Reverse Osmosis

Background to Market and Technology

Technology and Applications

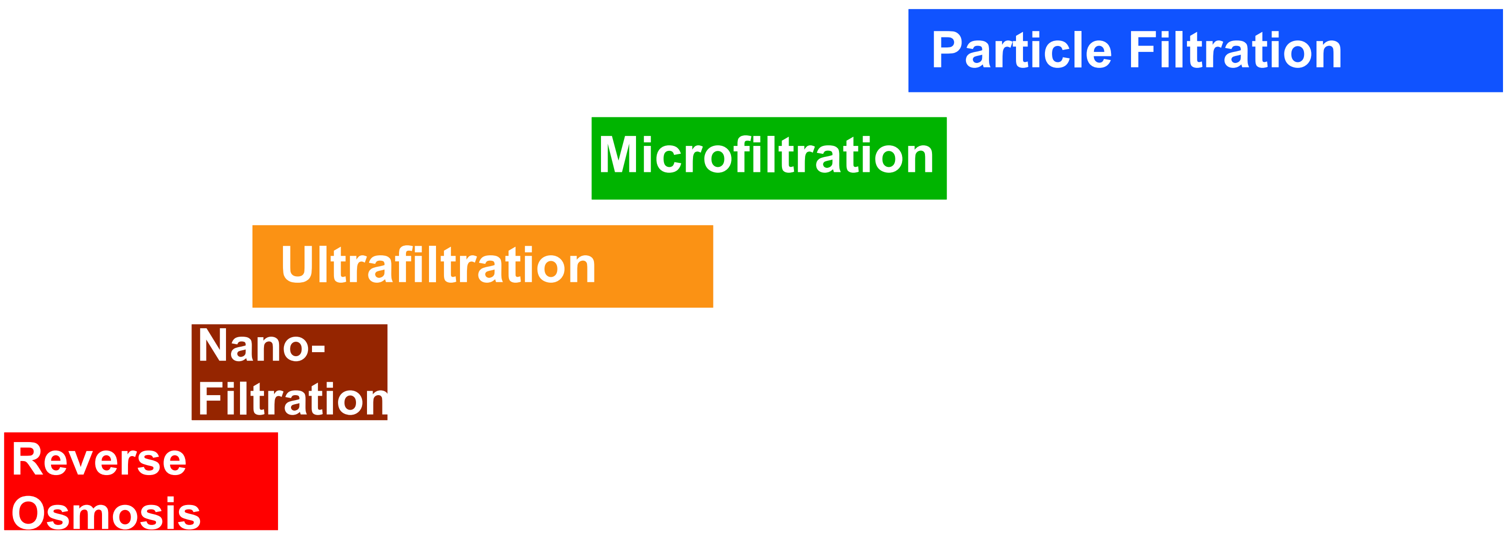
- Reverse osmosis has been commercial for over 25 years.
- 60MLD plants built in Saudi Arabia 20 years ago.
- Current sales of RO membranes world-wide are around $250 million per annum excluding Japan.
- RO System sales could be as high as $1.0b per annum

Membrane Market

- Growth sector of the water treatment industry driven by reduced energy consumption and increased awareness of environmental impact/cost of ion exchange operation
- Growth at 15-18% per annum
- Main manufacturers are from USA
  - Dow/Hydranautics/Fluid Systems USA
  - Koch/Dupont/Osmonics/Trisep Japan
  - Nitto Denko/Toray/Toyobo

Fundamentals of Membranes and Reverse Osmosis

Membrane Separation



Pressure Driven Membrane Processes - Pressures

Membrane Process	Typical Operating Pressure Range (PSI)
Reverse Osmosis	
seawater	800 - 1200
brackish water	100 - 600
Nanofiltration	50 - 225
Ultrafiltration	30 - 100
Microfiltration	2- 45

Impurities in Water

- Ionic
- Non Ionic
- Particulate
- Microbiological
- Gases

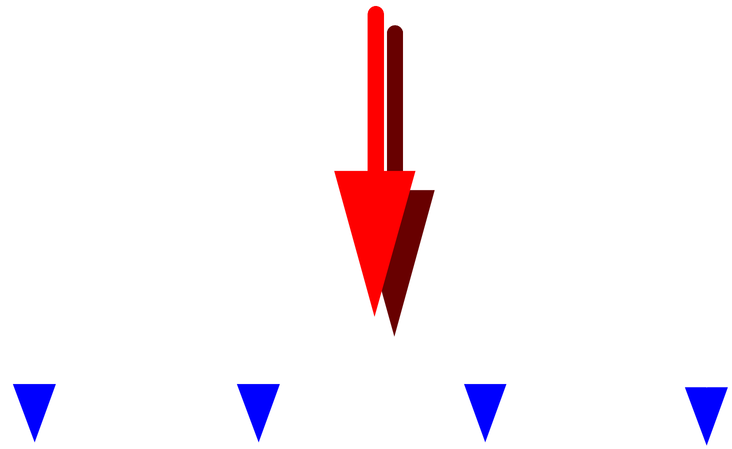
RO Removes

- Ionic
- Non ionic
- Particulate
- Microbiological

When to Consider RO

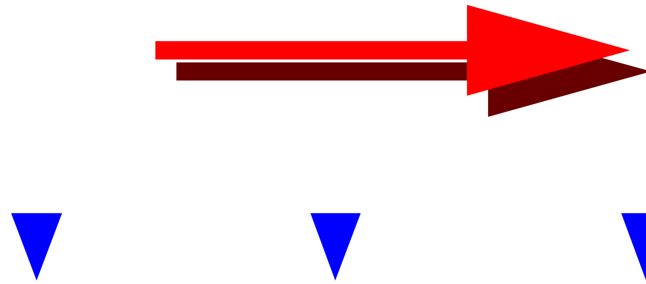
- Water with TDS greater than 150 mg/L
- Regenerant cost reduction
- Waste cost reduction
- Water conservation or recovery

Pressure Filtration



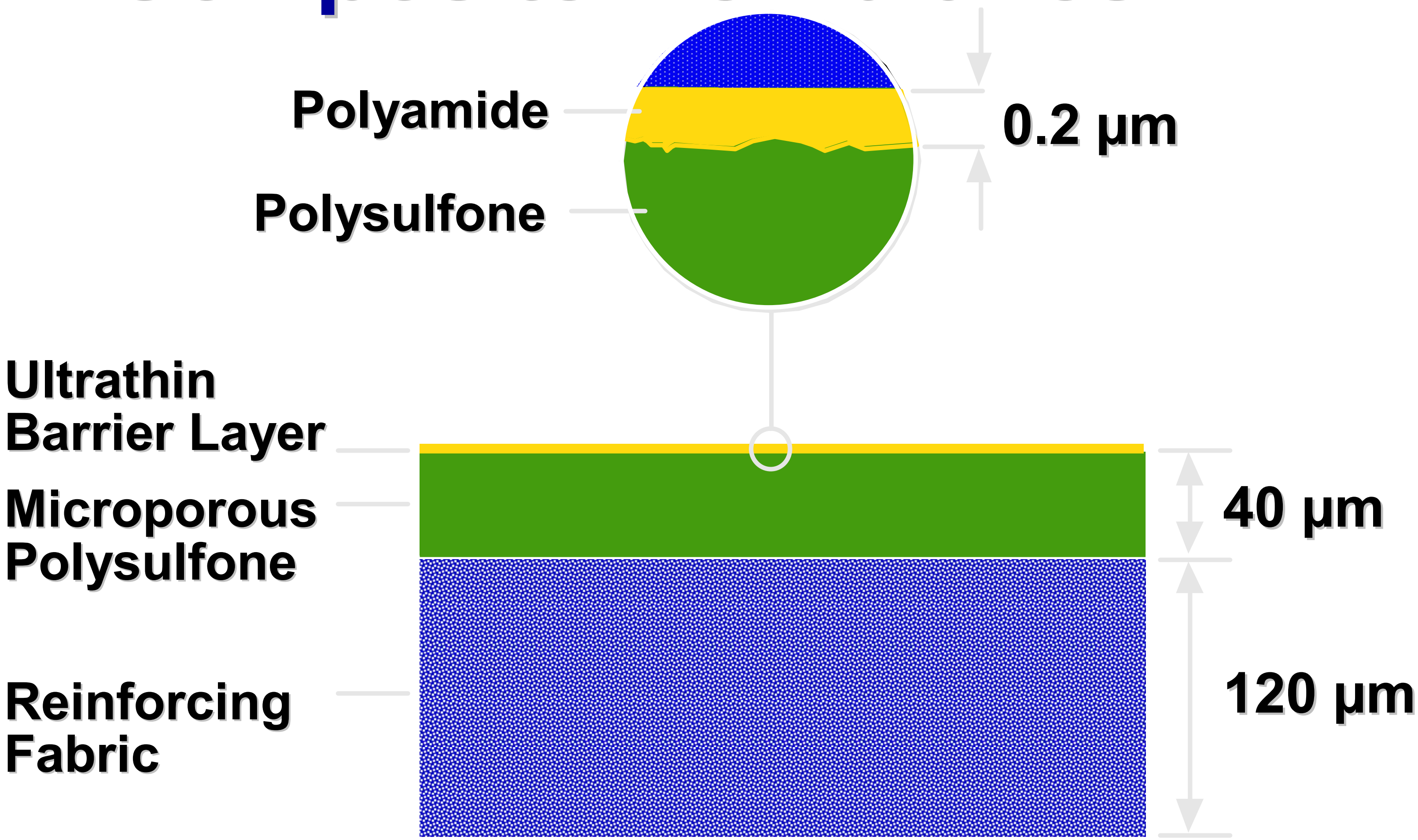
Not feasible for reverse osmosis

Cross Flow Filtration



Required for reverse osmosis and nanofiltration

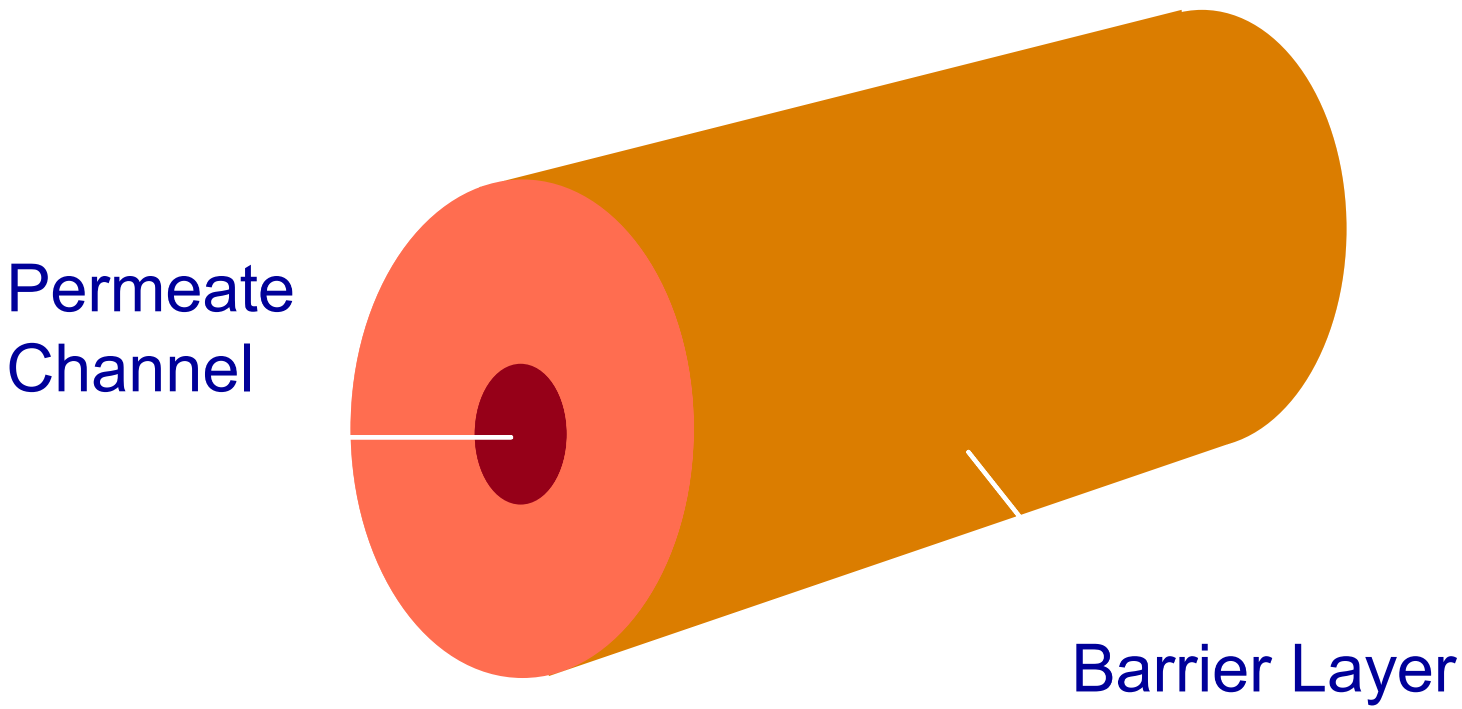
Cross-Section of Thin-film Composite Membranes



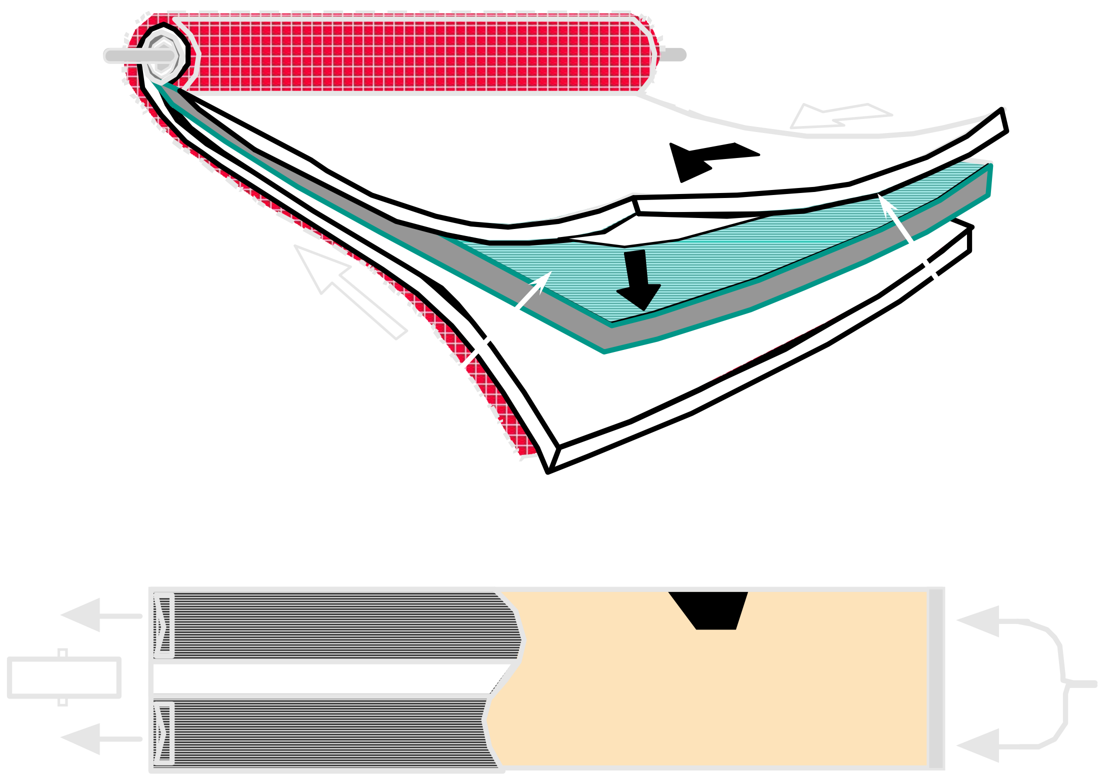
Thin-film Composite Membrane Chemistries

- Typical composition
  - Fully aromatic polyamide (Dow FT30)
  - Polypiperazineamide (Dow NF45)
  - Polyvinyl alcohol (Hydranautics)
  - Sulfonated polysulphone (Ionpure)

Schematic Cross Section



Spiral Wound Reverse Osmosis

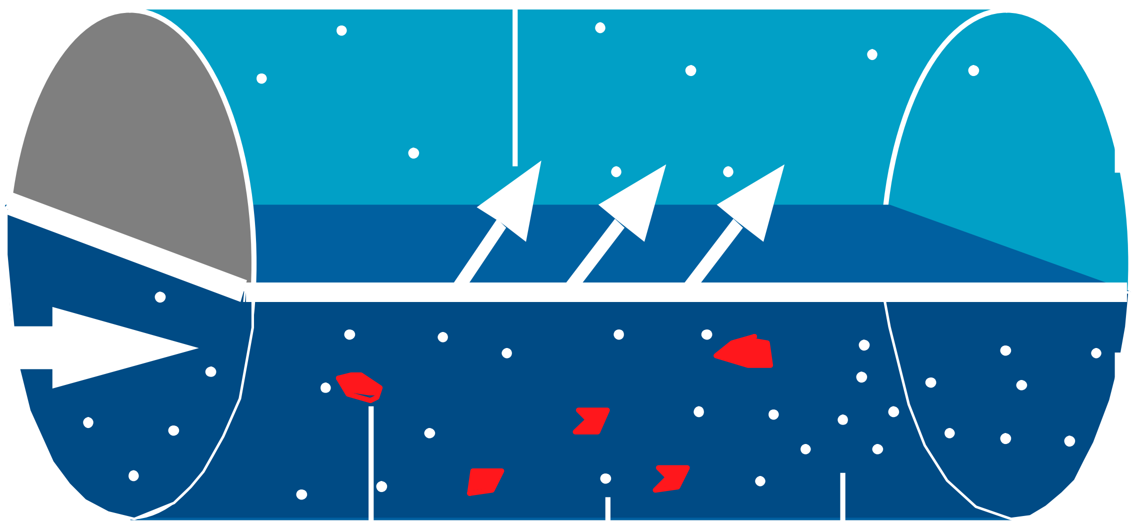


Reverse Osmosis

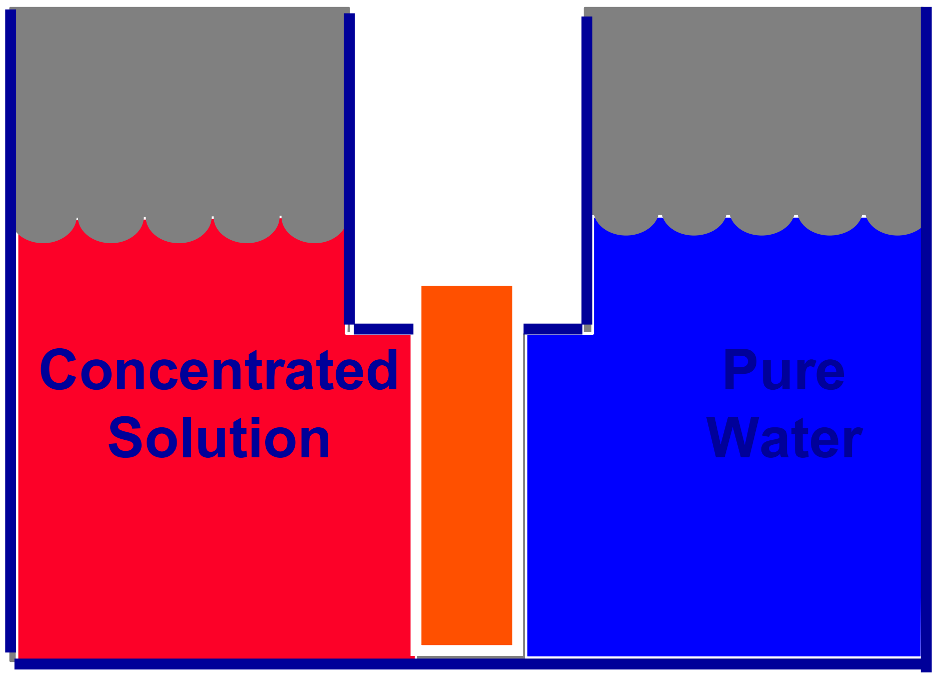
Nanofiltration Definition

- Minimum size rejected on order of one nanometer
- Between RO and UF
- Operates at ultra-low pressure
- Selective permeation of ionic salts and small solutes

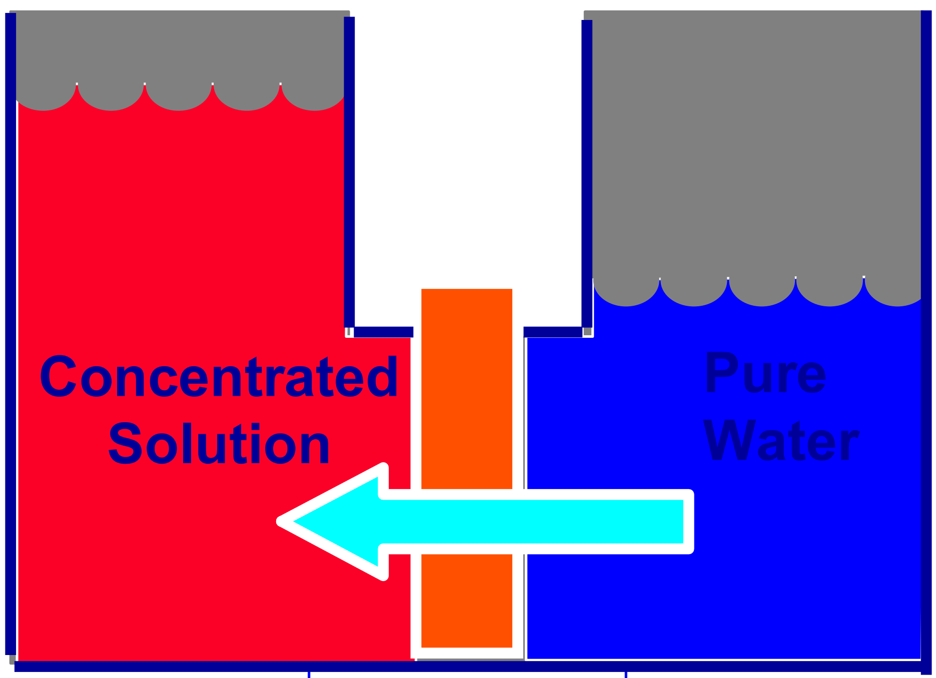
Nanofiltration



Osmotic Processes

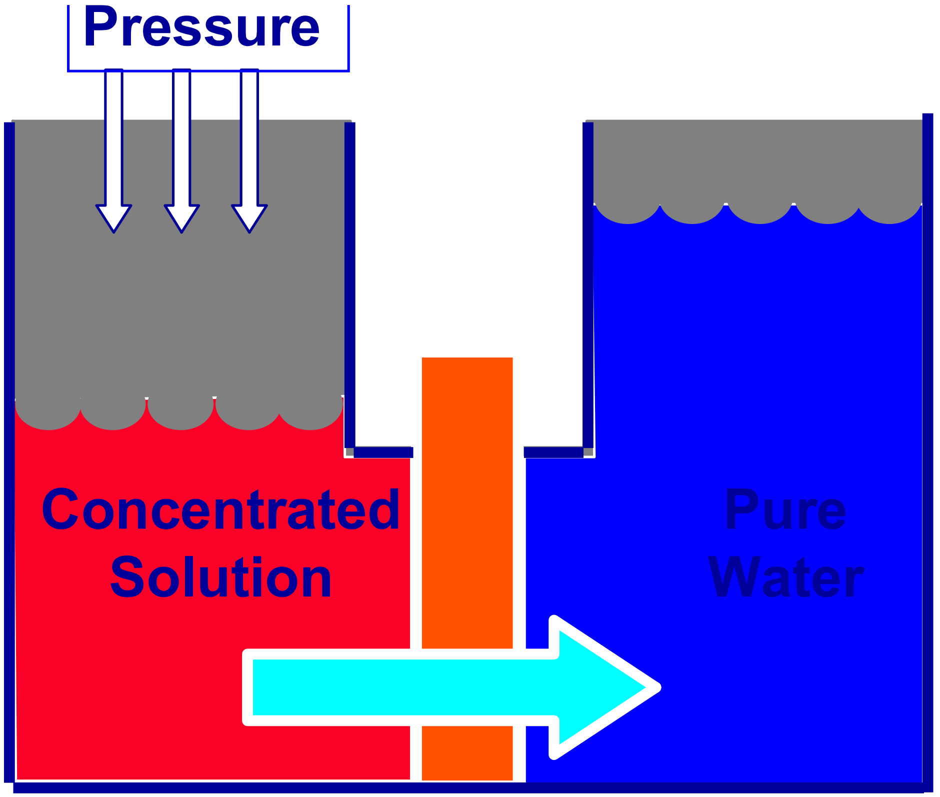


Osmotic Processes



Osmosis

Osmotic Processes



Reverse Osmosis

Reverse Osmosis Involves

- Application of pressure greater than osmotic pressure of solution
- Diffusion of water but not salt through a semipermeable membrane in direction opposite of natural flow
- Crossflow filtration to sweep away concentrated salts

Reverse Osmosis: What It Can Do

- Remove purified water from a feed stream (permeate)
- Concentrate chemicals in a feed stream (reject)
- Selectively separates small ions and molecules

Reverse Osmosis: What It Cannot Do

- Cannot concentrate to 100%
- Cannot separate to 100%
- Cannot reject gases

and is

Not always the most cost effective method

Mass Balance Equations

$$\text{Recovery (\%)} = \frac{\text{Permeate flow}}{\text{Feed flow}} \times 100$$

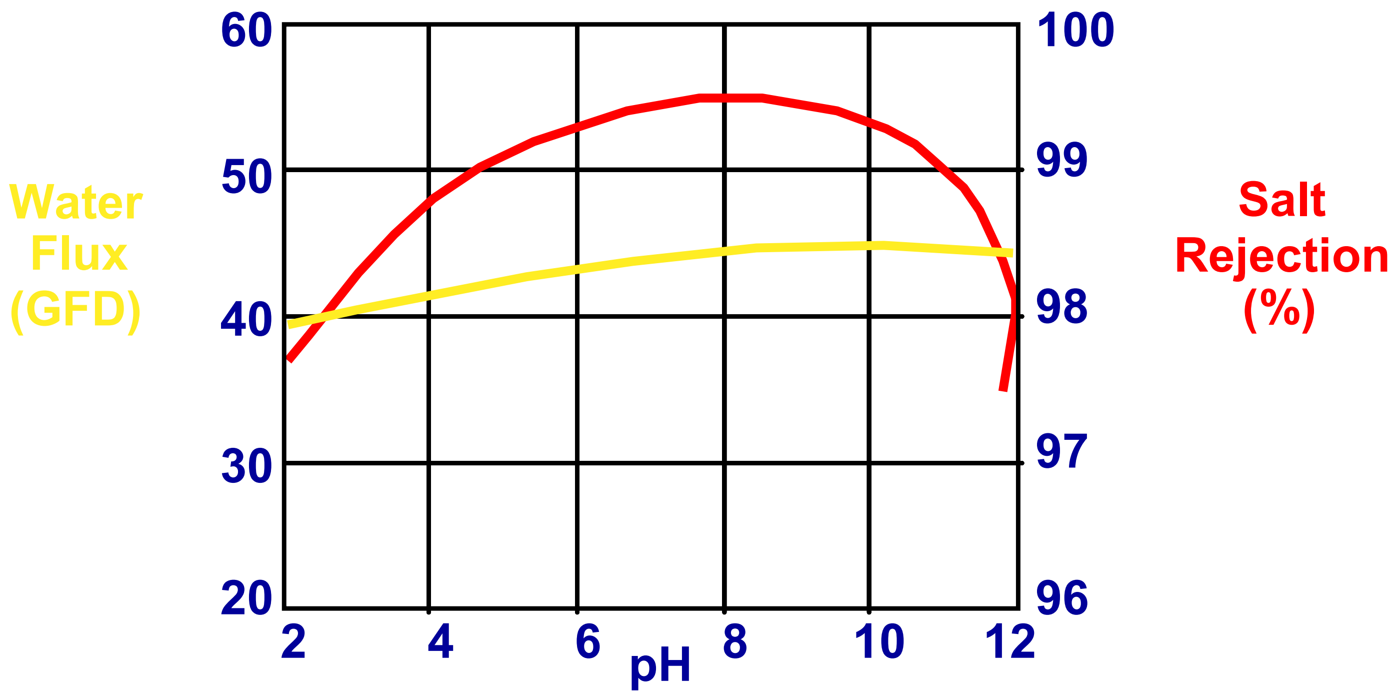
$$\text{Salt Passage (\%)} = \frac{\text{Permeate Salt Concentration}}{\text{Feed Salt Concentration}} \times 100$$

Salt Rejection (%) = 100 - Salt Passage

Normalization of Field Operating Data

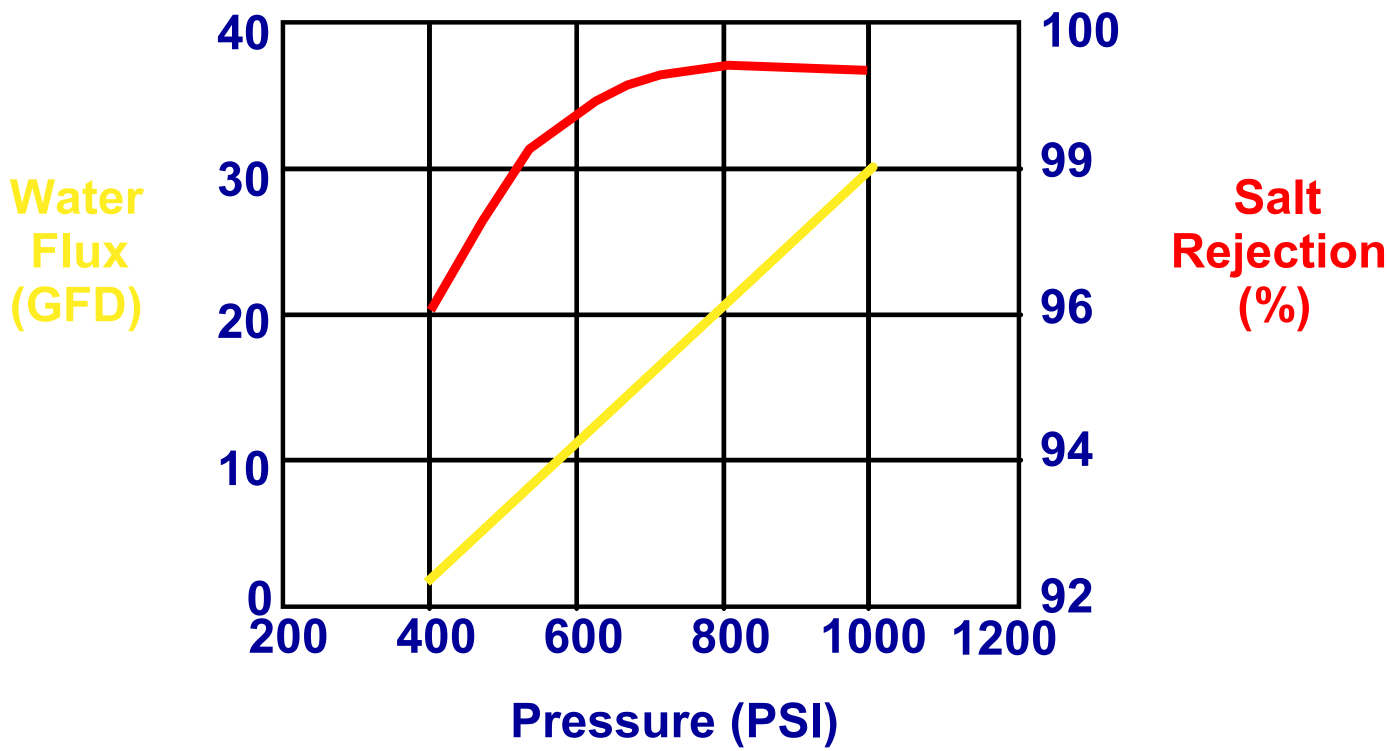
- Feedwater pressure
- Temperature
- Ionic concentration
- System recovery

pH vs Flux and Salt Rejection



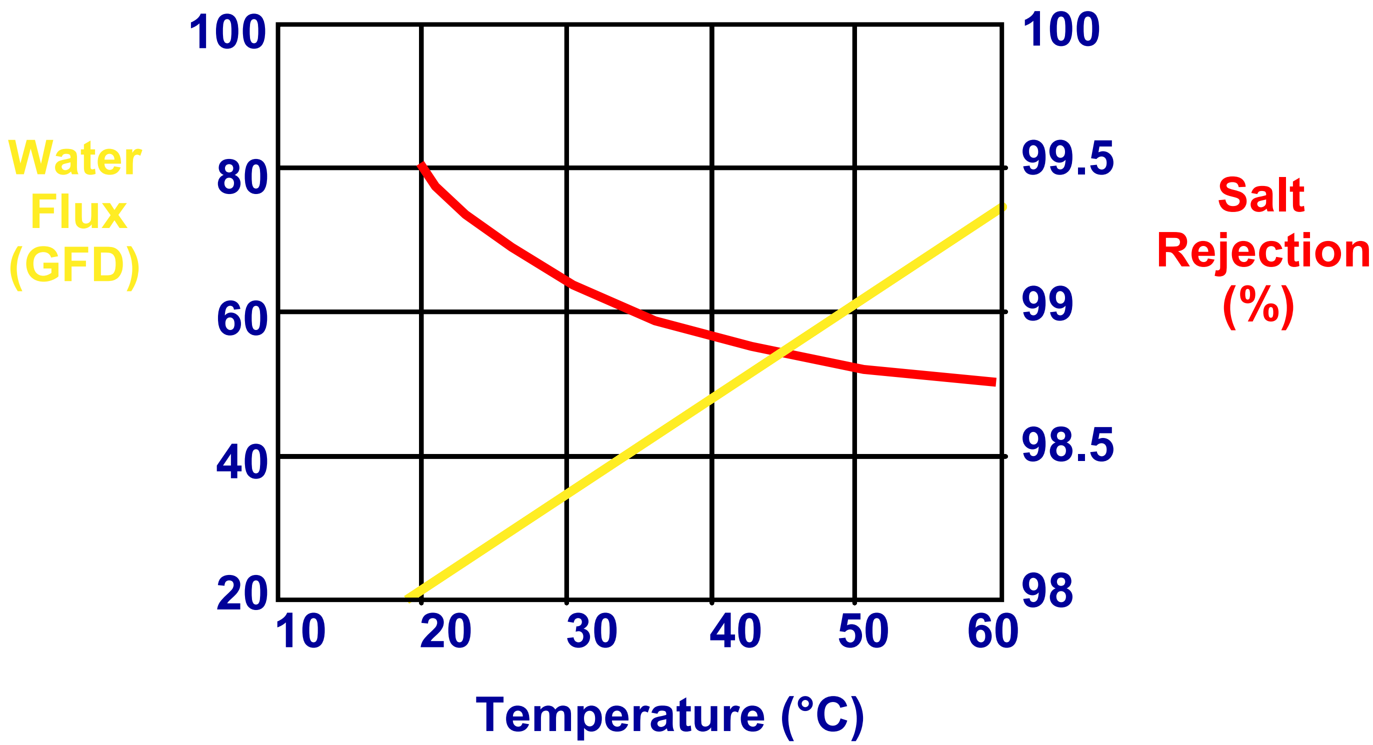
Data from DOW Filmtec

Pressure vs Flux+Rejection



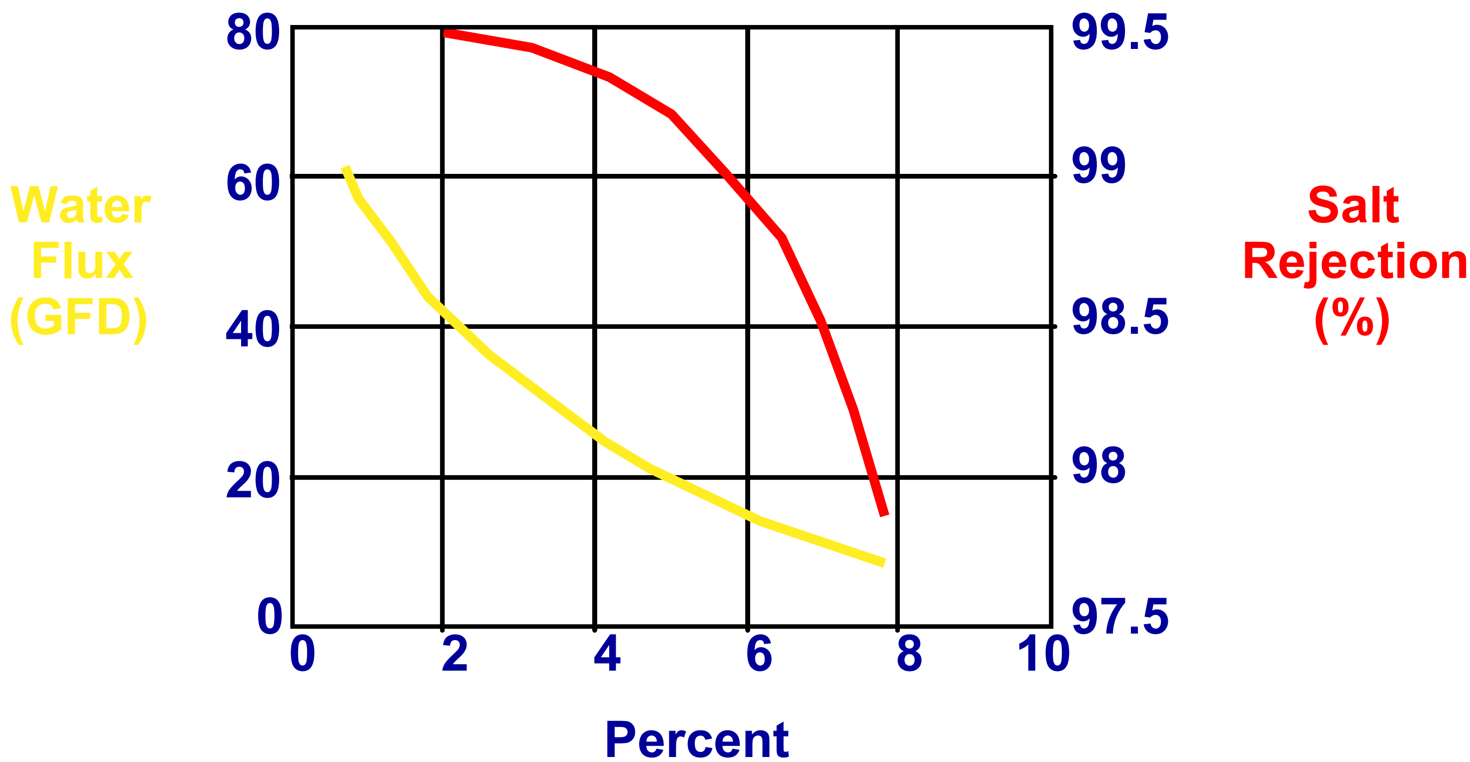
Data from DOW Filmtec

Temperature v Flux+Rejection



Data from DOW Filmtec

Salinity vs Flux and Rejection

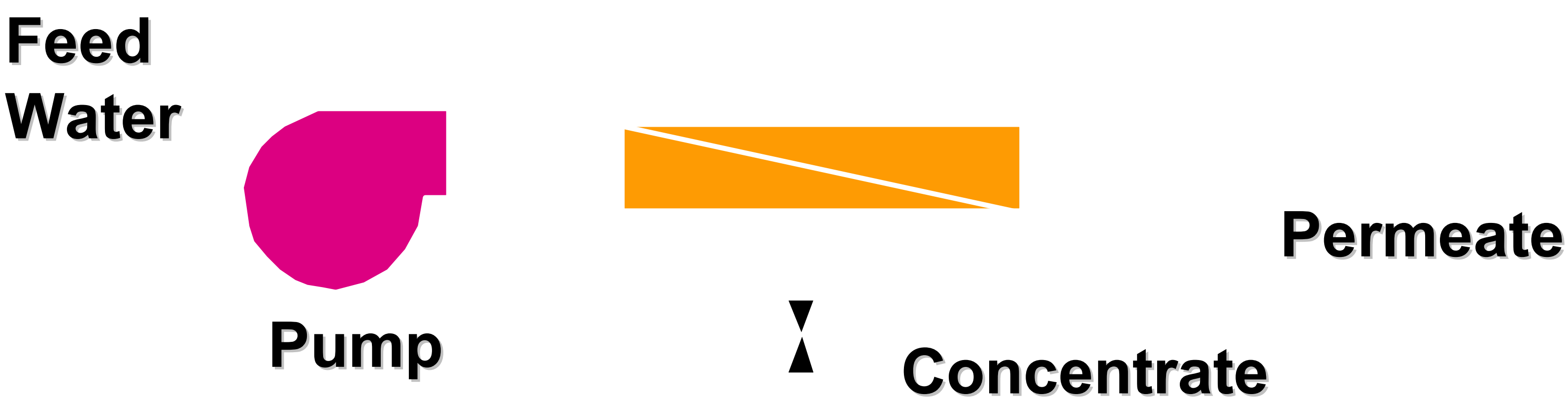


Data from DOW Filmtec

Factors Which Affect Performance of Membranes

- Feedwater Pressure
- Feedwater Temperature
- Feedwater Concentration
- Increased Recovery

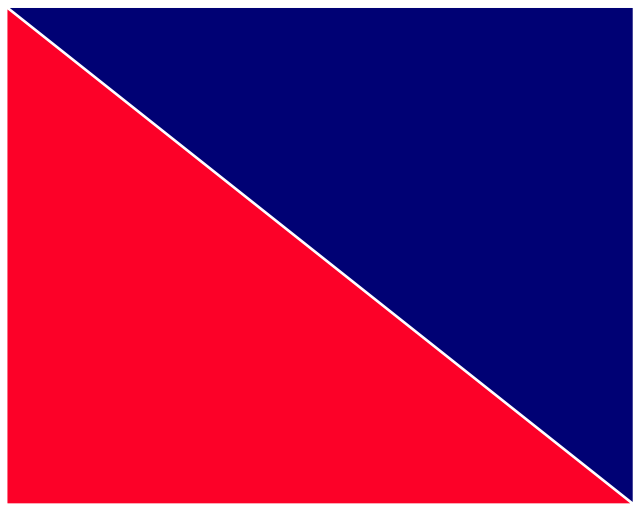
Simplified RO System



100 to 400 psi (brackish water)
800 to 1,200 psi (seawater)

Membrane Performance

Membrane Performance



RO Pretreatment Options

- Suspended Solids Removal
  - Clarification
  - Filtration
  - Primary Membrane UF/MF/EDR
- Control of biological activity
  - Chlorination/dechlorination
  - Chloramines
  - Non Oxidising Biocides
  - Ultraviolet Light

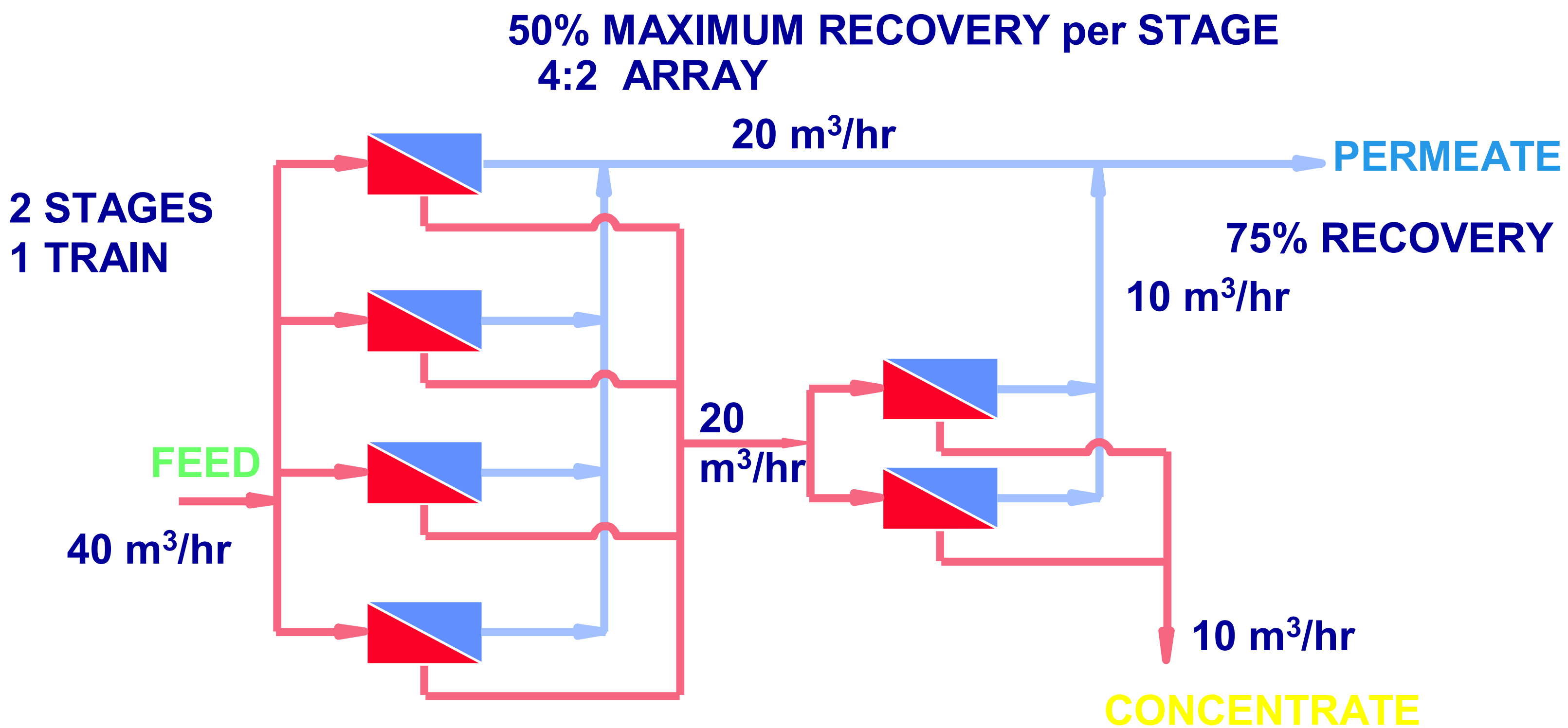
RO Pretreatment Options

- Scale control & pH adjustment
  - Antiscalant Addition
  - Acid Addition
  - Ion Exchange Pretreatment

RO Systems Design

- Module (Element): Contains Membrane
- Tube: Modules in Series (1 - 7)
- Stage: Set of Tubes in Parallel
- Array: No. of Stages, Tubes/Stage
- Train: Set of all of the Above

RO System Flow Diagram



Other Factors to be Aware of..

- One to seven elements per pressure vessel
- Maximum feed flow – physical limitations
- Minimum brine flow or maximum ratio of permeate flow to feed flow – concentration polarization
- Recovery

Other Factors to be Aware of.. System Design Guidelines

- Fouling and/or scaling tendency of feed most influences system design
- Tendency for fouling increases with increasing permeate flux and increasing element recovery
- Only experience can set limits on permeate flux and element recovery for specific feed
- Use system design guidelines when previous experience is not available

Other Factors to be Aware of.. Feed Composition on System Recovery

- Seawater recovery limitations
  - High osmotic pressure
  - Osmotic pressure limits recovery to 35-45%
- Brackish water recovery limitations
  - Brackish water chemistry tends to contain many sparingly soluble salts which cause scaling
  - Usually limits recovery to 70-85%

Factors Which Affect Performance of Membranes

- Feedwater Pressure
- Feedwater Temperature
- Feedwater Concentration
- Increased Recovery

Troubleshooting

Overview

- The Importance of Record Keeping
- The General Rule of Troubleshooting
- Signs of Trouble
- Causes and Corrective Measures of Trouble Signs
- Taking the Total System Approach

Why Keep Records?

- Necessary for observing trends
- Valuable tool for troubleshooting
- Required in the event of a warranty claim

General Rule of Troubleshooting

- First Stage Problem - Fouling
- Last Stage Problem - Scaling

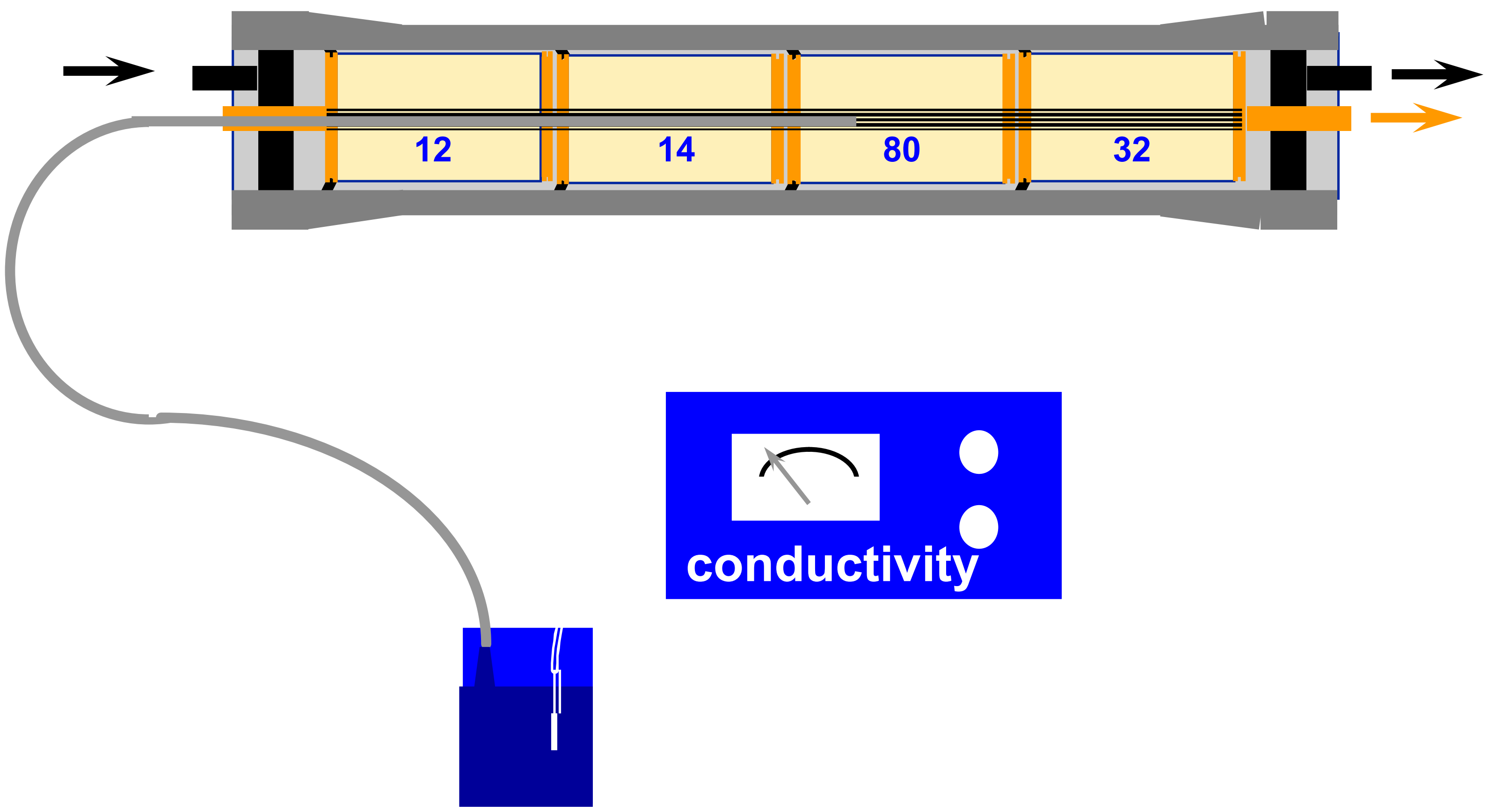
Troubleshooting

- Signs of trouble
  - Loss of permeate flow
  - Increase in salt passage
  - Increase in differential P

Probing

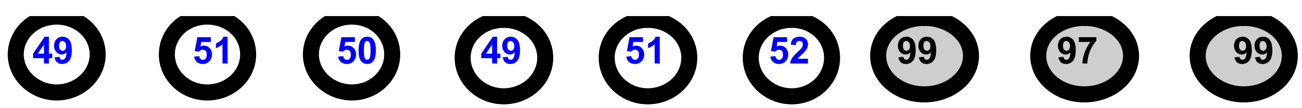
- Procedure to determine problem area in pressure vessel without unloading elements from vessel
- Probe if one pressure vessel shows a significantly higher permeate TDS than other vessels of the same array
- Plot TDS measurements on a conductivity profile to determine problem area in vessel

Troubleshooting - Probing



Troubleshooting - System

- Best recorded by preparing a series of circles arranged similar to the vessel rack assembly and writing each vessel's reading in its respective circle.
- Example: 24:12 array at 75% recovery



High Differential Pressure

²P is a measure of the resistance to the hydraulic flow of water through the system. This is very dependent on flow rates through the element brine flow channels and on water temperature

Lead element brine flow channels will show debris, foulants, and scalants

High Differential Pressure

- Causes
  - Cartridge filter by-pass
  - Media filter breakthrough
  - Pump impeller deterioration
  - Scaling
  - Brine seal damage / improper placement
  - Biological fouling
  - Precipitated antiscalants

High Differential Pressure

- Cause: Cartridge Filter By-pass
  - Filter improperly installed
    - Avoid cellulose-based filters
- Corrective Measure:
  - Properly install cartridge filter
  - Clean filter housings when replacing filters

Taking the Total System Approach

- Troubleshooting Steps
  - Investigate
  - Evaluate
  - Solve
  - Prevent

Troubleshooting

- Investigate entire system
  - Review normalized operating data
  - Check feedwater quality
  - Confirm chemical dose rates
  - Calculate material balance
    - Calibrate instruments, i.e. flow meters
  - Try to localize problems for further in-depth evaluation

If Source of Problem is Not Identified

- Check conductivities and probe if necessary
- Remove and inspect first element, first stage and last element, last stage
- Look for mechanical damage (torn O-ring, cracked fiberglass)
- Visually inspect elements; send to Anjou Recherche for autopsy if necessary
- Determine effect of first high pH then low pH cleaning
- Analyze cleaning solutions for metals and TOC

If Source of Problem is Still Not Identified

- Conduct a destructive autopsy of the elements:
  - Check for metals and organics on membrane surface
  - Conduct dye test for oxidative damage to the membrane
  - Visually examine the element for physical damage (wrinkles, glue line separation, etc.)

Clean In Place System

- 9 m3/hr per pressure vessel
- >4 bar Pressure
- In Line Filter
- Heater System
- 35-70 Litres per element to be cleaned
- Return Line below liquid in Tank

Design Faults with CIP

- Insufficient Flow
- Excessive Pressure
- Tank Heating Capacity too Small or Omitted
- Lack of Appropriate Monitoring - Flow/Pressure
- Plant Cannot be Cleaned in Stages
- Contents of Tank Cannot be Diverted
- Procedure Recommends incorrect Products for Fouling

Monitoring Requirement

- Feed System (by stage)
  - Salinity Concentration
  - pH
  - Temperature
- Permeate
  - Concentration/Flow/PressurePressure
- Concentrate
  - Flow/Pressure and Concentration (optional)