WATER & PROCESS SOLUTIONS

Advanced Reverse Osmosis System Design

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Previous Webinars:

Reverse Osmosis Design Basics – Scott Beardsley

1. Scope of system design
2. System configuration types
3. System design guidelines
4. Ten steps to design a membrane system

Previous Water Academy webinars can be found at:

www.dowwaterandprocess.com

Overview of Advanced RO Design

- RO system design guideline variables
- Drivers for RO system configuration selection
- Principles and benefits of RO array flux balancing
- Array selection criteria to achieve permeate quality target
- Energy recovery

Dichotomy of RO System Design

Focus on minimizing capital costs (CAPEX):

Implications:

- Maximize system flux
- Minimize number of elements and vessels

Focus on minimizing operational costs (OPEX):

Implications:

- Lower system flux
- Higher number of elements and vessels
- Prefer low energy membranes

Achieve the required permeate quality at the lowest total cost of water

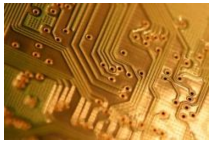
Complexity of RO Designs

VARIOUS APPLICATIONS

Industrial/ Power/UPW

1st & 2nd pass





Wastewater Reuse

1st & 2nd pass

Irrigation

1st pass

Municipal Potable

1st pass

SWRO

1st & 2nd Pass

VARIOUS FEED WATER SOURCES

- Waste water
  - Conventional
  - UF
- Surface water
  - Conventional
  - UF
- Well water
- RO permeate

Increasing Fouling Potable

Global Market

Global Project Development

VARIOUS QUALITY REQUIREMENTS

- B < 0. 3-1 mg/l
- Br < 0.1 mg/l
- TOC < 10 ppb
- NO_3 < 0.5 -35 mg/l
- NH_4 < 0.5 mg/l
- SiO_2 < 10 ppb
- Hardness 0.5 mg/l - 200 mg/l $CaCO_3$
- TDS: 0.1 mg/l - 500 mg/l

Regional Preferences

Regional Regulations

Strong Regional Variations

(TDS/Temp)

Market Segment Nuances for RO Design

Municipal

- Medium to large size plants
- Wide permeate quality targets
- Total cost of water is most critical

- Greater latitude in system design
- Larger selection of RO elements

Industrial

- Small to medium size plants
- Narrow permeate quality targets
- System reliability is most critical

- Narrow latitude in system design
- High rejection RO elements

Membrane Design Guidelines

Happy RO Elements Work Better and Live Longer!

Design Guideline Variables

Feed Water Variables

- Temperature
- pH
- Silt Density Index
- Turbidity
- Salinity

System Variables

- Element Flux
- Element Feed Flow
- Differential Pressure
- Element Recovery
- System Recovery
- Operating Pressure

Membrane Design Guideline Variables

Feed Water Variables	Design Considerations
Temperature	Min T = Max P; Max T = Max TDS & Flux
pH	Rejection; Rejection of spec. ions; Scaling
Silt Density Index	Fouling potential; Pretreatment
Turbidity	Fouling potential; Pretreatment
Salinity	Membrane choice; Recovery; Pressure

System Variables	
Element Flux	Number of RO elements and vessels
Element Feed Flow	Differential pressure; Number of vessels
Differential Pressure	Num. of elements/vessel; Spacer; Life
Element Recovery	System recovery; Salinity; flux balance
Operating Pressure	OPEX; Salinity; Temperature; Flux; Area;

Membrane Element Selection

According to feed water fouling potential

- Standard feed spacer thickness: 28 mil
- Feed spacer thickness for feeds with increased fouling potential: 34 mil
- Fouling resistant BW membrane for biofouling control

Membrane Element Selection

According to required product water quality and energy requirements

Higher salt passage	NF270	Lower feed pressure
	NF90	
	XLE	
	LE	
	XFRLE	
	HRLE	
	BW30 / TW30	
	ECO	
	BW30XFR	
	BW30HR	
	SEAMAXX	
	SW30ULE	
Lower Salt passage	SW30XLE	Higher feed pressure
	SW30HR	
	SW30HRLE	
	SW30XHR	

Selecting RO System Configuration

Typical RO System and Element Selection Drivers

- Controlling RO array flux balance
- RO fouling/scaling mitigation
- Required permeate or concentrate quality
- Optimization of RO system energy consumption

Typically, all of these selection drivers have an impact on the final RO system design.

Configuration – Number of stages selection

Number of serial element positions should be higher for

- Higher system recovery
- Higher fouling tendency of the feed water

Number of stages depends on

- Number of serial element positions
- Number of elements per pressure vessel

Configuration – Number of stages selection

Number of stages of a brackish water system

System Recovery (%)	Number of serial element positions	Number of stages (6-element vessels)
40 – 60	6	1
70 – 80	12	2
85 – 90	18	3

Number of stages of a sea water system

System Recovery (%)	Number of serial element positions	Number of stages (6-element vessels)	Number of stages (7-element vessels)	Number of stages (8-element vessels)
35 - 40	6	1	1	-
45	7 - 12	2	1	1
50	8 - 12	2	2	1
55 – 60	12 - 14	2	2	-

Multistage systems: Staging ratio calculation

$$R = \left[\frac{1}{(1-Y)}\right]^{\frac{1}{n}}$$

Y	**System recovery (fraction)**
n	**Number stages**

$$R = \frac{N_V(i)}{N_V(i+1)}$$

R	**Staging ratio**
$N_V(i)$	**Number of vessels in stage i**
$N_V(i+1)$	**Number of vessels in stage (i +1)**

Calculate number of vessels of first stage NV(1)

$$N_V(1) = \frac{N_V}{1 + R^{-1}}$$

For 2 stage system

$$N_V(1) = \frac{N_V}{1 + R^{-1} + R^{-2}}$$

For 3 stage system

Multistage Systems: Staging Ratio

Typical staging ratio:

1.5	sea water systems with 6-element vessels
2	brackish water systems with 6-element vessels
3	low feed salinity or 2nd pass RO systems

Multi-stage Systems: Managing Flux Balance

Why balance the permeate flow rate?

- Avoid excessive flux of lead elements
- Reduce fouling rate of first stage
- Make better use of tail end membranes
- Reduce number of elements
- Improve product water quality

Methods to balance the permeate flow rate

- Boosting the feed pressure between stages
- Permeate backpressure to first stage only
- Membranes with lower water permeability in lead positions - membranes with higher water permeability in tail positions

Advanced RO System Design Options

Managing Flux Balance

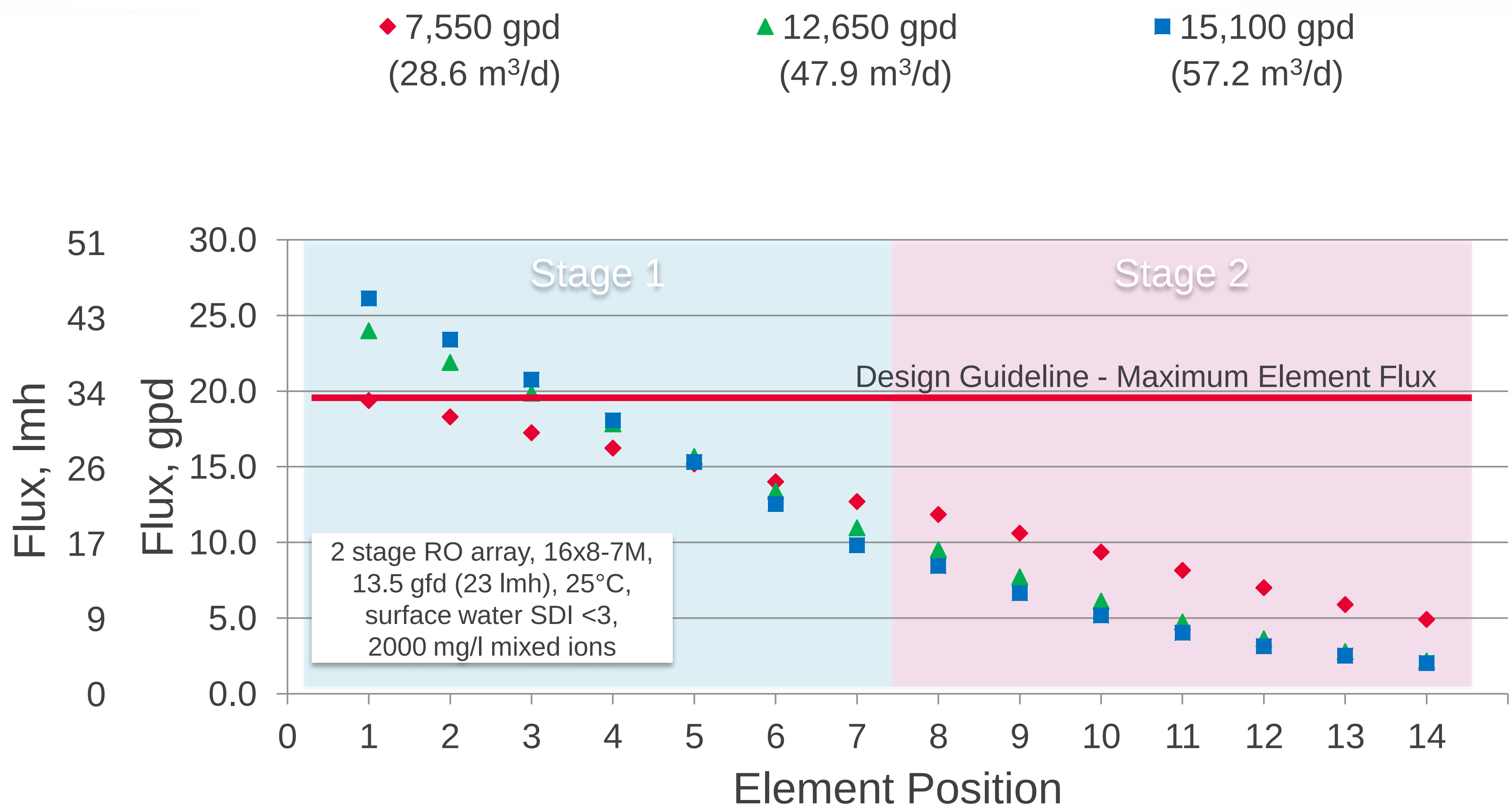
- Stage 1 permeate backpressure or stage 2 boost pump
- Multi-element hybrid array
- Internally Staged Design (ISD) array

Managing Permeate Quality

- RO with feed water/permeate blending
- 2 pass RO system
- 2 pass RO system w/ partial 2nd pass
- 2 pass RO system w/ permeate split design

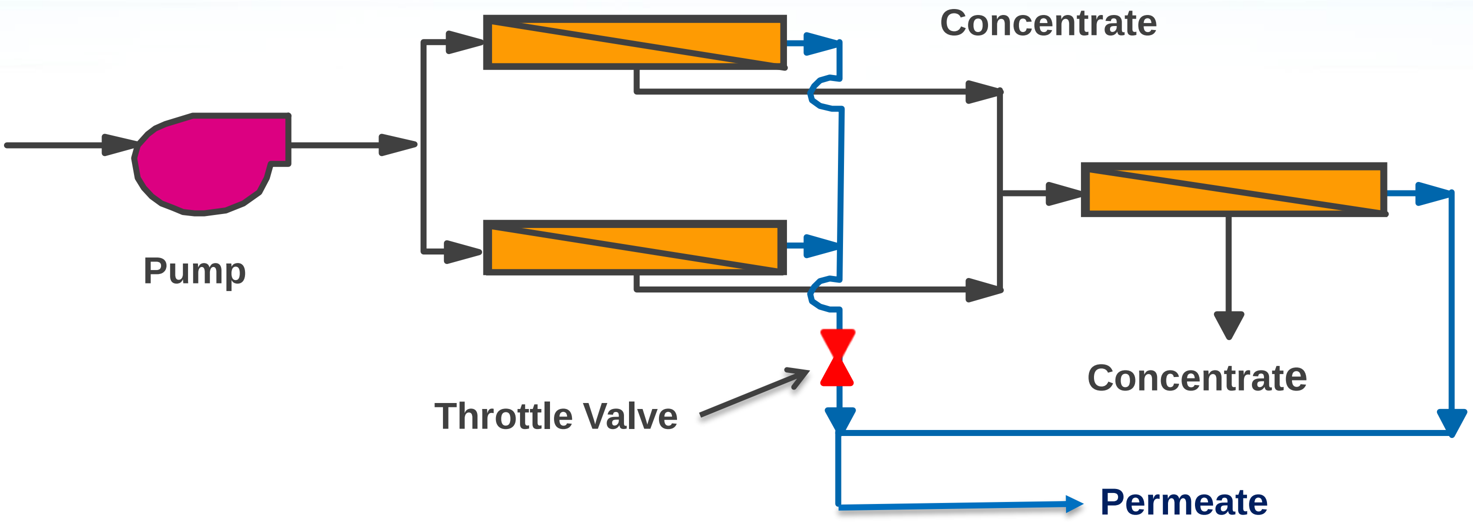
Stage-wise Flux Balancing

Element Flux Across 2 Stage Array



Element gpd tested at 150 psig (10.3 barg), 2000 mg/l NaCl, 25°C, pH 8, 15% recovery

Balancing Flux with Stage 1 Permeate Pressure

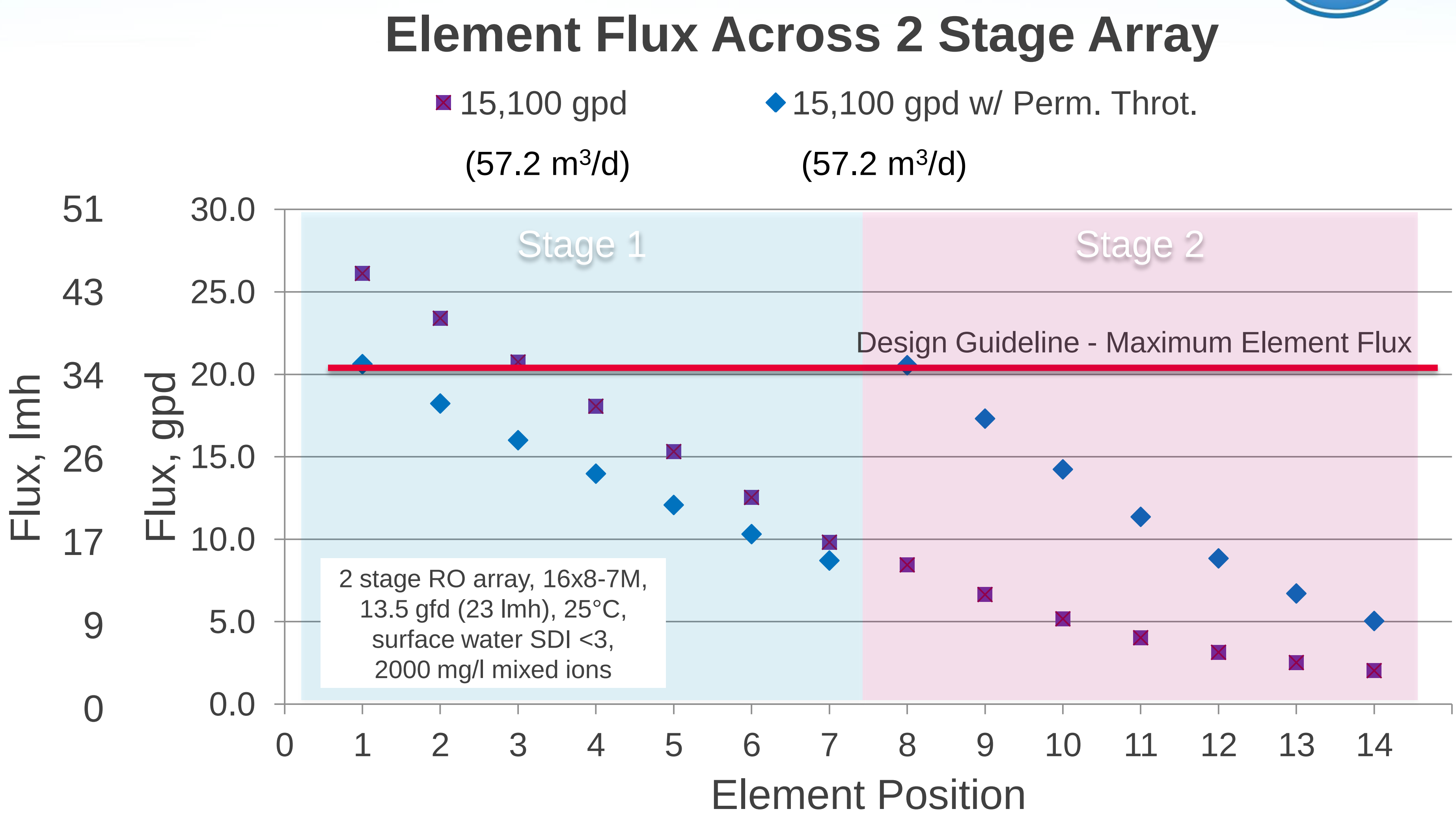


$$NDP = P_{feed} - \frac{DP}{2} - OP_{fb} - P_p + OP_p$$

Where:

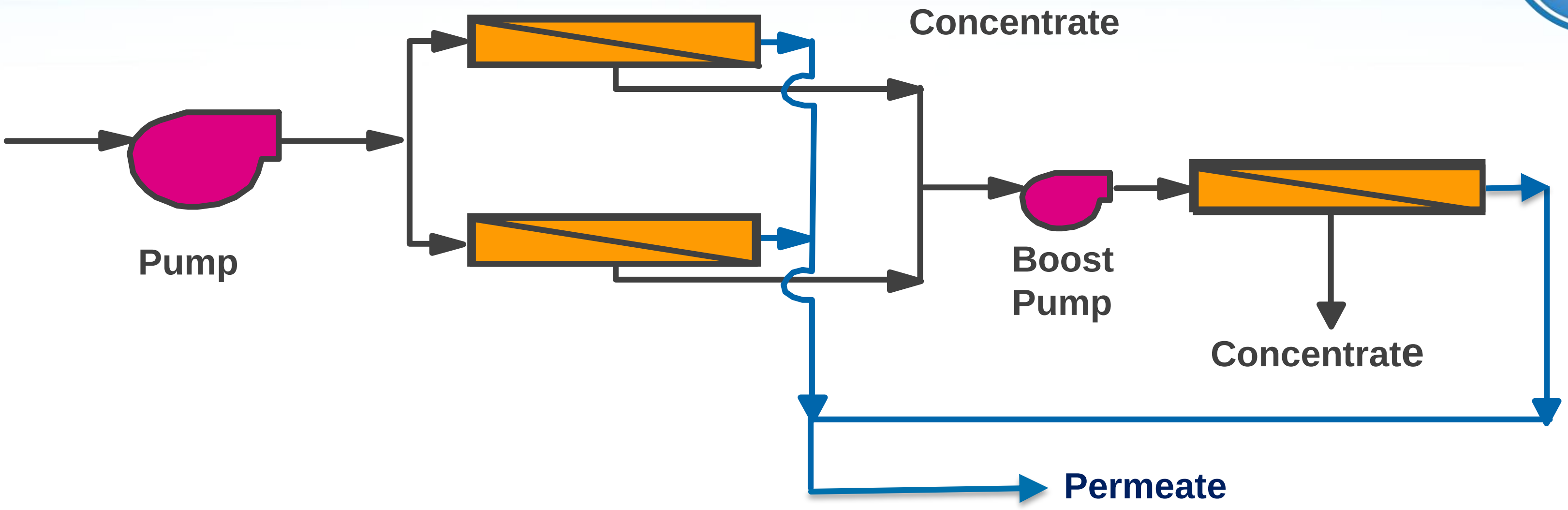
- NDP = Net Driving Pressure (psig)
- P_{feed} is feed pressure (psig)
- DP is differential pressure (psig)
- OP_{fb} is feed-brine osmotic pressure (psig)
- P_p is permeate pressure (psig)
- OP_p is permeate osmotic pressure (psig)

Balancing Flux with Stage 1 Permeate Pressure



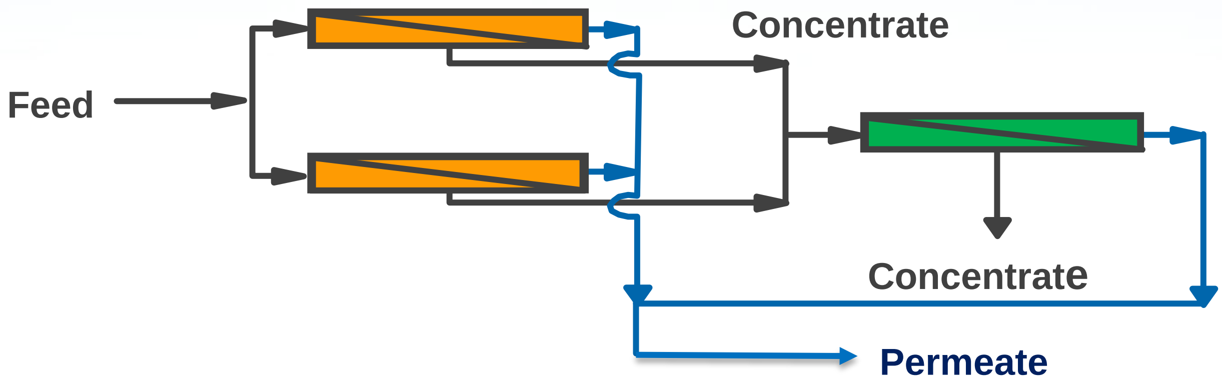
Element gpd tested at 150 psig (10.3 barg), 2000 mg/l NaCl, 25°C, pH 8, 15% recovery

Balancing Flux with Stage 2 Boost Pump



- Boost pump can be driven by electricity or by energy recovery device
- Stg 2 boost pressure = Stg 1 permeate throttle pressure
- Throttle valve is less expensive than boost pump
- Throttle valve has higher energy cost
- Throttle valves are typically limited to smaller systems

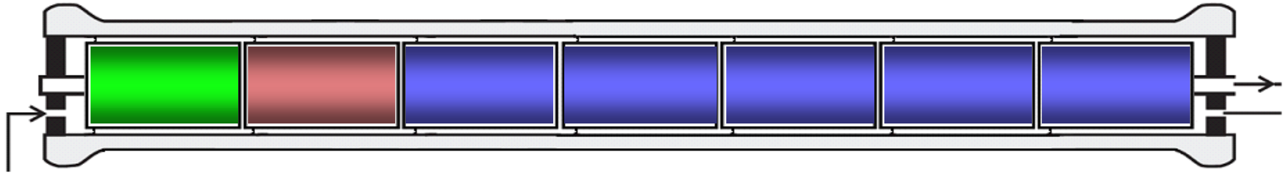
Multi-Element Hybrid Array



- Using different RO elements in each stage of the array…
  - to improve the flux balance between stages
  - to increase or decrease permeate TDS

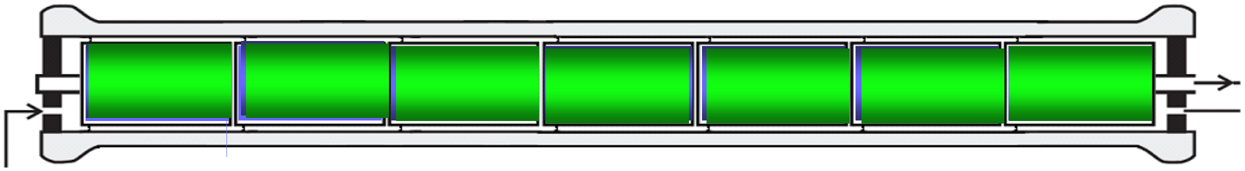
Internally Staged Design (ISD) RO Array

Internally Staged Design

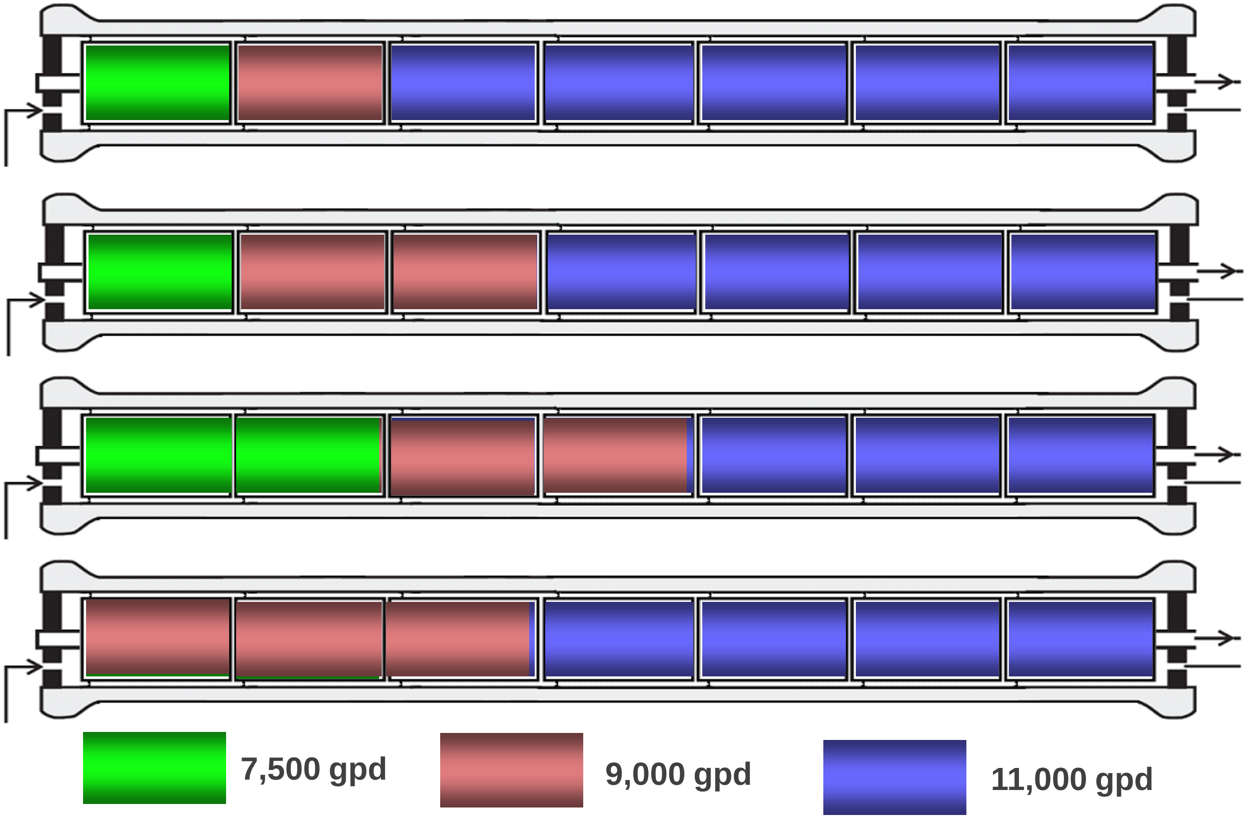


- Multiple RO element types used in a stage
- Common method to control element flux and to optimize energy consumption in seawater systems
- Common method to minimize post-treatment chemical addition in municipal drinking water RO/NF systems

SWRO Element Loading Options

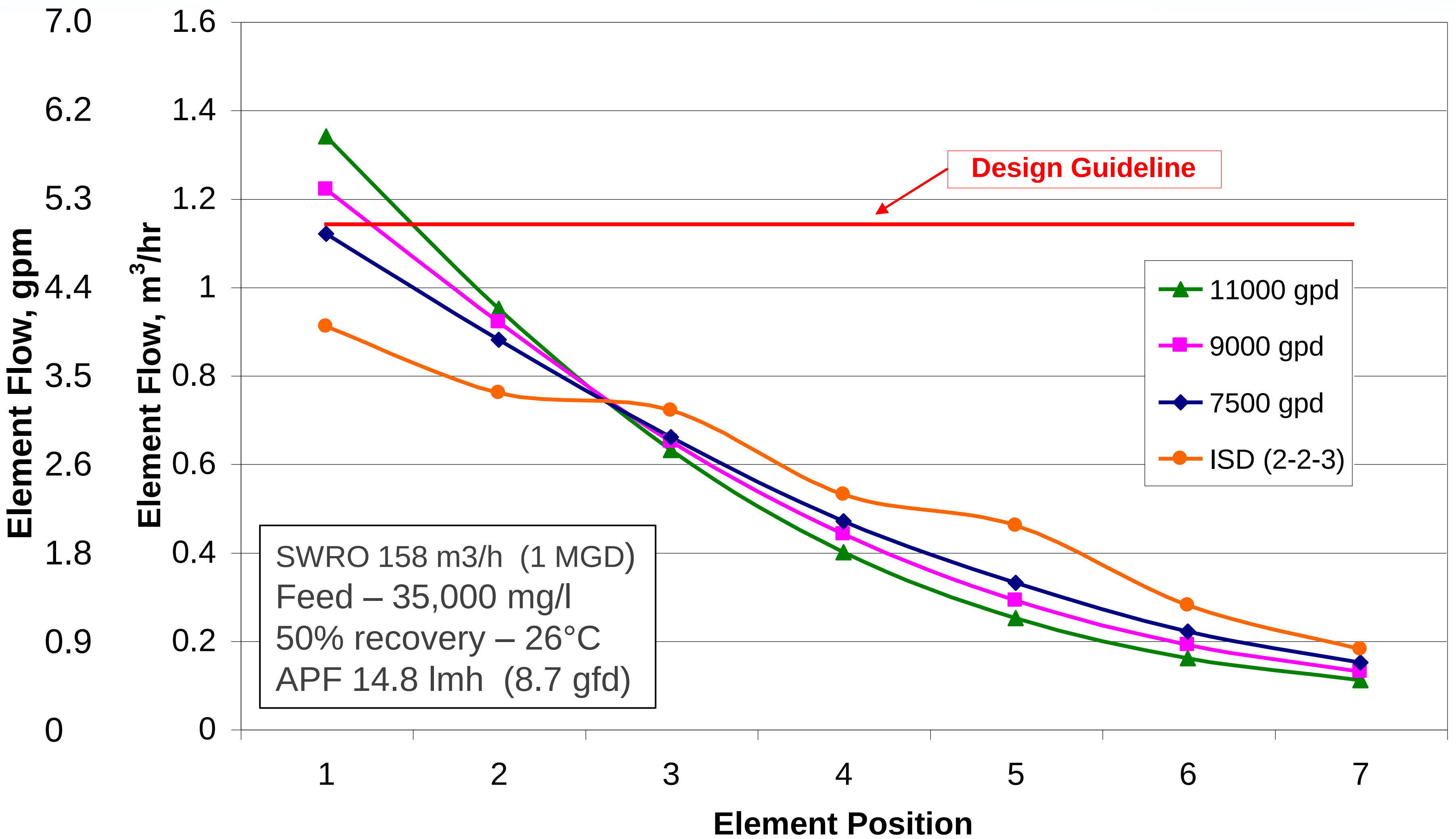


Examples of Potential FILMTEC™ ISD Element Loading Options

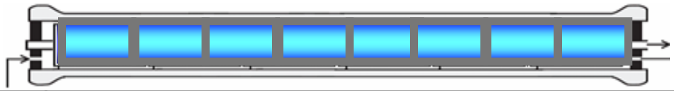


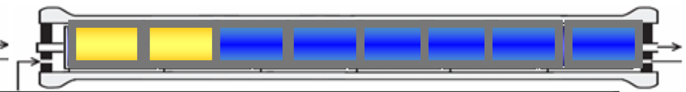
7,500 gpd 9,000 gpd 11,000 gpd

Using ISD to Optimize SWRO Performance



Configuration – Internally Staged Design



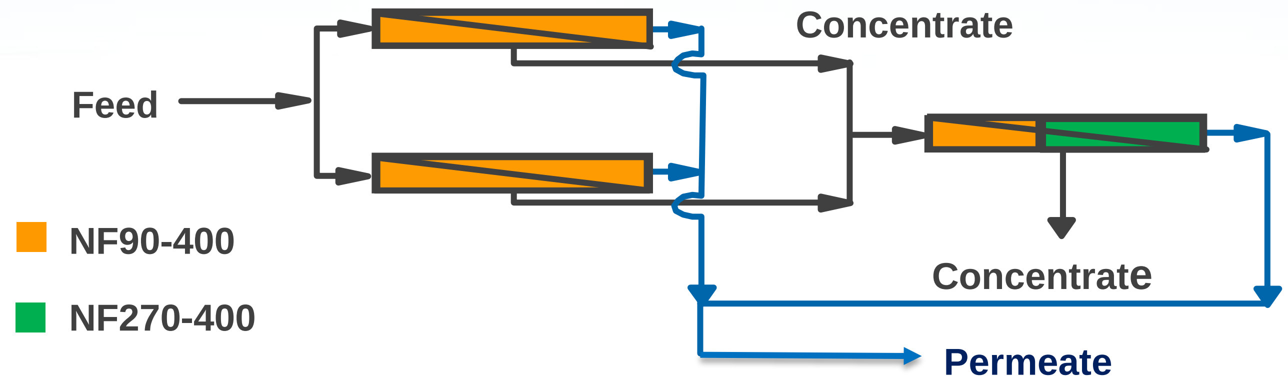


Average Flux of the vessel	14 lmh (8.2 gfd)	15.8 lmh (9.2 gfd)
Maximum permeate flow per element	0.99 m^3/h (4.4 gpm)	0.99 m^3/h (4.4 gpm)
COST of Water Highest FF & T	60.14 UScts/m^3 (228 UScts/kgal)	58.27 UScts/m^3 221 UScts/kgal)
COST of Water Lowest FF & T	63.65 UScts/m^3 (241 UScts/kgal)	60.05 UScts/m^3 227 UScts/kgal)
% savings on cost of water*	Highest FF & T Lowest FF & T	3.1% 5.7%

SW30HRLE-400i SW30XHR-400i SW30ULE-400i

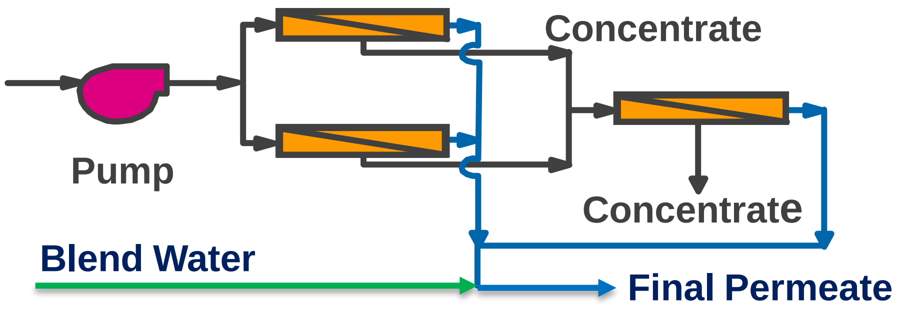
* COST CALCULATION (TOOLS): CAPEX and OPEX are taken into account. Model is prepared by a Consulting Company* for Dow *(John Tonner Water Consultants International Inc.)*

Using ISD to Minimize Post Treatment



- Municipal NF plant designed with multiple 44 x 22 – 7M trains with FILMTEC™ NF90-400 elements.
- The plant installed 4 NF270-400 elements in second stage to increase passage of hardness and alkalinity.
- Resulting increase in permeate total hardness and alkalinity levels allowed plant to eliminate problematic chemical addition in post treatment saving an estimated $1M/year in O&M costs.

RO with Feed Water/Permeate Blending



- Common in drinking water plants
- Increase overall system throughput
- Minimize post-treatment chemicals
- Blend water quality is critical
  - Determines the blend ratio
  - Low color
  - Low TOC and DBPFP

<u>Sources of Blend Water</u>

- Raw water
- RO feed water
- Lime softened water
- Permeate from different system

DBPFP = disinfection byproducts formation potential

Economic Impact of Permeate Blending

	XLE-440	ECO-440i w/ Blend
Rejection	99.0%	99.7%
Element Flow	14,000 gpd	12650 gpd
Test Conditions	125 psig – 2000 mg/l NaCl	150 psig – 2000 mg/l NaCl
Array	16 x 8 – 7M	14 x 7 – 7M
Flux	13.5 gfd	13.5 gfd
RO Recovery	80%	80%
System Recovery	80%	82%
Final TDS	72 mg/l	207 mg/l
Final Total Hardness	24 mg/l as $CaCO_3$	91 mg/l as $CaCO_3$
RO Specific Energy	1.22 kWh/kgal	1.11 kWh/kgal

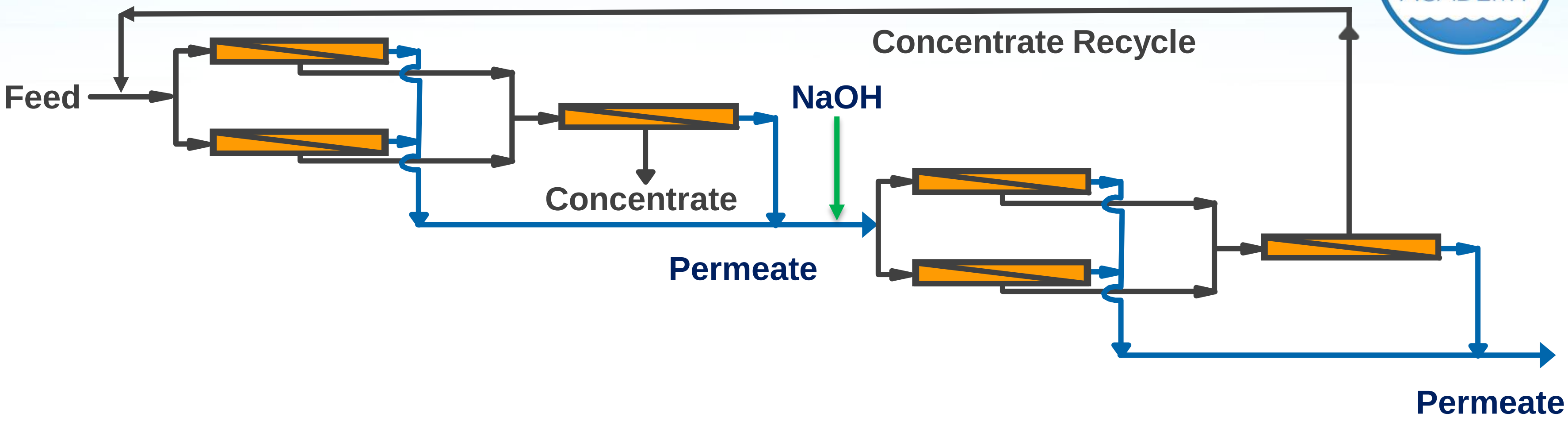
CAPEX Savings

- **12.5% fewer vessels**
- **12.5% fewer elements**

OPEX Savings

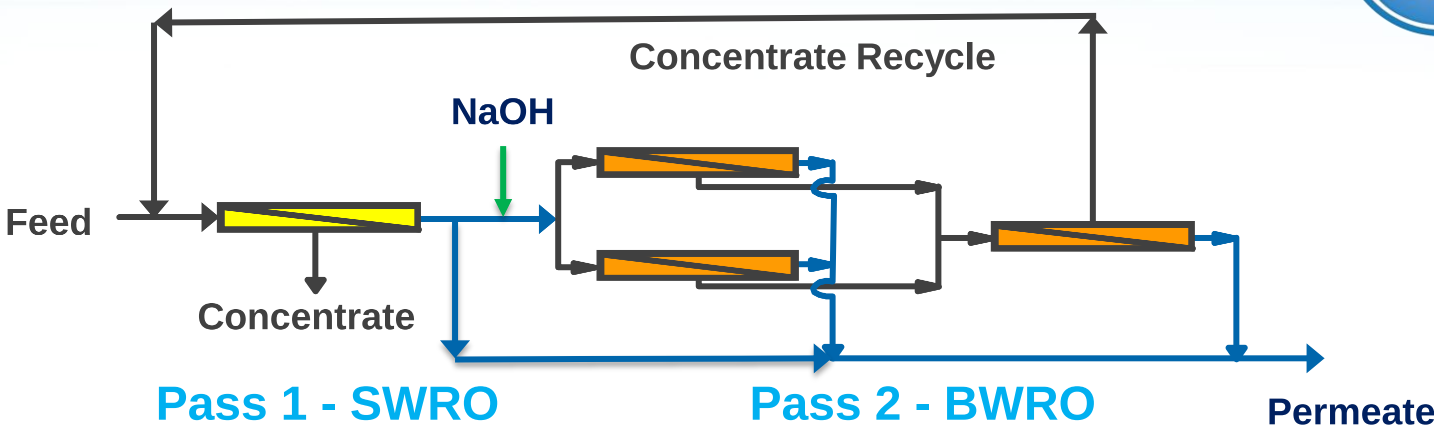
- **9% lower energy**
- **Reduced post-treatment**

2 Pass RO Design



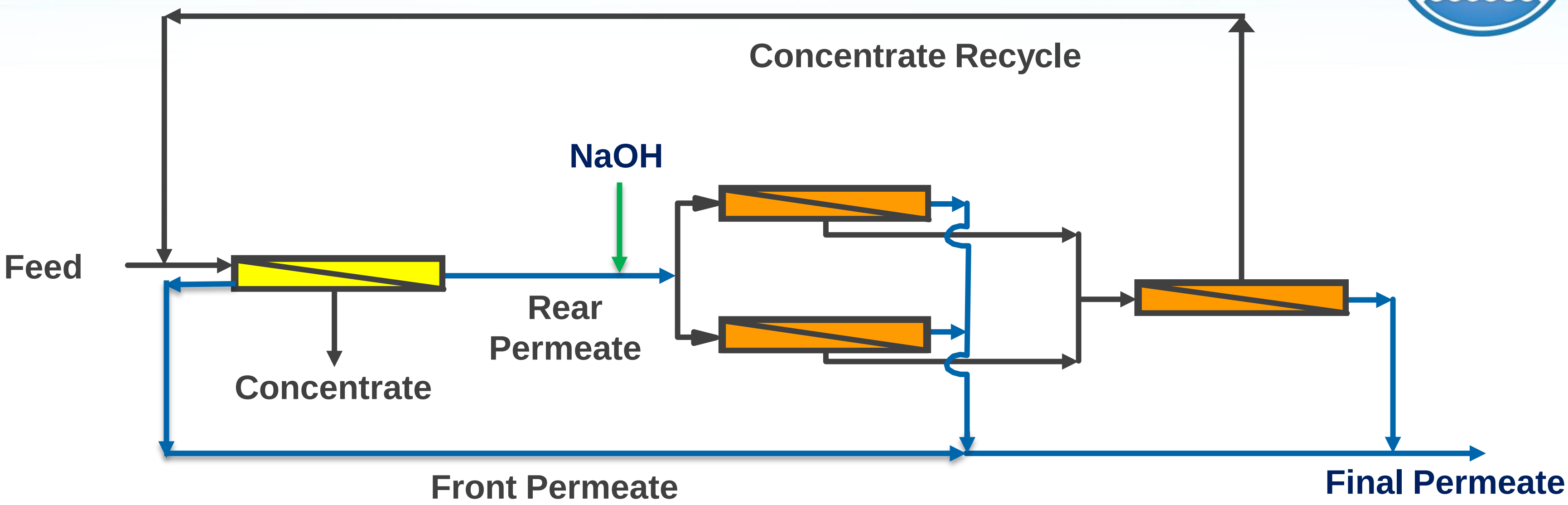
- 2 pass RO systems are primarily used when high purity permeate is required.
- Typical applications include boiler feed water, semiconductor rinse water, some seawater municipal plants, etc.
- Inter-pass pH adjustment with sodium hydroxide is commonly used to enhance rejection of alkalinity, boron, etc.

SWRO Design with Partial 2nd Pass



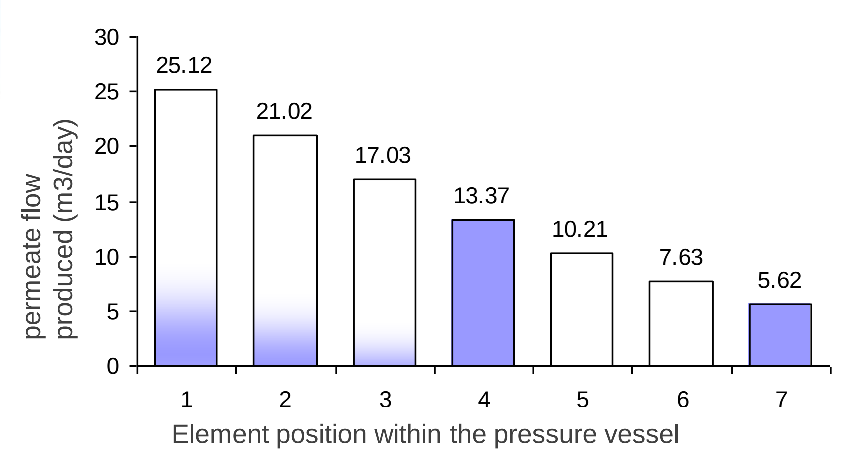
- SWRO design with a partial 2nd pass is primarily used to produce municipal drinking water
- This design saves both CAPEX and OPEX
- Percentage of 1st pass permeate treated with 2nd pass is a function of the feed water salinity and required final permeate salinity

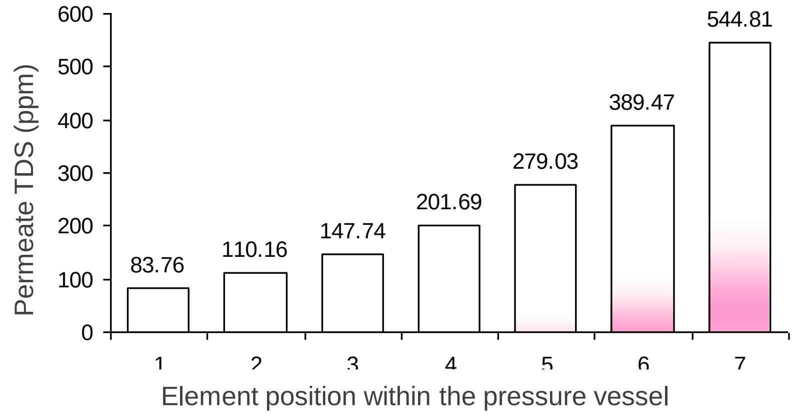
Split Permeate SWRO – Partial 2 Pass

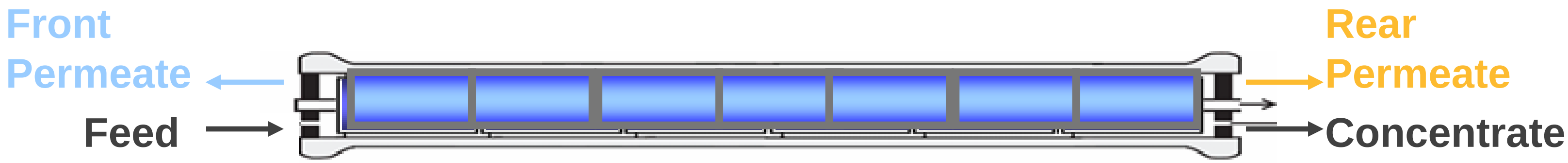


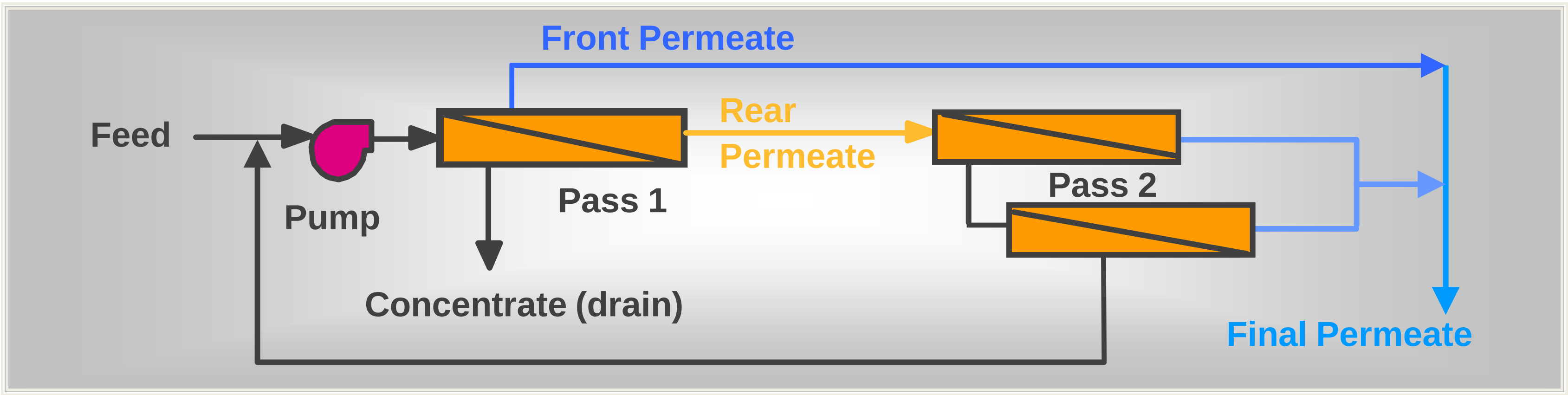
- Split permeate SWRO systems withdraw permeate from both ends of the first stage pressure vessels
- Front permeate is lower in salinity and is directly blended into the final permeate stream
- Ratio of front/rear permeate is typically controlled by pass 2 feed pump
- Many split permeate SWRO systems use ISD with elements chosen specifically to reduce front permeate TDS and/or control lead element flux

Double pass with permeate split-stream









Energy Recovery

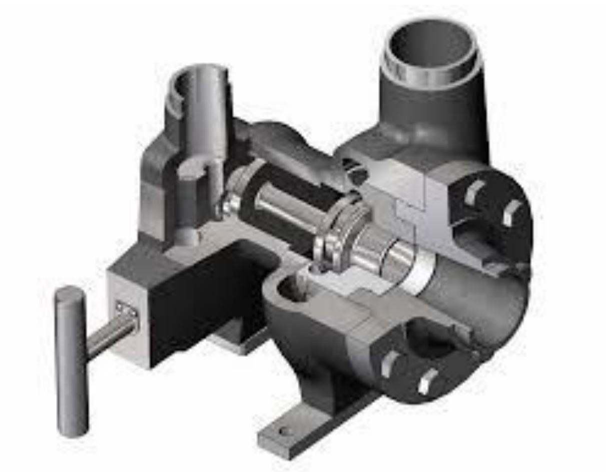
- Energy Recovery Devices (ERD) are used to capture and use residual concentrate stream pressure to:
  - Increase feed pressure prior to final high pressure pump (HPP)
  - Augment electrical drive motor on HPP
  - Provide inter-stage boost pressure on multi-stage RO and NF
- ERDs are used on virtually all SWRO plants and many BWRO plants to reduce power costs of RO
- Several manufacturers have combining ERDs with pumps in small configurations which make it economical to use energy recovery on both smaller and low pressure systems
- Concentrate streams can be combined from multiple low pressure trains to drive ERD on single HPP

Examples of ERDs

Pelton Wheel

DWEER Work Exchanger

ERI PX



FEDCO Turbine

Available Energy for Recovery Calculation

- All ERD manufacturers have sophisticated computer models to incorporate ERDs into systems
- Below is a simple equation to estimate available boost pressure from an ERD in an RO system.

$$P_{avail} = Pc * \frac{Q_c}{Q_f} * Eff$$

P = pressure

Q = flow rate

Eff = ERD efficiency

Subscripts:

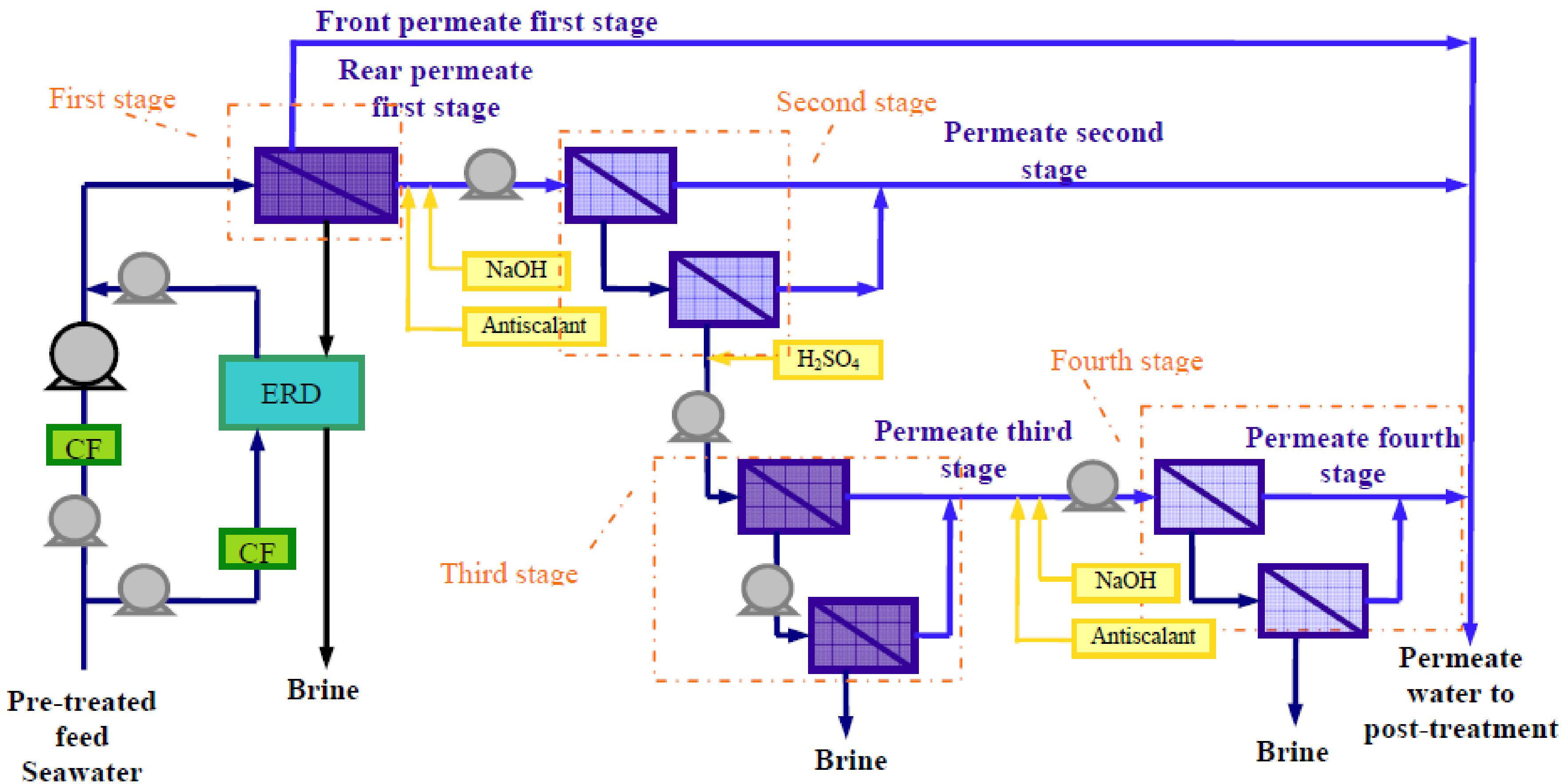
avail = available

c = concentrate

f = feed

Advanced RO Design Example

Diagram of IDE's Patented Cascade Process



KEY ASPECTS OF THE MEMBRANE TECHNOLOGY IMPLEMENTED IN THE CARLSBAD DESALINATION PROJECT

Authors: Eduard Gasia Bruch, Steven Coker, Boaz Keinan, Blanca Salgado

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Product

FILMTEC RO / NF Elements

Results 1 - 5 of 5 for blending

Summary
FILMTEC Membranes - Blending in ROSA
FILMTEC Membranes - Definition of % Recovery
FILMTEC Membranes - ROSA - Permeate Split
FILMTEC Membranes - High Rejection Seawater Elements Resist Fouling, Cut TDS and Costs (Case History)
FILMTEC Membranes - Design - Reduce Plant Capacity to Obtain Just Required Permeate Quality

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Summary

- RO is a highly versatile technology with many choices for optimization of CAPEX and OPEX
- Most important for a plant designer is to understand the starting point and customer's preferences
- Design within element operating guidelines and system guidelines for optimal performance and element life
- Recent advances in membrane chemistry and RO element construction enables several innovative designs
- Innovation continues…
- Seek out to Dow for guidance

RO System Design Webinar Series

Steven Coker
Technical Service Specialist

Advanced Reverse Osmosis System Design

Date & Time
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Advanced RO System Design with ROSA

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