Advanced Water Treatment
(DESALINATION)

EENV 5330 معالجة مياه متقدمة

PART 3

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❖ Membrane Desalination

- ❑ Overview
- ❑ Electordialysis (ED)
- ❑ Historical information
- ❑ Technology illustration
- ❑ Examples

1.5.1 Overview

- Membrane desalination:

is the process of separating minerals from the source water using semipermeable membranes.

- Two general types of technologies currently used for membrane desalination are:

1. Electrodialysis (ED)
2. RO.

1.5.1 Overview

- In ED systems, salts are separated from the source water through the application of direct current.

- RO is a process in which the product water (permeate) is separated from the salts contained in the source water by pressure-driven transport through a semipermeable membrane.

1.5.2 Electrodialysis (ED)

- This current drives the mineral ions and other ions with strong electric charge that are contained in the source water through ion-selective membranes to a pair of electrodes of opposite charges (Fig. 1.5).

- As ions accumulate on the surface of the electrodes, they cause fouling over time and have to be cleaned frequently in order to maintain a steady-state ED process.

- A practical solution to this challenge is to reverse the polarity of the oppositely charged electrodes periodically (typically two to four times per hour) in order to avoid frequent electrode cleaning.

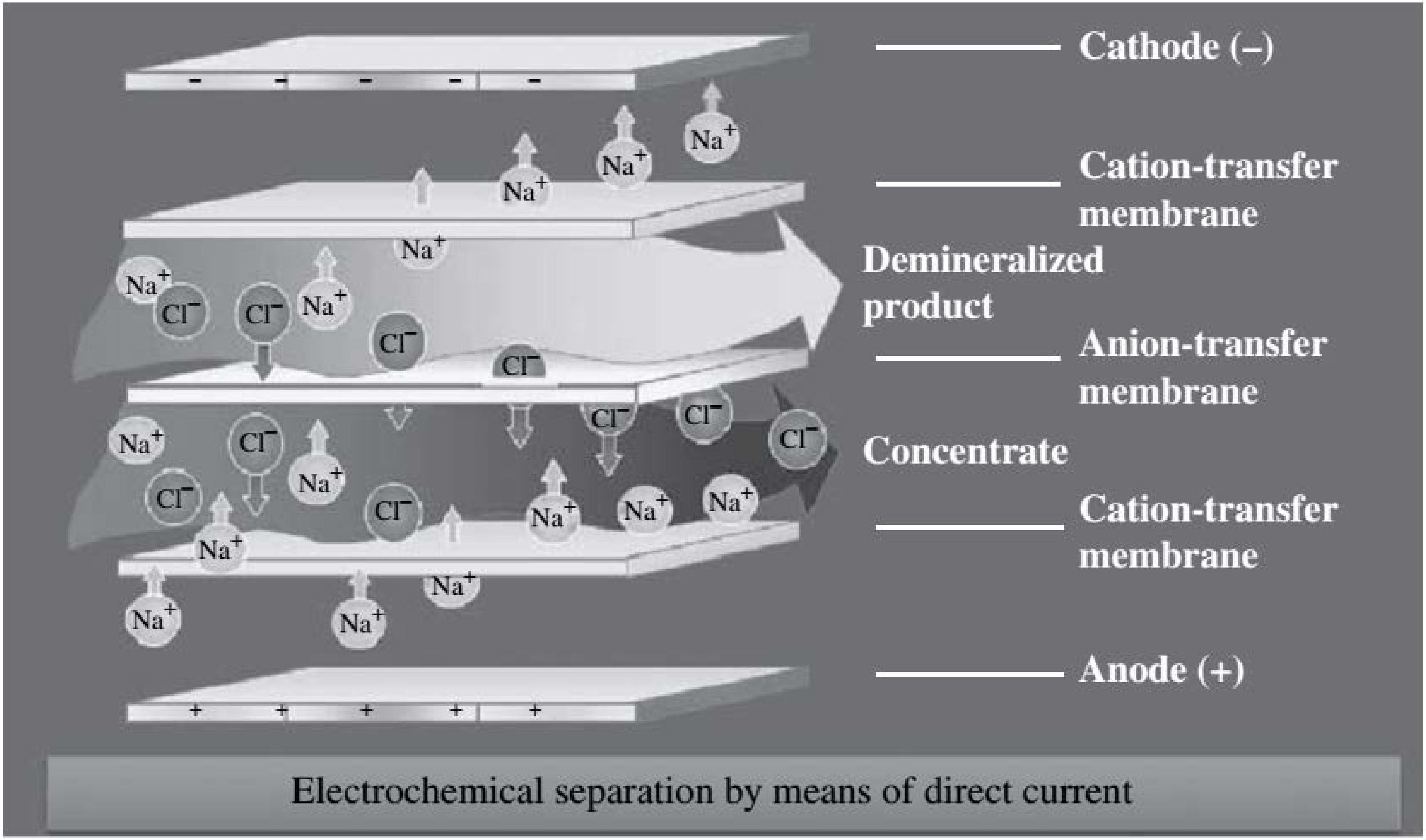
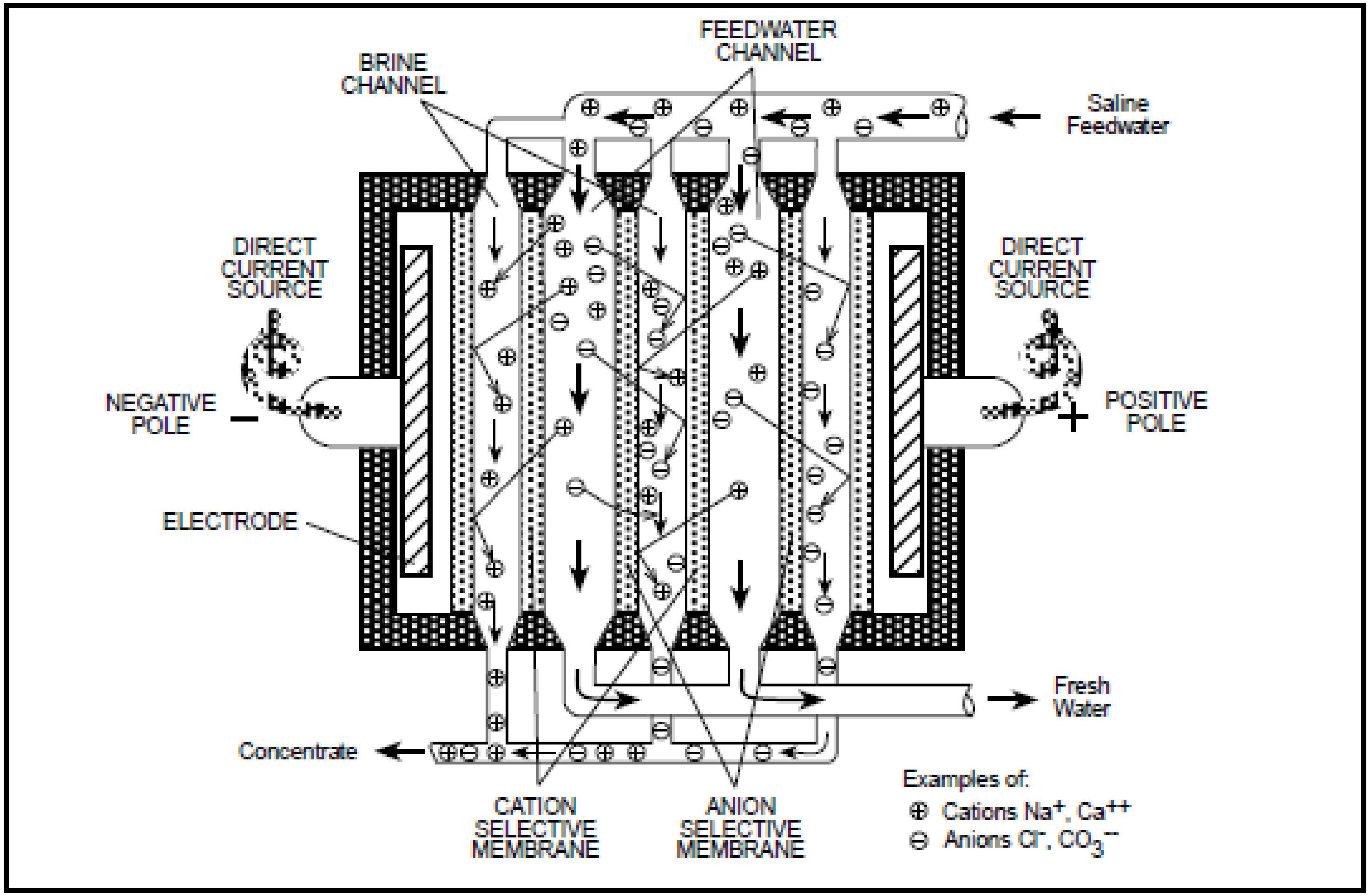


Figure1.5 Schematic of the electrodialysis process.



Movement of ions in the electrodialysis process *USAID*

http://www.water.ca.gov/pubs/surfacewater/abcs_of_desalting/abcs_of_desalting.pdf

…1.5.2 Electrodialysis (ED)

- An ED process that includes periodic change of the polarity of the system's electrodes is referred to as an electrodialysis reversal(EDR) process.

- ED systems consist of a large number (300 to 600 pairs) of cation and anion exchange membranes separated by dilute flow dividers (spacers) to keep them from sticking together and to convey the desalinated flow through and out of the membranes.

- The membranes used for ED are different from those applied for RO desalination—they have a porous structure similar to that of microfiltration and ultrafiltration membranes.

…1.5.2 Electrodialysis (ED)

- RO membranes do not have physical pores. ED membranes are more resistant to chlorine and fouling and are significantly thicker than RO membranes.

- A single set of EDR stacks can only remove approximately 50 percent of salts. As a result, multiple EDR stacks connected in series are often used to meet more stringent product water TDS targets.

- The energy needed for ED desalination is proportional to the amount of salt removed from the source water.

- TDS concentration and source water quality determine to a great extent which of the two membrane separation technologies (RO or ED) is more suitable and cost effective for a given application.

1.5.2 Electrodialysis (ED)

- ED is cost-competitive when TDS concentration is lower than 3000 mg/L.

- The TDS removal efficiency of ED desalination systems is not affected by nonionized compounds or objects with a weak ion charge (i.e., solids particles, organics, and microorganisms). Therefore, ED membrane desalination processes can treat source waters of higher turbidity and biofouling and scaling potential than can RO systems.

- However, the TDS removal efficiency of ED systems is typically lower than that of RO systems (15.0 to 90.0 percent versus 99.0 to 99.8 percent), which is one of the key reasons why they have found practical use mainly for brackish water desalination

1.5.2 Electrodialysis (ED)

- In general, EDR systems can only effectively remove particles that have a strong electric charge, such as mono- and bivalent salt ions, silica, nitrates, and radium.

- EDR systems have a very low removal efficiency with regard to low-charged compounds and particles – i.e., organics and pathogens.

- Table 1.2 provides a comparison of the removal efficiencies of distillation, ED, and RO systems for key source water quality compounds.

1.5.2 Electrodialysis (ED)

- Table 1.2 shows the ED only partially removes nutrients from the source water.
  - This fact explains why EDR is often considered more attractive than RO or thermal desalination (which remove practically all minerals from the source water) if the planned use of the desalinated water is for agricultural purposes—i.e., generating fresh or reclaimed water for irrigation of agricultural crops.

- Barcelona desalination facility in Spain: (200,000 m^3/day)
  - EDR was preferred to BWRO because the brackish surface water source for this plant – the Llobregat River contains very high levels of silica, which would limit recovery from a BWRO plant to only 65%; while the EDR system can achieve 90% recovery.
  - Also, the river was found to have very high organic content, which was projected to cause heavy fouling and operational constraints on a BWRO plant of this size.

Contaminant	Distillation (%)	ED/EDR (%)	RO (%)
TDS	>99.9	50–90	90–99.5
Pesticides, Organics/VOCs	50–90	<5	5–50
Pathogens	>99	<5	>99.99
TOC	>95	<20	95–98
Radiological	>99	50–90	90–99
Nitrate	>99	60–69	90–94
Calcium	>99	45–50	95–97
Magnesium	>99	55–62	95–97
Bicarbonate	>99	45–47	95–97
Potassium	>99	55–58	90–92

Table1.2 Contaminant Removal by Alternative Desalination Technologies

1.5.2 Electrodialysis (ED)

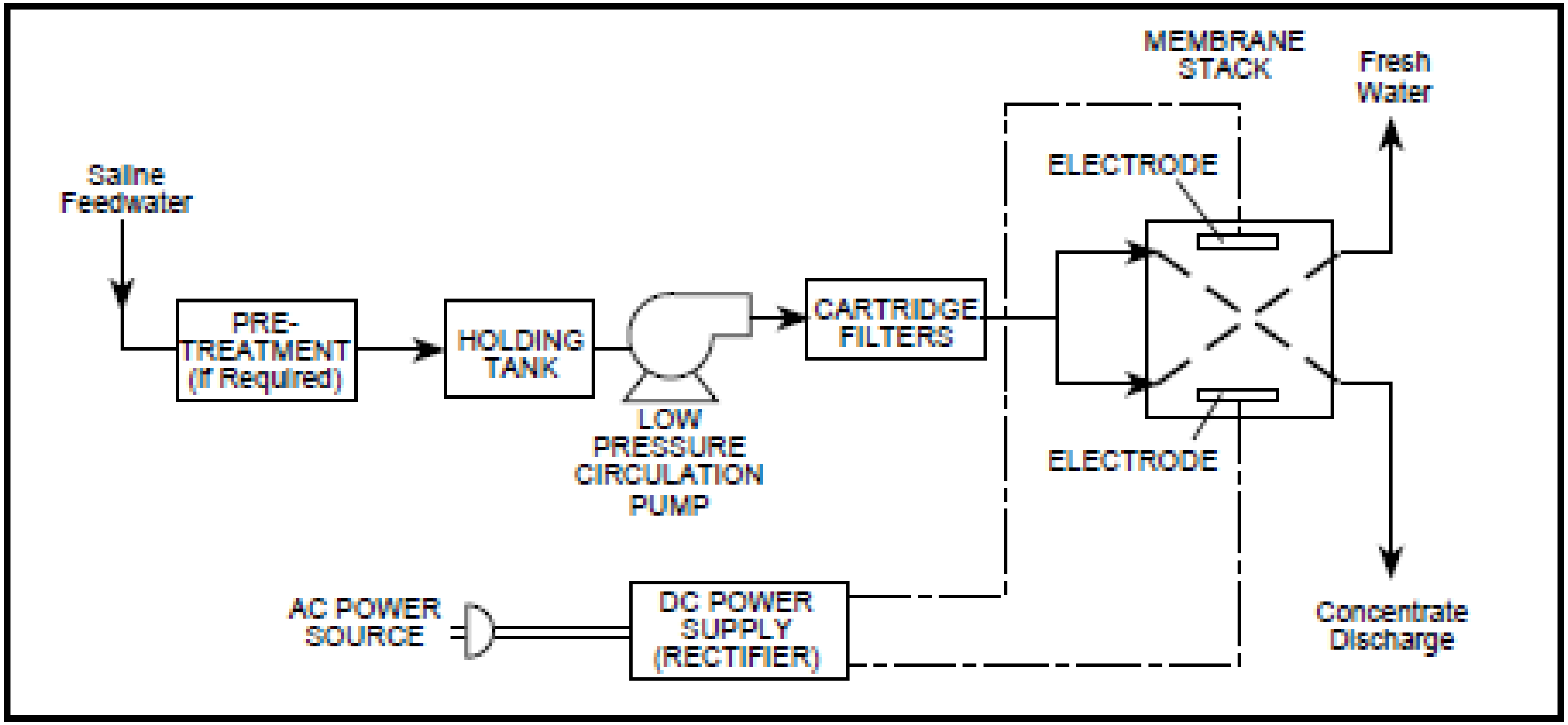
- EDR systems are not as commonly used as RO systems for BWRO desalination and are never applied for seawater reverse osmosis(SWRO) desalination.

- It should be pointed out:

  – however, that salinity is not the only criterion for evaluating the cost competitiveness of EDR and BWRO systems.

  – Often, other compounds such as silica play a key role in the decision making process.

1.5.2 Electrodialysis (ED)



Components of an electrodialysis plant *USAID*

1.5.3 Reverse Osmosis

- **Reverse osmosis (RO):**

  is a process where water containing inorganic salts (minerals), suspended solids, soluble and insoluble organics, aquatic microorganisms, and dissolved gases (collectively called source water constituents or contaminants) is forced under pressure through a semipermeable membrane.

- Semipermeable refers to a membrane that selectively allows water to pass through it at much higher rate than the transfer rate of any constituents contained in the water.

1.5.3 Reverse Osmosis

- Depending on their size and electric charge, most water constituents are retained (rejected) on the feed side of the RO membrane while the purified water (permeate) passes through the membrane.

- Figure 1.6 illustrates the sizes and types of solids removed by RO membranes as compared to other commonly used filtration technologies.

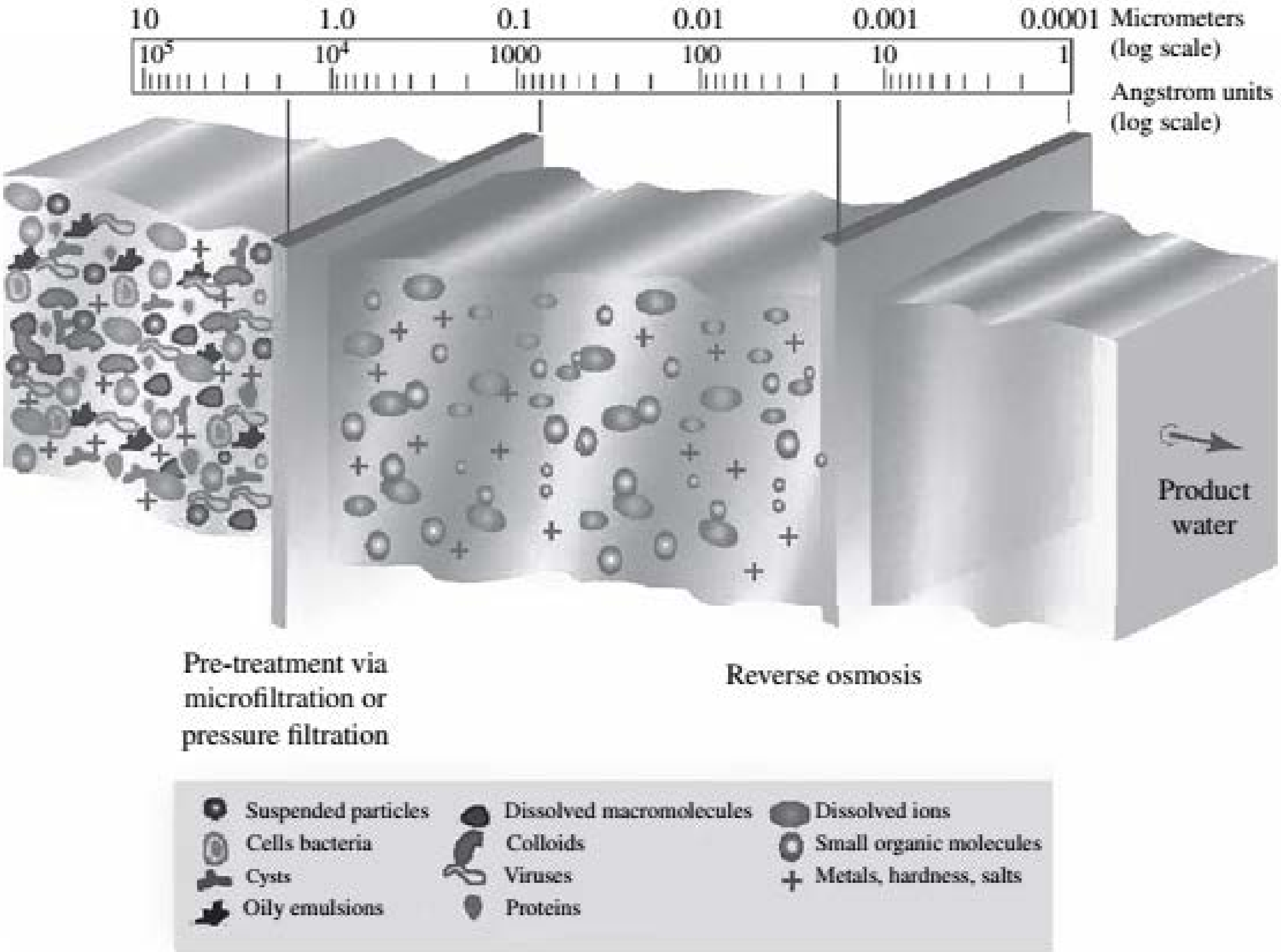


Figure1.6 Contaminant removal by RO membranes.

1.5.3 Reverse Osmosis

- RO membranes can reject particulate and dissolved solids of practically any size.
- However, they do not reject well gases, because of their small molecular size.
- Usually RO membranes remove over 90 percent of compounds of 200 daltons (Da) or more.
- One Da is equal to 1.666054 $\times 10^{-24}$ g.

1.5.3 Reverse Osmosis

- In terms of physical size, RO membranes can reject well solids larger than 1 Angstrom.
- This means that they can remove practically all suspended solids, protozoa (i.e., Giardia and Cryptosporidium), bacteria, viruses, and other human pathogens contained in the source water.
- While RO membranes can retain both particulate and dissolved solids, they are designed to primarily reject soluble compounds (mineral ions).

1.5.3 Reverse Osmosis

- The structure and configuration of RO membranes is such that they cannot store and remove from their surface large amounts of suspended solids.

- If left in the source water, the solid particulates would accumulate and quickly plug (foul) the surface of the RO membranes, not allowing the membranes to maintain a continuous steady-state desalination process.

- Therefore, the suspended solids (particulates) contained in source water used for desalination have to be removed before they reach the RO membranes.

1.5.3 Reverse Osmosis

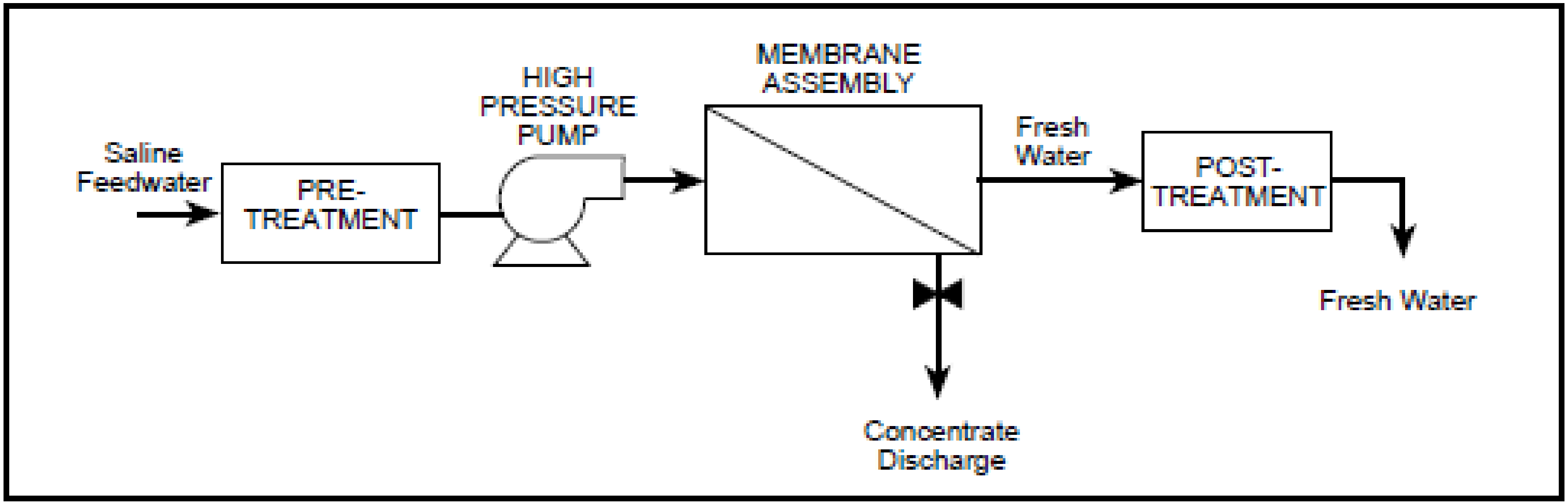
- Over the past 20 years, RO membrane separation has evolved more rapidly than any other desalination technology.
  - Why? Mainly because of its competitive energy consumption and water production costs (table 1.3)

- BWRO desalination yields the lowest overall production costs of all the desalination technologies.

- The latest MED projects built over the last 5 years have been completed at costs comparable to those of similarly sized SWRO plants.

- For the majority of medium and large projects, however, SWRO desalination usually is more cost competitive than thermal desalination technologies.

1.5.3 Reverse Osmosis



Basic components of a reverse osmosis plant *USAID*

1.5.3 Reverse Osmosis

Energy Type	MED	MSF	VC	BWRO	SWRO
Steam pressure, ata	0.2–0.4	2.5–3.5	Not needed	Not needed	Not needed
Electric energy equivalent, kWh/m³ (kWh/1000 gal)	4.5–6.0 (17.0–22.7)	9.5–11.0 (35.9–41.6)	NA	NA	NA
Electricity consumption, kWh/m³ (kWh/1000 gal)	1.2–1.8 (4.5–6.8)	3.2–4.0 (12.1–15.1)	8.0–12.0 (30.3–45.4)	0.3–2.8 (1.1–10.6)	2.5–4.0 (9.5–15.1)
Total energy use, kWh/m³ (kWh/1000 gal)	5.7–7.8 (21.5–29.5)	12.7–15.0 (48.0–56.7)	8.0–12.0 (30.3–45.4)	0.3–2.8 (1.1–10.6)	2.5–4.0 (9.5–15.1)
Water production costs, US$ per cubic meter (US$ per 1000 gal)	0.7–3.5 (2.6–13.2)	0.9–4.0 (3.4–15.1)	1.0–3.5 (3.8–13.2)	0.2–1.8 (0.8–6.8)	0.5–3.0 (1.9–11.3)

Note: NA = Not applicable.

Table1.3 Energy and Water Production Costs for Alternative Desalination Technologies