Moving From Reverse to Forward

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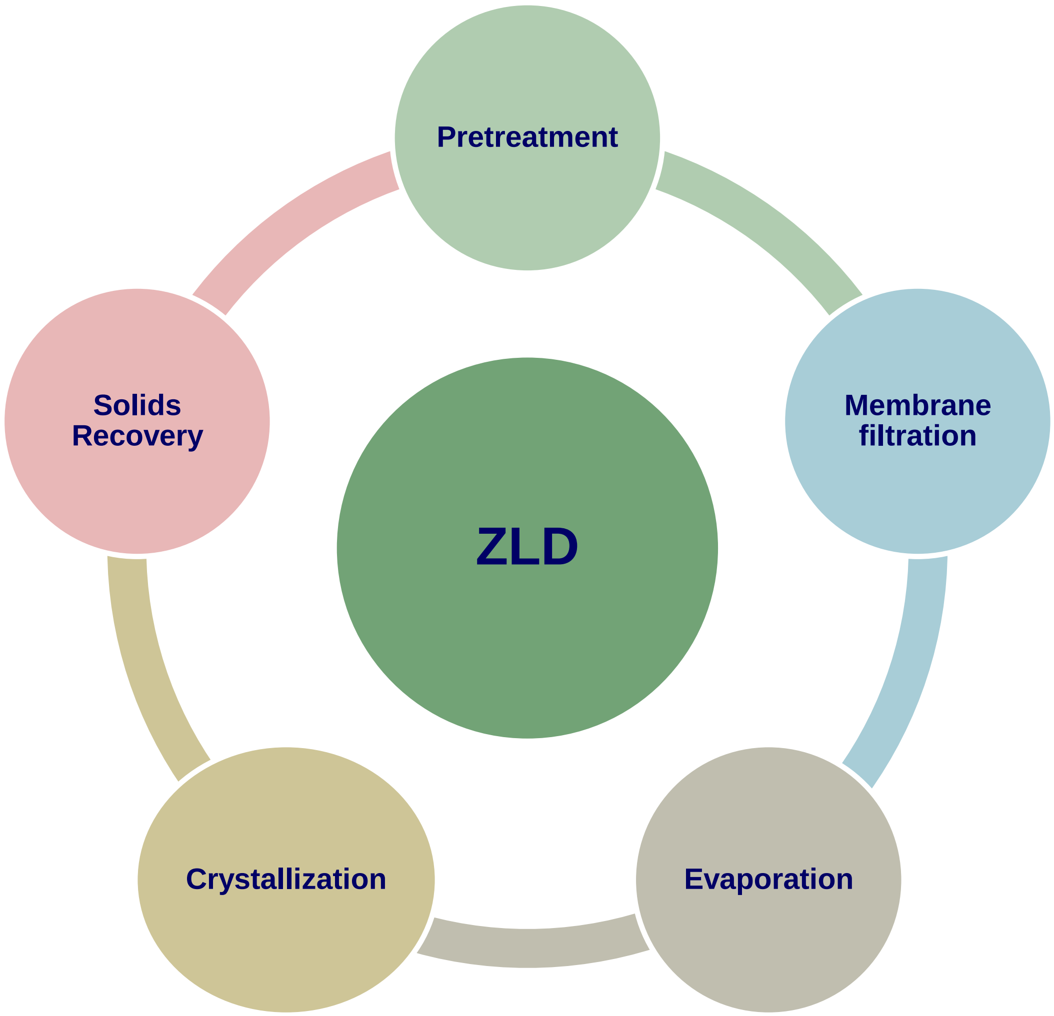
Talking Points

- Forward Osmosis – An Overview
- FO – How it works & Why it is important?
- FO vs RO
- Challenges and Ways to overcome
- Enhanced Recovery of water and nutrients

Zero Liquid Discharge

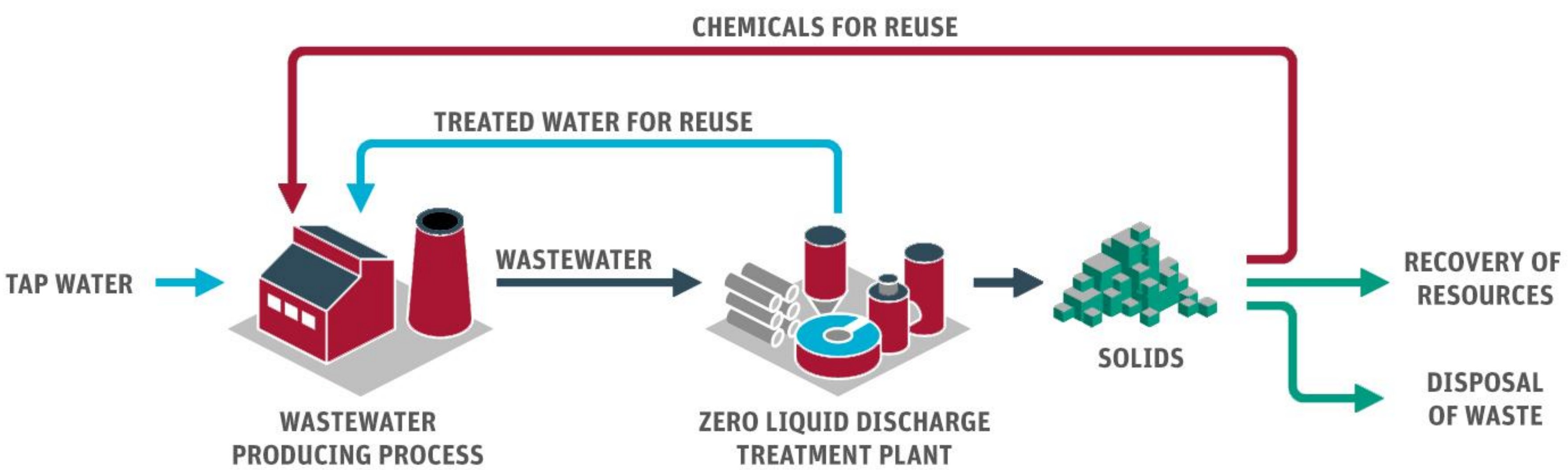


Zero Liquid Discharge (ZLD) is an <u>advanced treatment</u> process in which almost all wastewater from various industrial processes is treated and reused, therefore leaving behind zero effluent or liquid discharge.

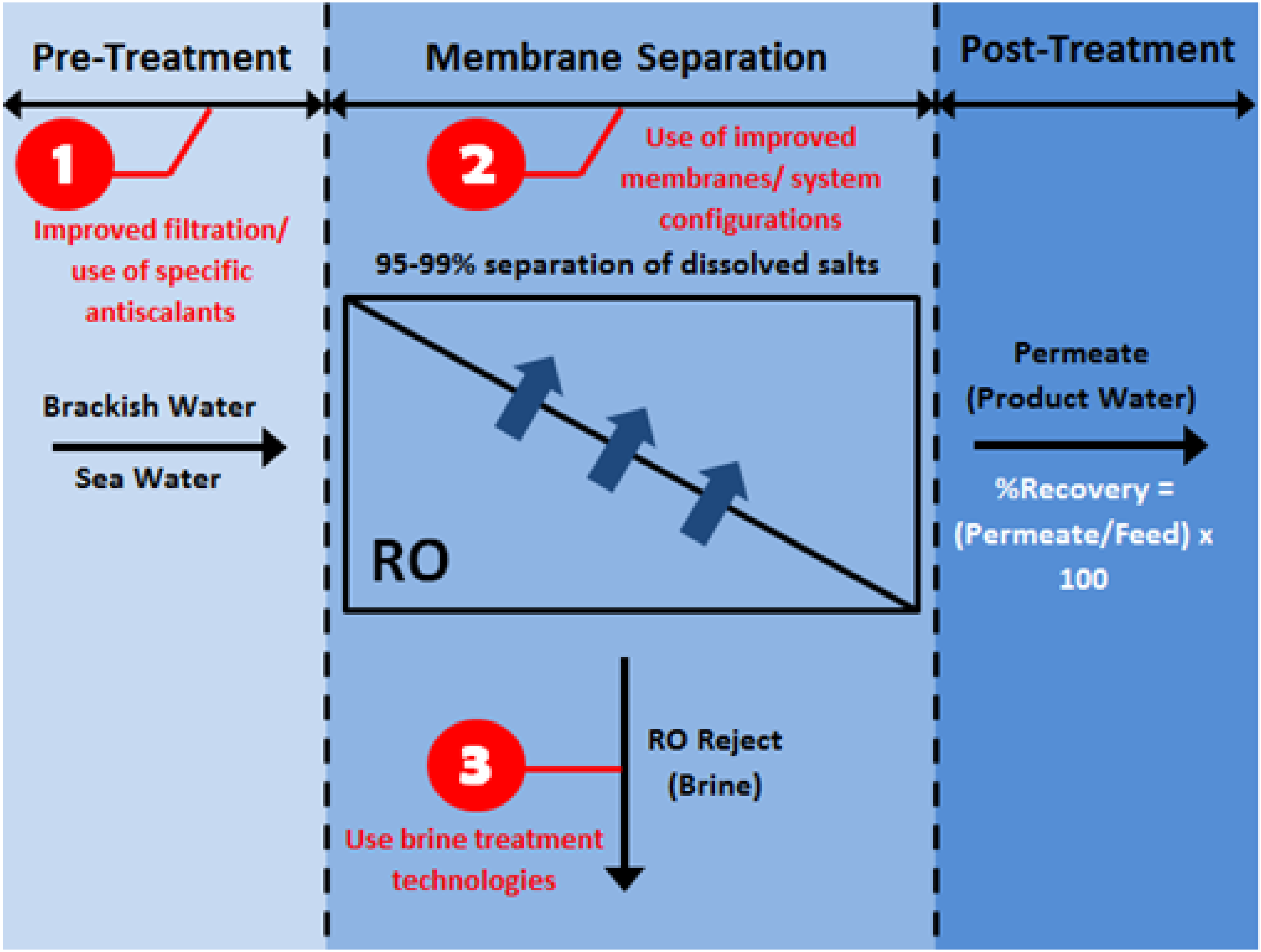
Need for ZLD

- High Salinity Wastewater (TDS> statutory limit of 2100 mg/L)
- High cost of water (> Rs 40) prime driver for ZLD
- Environmental regulation on discharge of specific solutes

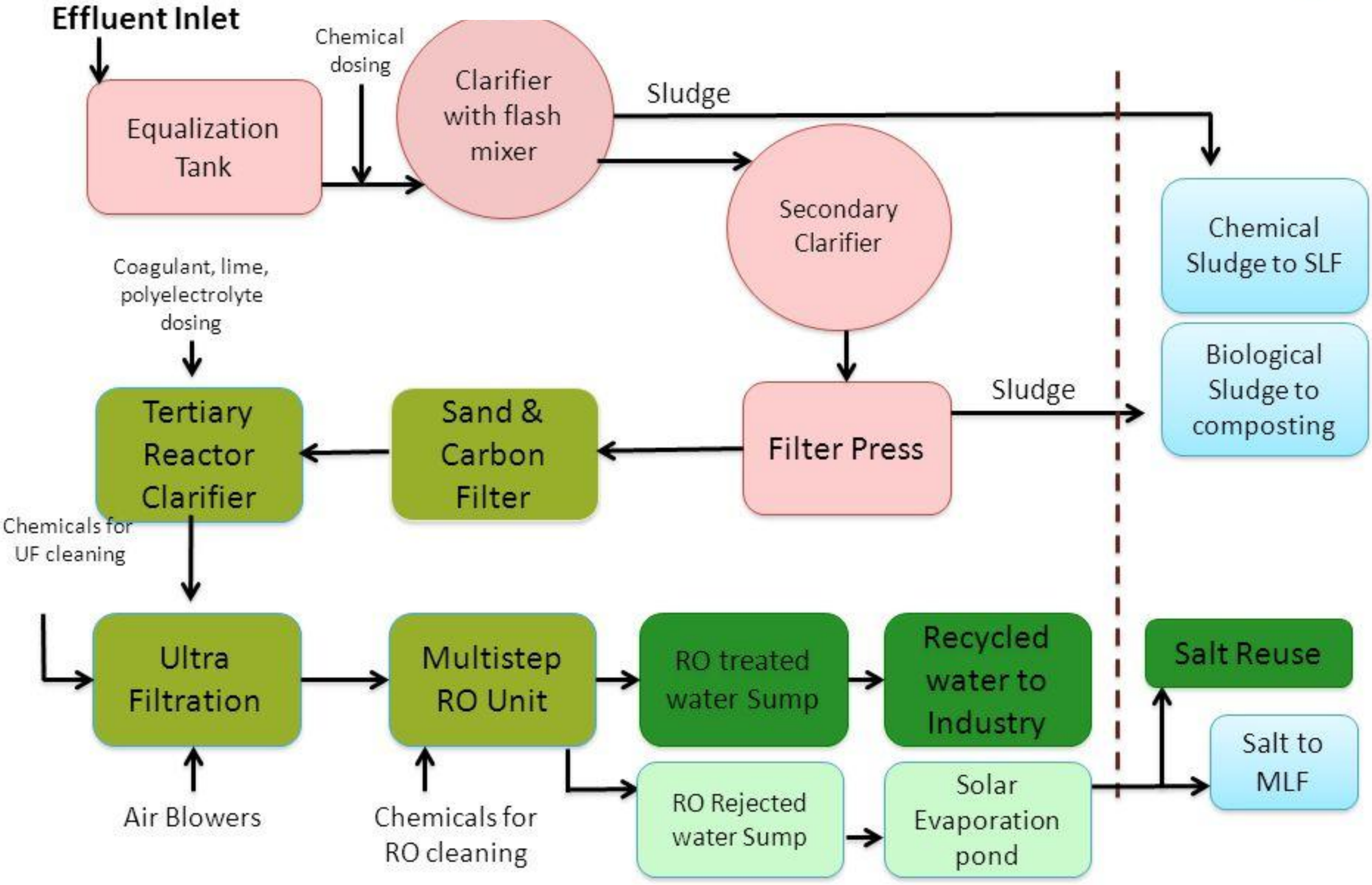
Brackish water: 1,000 -10,000 mg/L TDS
Salt water from the ocean: ~35,000 mg/L TDS



ZLD


Pre-Treatment
Membrane Separation
Post-Treatment
1
Improved filtration/
use of specific
antiscalants
2
Use of improved
membranes/ system
configurations
95-99% separation of dissolved salts
Brackish Water
Sea Water
RO
Permeate
(Product Water)
%Recovery =
(Permeate/Feed) x
100
3
RO Reject
(Brine)
Use brine treatment
technologies

Typical CETP Process



ZLD System

1. **Primary treatment removes 65-70% and 40-45% of incoming suspended solids and BOD respectively.**

2. **Extended Aeration Type Activated sludge process in Aeration tank I**

3. **Aeration Tank -2 where we have to maintain a D.O between 1.5 to 2.0 mg/lit and the outflows from the Clarifiers have a BOD of around 30 mg/l.**

4. **The treated effluent reaching the RO system is first subjected to softening and the softened effluent is further filtered and very fine filtration is obtained in an ultrafiltration system employing hollow fibre UF membranes.**

5. **The ultra-filtered effluent is desalinated in two stages Reverse Osmosis unit**.

6. **The reject from the RO are again subjected to third stage High Pressure RO to recover additional permeate and thereby reduce the volume of reject fed to the Multiple Effect Evaporator**

ZLD System

7. **The fuel used for producing steam is firewood and biomass briquette. The salt-laden solid residue is separated out in a pusher centrifuge.**

8. **The permeate from RO system and the condensate from evaporator are combined and distributed back to the industry for use in manufacturing process**

9. **The Sludge from the Primary, Secondary clarifiers and Reactivated clarifier are dewatered filter presses.**

10. **The dried sludge is then disposed of to the Secure Land Fill (SLF) system .**

11. **The salt-laden solid residue is stored in bags and a huge salt storage yard has been constructed for the purpose.**

ZLD Common Operations

While ZLD cost is high in most cases, it might be a more economic solution when waste needs to be transported in large volumes over long distances

Still ZLD has drawbacks, probably, the most significant are

Very high cost (both CAPEX and OPEX)
Custom-design on case-to-case basis
Difficulties to deal with complex streams (e.g., petrochemical)

- ZLD means all incoming TDS goes out as a sludge/solid
- Additional Brine concentration via RO
- Then evaporation, and crystallizer

O&M Cost for 5.5 Mld capacity

S No	Description	Operating Cost (Rs/m^3)
1	Variable Cost	112.4
2	Fixed cost	
	Manpower, Maintenance	34.5
3	Basic Operating cost	146.9
	Total Operating Cost	181.2
4	Recovery Cost – Water (70/KL)	68.6
	Recovery Cost – Salt (10/Kg)	63
5	Total Recovery cost	131.6
6	Net Operating Cost	49.6

Financial Impact of ZLD

S No	Items	Unit
1	Capacity	5500m3/day
2	Water consumption	60L/Kg
3	Production Capacity	92 t /day
4	Processing cost	Rs 80/kg
5	Processing cost /day	Rs 74 lakhs
6	Cost of ZLD (Rs 49.6/KL)	Rs 2.73 lakhs
7	Cost of ZLD per Kg	Rs 2.97/kg
8	% of ZLD cost on Processing cost	3.7%

Pressure Driven Technologies

Technology	Claimed Overall Recovery	Comments
Dual RO with Intermediate Chemical Demineralization	90% - 98%	• Combination of mature technologies. • Increased chemical dosage and sludge disposal required.
Dual RO with Pellet Softener (PS) or Fluidized Bed Crystallizer (FBC)	90% - 98%	• Combination of mature technologies. • Increased chemical dosage and sludge disposal required.
Seeded Slurry Precipitation and Recycle (SPARRO)	90% - 95%	• Proprietary technology. • Limited full-scale applications for municipal water treatment.

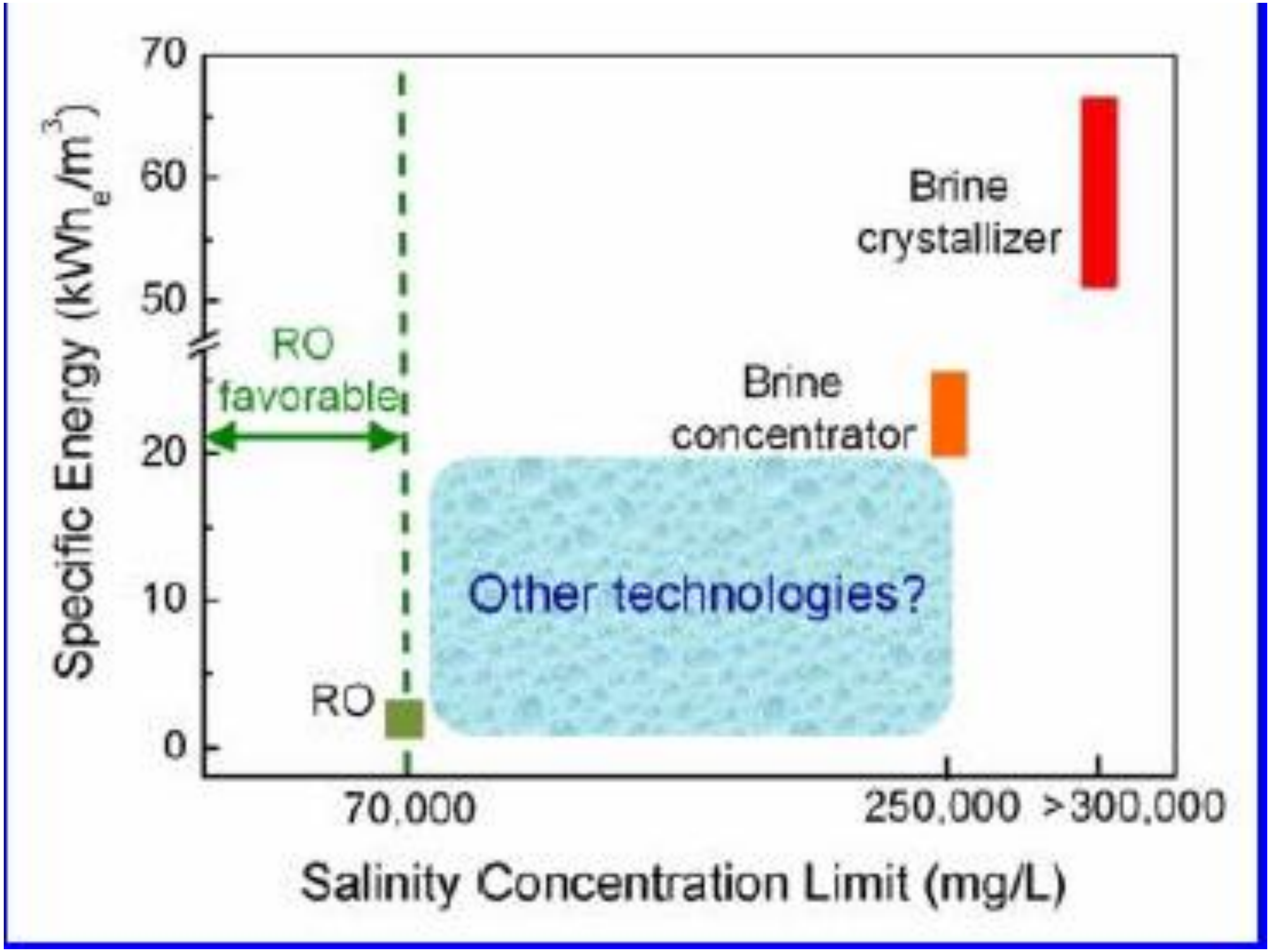
Technology	Claimed Overall Recovery	Comments
High Efficiency RO (HERO)	95% - 99%	• Proprietary technology. • High capital and O&M cost
High Efficiency Electro-Pressure Membrane (HEEPM)	95% - 99%	• Proprietary technology. • No applications for municipal water treatment.
Advanced Reject Recovery of Water (ARROW)	Up to 95%	• Proprietary technology. • No applications for municipal water treatment.
Optimized Pretreatment and Separation (OPUS)	90% - 98%	• Proprietary technology. • High capital and O&M cost.

Electric Potential/Thermal Technologies

Technology	Claimed Overall Recovery	Comments
Electrodialysis (ED) and Electrodialysis Reversal (EDR)	Up to 95%	• Effective for high silica content. • Limited effectiveness with high calcium sulfate saturation
Electrodialysis Metathesis (EDM)	Up to 98%	• Effective for high silica content. • Effective for operation of water with high calcium sulfate saturation.

Technology	Claimed Overall Recovery	Comments
Brine Concentrator	90% to 95%	• Mature technology • High capital and energy cost
Brine Crystallizer	Up to 98%	• Mature technology • High capital and energy cost

Why other technologies?



Nature of the Problem in the Evaporator.. 1

Fig: MVR type Evaporator System installed in all CETPs

- **Design Performance:**

  The Main MVR-Evaporators was designed to handle 15% of the R.O reject. The Auxiliary Evaporator is designed to handle 2% of the regenerate liquor from Softener and Decolourant Resin filters. The MVR-Evaporator is designed for an overall recovery of >87.5% as condensate. The remaining concentrate was to be evaporated in an MEE along with crystallization of salt.

- **Reasons for the Choice of MVR**:
  - Typically replaces 4 or 5 stage of MEE.
  - Polymeric Heat Exchangers not prone to corrosion and replaceable.
  - Lower O&M cost than MEE due to lower steam requirements.

Nature of the Problem in the Evaporator.. 2

- **Actual Performance of MVR:**
  - MVR Feed at 80-85% of design
  - MVR Recovery at <70% (due to elevation in b.p).
  - Reduced recovery resulted in lower TDS in the concentrate and higher volume, resulting in overloading of the downstream MEE/ Crystallizer.
  - No glauber Salt crystallization. Reduced recovery in MVR required additional MEE stages and an Adiabatic Chiller to achieve desired feed volume, recovery and concentration to achieve crystallization.
  - Inability to handle BDTRF (decolorant and Softener resin regenerate) liquor due to choking of the polymeric heat exchangers due to higher hardness and organics.
  - Based on the above situation it was estimated that two streams of Seven effect Evaporators for MVR concentrate and BDTRF+Chiller Mother liquor will be required which will not only increase the capital cost by Rs. 10 Crores per MLD but also increase the operating cost to Rs. 300-350 per m3 of reject for evaporation and crystallization.

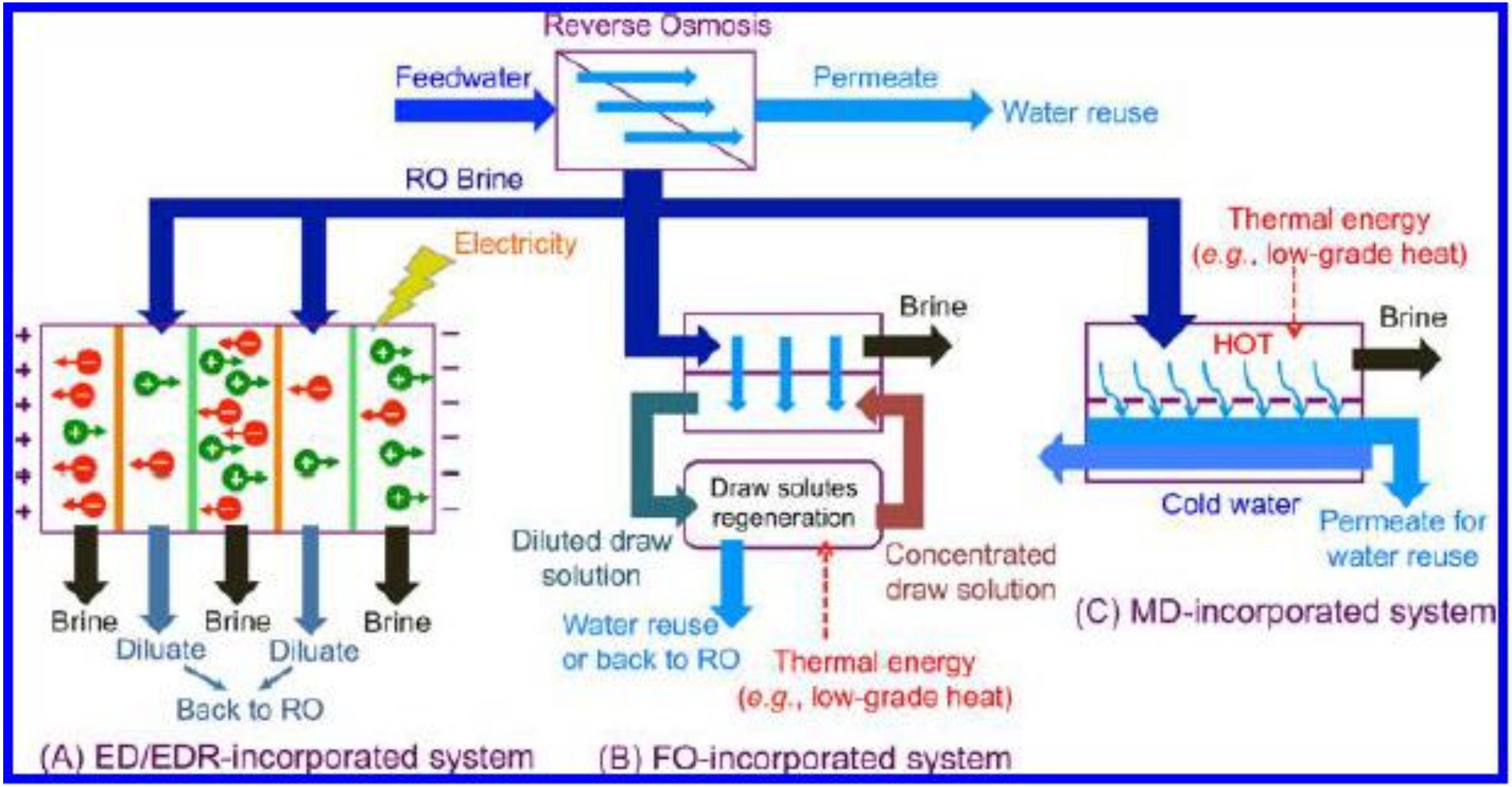
Other issues with Evaporator.. 1

- Use of the conventional Sodium Chloride based dyeing is problematic since crystallization of Chloride salt will produce a salt contaminated with Hardness and Colour due to its crystallization nature.
- Although the industry has accepted to use Sodium Sulphate for dyeing , the effluent typically contains Chlorides too (about 20% of the total salt load). Therefore it is a mixed salt.
- Separate crystallization strategies are required for Sulphate (adiabatic chiller) and the mixed salt (from the mother liquor of the chiller).
- >99% purity sodium sulphate can be obtained by Chilling, however the mother liquor of the chiller will be a mixed salt and will be contaminated with Hardness & Colour and therefore unfit for reuse.
- At best 80% of the sulphate (or 60 % of the total salt assuming 80: 20 ratio of Sulphate : Chloride) can be recovered in the adiabatic chiller. Meaning atleast 40% of the total salt in the effluent which is present in the chiller mother liquor would be a mixed salt and will need to be evaporated. Since mother liquor will have high, hardness, colour, silica etc, this will be a waste salt unfit for reuse.

Other issues with Evaporator.. 2

- R.O Rejects contain Hardness, Organics, Silica and other contaminants which affect Evaporator performance as their concentration increases during evaporation.
- Possibility of salt produced being contaminated with above contaminants. Waste salt disposal is an issue.
- High Scaling (due to hardness) and corrosion (due to chlorides) resulting in poor performance and life of equipment.
- Crystallization of mixed salt in industrial effluent difficult and not easily predictable unlike single salts. Formation of complex double salts.
- Very high operating costs. Typical crystallization costs after MVR is in the range of Rs. 600 to 650 per m3 of feed.
- Ideal solution would be one which eliminates the Evaporator! But can we?

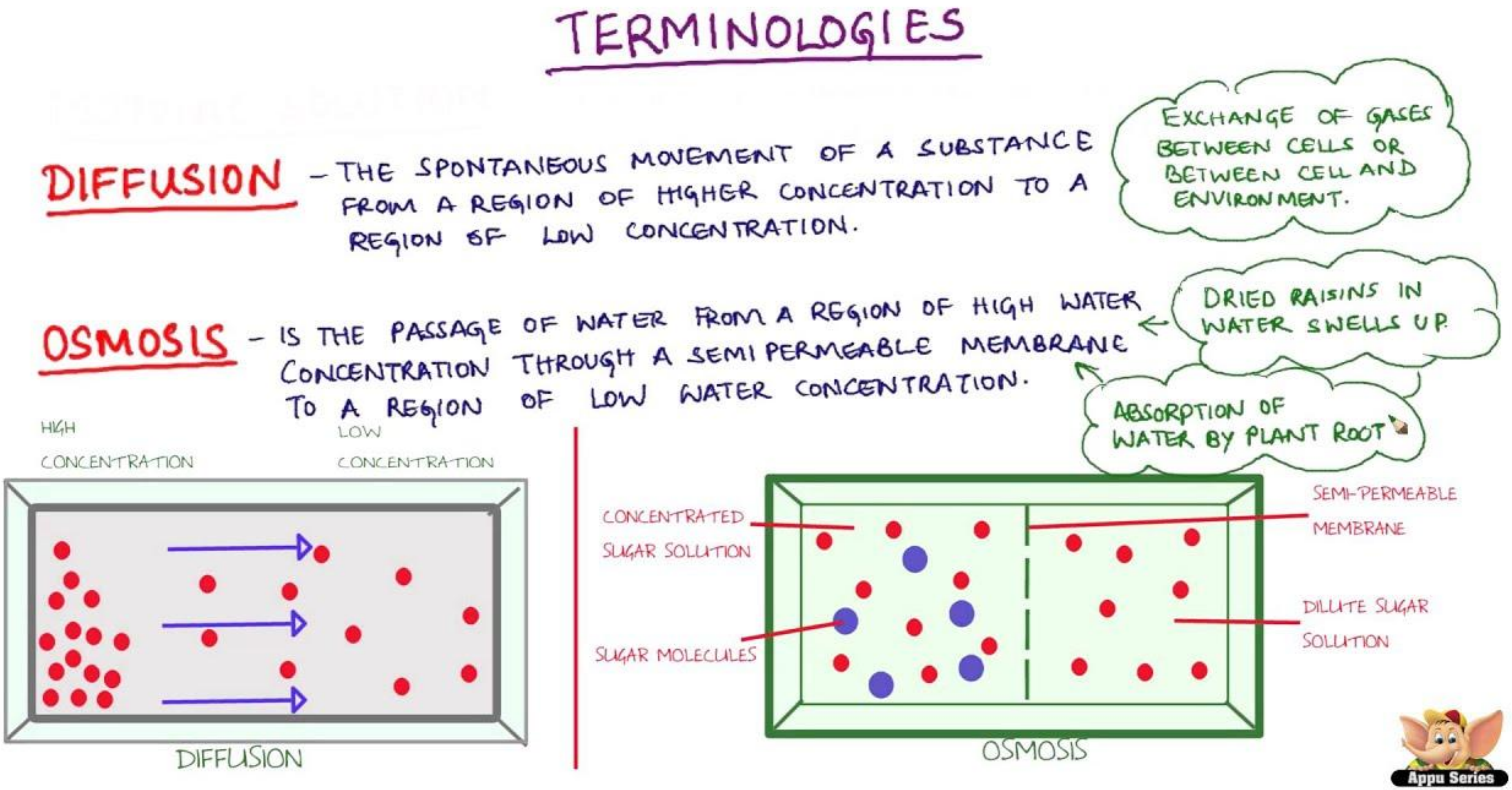
Why other technologies?



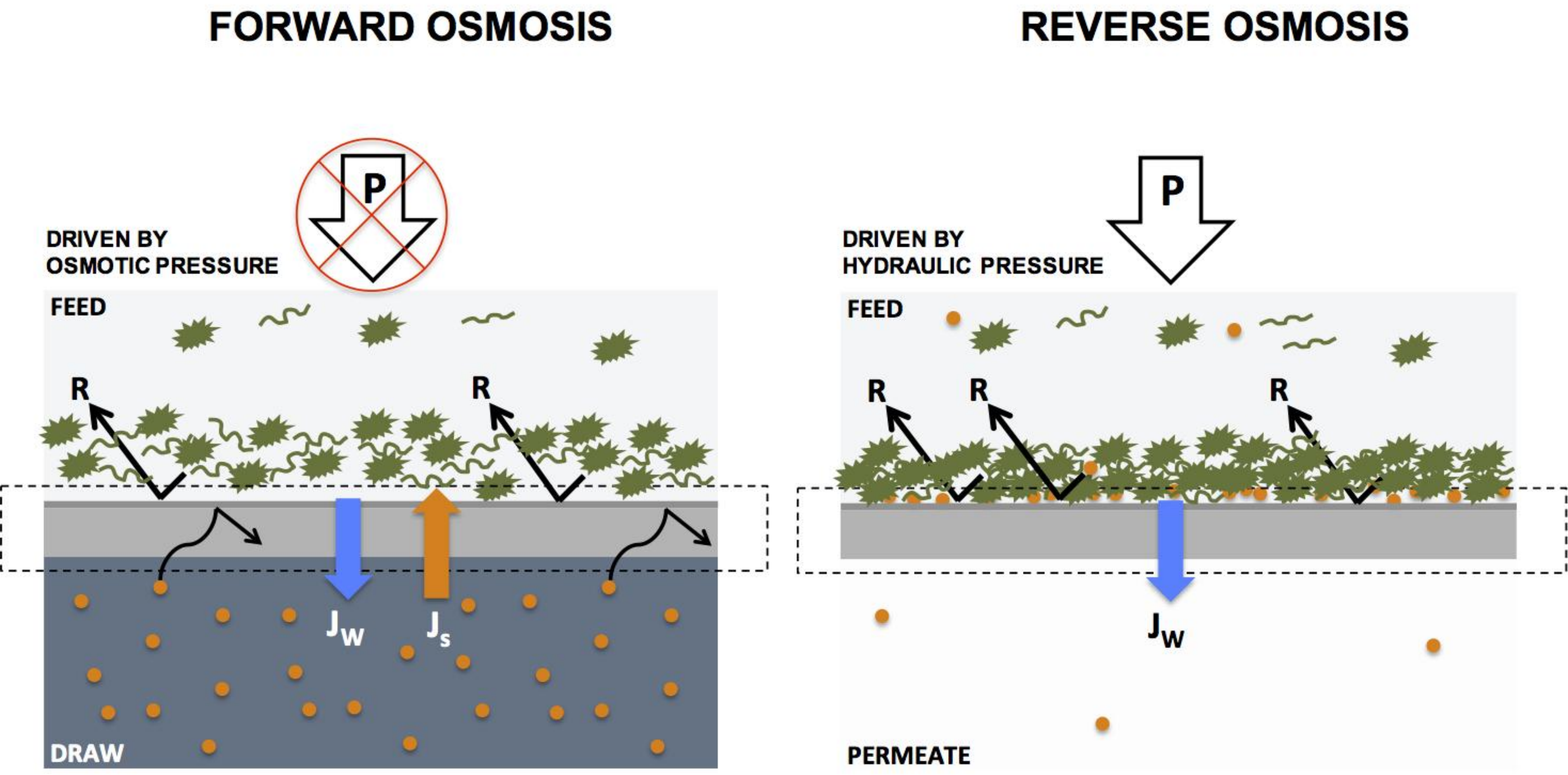
Why FO?

technology	Advantages	Limitations	Energy consumption
RO	Modular Technical maturity	Limited salinity High fouling	2-6 KWh/m3 of product water
ED/EDR	Low fouling High salinity limit	High energy consumption Cannot remove non charged particles	7-15 KWh/m3 of feed water
FO	Low fouling Much High salinity limit	Low water flux Reverse solute flux	21 KWh/m3 of feed water
MD	Low fouling Much High salinity limit	Low water flux Low water recovery	40-45 KWh/m3 of product water
MVC	Technical maturity	High temp High energy High capex	20-25 KWh/m3 of feed water

Diffusion


TERMINOLOGIES
DIFFUSION - THE SPONTANEOUS MOVEMENT OF A SUBSTANCE FROM A REGION OF HIGHER CONCENTRATION TO A REGION OF LOW CONCENTRATION.
EXCHANGE OF GASES BETWEEN CELLS OR BETWEEN CELL AND ENVIRONMENT.
OSMOSIS - IS THE PASSAGE OF WATER FROM A REGION OF HIGH WATER CONCENTRATION THROUGH A SEMI PERMEABLE MEMBRANE TO A REGION OF LOW WATER CONCENTRATION.
DRIED RAISINS IN WATER SWELLS UP.
ABSORPTION OF WATER BY PLANT ROOT
HIGH CONCENTRATION
LOW CONCENTRATION
DIFFUSION
CONCENTRATED SUGAR SOLUTION
SUGAR MOLECULES
SEMI-PERMEABLE MEMBRANE
DILUTE SUGAR SOLUTION
OSMOSIS
Appu Series

Osmosis: An Overview



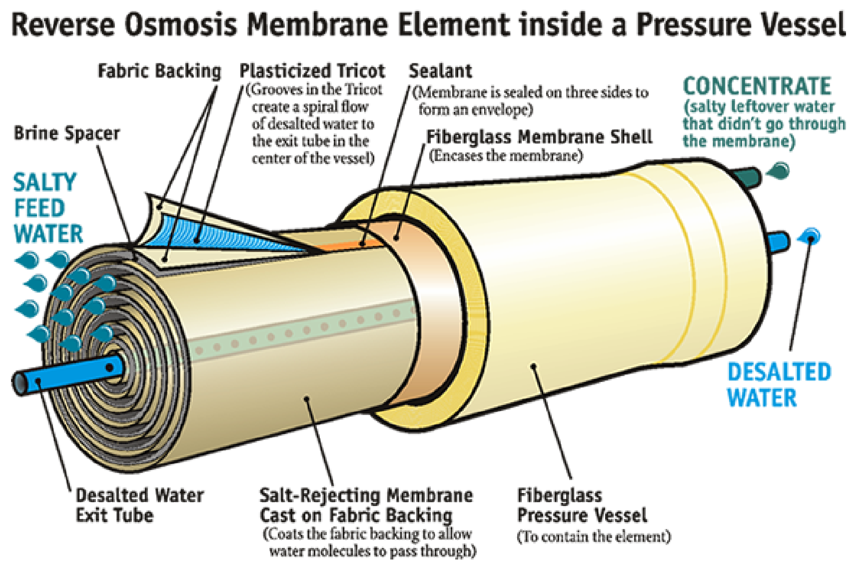
Draw Solutions for FO consist of concentrated solutions that can be more easily separated from the filtered water

RO and FO

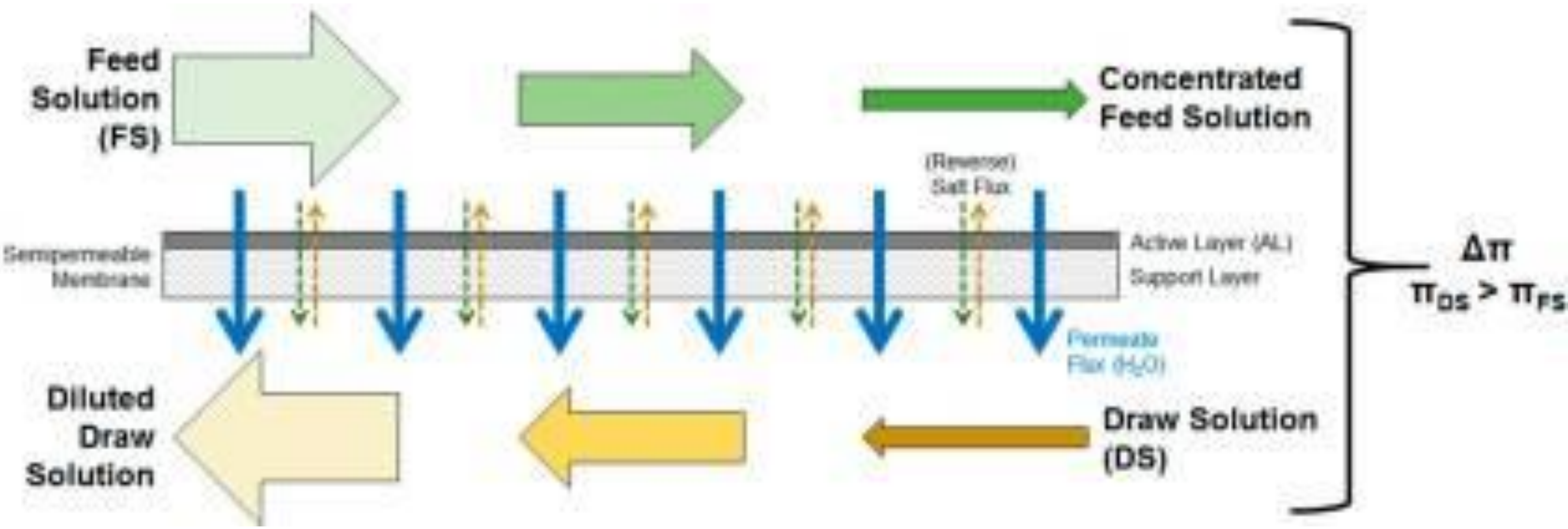
RO uses hydraulic pressure to oppose, and exceed, the osmotic pressure of an aqueous feed solution to produce purified water.

In RO, the applied pressure is the driving force for mass transport through the membrane; in osmosis, the osmotic pressure itself is the driving force for mass transport.

$$J_w = A(\sigma \Delta\pi - \Delta P)$$



Forward Osmosis: An Overview



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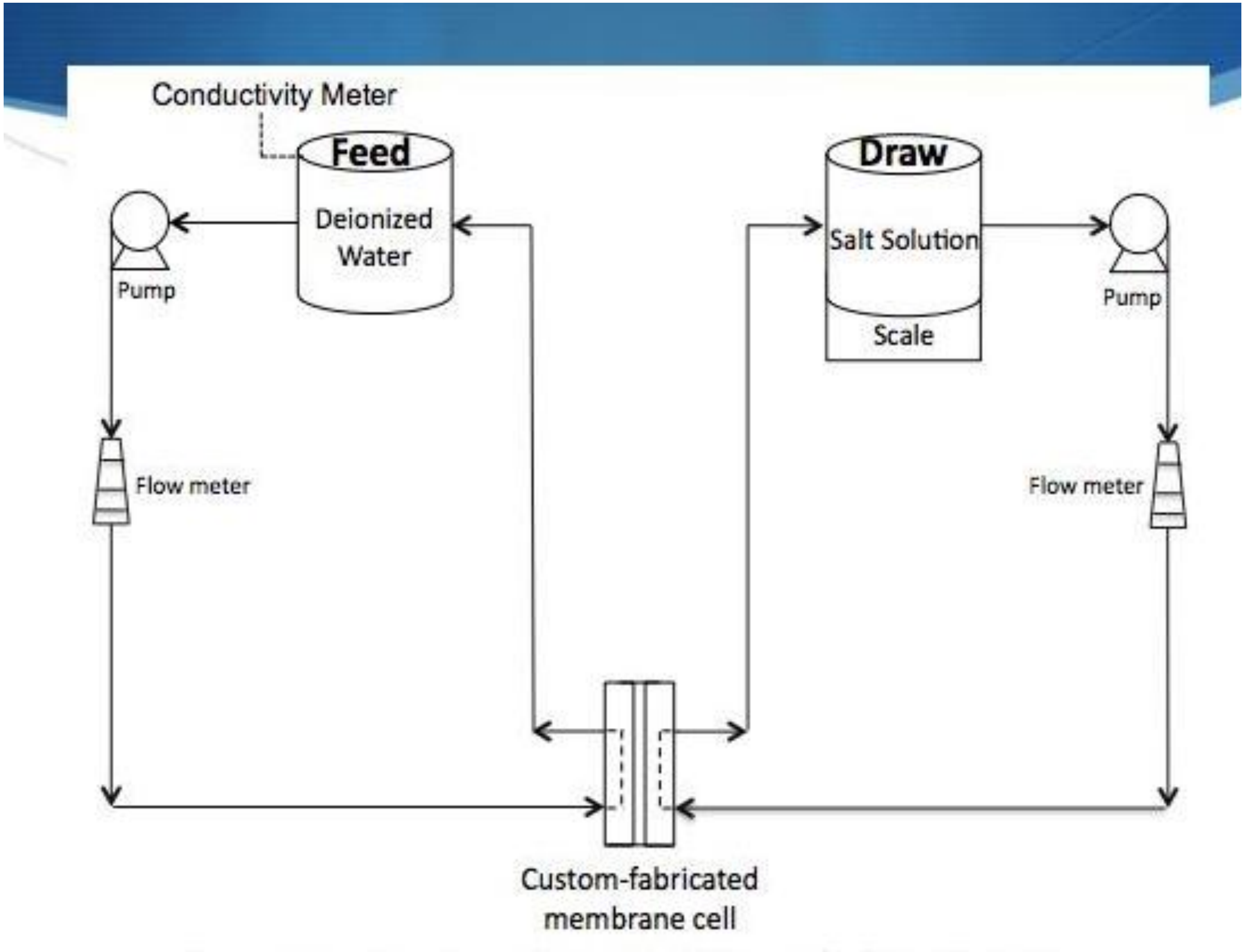
FO Lab Set up



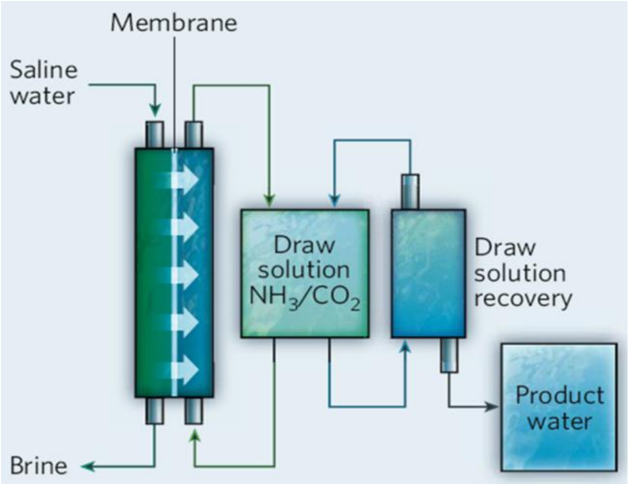
Conductivity Meter
Feed
Deionized Water
Pump
Flow meter
Draw
Salt Solution
Scale
Pump
Flow meter
Custom-fabricated membrane cell

FO Lab Scale Set up

What is FO?

The Forward Osmosis (FO) process is a membrane process that utilizes the natural osmosis phenomenon for the transport of water from a feed solution of lower salt concentration to a draw solution of higher salt concentration across a highly-selective membrane .

The main advantages of FO over current technologies used water reclamation includes <u>lower energy requirement</u> and <u>lower membrane fouling propensity</u>.

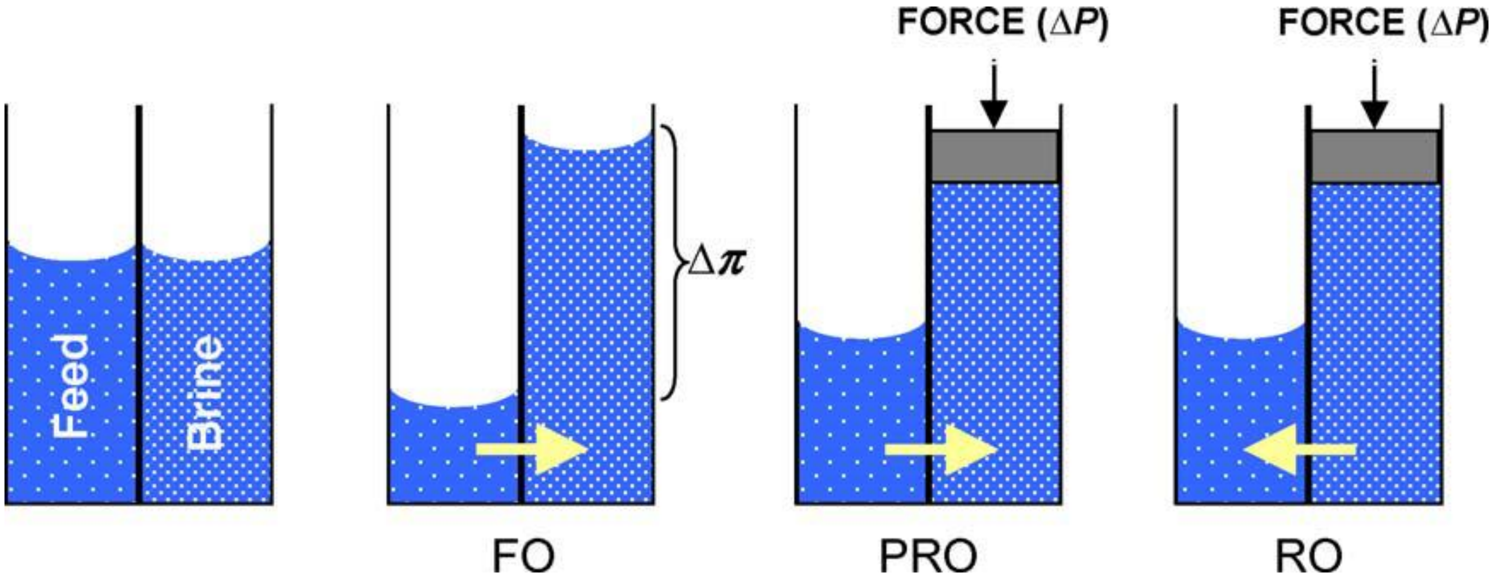


In-house R&D team based in Singapore Tritech Water Institute has developed the novel FO membrane. The TFC FO membrane has superior performance than current commercialized CTA FO membrane.

The high performance membrane can be applied in

- **Desalination**
- **Water Reclamation**
- **Emergency water supply**
- **Oil & Gas Exploration**
- **Landfills**
- **Food Processing**
- **MBR**
- **WW treatment**

RO, FO and PRO



Typically a seawater RO plant produces 55-65 liters of fresh water for 100 liters of seawater

Where the energy is used: pumping the water through the pre-filtering, the semi-permeable membrane, and desalted/brine outputs

Energy Consumption 3.5-5.0 kWH of electricity / m^3

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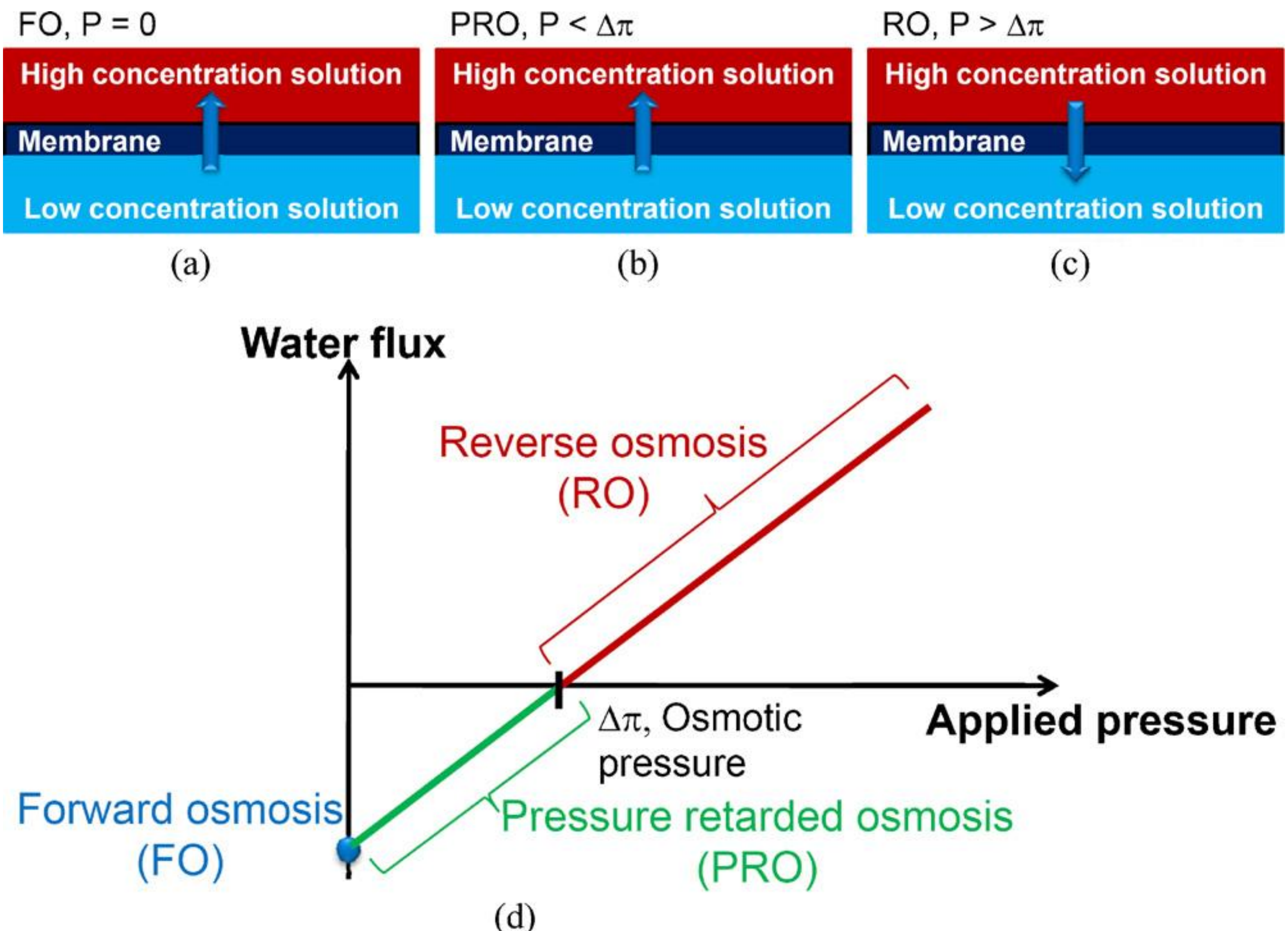
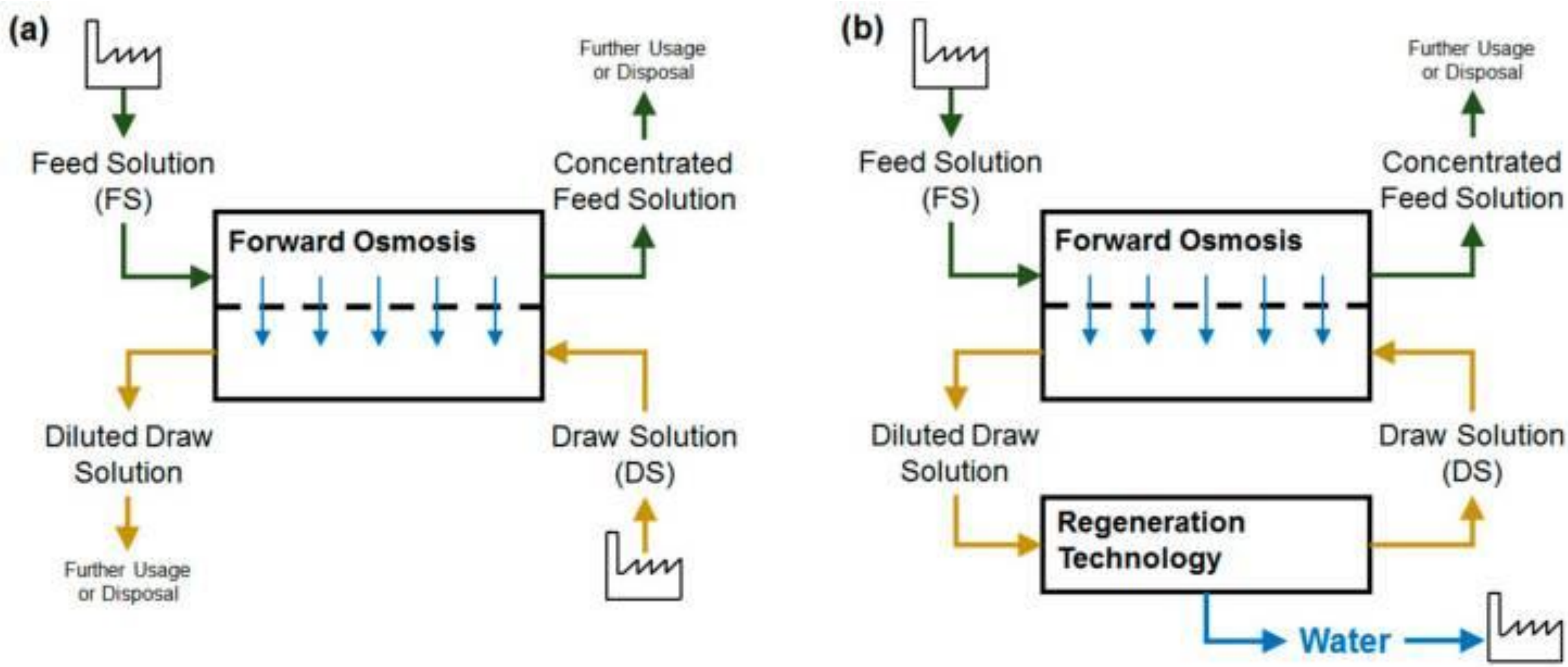

FO, P = 0
High concentration solution
Membrane
Low concentration solution
(a)
PRO, P < Δπ
High concentration solution
Membrane
Low concentration solution
(b)
RO, P > Δπ
High concentration solution
Membrane
Low concentration solution
(c)
Water flux
Reverse osmosis
(RO)
Δπ, Osmotic
pressure
Applied pressure
Forward osmosis
(FO)
Pressure retarded osmosis
(PRO)
(d)

FO Technology



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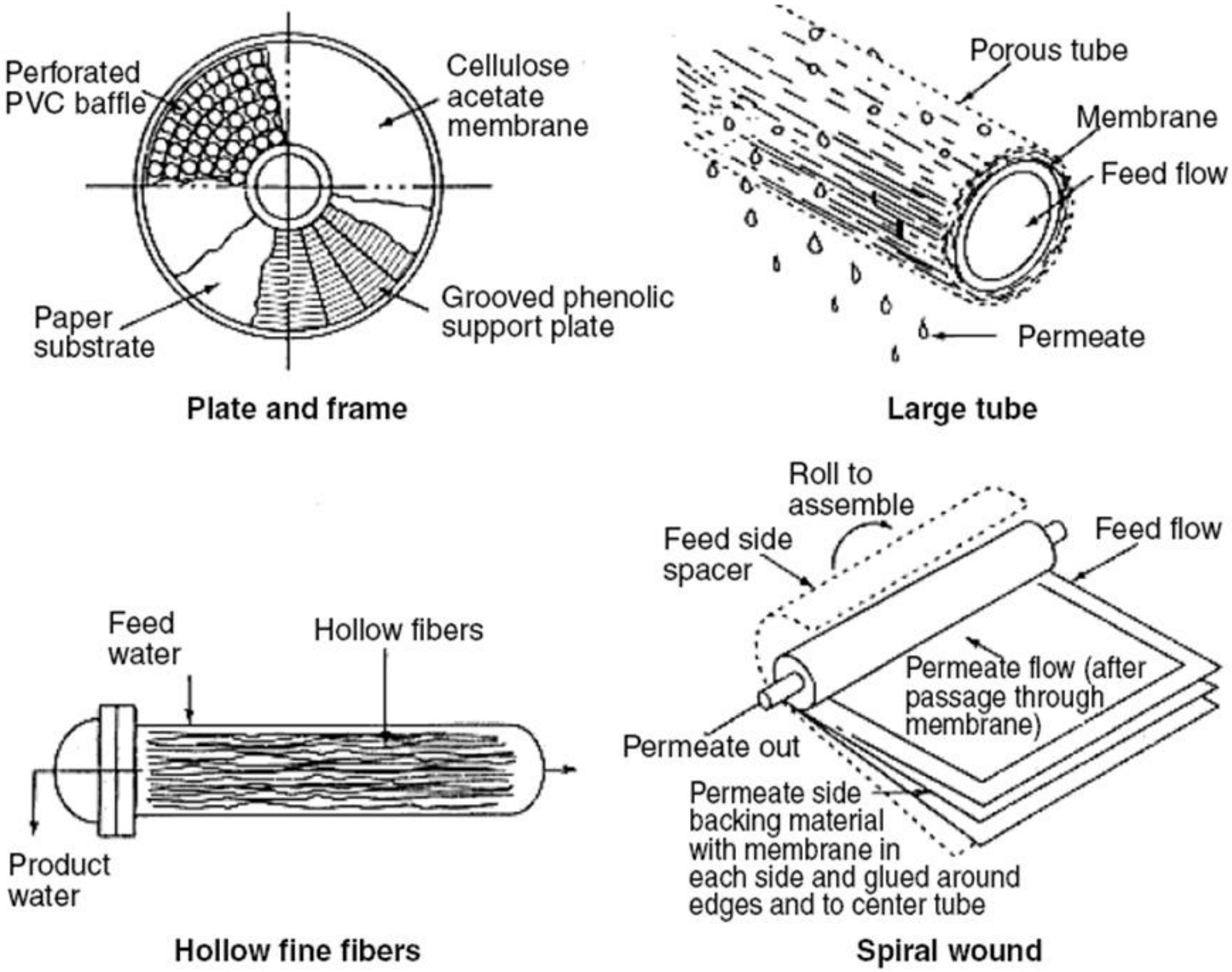
Challenges – Membrane Selection

- Lack of efficient membranes prevents FO from being a viable option,
- CTA membranes hydrolyses and breaks down in high pH solutions,
- low water flux and salt rejection
- limits options for draw solutions

Challenges – Membrane Selection

Optimization of thickness, porosity, tortuosity of active/support layer of FO membrane to increase water flux and decrease ICP



Membrane Characterization

- Commercial Hydration Technology Innovations (HTI) cartridge FO membranes were used for testing.
  - Cellulose acetate cast on a polyester screen mesh
- Membranes were tested in a HP4750 Sterlitech Stirred RO cell in order to determine parameters of membranes.
- Four increments of 100 psi pressure were applied to a feed of deionized water.
  - Water flux was compared with pressure to determine the water permeability coefficient, A.
- Procedure was also repeated with a feed of 50 mM sodium chloride to determine salt rejection in response to pressure.

Challenges – Reverse draw flux

- Need for draw solutions that work well with currently available membranes.
- Reverse draw flux describes the process of ion transfer to the feed solution while water is simultaneously flowing to the draw solution.
- This phenomenon must be minimized to prevent waste of draw solutes.

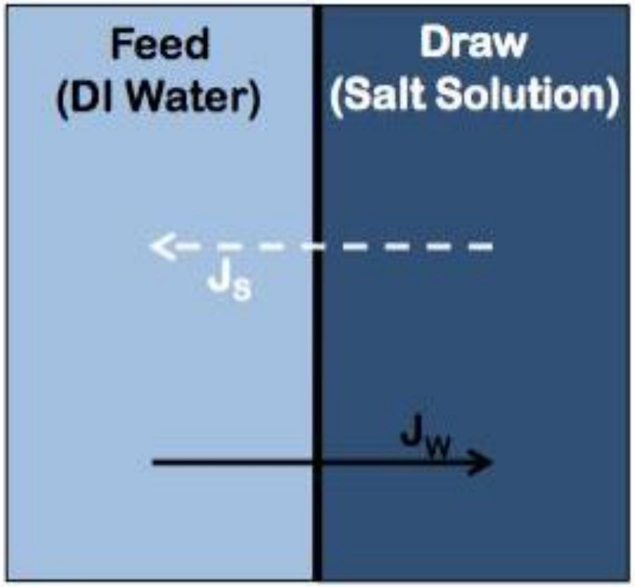


Figure 2. Reverse Draw Flux
Illustration of flux that occurs across a membrane during forward osmosis

Water Permeation

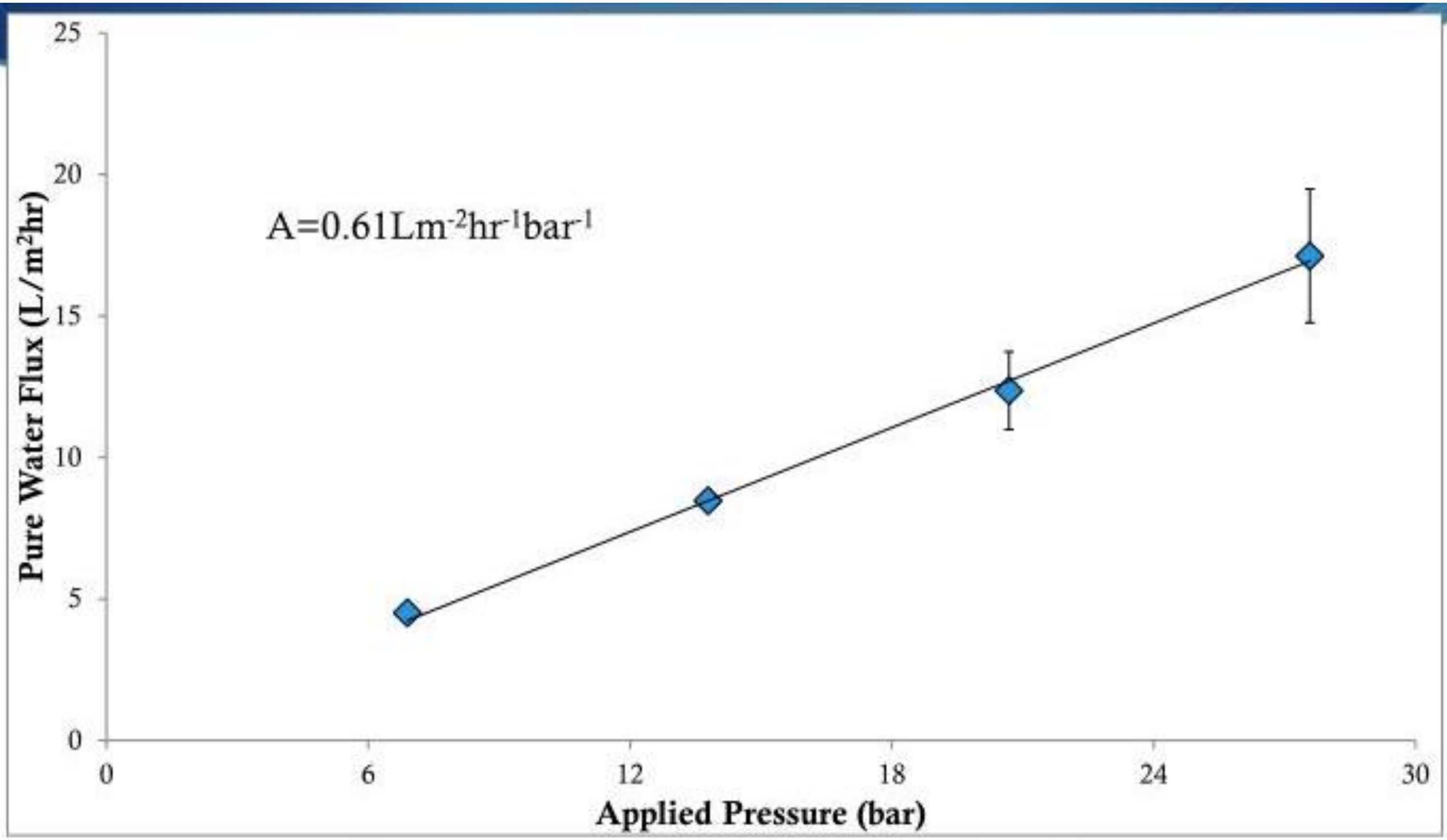
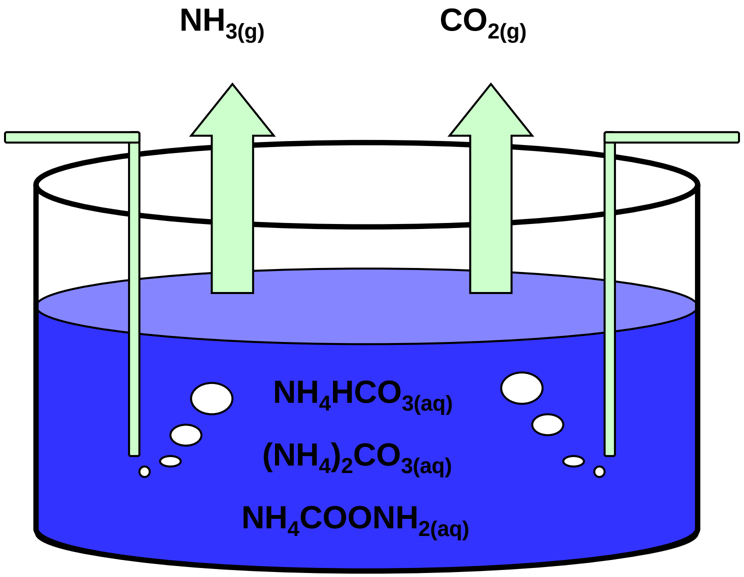


Figure 4. Water Permeability Characterization Data

Challenges – Draw Solute

Potential synthetic DS are:

- gases and volatile compounds,
- inorganic draw solutes (e.g., salts),
- organic draw solutes (e.g., sugar, organic ionic liquids),
- switchable polarity solvents (SPS), organic ionic salts, polyelectrolytes, polymers, hydrogels),
- functionalized nanoparticles.



Water Flux

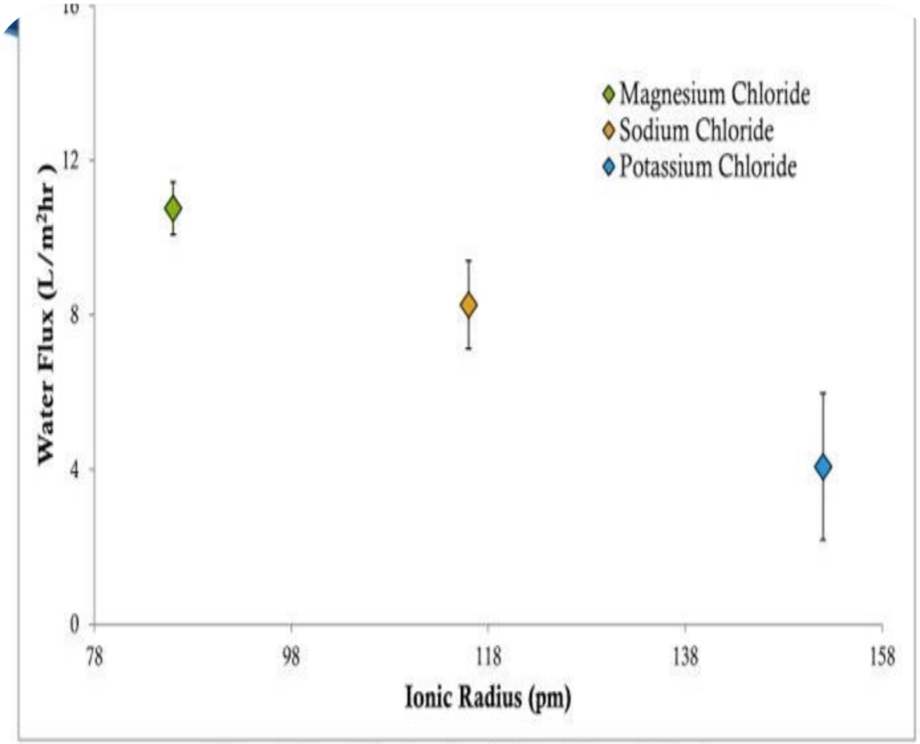


Figure 6. Water Flux Results of Forward Osmosis Testing

Reverse Flux

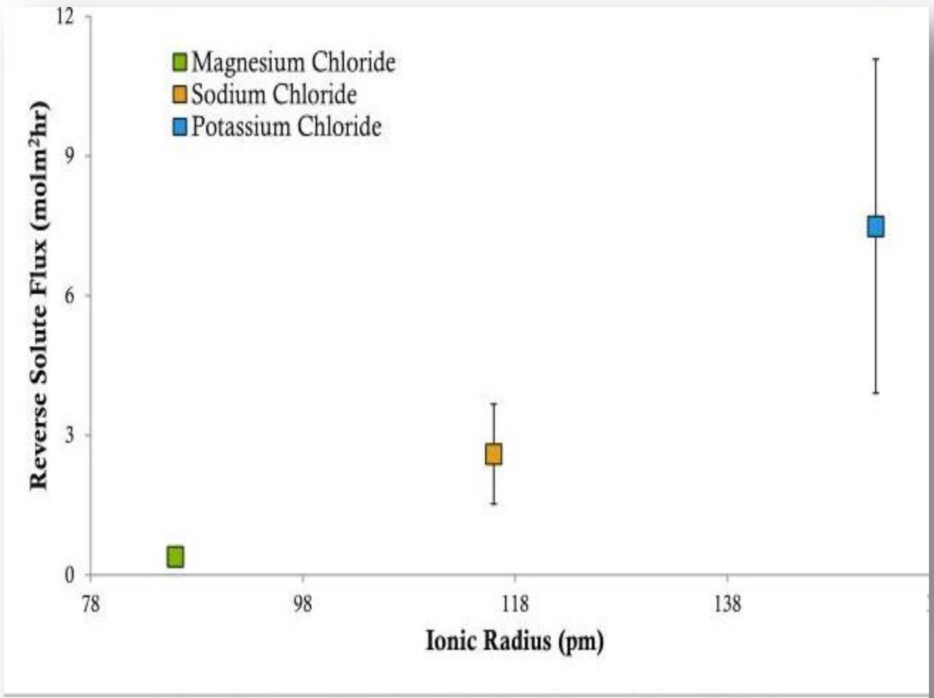
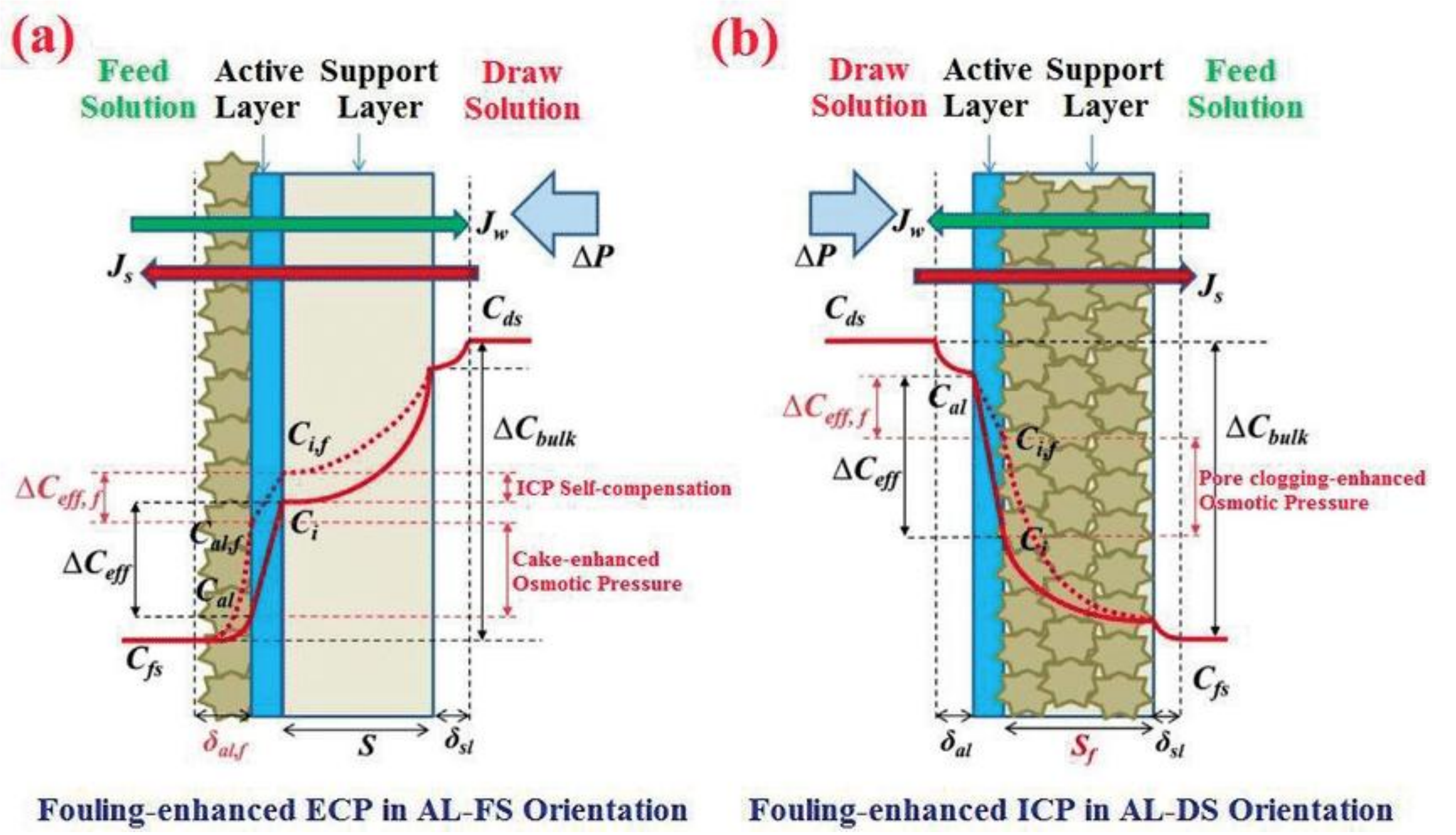


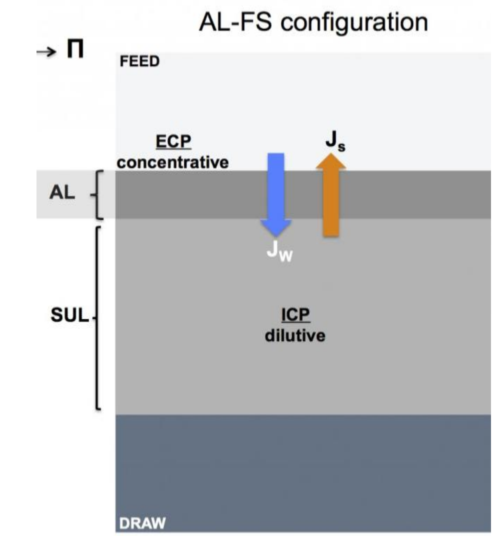
Figure 7. Reverse Solute Flux Results of Forward Osmosis Testing

Challenges - CP

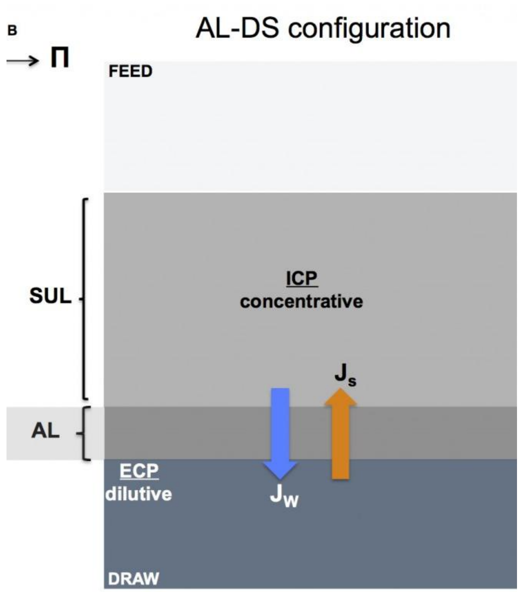
CONCENTRATION POLARIZATION IS THE BUILD-UP OF CONCENTRATION GRADIENTS BOTH INSIDE AND AROUND FO MEMBRANES DURING OPERATION.



Challenges - CP



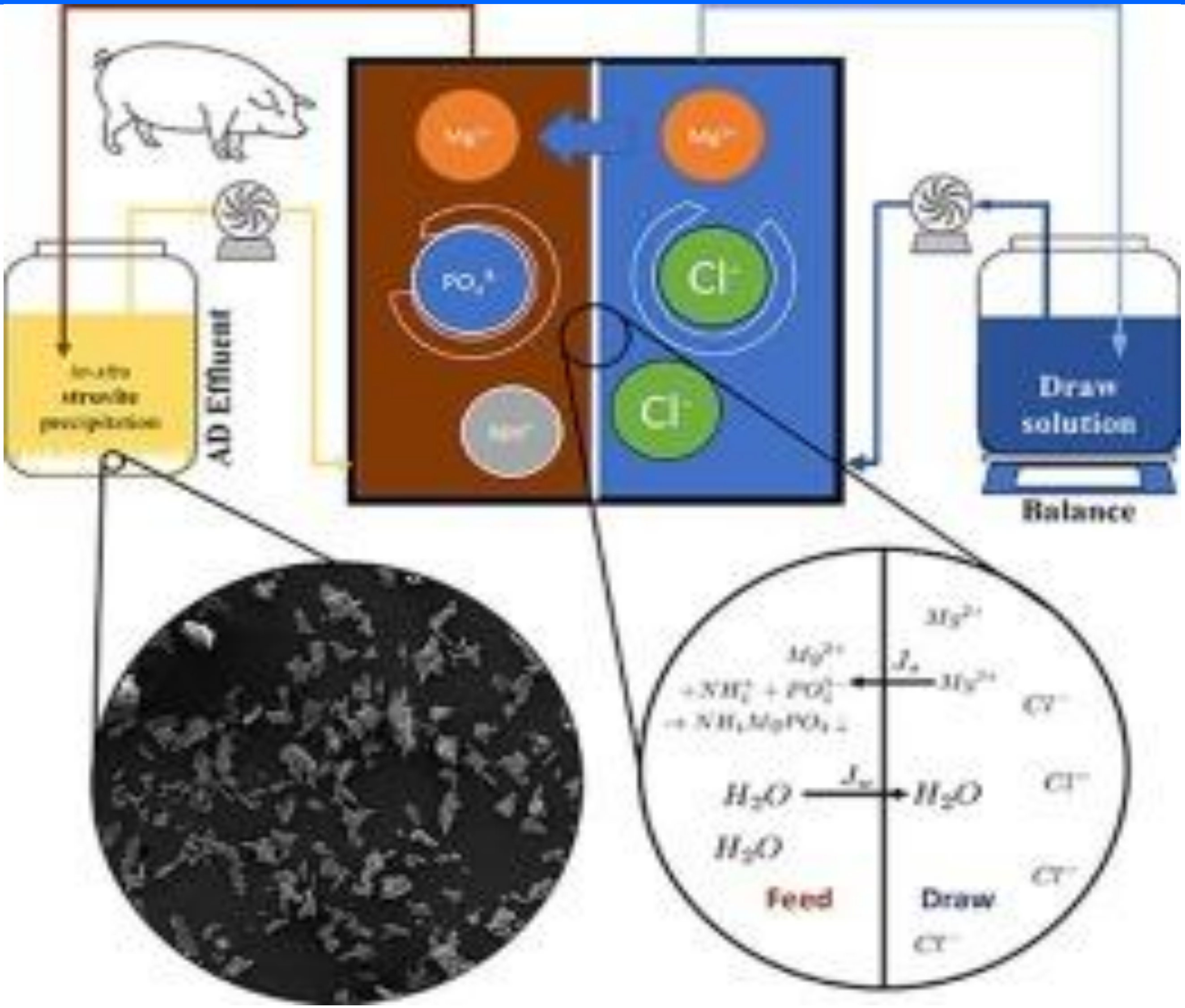
When the dense rejection layer faces the feed solution (known as AL-FS or “FO-mode” configurations), the water permeating through the porous support layer dilutes the draw solutes inside the support, giving rise to **dilutive ICP**. In addition, **concentrative ECP** takes place on the dense rejection layer



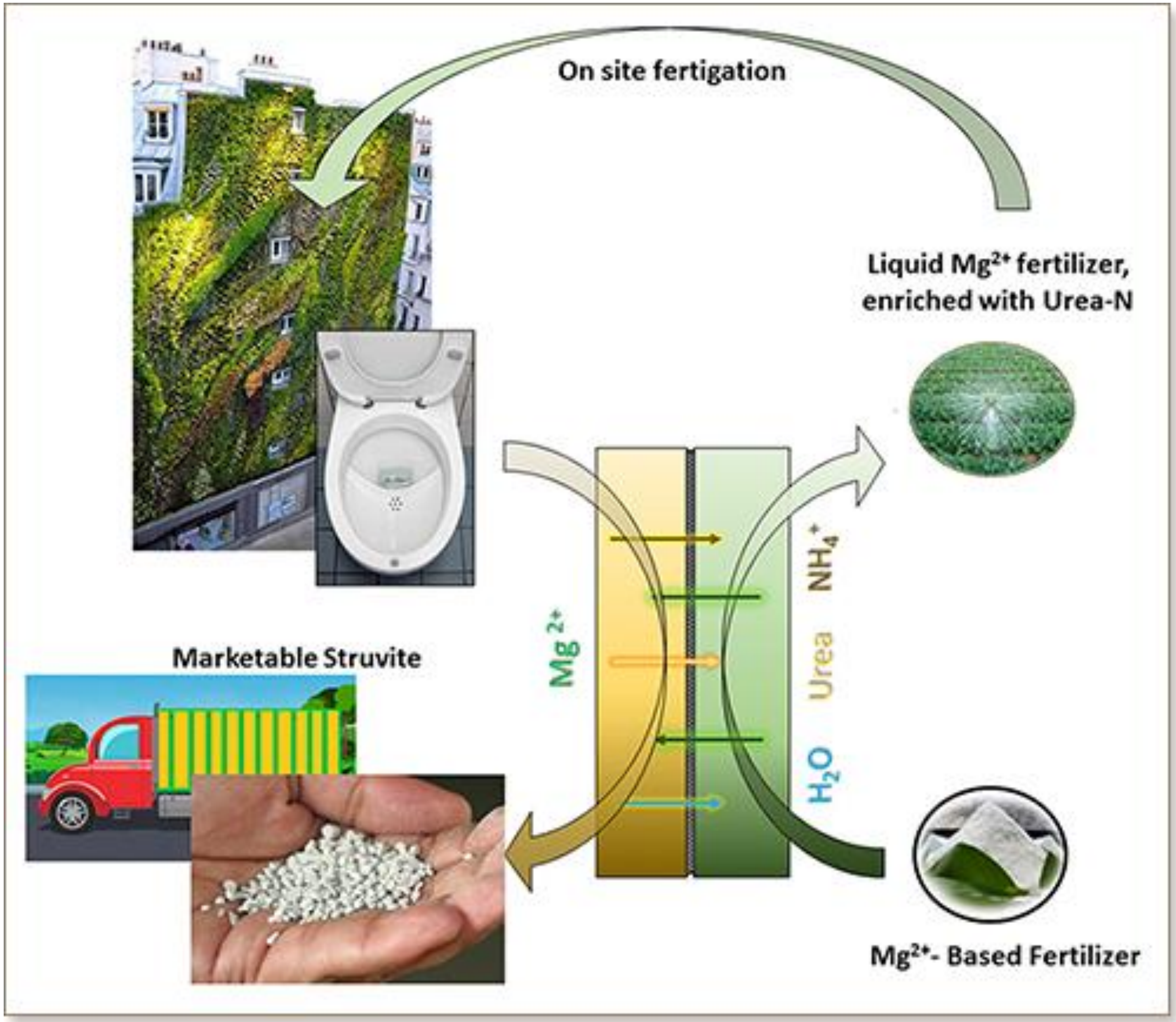
When the dense rejection layer faces the draw solution (known as AL-DS or “PRO-mode” configurations), solutes inside the support are concentrated as water permeates through the membrane, giving rise to **concentrative ICP**. In addition, **dilutive ECP** takes place on the dense rejection layer

Applications

Applications

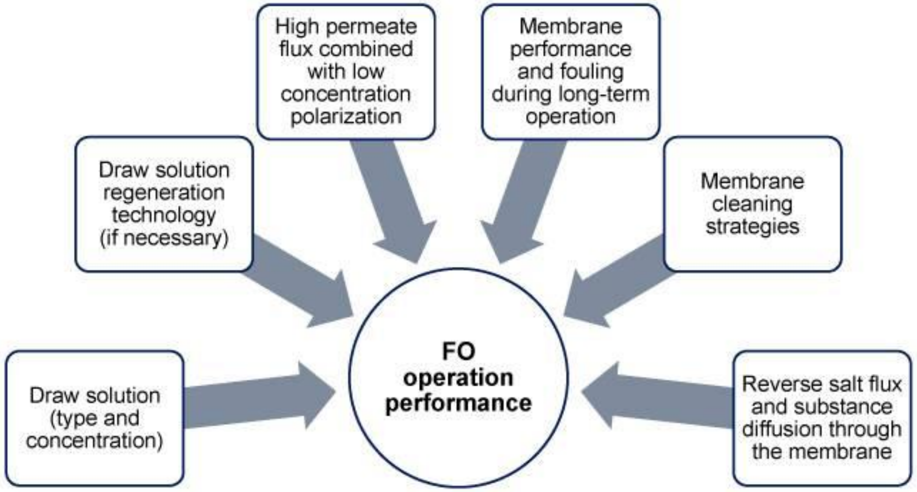


Applications



Take industry messages

- Operates at reduced pressures.
- Reduced energy consumption; especially in solutions of high osmotic pressure.
- High resistance of membranes to fouling.
- Good tolerance of membranes to chlorine.
- Longer membrane life.
- Lower operating costs.



- Water production in areas with a shortage of water.
- Effluent treatment when legislation requires reuse.
- Implementation of a zero discharge system.
- Treatment of complex effluents, which are difficult to deal with using conventional technologies.
- Viable alternative when reduced energy consumption is required.

Users

- Aquaporin A/S (Kongens Lyngby, Denmark) [66,67],
- Aquaporin Asia Pte. Ltd. (Singapore) [68,69],
- BLUE-tec BV (Renkum, The Netherlands) [56,70],
- Darco Water Technologies Ltd. (Singapore) [71,72],
- De.mem Ltd. (Singapore) [73],
- Fluid Technology Solutions, Inc. (FTS, Albany, OR, USA) [74],
- Hydration Technology Innovations, LLC (HTI, Albany, OR, USA)
- Oasys Water, Inc. (Cambridge, MA, USA) [75,76],
- Porifera, Inc. (Hayward, CA, USA) [55],
- Toray Chemical Korea, Inc. (Seoul, Korea) [52],
- Trevi Systems, Inc. (Petaluma, CA, USA) [77],
- W.O.G. Technologies Pte Ltd. (Singapore) [69].

Thank You