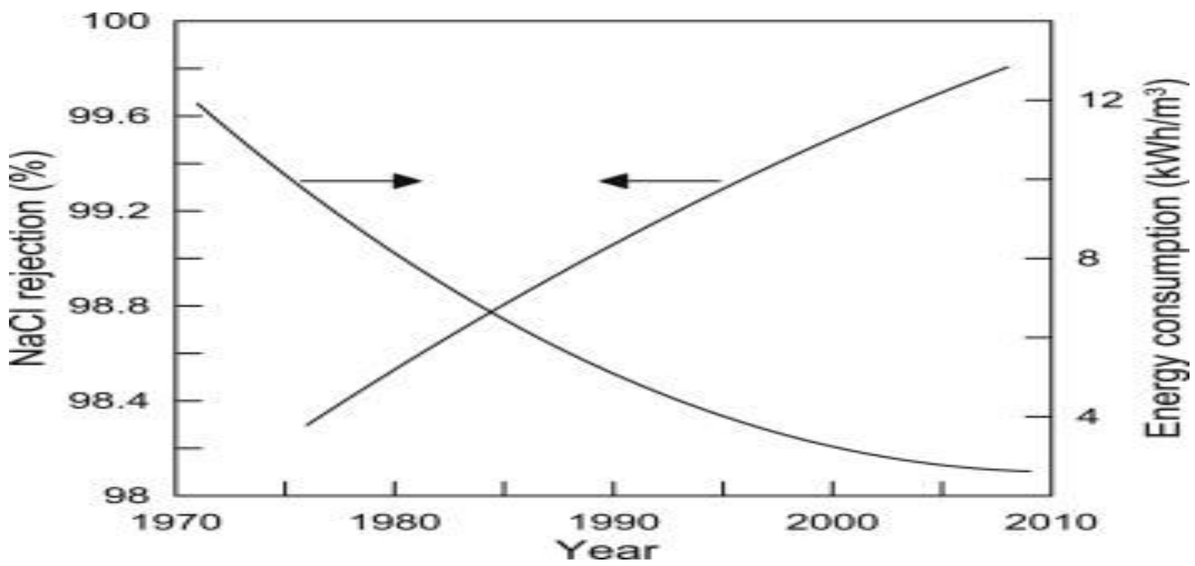
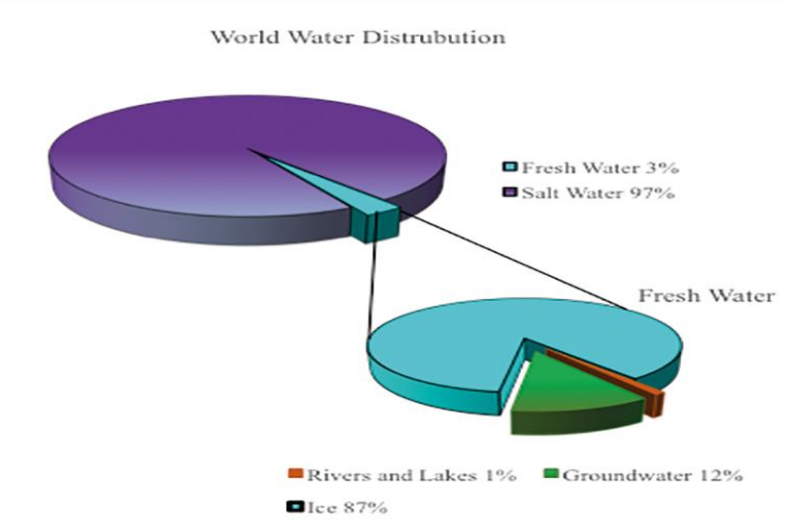


Figure 2 . improvement of salt rejection (%) and energy consumption (kWh/m^3) of SWRO technology.

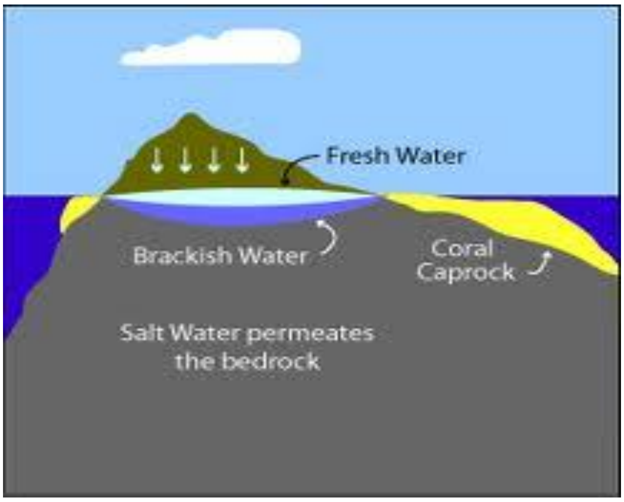
4.WATER CHARACTERS AND IMPORTANT DEFINITION:

Sea water:

The water with TDS 35000-44000 mg/l, is a complex mixture of 96.5 percent water, 2.5 percent salts, and smaller amounts of other substances, including dissolved inorganic and organic materials, particulates, and a few atmospheric gases.



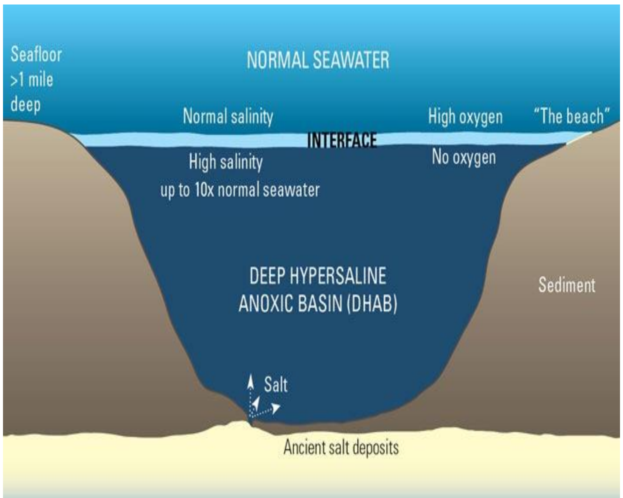
Brackish water:



Brackish water, also sometimes termed brack water,[1][2] is water occurring in a natural environment having more salinity than freshwater, but not as much as seawater.

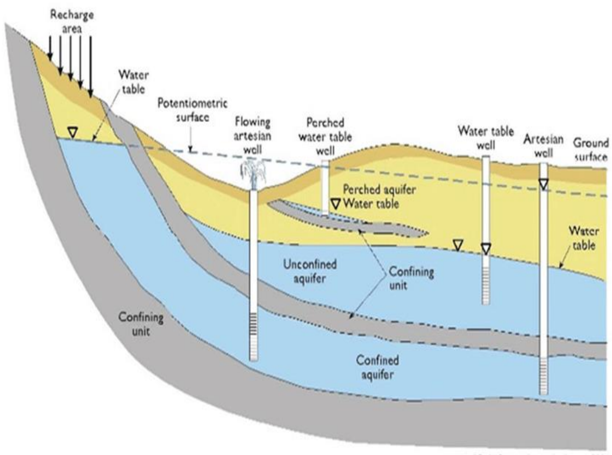
water generally defined as water with TDS content between the fresh water <500 mg/l and sea water 3300 mg/l, with less boron.

Brine water:



Salt water particularly a highly concentrated water solution of salt (sodium chloride)3.5%. Natural brines occur underground, in salt lakes, or as seawater and are commercially important sources of common salt and other salts, such as chlorides and sulfates of magnesium and potassium. Also, Modification of seawater via evaporation results in the concentration of salts in the residual fluid.

Ground water:



Groundwater is the water found underground in the cracks and spaces in soil, sand and rock. It is stored in and moves slowly through geologic formations of soil, sand and rocks called aquifers with high TDS and low turbidity.

Table 1: type of water according to TDS

Water type	TDS	source
Fresh and marginal	500-1000	Surface water as river
brackish	1000-2000	Ground water, sanitary water, industry water
saline	2000-35000	Ground and sea water and same lacks
Sea water	32000-44000	Ocean
Brine	>35000	Sea water and concentrated from sea water desalination

5.IMPORTANT EQUATION USED IN DISTILLATION:

Permeate flux

Q / S

Where Q is the permeate flow rate and S is the Area of the membrane

Salt rejection (R)

(1-CP /Cave)*100

Cave = (Cf +Cc) / 2

Where Cp is permeate concentration, Cf is the feed permeate, Cc is the concentrated concentration.

Recovery rate (Y)

Qp /Qf

Where Qp is the permeate flow rate and Qf is the feed flow rate

Trans membrane pressure (TMP)

[(Pf + Pc) / 2]-Pp

Where Pf is the feed pressure, Pc is the concentrated pressure and Pp is the permeate pressure.

6. TRADITIONAL RO MEMBRANE IN MARKET:

There are many common companies in membrane market such as:

1- DuPont- filmetic

2- Hydranautics

3- Toray membrane

4- LG CHEM

5- Porex membrane

6- SUEZ membrane

7- Synder membrane

8- Akkim membrane

9- LEENTECh membrane

American company in Delaware in 1802, 2015 merge with DOW

RO membrane can be classified into 5 categories according to water feed

1- Tap water RO membrane (21 module) TW
2- Brackish water RO membrane (19 module) BW
3- Sea water RO membrane (26 module) SW
4- Food and medicine RO membrane (HR-HS-LC-LF-LP-NF-RO-XLE)
5- Sanitary water RO membrane (SG)

Nomenclature of elements according to FilmTec™ Membranes

BW30 – High-rejection brackish water FT30 membrane for brackish water RO

BW30HR – Very high rejection proven at broad total dissolved salts (TDS) range, coupled with reduced footprint installations

BW30HRLE – Delivers low operating pressure coupled with a good permeate purity

Eco – State-of-the-art solution to deliver high salt rejection at low operating pressure, reducing CAPEX and OPEX

Fortilife™ – A forward-thinking portfolio of low-salinity membranes which combine durability, fouling-resistant properties and excellent cleanability for the most challenging waters and applications.

HSRO – Heat-sanitizable version of the RO membrane used in fullfit elements

NF – Nanofiltration membrane used in non-water applications

NF245 – Food and dairy membrane for a variety of desalting, purification, and other separations

NF270 – High-productivity nanofiltration membrane for removal of organics with medium salt and hardness passage

DOW®
FILMTEC
MEMBRANES

NF90 – Nanofiltration membrane for 90% salt removal, high removal of iron, pesticides, herbicides, TOC

RO – Reverse osmosis membrane used in fullfit elements for sanitary applications

Seamaxx™ – Smart choice for systems treating high-salinity waters targeting the lowest energy consumption

SW30 – Seawater RO membrane, typically used for low-salinity or cold seawater RO and high-salinity brackish water RO

SW30HR – Seawater RO membrane with high salt rejection, typically used for single-pass seawater desalination

SW30HRLE – Seawater RO membrane with high salt rejection, typically used for low-energy seawater desalination

SW30XFR – Designed specifically to handle biofouling in seawater desalination plants and equipped with advanced fouling-resistant and cleanability features

SW30XHR – Highest rejection seawater RO element enabling stringent water quality requirements

SW30XLE – Membrane for seawater desalination with extremely low energy consumption

TW30 – High rejection brackish water FT30 membrane, typically used for tap water RO

XLE – Extremely low-energy RO membrane for lowest pressure brackish water RO

HYDRANAUTICS Nitto Group Company

- A Nitto group company started at 1970 in RO membrane. The Nitto Global Membrane Division comprises of three production facilities: Hydranautics, headquartered in Oceanside, California, USA; a membrane manufacturing plant in Shiga Prefecture, Japan and an element assembly facility in Shanghai, China.

RO membrane can be classified into 5 categories according to Technique

1- CPA (high rejection) 12 module

2- ESNPA (nano-filter) 10 module

3- ESPA (saving energy) 28 module

4- LFC (low fouling) 9 module

5- SWC (sea water) 27 module

'TORAY'

Innovation by Chemistry

Started at 1926 in Japan, begin in RO production in 1980.

RO membrane can be classified into 3 categories according to Type of membrane

1- SC (6 modules)
2- SU (24 modules)
3- TM (52 modules)

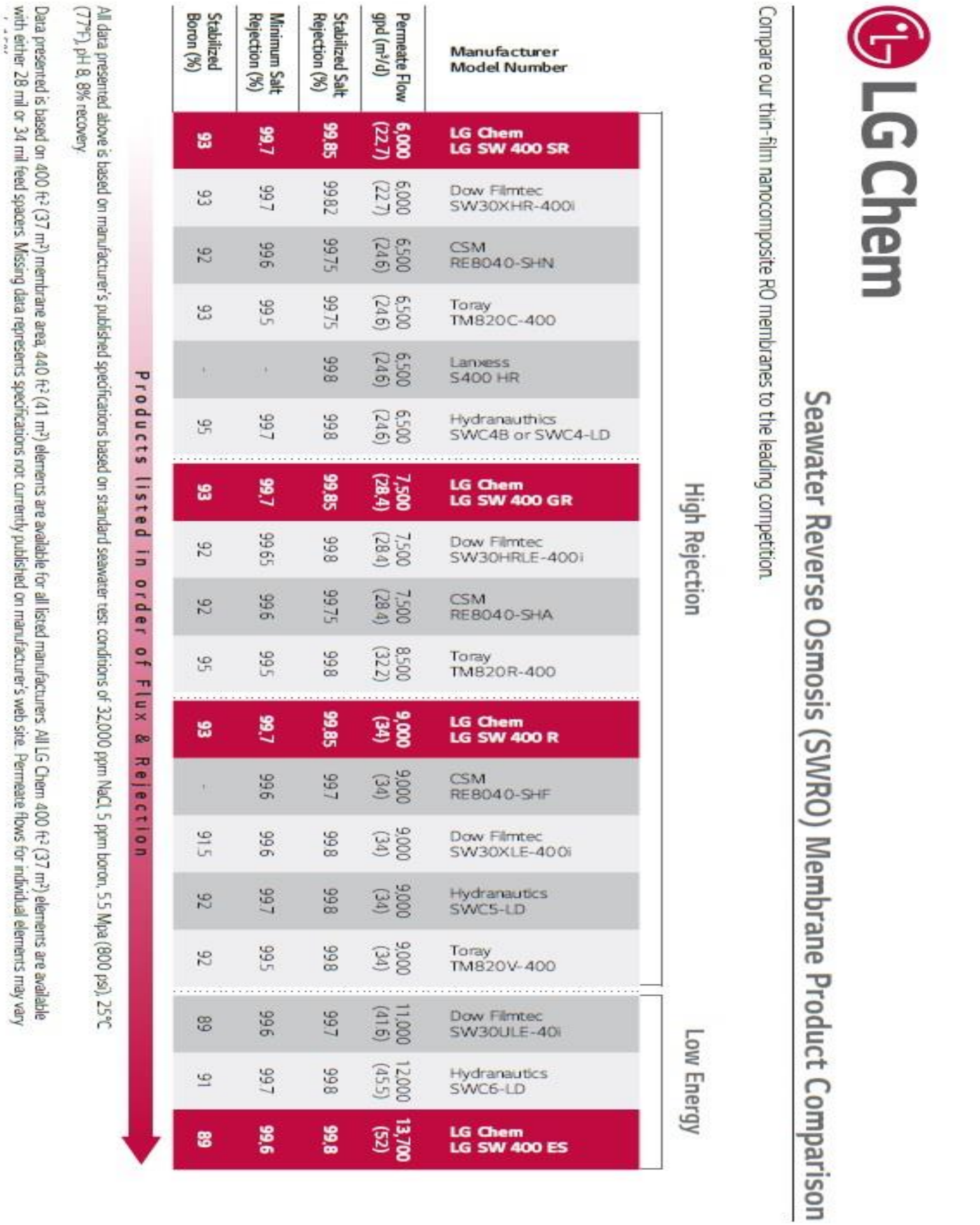
LG Chem

Since its establishment in 1947, LG Chem has continuously achieved growth through stiff challenges and innovations as the Korea's leading chemical company.

RO membrane can be classified into 3 categories according to water feed

1- TW (Tap water) 7 modules
2- SW (sea water) 15 modules
3- BW (Brackish water) 24 modules

Table 2: Comparison between RO company from LG site



LG Chem

Seawater Reverse Osmosis (SWRO) Membrane Product Comparison

Compare our thin-film nanocomposite RO membranes to the leading competition.

Manufacturer Model Number	Permeate Flow gpd (m³/d)	Stabilized Salt Rejection (%)	Minimum Salt Rejection (%)	Stabilized Boron (%)
High Rejection				
LG Chem LG SW 400 SR	**6,000 (22.7)**	**99.85**	**99.7**	**93**
Dow Filmtec SW30XHR-400i	6,000 (22.7)	99.82	99.7	93
CSM RE8040-SHN	6,500 (24.6)	99.75	99.6	92
Toray TM820C-400	6,500 (24.6)	99.75	99.5	93
Lanxess S400 HR	6,500 (24.6)	99.8	-	-
Hydranauthics SWC4B or SWC4-LD	6,500 (24.6)	99.8	99.7	95
LG Chem LG SW 400 GR	**7,500 (28.4)**	**99.85**	**99.7**	**93**
Dow Filmtec SW30HRLE-400i	7,500 (28.4)	99.8	99.65	92
CSM RE8040-SHA	7,500 (28.4)	99.75	99.6	92
Toray TM820R-400	8,500 (32.2)	99.8	99.5	95
LG Chem LG SW 400 R	**9,000 (34)**	**99.85**	**99.7**	**93**
CSM RE8040-SHF	9,000 (34)	99.7	99.6	-
Dow Filmtec SW30XLE-400i	9,000 (34)	99.8	99.6	91.5
Hydranautics SWC5-LD	9,000 (34)	99.8	99.7	92
Toray TM820V-400	9,000 (34)	99.8	99.5	92
Low Energy				
Dow Filmtec SW30ULE-40i	11,000 (41.6)	99.7	99.6	89
Hydranautics SWC6-LD	12,000 (45.5)	99.8	99.7	91
LG Chem LG SW 400 ES	**13,700 (52)**	**99.8**	**99.6**	**89**

Products listed in order of Flux & Rejection

All data presented above is based on manufacturer's published specifications based on standard seawater test conditions of 32,000 ppm NaCl, 5 ppm boron, 5.5 Mpa (800 psi), 25°C (77°F), pH 8, 8% recovery.

Data presented is based on 400 ft² (37 m²) membrane area, 440 ft² (41 m²) elements are available for all listed manufacturers. All LG Chem 400 ft² (37 m²) elements are available with either 28 mil or 34 mil feed spacers. Missing data represents specifications not currently published on manufacturer's web site. Permeate flows for individual elements may vary

Table 3: Product specifications of selected seawater desalination modules

NO	M	M code	area (fit)	Product flow rate(m^2/day)	Min.salt rejection %	Boron rejection%	Max pressure (psi)
1	filmetic	SW30-2514	2.5	0.6	99.4	------	800
2	filmetic	SW30--2521	2.5	1.1	99.4	---------	800
3	filmetic	SW30-2540	2.5	2.6	99.4	-------	800
4	filmetic	SW30-380	380	---------	-----	--------	800
5	filmetic	SW30-4021	400	3	99.4	---------	800
6	filmetic	SW30-4040	400	7.4	99.4	----------	800
7	filmetic	SW30-6040	NA				
8	filmetic	SW30-8040	NA				
9	filmetic	SW30HR-2514	NA				
10	filmetic	SW30HR-2521	NA				
11	filmetic	SW30HR-2540	NA				
12	filmetic	SW30HR-320	NA				
13	filmetic	SW30HR-380	380	23	99.5	----	800
14	filmetic	SW30HR-4021	NA				
15	filmetic	SW30HR-4040	NA				
16	filmetic	SW30HRLE-4040	7.9	6.1	99.6	-	1200
17	filmetic	SW30HRLE-370-34i	370	25	99.8	92	1200
18	filmetic	SW30HRLE-400	400	28	99.8	92	800
19	filmetic	SW30HRLE-400i	400	28	99.65	92	1200
20	filmetic	SW30HRLE-440i	440	31	99.65	92	1200
21	filmetic	SW30ULE-400i	400	41.6	99.6	89	1200
22	filmetic	SW30ULE-440i	440	45.2	99.5	89	1200

23	**filmetic**	**SW30XHR-400i**	**400**	**22.6**	**99.6**	**93**	**1200**
24	filmetic	SW30XHR-440i	440	25	99.82	93	1200
25	filmetic	SW30XLE-400i	400	33.9	99.6	91.5	1200
26	filmetic	SW30XLE-440i	440	37.4	99.8	91.5	1200
1	Hydra.	Swc6max(low p.)	440	25	99.4	83	1200
2	Hydra.	Swc6max(high f..)	440	50	99.7	91	1200
3	Hydra.	Swc6 LD(low p.)	400	22.7	99.4	83	1200
4	Hydra.	Swc6 LD(high f.)	400	45.5	99.7	91	1200
5	Hydra.	Swc6 -8040	400	34.1	99.7	92	1200
6	Hydra.	Swc6 -4040	85	7.2	99.5	------	1200
7	Hydra.	Swc5-max	440	37.5	99.7	92	1200
8	Hydra.	Swc5-LD4040	80	6.62	99.7	------	1200
9	Hydra.	Swc5-LD	400	34.1	99.7	92	1200
10	Hydra.	Swc5-4040	85	7.2	99.5	------	1200
11	Hydra.	Swc4Bmax8040	440	27.3	99.7	95	1200
12	Hydra.	Swc4Bmax	440	27.3	99.7	95	1200
13	Hydra.	Swc4B-8040	440	24.5	99.7	95	1200
14	Hydra.	Swc4B	400	24.5	99.7	95	1200
15	Hydra.	Swc4 Plus	400	24.5	99.7	----	1200
16	Hydra.	Swc4 max	440	27.3	99.7	93	1200
17	Hydra.	Swc4-LD	400	24.6	99.7	93	1200
18	Hydra.	Swc4+8040	400	24.5	99.7	------	1200
19	Hydra.	Swc3 Plus	400	26.4	99.7	NA	1200
20	Hydra.	Swc3-8040	NA				
21	Hydra.	Swc2-8040	NA				
22	Hydra.	Swc2-4040	70	5.7	99		1000

23	Hydra.	Swc1-8040		NA			
24	Hydra.	Swc1-4040	70	5.7	99	---	1000
25	Hydra.	Swc-4025	28.6	2.4	99	----	1000
26	Hydra.	Swc-4014	16.8	1.4	99		1000
27	Hydra.	Swc-2540	25.5	2.4	99	-	1000
28	Hydra.	Swc-2521	9.9	0.8	99	-	1000
29	Hydra.	Swc-2514	5	0.4	99	-	1000
1	Toray	TM820-370	370	21.9	99.5	93.0	1000
2	Toray	TM820-400	400	24.5	99.5	93.0	1200
3	Toray	TM820A-370	370	21.1	99.5	93.0	1200
4	Toray	TM820A-400	400	22.6	99.5	93.0	1200
5	Toray	TM820C-370	370	22.6	99.5	93.0	1200
6	Toray	TM820C-400	400	24.5	99.5	93.0	1200
7	Toray	TM820E-400	400	28.3	99.5	91.0	100
8	Toray	TM820F-370	370	31.3	99.5	-	100
9	Toray	TM820F-400	400	33.9	99.5	--	1200
10	Toray	TM820H-370	370	21.1	99.5	-	1200
11	Toray	TM820H-400	400	22.6	99.5		1200
12	Toray	TM820K-400	400	21.9	99.5	96.0	1200
13	Toray	TM820L-400	400	46.0	99.5	92.0	1200
14	Toray	TM820L-440	440	50.9	99.5	92.0	1200
15	Toray	TM820R-400	400	32.0	99.5	95.0	1200
16	Toray	TM820R-440	440	35.4	99.5	95.0	1200
17	Toray	TM820S-400	400	33.9	99.5	90.0	1200
18	Toray	TM820S-440	440	37.3	99.5	90.0	1200
19	Toray	TM820V-400	400	33.9	99.5	92.0	1200

20	**Toray**	**TM820V-440**	**440**	**37.3**	**99.5**	**92.0**	**1200**
21	Toray	TM840M-1760	1760	116.1	99.5	95.0	1200
22	Toray	TM840R-1760	1760	141.7	99.5	95.0	1200
23	Toray	TM840V-1760	1760	149.2	99.5	92.0	1200
24	Toray	SUL-G20	380	29.8	99.0	-	600
25	Toray	SUL-G20F	420	36.9	99.5	-	600
26	Toray	SUL-G10	75	6.4	99.0	-	600
1	LG	Sw400ES	400	51.9	99.6	89	1200
2	LG	SW400GRG2	400	28.4	99.75	93	1200
3	LG	Sw400GR	400	28.4	99.7	93	1200
4	LG	Sw400RG2	400	34.1	99.75	93	1200
5	LG	Sw400R	400	34.1	99.7	93	1200
6	LG	Sw400SRG2	400	22.7	99.75	93	1200
7	LG	Sw400SR	400	22.7	99.7	93	1200
8	LG	Sw440R	440	7.4	99.5	-	1200
9	LG	Sw440ES	440	57.0	99.6	89	1200
10	LG	Sw440GRG2	440	31.2	99.5	93	1200
11	LG	Sw440GR	440	31.2	99.7	93	1200
12	LG	Sw440RG2	440	37.5	99.75	93	1200
13	LG	Sw440R	440	37.5	99.7	93	1200
14	LG	Sw440SRG2	440	25.0	99.75	93	1200
15	LG	Sw440SR	440	25.0	99.7	93	1200

Note:

Maximum operating temperature	45°C
PH range	2-11
Maximum feed silt density index SDI	5 SDI
Maximum turbidity	1 NTU
Maximum free chlorine	<0.1 ppm

Table 4. Product specifications of selected seawater desalination modules

Element model	Filmtec™ SW30HR-380[a]	Toray Standard SWRO TM820C-400[b]	Nitto/Hydranautics SWC4-LD[c]	Koch Membrane Systems/Fluid Systems® TFC®-SW 400-34[d]
Active area (m^2)	35	37	37.1	37.2
Permeate flow rate (m^3/day)	23	24.6	24.6	27.2
Stabilized salt rejection (%)	99.7	99.75	99.8	99.75
Diameter (inch)	8	8	8	8
Applied pressure (bar)	55	55	55	55
Membrane type	Polyamide thin-film composite	Cross-linked, fully aromatic polyamide composite	Composite polyamide	TFC polyamide

Note:

A: Test conditions: 32,000 ppm NaCl, 55 bar, 25 °C, 8% recovery, pH 8.

B: Test conditions: 32,000 ppm NaCl, 5.52 MPa, 25 °C, 15% recovery, pH 7.

C: Test conditions: 32,000 ppm NaCl, 5.5 MPa, 25 °C, 10% recovery, pH 6.5–7.

D: conditions: 32,800 ppm NaCl, 5.52 MPa, 25 °C, 7% recovery, pH 7.5.

Table 5. Product specifications of selected brackish water desalination modules

Element model	Dow™ Filmtec™ BW30-365[a]	Toray Standard BWRO TM720-370[b]	Nitto/Hydranautics ESPA1[c]	Koch Membrane Systems/Fluid Systems® TFC®-FR 400-34[d]
Active area (m^2)	34	34	37.1	37.2
Permeate flow rate (m^3/day)	36	36	45.4	41.6
Stabilized salt rejection (%)	99.5	99.7	99.3	99.55
Diameter (inch)	8	8	8	8
Membrane type	Polyamide thin-film composite	Cross-linked, fully aromatic polyamide composite	Composite polyamide	TFC polyamide

Note:

A: Test conditions: 2000 ppm NaCl, 15.3 bar, 25 °C, 15% recovery, pH 8.

B: Test conditions: 2000 ppm NaCl, 1.55 MPa, 25 °C, 15% recovery, pH 7.

C: Test conditions: 1500 ppm NaCl, 1.05 MPa, 25 °C, 15% recovery, pH 6.5–7

D : Test conditions: 2000 ppm NaCl, 1.55 MPa, 25 °C, 15% recovery, pH 7.5.