Application of membrane technologies for water reuse

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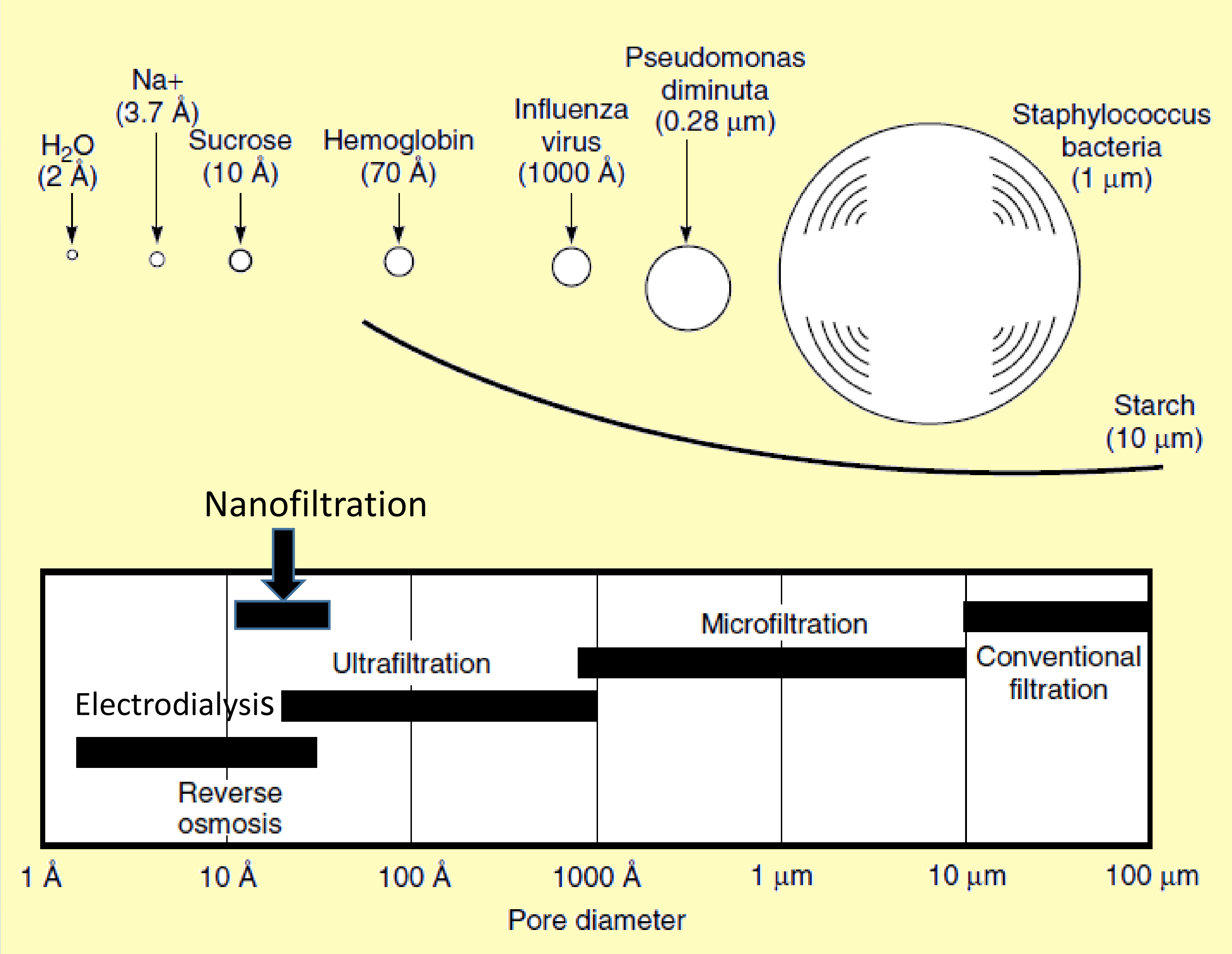
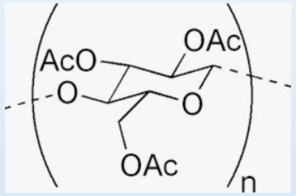
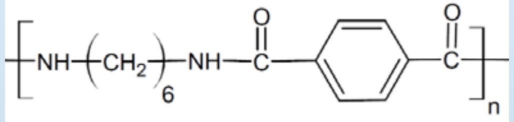
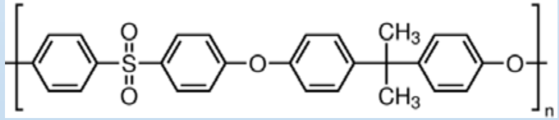
MEMBRANE TECHNOLOGIES DEPENDING ON THE SIZE OF THE RETAINED MATERIAL

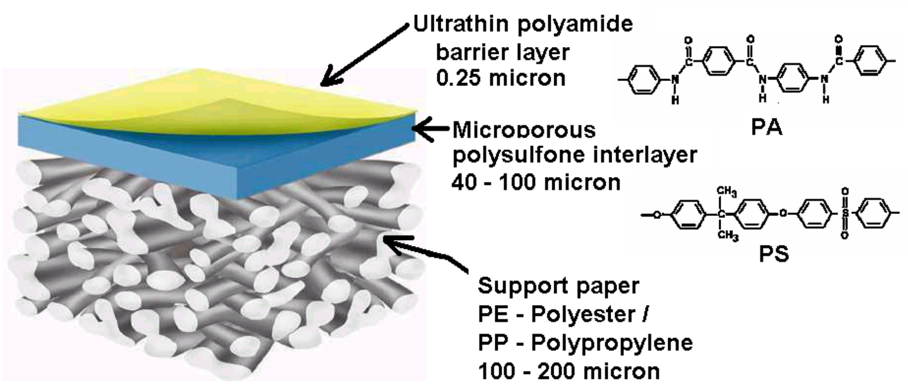


MEMBRANE COMPOSITION AND STRUCTURE

MODIFIED NATURAL PRODUCTS	**Cellulose triacetate**	
SYNTHETIC POLYMERS	**Polyamide**	
	Polysulfone	
CERAMICS AND METALLIC	**TiO_2 , ZrO_2 , Zeolite, Stainless steel …**	

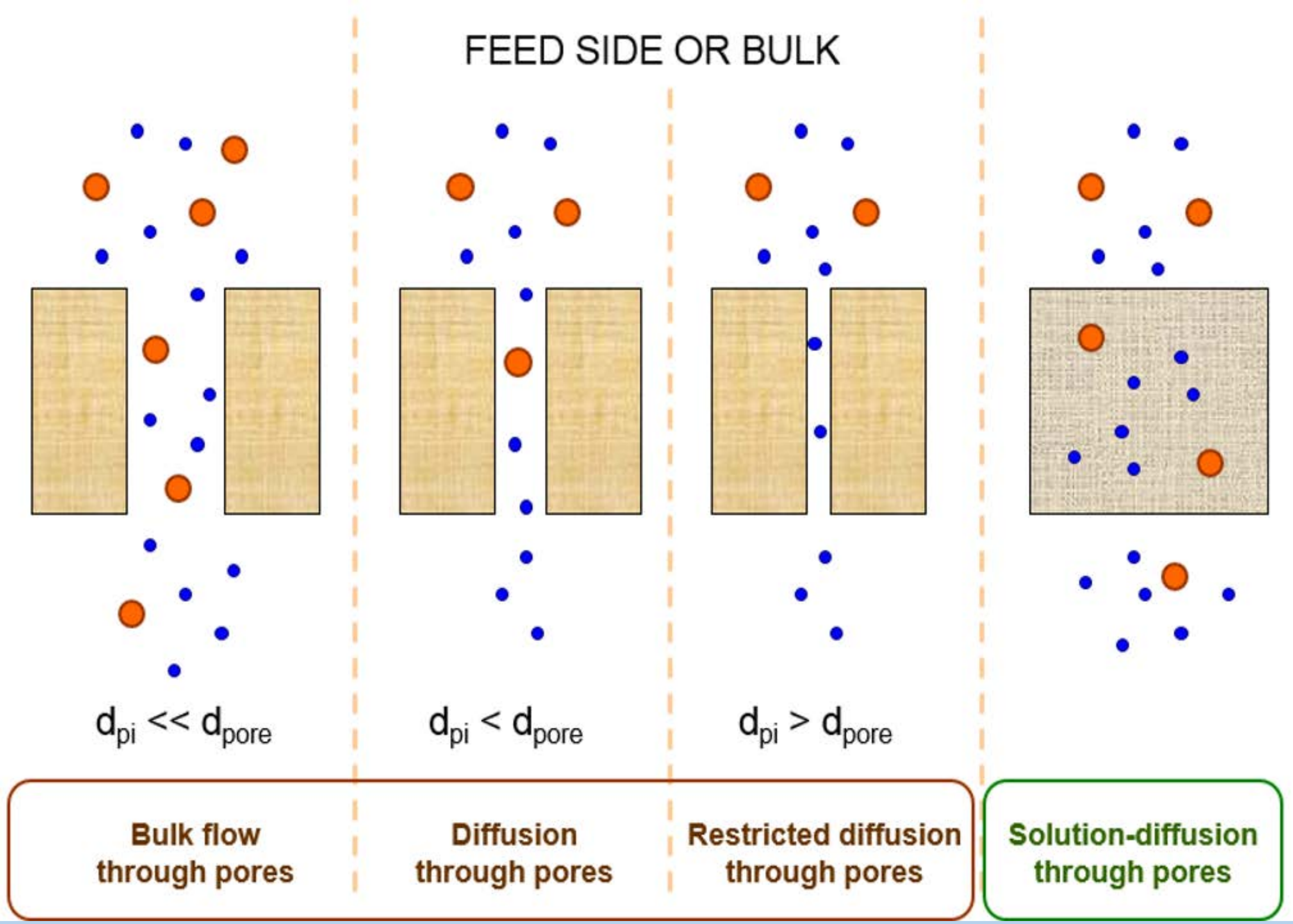
Ceramic Porous Ultrafilter

Composite Reverse Osmosis membrane



Stainless steel Porous Microfilter

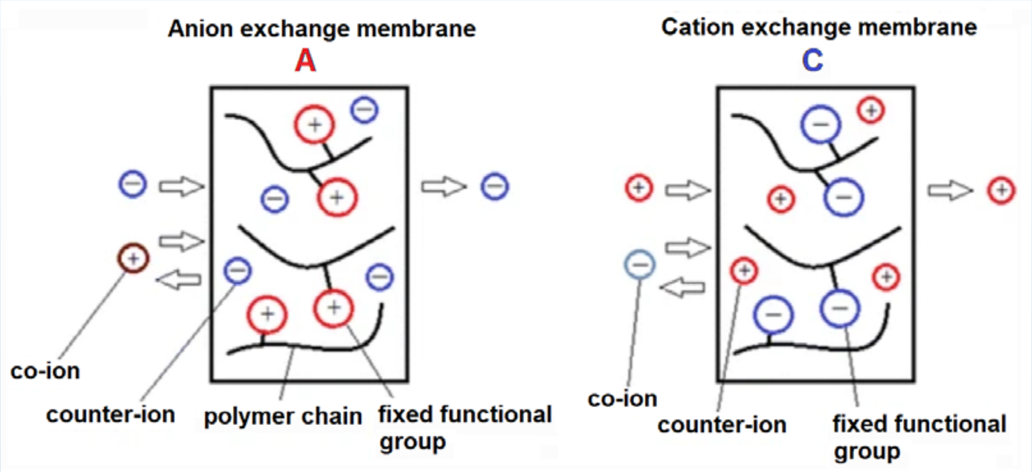
SEPARATION MECHANISMS

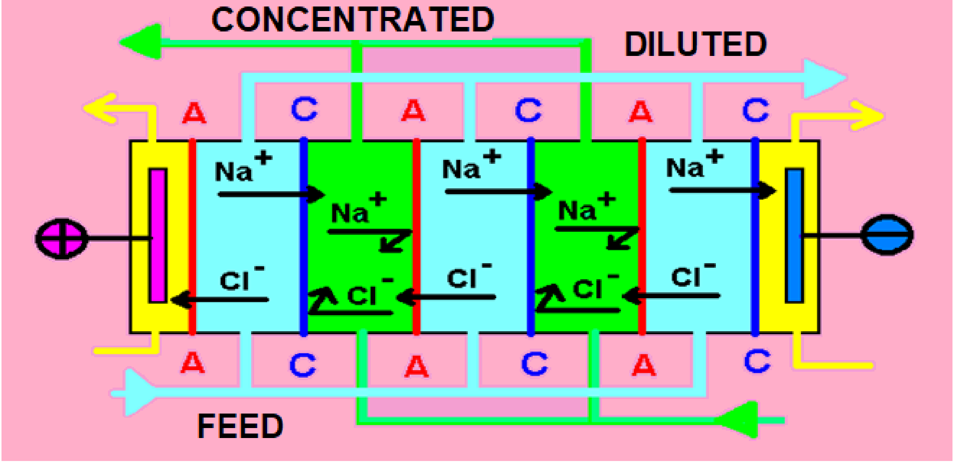


Microfiltration and Ultrafiltration

Reverse Osmosis
Forward Osmosis

Ion-exchange Membranes





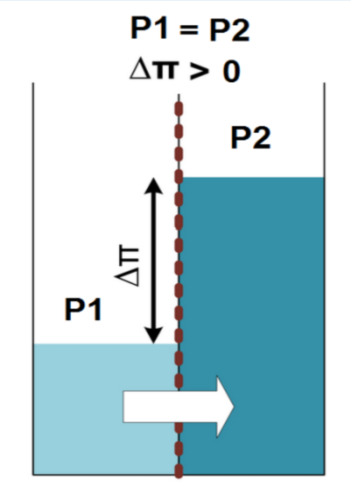
Electrodialysis

OSMOSIS PROCESSES

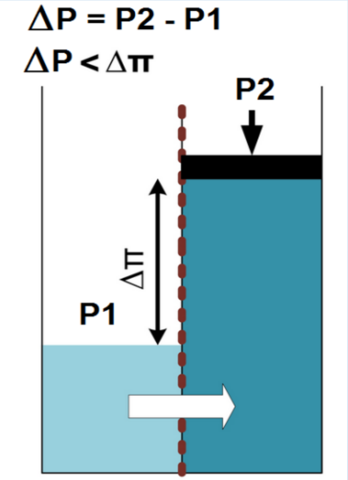
FORWARD OSMOSIS
The osmotic pressure difference between the two solutions is the driving force for water transport through the membrane

PRESSURE RETARDED OSMOSIS
The hydraulic pressure minus the osmotic pressure difference between the two solutions is the driving force for water transport through the membrane.

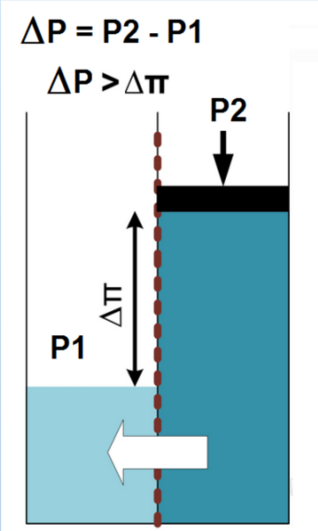
REVERSE OSMOSIS
The hydraulic pressure minus the osmotic pressure difference between the two solutions is the driving force for water transport through the membrane.



Forward Osmosis (FO)



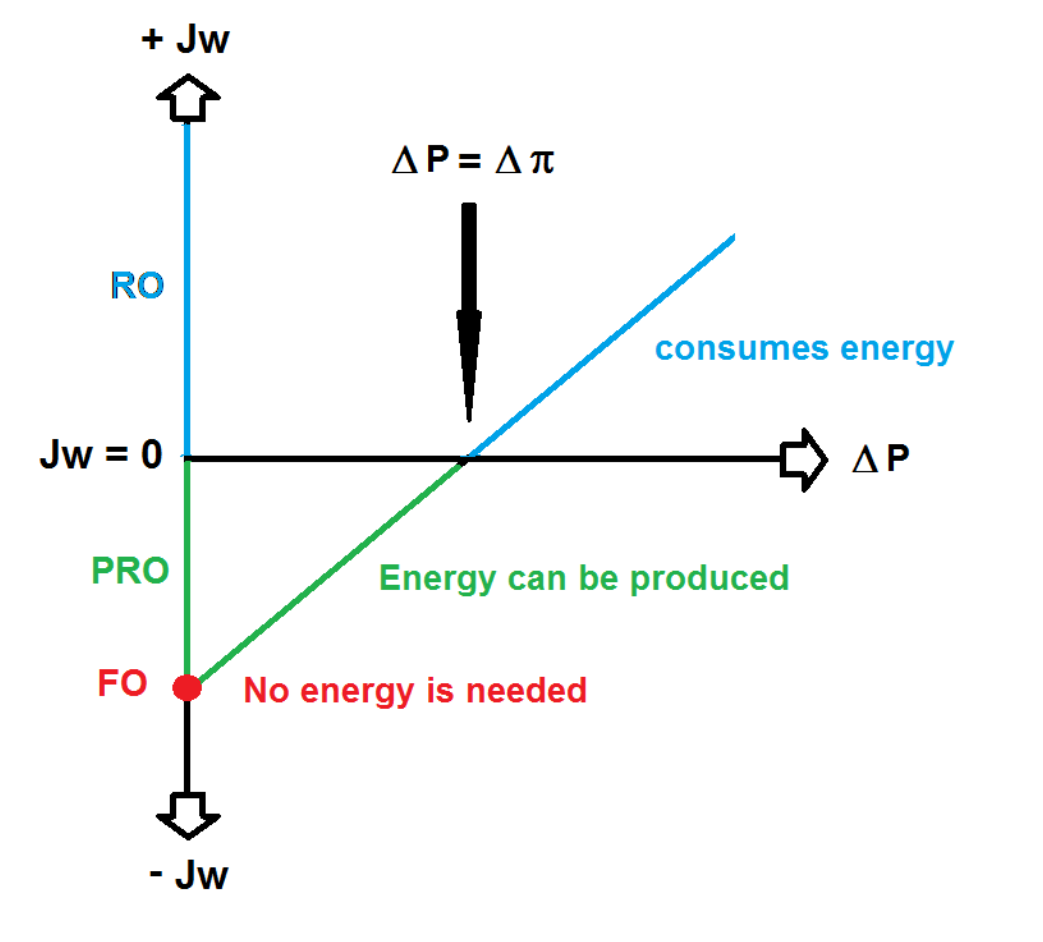
Pressure Retarded Osmosis (PRO)

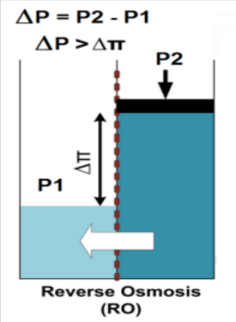


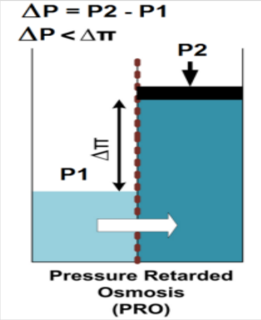
Reverse Osmosis (RO)

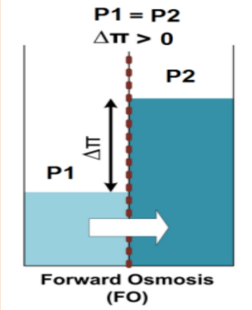
In PRO mode the hydraulic pressure cannot counteract the osmotic pressure and therefore the water transport through the membrane is going from the dilute solution to the concentrated.

PRESSURE, FLUX OF WATER AND ENERGY IN THE OSMOSIS PROCESSES









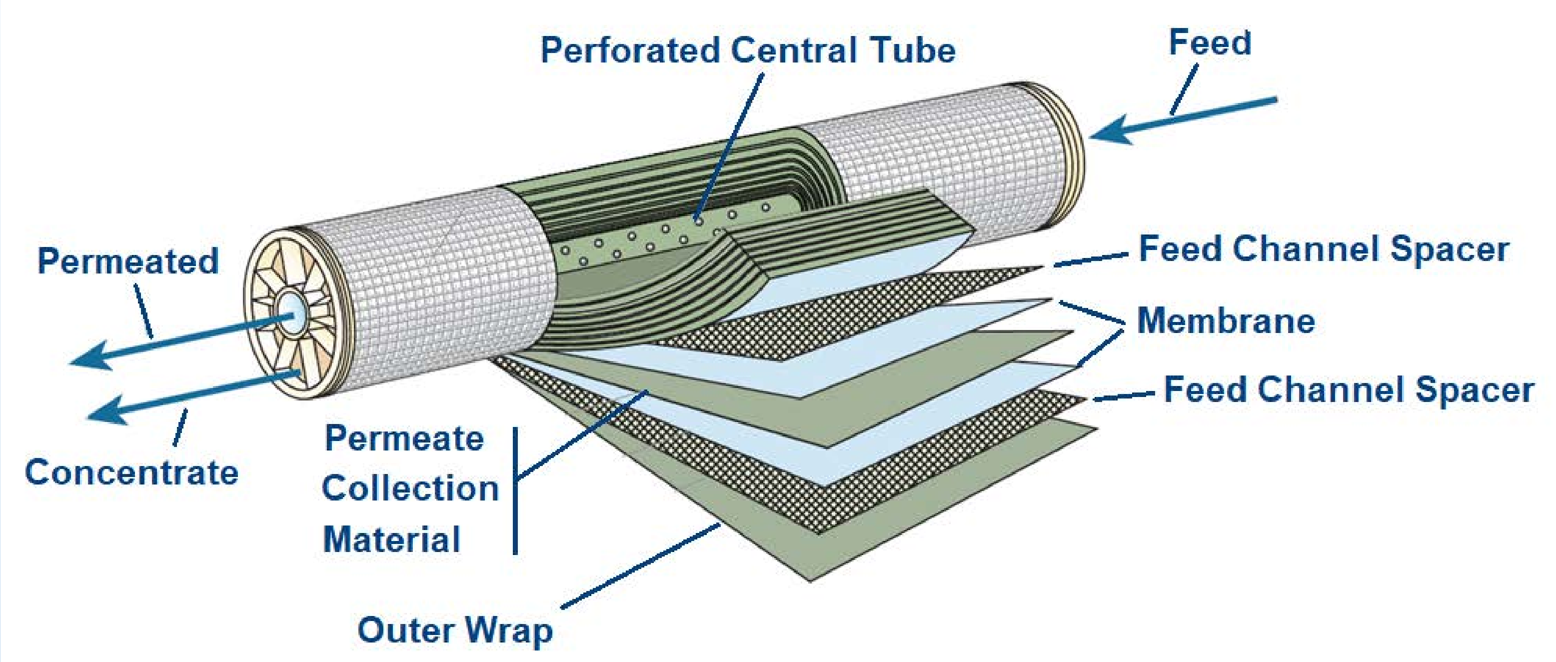
$$\textit{Power generated} = \Delta P \cdot (-J_w)$$

MEMBRANE PROCESSES, MECHANISMS, PORE SIZE AND MEMBRANE STRUCTURE

Membrane processes	Mechanisms	Pore size (Å)	(nm)	Membrane structure
MF	Size exclusion	500-50000	50-5000	Macropores
UF	Size exclusion	20-50	2-5	Mesopores
NF	Size exclusion + Solution-diffusion	<20	< 2	Micropores
RO	Solution-diffusion + Size exclusion	<5	< 0.5	Dense
ED	Ionic exchange	-	-	Ionic exchange

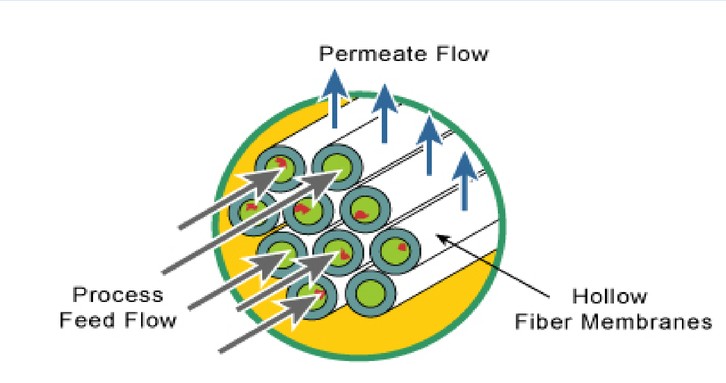
MEMBRANE CONFIGURATION

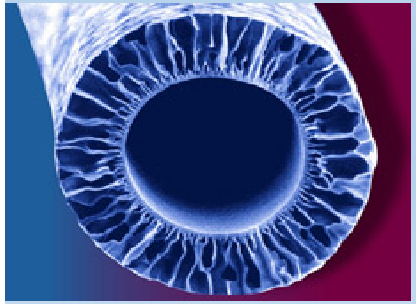
Spiral Wound Membrane



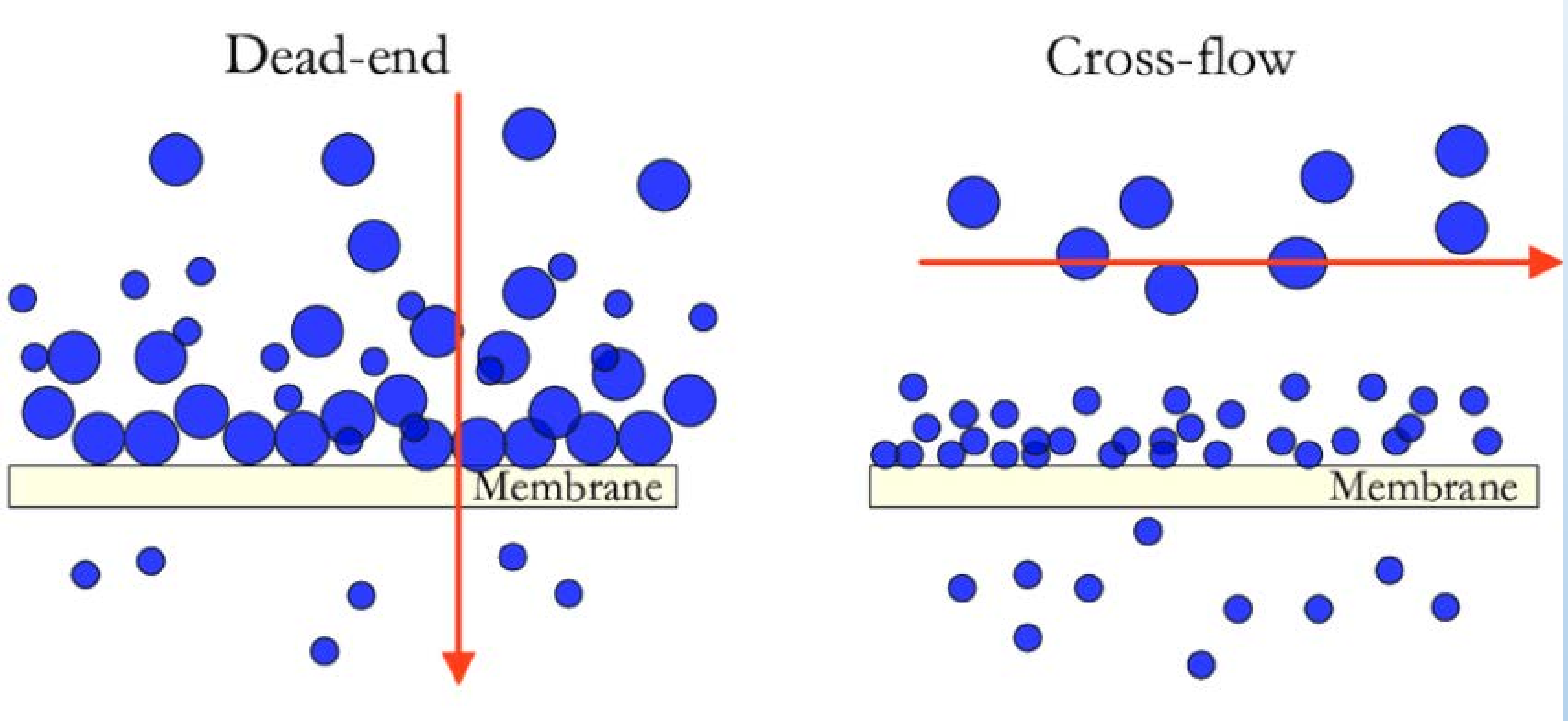
Tubular Membrane

Hollow Fiber Membrane





DEAD END FILTRATION AND CROSS FLOW FILTRATION

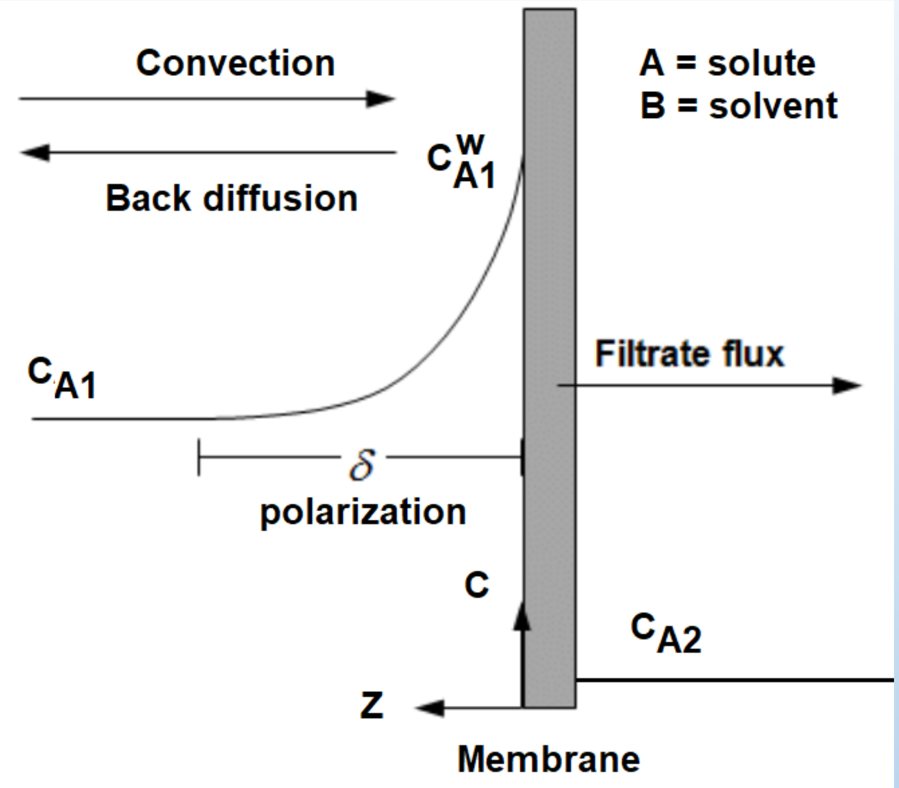


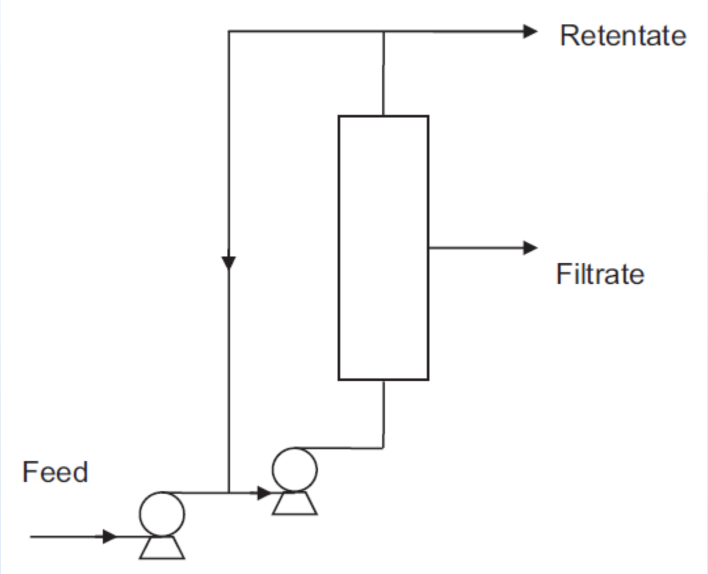
CONCENTRATION POLARIZATION

Typically, the flowrate through the module greatly exceeds the feed flowrate, and thus the increased flowrate through the module as a result of the recirculation loop also increases the mass transfer coefficient.

$$N_B = C_B \cdot \frac{D_{AB}}{\delta} \cdot \ln \frac{C_{A1}^{w} - C_{A2}}{C_{A1} - C_{A2}}$$

K_L

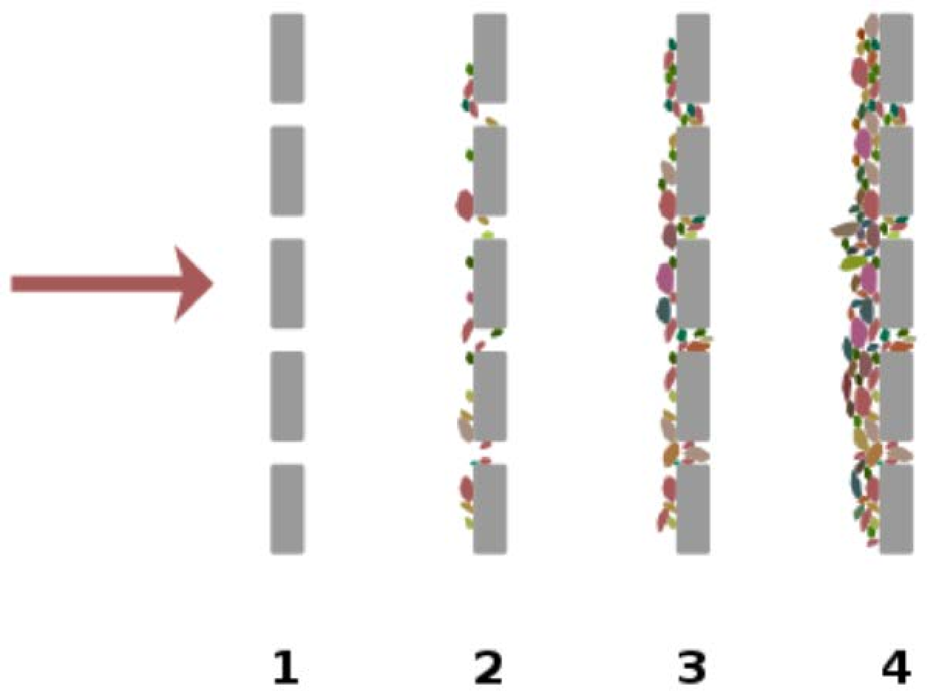




Continuous feed-and-bleed

Concentration Polarization refers to the concentration gradient of salts on the high pressure side of the membrane surface. The salt concentration in this boundary layer exceeds the concentration of the bulk water. This phenomenon impacts the performance of the process by increasing the osmotic pressure at the membrane's surface, reducing flux, increasing salt leakage and increasing the probability of scale development. Increasing the velocity (turbulence) of the concentratde stream helps to reduce concentration polarization.

MEMBRANE FOULING



Silt density Index (SDI)

Silt Density Index testing is a widely accepted method for estimating the rate at which colloidal and particle fouling will occur in reverse osmosis (RO) membranes.

The test is defined in ASTM Standard D4189. It measures the time required to filter a fixed volume of water through a standard 0.45µm pore size microfiltration membrane with a constant given pressure of 30 psi (2,07 bar). The difference between the initial time and the time of a second measurement after normally 15 minutes (after silt-built up) represents the SDI value.

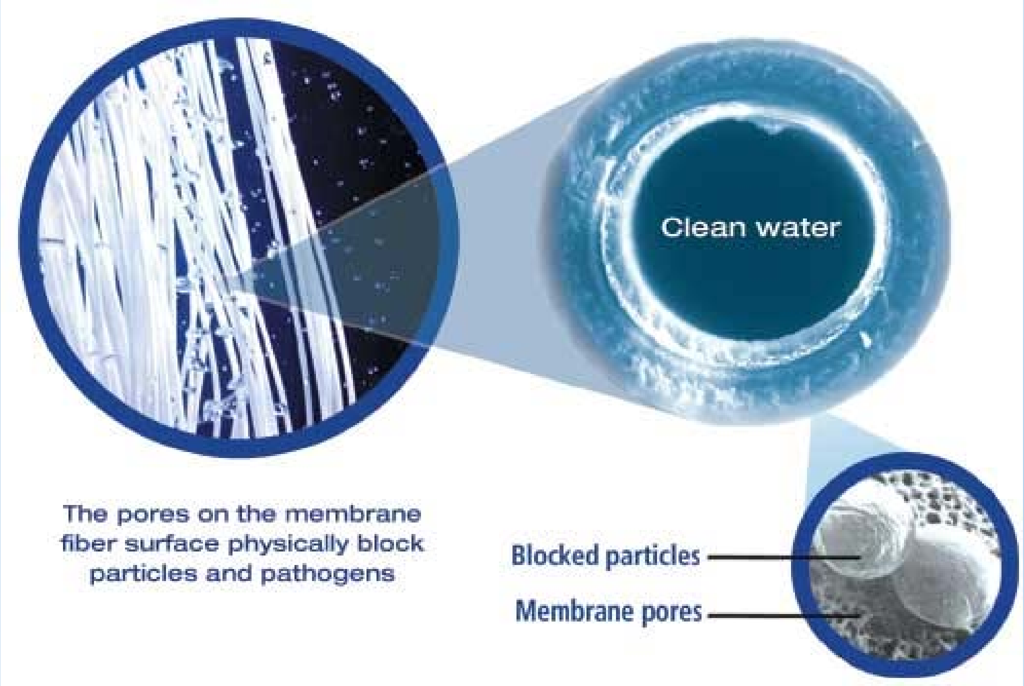
SDI < 1	Several years without colloidal fouling
SDI < 3	Several months between cleaning
SDI 3 – 5	Particular fouling likely a problem, frequent cleaning
SDI > 5	Unacceptable, additional pre-treatment is needed

PRETREATMENT TO PREVENT COLLOIDAL FOULING

MF and UF may be an ideal pretreatment method for RO because it allows removing suspended solids (SS) and colloidal materials completely and reliably without chemicals.

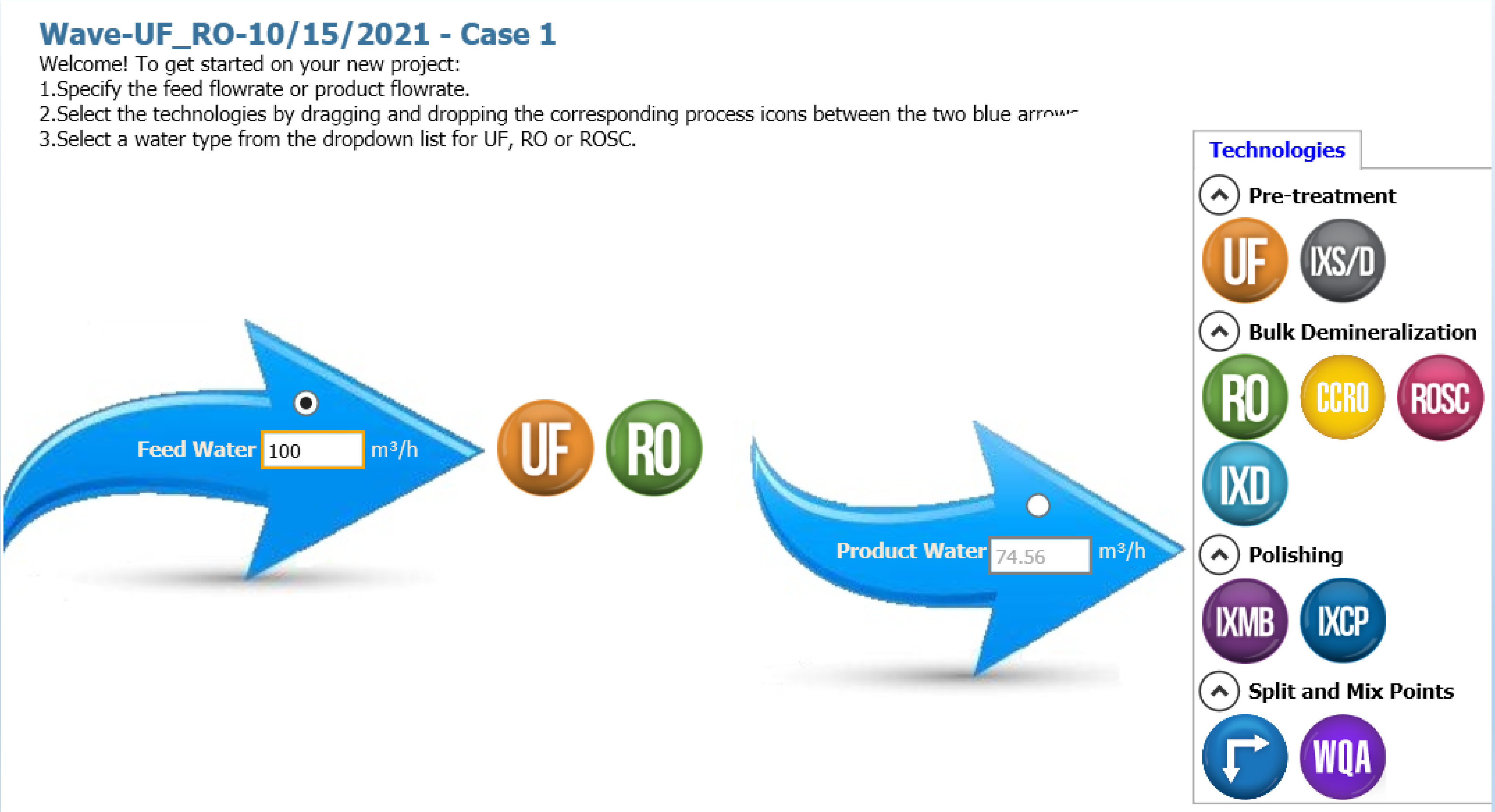
Ultra filtration (UF) hollow fiber (HF) membranes are very effective in this process.

In these pretreatments, a flux as high as 100 $L/m^2 \cdot h$ (100 LHM) can be attained at a transmembrane pressure of 0.15 - 0.20 bar.



Membrane feed water quality criteria is SDI less than 3 and turbidity less than 0,2 NTU

SOFTWARE FOR WATER-TREATMENT PLANT DESIGN: WAVE (DuPont)



ULTRAFILTRATION PRETREATMENT

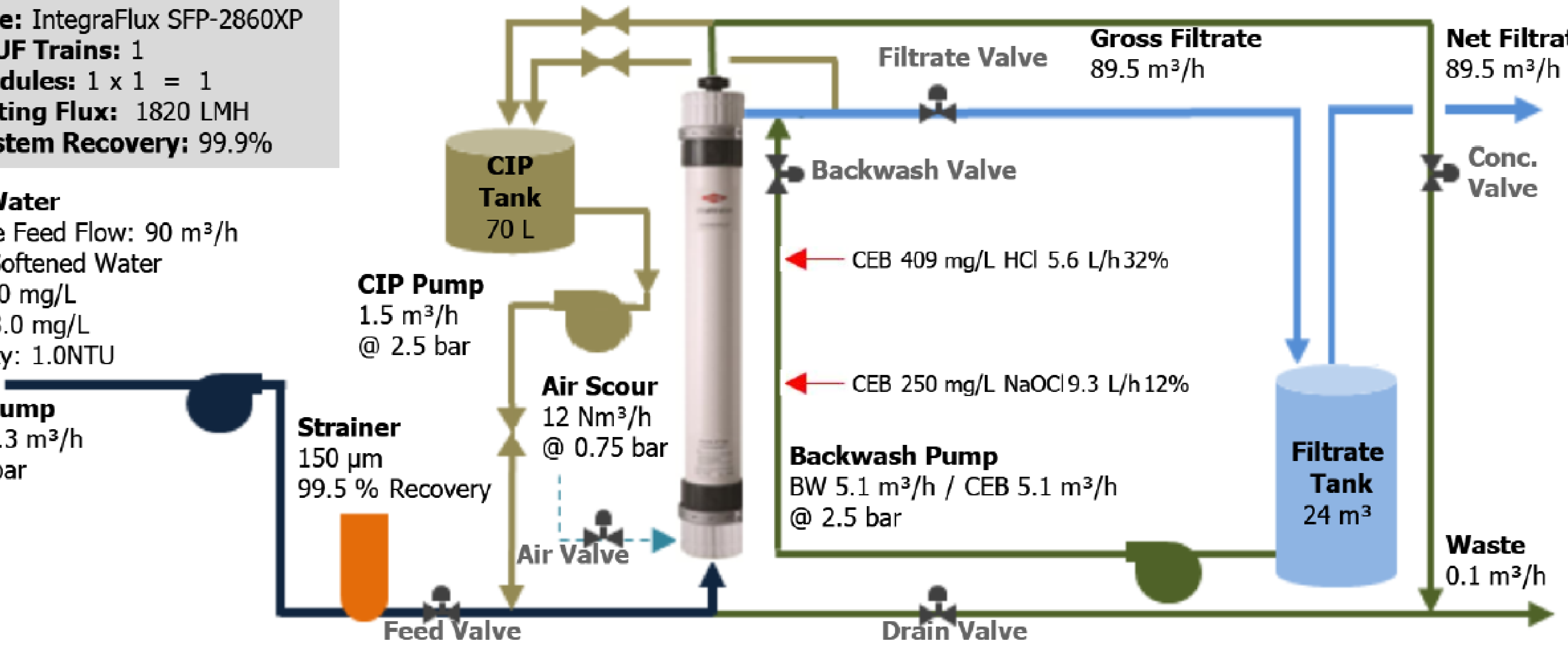
WATER APPLICATION VALUE ENGINE
WATER SOLUTIONS

UF Detailed Report

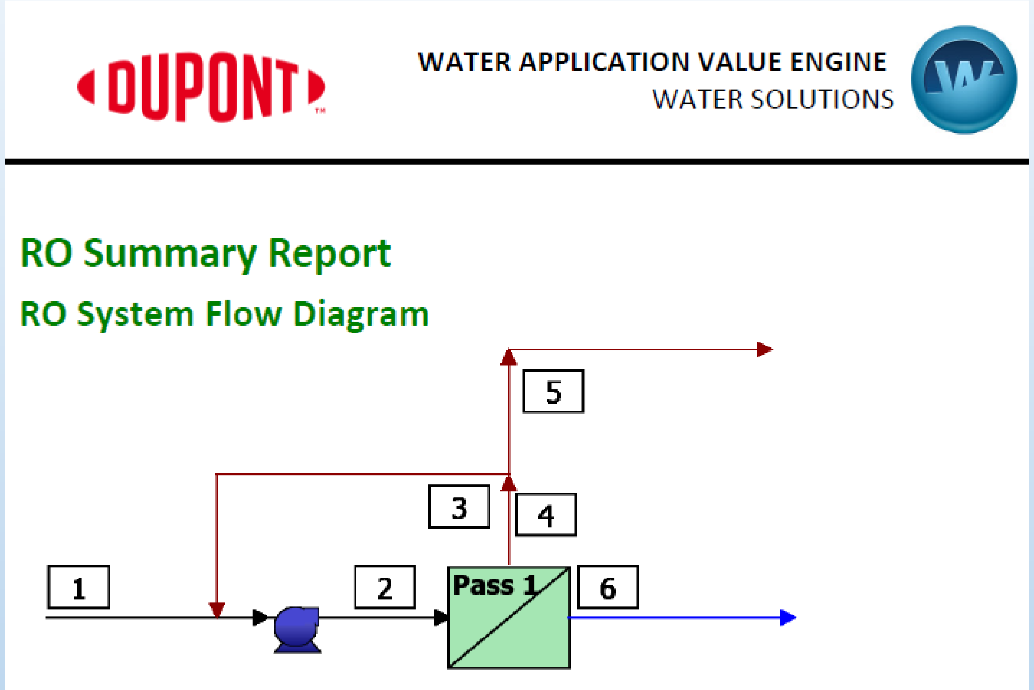
Module: IntegraFlux SFP-2860XP
Total UF Trains: 1
UF Modules: 1 x 1 = 1
Operating Flux: 1820 LMH
UF System Recovery: 99.9%

Feed Water
Average Feed Flow: 90 m³/h
Type: Softened Water
TSS: 0.0 mg/L
TOC: 3.0 mg/L
Turbidity: 1.0NTU

Feed Pump
Max 93.3 m³/h
@ 3.3 bar

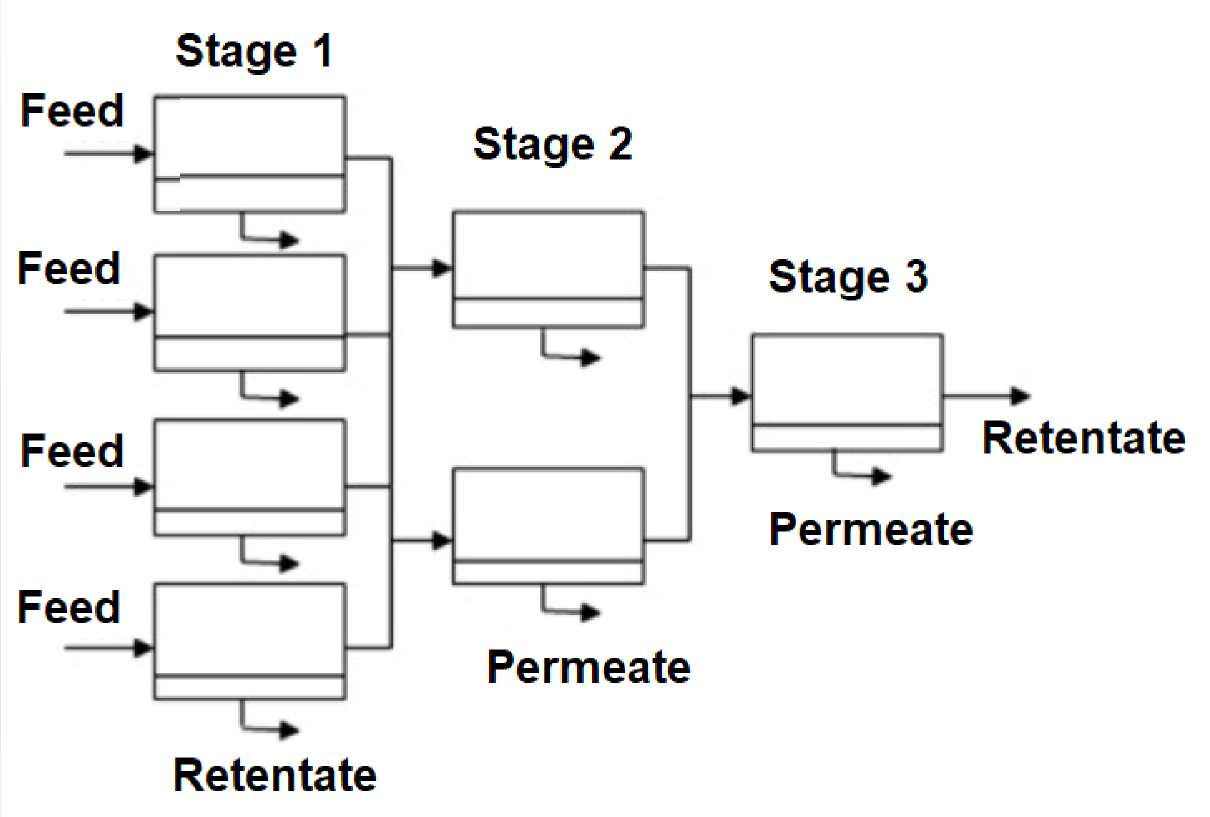


REVERSE OSMOSIS (RO)



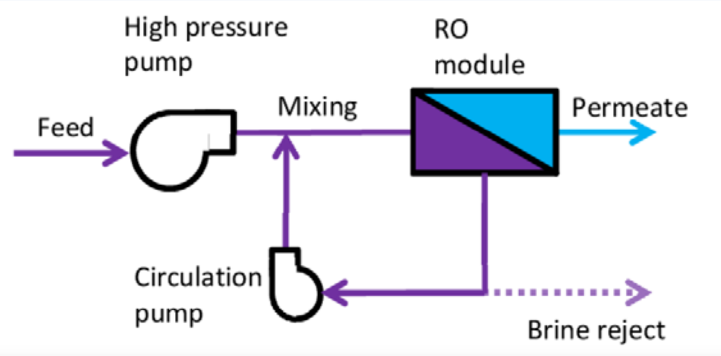
Conventional large-scale RO systems that typically employ pressure vessels containing six to eight membranes modules connected in series and arranged in stages in “Christmas Tree” configurations.

The **global recovery**, (total permeate) / (final retentate), can reach values 0.8 - 0.9. The recovery in each membrane module is less than 0.2.

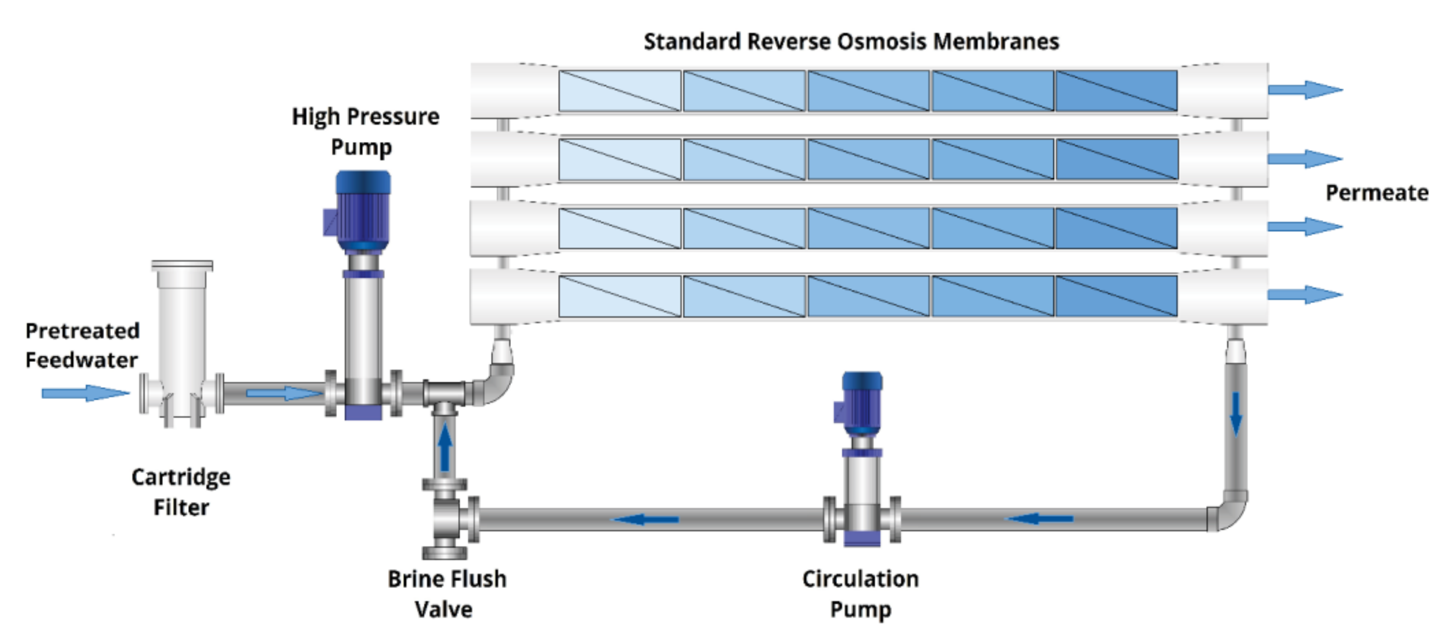


CLOSED CIRCUIT REVERSE OSMOSIS (CCRO)

Closed Circuit Reverse Osmosis (CCRO) combines the benefits of dead-end filtration with crossflow filtration recirculating pressurized retentated until a desired recovery level is reached.



Using standard components configured in an **single-stage design**, recovery, flux and crossflow are uncoupled with standard triggers to purge concentrate based on volumetric recovery, pressure and/or conductivity. The global recovery, (total permeate) / (final retentate), can **reach values as high as 0,95**.

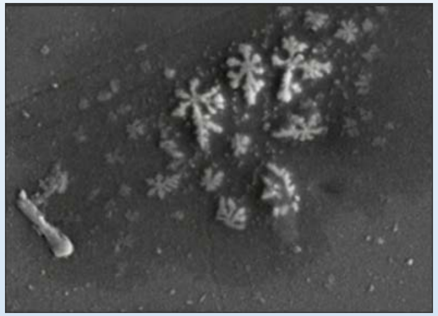


RO ANTISCALANT

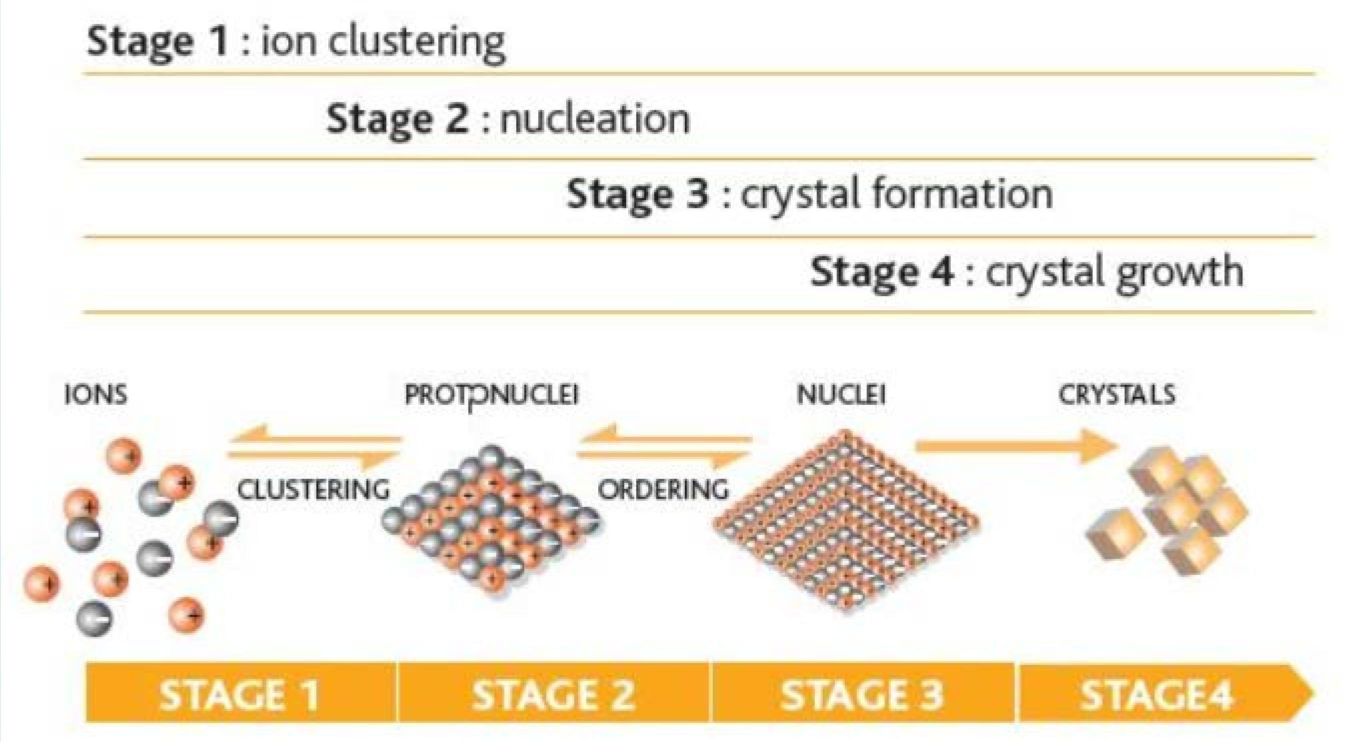
The presence of carbonates, sulfates, fluorures, calcium, barium and silica in the feed stream can produce precipitates on the membrane surface.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow$$

$$Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4 \downarrow$$



Antiscalant chemicals are used to prevent the scaling & fouling of the RO membranes. Scale may consist of mineral fouling such as calcium sulfate, calcium carbonate, barium sulfate, silica, calcium fluoride, and strontium sulfate. The Antiscalant dosing should be done before reaching the RO membranes to break up sulfate precipitates, calcium carbonate, and other mineral fouling.



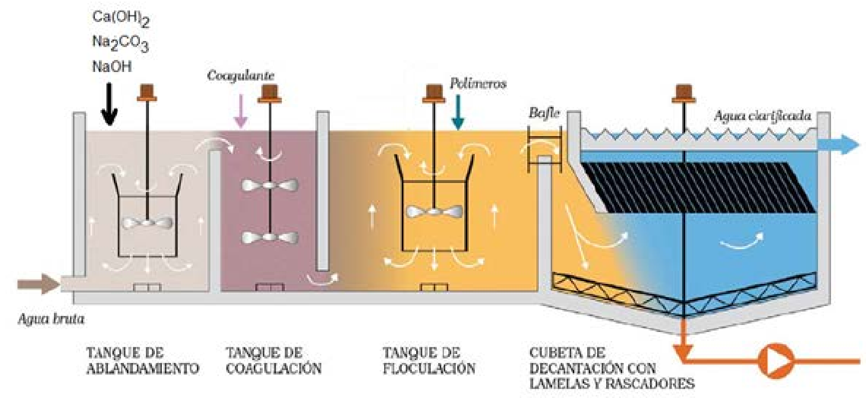
SOFTENING

$$Ca^{2+} + 2 \cdot HCO_3^- + CaO \rightarrow 2 \cdot CaCO_3 \downarrow + H_2O$$

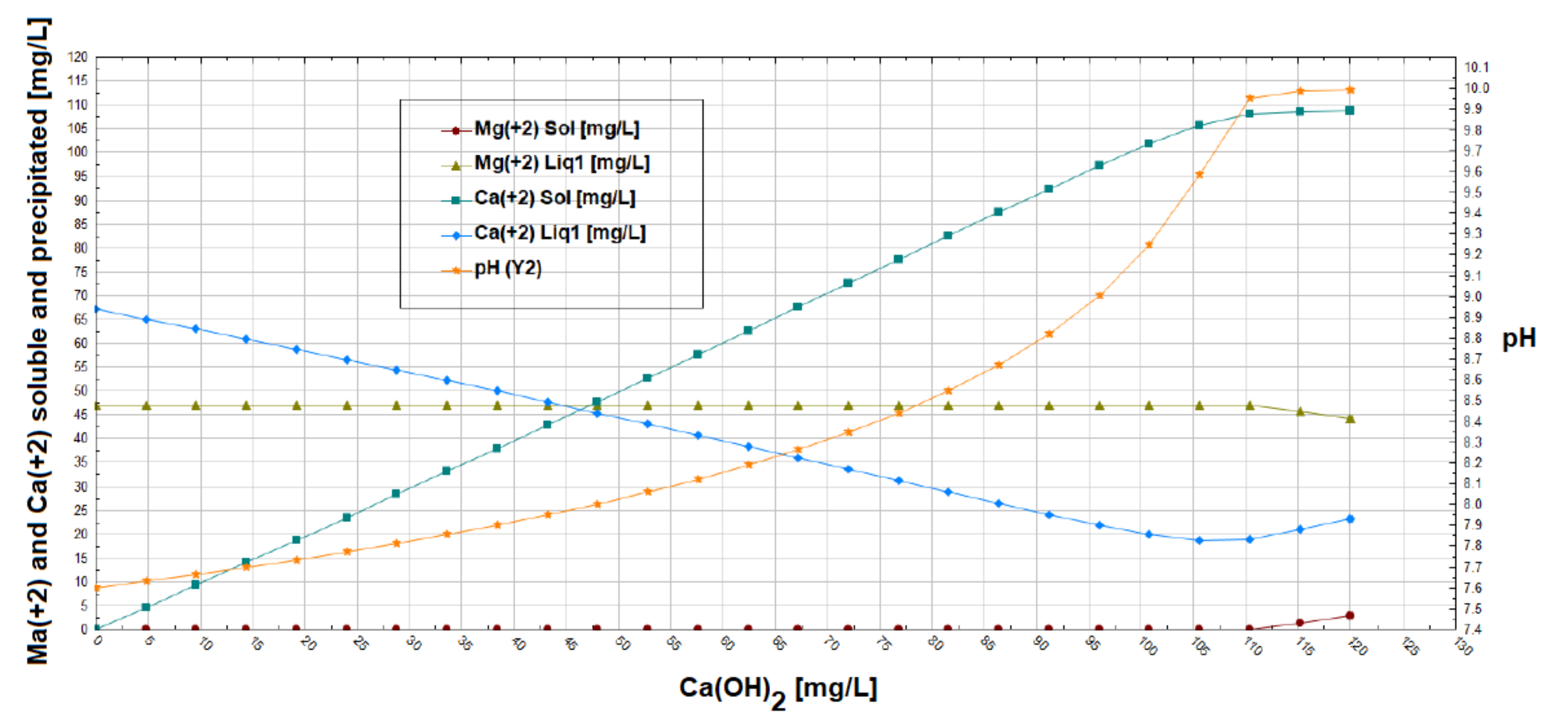
$$Ca^{2+} + Na_2CO_3 \rightarrow CaCO_3 \downarrow + 2 \cdot Na^+$$

$$Mg^{2+} + 2 \cdot NaOH \rightarrow Mg(OH)_2 \downarrow + 2 \cdot Na^+$$

Water softening is the removal of calcium, magnesium, and certain other metal cations in hard water. The resulting soft water requires less antiscalant and the RO process can attain higher global recovery.

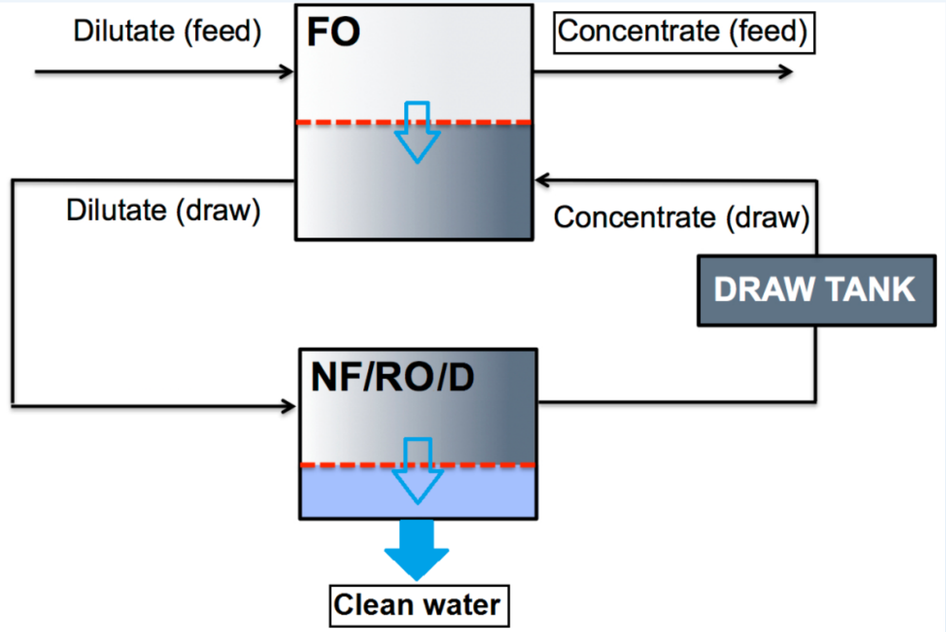


Esquema d'un equip de softening (estovament) convencional.



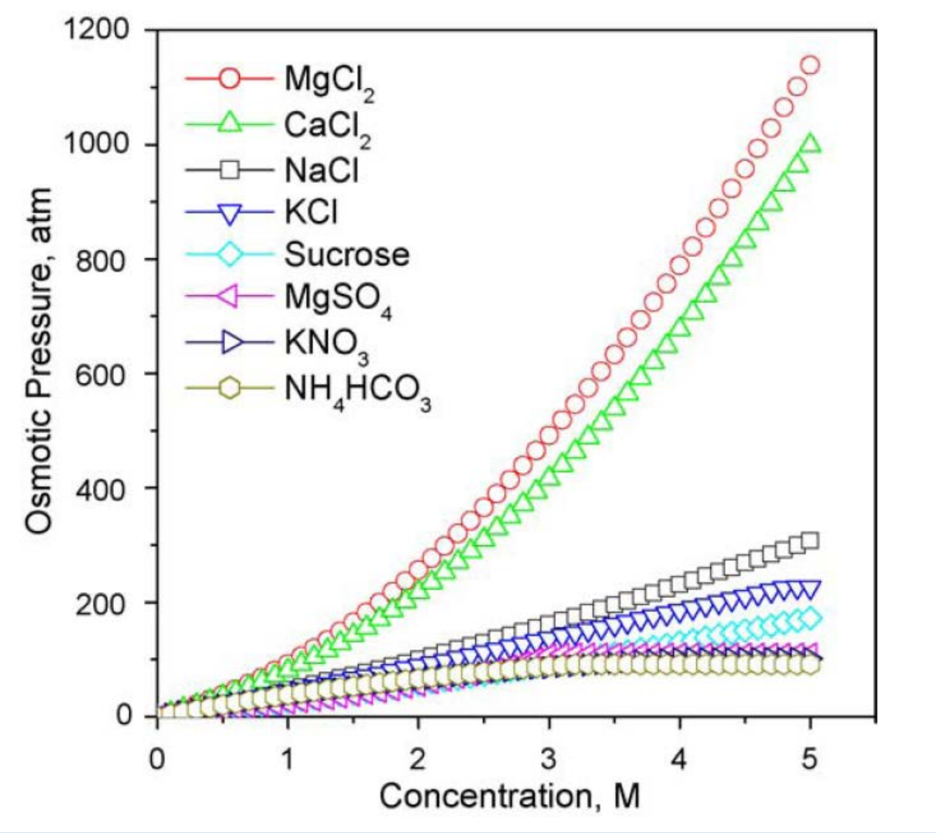
$$Ca^{2+} + 2 \cdot HCO_3^- + CaO \rightarrow 2 \cdot CaCO_3 \downarrow + H_2O$$

FORWARD OSMOSIS, FO.



Outputs of FO are a **concentrated feed solution** and **permeate clean water**. Diluted draw solution is regenerated via RO, NF or a distillation process (D).

OSMOSTIC PRESSURES OF SOME DRAW SOLUTIONS, DS

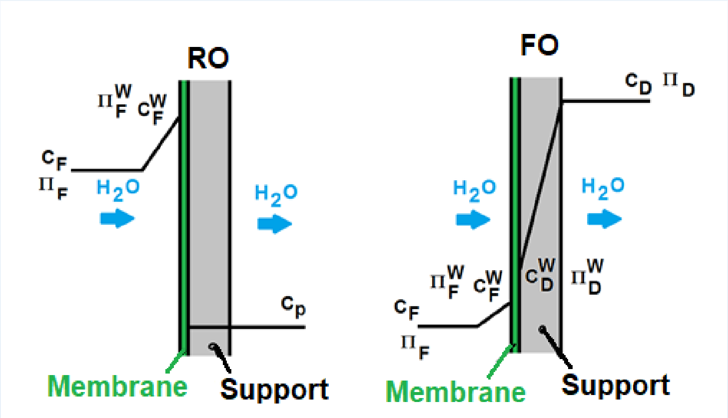


Draw solutions with high osmotic pressure (> 150 bar) are especially interesting because the hybrid FO process can treat concentrated solutions that are not treatable with RO

Characteristics of draw solutions

- High solubility (high osmotic pressures and avoiding scaling during RO)
- Low permeability through the FO membrane (uncontaminated feed)
- Low viscosity and high diffusivity (less internal concentration polarization)
- Easy regeneration (efficient recovery)

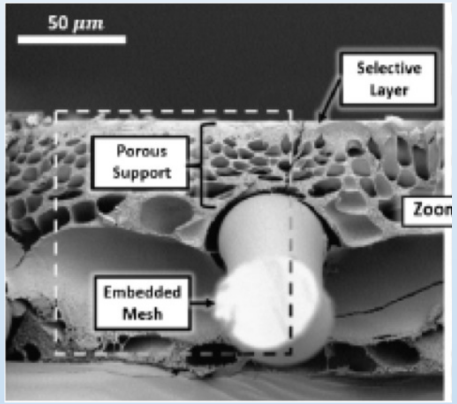
INTERNAL CONCENTRATION POLARIZATION IN FORWARD OSMOSIS



FO mathematical model:

$$J_w = A \cdot \sigma \left(\Pi_D^w - \Pi_F^w\right) \left[\frac{m^3}{m^2 \cdot s}\right]$$

$$\Pi = n \cdot R_g\, T \cdot C\, [Pa]$$



HTI Thin Film Composite (TFC) membrane. (Desalination 343, 2014, 187-193)

$$J_s = (1-\sigma) J_w \frac{C_D^w + C_F^w}{2} - (1-\sigma) J_w \frac{C_D^w - C_F^w}{2} Coth\left(\frac{J_w(1-\sigma)}{2B}\right) \left[\frac{mol}{m^2 \cdot s}\right]$$

External concentration polarization

$$\frac{C_F^w}{C_F} = Exp\left(\frac{J_w}{k_F}\right)$$

Internal concentration polarization

$$\frac{C_D^w}{C_D} = Exp\left(\frac{-J_w}{k_D}\right) ; \quad k_D = \frac{D_s}{S} ; \quad S = \frac{t \cdot \tau}{\varepsilon}$$

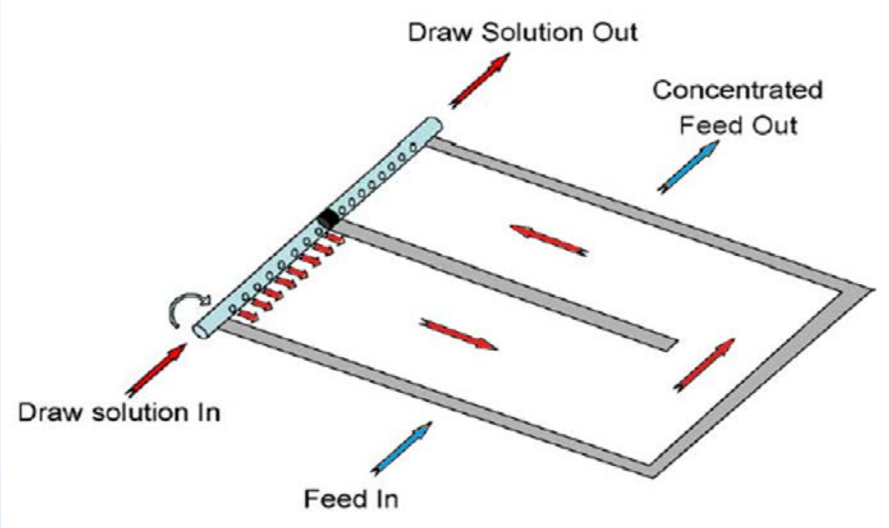
The support structural parameter, S, can be determined with FO experiments

$$S = \frac{D_s}{J_w} Ln\left(\frac{B + A \cdot \Pi_D}{B + A \cdot \Pi_F + J_w}\right)$$

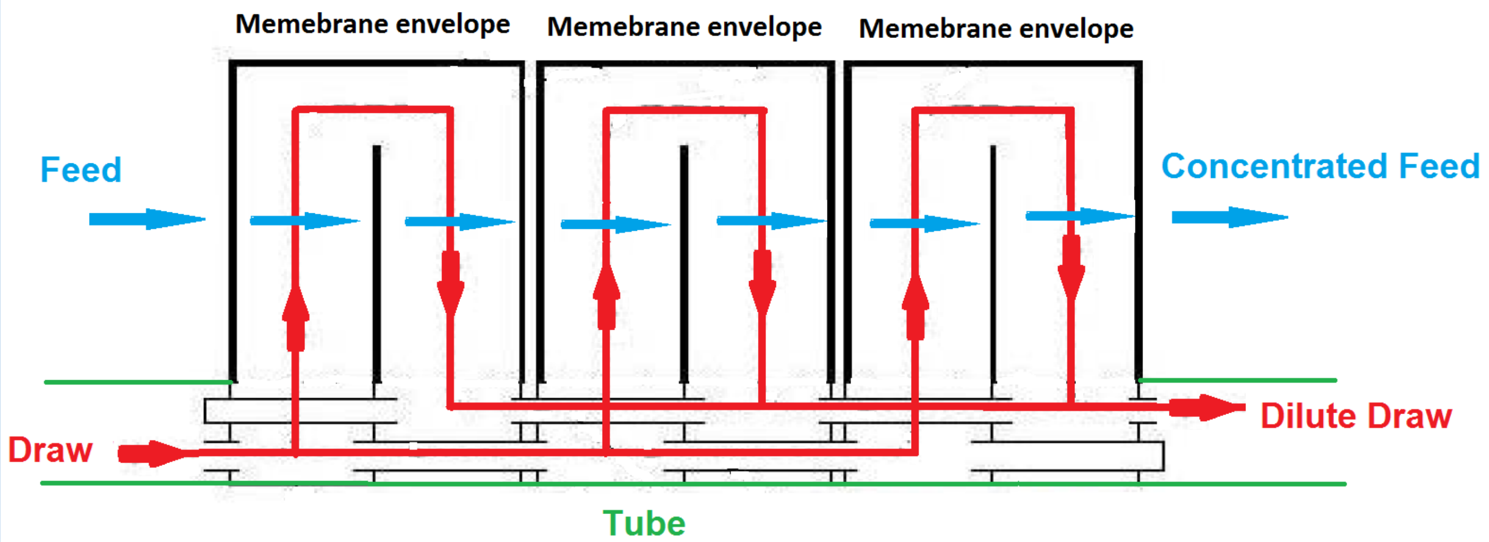
Parameters:

A, B, S y σ

SPIRAL WOUND MEMBRANE MODULES FOR FO



Spiral wound modules for FO are different of spiral wound modules for RO. They are modified to allow forced-flow inside the membrane envelopes. Membranes for FO are also different for FO.



THANK YOU

FOR

YOUR ATTENTION