Technical Application Bulletin

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Technical Position Paper

High Recovery Energy Efficient Seawater RO

Executive Summary

New advances in membrane treatment technology have given designers new options to improve system designs to lower capital and operating costs. One of the recent advances is the use of multi-stage, high efficiency energy recovery devices for high pressure systems. Hydranautics now offers the IMSDesign Cloud RO projection program unique capability to evaluate increased SWRO (Seawater RO) system recovery from the current 38-45% up to 55-65%**(1)**, depending on original feed water salinity and temperature. Hydranautics' popular projection software IMSDesign Cloud allows the RO system designer to simulate the high recovery SWRO systems using a multi-stage turbo design (Figure 1) which allows more complex design alternatives with multiple benefits, including:

- Higher permeate recoveries
- Reduced feed flows
- Increased permeate flows
- Reduced concentrate flows
- Better flux balances for reduced fouling
- Potential for lower CAPEX plant costs
- Potential for lower OPEX plant costs
- Results in a "greener" system design

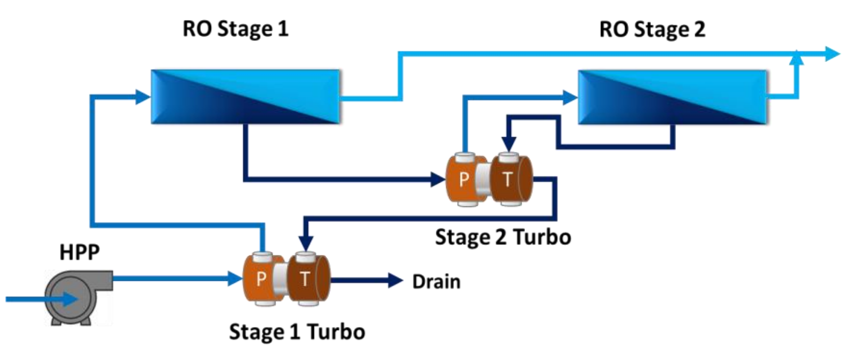


Figure 1: Diagram of a 2-Stage Multi-stage Turbo design

Why High Recovery SWRO?

Engineers historically designed SWRO plants at 35 to 45% recoveries - limited by the maximum pressure limit of the membranes, lead element flux limits and permeate quality. As shown in Figure 2, one stage SWRO systems have significant flux difference between the lead and tail elements, which can lead to higher fouling rates for the lead element. This issue is more acute when higher permeable membranes are used. Figure 2 shows the comparison of flux distribution in a vessel for high flux SWRO elements

(SWC5) and ultra-high flux SWRO elements (SWC6). Although higher permeable membranes offer the potential of energy savings, they are also more at risk for higher fouling due to the high lead element flux. Recoveries greater than 50% require a 2-stage SWRO system to maintain the minimum concentrate flow per pressure vessel and lower lead element flux for fouling control. The flux balancing between the two stages is also important for improved permeate quality. There are a few two-stage SWRO plants, such as the Kindasa SWRO plant in Saudi Arabia **(2)**. Plants such as these use an electric driven motorized booster pump between stages. With the better flux balancing between stages, it is possible to go to higher recovery, which minimizes the size of the intake, pretreatment, and brine line discharge. The combination of these savings can be significant for a seawater plant.

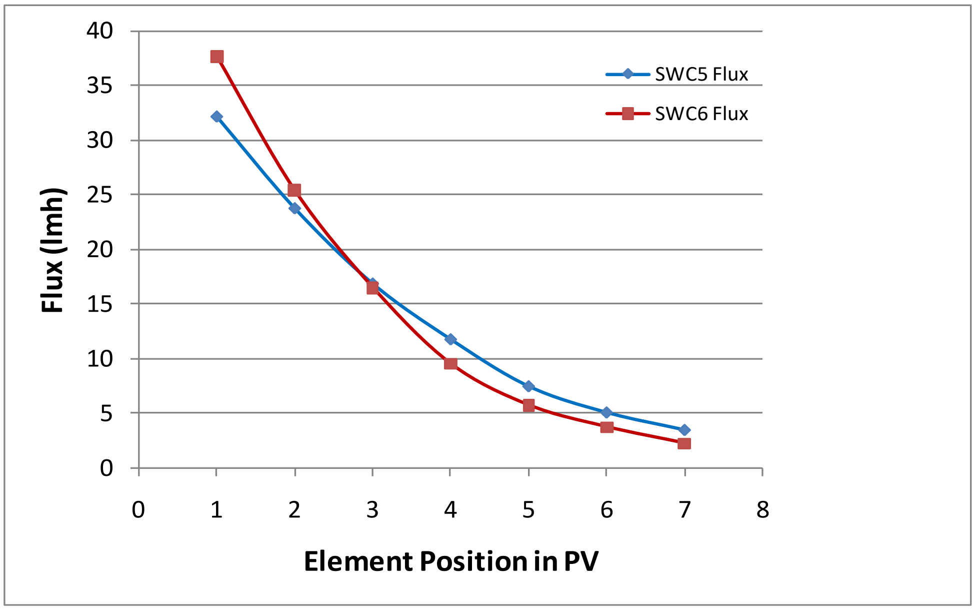


Figure 2: Flux distribution in a vessel with high rejection or high flow SWRO membranes

Another option to better balance flux in a SWRO system, is using hybrids without the use of a booster pump. In such a case, higher rejection, lower flow elements are used in the front of the vessel, and lower rejection/higher flow elements are used in the back of the vessel. An example of this is shown in Figure 3 and Table 1. This design improves flux balance in the vessel but results in higher salinity permeate and is often more complex to manage. Although the hybrid improves flux balance, it does not optimize the flux balance to always meet the designer's target. As seen in Table 1 pilot data, the lead SWC4 elements operated at 18.3 lmh versus 9.7 lmh for the tail SWC6 elements. If the higher flow/lower rejection elements in the back of the vessel could be run at more normal flux rates, this would help improve the permeate quality. This is one of the key features that is possible with the use of multiple stage turbos.

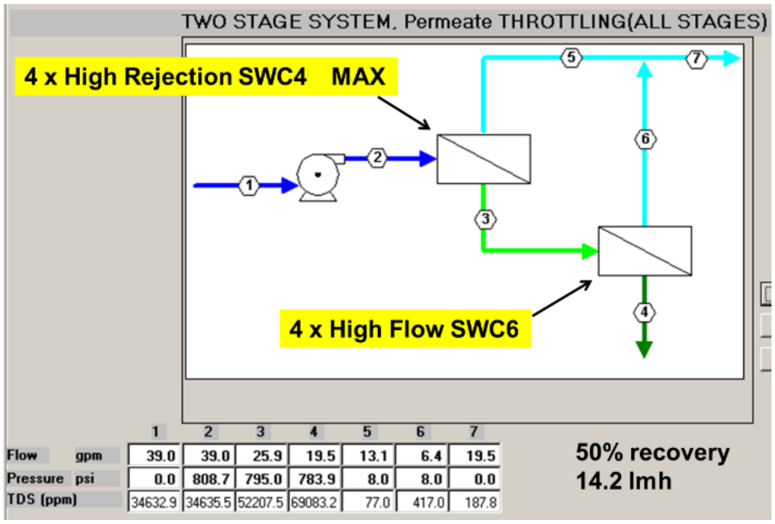


Figure 3: Schematic of a pilot run on Pacific Seawater with a Hybrid Element Design

Table 1: Performance of the Pacific Seawater Pilot with Hybrid Element Design

	Flow (gpm)	Flux (lmh)	Actual Rec. (%)	Actual Pres. (psi)	pH	Temp (C°)	Cond (µS/cm)	Actual TDS (mg/l)
Feed	39.0	x	x	811	7.6	19.5	49,640	34,633
Conc.	19.5	x	x	799	7.4	21.4	90,410	69,083
Vessel 1 (SWC4-MAX)	13.2	18.3	33.9%	x	6.9	19.7	120	55
Vessel 2 (SWC6)	6.3	9.7	24.4%	x	6.9	20.0	1,002	461
Total Permeate	19.5	14.2	50.0%	x	7.0	19.9	390	180

Thus, both approaches, interstage booster pump and membrane hybrid, have design limitations. To address this, some equipment suppliers have offered a new concept using multiple-stage turbo chargers to efficiently recover energy and balance flux within both stages, while providing a simple system design. New studies have shown that the use of these multiple stage turbos can provide the most efficient membrane design. In some cases where the feed salinity is 40,000 mg/l or higher, the second stage would require ultra-high pressure RO elements. Therefore, it is important to look for a membrane supplier with a broad membrane offering.

Hydranautics SWRO and PRO-XP RO element offerings

Hydranautics supplies a wide range of SWRO membrane products, including the SWC series rated at 83 bar (1200 psi).

- The SWC4-LD and SWC4 MAX have the best rejection of salts and organics.

- The SWC5-LD and SWC5 MAX have the optimum salt and organic rejection combination and feed pressure requirement.
- The SWC6-LD and SWC6 MAX offer the lowest feed pressure SWRO membrane with good salt and organic rejection.

In some instances, the second stage feed pressures can exceed the 83 bar (1200 psi) SWRO membrane limit. Hydranautics has launched a new Ultra High-Pressure ULP membrane called PRO-XP.

- PRO XP series SWRO membranes rated up to 124 bar (1800 psi). The PRO-XP1 is an Ultra High-Pressure RO element that allows maximum recovery designs while producing good permeate quality.

The Multi-Stage SWRO designs can be used in a variety of RO markets including MLD and ZLD:

- **SWRO** system design recovery can be increased from the current 35-45% up to 55-70% depending on the feed salinity and temperature. The SWRO can use the Hydranautics standard **SWC** series membranes up to 83 bar (1200 psi). Technical Services Bulletin, TSB105 provides a pressure versus temperature chart for SWC membranes.
- **UHPRO** (Ultra High-Pressure RO) systems using the **PRO-XP** series membranes with pressure limits up to 124 bar (1800 psi) allow higher recoveries and reduced concentrate volumes.

- **ZLD** (Zero Liquid Discharge) and **MLD** (Minimum Liquid Discharge) systems can minimize the CAPEX and OPEX costs versus thermal evaporators and crystallizers by increasing the membrane system recoveries using Hydranautics SWC and XP membranes.

Improved Energy Efficiency while Balancing Stage Flux

Hydranautics has historically offered a computer design software with hydraulic turbocharger boost the 2^{nd} stage feed pressure and better balance the flux in each stage. This method of reusing the energy in the final concentrate stream for boosting inter-stage pressure has been commonly used in brackish water RO. For high pressure, seawater systems, however, there is excess and unused energy remaining in the turbocharger exhaust after stage flux balancing. If not used, it would be wasted. Therefore, Hydranautics has upgraded in IMSDesign Cloud Software to allow users to add a second turbocharger on feed to stage one that utilizes the substantial exhaust pressure and reduces the pressure requirements of the high-pressure pump. This multi-stage turbo arrangement self regulates pressure changes, runs quietly and conserves energy. IMSDesign also uses new calculation routine which reflects the improved efficiency of new turbochargers. As a result, for the same interstage boost, they will yield higher exhaust pressures, which results in a greater boost on stage 1 (Figure 4).

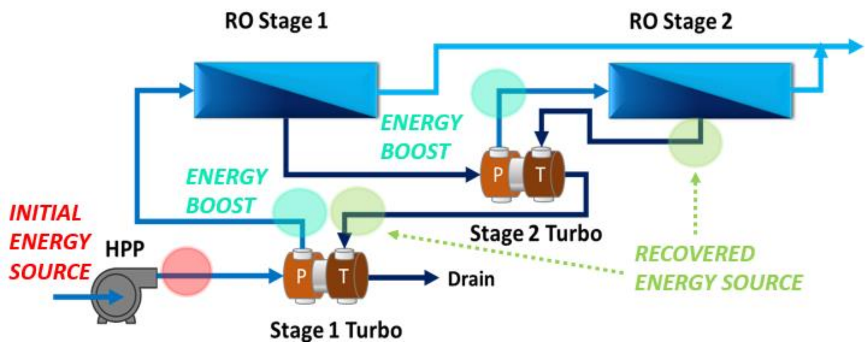
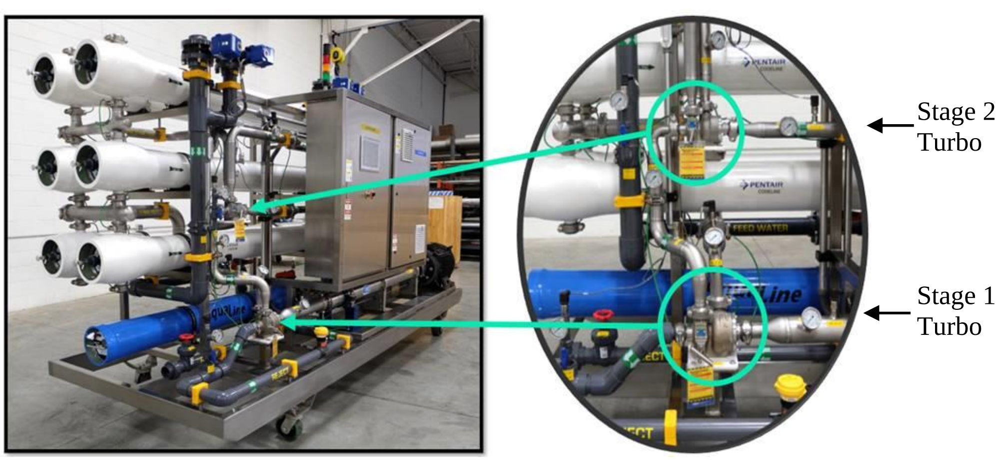


Figure 4: Multistage Turbo Energy Summary

A major turbo manufacturer has performed studies for 100 to 30,000 m3/day (18 to 5,500 gpm) SWRO systems (Table 2). Results estimate a potential for 9-28% lower CAPEX, 6-14% lower OPEX, and a lower Cost of Permeate of 8-18%. These cost savings enabled increased system recovery of 60% from the current 35-45% with a multi-stage turbo design **(3)**.



Multi-stage turbo pilot by FEDCO using their patented BiTurbo design (used with permission by FEDCO)

Multi-Stage Turbo Design using IMSDesign Cloud Software

Hydranautics upgraded its IMSDesign Cloud projection software that allows the designer to discover benefits of the novel Multi-stage Turbo RO design feature. This feature is available only in the Cloud-based software and not the Desktop version. The Cloud version is available at www.membranes.com.

- The Stage 2 Turbo provides the desired interstage boost of 2nd stage feed pressure, which results in desired flux balance, increased permeate production and improved permeate quality.
- The Stage 1 Turbo recovers the unused hydraulic energy from the Stage 2 Turbo and boosts the 1st stage feed pressure. This “boost” has the added benefit of reducing the energy requirement and the size of the HPP (High-Pressure Pump) to the 1st stage.
- The design strategy is to balance fluxes between the 1st and 2nd stages using the two turbos to develop an optimal permeate quality and reduced fouling rate as well as conservation of system energy. The flux balancing of the stages can be performed with one RO or NF or with a hybrid combination of membrane types.
- The software gives instantaneous results of fluxes, flows, pressures, permeate quality, alarms, and specific energy usage in kWh per m3 or kWh per 1000 gallons of permeate produced.
- The control scheme and turbos used are well-proven over time, robust and straightforward.
- IMSDesign Cloud, by default with the Multi-Stage Turbo option selected, will automatically design the Stage 1 Turbo to have 1.0 bar exhaust concentrate pressure to drain and then design the Stage 2 Turbo to give a balanced flux between the stages. No data entry and trial and error are required. The user, however, can enter the values of his choice after the initial automatic design.

Table 2: Projected SWRO Multi-Stage Turbo Startup Designs from Around the World

	Units	Pacific	Caribbean (60%)	Caribbean (65%)	Middle East
Feed Salinity (as mixed ions)	mg/l	36,177	37,853	37,853	45,056
Temperature	C	25 C	25 C	25 C	35 C
Array (2-stage | 7M)	-	300 x 200	300 x 200	330x200	330x200
1st Stage elements	-	SWC4-MAX	SWC4-MAX	SWC4-MAX	SWC4-MAX
2nd Stage elements	-	SWC6-MAX	SWC6-MAX	***PRO-XP1***	***PRO-XP1***
% Recovery	**%**	**60%**	**60%**	**65%**	**55%**
Permeate flow	m3/h	2,000	2,000	2,000	2,000
Concentrate flow (size of out-takes)	m3/h	1,333	1,333	1,077	1,636
Feed flow (size of pretreatment)	**m3/h**	**3,333**	**3,333**	**3,007**	**3,636**
Pump Energy (per m3 of permeate)	**kWh**	**2.40**	**2.50**	**2.79**	**3.10**
Permeate Salinity	mg/l	279	293	408	600
Concentrate Salinity	mg/l	90,000	94,000	107,000	99,000
RO feed pump discharge	Bar	42	43	52	49
Stage 1 Turbo boost	Bar	11	11	6	13
1st Stage feed pressure (after Stage 1 turbo boost)	Bar	52	54	58	62
1st Stage maximum pressure (at design temperature)	Bar	77	77	77	73 at 35C
Stage 2 Turbo boost	Bar	21	22	41	41
2nd Stage feed pressure (after Stage 2 turbo boost)	Bar	70	73	96	100
2nd Stage maximum pressure (at design temperature)	Bar	77 at 25C	77 at 25C	124 at 25C	108 at 35C
Concentrate Exhaust pressure (to outfall or discharge)	Bar	1	1	1	1
1st Stage Flux	lmh	14.4	14.4	14.4	14.4
2nd Stage Flux	lmh	13.4	13.4	13.4	13.4
Feed Boron (at feed pH = 8.2)	mg/l	4.8	5.1	5.1	6.0
Permeate Boron (as B)	mg/l	1.2	1.3	1.5	2.6

Case Study Projection: Multi-stage Turbo at 60% Recovery for Caribbean SWRO

When designing for high pressure applications, the pressure-temperature limits of Hydranautics PRO (Figure 5) and SWC elements will apply (Figure 6).

Attached are screenshots and printouts of the Hydranautics IMSDesign Cloud program for the Caribbean 60% recovery SWRO. Designing with the multi-stage turbo option is relatively straightforward:

- **1st step** is to enter the feed water analysis on the Analysis screen.
  - Cations and anions need to be balanced within 100% ± 10%
  - Seawater quality can use Conventional or MF/UF quality pretreatment. MF/UF is preferred if the source is an open-intake.
  - Temperature is a critical parameter, and the entire range should be projected
  - pH is important for determining permeate quality and concentrate solubilities
- **2nd step** is to enter the design data on the Design screen.
  - In this case, recovery is set at 60%
  - The permeate flow rate for the train is entered at 2,000 m3/h
  - Select the element you want to use for the 1st stage. SWC4 MAX
    - The elements you want to use are selected. This design uses SWRO elements with a low flow/high-pressure SWC4 MAX element in the 1st stage and a higher flow/lower pressure SWC6 MAX element in the 2nd stage. Using a tighter membrane in the 1st stage reduces the flux and throttles back permeate production and forces more permeate to be produced in the 2nd stage.
  - The program will automatically design a single preliminary stage 7M array with seven elements per pressure vessel. In this case, 500 vessels.
    - The required pressure vessels and elements meet the maximum allowable system flux for the feed water quality following IMSDesign guidelines.
  - Select two stages in Pass 1, and in this case, select the higher flow/lower pressure SWRO element Model SWC6 MAX for the 2nd stage.
  - Take the original number of pressure vessels, and in this case, use a 3:2 ratio of 1st stage vessels to 2nd stage vessels - 300 vessels in the 1st stage and 200 vessels in the 2nd stage.
  - Now select the Turbo option.
  - Check the Turbo box next to Stage 1, and it will automatically load in the 1.0 bar for Stage 1 Turbo Exhaust pressure.
    - 1.0 bar is the default minimum to prevent cavitation and can be higher if desired if required for sufficient concentrate disposal requirements.
  - Select Run or Print
  - The automatic design will balance fluxes between stages 1 and 2 within one lmh. The Stage 2 Turbo is designed to achieve the stage 2 boost pressure required for nearly balanced fluxes. The residual Stage 2 Turbo exhaust, which in the past would be sent to drain, is then sent to the Stage 1 Turbo to boost up the 1st stage feed pressure. This means the HPP (High-Pressure Pump) does not have to, and therefore is smaller and requires less energy.
- **3rd step** is the designer can modify the “automatically created” design above as desired to meet his combination of needs which can be:
    - Balance flux by stage
    - Design for lowest lead element flux
    - Best permeate quality
    - Lowest energy requirement
    - Avoid high-pressure alarms

For more detailed instructions on the operation of the IMSD Cloud, you can reference the FAQs sheet found on the top menu bar of the design screen.

References:

1. FEDCO, white paper "A Significant Process Improvement for SWRO", 2022
2. Proceedings of the AMTA/DESA Joint Conference and Exposition, "FOUR YEAR OPERATION EXPERIENCE OF A LARGE-SCALE UF/SWRO INTEGRATED MEMBRANE PLANT" Craig R. Bartels, Roman Boda, Aziz H. Gulamhusein and Ashraf Al-Sheikh Khalil, Miami Beach, FL, 2011.
3. FEDCO, white paper "The Case for High Recovery SWRO", 2022

Appendix:

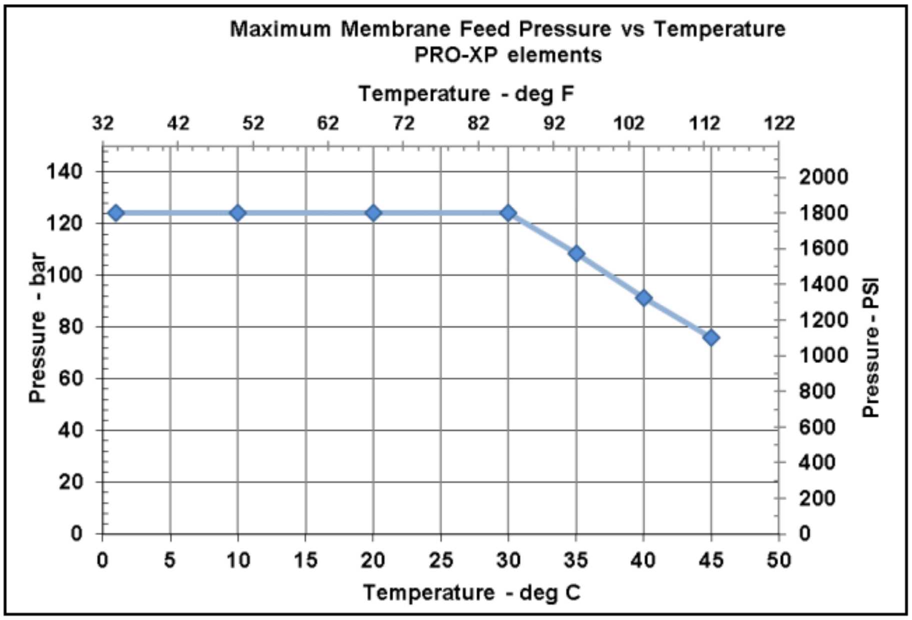


Figure 5. Maximum Membrane Feed Pressure-Temperature Curve for PRO-XP elements

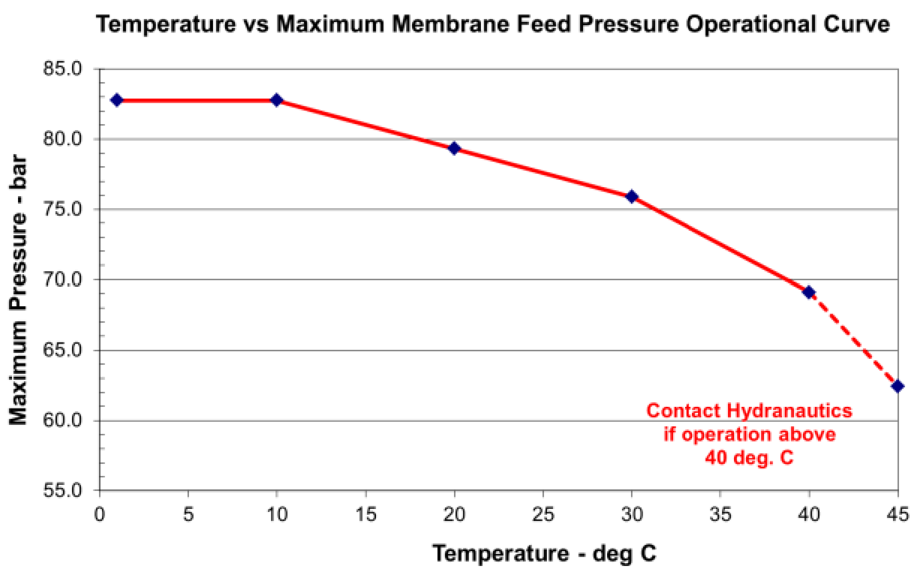
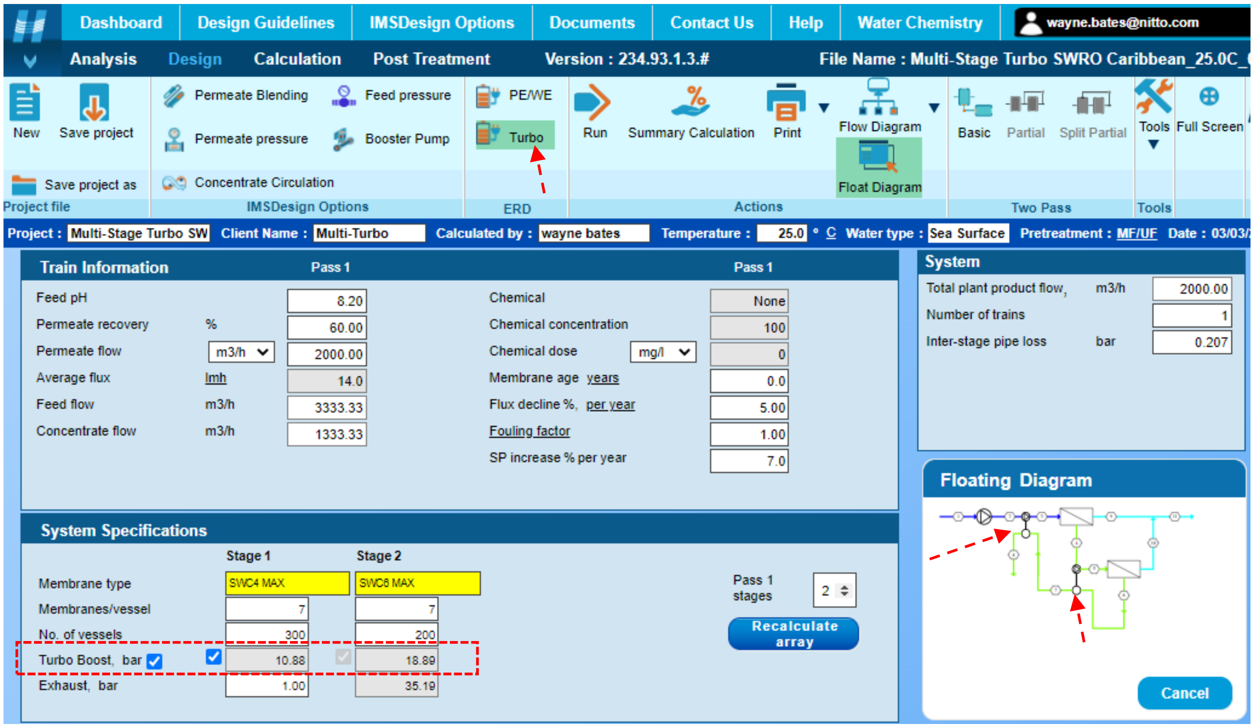
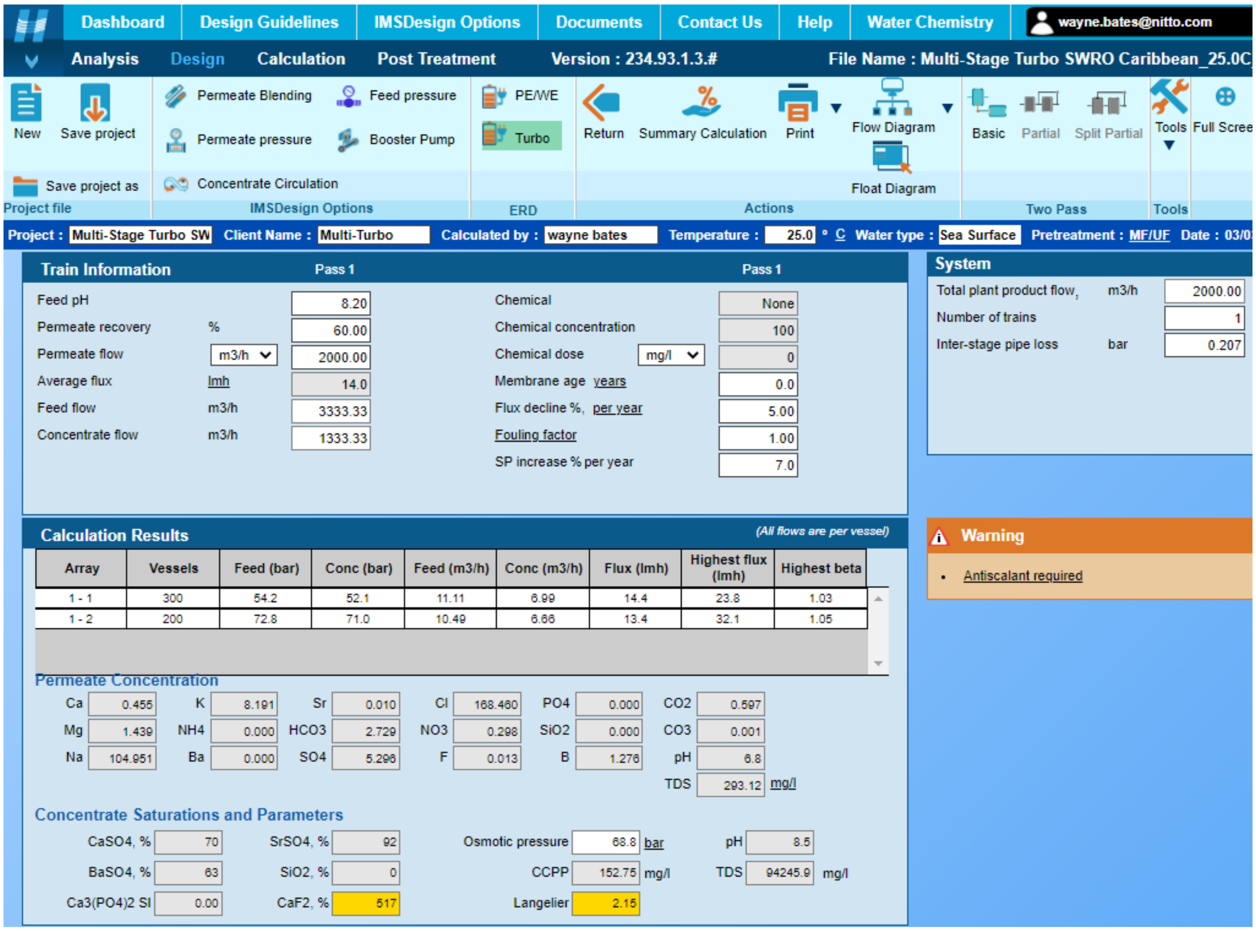


Figure 6. Temperature vs Pressure Operation Limits for SWC Membranes (with ABS/GF core tubes- Metric values)

2nd and 3rd Step: IMSDesign data entry screen



2nd and 3rd Step: Design Screen calculated output



IMSDesign Printout Page 1: Design Summary

Turbo (Stage1: 79.7 % ,Stage2: 83.2 %)

Project name	Multi-Stage Turbo SWRO Caribbean		1/4
Client Name	Multi-Turbo	Permeate flow/train	2000.00 m3/h
Calculated by	wayne bates	Raw water flow/train	3333.33 m3/h
HP pump flow	3333.33 m3/h	Permeate recovery	60.00 %
HP Pump pressure	43.3 bar	Membrane age	0.0 years
Feed pressure	54.2 bar	Flux decline,per year	5.0 %
Feed temperature	25.0 °C	Fouling factor	1.00
Feed Water pH	8.20	SP increase, per year	7.0 %
Chemical dose, mg/l	None	Inter-stage pipe loss	0.207 bar
Pumping specific energy	2.50 kWh/m3	Feed type	Sea Surface
Pass NDP	17.4 bar	Pretreatment	MF/UF
Average flux	14.0 lmh		

Pass-	Perm.	Flow / Vessel		Flux	DP	Flux	Beta	Stagewise Pressure				Perm.	Membrane	Membrane	PV# x
Stage	Flow	Feed	Conc			Max		Perm.	Boost	Exhaust	Conc	TDS	Type	Quantity	Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	bar	mg/l			
1-1	1235.5	11.1	7.0	14.4	2.1	23.8	1.03	0.0	10.9	1.0	52.1	137.0	SWC4 MAX	2100	300 x 7M
1-2	766.5	10.5	6.7	13.4	1.9	32.1	1.05	0.0	18.9	35.2	71.0	544.0	SWC6 MAX	1400	200 x 7M

Ion (mg/l)	Raw Water	Feed Water	Permeate Water	Concentrate 1	Concentrate 2
Hardness, as CaCO3	7220.78	7220.78	7.035	11471.7	18069.5
Ca	467.00	467.00	0.455	741.9	1168.6
Mg	1477.00	1477.00	1.439	2346.5	3696.1
Na	11251.00	11251.00	104.951	17848.6	28013.6
K	703.00	703.00	8.191	1114.8	1747.9
Ba	0.006	0.006	0.000	0.0	0.0
Sr	10.000	10.000	0.010	15.9	25.0
CO3	33.94	33.94	0.001	69.4	151.4
HCO3	190.00	190.00	2.729	263.1	309.5
SO4	2644.00	2644.00	5.296	4199.8	6612.3
Cl	21067.00	21067.00	168.460	33428.4	52496.5
F	0.80	0.80	0.013	1.3	2.0
NO3	5.05	5.05	0.298	7.9	12.2
B	5.05	5.05	1.276	7.7	10.7
CO2	0.60	0.60	0.60	0.78	0.84
NH3	0.00	0.00	0.00	0.00	0.00
TDS	**37853.85**	**37853.85**	**293.12**	**60045.27**	**94245.88**
pH	**8.20**	**8.20**	**6.84**	**8.22**	**8.47**

Saturations	Raw Water	Feed Water	Permeate Water	Concentrate	Limits
CaSO4 / Ksp * 100, %	22	22	0	70	400
SrSO4 / Ksp * 100, %	29	29	0	92	1200
BaSO4 / Ksp * 100, %	22	22	0	63	10000
SiO2 Saturation, %	1	1	0	1	140
CaF2 / Ksp * 100, %	0	0	0	0	50000
Ca3(PO4)2	0.0	0.0	0.0	0.0	2.4
CCPP, mg/l	55.47	55.47	-1.71	162.17	0
Langelier index	1.21	1.21	-4.79	2.11	2.8
Ionic strength	0.75	0.75	0.01	1.88	
Osmotic pressure, bar	27.6	27.6	0.2	68.8	
TDS / Osmotic pressure, mg/l.bar	1369.1	1369.1	1304.2	1369.4	

IMSDesign Print Page 2: Stage and Element Summary

Turbo (Stage1: 79.7 % ,Stage2: 83.2 %)

Project name	Multi-Stage Turbo SWRO Caribbean		2/4
Client Name	Multi-Turbo	Permeate flow/train	2000.00 m3/h
Calculated by	wayne bates	Raw water flow/train	3333.33 m3/h
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Feed temperature	25.0 °C	Fouling factor	1.00
Feed Water pH	8.20	SP increase, per year	7.0 %
Chemical dose, mg/l	None	Inter-stage pipe loss	0.207 bar
Pumping specific energy	2.50 kWh/m3	Feed type	Sea Surface
Pass NDP	17.4 bar	Pretreatment	MF/UF
Average flux	14.0 lmh		

Pass-Stage	Perm. Flow m3/h	Flow / Vessel Feed m3/h	Flow / Vessel Conc m3/h	Flux lmh	DP bar	Flux Max lmh	Beta	Stagewise Pressure Perm. bar	Stagewise Pressure Boost bar	Stagewise Pressure Exhaust bar	Conc bar	Perm. TDS mg/l	Membrane Type	Membrane Quantity	PV# x Elem #
1-1	1235.5	11.1	7.0	14.4	2.1	23.8	1.03	0.0	10.9	1.0	52.1	137.0	SWC4 MAX	2100	300 x 7M
1-2	766.5	10.5	6.7	13.4	1.9	32.1	1.05	0.0	18.9	35.2	71.0	544.0	SWC6 MAX	1400	200 x 7M

Pass-Stage	membrane no.	Feed Pressure bar	Pressure Drop bar	Conc Osmotic pressure bar	NDP bar	Permeate Flow m3/h	Water Flux lmh	Recovery (%)	Beta	TDS mg/l	Econd (@ 25.0 °C) µS/cm	Ca mg/l	Na mg/l	Cl mg/l
1st Stage	1	54.2	0.41	30.3	24.1	1.0	23.8	8.7	1.03	66.6	78.0	0.103	23.857	38.280
1-1	2	53.8	0.36	33.0	21.4	0.8	20.2	8.1	1.03	75.2	88.1	0.116	26.929	43.209
1-1	3	53.4	0.32	35.5	18.4	0.7	16.6	7.3	1.03	85.2	99.8	0.132	30.512	48.958
1-1	4	53.1	0.29	38.0	15.7	0.6	13.6	6.4	1.02	96.4	113.0	0.149	34.540	55.422
1-1	5	52.8	0.27	40.2	13.1	0.4	10.9	5.5	1.02	108.9	127.6	0.169	38.990	62.564
1-1	6	52.6	0.25	42.2	10.9	0.4	8.7	4.7	1.02	122.4	143.4	0.190	43.839	70.344
1-1	7	52.3	0.23	43.8	8.9	0.3	7.0	3.9	1.01	137.0	160.5	0.212	49.057	78.719
2nd Stage	1	72.8	0.36	50.1	23.4	1.3	32.1	12.5	1.05	182.7	213.8	0.283	65.354	104.900
1-2	2	72.5	0.31	55.5	18.1	0.9	21.7	9.7	1.04	230.1	269.3	0.357	82.314	132.124
1-2	3	72.2	0.27	59.7	13.4	0.6	14.6	7.2	1.03	283.9	332.4	0.440	101.591	163.069
1-2	4	71.9	0.25	63.1	9.7	0.4	10.2	5.4	1.02	342.4	400.9	0.531	122.526	196.677
1-2	5	71.6	0.23	65.7	6.9	0.3	7.0	3.9	1.01	405.5	474.9	0.629	145.119	232.949
1-2	6	71.4	0.22	67.5	4.8	0.2	4.8	2.8	1.01	472.9	584.7	0.734	169.249	271.691
1-2	7	71.2	0.21	68.8	3.2	0.1	3.2	1.9	1.01	544.1	658.8	0.845	194.759	312.653

Permeate (Stagewise cumulative): columns Beta through Cl.

IMSDesign Printout Page 3: Flow Diagram

Turbo (Stage1: 79.7 % ,Stage2: 83.2 %)

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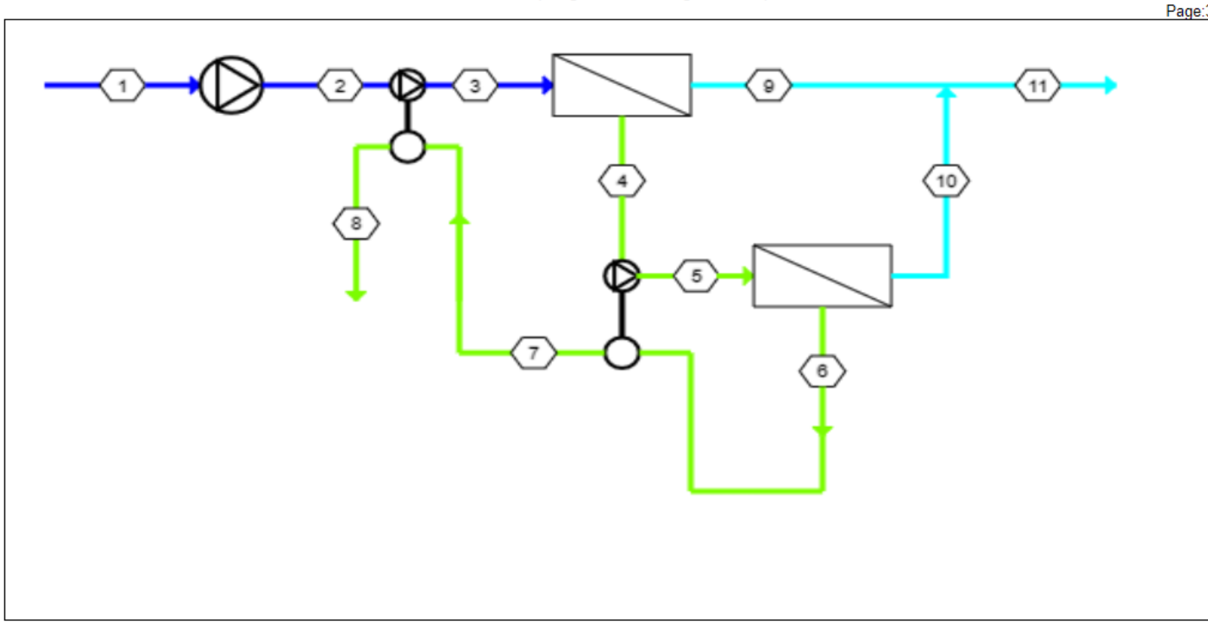
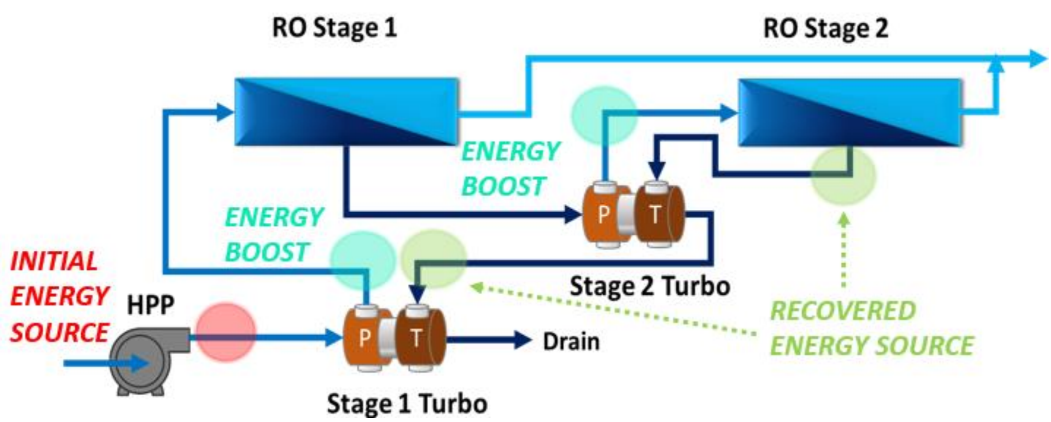


Stream No.	Flow (m3/h)	Pressure (bar)	TDS (mg/l)	pH	Econd (µS/cm) (@ 25.0 °C)
1	3333	0	37854	8.20	58991
2	3333	43.3	37854	8.20	58991
3	3333	54.2	37854	8.20	58991
4	2098	52.1	60045	8.22	91317
5	2098	72.8	60045	8.22	91317
6	1331	71.0	94246	8.47	140199
7	1331	35.2	94246	8.47	140199
8	1331	1.00	94246	8.47	140199
9	1236	0	137	6.52	293
10	767	0	544	7.10	1204
11	2000	0	293	6.84	628



IMSDesign Printout Page 4: Power Calculations

Turbo (Stage1: 79.7 % ,Stage2: 83.2 %)

Project name	Multi-Stage Turbo SWRO Caribbean			4/4
Client Name	Multi-Turbo		Permeate flow/train	2000.00 m3/h
Calculated by	wayne bates		Raw water flow/train	3333.33 m3/h
HP pump flow		3333.33 m3/h	Permeate recovery	60.00 %
HP Pump pressure		43.3 bar	Membrane age	0.0 years
Feed pressure		54.2 bar	Flux decline,per year	5.0 %
Feed temperature		25.0 °C	Fouling factor	1.00
Feed Water pH		8.20	SP increase, per year	7.0 %
Chemical dose, mg/l		None	Inter-stage pipe loss	0.207 bar
Pumping specific energy		2.50 kWh/m3	Feed type	Sea Surface
Pass NDP		17.4 bar	Pretreatment	MF/UF
Average flux		14.0 lmh		

Pass-	Perm.	Flow / Vessel		Flux	DP	Flux	Beta	Stagewise Pressure				Perm.	Membrane	Membrane	PV# x
Stage	Flow	Feed	Conc			Max		Perm.	Boost	Exhaust	Conc	TDS	Type	Quantity	Elem #
	m3/h	m3/h	m3/h	lmh	bar	lmh		bar	bar	bar	bar	mg/l			
1-1	1235.5	11.1	7.0	14.4	2.1	23.8	1.03	0.0	10.9	1.0	52.1	137.0	SWC4 MAX	2100	300 x 7M
1-2	766.5	10.5	6.7	13.4	1.9	32.1	1.05	0.0	18.9	35.2	71.0	544.0	SWC6 MAX	1400	200 x 7M

Calculation of Power Requirement

	Pass 1	Total system power
Pump / Boost pressure, bar	43.3	
Product flow, m3/h	2000.0	
Pump flow, m3/h	3333.3	
Pump efficiency, %	87.0	
Motor efficiency, %	95.0	
VFD efficiency, %	97.0	
Pumping power, BHP	6694.0	
Pumping power, kW	4993.7	4993.7
Pumping energy, kWh/m3		2.50

Pictures Courtesy of FEDCO

(front rotor shroud removed for clarity)