# Membrane Processes and Applications in Industrial Water and Wastewater Treatment

Aslıhan Kerç

ENVE 420

# General Definition

- Membrane Processes include a broad range of *seperation processes* from filtration to ultrafiltration and reverse osmosis.

# Types of Membrane processes

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO)
- Dialysis / Electrodialysis (ED)

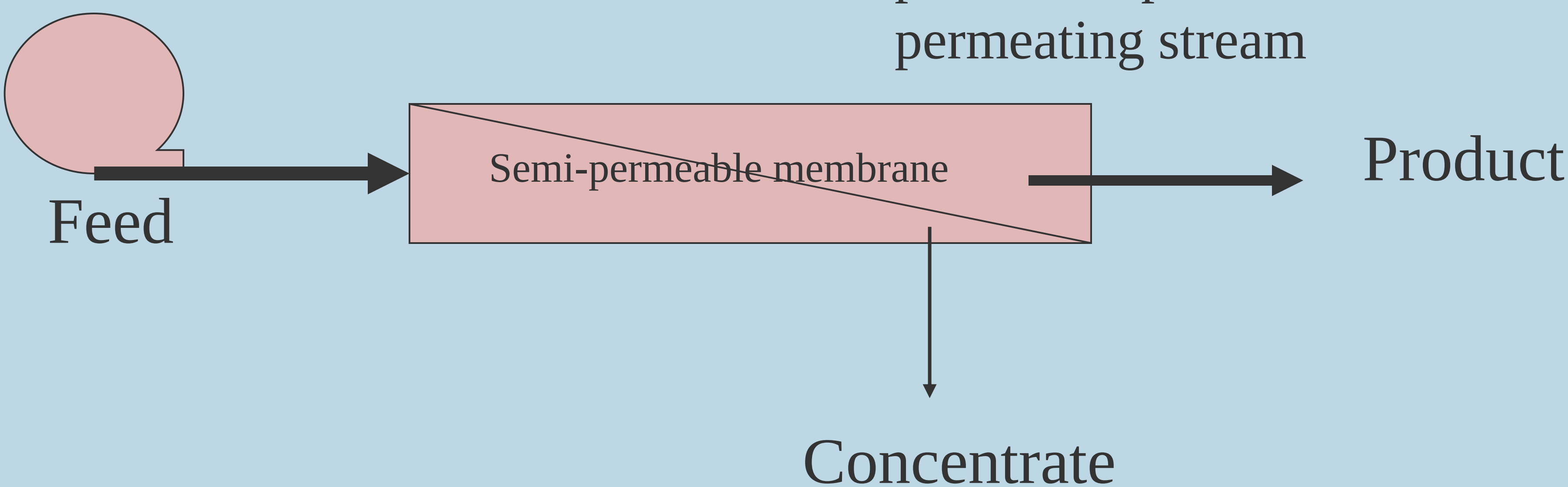
# Examples for Applications of Membrane Processes

- Desalting seawater
- Holding back seawater intrusion
- Treating brackish groundwater
- Water softening
- Waste water recovery
- Removing color, odor, and other organic contaminants

# Process Configuration - General

**Influent to the membrane module:**
Feed water / feed stream

**Liquid that passes through the semi-permeable membrane**:
permeate / product stream / permeating stream




**Liquid containing the retained constituents**:
Concentrate / retentate / reject / retained phase / waste stream

# A membrane is a film.

- A semi-permeable membrane is a VERY THIN film that allows some types of matter to pass through while leaving others behind.

# Flux / Rate of flux

- Rate at which the permeate flows through the membrane
- Units: kg /m$^2$d
  gal / ft$^2$d

- Molecular size
- Polarity
- Molecular shape

are influential in removal efficiency.

# Membrane Types

| | ED | MF | UF | NF | RO |
|---|---|---|---|---|---|
| **Retained** | Water, TSS, microbes uncharged molecules | Larger particles | Larger molecules | Higher charged ions | almost everything |
| **Transported** | Dissolved salts | Dissolved salts, small particles | Small molecules and ions | Mono-valent ions, small molecules | Very small uncharged molecules |

# Ultrafiltration

- Primarily a concentration process
- Pumping energy is required to force liquid through the membrane
- Relatively large size particles (MW 10000 – 40000<) are retained and concentrated
- Potential use in the recycling of metal containing alkaline cleaner wastes and paints (concentrate)
- Reduction of metals in industrial wastes

# Ultrafiltration

- Does not change the chemistry of water.

For example to obtain potable water from surface water, which is chemically clean, but contains algea and bacteria, UF can be used.

Same water quality with coagulation / flocculaltion
→ Removes turbidity

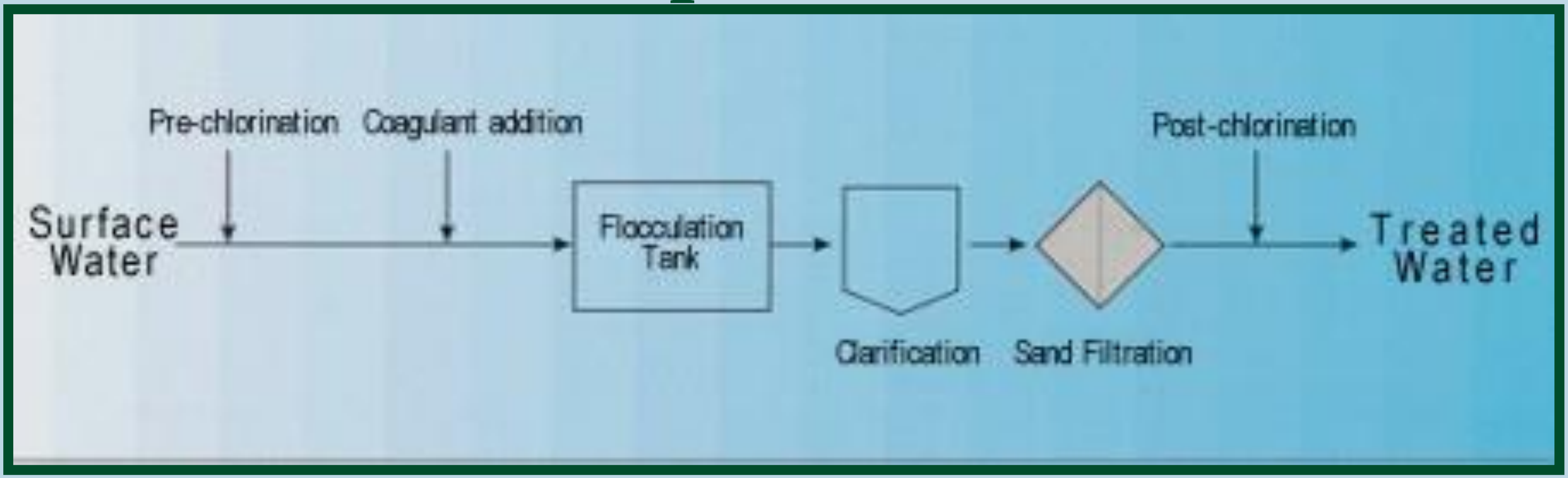
- UF removes larger organics, colloids, bacteria while allowing most ions and small organics to permeate the porous structure.

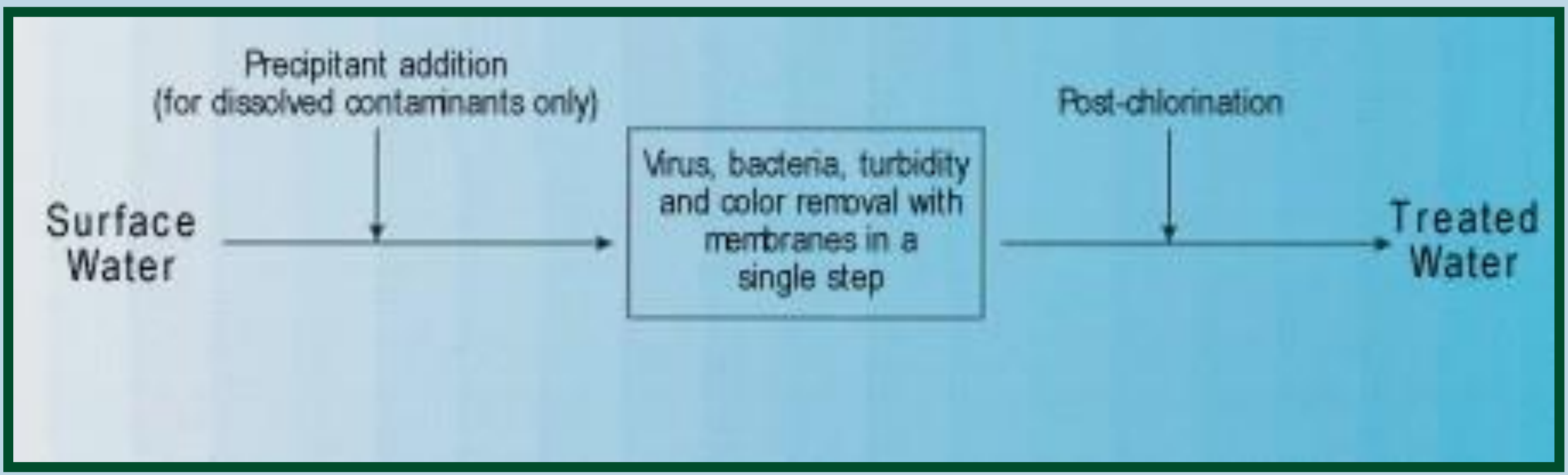
- Larger pore size → Requires much lower differential operating pressure.

# Ultrafiltration

- Cross flow or transverse flow
- Any membrane configuration
- Use re-circulation for high TSS
- Operating pressures ~ 50 psi
- Uses back flush to loosen fouling
- Excellent pretreatment for RO or Post treatment for ED.

# UF can replace several conventional processes



# Ultrafiltration

- May be considered as pre-treatment before R/O to prevent clogging of membranes.

Applications in industrial wastes:

Metal industry → Seperation of water-oil emulsions

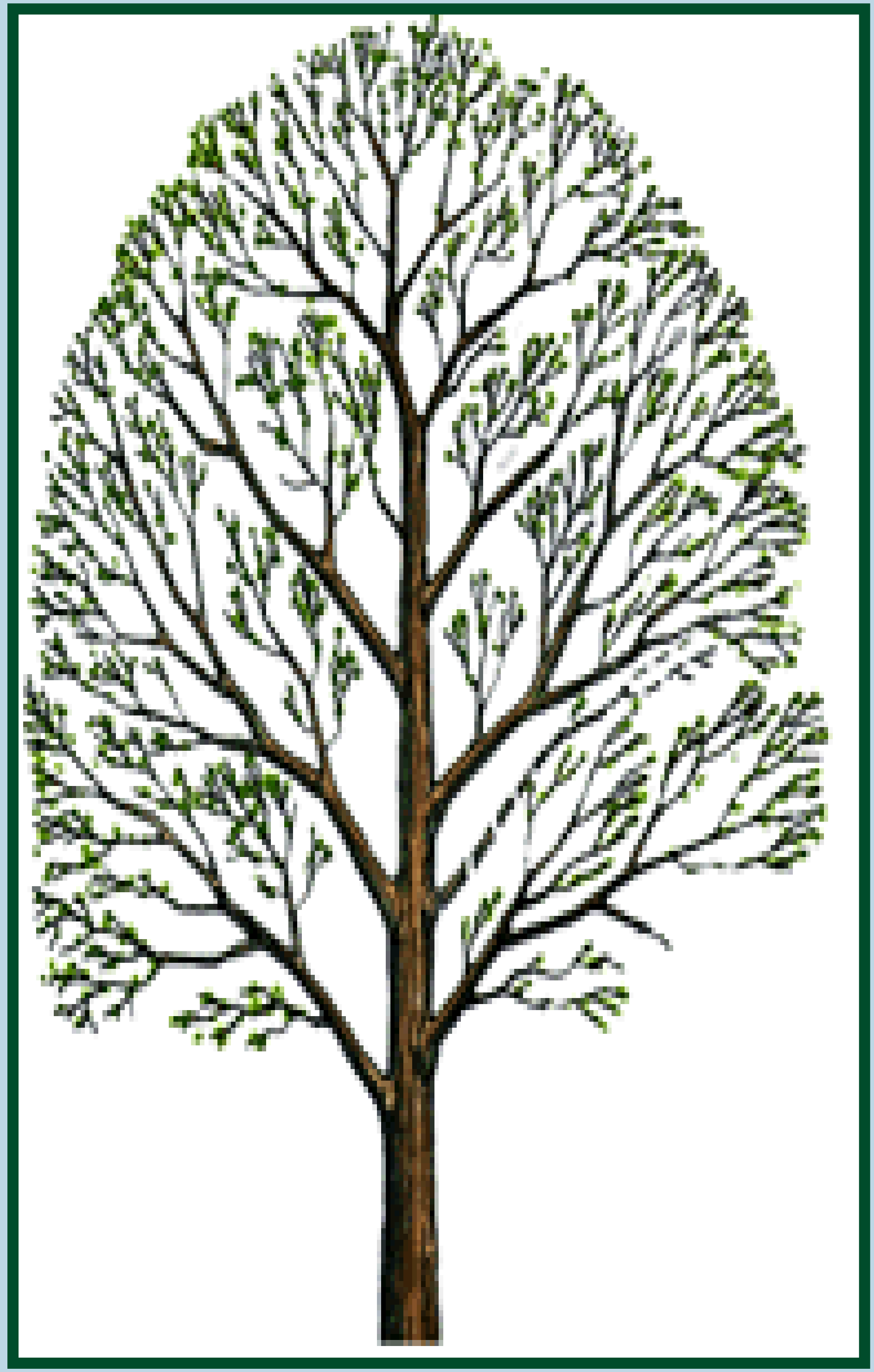
Automotive painting industry → to seperate dye from washing water

Pharmaceutical industry → Seperation of enzymes

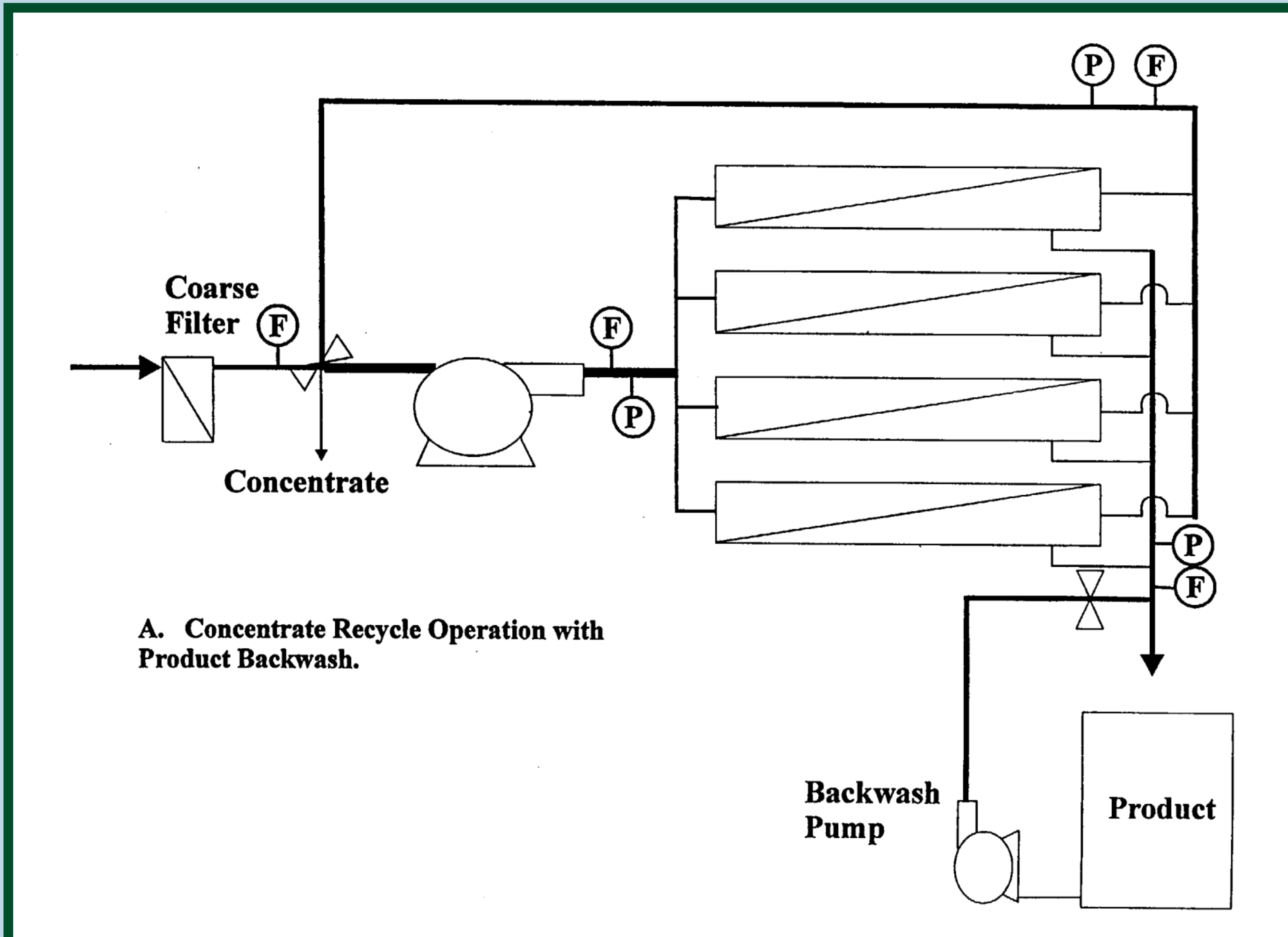
Food industry → Cheese waste

# Reverse Osmosis - a Natural Process

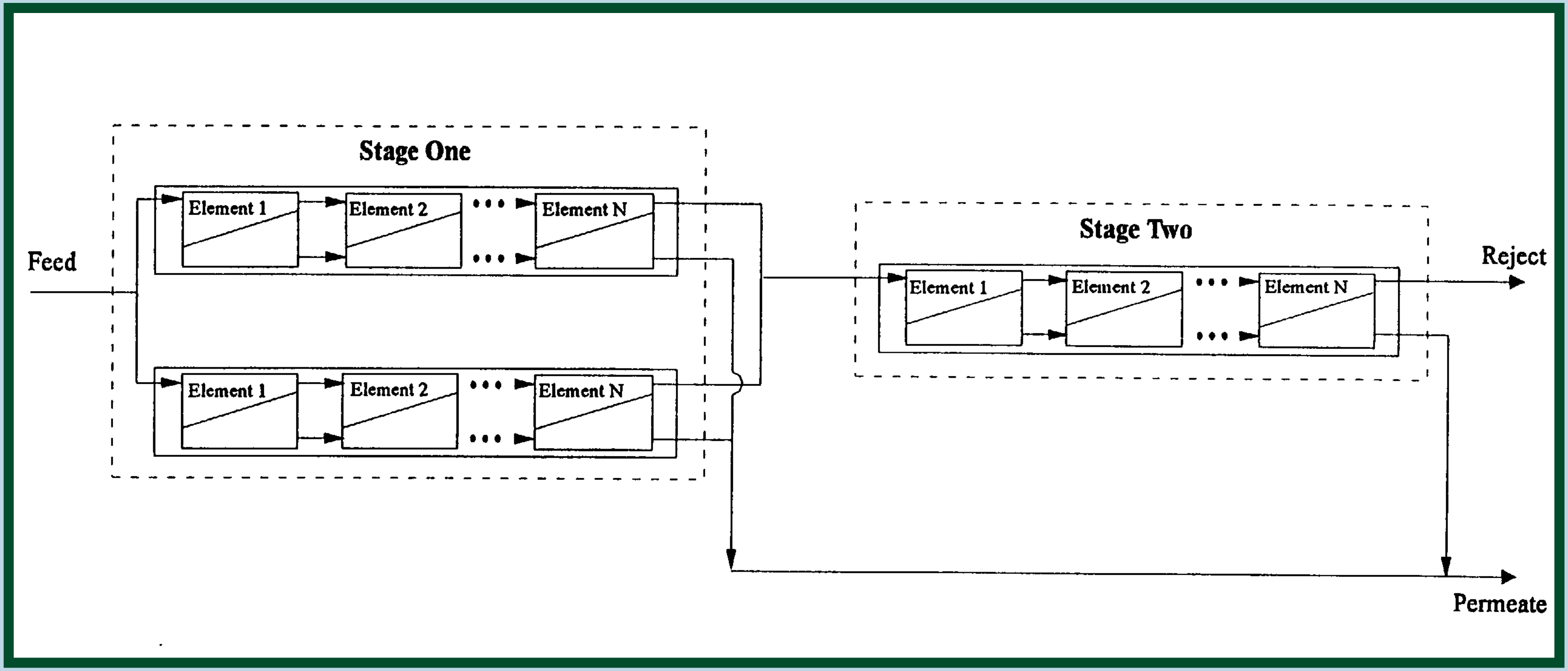
- Water is drawn from a low to a high concentration.   Evapo-transpiration creates a suction which draws water up through the  root hairs to the leaves.
- In RO systems pressure is applied to the high concentration side of the membrane to induce osmotic flow of clean water to the low concentration side.



# One Stage - Elements in Parallel



# Two Staged System - 2:1 array



# Reverse Osmosis

- Spiral wound or hollow fine fiber
- Pretreatment is critical to success
- NTU <1, SDI<3
- Operating pressures from 150 - 1000 psi
- Removes >95-99% TDS
- Concentrate Stream is 15-25% of flow with 4 to 6 times the TDS.

# Reverse Osmosis

- Concentrates dissolved materials from dilute solutions.
- Both size and chrage are effective

  Single charged H ions pass readily

  Large metallic ions with higher + charge cannot pass easily (Ni, Zn, Cu, Cd)

  Lower + charges ions can pass (Na, K)

# Reverse Osmosis

Pumping energy is required to force the liquid through membrane from lesser to more concentrated solution, because the pressure must overcome the osmotic pressure between solutions.

R/O used by metal platers for controlling Ni in the rinse discharge.

Proposed method by USEPA for “zero discharge”.

R/O successfully applied for removing fats, oils, grease.

# Nanofiltration

- Cross flow or transverse flow
- Any membrane configuration
- turbidity $<1$ NTU, SDI $<5$
- Operating pressure 50 - 200 psi
- Used for softening or special applications

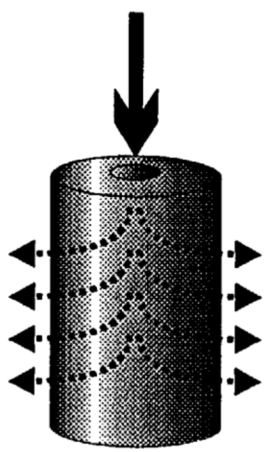
# Nanofiltration

- Nanofiltration → Membrane softening
  Ecomomically softens water
- NF removes organic compounds
  (250 – 1000 mW)
- Rejects some salts (divalent, $Cu^{2+}$, $Mg^{2+}$)
- Lower driving pressure than R/O

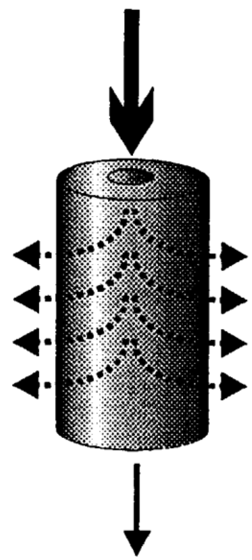
# Membrane Configurations

1. Spiral wound: Flexible permeate spacer between 2 flat membrane sheets
2. Hollow fibre: inside out / outside in flow
3. Tubular : either single or in a bundle, inside – outside
4. Plates and frame: Series of flat membrane sheets and support plates
5. Pleated cartridge filters: Microfiltration applications (e.g. Concentrate virus from treated water)

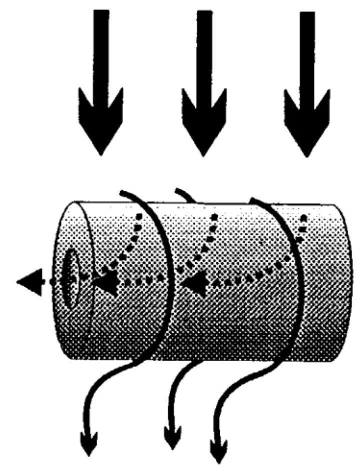
# Filtration Mode terms -



Dead end flow: All water passes through the membrane, particles are trapped within the membrane structure.

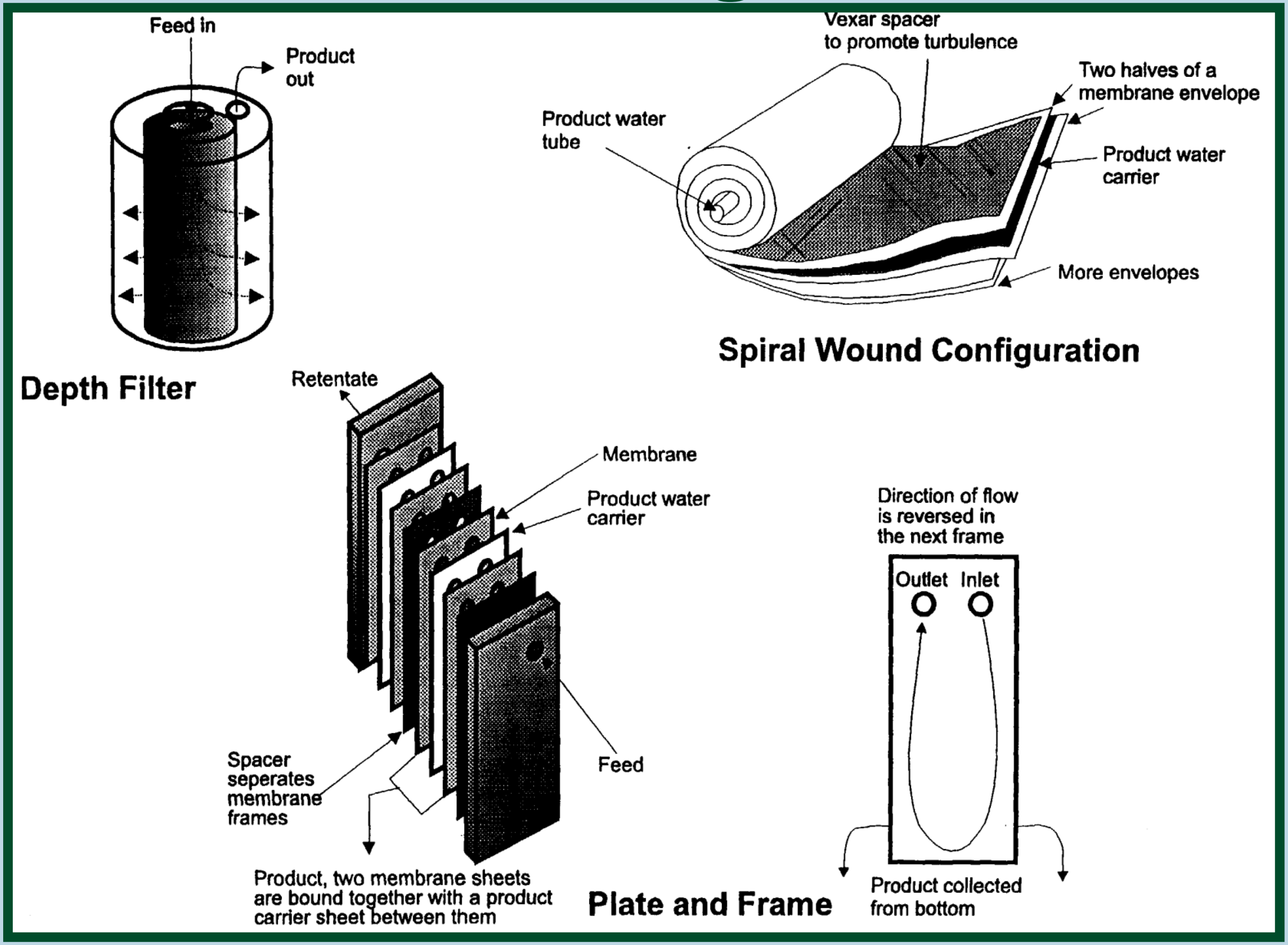


Cross flow: Feed water passes parallel to the membrane surface, product water permeates through the membrane, the concentrated stream helps carry particles out of the system.

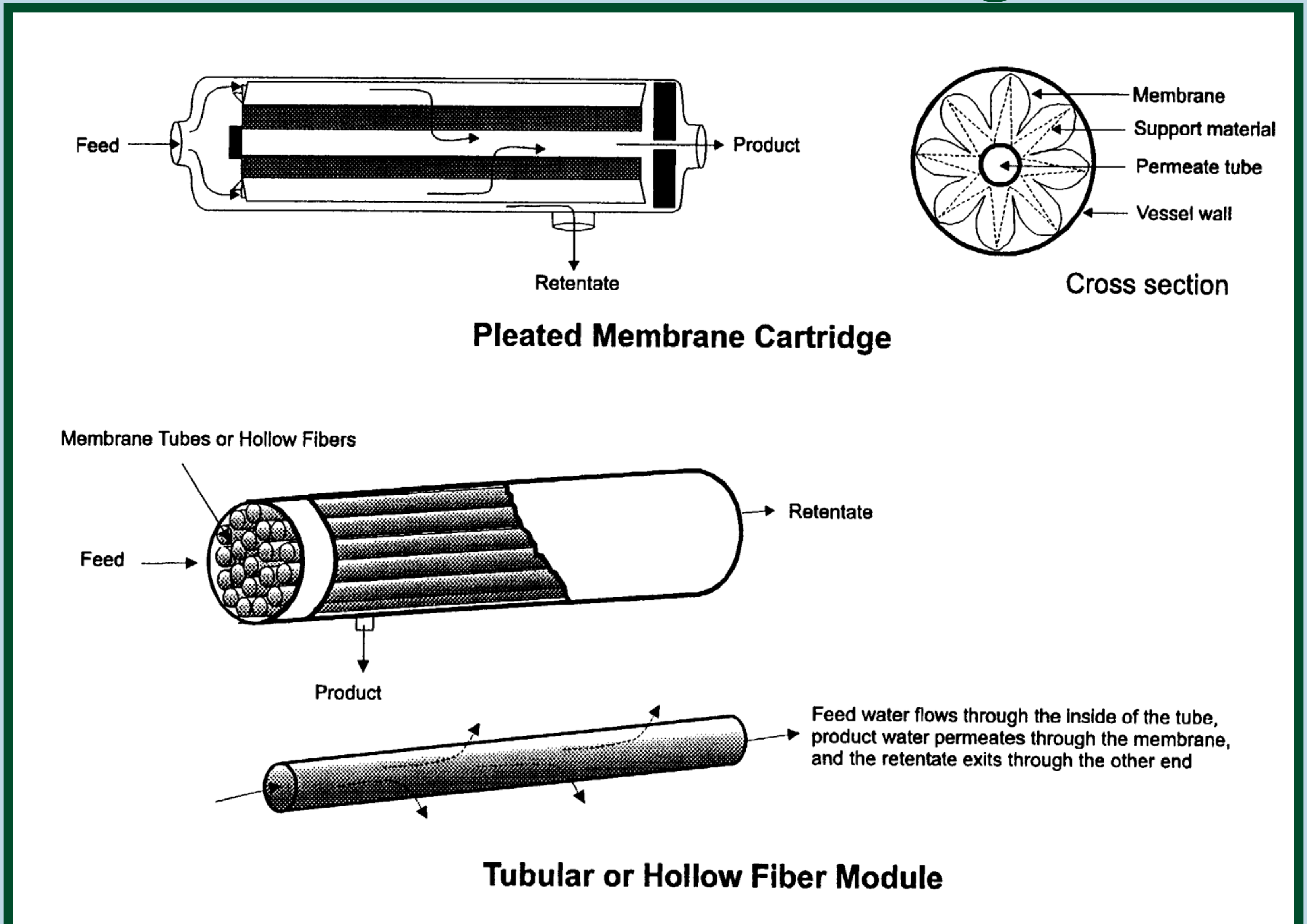


Transverse flow: Feed water meets the membrane surface at right angles, product water permeates through to the inside of the tube, concentrate washes over the outside of the tube removing particle build-up.

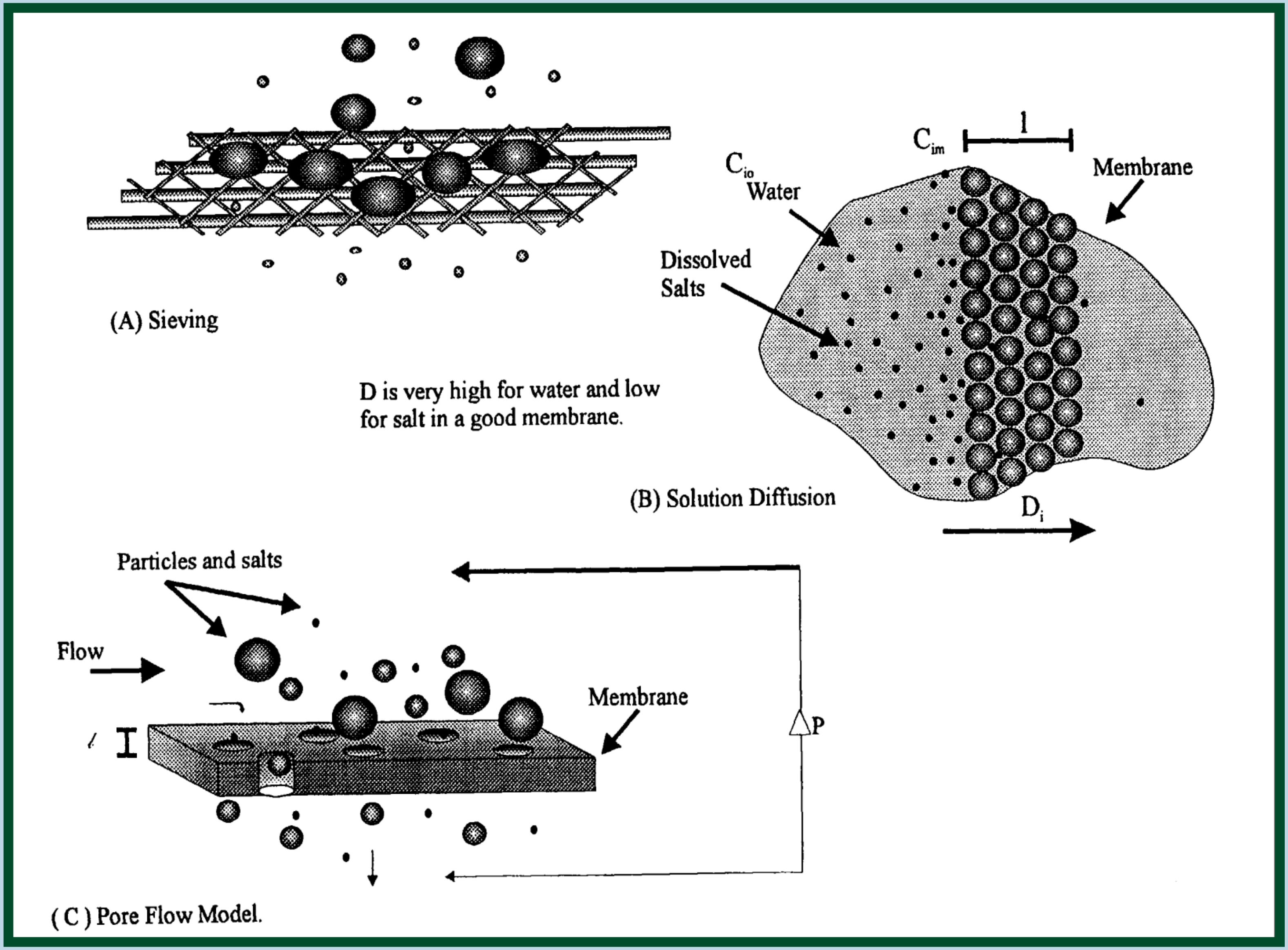
# Membrane Configurations



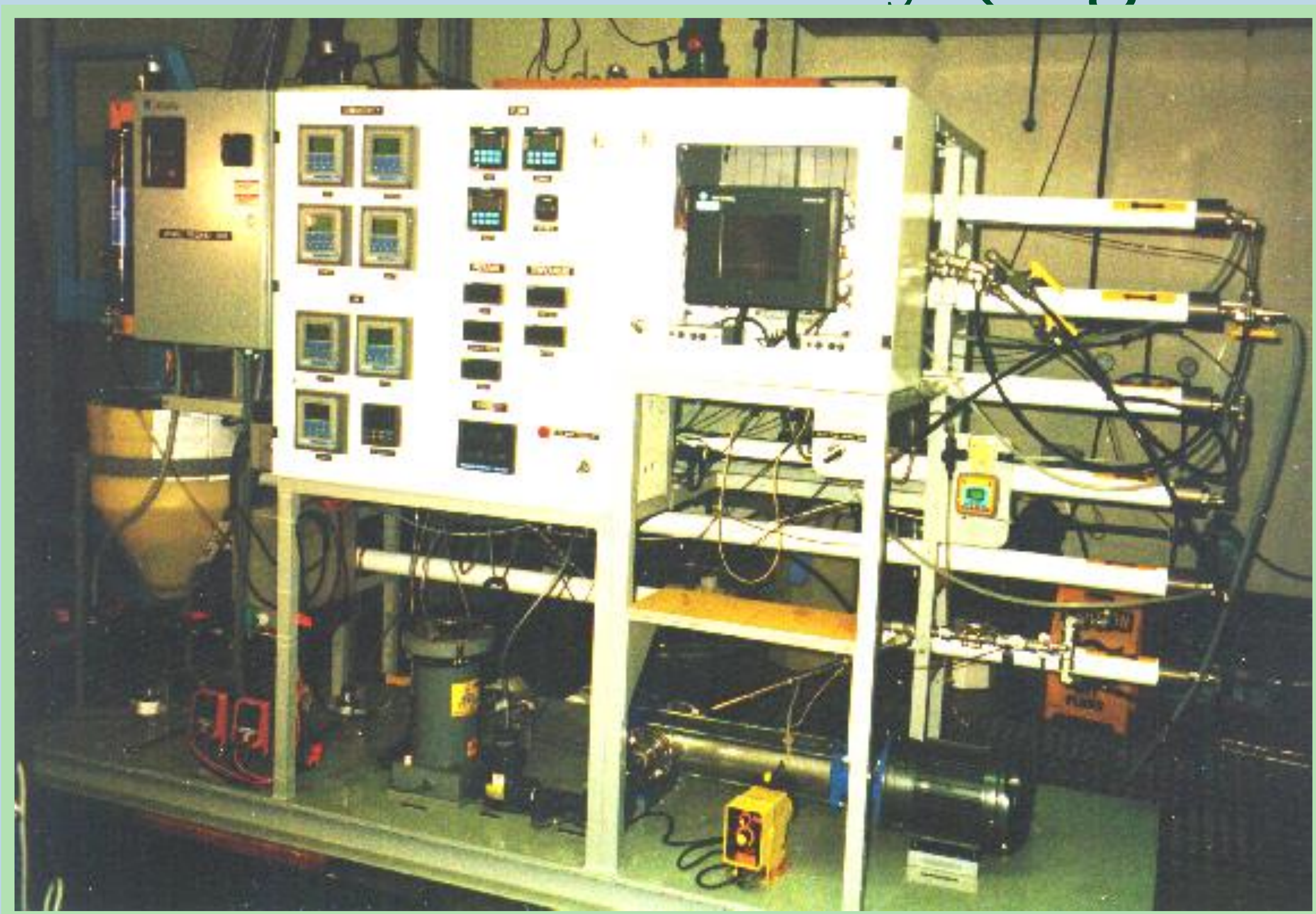
# More Membrane Configurations



# Sieving, Diffusion & Pore Flow



# McAllen, TX
# Waste Water Recovery (6 g/min)



# 0.1 MGD RO Package System

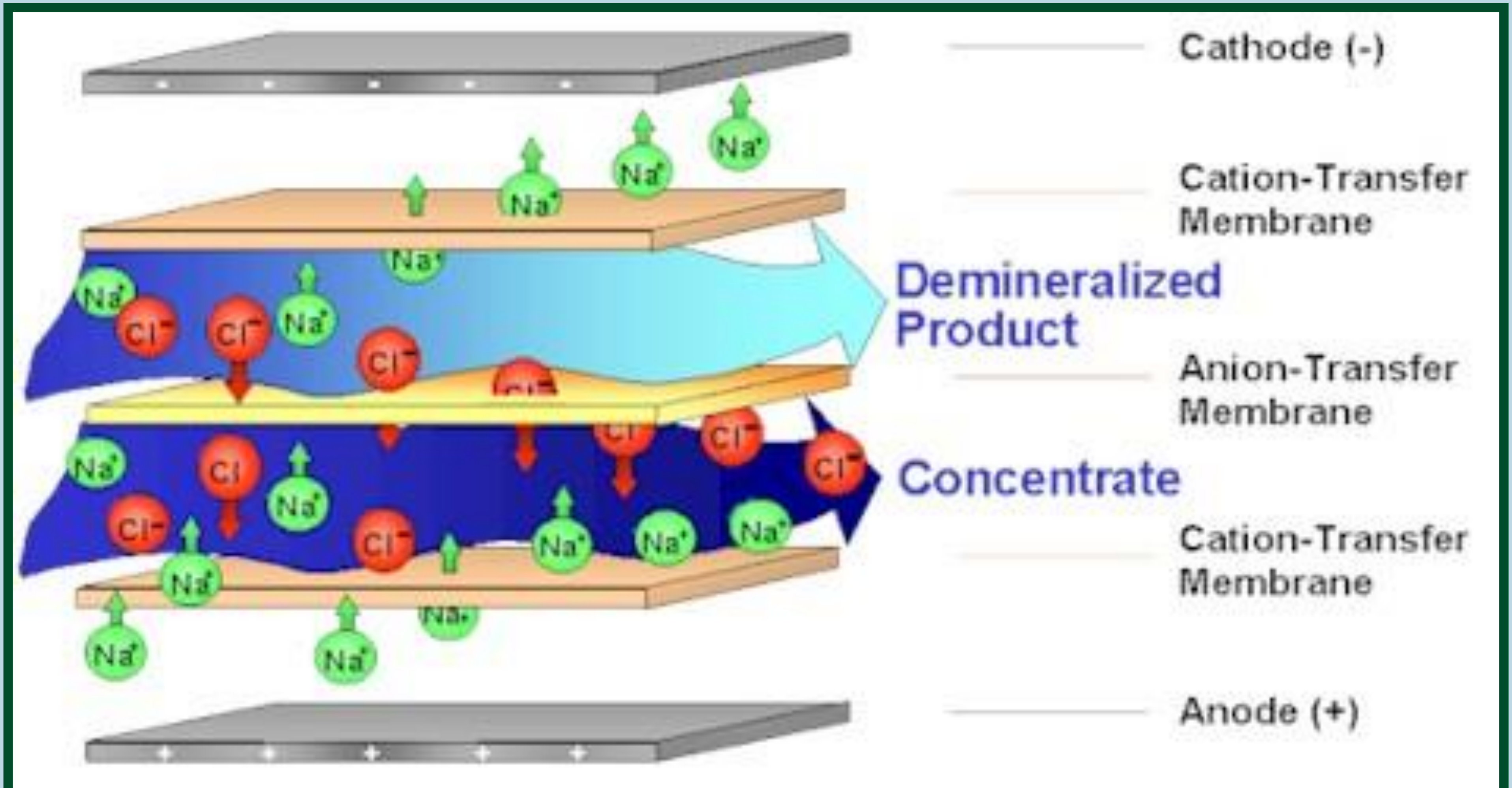
# Yuma Desalting Plant (100 MGD)

# Electrodialysis

- Some chemicals cannot pass through charged membranes as easily as water.
- Direct current electricity is applied through wastewater. Charged impurities move through alternating + and – resin membranes that remove ionic impurities from water.
- Used for the removal of sulfates, fluorides, chromates..

# Electrodialysis

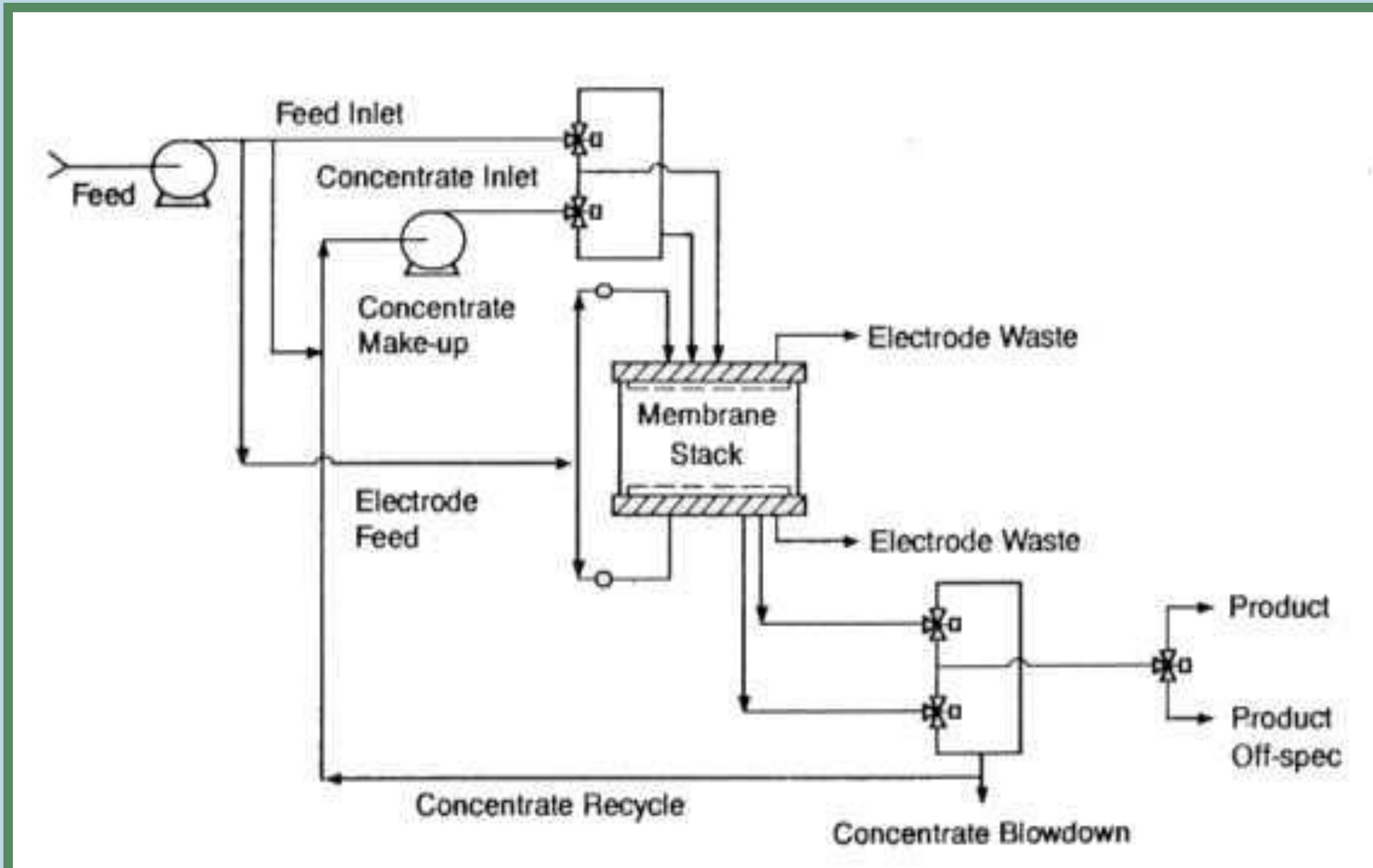
- Uses electrical power to draw ions from product water to the concentrate stream.



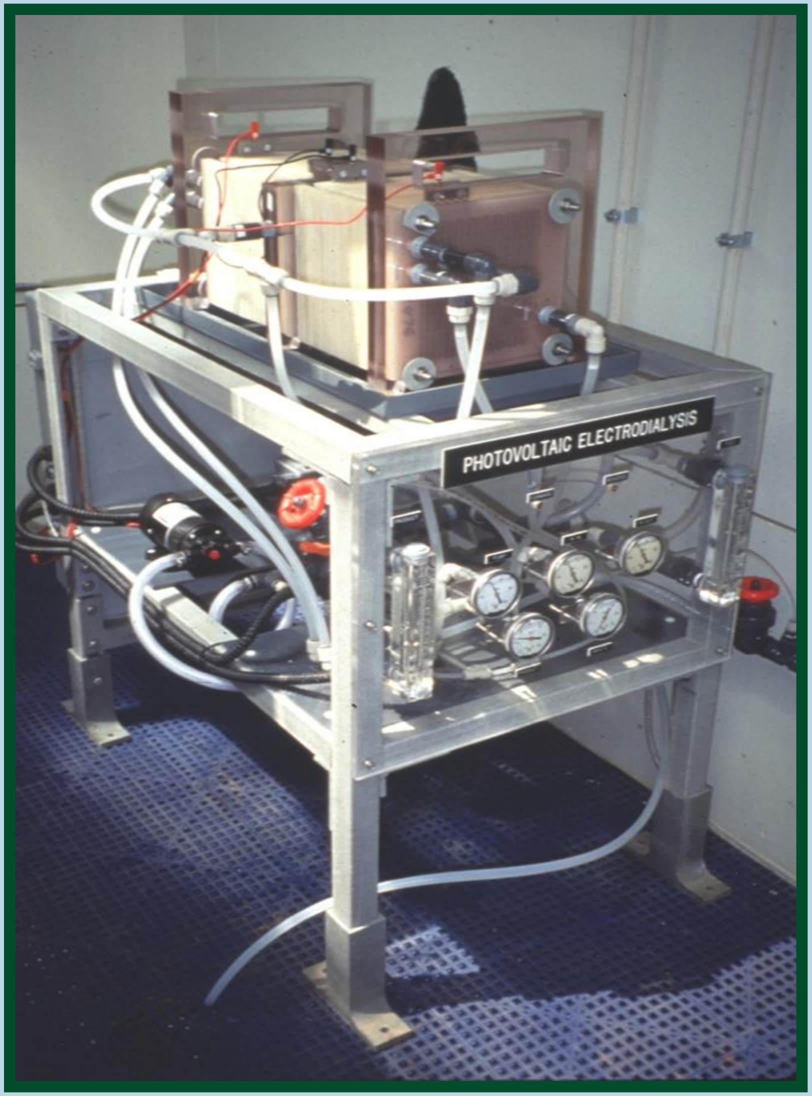
# Electrodialysis

- Membrane fouling and scaling problems are very common.
- Used to treat brackish water.

# Plumbing for EDR

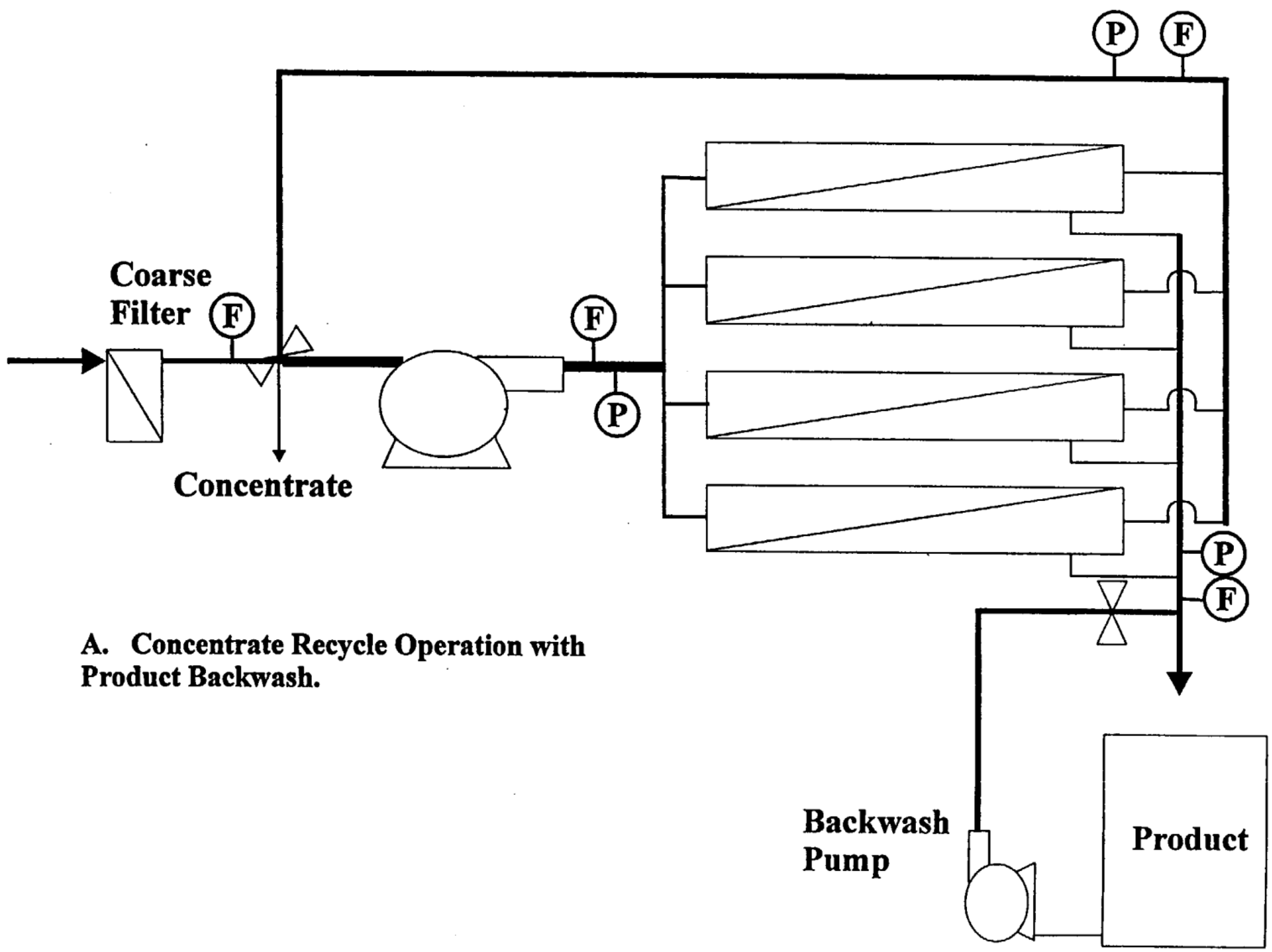


# PV EDR, 1 g/min



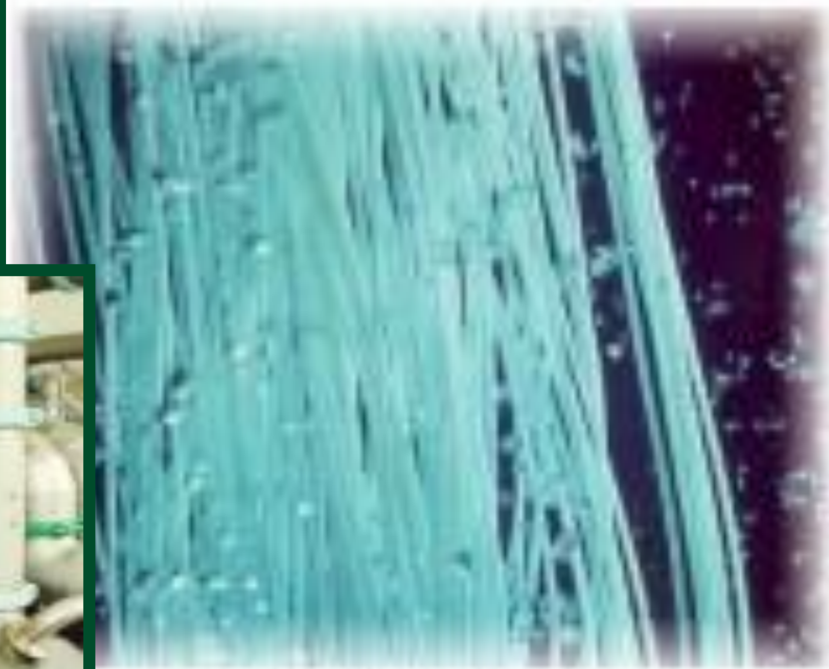
# Photovoltaic Electrodialysis

# Re-circulation to Increase Cross-Flow Velocity, Decrease Fouling




A. Concentrate Recycle Operation with Product Backwash.

# Vacuum driven separation MF or UF-



The ZeeWeed® Hollow Fiber Membrane

The ZeeWeed® membranes are immersed in the process tanks

# Microfiltration

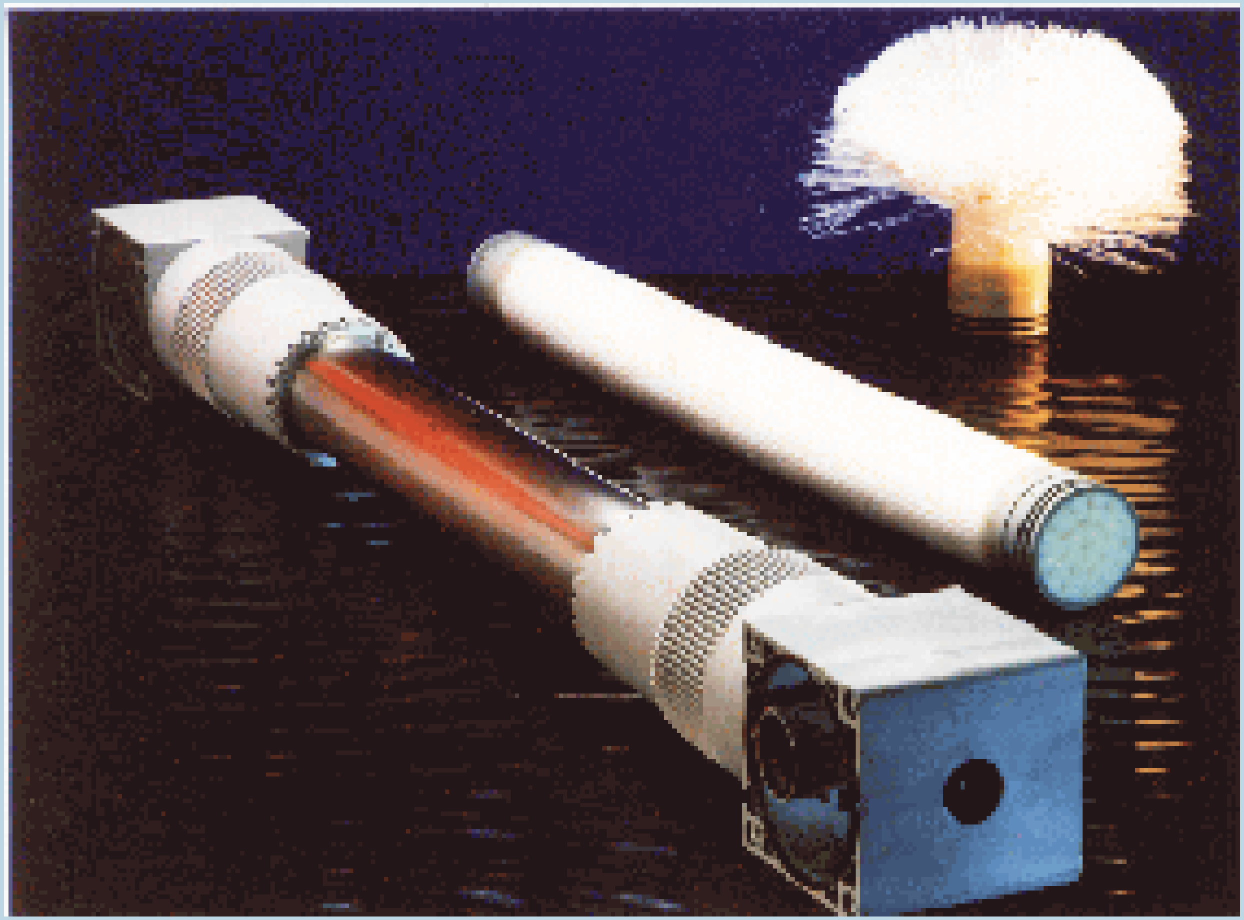
- Any filtration mode
- Any membrane configuration
- Needs back flushing and air scour
- Operating pressure ~ 20-30  psi
- Highly automated!
- Can add coagulants to enhance filtration
- Can be a good pretreatment for RO or NF

# Bolinas Woodrat WTP
# 0.2 MGD MF

- High Turbidity
- 80% Recovery
- Product - .04 NTU
- Concentrate is discharged to surface water

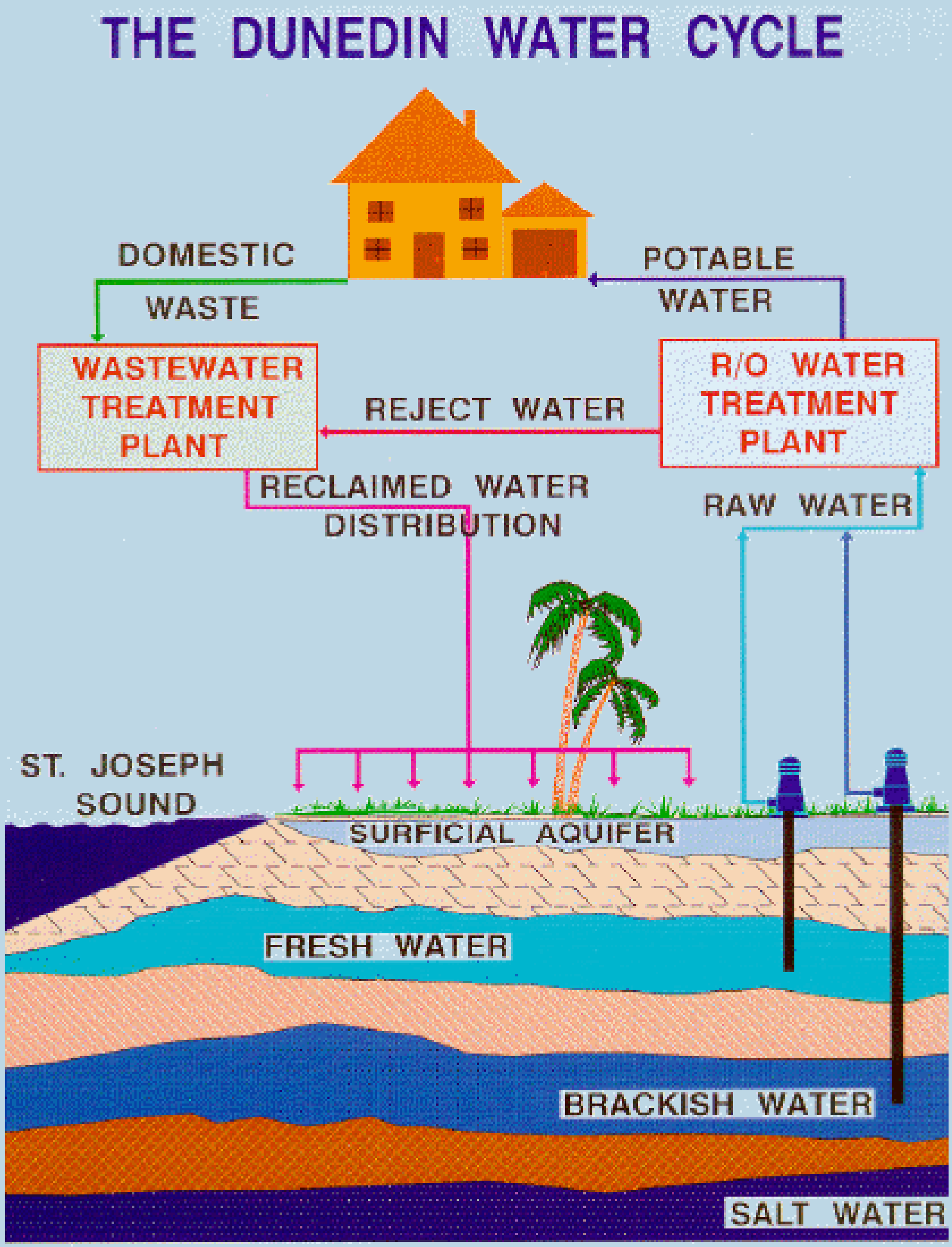
# MF Hollow Fiber Modules

- Removes Giardia, Cryptosporidium, virus, turbidity:
- Great for waste water recovery.



# Concentrate Disposal

- Combine with reclaimed water and release to surface water.
- Deep Well injection - Limited by Geology
- Evaporation/Crystallization - Capacity limited
- Irrigating golf courses and roadway vegetation - Environmental limitations
- Saline wetlands - Capacity Limited


THE DUNEDIN WATER CYCLE
DOMESTIC
WASTE
POTABLE
WATER
WASTEWATER TREATMENT PLANT
REJECT WATER
R/O WATER TREATMENT PLANT
RECLAIMED WATER DISTRIBUTION
RAW WATER
ST. JOSEPH SOUND
SURFICIAL AQUIFER
FRESH WATER
BRACKISH WATER
SALT WATER

# Saline Wetlands

# Irrigation -

- Not a long term solution
- TDS should be <1000 mg/L
- Need careful irrigation management
- Need soil moisture monitoring equipment
- Good for golf courses with no surface discharge

# In Summary

- There is a membrane system to treat most any water problem.

- RO and NF systems should be used to remove only **dissolved** solids - they need VERY clear feed water.

# Electrodialysis

- ED removes IONS from water - it does NOT remove crypto, giardia, uncharged molecules, suspended solids etc.

# UF and MF

- UF can remove color and odor causing organics, virus, and other microbiological pests.  Not dissolved salts.
- MF can remove suspended solids, turbidity, crypto and giardia.  Not color, virus, or dissolved solids.

# Membrane Fouling

- Potential deposition and accumulation of constituenst in the feed stream on the membrane.

**<u>Biological fouling: </u>** Various microorganisms can deposit on membrane surface.

Controlled by disinfection of ww. Chlorination,

UV application in upstream of the membrane

Avoid damage of the membrane by the disinfectant.

# Membrane Biological Reactor (MBR)

- Consists of a biological reactor with suspended biomass and solids seperation by microfiltration membranes.
- Nominal pore size 0.1 – 0.4 micron
- MBRs can be used with:

  Aerobic / anaerobic suspended growth bioreactors to seperate treated ww from active biomass
- Used for industrial ww, municipal ww, water re-use

# Membrane Biological Reactor (MBR)

- Supplementary solid seperation in secondary clarification and effluent filtration
- Eliminates secondary clarification and operate at higher MLSS.
- Advantages:

- Higher volumetric loading rates?

→shorter HRT, lower volume

- Longer SRT ?

→ less sludge production

# MBR advantages (cont.)

- Operation at low D.O.

  → Potential for simultaneous nitrification – denitrification in long SRT systems

- High effluent quality: low turbidity, bacteria, TSS, BOD

  (95% COD, 98% BOD, 99% SS removal)

- Less space
- Suitable for reuse following disinfection

# MBR disadvantages

- High capital cost
- Limited data on membrane life
- High cost of membrane replacement
- Energy cost
- Membrane fouling

## MBR Types

1. Integrated MBR with immersed membrane module.

   Membranes are mounted in modules / casettes

   Parts: membranes + support structures + inlet / outlet connections

2. Bioreactor with an external membrane seperation unit.

   Recirculated MBR. Mixed liquor is circulated through membrane unit.

# MBR Modules

# MBR

- Vacuum < 50 kPa draws water through membrane, solids retain in the reactor
- At the base of the module, there is an air distribution manifold.
- Air helps to:

  -maintain TSS in suspension within the bioreactor

  - clean exterior of membrane surface (scouring)

  - provide oxygen

# Support Facilities of MBR Systems

- Permeate pumps
- Chemical storage tanks
- Chemical feed pumps
- Process control
- Air scour system: Course bubble diffusers located in aeration basin. Provides continuous agitation on the outside of the membrane to minimize solids deposition

# MBR Companies in the Market

- Zenon
- Kubota
- Koch
- Mitsubishi
- Lyonaise des Eaux - Degremont

# In-line Recirculated MBR Design

Activated sludge from the bioreactor is pumped to a pressure driven tubular membrane (solids retained inside)

Solids are recycled to activated sludge basin.

Membranes are backwashed.

No problem of filamentous sludge bulking, floc settling.

# MBR Design

Higher MLSS

- Operation 15 000 – 25 000 mg/L (reported)
- Optimum 8 000 – 10 000 mg/L

Membrane flux rate (L/m$^2$h) is an important design and operation parameter

Lower flux rates @ higher MLSS

# MBR Design - FLUX

Inner skin membranes flux 0.5 – 2 m/d

Outer skin membranes flux 0.2 – 0.6 m/d

Most promising tech.

Low energy consumption, reduction in skid manufacturing costs.

Current research → optimization of fluxes (3 times lower than internal membranes)

# Membrane Fouling

Biomass coats the outer layer of membranes

Finer particles may penetrate the inner pores
→ increase in pressure loss

Periodic more aggresive cleaning may be
needed to maintain filtration capacity.

# 3 Step Cleaning Process

1) Course bubble aeration: Air bubbles rise between vertically oriented fibers. Fibers agitate against one another
   → Mechanical scouring
2) Filtration is interrupted at every 15-30 minutes. Membrane fibres are backwashed with permeate for 30 – 45 sec.

   Chlorine is added to back flush water (<5 mg/L) to inactivate and remove microbes that colonize on the outer membrane surface

# 3 Step Cleaning Process

3) Maintenance clean → ~ 3 times / week

Backwash with strong sodium hypochlorite (100 mg/L) or citric acid for 45 min, then with permeate.

Downtime ~75 min for cleaning.

# External Cleaning

3-6 months

Casettes are taken out of the bioreactor and submerged in high concentration chlorine solution bath (1500 – 2000 mg/L) for 24h

Pressure drop across the membranes is monitored to indicate fouling problems and cleaning needs.

~60 kPa pressure drop → needs recovery cleaning

Spare membranes are installed during recovery cleaning.