Membrane Desalination Technology

Mohamed Shaaban

B.Sc. Chemistry – Cairo Univ.
M.Sc Chemistry – Cairo Univ.
Phd Chemistry Candidate – Cairo Univ.
AUC certificate of Professional Engineering Program ESS

Mob. : +201030663807 -+201146139692
E-mail : Mo7amed.sci@gmail.com

Desalination Technologies

Terminology

Introduction

Different desalination technologies

Reverse Osmosis in detail

Reverse Osmosis unit main component

Reverse Osmosis Classification

Reverse Osmosis Manufacturer differences

Terminology

TS …. ……………………..Total solids
TDS …. ……………………Total Dissolved Solids
TSS ………………………..Total Suspended Solids
Surface water ………… Water we can see it's flow such as rivers -lakes
Sub-surface water …. Water founded on small depth 5-15m
Ground water ……….. Water under ground on large depth such as well & springs
Well water …………….. Underground water that need hydraulic mechanical force to bring it to the surface

Spring water …. Underground water that flow under natural ground pressure to the surface without any mechanical force

R.O ………………… Reverse Osmosis
N.F …………………. Nano Filtration
U.F …………………. Ultra Filtration
M.F ………………… Micro Filtration
M.S.F ……………… Multi Stage Flash
M.E.D ……………. Multi Effect Distillation
E.D_…………………. Electro-Dialysis
EDI …………………. Electro-Deionization
BWRO ……………. Brackish water reverse osmosis
SWRO ……………. Sea water reverse osmosis

Desalination ………… Separation process of salts from salty water to reduce the TDS which also called (Desalting process)

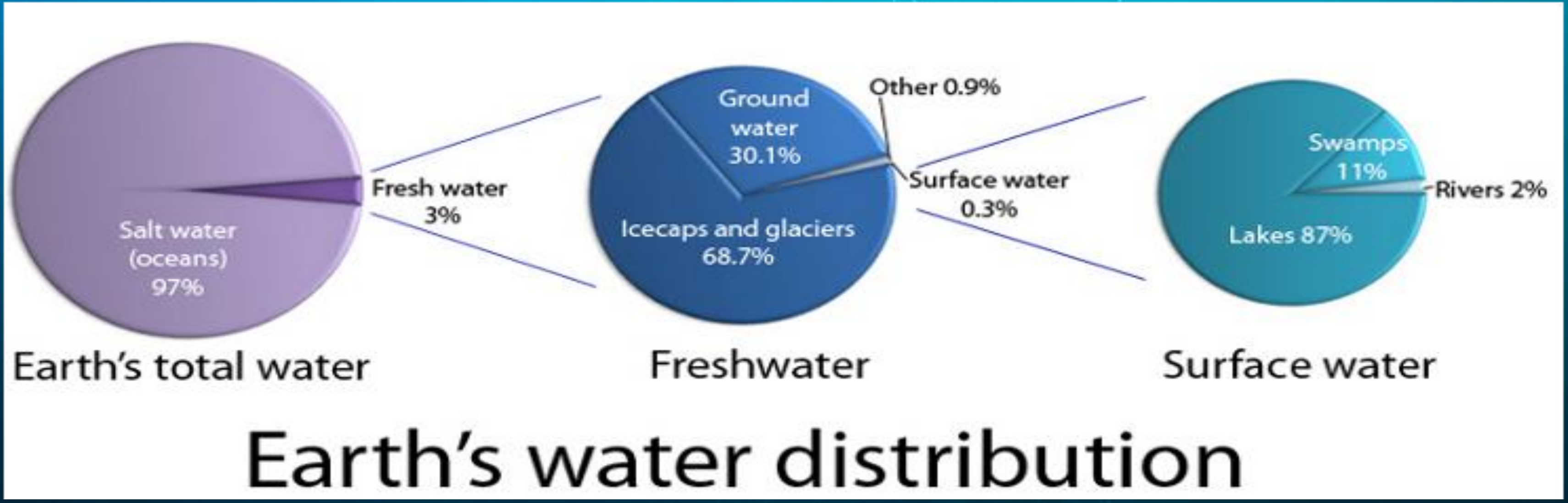
Distillation …………… Desalination technique which use steam & heat in production of purified water

Demineralization …. Separation process to approaching complete removal of the TDS and mainly refer to ion exchange method

Introduction

Desalination :

it is a separation process used to reduce the dissolved salt content of saline water to acceptable levels

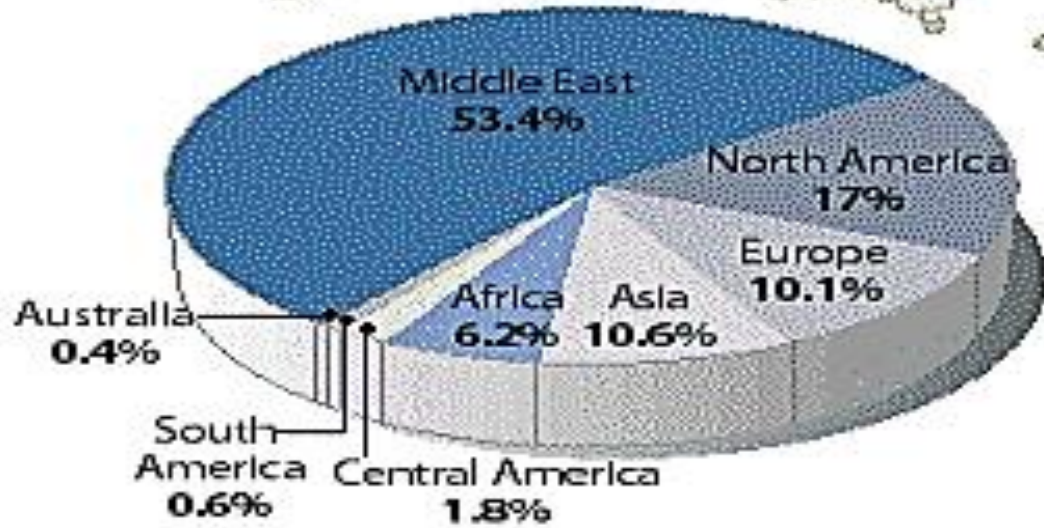


MAJOR DESALINATION PLANTS WORLDWIDE

The United States has 2 major municipal seawater-desalination plants — 1 under construction in Tampa and another inactive plant in Santa Barbara, Calif. Other countries with 1 or more major plants are marked with red dots.

Capacity by region

A breakdown of where desalination technology is used on seawater, salty underground water and in other water treatments around the world.

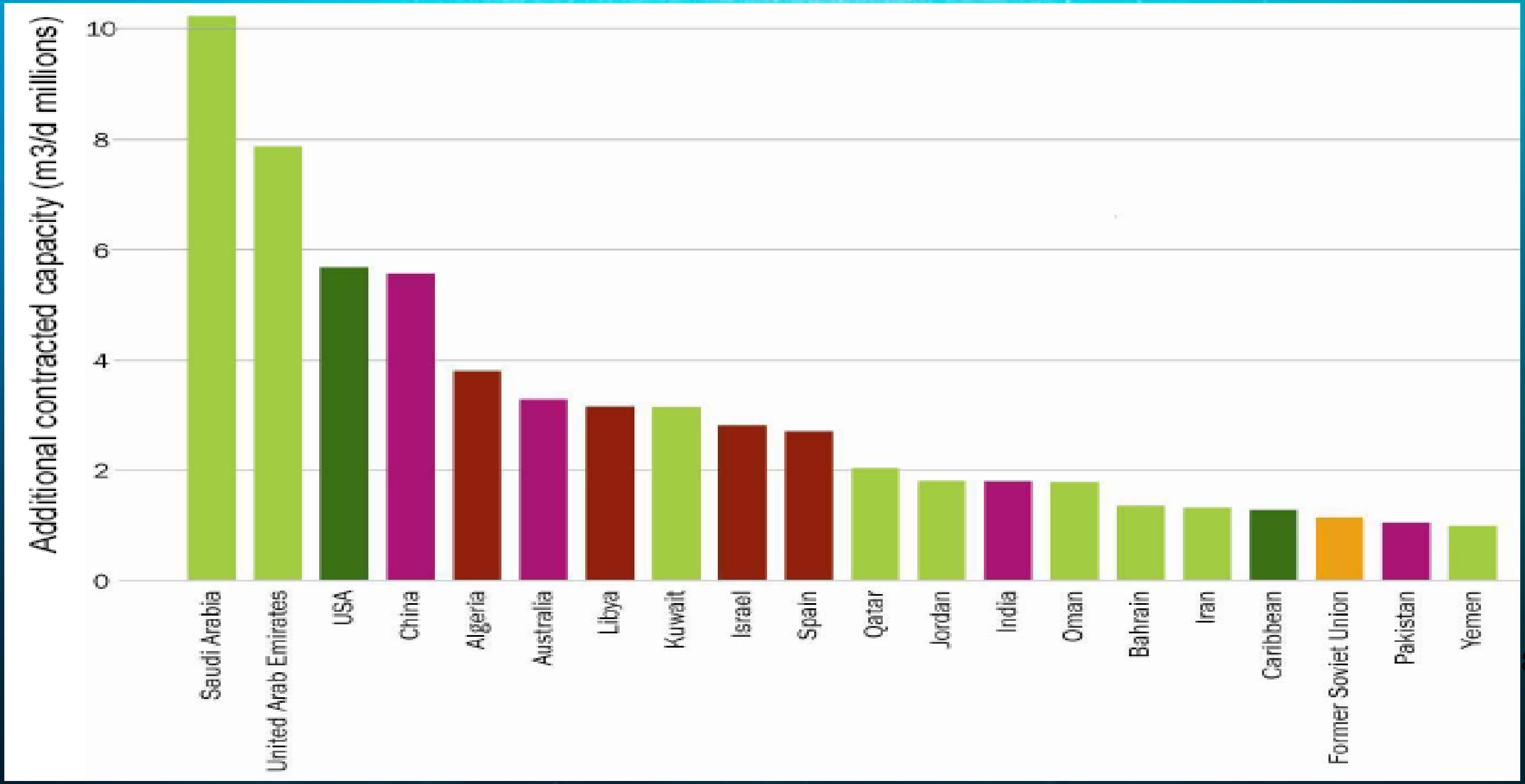


SOURCES: Engineering News-Record; Aqua Resources International Corp.; International Desalination Association

SCOTT HIESTAND/ORLANDO SENTINEL

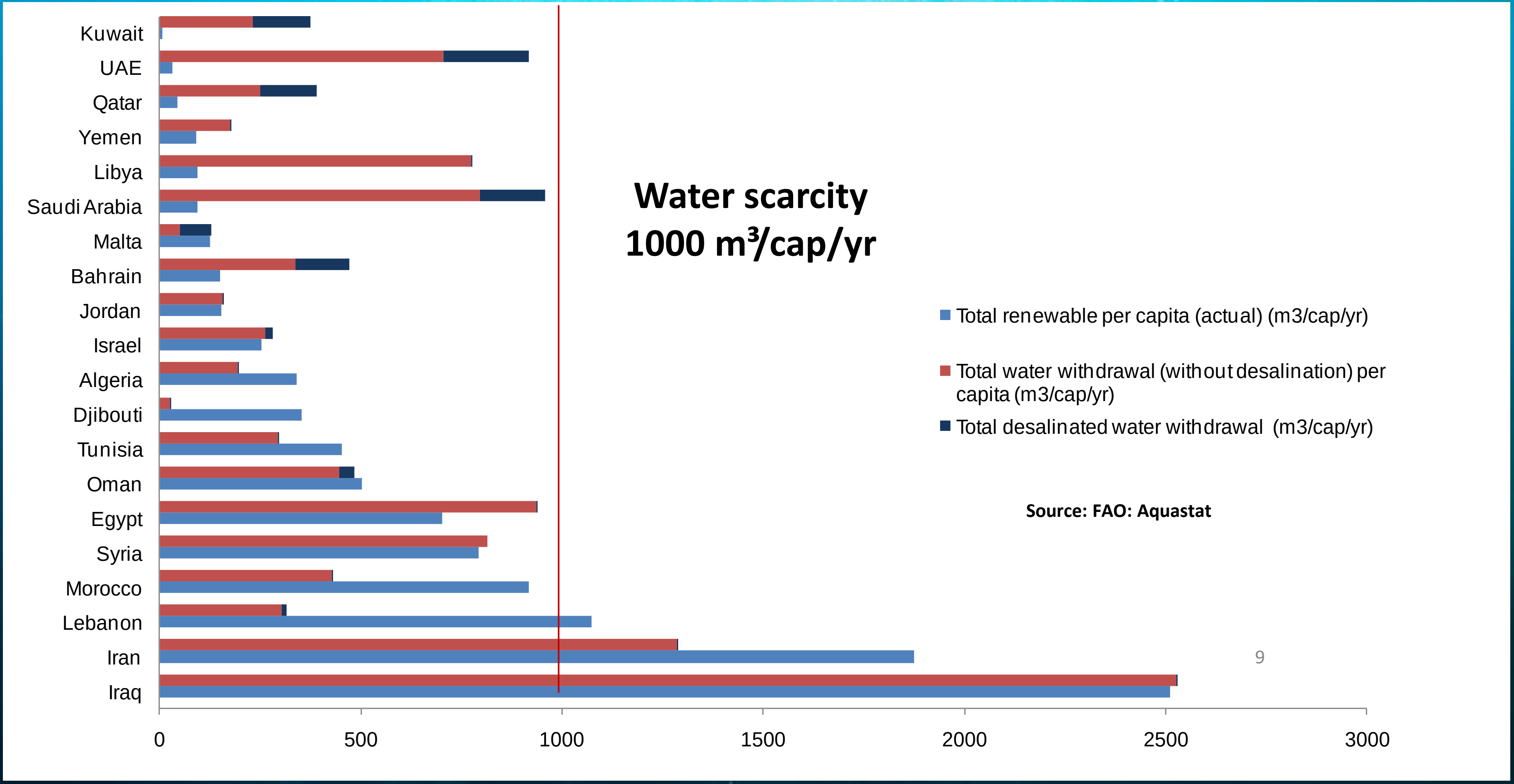
Desalination Market

Additional Desalination Capacity (2008-2016), 12 MENA countries in TOP 20 !



Desalinated Water-Share in MENA

Water Resources and Water Withdrawals



Water types According salinity

Fresh water ……. ……….. … .. TDS < 500 ppm
Brackish water .. ……….. …….. TDS < 30,000 ppm
Sea water ……….. ………   … TDS > 30,000 ppm

According to matching between the two columns we select the suitable water treatment treatment technique

Water Resources

- Surface water (rivers-lakes..)
- Sub-surface water
- Rain water
- Ground water (well-springs)
- Sea water

Target water usage

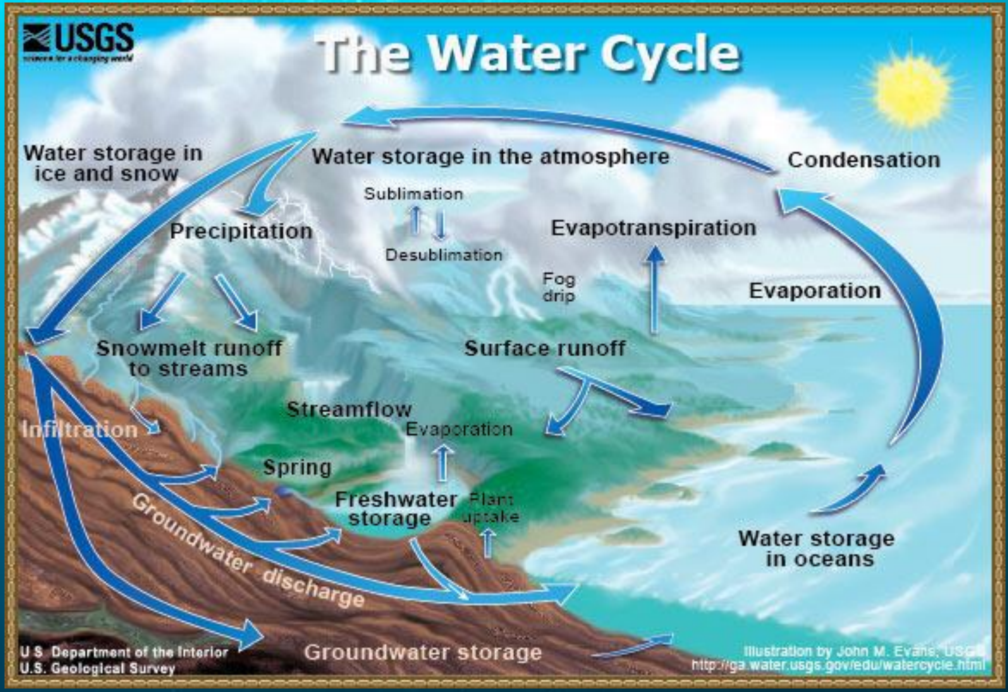
- Agriculture & irrigation
- Industrial use
- Drinking
- Medical use

Different desalination technologies

Natural Desalination Water Cycle!

Major Stages

1. Evaporation
2. Condensation
3. Precipitation
4. Collection

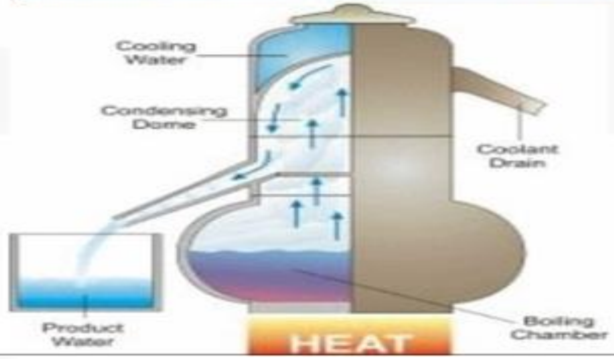


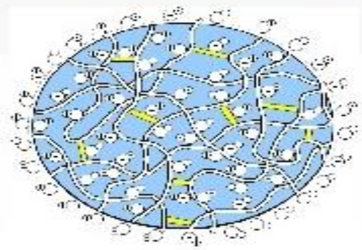
Distillation | Desalination | Membrane

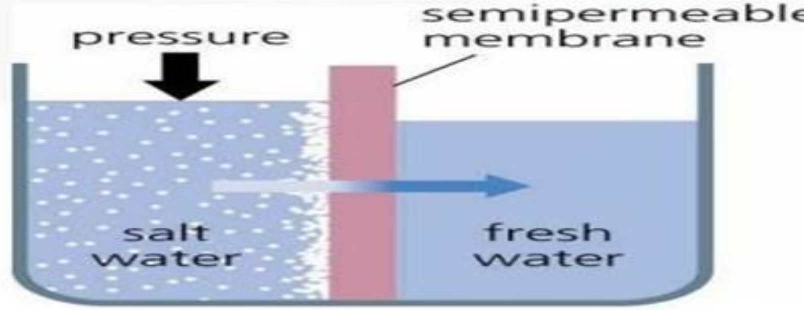
Distillation
- Multi Stage Flash MSF
- Multi Effect Distillation MED

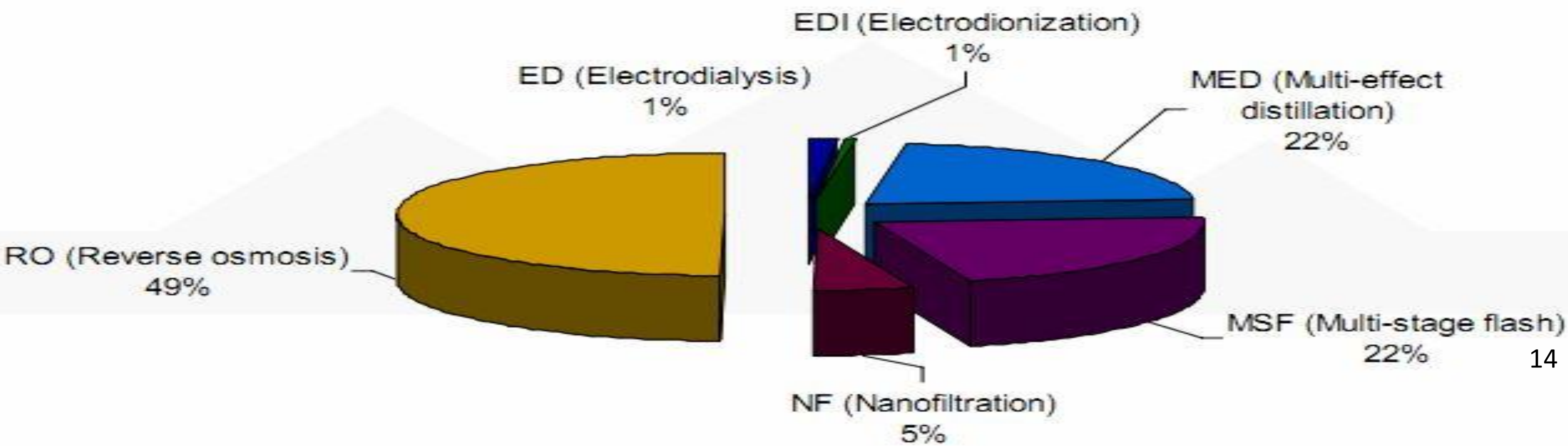
Ion Exchange

Membrane
- Reverse Osmosis RO
- Electrodeionization EDI
- Electrodialysis ED



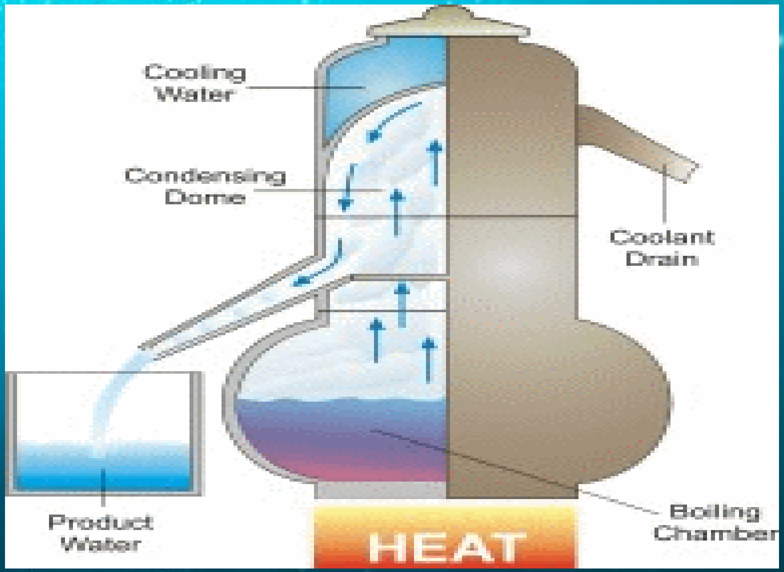






Thermal Desalination Processes (Distillation)

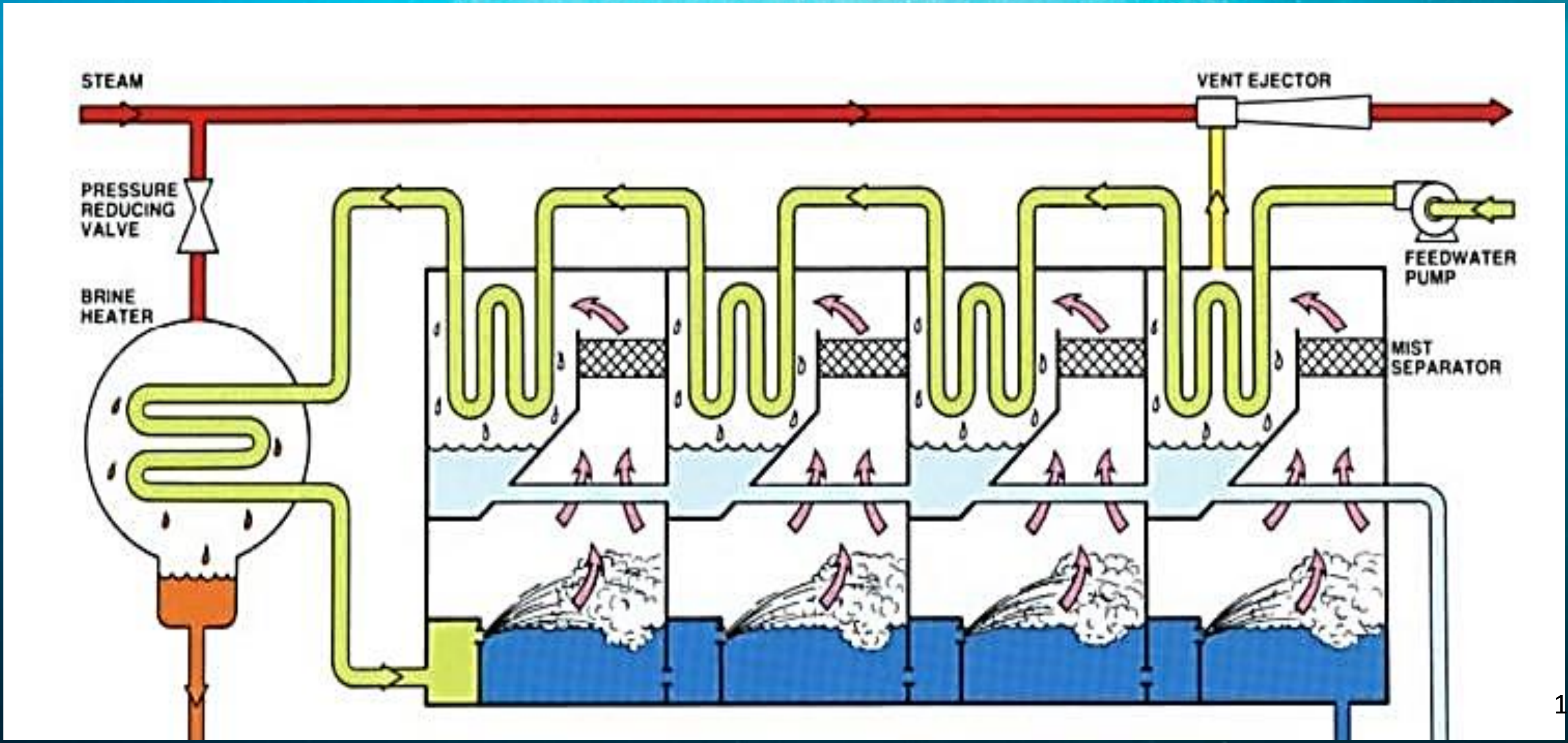
- Similar to the Earth's natural water cycle
- Water is heated, evaporated and collected
- Produces clean water and brine



- Types of Thermal Desalination :

1. Single Stage Distillation
2. Multi Effect Distillation (MED)
3. Multi Stage Flash (MSF)

MSF Technology



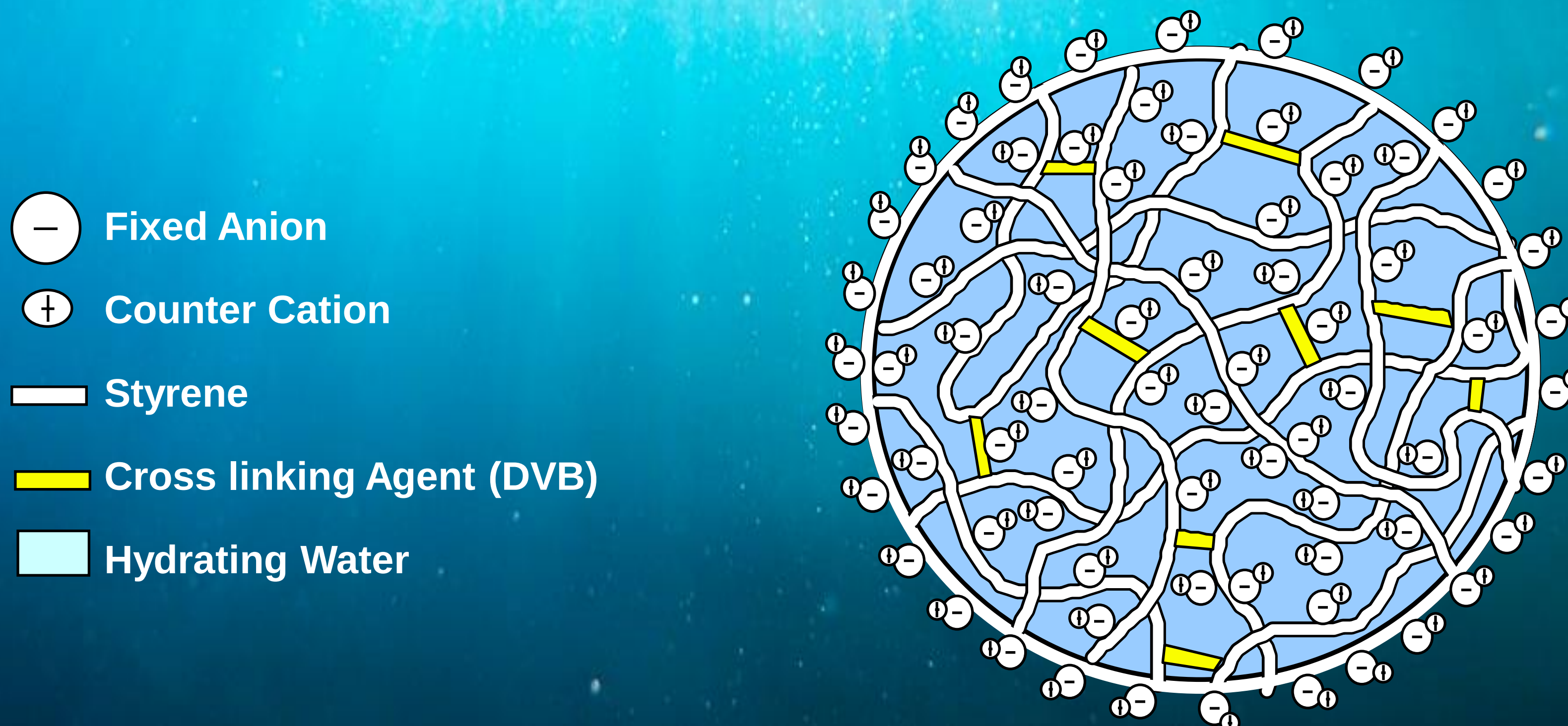
MSF Desalination Plant Hidd in the Kingdom of Bahrain

Ion Exchange

- Ion exchange resins are synthetic polymers that are capable of exchanging exchanging particular ions within the polymer with ions in the solution that is that is passed through them.

- This synthetic resins are used mainly in water treatment and the aim is usually either to soften the water or demineralized it.

Ion-Exchange Resin Bead model



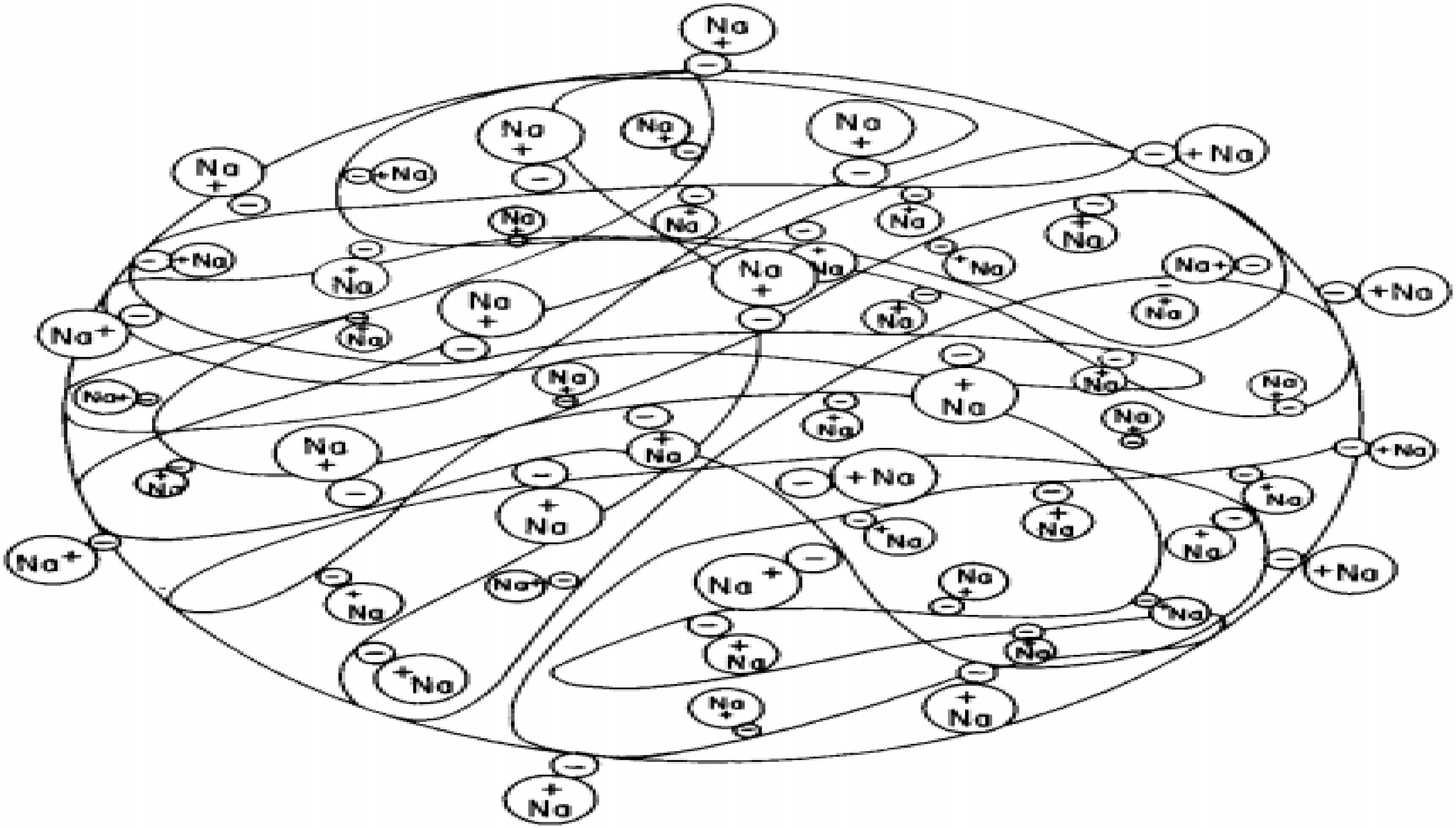
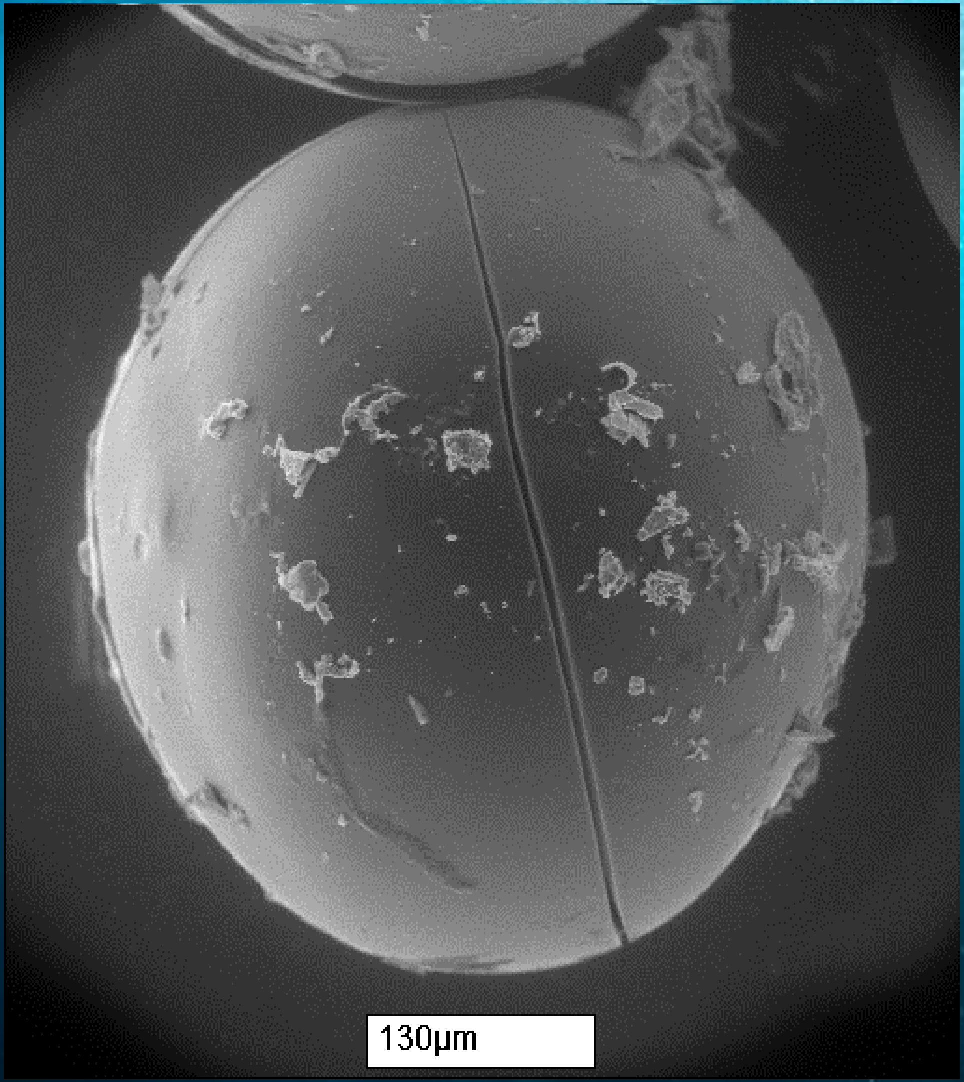


FIG. 12.1 Model of a cation exchanger, showing negatively charged exchange sites on the skeleton holding sodium ions like grapes on a vine.

SEM of Ion-Exchange Resin Bead



Bead diameter:
300 to 1200 µm
(0.3 to 1.2 mm)

Beads pores:
1 to 100 nm
(0.001 to 0.1 µm)

Bead dry weight
40 to 60%

- **softener resin**

the resin containing Na^+ cations can binds to Ca^{++} and Mg^{++} more strongly than Na^+. As the water passes through the resin the resin take up Ca^{++} and Mg^{++} and release Na^+ making for softer water

- **De-ionizing resins:**

If the water needs to have the mineral content entirely removed it is passed through a cationic resin containing H^+ (which replace all cations) and then though a anionic resin containing OH^- (which replace all anions) , the H^+ and OH^- are then react together to give more water.

Softening Process

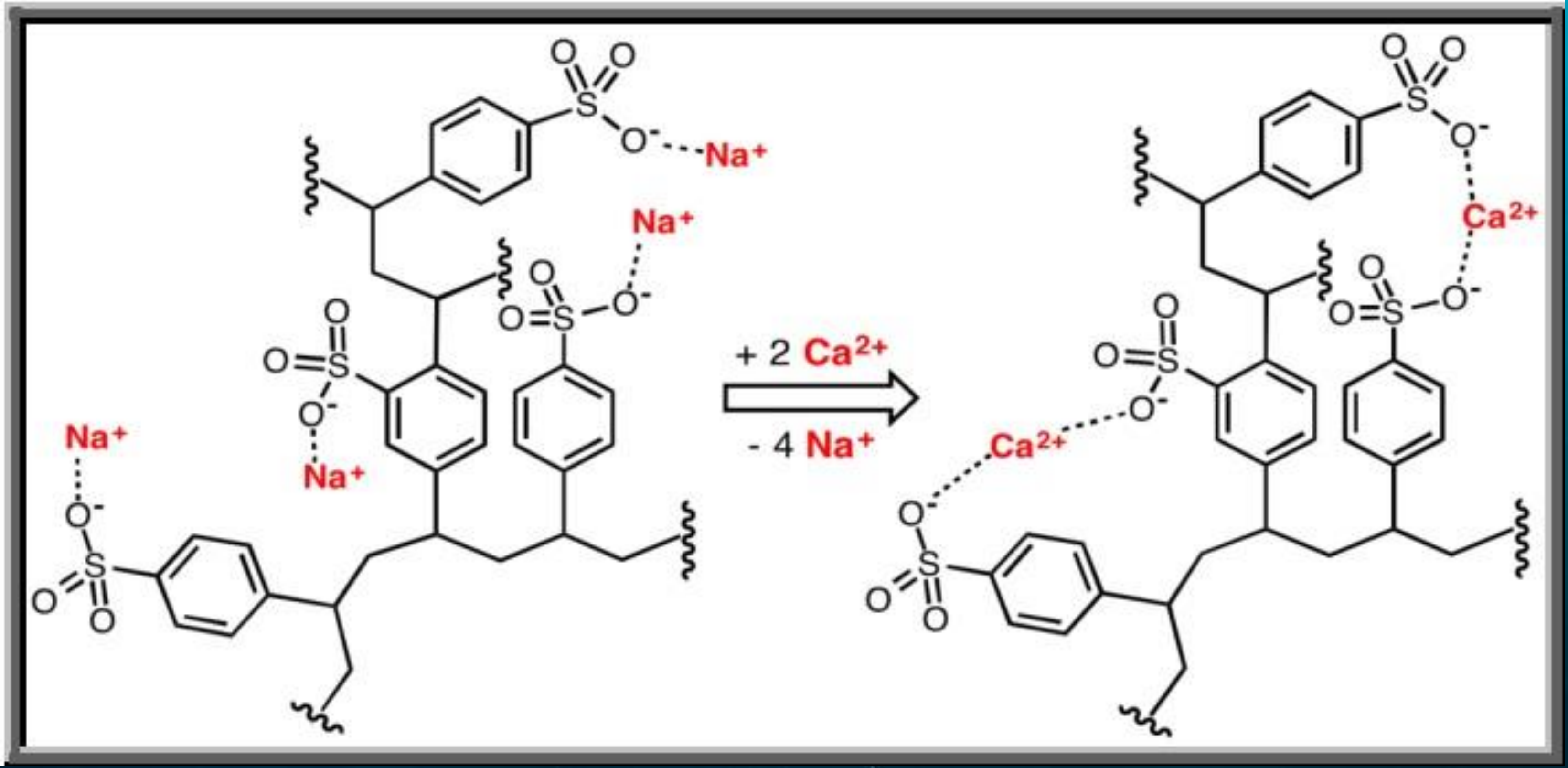


TABLE 12.1 General Order of Ion Selectivity in Water below 1000 mg/L TDS

Cations	Anions
Fe^{3+}	CrO_4^{2-}*
Al^{3+}	SO_4^{2-}*
Pb^{2+}	SO_3^{2-}*
Ba^{2+}	HPO_4^{2-}*
Sr^{2+}	CNS^-
Cd^{2+}	CNO^-
Zn^{2+}	NO_3^-
Cu^{2+}	NO_2^-
Fe^{2+}	Br^-
Mn^{2+}	Cl^-
Ca^{2+}	CN^-
Mg^{2+}	HCO_3^-
K^+	$HSiO_3^-$
NH_4^+	OH^-
Na^+	F^-
H^+	
Li^+	

* These ions may be displaced as they are protonated at low pH to: $HCrO_4^-$, HSO_3^-, $H_2PO_4^-$

Notes: Changes in position may occur between products of different manufacture or having slightly different skeletons or exchange groups. In general, selectivity is affected by:

(*a*) Ionic valence: $3 > 2 > 1$.

(*b*) Atomic number: Ba > Sr > Ca > Mg in Group IIA.

(*c*) Hydrated ionic radius: the larger the radius, the lower the selectivity and exchange capacity.

Example for Cationic Resin:

acidic Sulphonated polystyrene cation exchange resin
Functional group is SO_3^- H^+/Na^+

Example for Anionic Resin :

basic quaternary ammonium anion exchange resin
Functional group is $-CH_2NR_3^+$ OH^-/Cl^-

Table 2 — *Types of ion exchange processes*

Typical Minerals in Influent		Types of Exchanger		Minerals Converted to
(A) $Ca(HCO_3)_2$ $CaSO_4$	→ →	Cation $\boxed{Na+}$ Exchanger	→ →	$NaHCO_3$ Na_2SO_4
(B) $Ca(HCO_3)_2$ $CaSO_4$	→ →	Cation $\boxed{H+}$ Exchanger	→ →	H_2CO_3 H_2SO_4
(C) $Ca(HCO_3)_2$	→	Cation $\boxed{H+}$ Exchanger (Weak Acid)	→	H_2CO_3
(D) Na_2SO_4 $NaHCO_3$	→ →	Anion $\boxed{Cl-}$ Exchanger	→ →	NaCl NaCl
(E) H_2CO_3 H_2SO_4	→ →	Anion $\boxed{OH-}$ Exchanger	→ →	H_2O H_2O

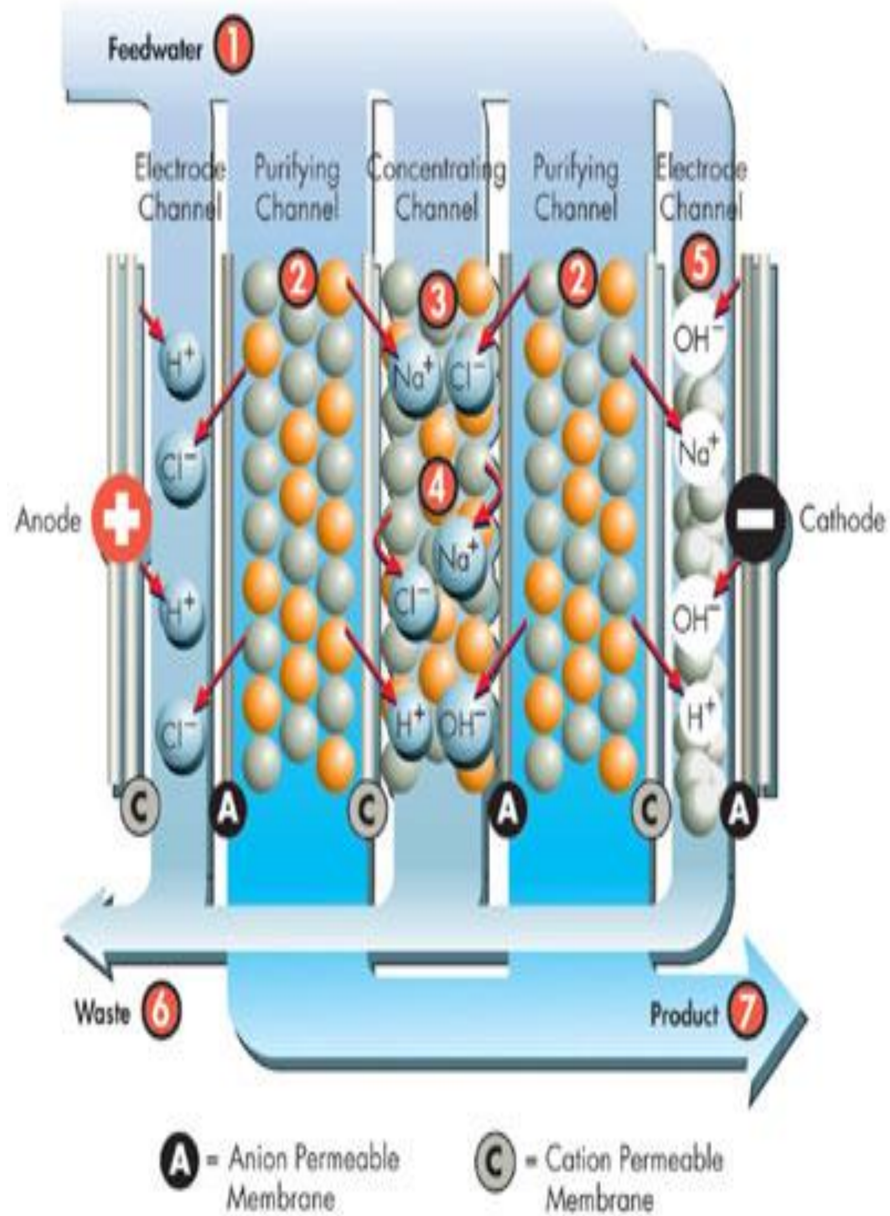
Electro-Deionization

(EDI – CDI)

-Mainly it is physiochemical process which combines three technologies (semi-permeable membrane separation technology , ion exchange media and electrical separation processes) to provide high efficiency demineralization process .

- The electrical current is used to continuously regenerate the resin eliminate the periodical need to regeneration and avoid chemical hazardous.

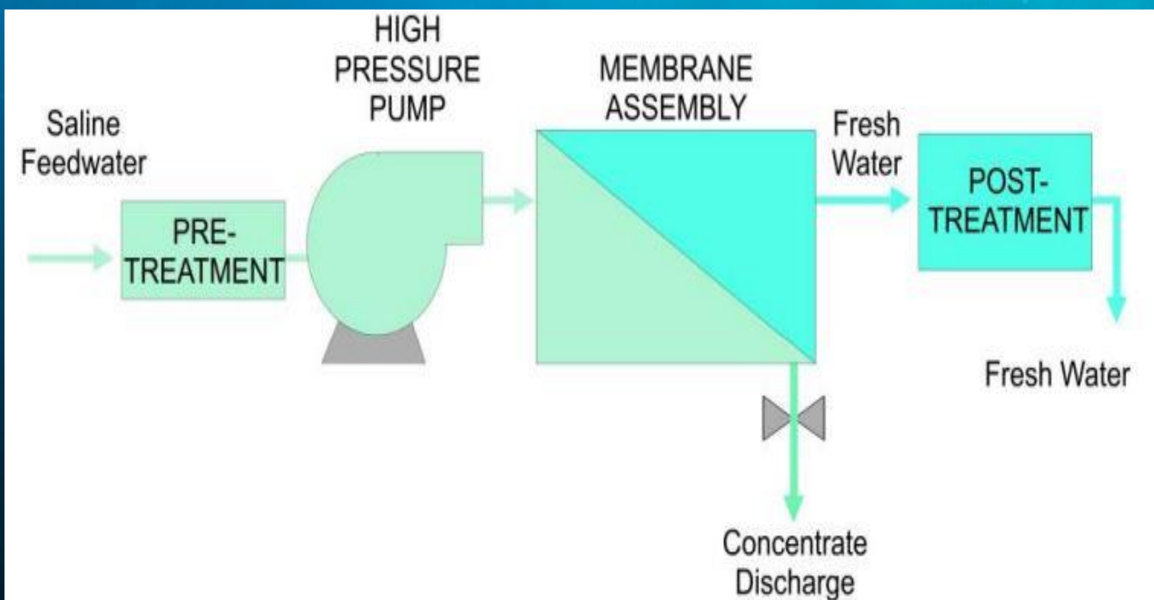

FEDI


Feedwater 1
Electrode Channel
Purifying Channel
Concentrating Channel
Purifying Channel
Electrode Channel
2
3
2
5
H^+
Cl^-
Na^+
Cl^-
OH^-
Na^+
4
Anode
Cathode
Na^+
H^+
Cl^-
OH^-
Cl^-
H^+
OH^-
H^+
C
A
C
A
C
A
Waste 6
Product 7
A = Anion Permeable Membrane
C = Cation Permeable Membrane

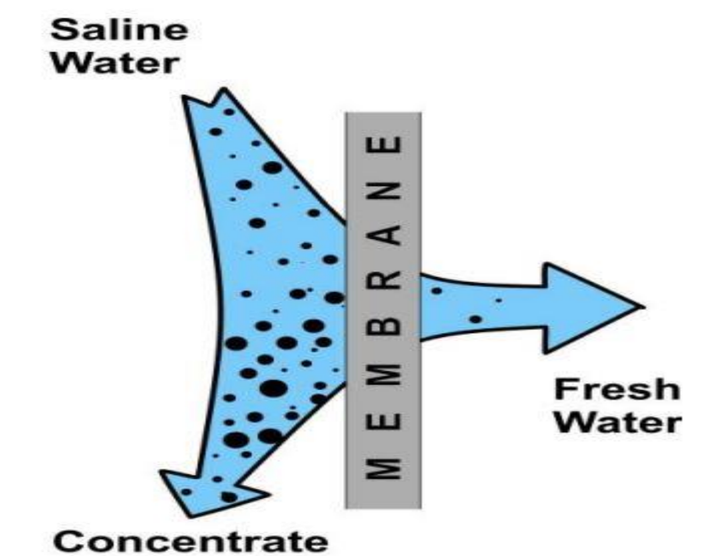
Membrane Desalination Processes

Reverse Osmosis

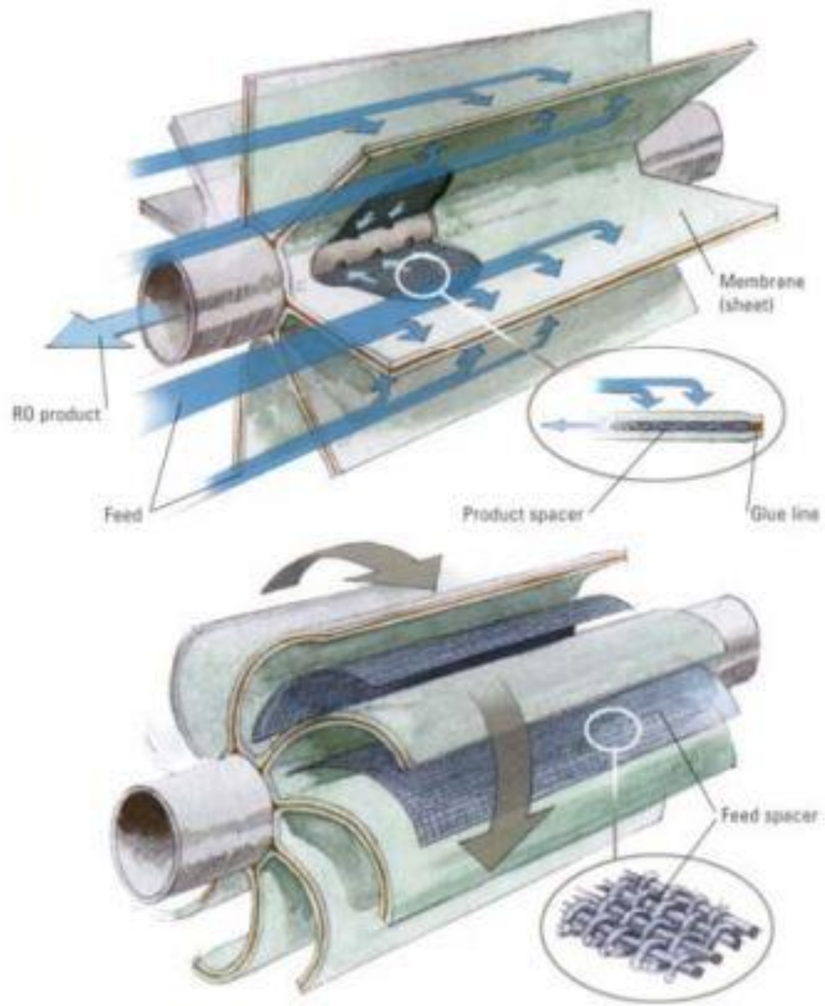
- Saltwater is forced through membrane sheets at high pressures
- Membrane sheets are designed to catch salt ions
- Process produces clean water and brine



Principle set-up of a RO desalination plant



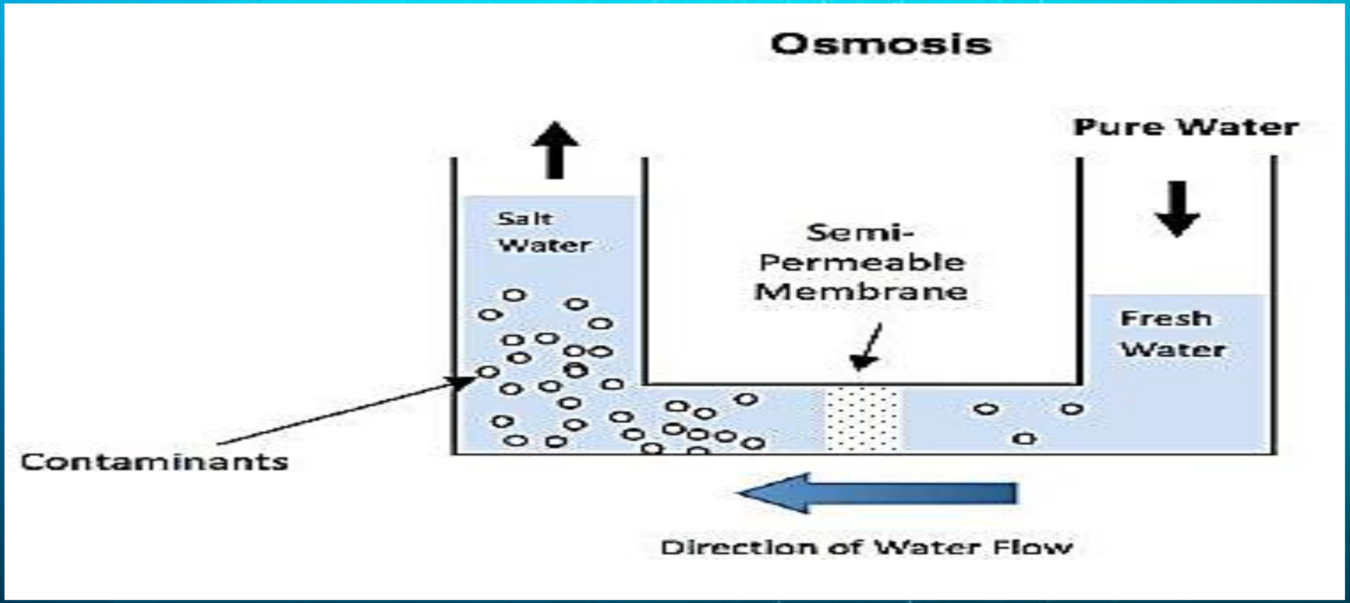
Flow pattern in a membrane operating in cross flow mode



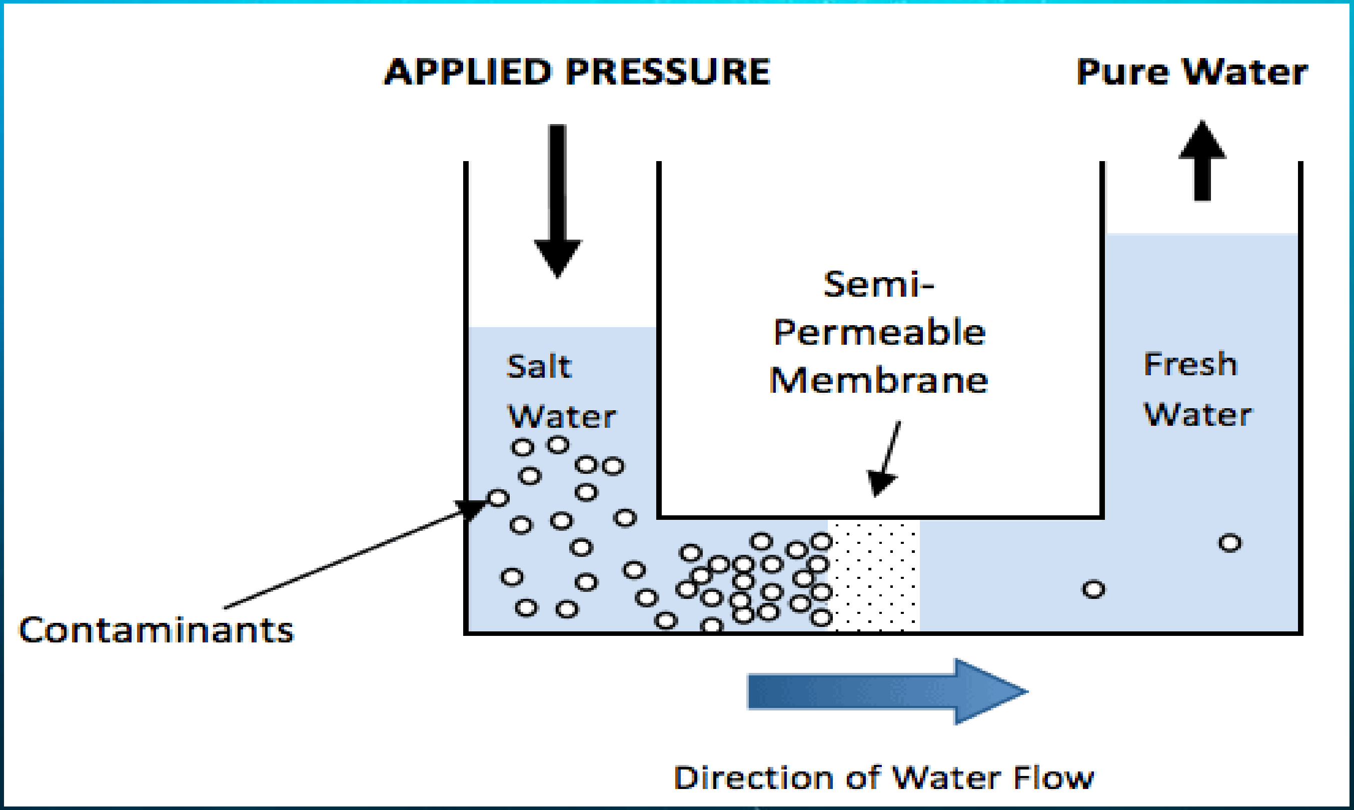
Spiral wound membrane

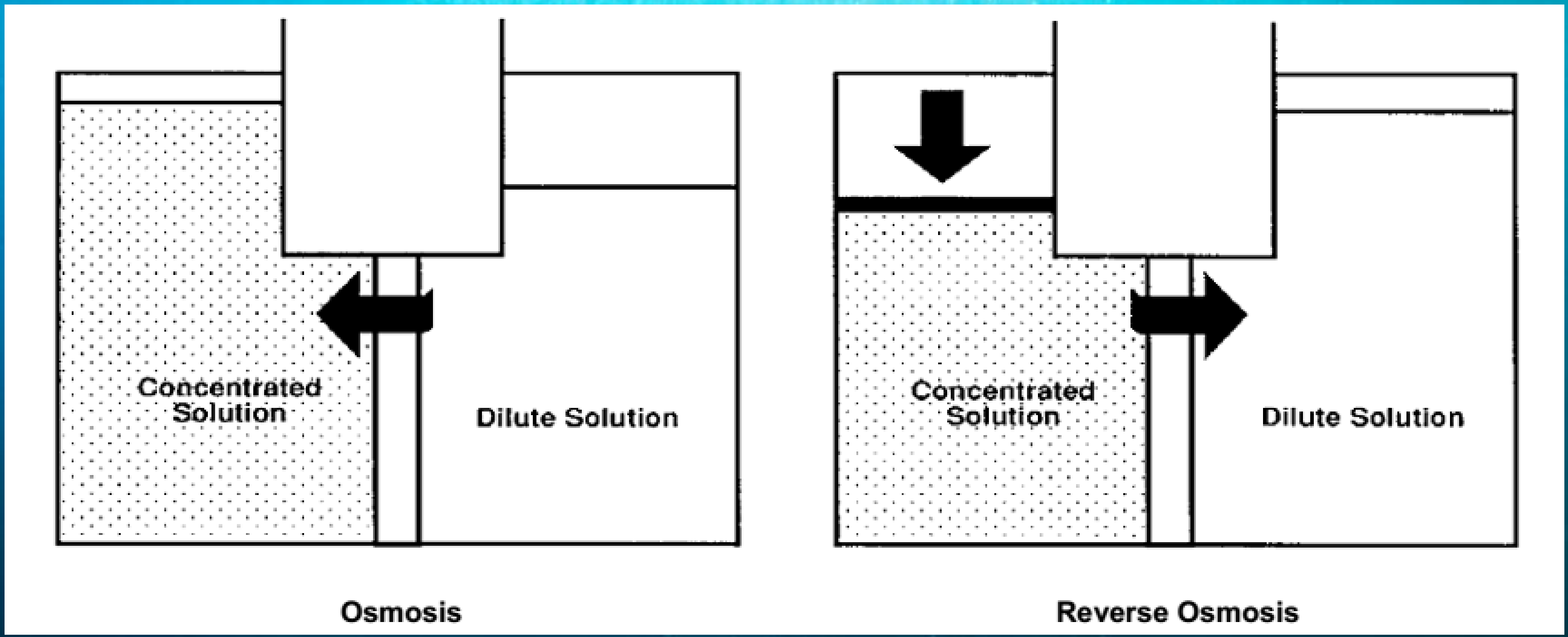

Stack of pressure vessels

Osmosis:


Osmosis
Pure Water
Salt
Water
Semi-
Permeable
Membrane
Fresh
Water
Contaminants
Direction of Water Flow

Reverse Osmosis




Concentrated Solution
Dilute Solution
Osmosis
Concentrated Solution
Dilute Solution
Reverse Osmosis

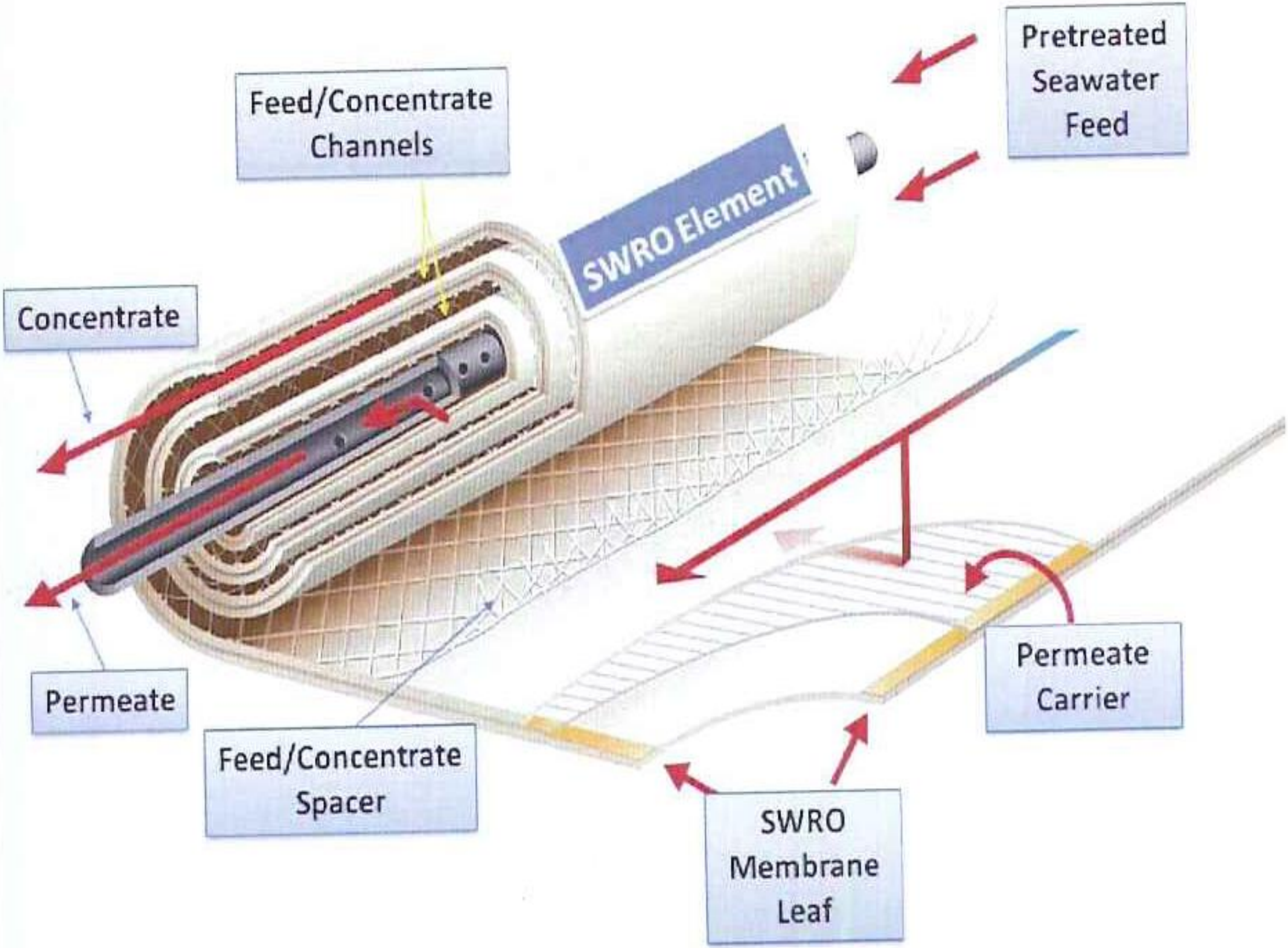
Osmotic Pressure –Rule of Thumb

- Convert TDS to osmotic pressure:
  - TDS in ppm divided by 100: osmotic pressure in psi
  - TDS in ppm divided by 1400: osmotic pressure in bar
- Examples:
  - 100 ppm TDS » 1 psi osmotic pressure (» 0.07 bar)
  - 1,000 ppm TDS » 10 psi osmotic pressure (» 0.7 bar)
  - 35,000 ppm TDS » 350 psi osmotic pressure (» 25 bar)

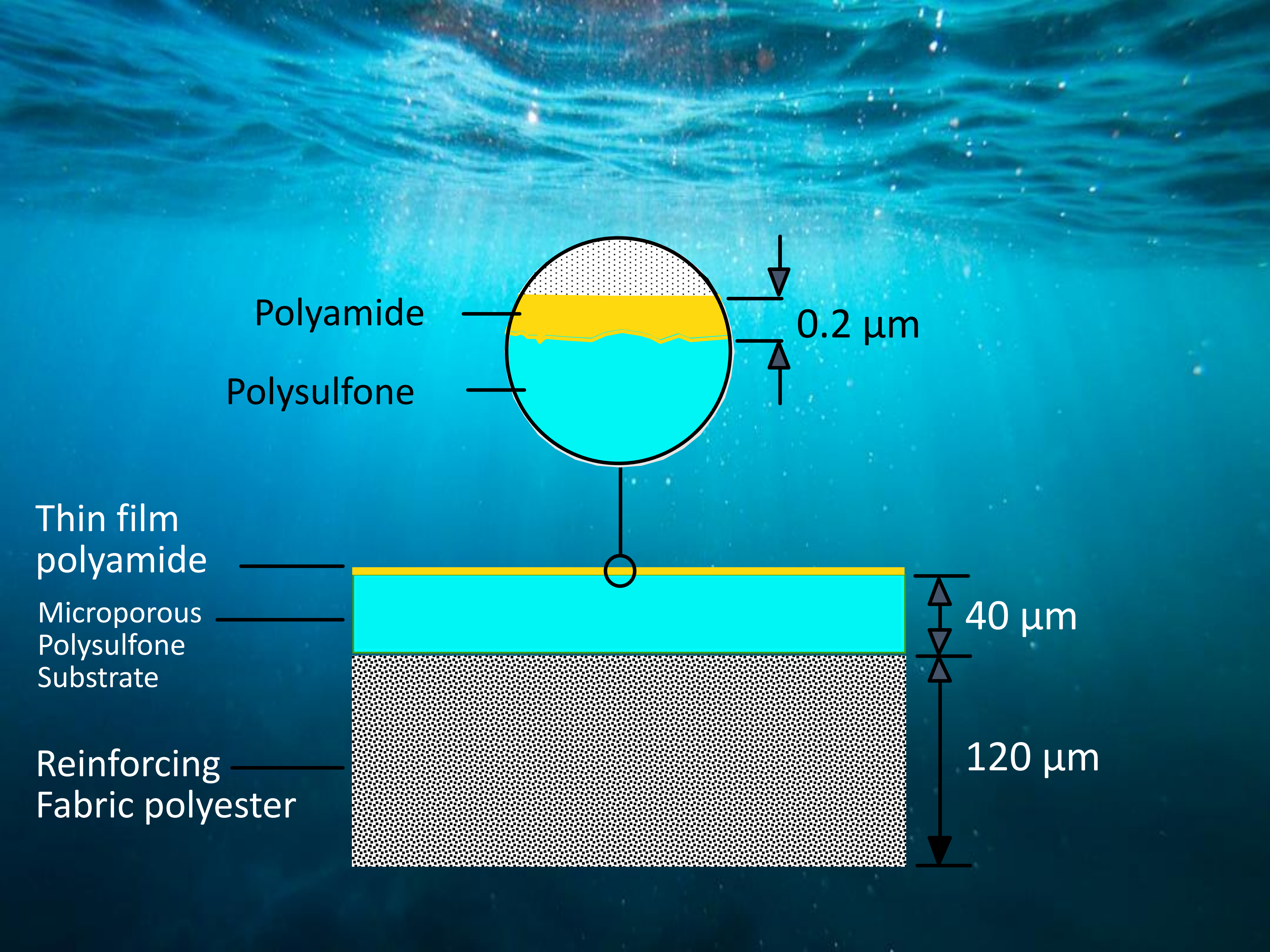
Typical Operating Pressures of different pressure driven processes

Membrane Process	Typical Operating Pressure Range (bar)
Reverse Osmosis Seawater Brackish water	 55 – 70 10 - 40
Nanofiltration	3.5 - 15
Ultrafiltration	2 – 7
Microfiltration	0.1-3

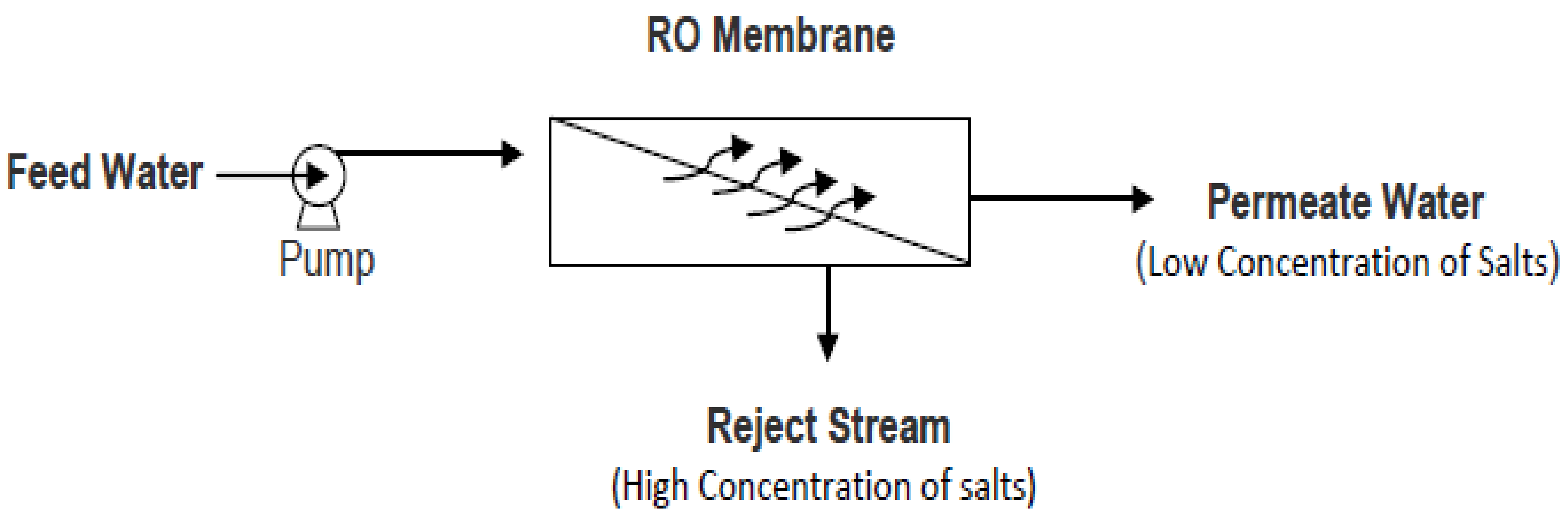
Membranes



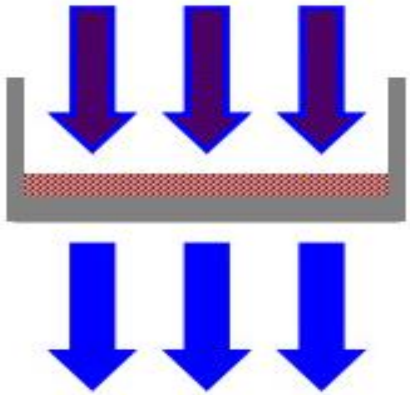
Pretreated Seawater Feed
Feed/Concentrate Channels
SWRO Element
Concentrate
Permeate
Feed/Concentrate Spacer
Permeate Carrier
SWRO Membrane Leaf


Polyamide
Polysulfone
0.2 µm
Thin film polyamide
Microporous Polysulfone Substrate
Reinforcing Fabric polyester
40 µm
120 µm

How does Reverse Osmosis work?



Membrane Operation Modes

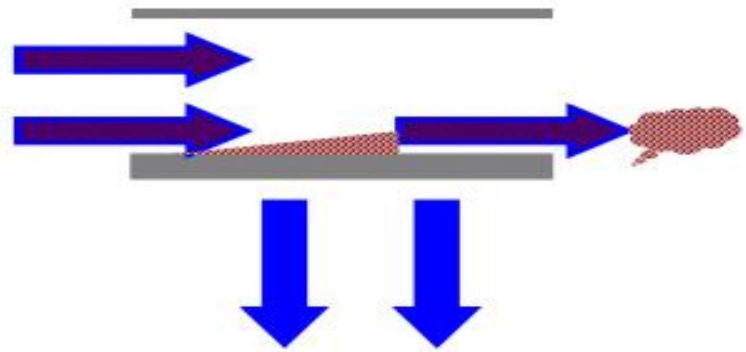


Dead-end filtration

Not feasible for RO/NF:

A. Sparingly soluble salts precipitate and foul the membrane.

B. Filter cake build-up



Cross-flow filtration

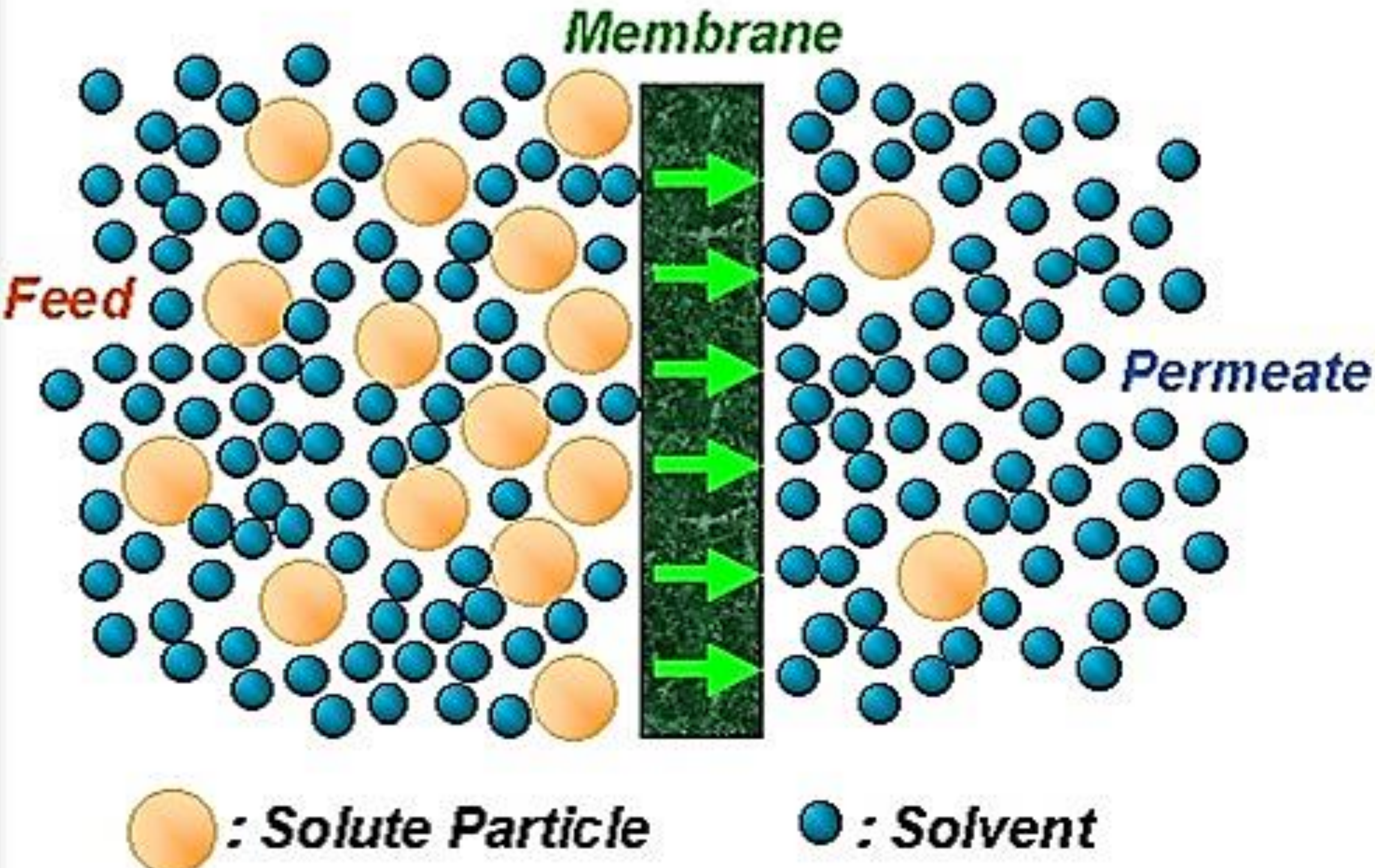
Required for RO/NF:

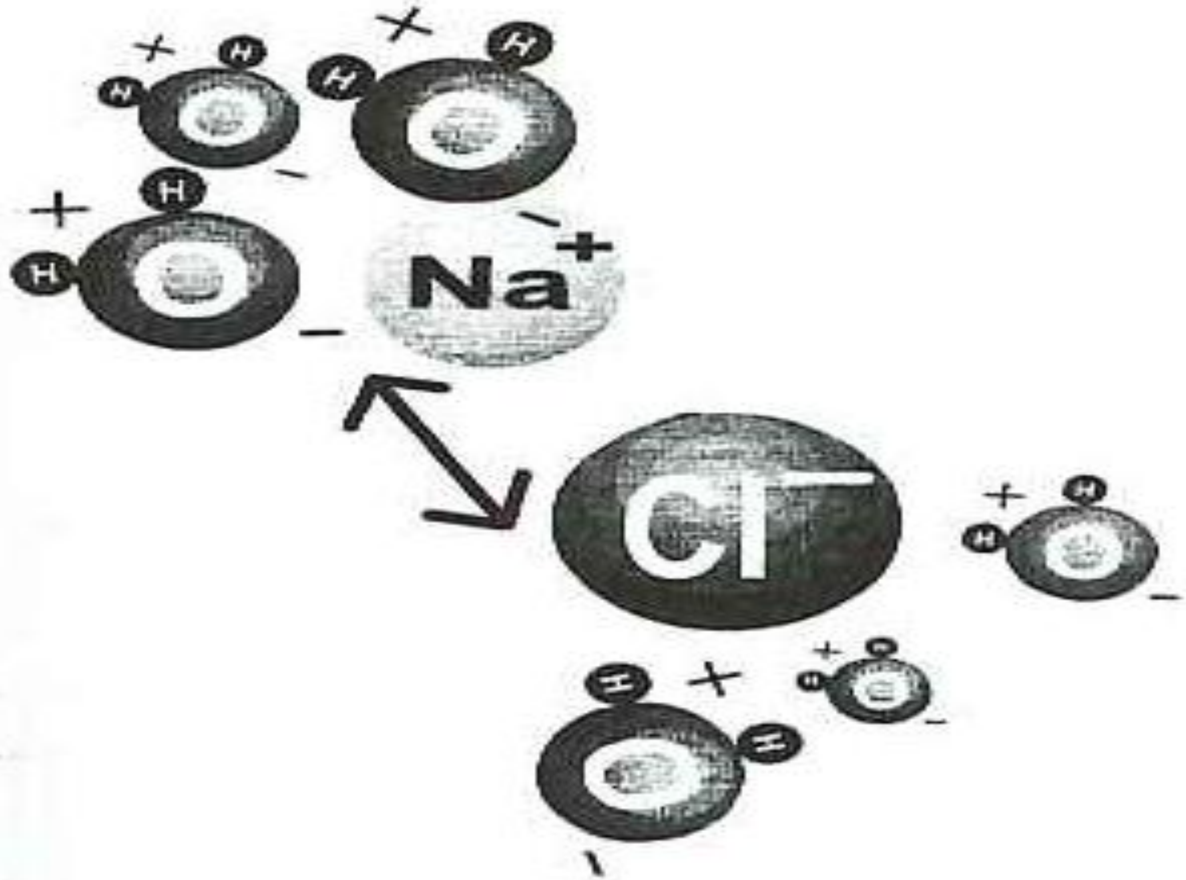
A. Sweeps away membrane foulants

B. Minimizes concentration polarization

C. Generates a concentrate stream and a permeate stream

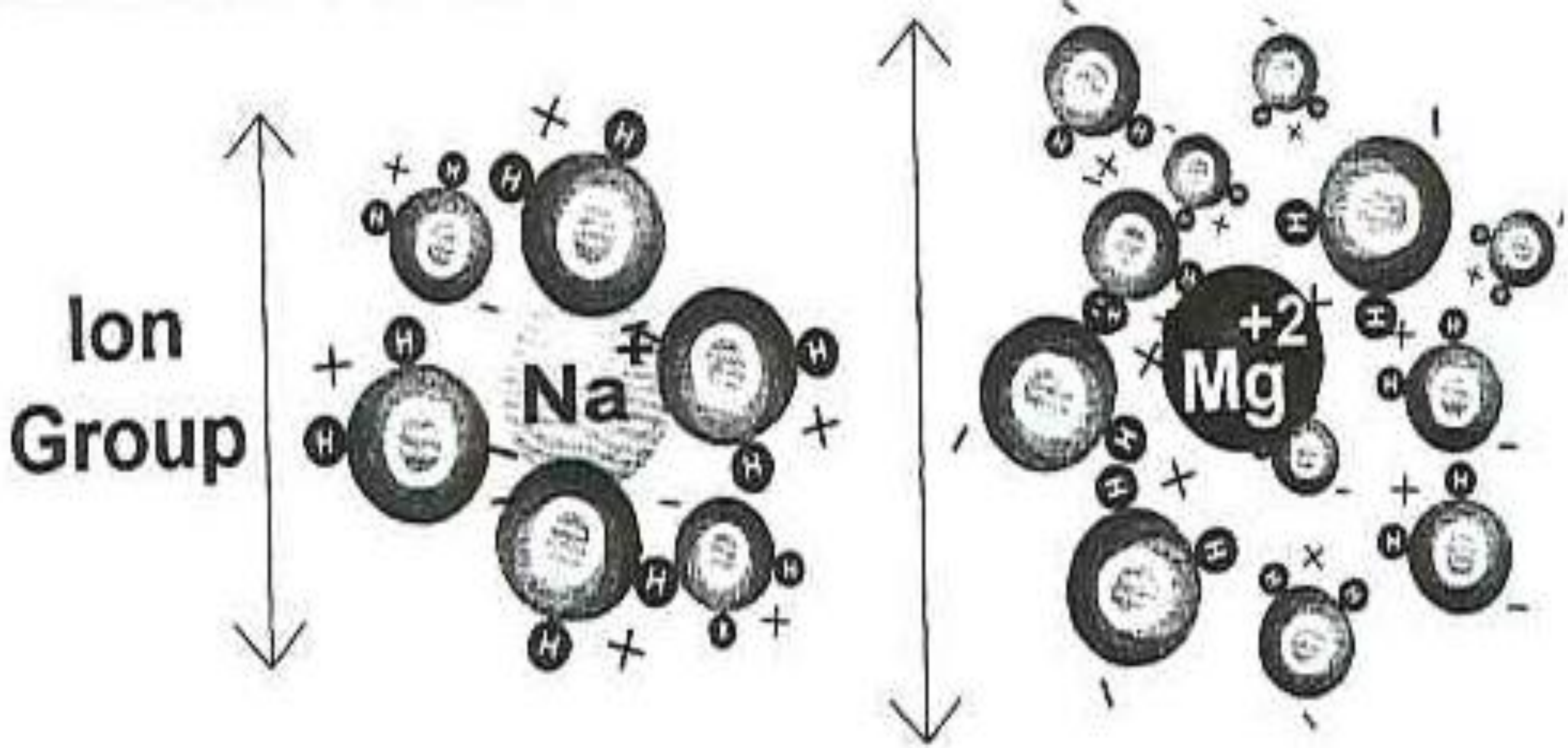
Membrane Separation





The polar water molecules are able to pull apart salt into its ions, causing it to dissolve.

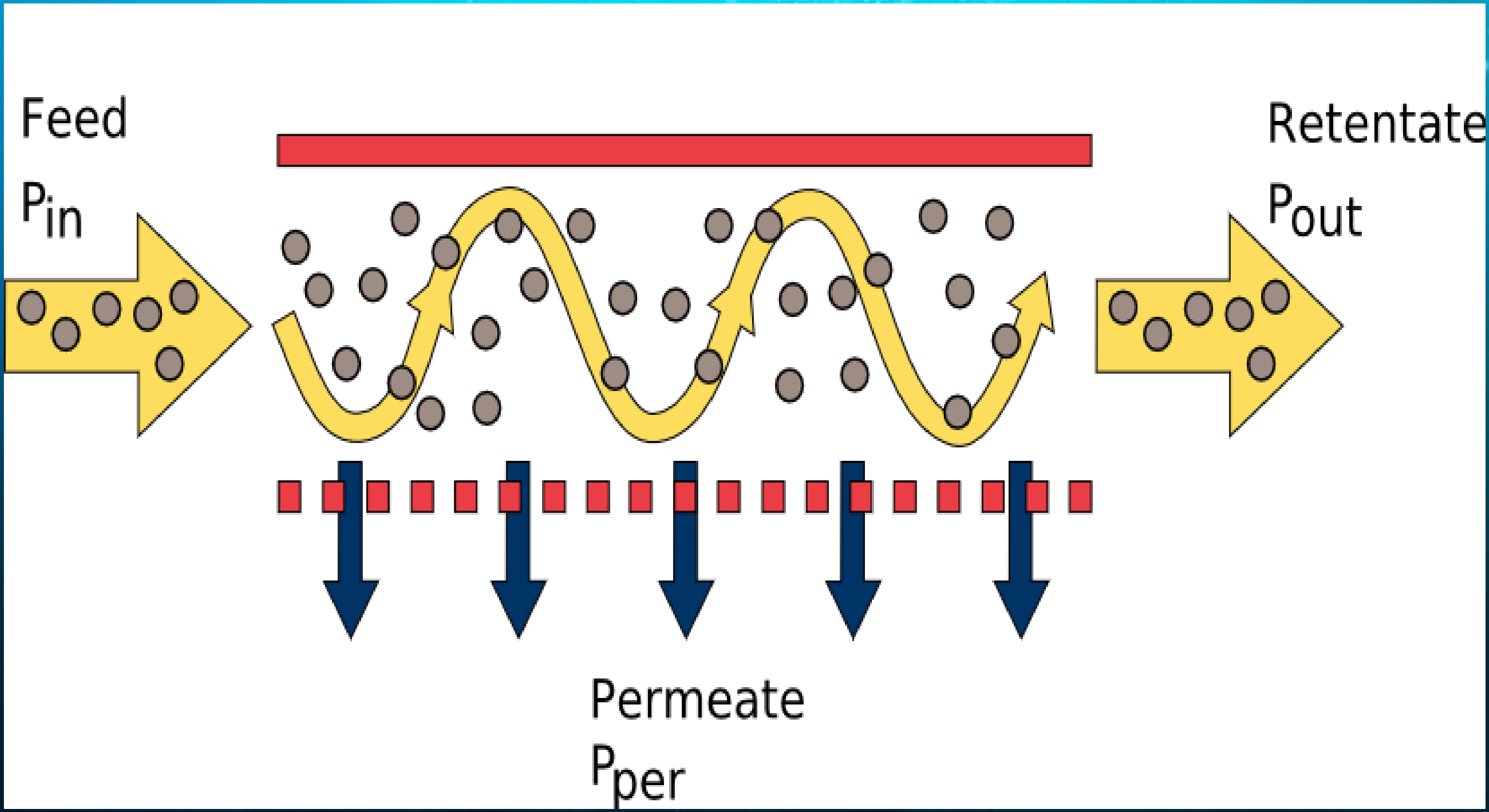
Figure 1-10. Polarity of water molecules.



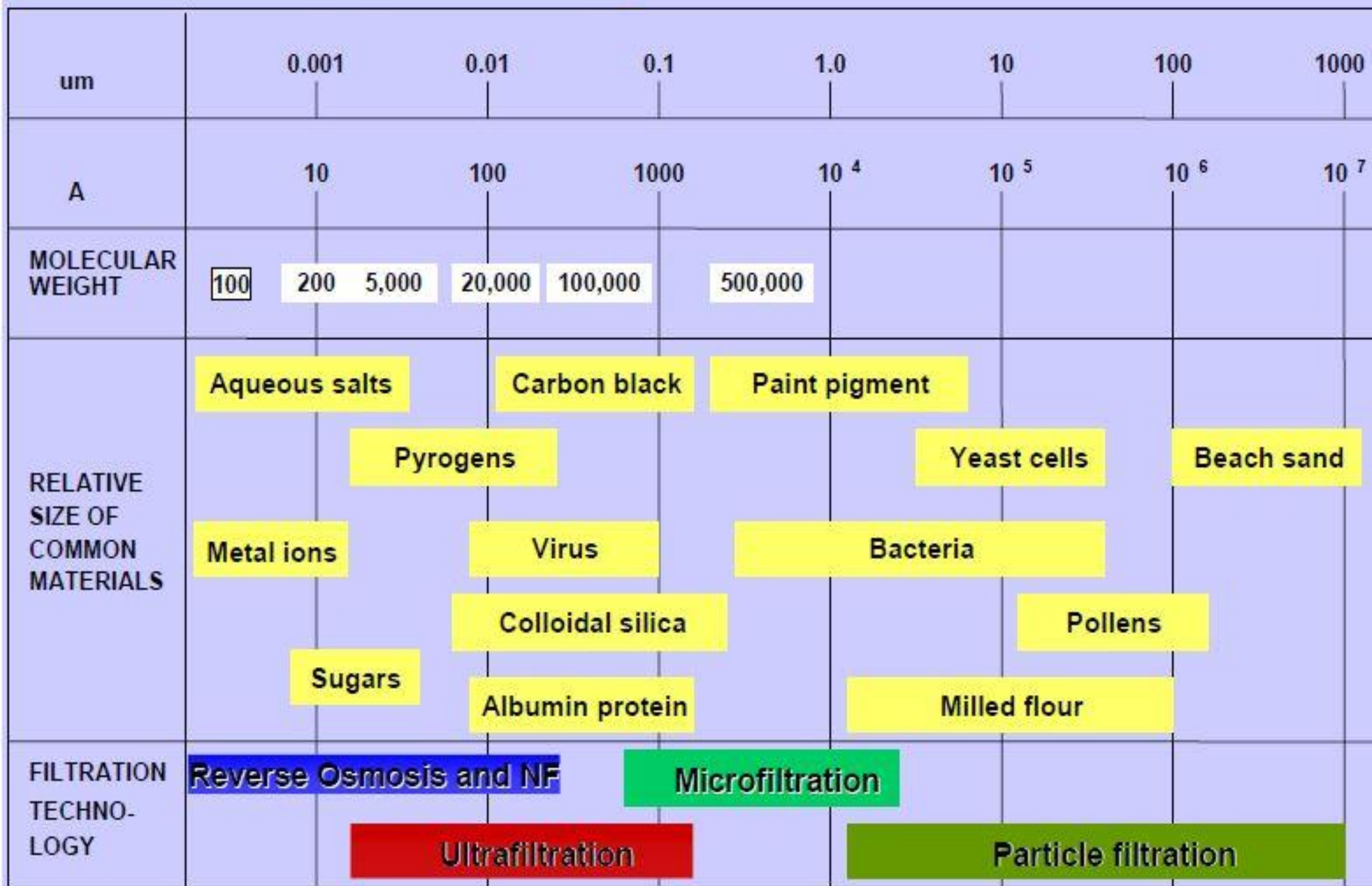
Ions with greater charge will hydrate with a greater number of water molecules, resulting in a larger apparent size.

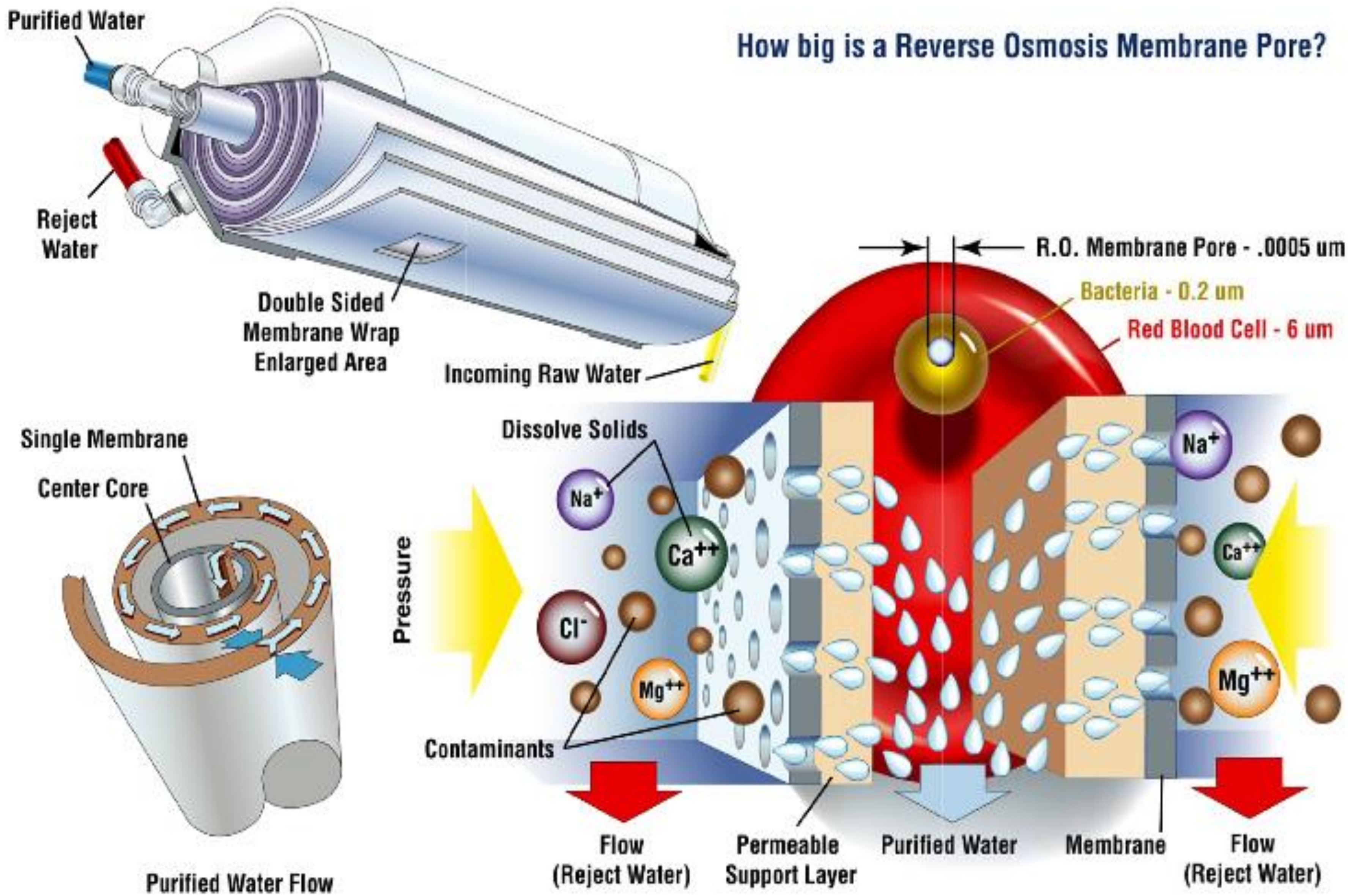
Figure 1-11. Hydration of ions.

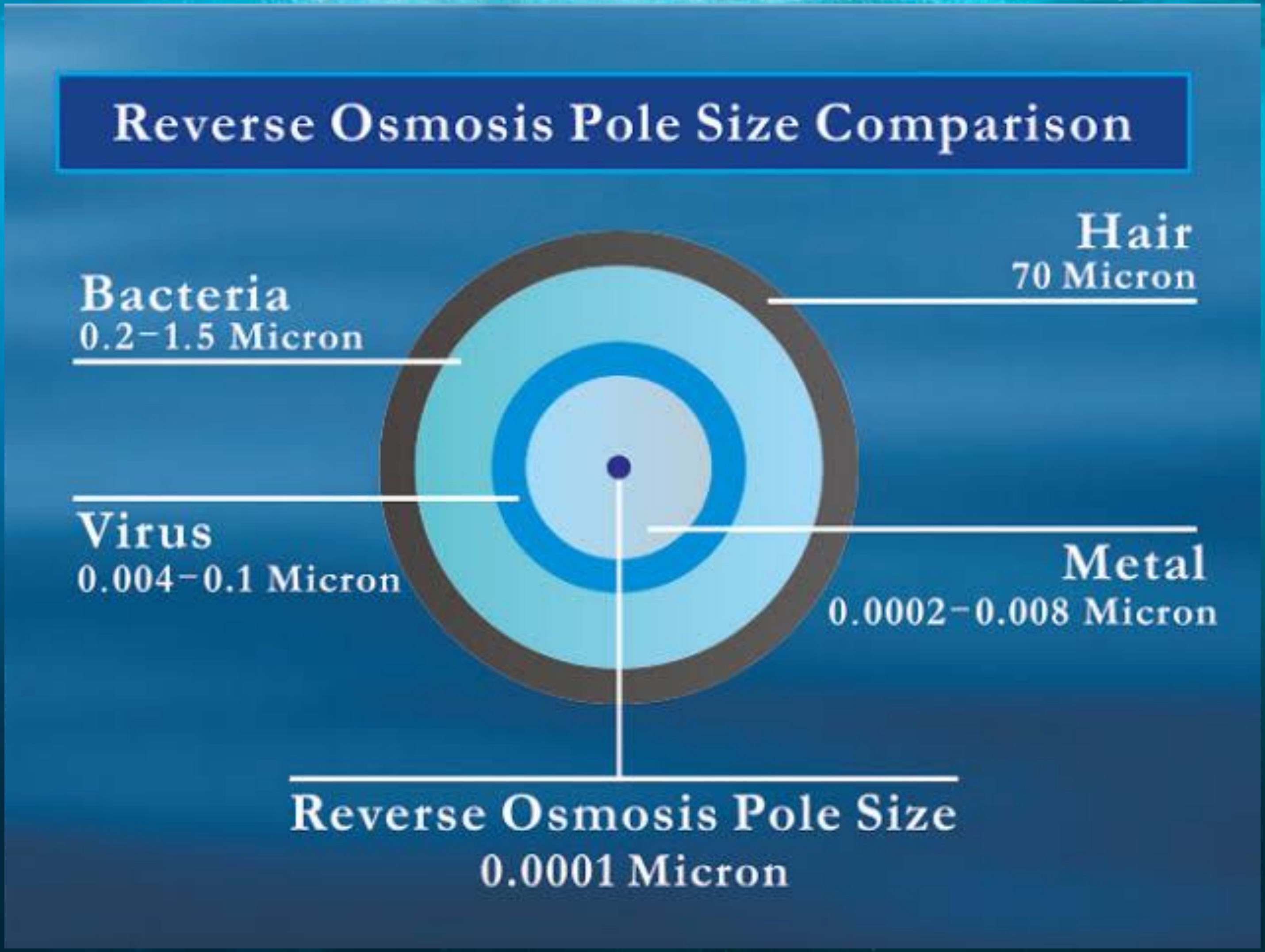
Turbulence cross flow of feed water on membrane sheet



THE FILTRATION SPECTRUM




How big is a Reverse Osmosis Membrane Pore?
Purified Water
Reject Water
Double Sided Membrane Wrap Enlarged Area
Incoming Raw Water
R.O. Membrane Pore - .0005 um
Bacteria - 0.2 um
Red Blood Cell - 6 um
Single Membrane
Center Core
Purified Water Flow
Dissolve Solids
Na+
Ca++
Cl-
Mg++
Contaminants
Pressure
Pressure
Flow (Reject Water)
Permeable Support Layer
Purified Water
Membrane
Flow (Reject Water)


Reverse Osmosis Pole Size Comparison
Hair
70 Micron
Bacteria
0.2-1.5 Micron
Virus
0.004-0.1 Micron
Metal
0.0002-0.008 Micron
Reverse Osmosis Pole Size
0.0001 Micron

TERMINOLOGY

Permeate water :

The good produced water that comes out of an RO system has the majority of contaminants removed

Concentrate , Reject , Brine :

is the water that contains all of the contaminants that were unable to pass through the RO membrane.

Recovery % :

Percent Recovery is the amount of water that is being 'recovered' as good permeate water.

$$\% \text{ Recovery} = \frac{\text{Permeate Flow Rate (gpm)} \times 100}{\text{Feed Flow Rate (gpm)}}$$

Salt Rejection % :

This equation tells you how effective the RO membranes are removing contaminants.

$$\text{Salt Rejection \%} = \frac{\text{TDS of Feed Water} - \text{TDS of Permeate Water} \times 100}{\text{TDS of Feed}}$$

Salt Passage % :

This is the amount of salts expressed as a percentage that are passing through the RO system.

$$\text{Salt Passage \%} = (1 - \text{Salt Rejection\%})$$

Concentration Factor :

The concentration factor is related to the RO system recovery and is an important equation for RO system design. The more water you recover as permeate (the higher the % recovery), the more concentrated salts and contaminants you collect in the concentrate stream.

$$\text{Concentration Factor} = (1 / (1\text{-Recovery }\%)$$

Flux :

It’s the rate of permeate transferred per unit membranes area (gfd) or (L/m2.h)

$$\text{Flux (Gfd)} = \frac{\text{permeate flow (gpd)}}{\text{total no of membranes X membrane surface area}}$$

Flux value is Known depending on the source of feed water and type of used membranes for example for DOW filmtec mem. LE---440i

Feed Water Source	Gfd
Sewage Effluent	5---10
Sea Water	8---12
Brackish Surface Water	10---14
Brackish Well Water	14---18
RO Permeate Water	20---30

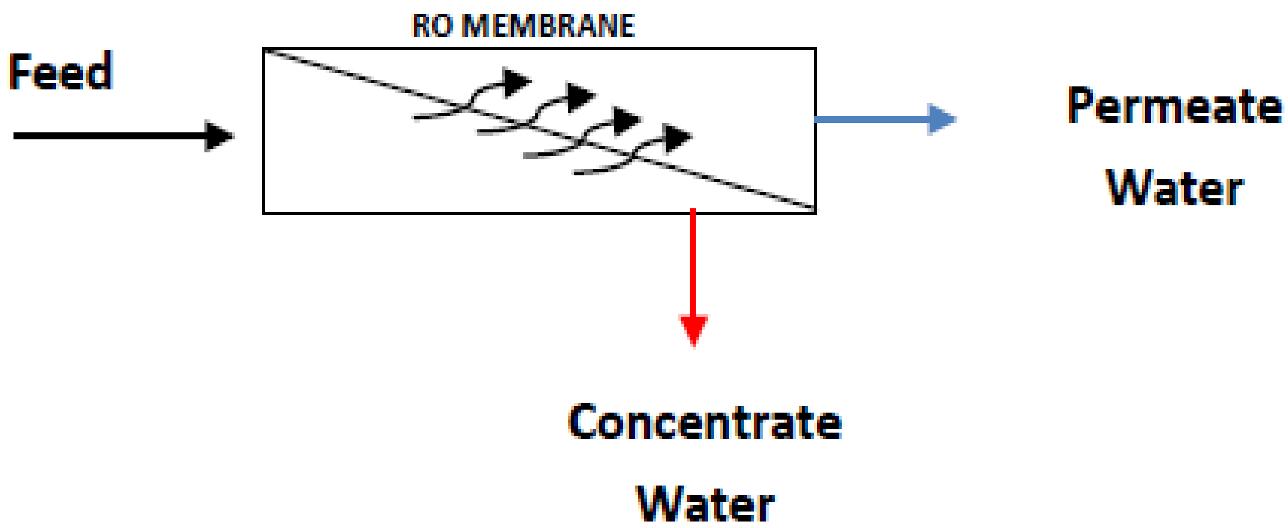
passes and stages in a Reverse Osmosis (RO) system

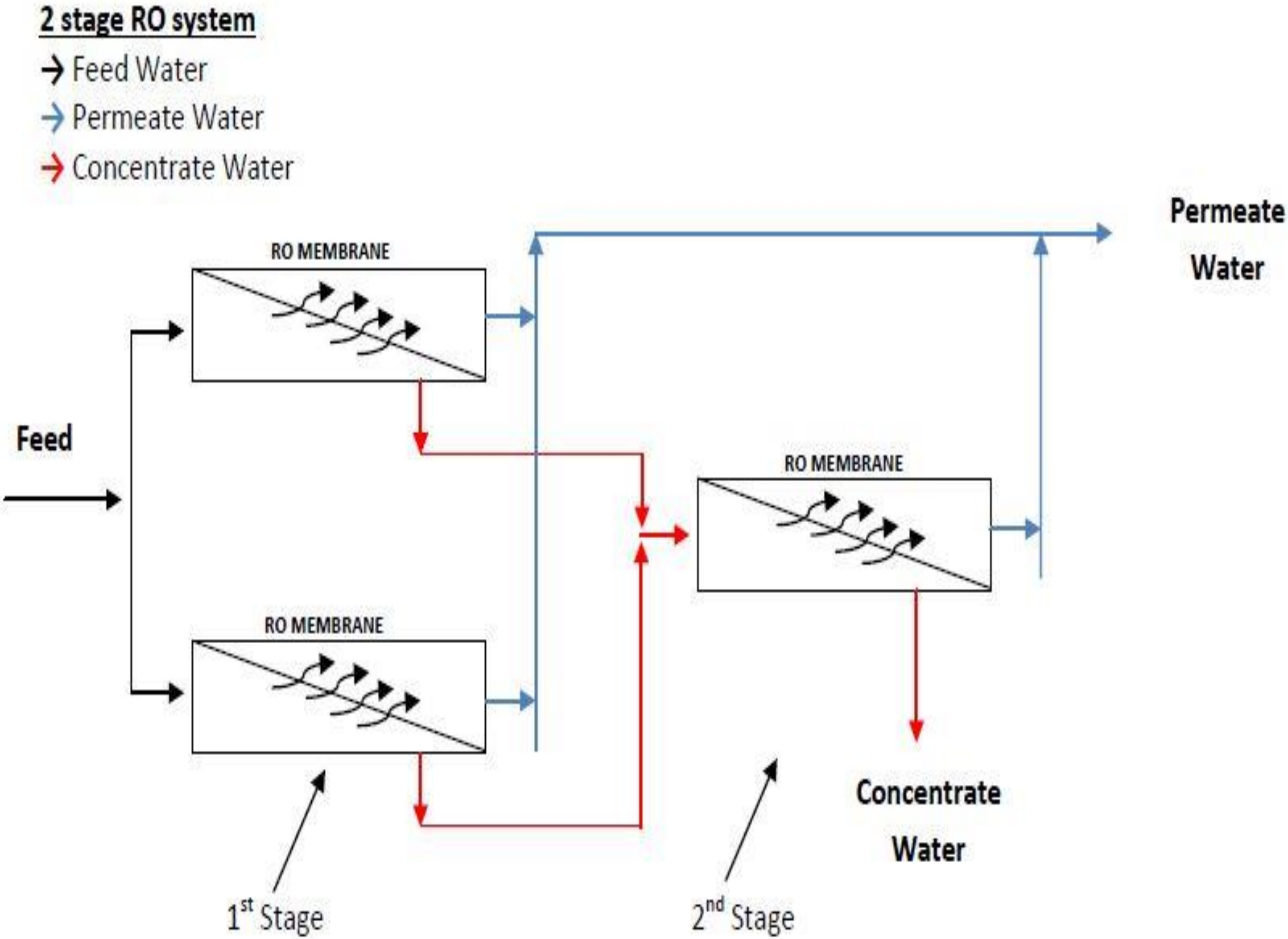
1 stage RO system

→ Feed Water

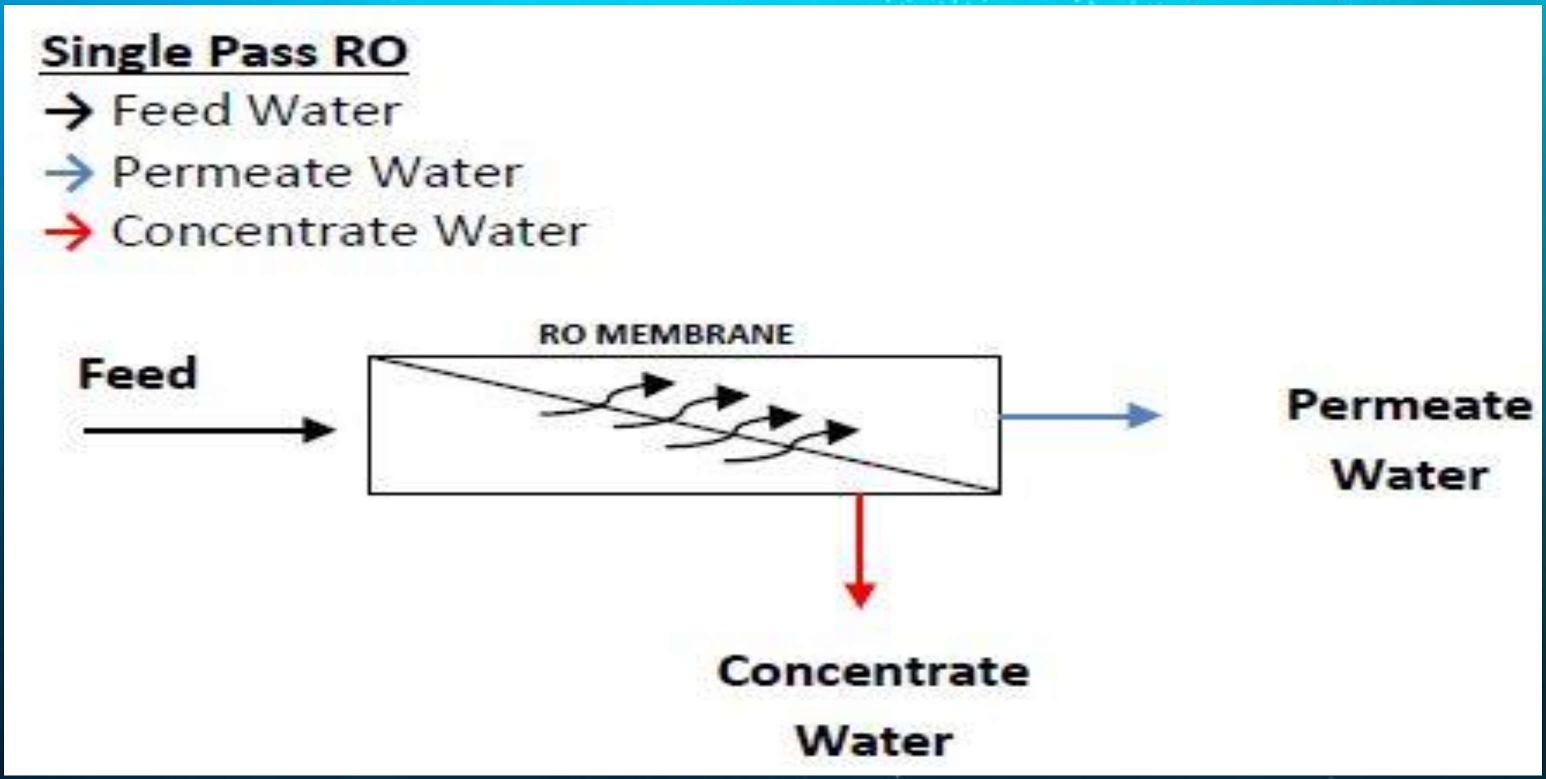
→ Permeate Water

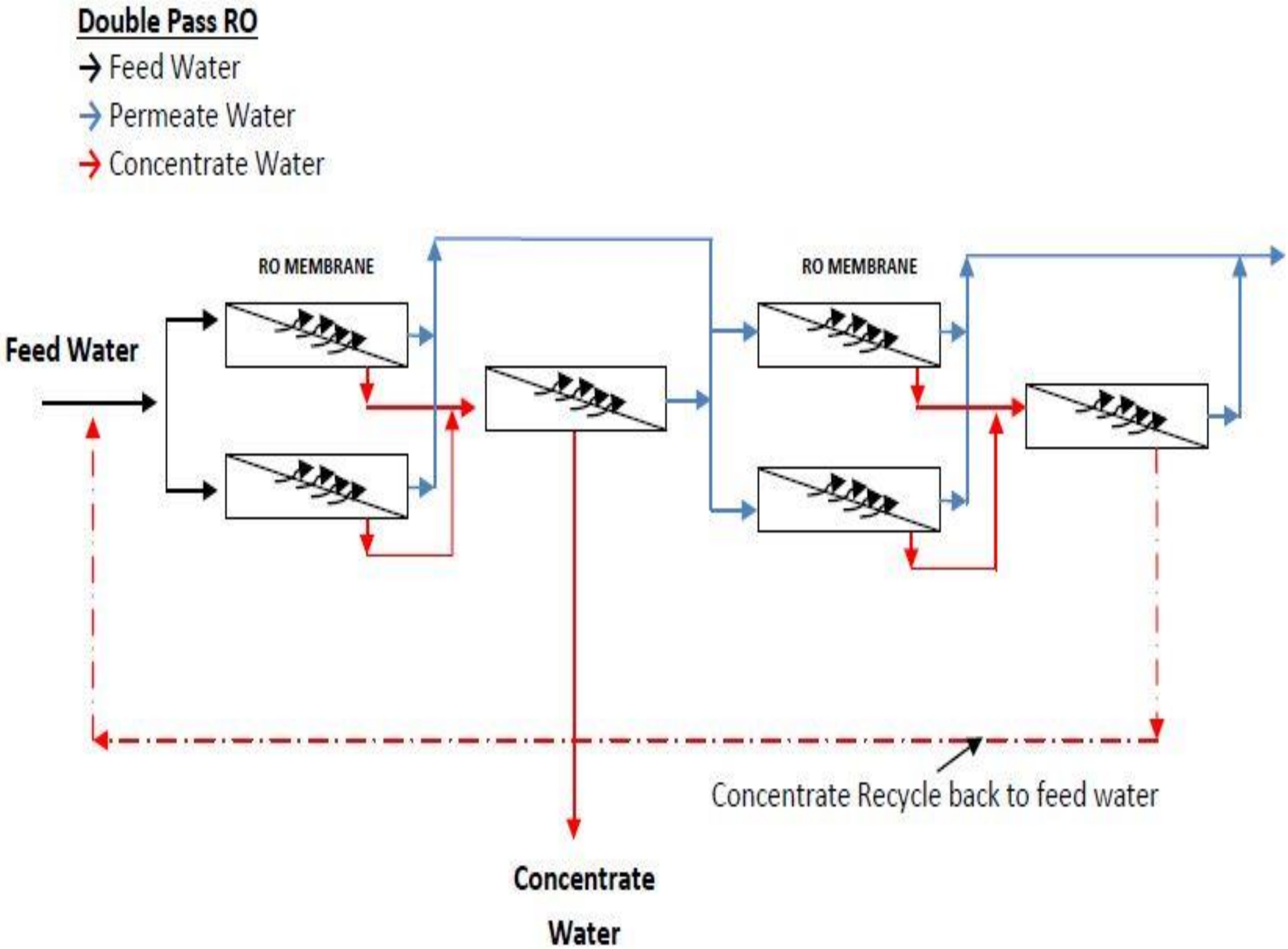
→ Concentrate Water




2 stage RO system
Feed Water
Permeate Water
Concentrate Water
Permeate
Water
RO MEMBRANE
RO MEMBRANE
RO MEMBRANE
Feed
Concentrate
Water
1st Stage
2nd Stage

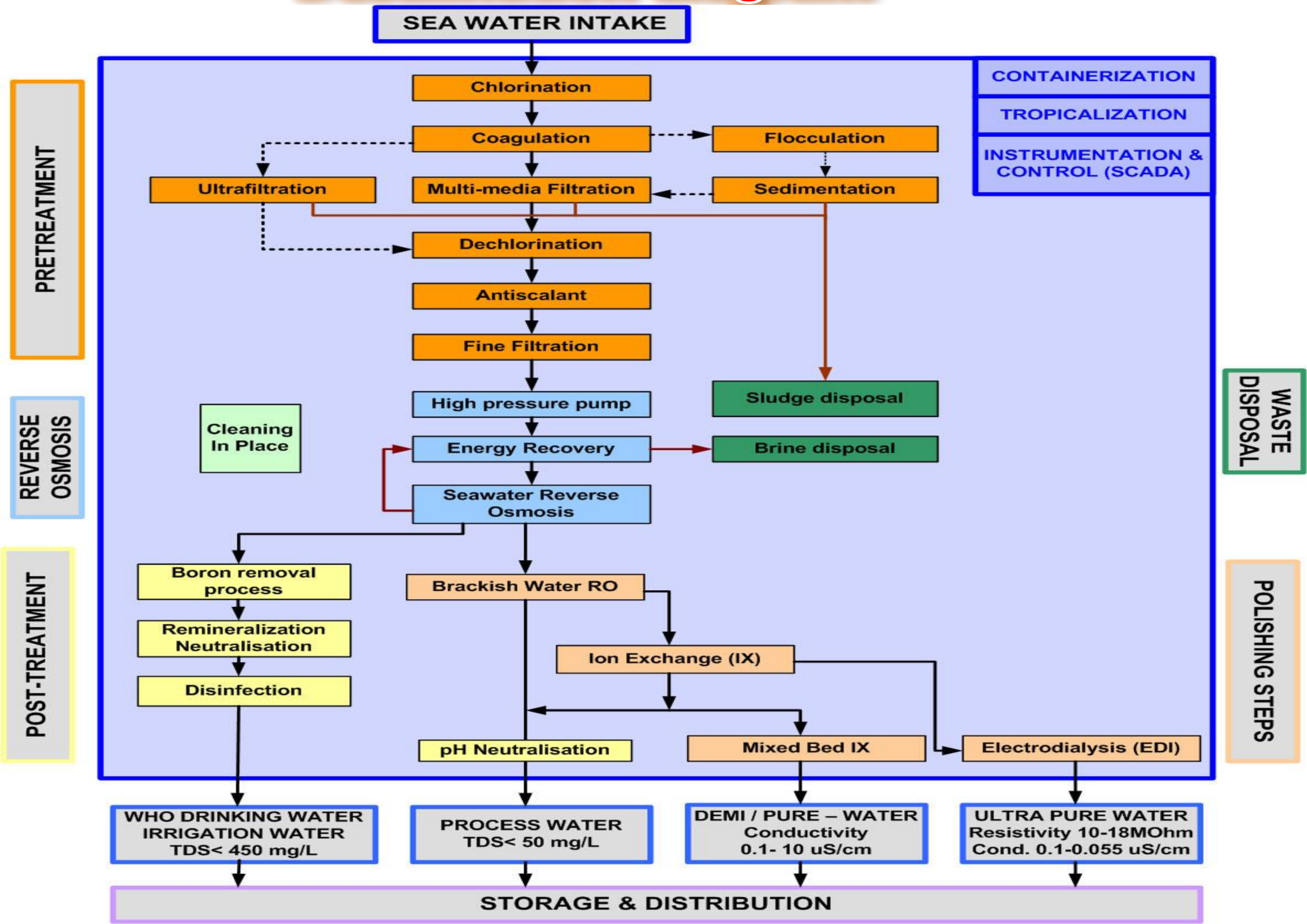
Passes


Single Pass RO
Feed Water
Permeate Water
Concentrate Water
RO MEMBRANE
Feed
Permeate
Water
Concentrate
Water


Double Pass RO
Feed Water
Permeate Water
Concentrate Water
RO MEMBRANE
RO MEMBRANE
Feed Water
Concentrate Recycle back to feed water
Concentrate
Water

Reverse Osmosis
Main Components

Desalination diagram



Pre-Treatment

Chlorination

- It’s a process of addition of free chlorine to the inlet water using some chemicals such as Calcium & Sodium Hypochlorite

- this process do two functions in the water treatment series (Oxidation & Disinfection)

- **Oxidation process :**

Inorganic metal species (e.g., iron or manganese) are oxidized to insoluble forms and are removed by precipitation. Other inorganic species such as hydrogen sulfide, an odorous gas, is oxidized to non-odorous sulfate.

Disinfection is used to refer to two activities:

(1) primary disinfection—the inactivation of microorganisms in the Water

(2) secondary disinfection—maintaining a disinfectant residual in the treated-water distribution system.

Sedimentation by HRT (Gravity Separation)

- The oldest and most widely used process in separation of suspended material from water using gravity .
- Gravity separation is time settling basin.
- Most raw surface waters will contain suspended particles and bodies.
- More recently, air bubbles have been used to float particles to the water surface for removal. Adding air bubbles to the water is known as dissolved air flotation (DAF)

Coagulation and Flocculation

Due to presence of T.S.S which cause :

1- Reduce the clarity of water to unacceptable levels (i.e., cause turbidity) as well as impart color to water.
2- Be infectious agents (e.g., viruses, bacteria, and protozoa)
3- Have toxic compounds adsorbed to their external surfaces
4- many of the constituents that comprise dissolved NOM are precursors to the formation of disinfection by-products when chlorine is used for disinfection

Coagulation & Flocculation

When natural sedimentation Fail to settle all suspended particles such colloids

So the addition of coagulant target the removal of suspended tiny particles from the water.

ALUM

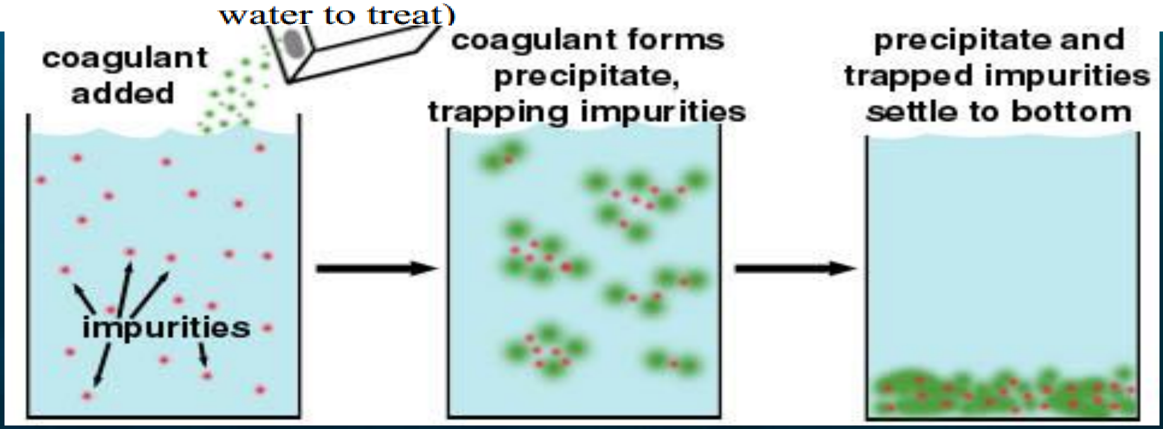
$Al_2(SO_4)_3$	+	$3\ Ca(HCO_3)_2$	----------->	$2\ Al(OH)_3$	+	$3CaSO_4$	+	$6\ CO_2$
Aluminum Sulfate	+	Calcium Bicarbonate (already in the water to treat)	gives	Aluminum Hydroxide	+	Calcium Sulfate	+	Carbon Dioxide

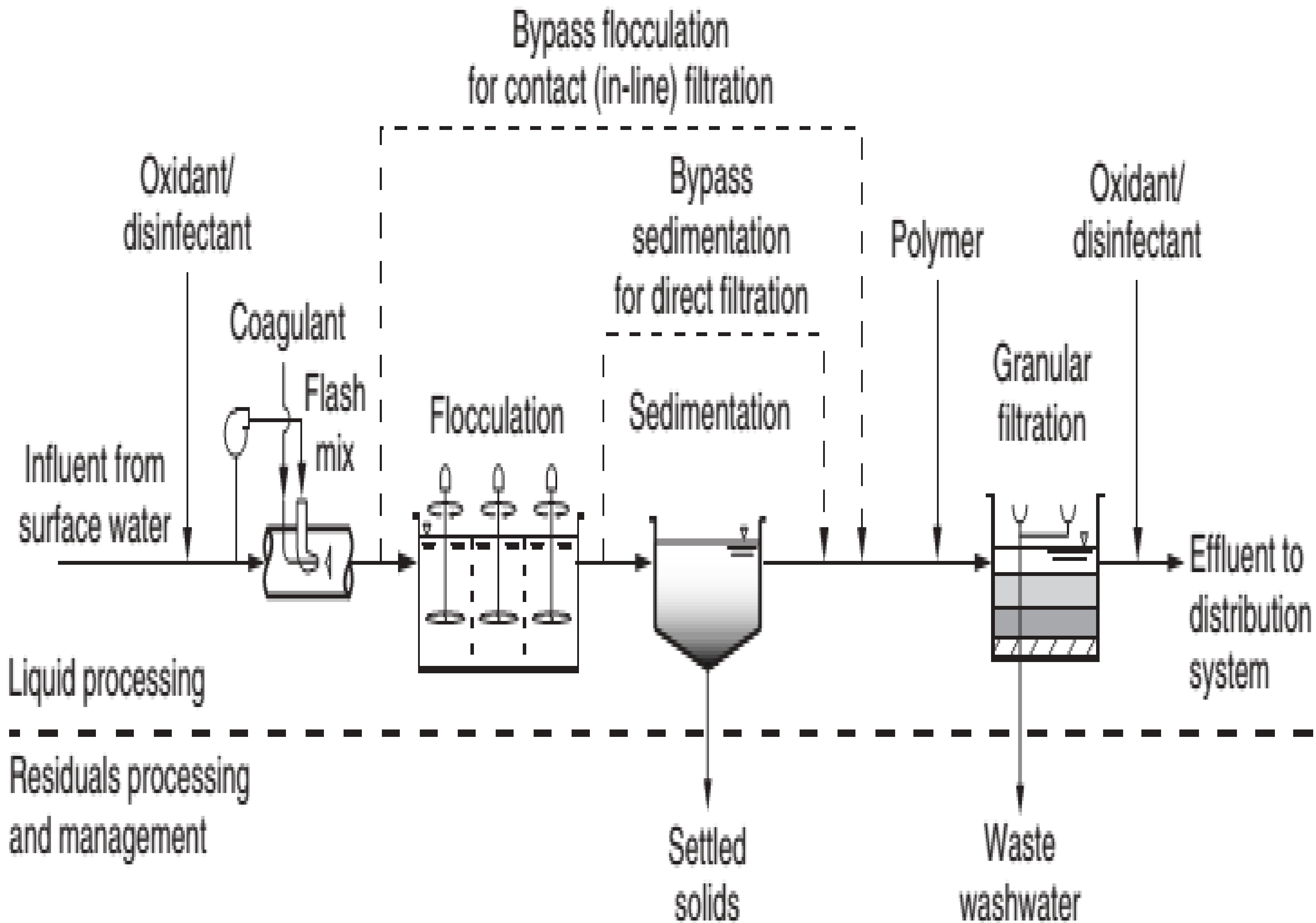
FERRIC SULFATE

$Fe_2(SO_4)_3$	+	$3\ Ca(HCO_3)_2$	----------->	$2\ Fe(OH)_3$	+	$3CaSO_4$	+	$6\ CO_2$
Ferric Sulfate	+	Calcium Bicarbonate (present in the water to treat)	gives	Ferric Hydroxide	+	Calcium Sulfate	+	Carbon Dioxide

FERRIC CHLORIDE

$2\ Fe\ Cl_3$	+	$3\ Ca(HCO_3)_2$	----------->	$2\ Fe(OH)_3$	+	$3CaCl_2$	+	$6CO_2$
Ferric Chloride	+	Calcium Bicarbonate (present in the water to treat)	gives	Ferric Hydroxide	+	Calcium Chloride	+	Carbon Dioxide





Bypass flocculation
for contact (in-line) filtration
Oxidant/
disinfectant
Bypass
sedimentation
for direct filtration
Polymer
Oxidant/
disinfectant
Coagulant
Flash
mix
Flocculation
Sedimentation
Granular
filtration
Influent from
surface water
Effluent to
distribution
system
Liquid processing
Residuals processing
and management
Settled
solids
Waste
washwater

Filtration

Filtration can be defined as any process for the removal of solids (suspended or dissolved) particles from water.

1- Granular filtration : (Sand filter)

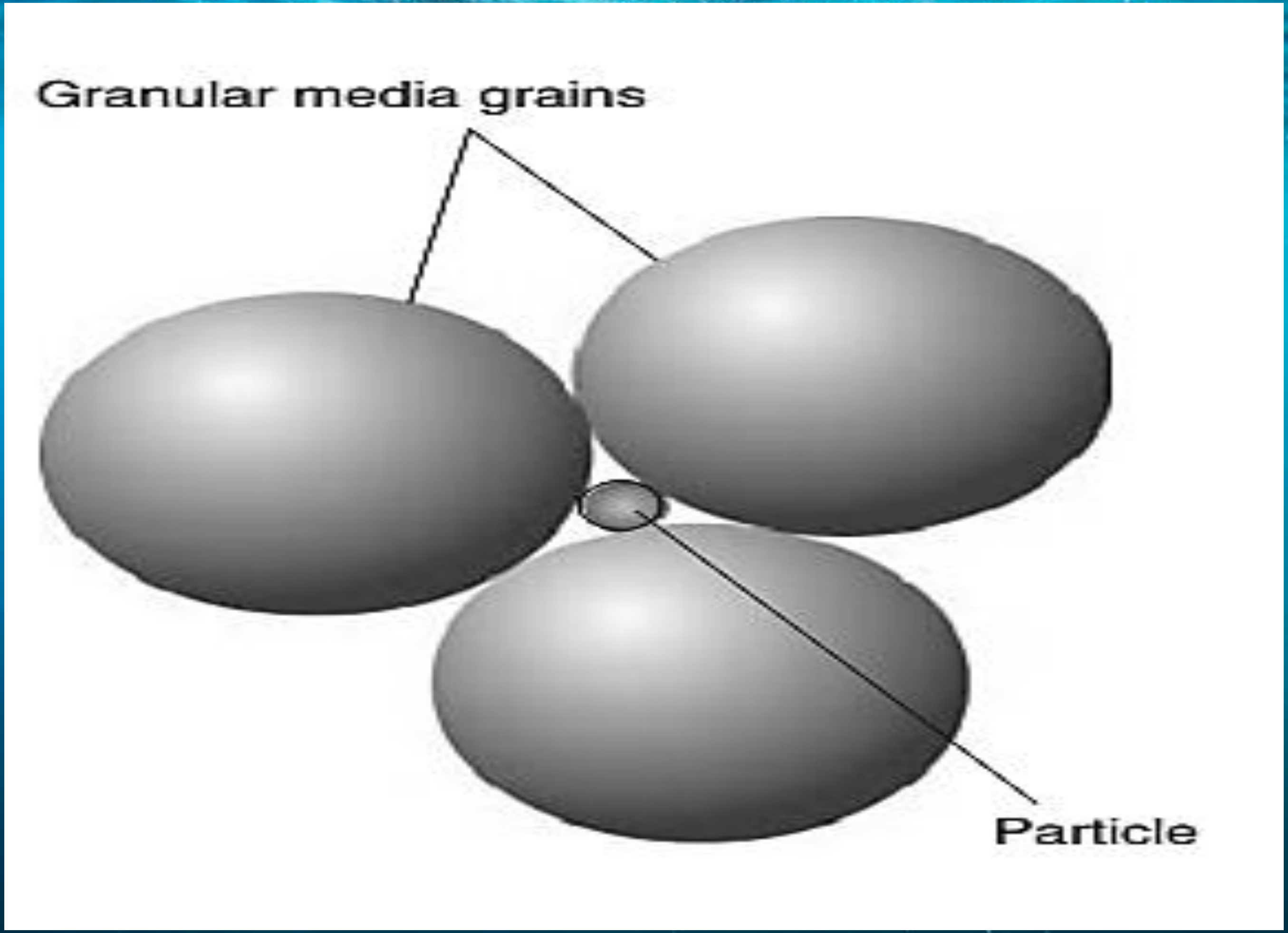
Filtration done by passage of the suspension through a porous medium. In granular filtration, the porous medium is a bed of granular material such as sand , there are two types of sad filtration:

- **Slow filtration :**

process during which water passes slowly down through a bed of sand. Filtration occurs primarily by straining at the surface of the Schmutzdecke located at the top of the bed.

- **rapid filtration (include depth filtration)**

process engineered to achieve filtration rates about 100 times greater than slow sand filtration. Key requirements include coagulation pretreatment, granular media sieved for greater uniformity, and backwashing to remove accumulated particles.


Granular media grains
Particle

De-Chlorination

- It's a process of removal of free chlorine from water using Physical adsorption technique or Chemical removal technique.

- Physical adsorption done by using GAC (Granulated Active Carbon) which has great ability to adsorb the free chlorine and it's byproduct (halo-organics) from water.

- Chemical removal done by using free chlorine scavenger such as SMBS (sodium meta bi-sulfite)

When dissolved in water, sodium bisulfite (SBS) is formed from SMBS:

$$Na_2S_2O_5 + H_2O \rightarrow 2\ NaHSO_3$$

SBS then reduces hypochlorous acid according to:

$$2NaHSO_3 + 2HOCl \rightarrow H_2SO_4 + 2HCl + Na_2SO_4$$

Antiscalent

• An antiscalent is a pretreatment chemical injected into the feed-water before the feed-water enters the RO membranes.

• Its presence affect the precipitation tendency of calcium & magnesium carbonate and sulfates .

•This results is scale not forming as the water is being purified by the RO.

•As the duration of the water in the membrane system is relatively short during the treatment, scale formation is prevented.

•The most widely used antiscalent is

- Sodium hexameta-phosphate (SHMP)
- Organophosphates
- Polycarboxylic compounds

Antiscalent prevents the formation of crystals from water hardness by blocking crystal growth (Threshold effect).

Fine filtration

- **It’s process that eliminate or remove the suspended matter especially fine suspended particles that may done by (cartridge filters , microfiltration)**

Post-Treatment

Boron removal

Current Technologies for Boron Removal

- Distillation.
- Special Reverse Osmosis membranes .
- Ion Exchange.

pH adjustment

In most cases the R.O produce slightly acidic permeate water so need to adding some caustic soda to make it neutral and vice versa if we need more acidic water we must add some acids such hydrochloric acid

Reverse Osmosis Classification

According chemical construction

cellulose acetate (CA)
thin film composite (TFC) Polyamide

Table 1. Membrane Properties

Feature	CA Membranes	TFC Membranes
Filtration of organic compounds	Low	High
Water flux	Medium	High
pH tolerance	4-8	2-11
Temperature stability	Max 35 °C	Max 45 °C
Oxidant tolerance	High	Low
Compaction tendency	High	Low
Cost	Low	High

Reverse Osmosis Manufacturer differences

Thank you

Mohamed Shaaban
01555467892 – 01030663807
Mo7amed.sci@gmail.com